UNIVERSIDADE DO ALGARVE
FACULDADE DE CIÊNCIAS DO MAR E DO AMBIENTE

FLEET DYNAMICS IN MULTISPECIES TRAWLERS: A STUDY BASED ON FISHERIES-DEPENDENT DATA

Tereza Cristina Pilar-Fonseca

Dissertação
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Ramo das Ciências e Tecnologias das Pescas
Especialidade em Avaliação e Gestão de Recursos

Trabalho efectuado sob a orientação de:

Professor Doutor Manuel Seixas Afonso-Dias
Universidade do Algarve / Centro de Investigação Marinha e Ambiental - CIMA
Doutora Maria Aida Viana da Silva Campos
Instituto Português do Mar e Atmosfera - IPMA / Departamento do Mar e Recursos Marinhos - DMRM

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Declaração de autoria de trabalho

Declaro ser a autora deste trabalho, que é original e inédito. Autores e trabalhos consultados estão devidamente citados no texto e constam da listagem de referências incluída.

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Resumo

Ao longo deste estudo, foram integrados diversos tipos de dados dependentes da pesca com vista a examinar a segmentação da frota portuguesa de arrasto costeiro, bem como estimar o esforço de pesca e os desembarques por unidade de esforço para as espécies comerciais mais importantes. Numa primeira fase, foram analisados dados de desembarques por viagem com o objectivo de identificar perfis de desembarque (LPs), ou seja, grupos homogéneos de viagens de pesca em termos da respectiva composição específica, definidos pela importância relativa das espécies-alvo e espécies acessórias. Complementarmente, foram definidos componentes da frota (FC) associados a estes LPs, correspondendo a grupos de embarcações envolvidos nas mesmas estratégias de pesca ao longo do tempo. A dinâmica da frota de arrasto de peixe foi analisada utilizando uma série temporal correspondente a 13 anos de viagens de pesca, de 1995 a 2007, para um total de 74 arrastões da frota, com o objectivo de definir padrões consistentes de actividade. A aplicação de métodos partitivos de análise multivariada (*Clustering Large Applications* - CLARA) às proporções de espécies desembarcadas em cada viagem, permitiu identificar seis perfis de desembarque distintos. Dois destes LPs corresponderam a grupos de viagens que tiveram como espécies-alvo o carapau (*Trachurus trachurus*) e o verdinho (*Micromesistius poutassou*); nos restantes quatro, as lulas (*Loligo spp*.), o carapau e os polvos (Octopodidae) foram as espécies mais representadas, juntamente com a faneca (*Trisopterus luscus*), a cavala (*Scomber colias*) e a sarda (*Scomber scombrus*).

A correspondência entre LPs e arrastões permitiu definir três FCs, constituídas por grupos de embarcações distintas em termos das respectivas características técnicas e perfis de desembarque preferencial, dirigidas a diferentes grupos de espécies.

Foram registados desembarques num total de 21 portos diferentes, quatro (Matosinhos, Aveiro, Figueira da Foz e Nazaré) dos quais contribuíram com 66% do total de viagens de pesca. A actividade desta frota relativamente aos diversos perfis de desembarque foi caracterizada recorrendo a critérios de estabilidade (proporção das FTs consecutivas com o mesmo LP), polivalência (importância da LP principal em relação às restantes LPs), e fidelidade (proporção das FTs realizadas numa dada região), das embarcações aos respectivos LPs e portos de desembarque, permitindo uma análise preliminar das estratégias e tácticas de pesca.

Foi identificado um grupo de embarcações de maiores dimensões, com comprimento (fora a fora) médio de 30 metros e 900 HP (662 kW) de potência, dirigido à captura dos pelágicos como o carapau e o verdinho. Apesar de mais activos na zona centro do país, com mais de 40% das viagens nesta zona, estes arrastões operaram ao longo de toda a costa durante o período em análise. Um segundo grupo de embarcações de menores dimensões (comprimento médio de 25 metros) e potência mais reduzida (600 HP/441 kW) concentra a sua actividade na região centro, desembarcando um conjunto de espécies que inclui carapau e cefalópodes, entre outras. Estas embarcações apresentam grande polivalência em relação às tácticas de pesca adoptadas, alternando entre LPs em viagens consecutivas. Finalmente, um grupo muito reduzido, compreendendo os arrastões mais antigos da frota, com cerca de 17 metros e 250 HP (184 kW), opera exclusivamente na costa algarvia, capturando cefalópodes e peixes bentónicos.

Os padrões temporais e espaciais relativos aos diversos LPs foram analisados, tendo sido registadas variações sazonais bem marcadas a nível das viagens onde o carapau e a lula foram espécies-alvo, e variações, embora menos evidentes, no LP dedicado aos polvos. Nas viagens dirigidas ao carapau e ao polvo, foram registados desembarques ao longo de toda a costa. Já no LP onde o verdinho foi espécie-alvo, 80% dos desembarques foram registados no Norte e Centro, o mesmo acontecendo para a lula, desembarcada quase exclusivamente nas regiões Centro e Norte, revelando um padrão geográfico de captura bastante restrito.

O potencial da informação georreferenciada, correspondendo aos registos do MONICAP, o sistema *Vessel Monitoring System* (VMS) nacional, das viagens de pesca das embarcações em estudo, foi demonstrado ao longo desta análise, quer na quantificação do esforço de pesca, quer na identificação de tácticas de pesca e padrões geográficos de actividade. Para este estudo, a Universidade do Algarve disponibilizou um conjunto de dados relativos às viagens de pesca da frota de arrasto de peixe durante o ano de 2003, compreendendo registos com intervalo de 10 minutos. Estes dados, previamente processados com recurso a um software específico - GeoCrust 2.0 -, foram reanalisados para esta frota, com vista à identificação mais precisada duração das viagens de pesca das diferentes embarcações e, dentro destas, dos lanços de pesca. Para efeitos práticos da estimação do esforço, foram identificadas, com base em regras de velocidade definidas para esta frota, duas fases operacionais durante as viagens, correspondendo à fase de arrasto (pesca) e não-arrasto (outras operações, compreendendo a navegação entre o porto e pesqueiro; navegação entre pesqueiros; e manobras de largada e viragem da arte). A estimação efectiva do esforço envolveu pois, individualmente, para cada viagem, a quantificação do tempo de duração da viagem em número de horas, bem como a quantificação do número total de horas de pesca ao longo dos diversos lanços da viagem, para um total de 44 embarcações, das 74 inicialmente seleccionadas.

A combinação das quantidades desembarcadas por espécie, em cada viagem, com o esforço de pesca estimado deste modo, permitiu a estimação dos desembarques por unidade de esforço (LPUE, *proxy* das capturas por unidade de esforço por sua vez podendo ser considerado um *proxy* da abundância do recurso): desembarques por dia no mar (LPDAS) e desembarques por hora de arrasto (LPHT). Estas estimativas foram obtidas para as principais espécies-alvo (carapau, verdinho, lula e polvo), a nível dos respectivos LPs, para as viagens individuais do subconjunto de navios acima referidos, integrantes da frota em 2003. A integração desta informação com dados georreferenciados correspondentes aos registos VMS, permitiu o mapeamento e a visualização das actividades da pesca, demonstrando a existência de diversos padrões de actividade e das estratégias de captura específicos para esta frota.

Para os cefalópodes, os dados georreferenciados foram integrados com dados relativos à estrutura populacional, permitindo a estimação do esforço por intervalo de comprimentos e a análise de padrões geográficos da estrutura populacional. São apresentados dois casos-de-estudo, relativos ao polvo e à lula capturados em 2003, onde a amostragem por comprimentos recolhida no âmbito do PNAB/DCF (Plano Nacional de Amostragem Biológica/*Data Collection Framework*), em viagens de pesca posteriormente classificadas em termos dos LPs definidos, foi integrada com os registos VMS correspondentes. A intensidade de pesca foi então mapeada, juntamente com a estrutura populacional, associando estes registos à quadrícula adoptada pelo ICES (0.5º em latitude x 1.0º em longitude), sugerindo uma possível relação entre o padrão geográfico de exploração e a estrutura populacional destas duas espécies. Para o polvo, os resultados mostram que a pressão de pesca é mais intensa na zona de Aveiro, coincidindo com as zonas de reprodução e com as maiores concentrações de biomassa para esta espécie. A lula está sujeita a uma maior exploração na zona Centro, em áreas próximas da costa onde ocorrem concentrações de juvenis, e ainda no barlavento algarvio.

Da análise conjunta dos desembarques da frota por viagem para o período de 1995 a 2007, bem como de registos VMS existentes para um período de cinco anos, 2000 a 2004 (correspondendo a dados de qualidade com intervalo de 10 minutos entre registos), foi escolhido um grupo de arrastões, desembarcando regularmente ao longo da maior parte do primeiro período, com informação georreferenciada distribuída regularmente ao longo dos cinco anos. Estas embarcações, com actividade cobrindo os diversos LPs definidos, foram seleccionadas com o objectivo de constituírem uma amostra representativa da frota de arrasto de peixe para o efeito de estimação do esforço de pesca e dos LPUEs, para as espécies-alvo definidas nesta pescaria. Os registos VMS pertencentes a este conjunto de embarcações foram inteiramente processados para o período de 2000 a 2004 permitindo obter o esforço de pesca efetivo por viagem: a sua duração total e o número de horas arrastadas, e as estimativas dos respectivos LPUEs (LPDAS e LPHT). Os dois estimadores dos esforços (duração da viagem e número de horas arrastadas) foram obtidos por LP, para o ano de 2003 e para o conjunto dos cinco anos de 2000 a 2004. Os estimadores LPDAS e LPHT, acima definidos, foram também obtidos por LP para este conjunto de embarcações em 2003.

A comparação entre os estimadores de esforço para o período de 2000 a 2004 envolveu, numa primeira fase a comparação entre a frota seleccionada e as restantes embarcações para o ano de 2003. Numa segunda fase estes estimadores foram comparados, dentro da frota de referência entre o ano-base e o conjunto dos restantes quatro anos. O comportamento da frota, i.e., a duração das viagens e o tempo de arrasto, manteve-se relativamente constante dentro de cada LP ao longo deste período.

A representatividade deste conjunto de embarcações em termos da estimação do LPUE foi examinada no período de 2000 a 2004, comparando os LPUE observados na frota seleccionada, para as diferentes espécies/grupos analisados, com os valores -correspondentes estimados para esta mesma frota. Estes resultados foram ainda comparados, para o mesmo período, com uma terceira série de LPUEs, estimados com base nos mesmos indicadores de esforço, mas onde as viagens de pesca são as viagens da frota na sua totalidade. Esta frota demonstrou ser uma possível candidata para a amostragem do LPUE para algumas das principais espécies comerciais, num programa de amostragem dirigido.

Os resultados globais desta tese demonstram o potencial decorrente da integração de dados dependentes da pesca na produção de informação específica, contribuindo para a gestão e planeamento integrados da pesca por arrasto de fundo, em consonância com os objectivos da nova Política Comum das Pescas (PCP) e da Directiva-Quadro da Estratégia Marinha (DQEM) da União Europeia.

Palavras chave: Dados dependentes da pesca; Esforço de pesca; Desembarques por unidade de esforço (LPUE); Informação georreferenciada; Dados VMS (*Vessel Monitoring System*); DCF (*Data* C*ollection Framework*).

Abstract

Fishery-dependent data from the Portuguese coastal fish trawl fleet were integrated to examine fleet segmentation and dynamics along a 13-year period, and estimate species-directed effort and abundance. Six landing profiles (LPs) were based on the relative importance of target and by-catch species, including horse mackerel (*Trachurus trachurus*) and blue whiting (*Micromesistius poutassou*) almost exclusive LPs, three others corresponding to trips targeting squids (*Loligo spp*.), horse mackerel and octopuses, as the main species. LPs were assigned to trawlers, defining fleet components with specific technical characteristics and fishing strategies. This showed that large vessels target pelagics along the entire coastline, average-powered units fished a diverse catch off the Central zone of the western coast, including horse mackerel and cephalopods and a group of trawlers targeted cephalopods and benthic species off the south coast.

Vessel Monitoring System (VMS) data, processed by GeoCrust 2.0, was used to quantify effective fishing effort and define geographic patterns of fishing activity. VMS-based species-specific effort from 2003 was integrated with landings to estimate landings per unit effort (landings per day at sea and landings per hour trawled. Integration of cephalopod size-classes data with VMS information enabled the estimation of size-dependent effort and analysis of geographical patterns of population structure.

A group of vessels with landing activity and VMS coverage of trips belonging to distinct LP were selected to constitute a potential sample fleet for estimating species-directed LPUE. Their representativeness in terms of effort and LPUE was examined by comparing these results with those obtained for the entire fleet. This reduced fleet was found to be a possible candidate for a sampling programme under the EU Data collection Framework. Overall findings highlight the benefits of combining fisheries-dependent data, to produce information relevant for integrated management, in accordance with the Common Fisheries Policy and Marine Strategy Framework Directive objectives.

Keywords: Fishery-Dependent Data; Fleet dynamics; Fishing Effort; Landings per unit effort; Vessel monitoring system; Geo-referenced information.

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List of Abbreviations

CFP	Common Fisheries Policy
CPUE	Catch per unit effort
DCF	Data Collection Framework
DGRM	Directorate-General for Natural Resources, Safety and Maritime Services
EAFM	Ecosystem-based approach to fisheries management
EC	European Commission
EU	European Union
FC	Fleet component
FT	Fishing trip
GIS	Geographical information system
GPS	Global Positioning System
GT	Gross tonnage
ICES	International Council for the Exploration of the Sea
IPMA	Instituto Português do Mar e da Atmosfera (in Portuguese), Portuguese Institute of Sea and Atmosphere
MONICAP	MONItorização Contínua das Actividades da Pesca (in Portuguese)

MSFD	Marine Strategy Framework Directive
MSP	Maritime Spatial planning.
IMP	Integrated Maritime Policy
HP	Horse power
UNCLOS	United Nations Convention of Law of the Sea
LP	Landing profile
LPDAS	Landings per day at sea
LPHT	Landing per hour trawled
LPT	Landing per trip
LPUE	Landings per unit effort
PNAB	national biological sampling plan
TAC	Total allowable catch
VMS	Vessel monitoring system
EEZ	Economic Exclusive Zone
kg	kilogrammes
kW	Kilowatts
g	gram
m	meters
mm	millimeters
nm	nautical miles
t	tonnes

Aim of the study and list of papers

In this study fishery-dependent data were analysed and integrated to examine fleet segmentation, temporal and spatial patterns of activity and to estimate species-directed effort for the Portuguese coastal fish trawl fleet. Available data on landings (in weight and value) were used to identify landing profiles (LPs), and associated fleet components.

High-resolution Vessel Monitoring System (VMS) processed data was used to quantify effective fishing effort and define geographic patterns of fishing activity. VMS-based species-dependent effort was integrated with landings to estimate landings per unit of effort (LPUE) as a *proxy* of abundance. Integration of size data with VMS information was carried out for two species targeted by this fleet, allowing estimation of size-dependent effort and analysis of geographical patterns of population structure.

A group of vessels with regular landing activity and VMS coverage in trips belonging to the distinct LP was selected to constitute a sampling fleet for estimating species-directed abundance for this fishery.

The objectives of this study are:

- to examine fleet segmentation and fleet dynamics, analysing time and spatial patterns of fleet activity (Papers 1 to 3);
- to analyse spatial information from existing high-resolution VMS data in order to estimate effective fishing effort and LPUE for the most important species targeted by this fleet (Papers 4 to 7);
- to map geographical patterns of fishing activity, demonstrating the existence of time and spatial targeting strategies (Papers 2, 4, 5, 6 and 7);
- to show how fishery-dependent data regularly collected can be optimized to gain a better understanding of this fishery (all papers).

The results demonstrate the utility of fisheries dependent data to produce specific information tools in support of fisheries management, in accordance with the objectives of the Common Fisheries Policy (CFP) and the Marine Strategy Framework Directive of the European Union (EU).

These questions have been addressed in a total of three sections and seven papers. In section 1 (Introduction) the framework for the new Common Fisheries Policy is presented and management measures are described. The Portuguese coastal bottom trawl fisheries are characterized. Section 2 (Data Analysis) is a description of work, where the relevant aspects on methodology and results are presented and discussed. Section 3 is a general discussion with final considerations and recommendations. Papers 1 to 3 address fleet segmentation and activity patterns in the coastal trawl fleet; Papers 4 to 7 estimate and map species-specific and size-specific effort and abundance.

List of Papers

Paper 1

Campos, A., Fonseca, P., **Fonseca, T.**, Parente, J., 2007. **Definition of fleet components in the Portuguese bottom trawl fishery.** Fisheries Research 83: 185-191.

In this study, landing profiles (LPs) were defined by the relative importance of their target and by-catch species, based on monthly aggregated landings of the entire trawl fleet during the 2002-2004 period. A correspondence was established between these LPs and three main fleet components, or groups of trawlers involved in the same fishing pattern over time: the crustacean fleet, licensed for 55-59 and 70 mm codend mesh sizes, targeting the rose shrimp, *Parapenaeus longirostris* and the Norway lobster, *Nephrops norvegicus*; the 'fish' fleet, licensed for 65 mm mesh size, mainly targeting semi-pelagic fish species such as the horse mackerel, *Trachurus trachurus*; and a small number of 65 mm codend mesh size trawlers having the cephalopods and benthic fish species as their most important landings.

Paper 2

Pilar-Fonseca, T., Campos, A., Afonso-Dias, M., Fonseca, P., Pereira, J., 2008. **Trawling for cephalopods off the Portuguese coast – fleet dynamics and landings composition.** Fisheries Research 92: 180–188.

This study focused on segmentation for the two latter components defined in Paper 1, also using monthly aggregated data from the same period. Within the fish fleet a total of 12 different LPs were identified, from which four were found to be related to cephalopods and associated species. Vessel monitoring information combined with landings data introduced a spatial analysis of the fishing trips (FT) targeting cephalopods, including vessels engaged seasonally and at full-time in cephalopod fisheries, mainly the octopus *Octopus vulgaris*, the squid *Loligo vulgaris* and the cuttlefish *Sepia officinalis*. The effects on the landing proportions of a number of variables, year, season and vessel, were analysed for each of the species studied.

Linkage between landings and VMS data provided for the definition of spatial patterns of activity by mapping the fleet trajectories and subsequently identifying geographical areas of activity.

Paper 3

Pilar-Fonseca, T., Campos, A., Fonseca, P. Afonso-Dias, M.. **Activity patterns for Portuguese fish trawlers based on a 13-year time-series of daily landings.** Submitted to Aquatic Living Resources.

In this study, the dynamics of Portuguese fish trawlers operating in western Iberian waters was analysed along a 13-year time-series of daily landings from 1995 to 2007, with the purpose of obtaining consistent patterns of activity over time. A total of six LPs differing in species composition were defined, using the classification method Clustering Large Applications (CLARA) applied to species proportions, in weight and value. Two distinct LPs were defined in weight, exclusively targeting pelagic horse mackerel (*Trachurus trachurus*) and blue whiting (*Micromesistius poutassou*). The remaining four LPs corresponded to mixed fisheries, where squid (*Loligo spp*.), horse mackerel and octopuses (Octopodidae) were identified as main targets. Three fleet components (FC) were identified, targeting distinct ecological groups that differed in their technical characteristics, LP stability and polyvalence, and fidelity to a geographic region. Large vessels targeting mainly pelagic species were found to be active along the entire coast. Average powered units concentrated their activity in the centre of Portuguese mainland waters, landing a diversified catch, including horse mackerel and benthic species. These vessels were observed to frequently change their fishing tactics, switching between LPs on a trip-by-trip basis. Low-powered and old vessels targeted cephalopods and benthic species off the south coast. Preliminary estimates of species-directed LPUE (Landings per Trip) were presented.

Paper 4

Pilar-Fonseca, T., Campos, A., Fonseca, P., Mendes, B., Henriques, V. and Afonso-Dias, M. 2012. **The importance of satellite-based vessel monitoring system (VMS) for fisheries management: A case study in the Portuguese trawl fleet.** *In* Maritime Engineering and Technology.

The purpose of this paper was to illustrate the usefulness of satellite-based VMS data consisting of vessel location and speed. Collected for fisheries control in fisheries research the outputs provided by this system make it possible to map and quantify the fishing activity. VMS data with 10-minute interval was processed for a Portuguese coastal trawler operating off the west coast, using GeoCrust 2.0, a geographical information system which identifies fishing trips and towing events (hauls) within trips. This information was then used to characterize vessel activity. It was shown that high-resolution VMS data provides an understanding of fishing tactics and derives more precise series of effort estimates.

Paper 5

<u>Pilar-Fonseca, T.</u>, Campos, A., Pereira, J. Moreno, A., Lourenço, S., Afonso-Dias, M. **Exploitation patterns and size composition of *Octopus vulgaris* in Portuguese waters (Northeast Atlantic) derived from fine-scale geo-referenced bottom-trawl commercial catches.** Accepted for publication in Fisheries Research.

This study represented a first attempt to integrate different sources of information obtained at commercial trip-level, with the objective of providing a perspective of octopus population structure and relative distribution, together with information on the exploitation pattern in 2003. High-quality resolution sequential geo-referenced data were obtained from the VMS for fishing trips targeting octopus. Fishing trips undertaken on the north-western coast were used to provide information on volume and size distribution of landings. Our results show that most of the fishing intensity was directed off the region of Aveiro, where the smaller octopus were found. This is an area where important fish nurseries are also located and coincides with known octopus biomass concentration.

Paper 6

<u>Pilar-Fonseca, T.</u>, Pereira, J., Campos, A., Moreno, A., Fonseca, P.., Afonso-Dias, M. **VMS-based Fishing Effort and Population Demographics for the European squid (*Loligo vulgaris*) off the Portuguese Coast.** Accepted for publication in Hydrobiologia.

This study presented a one-year synopsis of the trawl fishery for the European squid *Loligo vulgaris* in Portuguese waters, integrating length structured landings with corresponding geo-referenced fishing activities. From VMS, landings and biological sampling data, a “status-report” was obtained for 2003. Fishing pressure was found to be most intense in inshore areas of the northwest and the south coasts of Portugal. Larger squid were found offshore in the northwest and south coasts, whereas all inshore western areas showed larger proportions of small squid relative to those in the south.

Paper 7

Species-directed effort and LPUE indicators using fishery-dependent information (manuscript)

This study, based on Paper 3, shows an approach with a focus on fishery-dependent information to estimate the abundance and species-specific fishing effort for commercial species. Landings from individual fishing trips were combined with geo-referenced data obtained through VMS for the Portuguese finfish coastal trawlers operating in national waters. Processed VMS data from this fleet were used to examine exploitation patterns, through the definition of trips and hauls, with an estimation of trip duration and number of hours trawled by trip, using the GeoCrust 2.0 software. A fleet representative of the landing profiles (LPs) previously identified in Paper 3 is proposed, based on high-resolution 2000-2004 VMS data. These data provided an increase in the accuracy of in fishing effort and landings per unit of effort (LPUE) estimates, from previous figures obtained in LPT (landings per trip), to landings per day at sea (LPDAS) and finally, landings per hour trawled (LPHT), for the different LPs. Comparison of these estimates with those obtained for the entire fleet was carried out in order to check the representativeness of the selected fleet to estimate fishery-based species-specific abundance indexes for the fishery. The main objective was to define a sampling fleet that can be used to adequately sample fishing effort and abundance for the main commercial species.

This Ph.D. project includes and extends previous work in the theme of fleet segmentation using landings data, within the frame of the Programme “MARE: Fishing Technologies”, (MARE, FEDER, QCA-III, 22-05-01-FDR-00014; 2000-2007). This study started under the responsibility of the former INRB/L-IPIMAR (Portuguese Institute of Biological Resources/Fisheries and Sea Research Laboratory), currently integrated in the “Instituto Português do Mar e da Atmosfera” (hereinafter referred to as IPMA - Portuguese Institute of Sea and Atmosphere) as the Department of Marine Resources.

1. Introduction

In this section important aspects of the Common Fisheries Policy (CFP) are presented, and relevant management tools in support of the CFP reform are described. A description of the Portuguese coastal bottom trawl fisheries is provided.

1.1 Common Fisheries Policy (CFP), relevant concepts and management measures

The European CFP was established in 1983 for the conservation, management and sustainable exploitation of the Sea (Council Regulation (EEC) No 170/83). The principle of relative stability was adopted in the annual division of Total Allowable Catches (TACs) and distribution into fishing quotas by Member States based on their historical catches registry. The detailed rules for recording information of Member States' catches were set in Regulation (EEC) No 2807/83. The first reform of the CFP took place in 1992 (Council Regulation (EEC) 3760/92), with the need to tackle the overcapacity of the EU fleet by introducing fishing effort measures. A second reform (Council Regulation No 2371/2002, "Framework Regulation") provided the CFP with a longer-term perspective on fisheries management by establishing recovery and management plans, creating Regional Advisory Councils (RAC) and implementing the precautionary principle in fisheries management in order to minimize the impact of fishing activity on marine ecosystems and prevent environmental degradation.

The third reform of the CFP, which is still under discussion (COM(2009) 163) will focus on long-term sustainability, through the application of exploitation rates set at levels of maximum sustainable yield (MSY). Emphasis will be placed on a regionalized approach to fisheries management, with the establishment of fishery-based plans and mitigation measures to be tailored to specific fisheries. This will require a higher responsibility and improve compliance behavior by the fishing sector. The relevance and implementation of the ecosystem-based approach to fisheries management (EAFM) and the mitigation of the wasteful practice of discarding will also become central issues under the new CFP. A discard ban is being discussed for those species assessed in international *fora* such as the International Council for the Exploration of the Sea (ICES). This implementation is phased in according to species (pelagic/demersal) and fisheries.

The ecosystem approach to fisheries management is not easy to define; the concept behind EAFM is about ensuring that "benefits from living marine resources are high while the direct and indirect impacts of fishing operations on marine ecosystems are low and not detrimental to the future functioning, diversity and integrity of these ecosystems" (COM(2008) 187). This concept is derived from more general definitions in the Convention on Biological Diversity (CBD) and in the ICES, being partially related to the preservation of biodiversity and habitat conservation (Habitats Directive 92/43/EEC). The implementation of EAFM requires information on the state of the marine environment, including pressure indicators related to its different uses (SEC(2008) 449). The Marine Strategy Framework Directive (MSFD, Directive 2008/56/EC) establishes a framework to achieve or maintain good environmental status in the marine environment by 2020.

The importance of this approach is stated for the Atlantic Ocean in COM(2011) 782 "Developing a Maritime Strategy for the Atlantic Ocean Area". This document emphasizes the need for a reformed CFP based on regionalisation and simplification targets, in order to promote fisheries management that is able to react more quickly and efficiently to changing ecological or economic conditions. Within this context, EU instruments for an integrated maritime policy and territorial cooperation are supporting pilot projects on spatial planning and coastal zone management in the Atlantic. Single species management will be replaced by multi-species long-term plans, while the spatial component play an increasingly important role as a broader set of ecosystem interactions need to be considered.

The relevance and implications of analysing fleet dynamics for multi-species fisheries has been demonstrated as a spatial, fleet-based management and governance tool, in line with the EU Common Fisheries Policy, the Integrated Maritime Policy (IMP, COM (2007) 575) and the Maritime Spatial Planning (MSP, COM(2008) 791). The need to analyse fishery-data at a more regional (local) scale may also benefit various other EU directives and policies, including the MSFD (Directive 2008/56/EC) already transposed into Portuguese legislation (Decreto-lei nº 108/2010 altered by Decreto-lei nº 201/2012).

1.2 Management tools

Since the first CFP reform, fleet capacity has been progressively regarded as an important factor for the conservation policy. Limitations to this capacity were set with the objective of bringing it into line with available resources, hence ensuring fishing at a sustainable level. Management measures have thus evolved from control of catches (e.g. TAC) to effort control (e.g. days-at-sea). Fisheries management measures, or rules, are grouped into the following types: output control (catch limits), input control (fishing effort limitations), and technical measures. Output and input controls are related to fishing mortality, the former directly controlling quantities captured (TACs), and the latter indirectly controlling quantities by restricting fishing effort, and thus fleet capacity or fishing activity. Technical measures are directed at more specific goals and include gear restrictions (e.g. codend mesh size), real time closures and species minimum landing sizes (MLS). A combination of these three types of measures is used in European fishery policies.

Authorizations for the acquisition or construction of new fishing vessels and for the use of fishing gear, and annual fishing licenses are additional input instruments used to manage this activity. Licenses are granted on the basis of stock status, operating areas, vessel characteristics and condition, the amount of fishing gear per vessel, the previous year's catch, and any cases of repeated failure to comply with the rules. Since 2003 there has been a strict entry-exit rule, and the number of vessels per year has been kept relatively constant or has been reduced in order to adjust fishing effort to sustainable exploitation patterns and the state of the resources, namely in relation to fishing capacity (e.g., vessel parameters).

The main fishery conservation management tools used are Total Allowable Catches (TAC's) and quotas, fixed on an annual basis. The European Commission (EC) defines TAC's as "quantitative limits on landings that are set at the level of stocks or group of stocks" (Churchill and Owen, 2009). TAC's are decided upon by the Member States (MS) in the Council after a proposal from the Commission with scientific advice from ICES and the Scientific, Technical and Economic Committee for Fisheries (STECF). TACs are divided into quotas for each Member state, which can be further allocated among vessels if Individual Transferable Quotas (ITQs) are implemented.

Fishing effort is defined by the United Nations Food and Agriculture Organisation (FAO) as "the product of the capacity and the activity of a fishing vessel" with capacity measured in kilowatts (kW) of engine power and activity measured in time (days) (COM(2007) 39). Fishing activity can be more accurately estimated as the time during which the fishing gear is in operation and is effectively fishing (COM (2007) 39).

Fishing activity is frequently referred to in a vast number of ways such as fishing pressure (Lambert et al., 2012; Stelzenmuller et al., 2008), and fishing intensity (Piet and Quirijns, 2009), fishery footprint (Jennings et al., 2012), among others. Examples of fishing effort management measures are limitations in the number of fishing licenses (capacity) and in the number of fishing days (activity), as well as restrictions in the number and characteristics of vessels and/or gears.

Both TACs and effort measures (i.e. output and input control, respectively) are aimed at the regulation of fishing mortality. Conservation measures comprise a number of ways to regulate exploitation patterns while keeping the fishing level constant. They include the so-called technical measures for conservation purposes, which are used to prevent by-catch of juvenile fish or species that are not targeted. The Basic Regulation (Council Regulation (EC) No 1954/2003) provides the legal framework for the adoption of technical measures. Technical measures regulate the structure of fishing gear, the restriction or prohibition of fishing in certain zones and periods, limitations in size of individuals that may be retained on board and/or landed, and specific measures that may be used to reduce the impact of fishing activities on marine ecosystems and non-target species.

The EAFM (Jennings et al., 2001; Stergiou et al., 2003) calls upon a fleet- and area-based approach to fisheries management (Council Regulation (EC) No 1343/2007) requiring the integration of diverse fisheries information. Incorporating fleet- and fishery-based approaches into the advisory system is particularly relevant in multi-species fisheries (Scientific, Technical and Economic Committee for Fisheries, 2007).

The fisheries sector was initially monitored *via* fisheries-dependent information using a paper based format recording catches, landings and sales. Over the past decade the Electronic Recording and Reporting System (ERS) has been implemented to collect data on fishing activity and send the information to fisheries authorities in the Member States (Commission Implementing Regulation (EU) No 404/2011) and, increasing data accuracy in this way. One of the main instruments for control and compliance is the satellite-based vessel monitoring system (VMS), which tracks the geographical position for all vessels over 15 metres in length.

The Data Collection Framework (DCF, Commission Decision 2008/949/EC) is an important tool aimed at ensuring a sound basis for policy, decision-making, and support for scientific advice regarding the CFP. The DCF operates by adopting a multiannual Community program for the collection, management and use of data in the fisheries sector at biological, ecological, operational and economical levels.

The Portuguese legislation on conservation, management and control is consistent with regulations set by measures established at the international and European level. The main national and corresponding EU regulations (e.g. Decree Law 43/1987 and national legislation –Portaria- nº 1102-E/2000) are listed in Table 1.1. Currently, the main national entity responsible for controlling the fishing sector is the "Direção-Geral de Recursos Naturais, Segurança e Serviços Marítimos" (DGRM, Directorate-General for Natural Resources, Safety and Maritime Services, the former Directorate-General for Fisheries and Aquaculture, DGPA SEC(2007) 425).

Table 1.1 - Management measures and legal provisions for Portuguese fisheries, including trawl fisheries. Control is made by DGRM alone or in cooperation with other entities. Legislative Decrees and national legislation are listed (only number is shown).

Rules	Europe	National legislation
INPUT		
Permit for fishing vessels and gear Annual fishing licenses Fishing activity	Council Regulation 3094/86 Council Regulation (EC) No 1954/2003 Fishing effort Adjustment plans (FEAP)	DR 43/1987 (amended by DR 3/89, 28/90, 30/91 and 7/2000) Nº 301/2010 for the Southern Hake and Nephrops Recovery plan
OUTPUT		
Annual TACs and quotas (year 2012)	Council Regulation (EU) 44/2012 sets TACs for 2012	nº 177/2012 (for 2011)
Technical measures		
Mesh sizes Target species and species percentages (limits)	(EC) No 850/1998. (EU) No 579/2011. (EC) No 517/2008 Reg. (EC) 850/98	nº 1102-E/2000 (mesh size), nº 769/2006 Nº 27/2001 altered by nº 1266/2004 nº 1102-E/2000
Minimum Landing Sizes	(EC) 2166/2005, CR (EC) 850/98	nº 419-B/2001
Spatial and temporal restrictions		nº 296/94 establishing fishing closures
REPORTING AND COMPLIANCE		
Vessel activity at sea Logbooks, Landings, VMS First sale market	Council Regulation (EC) nº 1224/2009 Commission Implementing Regulation (EU) No 404/2011	Decree-Law n.º 310/98 nº 313/2011 Legislative Decree 81/2005

1.3 Portuguese coastal bottom trawl fisheries

1.3.1 Fleet capacity and area of activity

In Portuguese mainland waters, fishing is carried out by a total of three distinct fleet segments: trawl, seine and polyvalent fleets. In 2012, the trawl fleet landed 14456 tonnes and 36224 Euros which accounted for 9% and 12% approximately of the total national landings in weight and value, respectively (INE, 2013).

The trawl fleet activity is regulated by National legislation n. 1102-E/2000 ("*Regulamento da Pesca por Arte de Arrasto*"). This fleet is divided into two sub-segments: the bottom trawl (OTB) fleet and the beam trawl. The fleet selected for this study is the bottom trawl fleet corresponding to Portuguese trawlers operating in ICES areas VIIIc, IXa and IXb and exploiting demersal assemblages (segment 4k3, Commission Regulation (EC) No 2091/98, Figure 1.1). In 2002, a total of 110 coastal trawlers (4k3) were active with a fleet capacity of 19936 Gross Tonnage (GT, Council Regulation (CEE) Nº 2930/86) and 54894 kW (Kilowatts), with a corresponding cumulative fishing effort of $6.4*10^6$ GT*days ($17.3*10^6$ kW*days, COM(2003) 508). By the end of 2011 the number of vessels had been reduced to 82 units with a total of 38260 kW and 14977 GT.

The fleet operates all year round in the geographical area of the Northeast Atlantic waters of the Iberian Peninsula (ICES divisions VIIIc and IXa, excluding the Gulf of Cadiz. Fishing activity is mainly concentrated within the limits of the geological continental shelf (until 200 m depth), extending to the slope-edge. Vessels from the bottom trawl fleet may operate anywhere along the entire Portuguese continental coast (36º to 42ºN and 7º to 9ºW) covering an extension of approximately 523 nautical miles (n.m.). Some of the Portuguese trawl vessels are also licensed to operate in Spanish waters (including ICES division VIIb) according to a bilateral agreement between Portugal and Spain, signed in 2003. Vessels must operate at a minimum distance of 6 n.m. from the baseline but there is an exception for a small number of vessels that may operate within the 6 n.m. limit from the baseline provided that they operate outside the 6 mile of the coastline in the area between Capes of Raso and Espichel (National legislation No. 769/2006, 1102-E/2000).

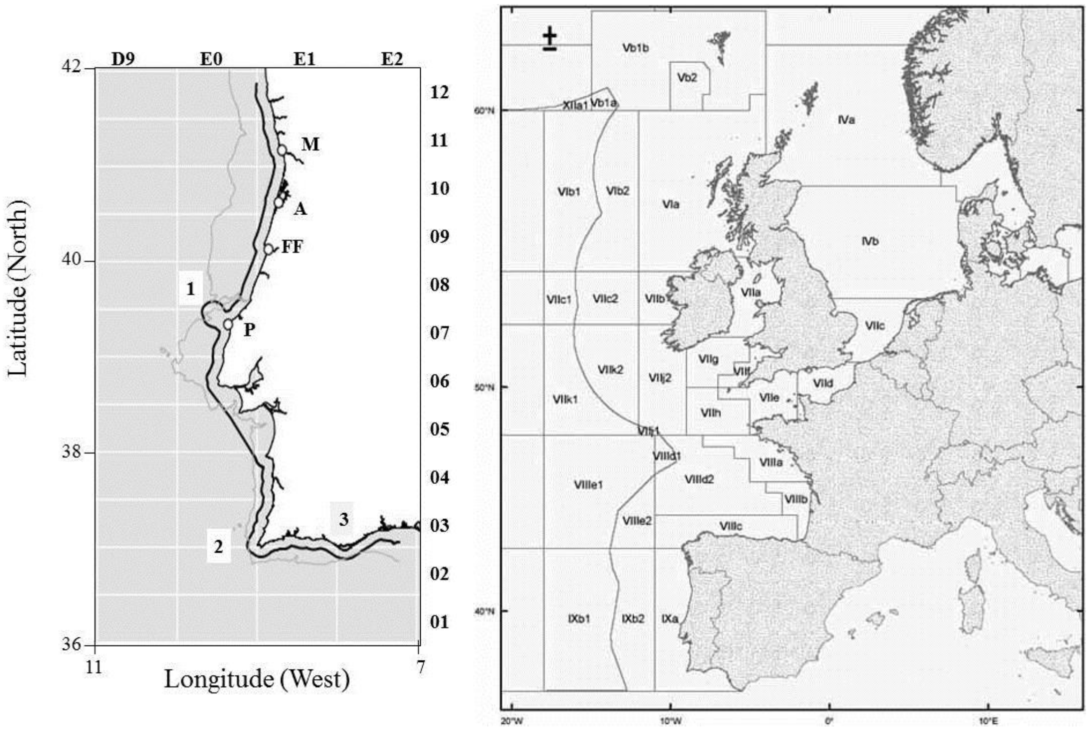

Figure 1.1 - Map of study area - Portuguese mainland waters. The gray contour marks the 200m isobath. The black contour is the 6 mile fishing limit from the baseline. Main fishing ports are identified: M-Matosinhos; A-Aveiro, FF-Figueira da Foz, P-Peniche. Cape Carvoeiro, Cape São Vicente (Sagres) and Cape Santa Maria (Faro) are indicated by numbers 1, 2 and 3, respectively. ICES statistical rectangles are identified in top and right axes. Left map spatial extent: 36 to 42ºN and 7º to 11ºW.

1.3.2 Geographical area and species assemblages

The Portuguese mainland is characterized by an L-shaped continental shelf and a steep slope-edge (Figure 1.1). The width of the continental shelf varies along the coastline, from around 40 km wide off the northern coast to 10 km wide south of Lisbon, increasing slightly to the southwest and southern coasts. This narrow shelf is cut by various topographical features including submarine canyons (Relvas et al., 2007), which constitute a physical constraint for trawling activity. Other constraints are related to the existence of patches of rough and rocky seafloors and steep slopes.

The mainland shelf is divided into four main areas according to bathymetric characteristics: north of Nazaré canyon; between Nazaré and Setúbal; Setúbal and São Vicente canyon; and South coast. In terms of the seabed substrate the area is divided into five sections (MAMAOT, 2012 - Portuguese MSFD): the northern platform from the north frontier to the Nazaré canyon; between Nazaré and the parallel of the Cape of Raso, known as Estremadura margin; between Capes of Raso and Espichel, also known as the mouth of the river Tagus; the southwest platform between Capes of Espichel and

S. Vicente; and finally the Algarve platform, between the Cape of S. Vicente and Guadiana river. In the north a sandy-gravel seafloor is observed between the coastline and the 100 m depth range. In the Estremadura margin, the sediment is mainly composed of sand, whereas at the mouth of the river Tagus the coastal area is dominated by sand, complemented by an extensive mud deposit at depths between 100 and 150m. Predominantly sandy in the southwest coast, the characteristics for the south platform are variable, from sandy-gravel to muddy seafloor.

Portuguese waters are found in a transitional zone located between the warmer waters of the Atlantic and the Mediterranean ecosystems to the south and the east respectively, and the colder Atlantic waters to the north. The Iberian system is under the influence of the seasonal upwelling of Eastern North Atlantic Central Water (ENACW), linked to the Canary Current and the North Atlantic Oscillation (NAO). The south coast is influenced by the high salinity water mass known as Mediterranean Outflow (MOW) (Relvas et al., 2007). These waters are also influenced closer to the coast and at a local level by freshwater runoff from the Iberian Peninsula. The river basins contributing to the freshwater runoff include Mondego, Vouga, Tagus and Guadiana. A recurrent buoyant plume Western Iberian Buoyant Plume (WIBP) is observed, mainly in winter (Peliz et al., 2002).

Situated in a transition zone between temperate and tropical ecosystems, the whole area is characterized by high biodiversity and relatively low abundance of marine species. The western coast is affected by the existence of seasonal upwelling, particularly up to the north of Nazaré canyon. Hydrological conditions are a determinant factor in the distribution and abundance of small pelagics such as sardine (*Sardina pilchardus*), mackerel (*Scomber spp*.) and horse mackerel (*Trachurus trachurus*). Moreover, the bathymetry, as well as bottom geological nature, strongly influences the distribution and abundance of pelagic and demersal species.

Analysis of groundfish trawl surveys (Sousa et al., 2005) conducted off the Portuguese coast identified the existence of five spatially distinct fish assemblages in the area in study. Most species are confined to certain depth and latitudinal ranges. On the shelf (<150 metres) horse mackerel and boarfish (*Capros aper*) dominate in autumn and summer assemblages, respectively. On the upper slope, the fish community is dominated by blue whiting (*Micromesistius poutassou*); in the south, this community includes a high number of deep-water species, including crustaceans.

Small pelagics represent a high fraction (58% in 2012 from six species, INE, 2013) of total landings for the continental coast. Among them, the most captured is sardine, exclusively targeted by coastal seiners in shallow waters. For the remaining pelagics, mackerels and mainly the horse mackerel, the bottom trawl fishery contributes to a high percentage of their landing weight.

1.3.3 Gear operation

The vessels engaged in coastal bottom trawling off the Portuguese coast are stern trawlers towing one net. In these vessels, the trawl is horizontally opened by means of the spreading force generated by the trawl doors, while the vertical opening is achieved by the use of floats and weights in the trawl headline and footrope, respectively. The footrope provides bottom contact for higher fishing efficiency, being adapted to the seafloor type. For hard bottoms bobbins are used to preserve the gear from possible abrasion and damage, whereas in soft sandy or muddy bottoms chains are used at the footropes to revolve the substrate. Figure 1.2 shows the various gear components and the rigging in the bottom trawl. The trawl net is bag-shaped starting with a pair of wings connected to the trawl body and ending in a codend, where the catch is retained. The top of the wings are connected to the bridles, the trawl doors (oval or rectangular structures made of iron) and the warps.

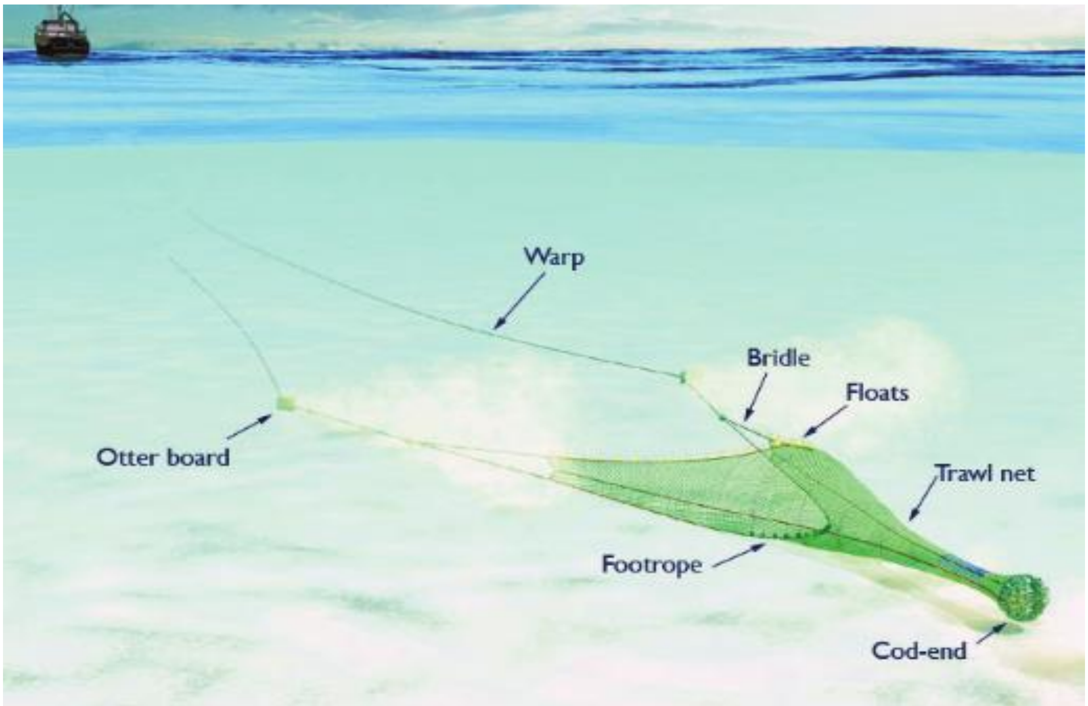

Figure 1.2 - Scheme of the various gear components of the otter bottom trawl (OTB). Warps, trawl doors (otter sweeps (bridles), wing, groundrope (footrope) with bobbins, headrope with floats (floatline), trawl net and codend.

During the haul operation, the organisms vulnerable to the trawl sweeping area, including benthic, demersal or semi-pelagic species, are guided (e.g. pelagic fish with higher swimming capacity and active behaviour towards the net) or passively directed (e.g. crustaceans and benthic fish species) from the wings to the codend, where they are retained. Retention requires that trawl duration and trawling speed is adapted towards the swimming behaviour of fish (Campos, 2003). Towing speeds generally vary from 2.5 to 5.0 knots, essentially depending on the swimming capacity of the target species, although for higher speeds vessel capacity and vessel power can be a limiting factor. Codend retention depends to a high extent on the amount of fish retained and on how the dimension and shape of the codend meshes adapt to the morphology of these organisms.

The trawl and rigging, in particular the doors and footropes, have a direct physical impact on the seabed, scraping and ploughing the sediments and causing re-suspension and physical destruction, removal or scattering of non-target benthos, with possible long-term destruction to the benthic habitats. The fishing operation further affects the seabed through post-fishing mortality of damaged or disturbed organisms, including discarding practices (Jones 1992; Kaiser and De Groot, 2000).

1.3.4 Catch composition and general characterization of trawl fleet segments

The Portuguese continental waters can be viewed as transition system between the Mediterranean and the North Sea, sharing characteristics of both. This feature and the fact that the area of operation of the fish coastal trawl fleet, extends for approximately 523 n.m., a number of fish assemblages, characterized by a high diversity, are exploited (Gomes et al., 2001; Sousa et al., 2005). Therefore, landings comprise a large number of pelagic and semi-pelagic fish species, as well as benthic fish and cephalopod species, and deep-water crustaceans. In 2012, horse mackerel, blue whiting, blue jack mackerel (*Trachurus picturatus*), hake, Spanish mackerel, rose shrimp, and pouting were the most important species regarding landings in weight (INE, 2013).

Some of the main management measures currently in force are shown in Table 1.2. Until 2000 the fleet was licensed by type of fishery (crustacean versus 'non-crustacean'/fish trawling, using 55 and 65 mm mesh size codends, respectively). Presently, it is regulated by (three different) classes of cod-end mesh size: 55-59 mm, 65-69 mm and >=70 mm. Target and by-catch percentage catch restrictions (minimum limits of target species and maximum for the by-catch) are set according to the cod-end mesh size intervals in this fleet. Minimum landing sizes (MLS) apply for a large number of species (Table 1.2).

Crustacean fleet

The crustacean fleet operates on the continental slope off the southwest and southern coasts (36 to 37ºN and 7º to 9ºW - Figueiredo and Viriato (1989) and consists of approximately 30 Portuguese vessels (27 vessels operating in 2012), plus a number of Spanish trawlers licensed by the scope of the Multilateral Agreement. These vessels target mainly rose shrimp (*Parapenaeus longirostris*) and Norway lobster (*Nephrops norvegicus*) at trawling speeds varying from 2.5 to 3.5 and even 4.0 knots (Afonso Dias and Pinto, 2008), using low-opening trawls rigged with footropes equipped with chains to revolve the soft substrates where they operate. Using VMS data, a total of nine fishing grounds were identified (Afonso-Dias et al., 2002): one in Lisbon Region (36 to 37ºN and 7º to 9ºW); two in the south-west (Alentejo coast, Sines and Arrifana area); and six on the south coast, covering an area of about 1412 nm^2, in a depth range between 50 and 1000 metres.

Table 1.2 - General information for the different species (or group of species) landed by the Portuguese trawl fleet. Name and FAO code. Ecology: Pelagic (P), bentho-pelagic (BP), demersal (D) and benthic (B). Species sampling priority group (G1 and G2, Commission Decision 2008/949/EC). Minimum Landing size (MLS, in cm). TAC for 2012 (Y – yes;N – no). Mesh classes (55, 65 and 70 mm), minimum percentage of target species, MPTS (30%, 70% and null) and target species indicated with X (National legislation, portaria 419-B/2001, decree-law 769/2004). Species with Total Allowable Catch (TAC) for 2012 (COM(2011) 717 final).

Species group		FAO Species code	Ecology	Priority Group*[1]	MLS (cm)	55-59	65-69	>=70	TAC2012
						MPTS			
Latin name	Common Name					30%	70%	Null	
Trachurus trachurus	Horse mackerel	HOM	P	G2	15	X	X	Y	
Micromesistius poutassou	Blue whiting	WHB	P	G1	-		X	X	Y
Scomber scombrus	Mackerel	MAC	P	G1	20		X	X	Y
Trisopterus luscus	Pouting	BIB	BP	G2*[2]	17		X	X	N
Scomber colias	Spanish mackerel	MAS	P	G1	20		X	X	N
Octopus vulgaris	Common octopus	OCT	D	G2*[2]	0.75kg		X	X	N
Merluccius merluccius	Hake	HKE	D	G1	27			X	Y
Sparidae	Sea breams		BP	G2			X	X	N
Loligo vulgaris	Long finned-squid	SQC	P	G2*[2]			X	X	N
Scyliorhinus spp	Catsharks	SCL	D				X	X	N
Raja spp	Rays and skates	SKA	D	G1				X	Y
Zeus faber	John Dory	JOD	BP	G2			X	X	N
Sepia officinalis	Cuttlefish	CTC	D	G2			X	X	N
Microchirus spp	Thickback soles	THS	D	G2*[2]	18*[3]		X	X	N
Lophius spp	Monkfish	MNZ	D	G2*[2]				X	Y
Mullus spp	Mullets	MUX	D	G2*[2]	15*[3]			X	N
Solea spp	Flatfishes	SOX	D	G1*[2]	24			X	Y
Nephrops	Norway lobster	NEP	D	G1	20			X	Y
Parapenaeus longirostris	Rose shrimp	DPS	D	G2	24	X		X	N
Aristeus antenatus	Red shrimp	ARA	D	-		X		X	N

***[1]Group 1 (G1): Species that drive the international management process including species under EU management plans or EU recovery plans or EU long term multiannual plans or EU action plans for conservation and management; Group 2 (G2): Other internationally regulated species and major non-internationally regulated by-catch species”**

***[2]– more general (e.g. *Trisopterus spp*) or specific/taxonomic (e.g. *Octopus vulgaris*).**

***[3] - relative to a particular species, e.g. *Microchirus azevia (18)*; *Mullus surmuletus* (15)**

The distribution of crustaceans partially overlaps, although they are characterized by different depth distributions. While rose shrimp can be found between 150 and 440 metres in sandy mud bottoms, Norway lobsters prefer compact mud between 300 and 500 m (Cascalho, 1995), and are targeted down to depths of 700 metres and more. Other less abundant target species are the shrimps *Aristeus antennatus* and *Aristaeomorpha* *foliacea,* captured between 400 and 700 m approximately (Cascalho, op.cit.; Figueiredo, 1989). Two minimum legal codend mesh size classes are allowed when trawling for crustaceans: a mesh size of 55-59 mm for shrimps, including the rose shrimp (*Parapenaeus longirostris*); and 70 mm for the Norway lobster *(Nephrops norvegicus*). No TACs apply to the rose shrimp, but a MLS is set (24 mm of carapace length). By-catch restrictions are also set, but only when 55-59 mm cod-ends are used (Council Regulation No 850/98 and in annex of the Portuguese National Legislation nº 1102-E/2000), with a minimum of 30% of shrimps regarding the total catch in weight and a maximum of 30% of protected by-catch species (Table 1.2), with the exception of blue whiting (*Micromesistius poutassou*), captured in high quantities in this fishery. However, when using different classes of mesh size during the same trip the percentage of shrimps can be reduced to 20%.

Fish fleet

The vessels licensed for 65-69 mm and/or 70mm codend mesh size (National legislation No 1102-E/2000; Commission Regulation (EC) no. 2244/2003) target a number of species including pelagic or semi-pelagic such as horse mackerel (*Trachurus trachurus*), blue whiting (*Micromesistius poutassou*), mackerels (*Scomber colias* and *S. scombrus*), and squids (*Loligo spp*.), as well as a number of cephalopods and benthic fish species such as octopuses (*Octopus vulgaris* and *Eledone cirrhosa*), hake (*Merluccius merluccius)*, flatfishes and several seabreams. In this case, trawling speed is adapted to the specific targets, ranging from 3.0 knots to 5.0 knots and more. Trawl dimensions and rigging also varies according to the target species and type of bottom.

This fleet operates along the entire coastline from 36 to 42ºN and 7º to 10 ºW. The main effective fishing effort occurs in the shelf area (up to 200m depth), although vessels may engage in fishing activity almost anywhere beyond the 6 n.m. distance.

By-catch restrictions for the 65 mm mesh size are set at a maximum of 30% in weight for species. The percentage of crustaceans catches were initially not allowed above 20% but since 2006 have increased to allow for percentages above 30% when the vessel uses more than one mesh size during a fishing trip (Portuguese National Legislation nº 1102/-E2000 amended by National Legislation nº 796/2006).

Recovery Plan for Southern hake and Nephrops

Southern hake and Norway lobster (*Nephrops*) stocks are managed under a Recovery Plan (Council Regulation (EC) No 2166/2005) that establishes measures for the recovery of these two stocks in the Cantabrian Sea and Western Iberian (ICES regions VIIIc and IXa, Figure 1.2). Under this Recovery Plan (Council Regulation (EC) No 2166/2005) there are output controls as well as input (effort, days-at-sea) restrictions, with 10% annual reductions, regulated yearly. Percentages of individual quotas for Southern hake can be found in national legislation, with a list of about 150 and 87 fishing vessels in 2007 (National Legislation no 612/2007) and 2012 (National Legislation no 177/2012), respectively, and include vessels from the crustacean and fish otter bottom trawl fleet. In 2009, 21 national vessels in various fleet segments were decommissioned with the support public subsidies as a result of the Southern hake and Nephrops recovery plan (COM(2011) 354 final). The number of fishing vessels has been declining, and those under this recovery plan are not an exception. Complementary reductions in effort comprising fishing closures in specific areas and times of the year (boxes, Reg. EC 2166/2005) are also set to avoid catches of juveniles or protect spawning stock for Nephrops and hake.

A management plan for the western pelagic stock of Atlantic horse mackerel is also being prepared (COM(2009) 189).

The management system for these fisheries, with a high number of legal provisions including enforcement of mesh sizes, by-catch limits and effort restrictions applying to individual species, corresponds to the standard CFP model of micro-management (COM(2011) 0425). Mismatches between MLS, minimum mesh sizes allowed and by-catch limits were in evidence for a number of fish and crustacean species, in codend selectivity studies (Campos et al., 2002, 2003; Fonseca et al., 2007), constituting one main reason for discarding or misreporting commercial by-catch.

1.3.5 Discards

Discards can reach high levels in Portuguese trawl fisheries. In the first study on discards of the Portuguese south coast (Project BYDISCARD), Borges et al. (2001) reported discard levels of about 70% of the mean catch per trip in crustacean trawlers targeting rose shrimp. These authors also quantified discard rates for fish trawlers operating in southern waters. The average discard rate recorded for 1998-1999 and

2000-2001 were about 59% and 44%, respectively. Discards included mainly non-commercial species such as the longspine snipefish, *Macrorhamphosus scolopax*, other with low commercial value (blue whiting) and fish below MLS.

Under the Community DCF Program (national biological sampling plan - PNAB), data collection on discards is presently carried out by IPMA on a number of co-operative crustacean and fish trawlers. Discard rates, estimated for 2009 and presented in (Pérez et al., 2011), do not include a global figure for this fleet. However, these rates are provided for a high number of species. Among these, a high number is always discarded due to low or null commercial value, such as the boarfish, the bogue (*Boops boops*), the Henslow´s swimming crab (*Polybius henslowi*), the scabbardfish (*Lepidopus caudatus*) and the longspine snipefish. Blue whiting was found to be mostly landed, while Spanish and Atlantic mackerels, hake and pouting were species for which discard rates highly varied.

Gear-based options to mitigate unwanted by-catch that forms the bulk of discards have been tested (see Campos, 2003). The first options tested used square mesh codends, followed by sorting panels and square mesh panels placed at different trawl sections (Campos and Fonseca, 2004, 2007) and sorting grid systems (Fonseca et al., 2005a, 2005b, 2006). However, the regulations applied to trawl fisheries in Portugal, including fishing closures within the scope of the Recovery Plan (Reg. EC 2166/2005), as well as existing control measures, do not encourage fishermen to adopt the gear modifications proposed or develop new options to reduce by-catches. The discard ban, recently proposed during the current CFP review, should become an incentive to use these types of devices that have already been introduced in a number of fisheries within the EU and abroad.

In developing integrated technical measures to avoid discard practices and protect special ecosystems, customized regional and local approaches are essential, and will probably include flexible spatial closures. This emphasizes the relevance of monitoring and analysing data from the fishery data reporting system, namely geospatial tracking information, which is one of the objectives of the present study.

1.3.6 Control and compliance

In Portugal, retained commercial catches are reported at the first sale auction known as the "lota" (Legislative Decree 81/2005), managed by the public company

DOCAPESCA – Portos e Lotas, SA. This company is licensed for the operations of reception, auction and handing over of fishery product, according to Decree Law 81/2005. Currently there are 12 official sale auctions distributed along the entire coastline, the majority of which are open during weekdays, but vary according to the point of sale and fleet. For example, in Portimão the trawl landings are sold in the afternoon after the landings from the artisanal fleet, whereas in Aveiro landings are sold between 9 a.m. and 9 p.m.. The legal regime for the first sale of fresh fish in Portugal was initially established in 1987 by Decree no 304/87, but was later repealed by Legislative Decree 81/2005.

Since 2000, in Europe fishing vessels exceeding 24 meters overall length and operating in the waters of the Community must be equipped with a Vessel Monitoring System (VMS) (Article 3(2) in Council Regulation (EEC) No 2847/93). This positional tracking system is compulsory for Community vessels to ensure compliance with the rules of the CFP (Council Regulation (EEC) No 2847/93). Vessels can be monitored for illegal, unreported and unregulated (IUU) activity, for example to check whether specific fishing vessels (i.e., bottom trawl fleet) are operating outside the six nautical miles line off the coast as required by law or are in compliance with fishing effort adjustment plans**.** Fishing vessels exceeding 18, 15 and 12 meters in overall length have been required to have this system operational since 1 January of 2004, 2005 and 2012, respectively. The Fisheries Monitoring Centres (FMCs) of each Member State receive VMS information at least once every hour from all fishing vessels flying their flag and registered in the Community. The data transmission can be at least once every two hours if the FMC has the possibility of polling vessels position (Regulation EC/2244/2003). The FMC can also require this geo-referenced tracking information at shorter time intervals. When the vessel is in a fishing port, the VMS frequency transmission is reduced to an 8-hour interval.

The VMS reporting obligations required from Member States comprise the list of vessels equipped with VMS, including those for which the location device repeatedly presents technical failure or deficiency, and extends to the number of communications of the positions received by the FMC and the total time spent in marine zones (Article 16 in Commission Regulation (EC) 2244/2003).

All of this fishery-dependent information is collected electronically and further sent to DGRM, where it is stored, analysed, aggregated and published as official statistics and reports (e.g. annually and monthly by Instituto Nacional de Estatistica, INE and

Datapescas, respectively). DGRM also has protocols with other entities (e.g. research institute IPMA and ICES) allowing the dissemination of information for further analysis.

2. Data analysis and main results

2.1 Fishery data reporting and information system

Member States are obliged to collect, manage and provide high quality fisheries data for the purpose of scientific advice according to the Data Collection Framework (DCF, Council Regulation (EC) N° 199/2008). The DCF succeeded the DCR (Data Collection Regulation, Commission Regulation (EC) No 1639/2001).

In Portugal, the trawl fleet is amongst the most fully documented fisheries, as in most member states. The data collected include information on landings and sales notes, fishing logbooks and vessel track information. The most easily accessible and standardized information is the data collected on landings, in weight and market value by species, date and port, and logbook information. The satellite-based Vessel Monitoring System (VMS) data that monitors fishing vessels and their activity is also collected. This control and surveillance geo-referenced tracking system transmits to the land-based FMC, at regular intervals, the location, speed and course of individual vessels.

2.1.1 Logbooks, landings and sales notes

The sampling unit for the sales notes is the fishing trip. However, information collected from paper logbooks is reported by day, as long as the vessel remained in the same ICES rectangle. Logbooks must report data on hauls location and duration, and detail catches in weight by species. It is not required to record all statistical rectangles in which fishing activity occurred, but only the rectangle in which most catches were made (EEC, 1983).

An electronic recording and reporting system (ERS, Commission implementing Regulation (EU) No 404/2011) is being implemented to record and report fishing activities (e.g. catches, landings, sales) to fisheries authorities. From January 2012, the electronic recording system is compulsory for vessels above 12 m, replacing paper logbooks. In Portugal, the electronic logbooks are currently being introduced, with the obligation to transmit to DGRM according to the rules established by this body, e. g. daily fishing activities reported before midnight every day, and trip retained catches reported before arrival to the port. With the enforcement of e-logbooks, the sampling unit will become the individual fishing event (e.g. tow) increasing the precision of the information obtained and its utility to characterize fishing activity. Besides geographical information and detailed catches in weight by species, information must comprise discards for commercial species for which the catch exceeds 50 kilograms (Kg).

2.1.2 VMS – Vessel Monitoring System

The Portuguese vessel monitoring system (MONICAP from the Portuguese MONItorização Contínua das Atividades da Pesca) tracks the activity of fishing vessels through the graphical representation over a digitalized chart. This system was the first of its kind to be implemented in Europe, was introduced in the Portuguese fishing fleet in 1992. MONICAP is part of the national integrated system of monitoring, control and surveillance in the fishing activities “Sistema Integrado de vigilância, Fiscalização e Controlo das Actividades da Pesca” (SIFICAP).

VMS positioning data for each vessel, consisting of a succession of geographical locations (latitude, longitude Datum WGS84), dates, times, speed and course, are received by a ‘blue-box’ (satellite-tracking device installed on board Community fishing vessels), recorded and automatically transmitted via the Inmarsat C satellite system to the national land-based monitoring system and authority responsible for marine surveillance, the Fisheries Monitoring Centre (Portuguese Fishery Directorate – DGRM, Fisheries Inspection).

The quality of this geo-referenced information will depend upon the frequency of information on vessel position. Until 2004, records were obtained every 10 minutes, but since then, EU regulations determined that the frequency of data transmission can be reduced, provided that records are obtained at least once every two hours.

VMS data does not contain information on the vessel status, namely when it is in fishing mode. This means that tracking data must be processed so that the effective fishing activity can be characterized. The first step in this characterization is the identification of fishing trips (FTs). A fishing trip consists of the following main operating phases: steaming from port to fishing ground and back; exploiting (fishing) and floating. For trawlers, fishing exploitation comprises a series of successive tows. While floating, the vessel is not fishing but it can be repairing the gear, processing the catch, or can be inactive because of bad weather. During a fishing trip, a vessel makes a number of tows, which involve deploying, towing, and hauling back the gear.

Speed, along with the geographical position, is one of the most important VMS attributes to assess if a vessel is in fishing activity. For trawlers, Skaar et al. (2011) assume that fishing takes place when speed values vary between 2.0 and 5.0 knots, while in the study by Giakoumi et al. (2012), spatial distribution was analysed by assuming that VMS records with speeds below 4.0 knots correspond to trawling and speeds above this value were classified as cruising speeds, being excluded. In Gerritsen et al. (2012) a speed filter was applied to the VMS records between 1.5 and 4.5 knots to separate fishing from other activities. Afonso-Dias and Pinto (2008) using a geographical information system (GIS) software and a semi-automatic procedure, identified average trawling speeds between 2.1 and 4.9 knots for the Portuguese fish trawlers. In the OSPAR Commission report (2009), VMS data with speeds between 1.0 and 5.0 knots where selected to obtain fishing activity belonging to the Norwegian vessels above 24 meters. The towing speed adopted in the European national research surveys (fishery-independent international bottom trawl surveys) corresponds to approximately 3.5 knots.

Nonsufficient data coverage and availability, irregular frequency transmissions and the existence of low quality data are some of the additional reasons why this type of tracking data requires some processing. Low quality data may include, for example, information of wrong positions (vessel on land), erroneous speed values, or the existence of two consecutive positions in which at least one must be wrong due to the speed traveled between them (ICES, 2010). VMS data does not necessarily require interpolation analysis when the time interval between two consecutive points is reduced, which is the case for high frequency data transmission such as the data from Portuguese trawl fleet (10-minute interval), processed in this study. The analytical methods (track reconstruction, density of position records) and grid-cell resolution used for the analysis significantly affect descriptions and indicators of fishing intensity (Lambert et al, 2012). According to this study, intervals of 30 min provide a desirable compromise between achieving precise estimates of fishing pressure on the seabed and minimizing the cost for data collection and handling. This preference for position reports every half hour to analyse the distribution of fishing activities is also confirmed by the Commission (COM(2008) 187 SEC/2008/0449, DCF). Bastardie et al. (2010) applied the simple grid-based fishing effort on 5-minute VMS ping rates and concluded that the spline interpolation method by Hintzen et al. (2010) achieved minor differences and that the former less intensive methodology is more than enough and more importantly avoids creating fishing effort where there is no fishing effort. Skaar et al. (2011) examined the accuracy of using VMS data to estimate trawled seabed areas using data at intervals of one or two hours, concluding that this resolution may not be high enough to reconstruct tracks with straight line interpolation, as an average of 15 and 20% underestimation was observed for trawl distance, respectively.

2.2 Integration of fisheries-dependent information in support of fisheries management

Fishery-dependent data can be optimized to gain a better understanding of the fishing activity and impacts, as well as of the marine biodiversity and species abundance. These fisheries vessel monitoring and control data can be extended to fisheries research, as the analysis of VMS data provide a better understanding of fleet spatial dynamics, such as the identification of fishing grounds and quantification of fishing activity (pressure indicator).

Moreover, dedicated GIS tools and application based on VMS data associated to catches (or proxies, e.g. landings or logbook data), constitute a valuable instrument in support of fisheries management, allowing the estimation of catches per unit effort (CPUE), often used as a proxy of stock abundance. The integration of fisheries geo-referenced information with landings and size data also provides explicit spatio-temporal information on population structure and relative distribution, together with information on the exploitation pattern that can also contribute to integrated planning and management, in accordance with the objectives of the Common Fisheries Policy (CFP) and Marine Strategy Framework Directive (MSFD).

2.2.1 Estimation of fishing pressure

One possible application of VMS data is the description of the spatial distribution of fishing effort (Afonso-Dias et al., 2002; Murawski et al., 2005; Mills et al., 2007; Mullowney & Dawe, 2009; Lee et al., 2010). Counting the number of times the VMS points fall into a certain cell of a spatial grid (Murawski et al., 2005, Lee et al., 2010) is a simple way to map the aggregated fishing effort.

Another current application of VMS data is the analysis of fishers' behaviour through the movement of vessels (Bertrand et al., 2005; Bertrand et al., 2007; Marchal et al., 2007; Mendes, 2008; Mullowney & Dawe, 2009).

VMS data have also been used to identify untrawled areas or to estimate how frequently an area is trawled (Eastwood et al., 2007; Stelzenmüller et al., 2008). Ragnarsson and Steingrımmsson (2003) analysed the spatial distribution of effort and the impacts of trawling activity in the benthic communities in Icelandic waters. Studies on trawling impact (disturbance) and habitat sensitivity was carried out by Jennings et al. (2012) for the further integration of environmental measures, in accordance with the need for an ecosystem approach. Spatial fishery data is thus gaining importance as there is a growing need to describe, delineate and protect marine areas (e.g. Murawski et al., 2005), including Vulnerable Marine Areas (VMAs, special protection areas and special areas of conservation which can become a part of a network of marine protected areas).

2.2.2 Estimation of species abundance and distribution

Landings information combined with VMS-effort distribution can be used to track the pattern in distribution of the target species (Bertrand et al., 2008; Afonso-Dias et al., 2004; Papers 2, 6 and 7 in this thesis). Some of the applications of integrated VMS and catch data that have been investigated included the use of CPUE maps as a proxy to fish density (Afonso-Dias et al., 2002), population-depletion estimates to determine fishing areas (Deng et al., 2005; Walter et al., 2007); and the quantification of misreporting (Palmer and Wigley, 2009). In this thesis, Paper 7 investigates the utility of integrating VMS and landings data to propose a sampling scheme for the most important commercial species landed by the Portuguese trawl fleet.

Integration of vessel activity and catches at a trip and haul level is of utmost importance for understanding vessel strategies in fishing effort allocation, particularly in a mixed-fisheries context.

There are a large number of possible applications to integrate VMS and logbook datasets. Several applications and projects have been developed using geo-referenced data with the purpose of assisting fisheries management. GeoCrust (Afonso-Dias et al., 2004; Afonso-Dias and Pinto, 2008) was the pioneer; other applications include the Fishery Analyst for ArcGIS 10, Fishing Effort Envelope Tool (Dunn et al., 2010), FAO-COPEMED Fishing activity Simulation Tool (FAST), TECTAC project, CEDER "Development of tools for logbook and VMS data analysis (MARE/2008/10 lot 2)", and the vmstools R package (Hintzen et al., 2012). The EU funded CEDER project (Catch, Effort and Discard Estimates in Real time, CEDER, 2008) used VMS tracking system to identify the minimum resolution required to characterize vessel activity, discriminating between vessel status including fishing and steaming. Risk and impact assessments also use geo-referenced data, including mapping of historical fishing effort and broadly designated fished areas (Penney, 2010).

Although VMS data is already being used by ICES to contribute to the assessment of the state of various species including flatfish species (ICES 2012, Report of the Benchmark Workshop on Flatfish Species and Anglerfish, WKFLAT) it is still not a common practice, as there is no well-defined methodology accepted and recognized by the scientific community. Currently, a Study Group in ICES (SGVMS) addresses the integration of VMS data in fisheries management.

Reliability of fisheries-dependent data is essential when using all the above information for the purpose of fisheries management. Validation of part of this information is possible when data can be cross-checked among different sources. Species catch information is collected from logbooks, landings and sales notes, while data on fishing activity are in logbooks and VMS reports, and finally, information on discards exclusively available from observer reports although more recently it is also required in logbooks. Cross-reference between logbooks and VMS data validates the accuracy of information on logbooks in what concerns vessel spatial position, as well as fishing activity (Afonso-Dias and Pinto, 2008). Depending on VMS data resolution and accuracy attained in the estimation of the number of fishing trips and hauls, the effective fishing time can also be checked in logbooks. Detailed information of trips and hauls in logbooks can also be used to validate VMS processed data. Gerritsen and Lordan (2011), when cross-checking data from logbooks and VMS in a study with the Irish fleet, found that more than 50% of all daily fishing operations were carried out in more than one rectangle according to the VMS data, *versus* 2% according to the logbook data.

2.3 Analysis of the Portuguese bottom trawl fleet

In this study, an attempt was made to find methodological applications to estimate species- (and size-class) specific fishing effort and abundance for the bottom coastal trawl fleet, through the analysis of fishery-dependent data. The utility of these data, including landings and satellite-based VMS information is also shown to map the activity of coastal trawlers and characterize fishing tactics and to examine species-specific distribution and abundance.

Two main fishery-based datasets were used, supplied by DGRM, including data from first sales landings, as well as VMS data. Landings were in weight and value, by species/taxa, vessel and port, for the period from 1995 to 2007, registered from the first sales for the bottom trawl fleet licensed to 55-59, 65-69, and >70 mm codend mesh size. High resolution tracking information (VMS data) for non-crustacean trawlers, consisting of vessel positions and speed, were available for the period 2000-2004. While landings are reported at the end of the trip, VMS data are available from transmissions every 10 minutes. For the second part of this study (Papers 5 and 6), port-based sampling length data obtained at the scope of the DCF was also used.

The technical characteristics of the trawlers in study were obtained from the Portuguese Institute of Ports and Maritime Transport (IPTM), including vessel name, port of registration, total length, beam and depth, engine power, gross tonnage and year of construction.

To analyse VMS tracking, the software application GeoCrust 2.0 (here was made available for this study by the University of Algarve. GeoCrust is a dedicated geographical information system (GIS) application (Afonso-Dias & Pinto, 2008; Afonso-Dias et al., 2004; 2006) at the scope of the Study Contract 99/059, designed to analyse fleet spatial dynamics, by processing VMS data with species information from landings and/or logbooks. Initially designed for the crustacean trawl fleet, GeoCrust was adapted for fish trawlers fleet and has also been used to analyse other Portuguese fisheries.

Preliminary analysis using this software allows the visual inspection of the spatial distribution of each vessel activity, with the possibility to filter by velocity, vessel and time. The GeoCrust system identifies fishing activity in a hierarchical two-step approach, using two different modules: the fishing trip (FT) and the fishing haul (FH) identification. Fishing trips (FT) are initially identified by a semi-automatic procedure which uses a buffer (radius of 0.1º) around the fishing port to identify the beginning and end of the trip. The algorithm then assigns each FT to a corresponding landing event. The fishing trip is classified according to a two-level quality index regarding completeness, with the trip being identified as a valid fishing trip when complete VMS data were available ("high" quality) and defined as partially valid FT ("low" quality) when VMS data was incomplete. This classification is necessary as this may affect haul identification to a high extent and, consequently, the precision of effective effort estimates. Within each FT, fishing hauls are detected and marked (i.e., identified) using a semi-automatic identification procedure based on the analysis of the monthly speed profile for each vessel (Afonso-Dias et al., 2004, 2002; Afonso-Dias and Pinto, 2008). Once the hauls are identified within a trip, the outputs include landings associated to hauls duration (hours) and distance trawled or travelled (nautical miles, n.m.). Fishing effort can therefore be estimated as hours and distance trawled at trip and haul level. These results can be found in Papers 4 and 7.

Processed data from 2003 was already available at the beginning of this study. These initial processed data consisted of 2672 valid FT, of which 77% (2062 FT) had identified hauls. Hauls identified belonged to 48 of the 55 vessels with MONICAP data stored in the GeoCrust software. In order to gain a better understanding of the fishing patterns and dynamics for the Portuguese trawl fleet, as well as of the operational aspects and working procedures of the software GeoCrust, VMS data already processed were re-analysed. Some trips and hauls had not been properly identified; in these cases they were either eliminated or re-defined. During the re-analysis big information gaps and incorrect data (geographic position and speed) were observed, in the VMS, landings and logbooks databases, thus it was not possible to merge all records.

The other software and applications for data management and statistical analysis used in this study were Microsoft Access, Open-source R (R-Development Core Team 2009), ArcGIS, STATISTICA and several different R packages (such as ca and cluster, Maechler et al. 2005; Greenacre and Nenadic 2007).

2.3.1 Fleet segmentation - landing profiles and associated fleet components

According to the DCF (Council Regulation EC No 199/2008, 2008), fleet segmentation is the first step to estimate species-directed effort and abundance, especially in multispecies/mixed fisheries. For this purpose, landing profiles, or homogeneous groups in terms of species compositions, were identified in this study based on landings data. The relationship between these groups and vessel types contributes to the definition of fleet components (FCs), groups of vessels that have the same exploitation pattern over time. The definition of such components can greatly contribute to the critical examination of by-catch and discards and the design of simpler and more efficient sampling schemes thereby contributing to more effective fisheries management.

The current analysis represents the first attempt to define landing profiles and fleet components in the bottom trawl fisheries off the Portuguese coast. In Papers 1 and 2, LPs were defined through classification techniques such as Agglomerative Hierarchical Clustering Analysis based on a data matrix including the monthly landings per vessel as cases and the different species/groups landed as variables, for the period from January 2002 to December 2004. In the absence of a reliable measure of fishing effort, the definition of LPs was based on the relative proportions of the species in the landings. The relationship between LPs and the 66 trawlers included in this study was analysed through Correspondence Analysis (CA), based on a frequency matrix of the 2195 monthly landing events. Groups of trawlers related to the different LPs corresponding to fleet components were then defined in a two dimensional space.

Due to the high species diversity (Afonso-Dias 2008; Costa et al., 2008; Fernandes et al., 2008), with over 200 species listed in the DGRM database for bottom trawl landings, some species were aggregated and the main species (or groups of species) were selected.

In the initial analysis (Paper 1) this matrix comprised a total of 66 trawlers, approximately 2/3 of the entire trawl fleet at that time, in a total of 2195 cases and 31 species/groups of species, representing 78% of the landings. Six different LP were identified, and a correspondence was established between these LPs and three main FCs, or groups of trawlers involved in the same fishing pattern over time. FC1 corresponds to the crustacean fleet, licensed for 55-59 and 70 mm codend mesh sizes, targeting the rose shrimp, *Parapenaeus longirostris* and the Norway lobster *Nephrops norvegicus* in two different landing profiles. The ‘fish’ fleet, licensed for 65 mm mesh size (FC2), comprises three different LPs targeting horse mackerel, *Trachurus trachurus*, blue whiting *Micromesistius poutassou*, and a mix of fish species comprising horse mackerel, mackerels (*Scomber spp.*) and blue whiting. Finally, FC3 comprises a small number of 65 mm codend mesh size trawlers having the octopuses and benthic fish species as their most important landings.

LPs defined within FC2 could not always be associated with an obvious target species. For these LPs, spatial and seasonal patterns emerged from more detailed analysis carried out in Paper 2. This paper focuses on segmentation for FC2 and FC3 defined in Paper 1, comprising monthly aggregated data from the same period for a total of 48 vessels licensed for 65-69 mm codend mesh sizes, corresponding to the fleet targeting fish and cephalopods, commonly designated as the fish fleet. A closer analysis of this fleet allowed the identification of a total of 12 different LPs, from which four were found to be related with cephalopods and benthic associated species within the two FCs under analysis. Seasonal alternation between landings of octopodidae and cuttlefish *Sepia officinalis* (LP10 and LP12 defined in Paper 2) was observed within the small group of old trawlers in FC3. For the larger group of more modern trawlers (FC2), operating mainly off the western coast, inter-annual shift between octopus and squid (LP8 and LP3) was found, together with a well-marked seasonal pattern between the catches of cephalopods and horse mackerel

In Paper 3, the dynamics of the fish fleet was analysed along a 13-year time-series (from 1995 to 2007) of daily landings from 74 trawlers. The purpose was to define consistent patterns of activity over time that could be used to obtain more precise estimation of fishing effort and species abundance. It was assumed that the analysis of this 13-year period would cover possible inter-annual fluctuations in species abundance.

Due to the high volume of data (the final matrix consisted of a total of 103693 landings, each corresponding to one FT, and 18 taxa), a non-hierarchical classification technique was applied - Clustering LARge Application (CLARA) consisting of a partitioning algorithm (partitioning around medoids) that divides the dataset into *k* clusters, where *k* needs to be specified *a priori*. This method deals with large datasets by considering data subsets, avoiding the need to store the dissimilarity matrix of the entire dataset. To define the ideal number of groups, *k* was chosen based on a quality index provided by the algorithm, the Overall Average Silhouette Width (OASW). Average silhouette width is used to define the importance of each group, allowing to define “reasonable” and “strong” quality groupings, as opposed to “weak” and “non-existing“ group structure, (Struyf et al., 1997).

Cluster analysis was run over two separate datasets, landings in weight and in value expressed as a percentage of the total daily trip landings. The first type of analysis evidences biological aspects of fisheries related to species abundance, while the analysis in value takes into consideration the economical dimension of this activity.

A total of six LPs were defined, based on species proportions in weight (Table 2.1). In two of them, pelagic species are targeted, horse mackerel (*Trachurus trachurus*) and blue whiting (*Micromesistius poutassou*). The remaining four LPs corresponded to mixed fisheries, where squid (*Loligo spp.*), horse mackerel and octopuses (Octopodidae) were identified as main targets.

Table 2.1 - Fleet segmentation: definition of landing profiles (LP) based on 17 species and a total of 103693 fishing trips conducted by Portuguese fish trawlers in the period 1995-2007. LP are defined according to target and by-catch species (only species with percentage above 10% are represented) using data corresponding to percentages of weight. Adapted from Paper 3.

LP	Target species (%)	By-catch species (%)	% FTs	% weight	% value
1	Octopodidae (26.3)	*T. luscus* (22.4), Others (17), *T. Trachurus* (12.8)	22.3	11.5	18.6
2	Others (54)	*S. colias* (19.6)	9.1	7.2	7.4
3	*T. trachurus* (44.9)	*T. luscus* (10.3)	32.1	28.1	33.7
4	*Loligo spp*. (44.9)	*T. trachurus* (25.7), *T. luscus* (11.3)	4.8	2.3	4.3
5	*T. trachurus* (75.9)		23.5	37.2	28.0
6	*M. poutassou* (58.7)	*S. colias* (19.6)	8.2	13.5	8.0

To define FCs within the fish trawl fleet LPs were assigned to trawlers through Correspondence Analysis. The relationship between LP in weight and the 74 trawlers included in this study was analysed using a frequency matrix of the 103693 FT. Three fleet components were defined in Paper 3 corresponding to distinct groups of vessels addressing different ecological groups and differing in their fishing strategies, namely the area of operation. Small units of GT around 50 target mainly Octopodidae and benthic species off the south coast (previously defined as FC3 in Paper 1); a class of "intermediate" trawlers (100-200 GT) target octopus and squid together with high proportions of horse mackerel; and a small number of high GT trawlers specialized in horse mackerel and blue whiting. These two last FCs correspond to vessels classified as FC2 in Paper 1.

In terms of landing ports, horse mackerel is the main target, together with squid, in Matosinhos the only northern port with significant landings, while the Octopodidae are landed, together with horse mackerel and squid, in the ports of Aveiro and Figueira da Foz, in accordance to what was observed in Paper 2. Octopuses decreases in importance as target species in the port of Nazaré, being definitely a non-target group in the remaining ports, with the exception of the port of Olhão, where they are again landed as target species, but not together with squid.

2.3.2 Time and spatial patterns of fleet activity

Using landing information with region and ports as spatial indicators

Time and regional patterns of fishing activity were first analysed at quarterly and yearly scales in Paper 3. Patterns of LP activity were investigated by analysing separate data matrices of landings, for this time-series, using both weight and value, in order to confirm LP stability over time. This exploratory analysis demonstrated that a number of vessels changed their fishing strategy across the study period, switching between distinct LP with more frequency than others. This was particularly observed between LP1 (Octopodidae) and LP3 (horse mackerel), sharing common species, and can possibly contribute to explain why these two groupings were defined as weak ones in the cluster analysis using proportions in weight.

From the analysis of quarterly distributions of FT frequencies by LP in weight (Paper 3), time patterns were not evident for LP6, targeting blue whiting, or LP2, targeting a mix of species. On the other hand, seasonal fluctuations were well marked mainly for LP5 and LP4, targeting horse mackerel and squid respectively. Time patterns were also observed to a lesser extent for LP3 in which horse mackerel is a target species and for LP1 targeting Octopodidae. Progressive annual increase in the number of FT in LP3 has been registered along the time-series, while marked inter-annual fluctuations were observed mostly in LP4 and LP5.

Spatial activity by LP was also investigated, in Paper 3, using region as a spatial indicator. All LPs had fishing trips in the four regions (North, Centre, Lisbon and South), with the exception of LP4 targeting squid, for which FT were almost entirely in the Centre (83% of the FTs) and North regions (Figure 2.1). This suggests spatially located distribution for this group. For LP6 (targeting blue whiting), almost 80% of the FT are from the North and Centre, while for LP2 60% of the FT are from the southwest and south regions, suggesting regional patterns of activity. For LP1 (targeting octopus) and LP3 and LP5 (targeting horse mackerel) a wide geographical distribution was recorded, LP5 with a higher activity in the North when compared to the other two.

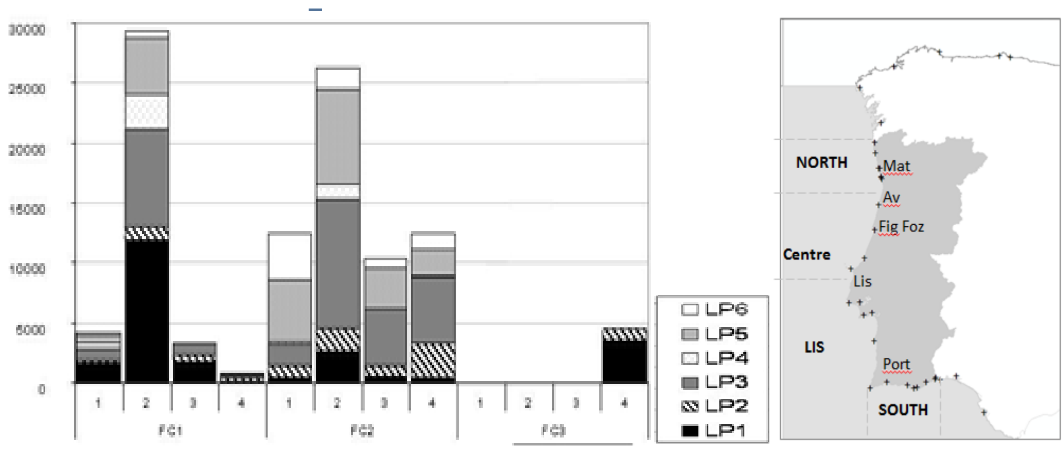

Figure 2.1 - Right - Number of fishing trips (y-axis) by landing profile (LP), grouped according to x-axis region and fleet component for the 74 vessels. Regions 1 to 4 correspond to North, Centre, Lisbon and South, respectively. Map of Portuguese coastline, including ICES subdivision IXa (limits are 36 to 43ºN and 5º to 12ºW, shaded in light grey), with geographical location of main fishing ports (Matosinhos, Aveiro, Figueira da Foz, Lisbon and Portimão), represented by dots. Adapted from Paper 3.

FC1 vessels are mainly active in the Centre (78% of FT). Vessels belonging to FC2, while more active in the centre (43% of FT), present a wider geographical activity, landing along the entire coastline. FC3 vessels, a small number of less active trawlers, operate exclusively in the south (Figure 2.1). Landings occurred in a total of 21 different ports; however, continuous landing activity across the entire 13-year period in study was observed only in ten ports. Four out of these ports (Matosinhos, Aveiro, Figueira da Foz and Nazaré) accounted for two thirds (66%) of the total number of FT.

Octopus and squid (LP1 and LP4) are mainly targeted by FC1, and blue whiting (LP6) by FC2. On the other hand, horse mackerel (LP3 and LP5) is targeted by FC1 in the Centre and FC2 along the entire coast. FC3 vessels present mixed landings composed of octopus and benthic species.

Description of vessel activity by LP is further characterized in Paper 3 through the use of two different metrics. The "polyvalence index" (Ulrich and Andersen, 2004) measures the relative importance of the LP and a "stability index", which quantifies the percentage ratio of consecutive FT with the same classified LP. The two indices provide an insight into individual short-term fishermen behaviour, in particular the tactical patterns associated to the FT. Differences of LP stability and polyvalence were observed between the three FC, with higher stability and lower polyvalence observed for the less active trawlers belonging to FC3 when compared to the remaining. FC1 and FC2 vessels presented similar stability and polyvalence values. A third index denoted as fidelity, was estimated for region. In general, vessels concentrate most of their landings in one port, displaying a high fidelity to region and fishing port.

Analysis of landing patterns using high-resolution tracking information

To gain a better understanding of the spatial activity for this fleet a first attempt to integrate landings and VMS data was carried out. In Paper 2, spatial patterns of activity were identified using the available VMS data. These data were combined by vessel and month, and mapped using GeoCrust 2.0 software (Afonso-Dias et al., 2004; Afonso-Dias and Pinto, 2008) to visually display fishing operations by LP in order to better define the geographic pattern of the fishing activity of this fleet. This integration of spatial data in this study was important to map fleet activity, demonstrating the existence of temporal and spatial cephalopod targeting strategies.

In Paper 4, the potential of VMS processed data to quantify the fishing activity is illustrated. A collection of VMS data with 10-minute interval corresponding to a year of activity was processed, analysed and interpreted for a single Portuguese coastal trawler operating off the west coast, to identify the main operating phases. For practical purposes, only two main activities were considered, towing and steaming (from port to fishing ground; between fishing grounds; and back to port). Accurate computation of fishing effort estimates were obtained, including trip and hauls duration, as well as distances trawled. The methodology to estimate species directed effort involved the cross analysis of effort with landings from individual fishing trips belonging to previously identified LPs. Fishing effort and abundance indices (landings per unit effort, LPUE) by LP could then be obtained for the vessel in study. It is demonstrated how high-resolution VMS data allows a better understanding of fishing tactics and derives more precise series of effort estimates.

In Papers 5 and 6 a selected number of cephalopod targeting trips containing landings, associated size-structure data and VMS points corresponding to fishing activity (ie fishing points) were analysed. Fishing intensity was mapped by allocating VMS records associated to fishing to the ICES statistical grid. Within each grid rectangle, the number of VMS fishing records was summed (points per grid cell), according to Afonso-Dias and Pinto (2008) and Lee et al. (2010), constituting a measure of fishing intensity which may be viewed as a proxy of fishing effort.

The methodology described in Paper 4 was used for processing VMS data corresponding to the fleet activity in 2003. In Paper 7, fishing activity within the different landing profiles was characterized using 5000 VMS identified trips. By quantifying the fishing activity within these individual trips, estimations of fishing effort were obtained and used to estimate species-specific abundance for the main species targeted.

2.3.3 Estimation of species- and size-specific effort and landings per unit effort

In Paper 3, a first approach for the quarterly estimation of the target species/groups abundance (species-directed landings per trip (LPT) is presented, using the landed quantities, associated to the number of trips in each of the LP defined. LPT monthly estimates were found to be higher (within the same order of magnitude) for pelagic fish, horse mackerel and blue whiting, decreasing for squid and octopus. Initial increase in LPT for horse mackerel is seen from 1995 to 1996, with a decrease and stabilization from 2000 onwards. For the remaining species, inter-annual variations were observed. Seasonal variations can also be noticed for all species, with the exception of blue whiting.

Integration of landings and size data with high resolution tracking information was carried out in Papers 5 and 6, with the estimation of size-dependent effort and analysis of geographical patterns of population structure for squid and octopus in 2003. This was done by integrating port-sampling length information collected within the DCF program for specific fishing trips belonging to LPs representative of these two groups, with geo-referenced data from fishing trips and hauls. Fishing intensity was then mapped by allocating VMS records associated to fishing to a grid corresponding to the ICES statistical rectangles (0.5 latitude * 1º longitude) for the period in study. Within each rectangle, the number of VMS fishing records was summed (points per grid cell), according to Afonso-Dias and Pinto (2008) and Lee et al. (2010), constituting a measure of fishing intensity which may be viewed as a proxy of fishing effort. The number of individuals by size category was then allocated to each ICES rectangle according to the proportion of number of VMS points identified by trip.

For octopus (Paper 5), differences in the distribution of fishing intensity among ICES rectangles were evaluated, together with differences in size distribution. The results show that most of the fishing intensity was directed at the rectangles off the region of

Aveiro on the west coast, where the smaller octopus are found (Figure 2.2ab). This is an area where important fish nurseries are also located (Cabral et al., 2007), and coincides with the largest concentration of octopus biomass that was determined by research surveys conducted along the years over the entire Portuguese coast (IPMA, unpublished data).

For squid (Paper 6), fishing pressure was found to be most intense in inshore areas of the northwest and the south coasts. Population size structure, classified into 3 categories, was not uniform throughout the fishing areas. Larger squid are found offshore in the northwest and in the south, whereas all inshore western coast rectangles showed larger proportions of small squid relative to the southern rectangles (Figure 2.2cd).

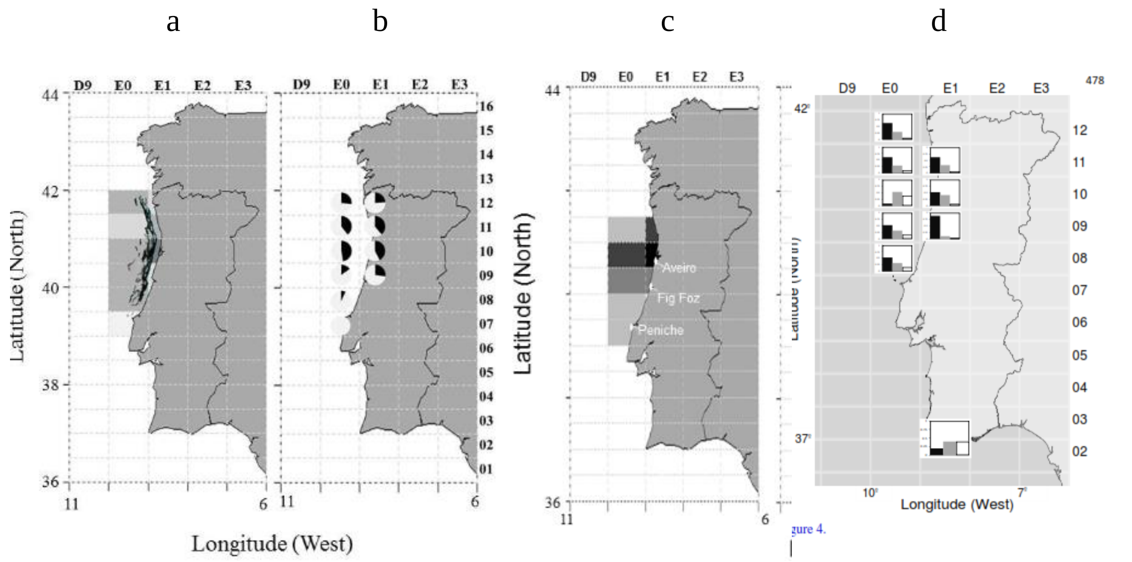

Figure 2.2 - Map of fishing intensity (a and c) and size-structure (b and d) for trips targeting octopus (a and b) and squid (c and d) with length and VMS data by ICES rectangles for 2003 in ICES division IXa. ICES rectangles are identified from top and right axes. Fishing intensity (number of VMS points) decreases from dark to light gray. A: Octopus fishing intensity. B: Octopus size structure from LP1 targeting Octopodidae. Pie diagrams represent proportions of the total number of individuals caught in each rectangle grouped into two size classes (under 12cm ML in black, and over 12cm ML in grey). C: Squid fishing intensity in LP4 targeting squid. Three fishing ports are indicated: Aveiro, Fig. Foz (Figueira da Foz) and Peniche. D: Squid size structure grouped into three size classes (under 16; between 16 and 21; and over 21 cm, in black, grey and white, respectively) shown as proportions (0 to 1, y-axis of the barplots). Figure adapted from Paper 5 and 6.

More accurate effort estimates could be obtained in Paper 7 using high-quality VMS information. A collection of data with 10-minute intervals was analysed for the entire fleet over a 12-month period corresponding to 2003, using GeoCrust. The potential of this software to identify the tracks corresponding to tows enabled the estimation of effective fishing effort (towing time) with a higher degree of precision. This had been illustrated in Paper 4, where accurate computation of fishing effort estimates was obtained from the system for one trawler.

Landings per day at sea, LPDAS, and landings per hour trawled, LPHT, were estimated in Paper 7 for individual trips in 2003 of the entire fleet, for the four commercial species/taxa selected (horse mackerel, blue whiting, squid and octopodidae). Fishing effort indicators (trip duration and total hours trawled) were estimated by LP for 2003. Species-specific LPDAS and LPHT could then be computed using these two last indicators together with the individual landings.

The high amount of available data for this fleet (44 trawlers) corresponding to landings data during the 13-year study period helped the search for a relationship between vessel and LP (Paper 3). This relationship is not bi-univocal (one LP – one vessel) but involves the choice of a group of vessels representative of all the fleet activity. In Paper 7, six out of these 44 trawlers were chosen with regular landing activity during most of this period and good geo-referenced information. Such vessels, with landings from the distinct LP defined in Paper 3 for this fleet, were selected with the purpose of constituting a sampling fleet for estimating species-directed abundance for this fishery.

High-quality non-processed VMS records for this fleet during 2000-2004 (the period corresponding to the existence of 10-minutes intervals between records) were also available. The amount of work required for processing all this information, together with the existence of a high number of trips with incomplete data, reinforced the need to use this "reference fleet" for the purpose of estimating species-directed fishing effort. All trips (valid and partially valid) and hauls within the trips from this fleet were then identified for the remaining years (2000 to 2002 and 2004). Abundance estimators referred to above, landings per day at sea, LPDAS, and landings per hour trawled, LPHT, were then obtained for the reference fleet by LP. By using these estimations for 2000 to 2004 it is assumed that the fleet behaviour has remained constant, i.e. trip duration and total hours trawled were constant over time.

The representativeness of this selected fleet in terms of effort and LPUE was examined in Paper 7 by comparing these estimators, for the species/groups selected with those obtained to the entire fleet within the period 2000-2004. The results suggest that this fleet is a possible candidate to adequately sample horse mackerel, while for cephalopods, in particular Octopodidae, there is a need for increasing the sampling effort. This is not surprising, since fast-growing and short-lived species such as octopuses and squids are particularly demanding in terms of sampling effort.

3. Discussion

3.1 Fleet segmentation – time and spatial patterns of activity

Following the segmentation of the entire coastal trawl fleet, based on the analysis of a three-year series of landings aggregated by month, the focus was directed to the 'fish' trawlers by examining its segmentation and dynamics along a 13-year period of daily landings. The latter results are consistent with, and build upon those obtained in previous studies, by providing an in-depth knowledge on the landing patterns for the different landing profiles and associated fleet components.

Taking the most important species caught by the fish trawling fleet as defined by landings weight and/or value, three main fishing patterns were highlighted. For squid and blue whiting, landings are concentrated in a group of FT, evidencing a direct-targeting behaviour. Benthic species, such as the Octopodidae, are caught over a larger range of FT but with landings concentrated in a restricted percentage of those trips. Conversely, horse mackerel is landed in almost all FT although in extreme variable proportions, either as a target or as a by-catch species.

The global patterns associated with the catch of the main target species are intrinsically related with their ecology (habitat, geographical distribution and abundance), therefore inducing seasonal fluctuations in landing profiles. LP targeting horse mackerel have a higher number of trips during the first two quarters (cf. Murta and Borges, 1994*)*, while those targeting squid are mainly concentrated in the second semester. These peaks in fleet activity coincide with the occurrence of large mature individuals (Moreno et al., 2007; Otero et al., 2007) of a higher commercial value, which constitute the leitmotif of the fishery.

Yearly variability is also observed along the study period. A progressive annual increase in the LP targeting horse mackerel and pouting was registered until 2005 with a downward trend thereafter. For LP where horse mackerel is the only species targeted, the latter trend is somewhat masked by large inter-annual fluctuations in the number of fishing trips. The LPs targeting cephalopods also displayed marked inter-annual fluctuations with a high negative correlation between them. These variations were particularly pronounced for the LP targeting squid, which presented a 3 to 4-year cycle in abundance. The successions of these LPs suggest that a shift in vessel strategy towards octopus is driven by the decrease in abundance of squid stocks.

The distribution of FT by ports reveals that the fleet activity is carried out mainly along the western coast, with only about 17% of the fishing trips landing in southern ports. The most striking event along the period analysed was the shift in port landings from the North to the Centre region, which may be closely related to operational improvements (new landing quay and auction facilities) in Aveiro, the main port of the Centre.

Data analyses supported a fleet segmentation into three components (FC), characterized by different fishing strategies and technical features (length, tonnage and engine power). The largest component, both in number of vessels and in capacity (tonnage and power), operates along the entire coast, targeting mainly fast-swimming species, such as horse mackerel and blue whiting. A second FC comprises vessels smaller in size, with about two thirds of the engine power when compared with the former group and landings carried out almost exclusively in the Centre region. The lower engine power naturally drives the activity of these vessels to cephalopods, which are slower or less capable of prolonged swimming activity when compared to pelagic species. However, seasonal fluctuations in cephalopods abundance imply the need for these vessels (even considering they are less powered), of redirecting their activity to horse mackerel, which dominates the catches in most of the alternative trips. The third component is constituted by older, smaller and low-powered vessels targeting mostly octopuses and an assortment of benthic species, and operates exclusively off the south coast. These vessels carry out a relatively low number of fishing trips throughout the year and exhibit high stability in terms of LP, in accordance with their specialised activity. This reflects a high dependency on certain stocks and thus a lower ability to adapt to changes in resource availability.When compared to these vessels, the remaining present higher polyvalence, reflecting a more opportunistic behaviour with a higher resilience to biological fluctuations in the abundance of target populations or changes in their first sale price.

Similar studies addressing the segmentation of bottom trawl fleets have been carried out in Iberian Spanish waters, namely in the Cantabrian Sea, by Punzón et al. (2010) and Jiménez et al. (2004) for the Gulf of Cadiz, where fish assemblages are similar to those occurring in Portugal. Punzón et al. (2010) identified a total of four different fishing tactics, targeting mackerel, horse mackerel, blue whiting and a mixture of species, and two different fleet components. Two of these tactics, aiming at horse mackerel and blue whiting, concur with LP defined within this thesis. Further south, in the Gulf of Cadiz , Jiménez *et al.* (2004) identified a total of 22 fishing trip types reflecting higher biodiversity typical of near-Mediterranean waters, of which horse-mackerel and common octopus (*Octopus vulgaris*) were the target species for three fishing trip types each, and blue whiting for a single one. Both of these studies evidence and support the importance of pelagic species and Octopodidae in conditioning fleet dynamics and segmentation for south European fisheries.

3.2 Estimation of effort and LPUE

The usefulness of LP identification to address species-specific fishing effort and landing per unit of effort was illustrated by estimating LPUE for the target species within each landing profile, by weight, per fishing trip, for the entire period in study. This approach provided a more accurate estimate than the traditional approach of considering the fishery as a single métier, although it is still a relatively crude estimation.

More accurate effort estimates were obtained using high-quality VMS data. A collection of data with 10-minutes interval was analysed for the entire fleet in 2003. The potential of this software to the delimitation of the tracks corresponding to tows, allowed for the estimation of effective fishing effort (towing time) with a higher degree of precision. Integration of these more precise effort data at trip level with landings, allowed LPUE estimations as landings per day at sea and landings per hour trawled, for the species/groups selected.

During this study, data processing was frequently challenging due to frequent gaps in the transmission. Furthermore, short haul durations created some uncertainty in individualizing single hauls. This may have caused some bias in the estimation of the effective time spent trawling. Logbooks could be useful for cross-validation of VMS data and contribute to the estimation of more reliable LPUEs. However, within the preliminary work within the scope of this thesis, it was found that the accuracy of the information contained in logbooks was often questionable.

3.3 Improving sampling programme at the scope of the Data Collection Framework

One of the objectives of the thesis was to identify a number of directed fisheries, consistent in time, which could be used as stratification levels in a sampling program for the fish trawling fleet. For this purpose, landing profiles were defined and subsequently the correspondence between these LP and specific fleet components (i.e., vessel groups), and specific-time frames was investigated. However, a full correspondence was not achieved. A single LP could not be assigned exclusively to individual vessels; rather they are the reflection of the activity undergone by each vessel at a specific time, possibly related to seasonal shifts in species abundance. The common situation observed is a group of vessels actively engaged in more than one LP, as they target different components of the fish assemblages at different times. The fact that there is no clear relationship between LP and vessels (although vessels in each FC display preferences for specific LP), may represent a difficulty in the design of a future sampling programme based on the definition of LP (Campos et al., 2011). Nonetheless, the identification of these LP, including seasonality, fleet components and the highlight of individual vessel's activity (stability and polyvalence relative to both LPs and landings ports) constitutes a working basis for the improvement of the existing sampling programme. Furthermore, to minimize sampling costs, one of the foremost principles to be addressed is the need for the selection of representative vessels to adequately estimate LPUEs for the main species in this fishery.

3.4 Final considerations

By providing a more reliable account of effective towing time, the use of VMS data allows for a precise estimation of fishing effort, and therefore of LPUE, thus contributing for better resource assessment and management. Even considering the major benefits arising from the use of VMS-derived effort data, reliability of LPUE estimates could be further improved if a trustworthy relationship between catch and individual hauls was established. This is particularly important for vessels switching between fishing tactics in the same trip. The future adoption, within the EU, of electronic logbooks may contribute to partially solve this problem, although the usefulness of e-logbooks will always be highly dependent on the correctness in its entries, in other words on the quality of the data.

Financial constraints related to data transmission led, in 2004, to the adjustment of transmission rate from 10-minute to 2-hour interval. This will compromise the use of more recent VMS data for the purposes described in this study. In this fishery, where mean tow duration is around 2 hours, a 2-hour-interval between the consecutive reception of VMS data points will preclude the correct identification of single tows.

Notwithstanding, this thesis constitutes a first attempt to define a number of vessels, representative of the different LP defined for the coastal bottom trawl fleet, to constitute the basis of a future sampling fleet.

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5. Papers

Paper 1

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Definition of fleet components in the Portuguese bottom trawl fishery

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Abstract

The bottom trawl fishery in Portuguese continental waters is a multi-species fishery where a large number of commercial species are landed by a fleet composed of about 100 trawlers. This paper presents the results obtained from applying ordination and classification methods to the 2002–2004 monthly landings per vessel with the purpose of defining landing profiles (LPs) and associated fleet components (FCs).

Six different LPs emerged from the analysis, each defined by the relative importance of target and by-catch species. A correspondence between these LPs and groups of trawlers was established, suggesting the existence of three main fleet components, or groups of trawlers involved in the same fishing pattern over time. The crustacean fleet, targeting the deep-water crustaceans, Norway lobster, *Nephrops norvegicus*, rose shrimp, *Parapenaeus longirostris*, and red shrimp, *Aristeus antennatus*, and comprising two different LPs, is composed of the most recent and technologically advanced vessels. The 'fish' fleet, mainly targeting semi-pelagic species such as the horse mackerel *Trachurus trachurus*, the Atlantic mackerel, *Scomber scombrus*, and the Chub mackerel, *Scomber japonicus*, constitutes a diversified group in terms of their technical characteristics and LPs. A small number of trawlers have the *Octopodidae*, the cuttlefish, *Sepia officinalis* and benthic fish species as their most important landings, constituting a well individualized, and previously unsuspected, fleet component.

Keywords: Bottom trawl fisheries; Landing profiles; Fleet components; Portuguese continental coast

1. Introduction

The Portuguese continental waters (ICES Sub-area IXa) are subjected to intense fishing pressure by the bottom trawling fleet. A large number of commercial species is landed by more than 100 trawlers, using cod-end mesh sizes from 55 to 70 mm.

The existence of a well-defined *métier* has traditionally been assumed within these fisheries, corresponding to approximately 30 vessels targeting Norway lobster, *Nephrops norvegicus*, rose shrimp *Parapenaeus longirostris* and red shrimp, *Aristeus antennatus*, off the continental slope of the southern and southwestern coasts. Until 2002, these vessels held fishing licences for small mesh cod-ends (55 mm stretched mesh size). Since 2003, a 70 mm mesh size has been enforced for vessels targeting Norway lobster, and at present all of the crustacean trawlers are licensed to both mesh sizes. The remaining vessels, targeting mainly fish species and holding fishing licences for 65 mm cod-end mesh size, are usually typified as a single *métier* for management purposes. However, this approach may be unsuitable in the case of heterogeneous fleets such as the one studied here, fishing over a wide geographical area corresponding to a coastal extension of more than 500 nautical miles and exploiting different fish assemblages. For this fleet in particular, there is a need to investigate the existence of homogeneous groups in terms of species compositions, based on landings data, as well as their spatial/temporal boundaries. Such groups, usually defined by means of multivariate analysis, have been referred to either as "fisheries" (Murawski et al., 1983); "directed fisheries" (Lewy and Vinter, 1994); "fishing trip types" (Silva et al., 2002; Jiménez et al., 2004); "fishing tactics" (Maynou et al., 2003) or "landings profiles" (Ulrich and Andersen, 2004). The relationship between these homogeneous groups and vessel types can lead to the definition of "sub-fleets" (Lewy and Vinter, 1994), "fleet components" (Silva et al., 2002; Jiménez et al., 2004), or "métiers" (Biseau, 1998), i.e., groups of vessels that have the same exploitation pattern over time.

The current analysis represents the first attempt to define fleet components in the bottom trawl fisheries off the Portuguese coast. The definition of such components can greatly contribute to the design of simpler and more efficient sampling schemes, allowing the critical examination of by-catch and discards; and a better estimation of species-specific effort and fishery-based

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abundance indexes such as catch per unit effort (CPUE), thereby contributing to more effective fisheries management.

2. Materials and methods

2.1. Characterization of landing profiles

The data, comprising monthly landings in weight from 180 species/groups for 113 trawlers during the period from January 2002 to December 2004, were supplied to IPIMAR by the Portuguese General-Directorate for Fisheries and Aquaculture (DGPA), following a protocol between the two institutions. This information was arranged in a two-way data matrix including the monthly landings per vessel as cases (rows) and the different species landed as variables (columns). A number of trawlers were excluded from the analysis, namely, vessels landing in Spanish ports, as well as those landing during less than 9 months in at least one of the years. Only those species which constitute at least 0.1% of the total landings were retained for the analysis.

In the absence of a reliable measure of effort from fishing logbooks, the definition of homogeneous groups in terms of species compositions (hereafter referred to as landing profiles, LPs) was based on the relative proportions of the species in the landings. Thus, matrix entry (i, j) is the amount of species j in the landings for month i, as a proportion of the total landings of the vessel in that month. The final matrix included data for only 66 trawlers, approximately 2/3 of the entire trawl fleet, in a total of 2195 cases and 31 species, representing 78% of the total weight of the landings.

Ordination (principal components analysis, PCA) and classification techniques (agglomerative hierarchical clustering analysis, HCA) were undertaken on the data matrix, with the purpose of defining landing profiles (LPs) that are relatively homogeneous with respect to species composition. HCA was run using Ward's minimum variance clustering algorithm (Ward, 1963) over the Euclidean distances of the final matrix, while ordination through PCA was based on the covariance matrix. The analyses were carried out in S-Plus® (Insightful Corp., 1999).

2.2. Definition of fleet components

The relationship between LPs and the 66 trawlers included in this study was analysed through correspondence analysis (CA), using the STATISTICA software package (StatSoft Inc., 2003), based on a (6×66) frequency matrix of the 2195 monthly landing events. Groups of trawlers related to the different LPs corresponding to fleet components were then defined in a two-dimensional space. The technical characteristics of the trawlers under study were obtained from the Portuguese Institute of Ports and Maritime Transport (IPTM), including vessel name, port of registration, total length, beam and depth, engine power, gross tonnage and year of construction, as well as a list of deck and navigation equipment.

2.3. Status of each species along the 3-year period

In this study, the status (target or by-catch) of each species in the fishery was first determined by their relative importance in the LP where that particular species was caught. However, some of the species that have contributed to the definition of a particular LP, were found to be representative of other LPs as well. Their importance as target species was then closely examined using two different indicators, according to Biseau (1998): (a)

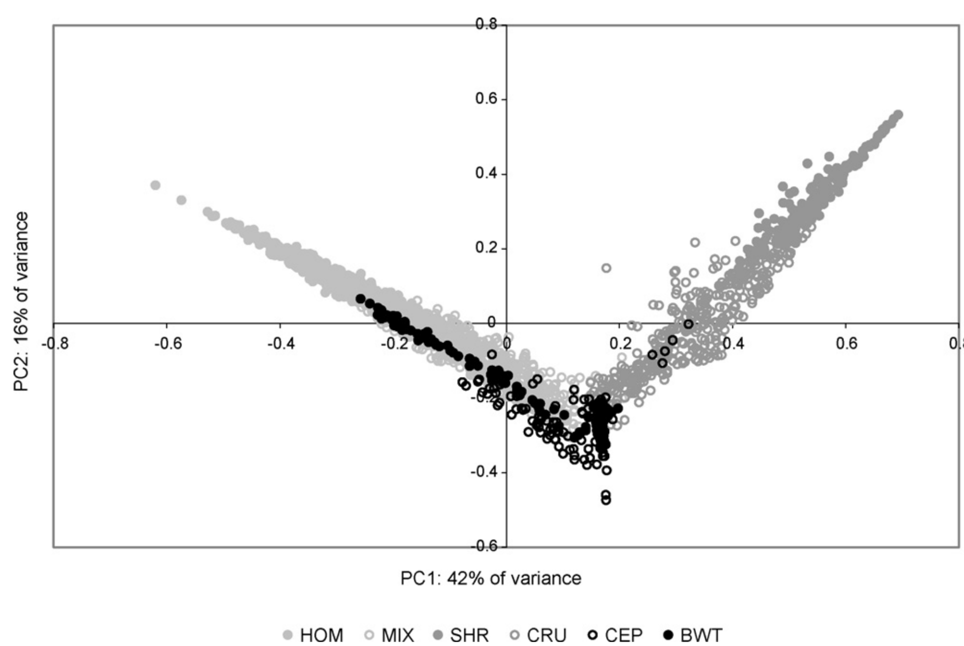

Fig. 1. PCA scores of the first two axes, accounting for 58% of the total variance. The first axis differentiates mainly between fishing trips targeting horse mackerel and crustaceans. The second axis is related to the octopus, blue whiting, pouting, squid and cuttlefish that are landed in much lower proportions. The patterns are related to the six different LPs defined. Light grey full circles: HOM; light grey open: MIX; dark grey full: SHR; dark grey open: CRU; black full: BWT; black open: CEP.

Table 1
PCA loadings for the most important species in the first two components

Species	PC1	PC2
T. trachurus	−0.778	0.532
P. longirostris	0.549	0.718
Octopodidae	0.030	−0.321
M. poutassou	−0.027	−0.154
T. luscus	−0.077	−0.124
Loligo spp.	−0.027	−0.112
N. norvegicus	0.245	0.060
S. officinalis	0.028	−0.138

the cumulative proportion of landings for each species, plotted against the respective proportions in the landings of the monthly fishing trips, was used to determine the level of efficiency in catching the considered species along the different LPs; (b) the cumulative proportion of (monthly) fishing trips, plotted against the landing proportion, determined to what extent the fishing effort is directed or not, i.e., the importance of specialized trips in terms of landings.

3. Results

3.1. Landing profiles

The first two PCA components explain 58% of the variability associated with monthly landings (Fig. 1). In the first axis of the PCA, fishing trips were separated by differences in the proportions of, on the one hand, horse mackerel (*Trachurus trachurus*), and on the other hand, rose shrimp and Norway lobster, evidencing the contrast between LPs targeting small pelagics and crustaceans (Table 1). In the second axis the influence of horse mackerel and rose shrimp contrasts with that of the *Octopodidae*, blue whiting (*Micromesistius poutassou*), pouting (*Trisopterus luscus*), squids (*Loligo* spp.) and cuttlefish (*Sepia officinalis*), landed in much lower proportions.

The same general pattern was found when applying HCA, with two distinct groups formed at the highest linkage distance, corresponding to LPs where fish and crustaceans are separately targeted (Fig. 2). The final number of LPs was determined by

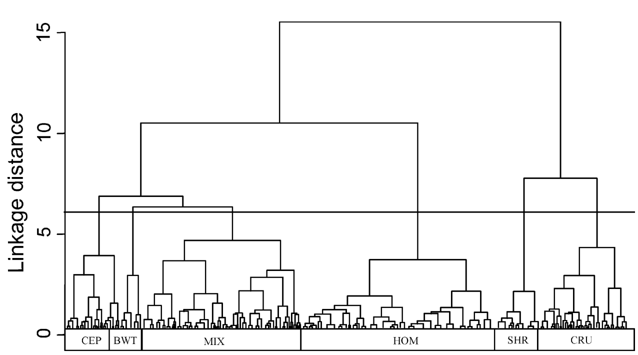

Fig. 2. Results from HCA. The six major groups individualized, corresponding to the different LPs, are named after their main target species. CEP: cephalopods; BWT: blue whiting; MIX: horse mackerel, Chub mackerel, Atlantic mackerel, blue whiting; HOM: horse mackerel; SHR: rose shrimp; CRU: Norway lobster and rose shrimp.

both a visual inspection of the dendrogram and the graphical approach adopted by Lewy and Vinter (1994), based on the plot (not shown herein) of the linkage distances against the number of clusters. This number corresponded approximately to the point where the rate of variation between adjacent linkage distances decreased sharply. Six different groups were identified that were considered representative of the different LPs. They are characterized in Table 2 using the original data matrices of monthly landings, with indication of their relative importance in terms of species composition, landed weight, landed value and number of fishing trips. HOM corresponds to a LP targeting horse mackerel, in which this species represents about 56% of the landings, while MIX is a mixed species LP landing horse mackerel, as well as Atlantic mackerel (*Scomber scombrus*) and Chub mackerel (*Scomber japonicus*). These are the two groups that contributed most to the total landings and to the overall number of fishing trips. In SHR the rose shrimp is the main target species, representing 72% of the total landings for this group, while in CRU, Norway lobster equals rose shrimp in proportion. Crustaceans represent low percentages (about 5%) of the total landings, but their economic importance is much larger, 27% of the total first sale values. CEP and BWT are LPs that are distinct from each other and from the remainder in terms of species composition as well as in their proportion in landings and number of fishing trips. In CEP, the octopuses and the cuttlefish are the main target species, while BWT is directed to blue whiting.

3.2. Fleet components

The first two axes of the correspondence analysis explain 69.2% of the total variance for these data (Fig. 3). A correspondence between vessels and LPs can be observed, suggesting the existence of three fleet components, i.e., groups of trawlers developing the same fishing pattern over time. These groups are characterized in Table 3 by the average characteristics of trawlers in each group and their relative contribution to the total num-

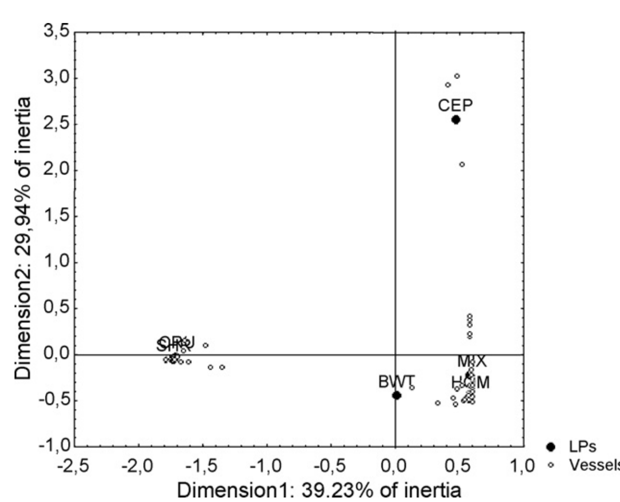

Fig. 3. First two axes of the CA, representing 69% of the total inertia. The crustacean fleet, comprising more recent and technologically advanced vessels, contrasts with fish trawlers along the first axis, while the small trawlers targeting cephalopods are clearly distinguished along the second axis from the remaining fleet.

Table 2
Definition of landing profiles (LPs) in terms of species composition, landed weight, landed value and number of monthly landings

LPs	Species composition (%)								Landed weight (t)	% of total landings	No. of monthly trips	% of total trips	Landed value (10^3 Euros)	% Value
MIX	*T. trachurus*	24.5	*S. japonicus*	10.7	*S. scombrus*	9.8	*M. poutassou*	8.7	12,502	28.8	621	28.3	21,055	24.0
CRU	*N. norvegicus*	27.4	*P. longirostris*	23.5	*M. merluccius*	14.1	*M. poutassou*	11.0	1,244	2.9	347	15.8	14,101	16.1
CEP	*Octopodidae*	33.5	*S. officinalis*	10.5	*T. luscus*	9.3	*T. trachurus*	7.3	1,144	2.6	209	9.5	4,081	4.7
HOM	*T. trachurus*	55.8	*M. poutassou*	7.3	*S. scombrus*	6.2	*S. japonicus*	5.1	23,061	53.1	753	34.3	34,282	39.1
BWT	*M. poutassou*	51.2	*T. trachurus*	26.7	*S. japonicus*	5.9			4,438	10.2	90	4.1	4,710	5.4
SHR	*P. longirostris*	71.6	*N. norvegicus*	8.5	*M. merluccius*	7.7			1,015	2.3	175	8.0	9,448	10.8
									43,403	100.0	2195	100.0	87,677	100.0

Table 3
Definition of fleet components (FCs)

FC	No. of vessels	LPs						No. of landings	% of landings	Vessel length (m)	GT	Hp	Vessel age (2004)
		MIX	CRU	CEP	HOM	BWT	SHR						
1	17	3	340	5	–	21	175	544	24.8	23.8 (1.6)	166 (35)	556 (67)	11 (9)
2	44	610	6	51	752	69	–	1488	67.8	28.6 (4.4)	201 (51)	783 (263)	22 (12)
3	5	8	1	153	1	–	–	163	7.4	16.5 (1.0)	26 (4)	193 (29)	39 (10)
Total	66	621	347	209	753	90	175	2195	100.0				

Each component is defined by the average characteristics of trawlers in each group and their relative contribution to the total number of monthly landings in each LP. The standard deviations are in brackets.

ber of monthly landings in each LP. The first axis differentiates between crustacean trawlers (the most recent and technologically advanced vessels) which exploit the deeper areas of the continental slope and are associated with LPs CRU and SHR, and the remaining vessels. In the second axis, the small trawlers, those involved in cephalopod coastal fisheries (CEP), contrast with the rest of the fleet.

A larger group of trawlers targeting mainly the horse mackerel in LPs HOM and MIX, and the blue whiting in BWT is individualized. Their engine power is higher than that of the remaining vessels, allowing them to attain higher towing speeds adapted to the capture of fast swimming pelagic fish.

3.3. Target and by-catch species

The relative importance of total landings across LPs, in terms of the 10 species/groups that contributed most to their definition, is given in Table 4. Landings of horse mackerel are mostly from HOM, while rose shrimp was mainly landed in SHR, Norway lobster in CRU and blue whiting in BWT, where these species were targeted. Chub mackerel, Atlantic mackerel, pouting and hake (*Merluccius merluccius*) were landed equally in two different LPs, HOM and MIX. In HOM, on the other hand, blue whiting was landed in only slightly lower proportion than it was in BWT. Also, the landings of cephalopods from both MIX and HOM, targeting horse mackerel, were found to exceed those in CEP.

The status of the species that contributed to the definition of BWT and CEP, but were found to be representative of other LPs as well, was examined along the 3-year period in analysis. Plots of the cumulative landing proportion versus landings proportions in the different fishing trips were used to investigate whether or not these species can be considered targets (Fig. 4a). Plots of the cumulative proportion of fishing trips versus the landings proportion, are indicative of the extent to which fishing effort is directed at the species under study (Fig. 4b), by showing whether a particular species is landed in a high or low proportion of the fishing trips. For comparison purposes similar plots are also presented for the remaining three species characterizing landing profiles: horse mackerel, rose shrimp and Norway lobster. As a result, it was possible to recognize three groups of species, according to their relative abundance, spatial distribution and proportion of occurrence throughout the fishing trips.

Horse mackerel, which is highly abundant along the coast and a target species for most fish trawlers, can be included in a first group. The most important part of the landings for horse mackerel is from trips where the proportion of that species is high (Fig. 4a) and it was landed in most fishing trips (Fig. 4b).

Crustaceans are included in a second group, with most landings also coming from trips with high proportions of these species, as is the case of rose shrimp in 2002 and 2003, or with intermediate proportions, for rose shrimp in 2004 and Norway lobster along the entire period. However, crustaceans were landed in a low proportion of fishing trips. They are also considered as target species, but their distribution is spatially localized, being exploited only by one group of vessels, the crustacean trawlers.

Finally, those species landed in a high proportion of fishing trips, but in smaller proportions, such as the octopus in 2002 and 2004 and blue whiting in 2002, are included in a third group. The status of these species is not easily determined, varying among LPs and along the 3-year period under study. Blue whiting showed increasing importance in 2004 when compared to 2002, when it was mostly landed in LPs targeting horse mackerel (HOM and MIX), and 2003, with landings in HOM, MIX, SHR and BWT. Cephalopods were landed in higher proportions in 2003, when they were targeted by a higher number of trawlers, including larger vessels which have landed in HOM and MIX in 2002 and 2004.

4. Discussion

The existence of a fleet component targeting crustaceans, including some of the most recent and technologically advanced vessels, licensed for 55 and 70 mm cod-end mesh sizes, comes as no surprise. However, although such a fleet segmentation was to be expected, with the trawlers engaged in this fishery falling into a main homogeneous group, the present results demonstrate the existence of two distinct species-oriented LPs: SHR, where the rose shrimp is by far the main target species and CRU, where the proportions of Norway lobster and rose shrimp are the same. It would be expected that these two LPs corresponded to two differ-

Table 4
Landings composition for the main species in each LP

Species	MIX	CRU	CEP	HOM	BWT	SHR	Landings (t)	% of total landings	Landings (10^3 Euros)	% of total value
T. trachurus	17.8	0.1	0.5	74.7	6.9	0.0	17231	39.70	24042	27.42
P. longirostris	0.1	28.4	0.5	0.0	0.3	70.7	1028	2.37	14574	16.62
Octopodidae	37.1	4.1	23.3	32.8	1.0	1.6	1641	3.78	5198	5.93
S. scombrus	42.8	0.2	1.3	50.5	5.1	0.1	2854	6.58	1488	1.70
M. poutassou	21.0	2.6	0.2	32.3	43.7	0.2	5207	12.00	2422	2.76
T. luscus	47.8	0.0	4.8	46.0	1.4	0.0	2189	5.04	2988	3.41
M. merluccius	35.5	9.4	2.0	44.4	4.5	4.2	1855	4.27	6888	7.86
S. japonicus	48.3	0.0	0.1	42.2	9.4	0.0	2768	6.38	825	0.94
N. norvegicus	0.1	76.3	0.5	0.1	3.7	19.3	447	1.03	7874	8.98
S. officinalis	18.3	0.0	68.5	12.7	0.5	0.0	175	0.40	654	0.75
Total (10 species)							35395	81.55	66953	76.37
Total (31 species)							43403	100.00	87677	100.00

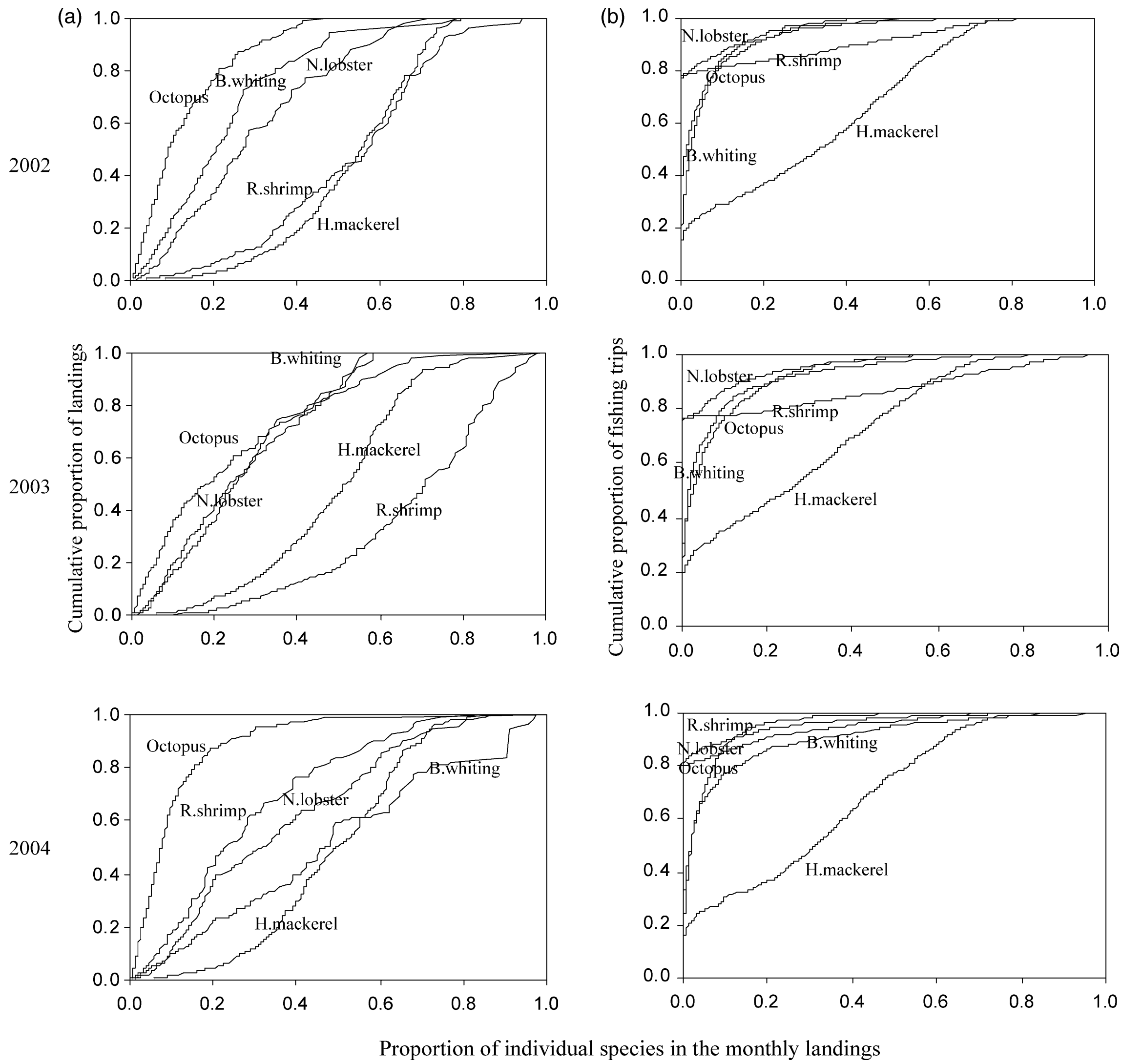

Fig. 4. Status of the different species along the 3-year period (2002–2004). On the *X*-axis is the proportion of individual species (in weight) in the landings of each fishing trip. On the *Y*-axis (a) is the cumulative proportion of landings; *Y*-axis (b) is the cumulative proportion of fishing trips.

ent métiers, according to the legal minimum mesh sizes enforced for shrimps and Norway lobster (SHR corresponding to the use of the 55 mm and CRU to the 70 mm mesh size, targeting Norway lobster). However, both mesh sizes can be alternately used by the same vessel during the same fishing trip, which makes the distinction between possible *métiers* too difficult in this context. Moreover, these species are not separately targeted, since their depth distributions partially overlap. Rose shrimp is usually targeted between 150 and 400 m depth, while *Nephrops* is fished between 250–300 and 750 m (often co-occurring with red shrimp from 400 m downwards). A reliable measure of effort by mesh size would be available only if information from fishing logbooks could be obtained at the individual-haul level for the entire fleet.

On the other hand, the fleet targeting fish, which includes three different LPs, constitutes a diversified group of vessels in terms of overall dimensions, engine power and technological level. The three LPs defined herein, HOM, BWT and MIX, show a considerable degree of overlap, both in terms of landed species and vessel types engaged in their capture, although in the first two, horse mackerel and blue whiting account for more than 50% of the landings in weight.

A number of trawlers, among the oldest of the fleet, land mainly octopus and cuttlefish, constituting a well individualized, and previously unsuspected, fleet component related to CEP.

For some of the species, fluctuations in landings were observed along the 3-year period in analysis. This is the case for rose shrimp, octopus and blue whiting. Inter-annual variations in the abundance can explain, at least in part, the observed shifts in the landings for the two former species. They are characterized by a short life-span, high growth rate and high reproductive potential, making them highly vulnerable to biotic and environmental variations, thereby causing marked inter-annual fluctuations in their abundance, similarly to what has been observed by other authors in eastern Atlantic areas (Sobrino et al., 2002; Sbrana et al., 2003; Erzini, 2005). The increasing importance of blue whiting along this 3-year period may, on the other hand, be explained by economic rather than environmental factors. Blue whiting is a small pelagic, dominant in the deep assemblage, which is captured together with crustaceans on the continental slope off the southern and southwestern Portuguese coast. However, it is known to be frequently discarded on board crustacean trawlers, given its low commercial value when compared to rose shrimp and Norway lobster (Borges et al., 2001; Monteiro et al., 2001). The fact that it was targeted and landed in higher proportions in 2004 explains the existence of the corresponding LP (BWT). Part of the landings was observed to be from crustacean trawlers, which is likely to be related to the decline of the rose shrimp from 2003 to 2004, and to a shift in the fishing strategy of those vessels, with the blue whiting partially compensating the lower revenues from shrimp sales.

For multispecies fisheries such as the one under study, the status of each species is primarily determined by fishermen, based on trade-offs where a combination of factors such as abundance, market value and the accessibility of fishing grounds among others, are taken into account. The high abundance of horse mackerel in Portuguese continental waters justifies the high proportions of landings in most fish trawlers, while the high market value of crustaceans makes these species attractive to fishermen even if their landings are small. For other species, such as octopus and blue whiting, it is likely that opportunistic fishing took place along the period under study. Whether the landings for these species were dependent on their relative abundance and their market value or a combination of these factors needs to be investigated.

A number of LPs defined in this study, particularly those not associated with an obvious target species, could possibly be broken down into groups with more homogeneous characteristics, both in terms of species composition and vessels characteristics. Consequently, spatial or seasonal patterns are likely to emerge from a future more detailed analysis on a longer time series of landings.

Previous studies on spatial distribution of fish assemblages based on analysis of trawl surveys (Gomes et al., 2001; Sousa et al., 2005) demonstrate that the species targeted in CRU, SHR and BWT are related to the deep assemblages. Crustaceans in particular, are part of the south deep assemblage comprising the southwestern and southern slope areas. The remaining species, targeted in HOM, MIX and CEP, correspond mainly to shallow fish assemblages of the continental shelf.

In future studies, effort should be directed to address the fleet's spatial dynamics and controlling factors by using the vessel's position data at the individual fishing trip level from MONICAP, the Portuguese Vessel Monitoring System. A dedicated GIS tool based on VMS data associated with landings data, has been under development for the trawl fleet (Afonso-Dias et al., 2004), and will constitute a valuable instrument in support of fisheries management, namely, by contributing to better precision of effort estimates.

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Paper 2

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Trawling for cephalopods off the Portuguese coast—Fleet dynamics and landings composition

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Abstract

Fleet dynamics was addressed for three cephalopod taxa of commercial interest, the squid *Loligo vulgaris*, the octopuses *Octopus vulgaris* and *Eledone cirrhosa*, and the cuttlefish *Sepia officinalis*, for 48 trawlers of the fish trawling fleet. Landing profiles (LP) were identified based on the species composition of the landings using hierarchical cluster analysis. Four out of a total of 12 different LP were related to cephalopods and other species associated with them.

The effects on the landing proportions of a number of variables, year, season and vessel, are analysed for each of the species studied using generalized linear models (GLM). The factor "vessel", including an ensemble of technical characteristics as well as the abilities of individual skippers, explained most of the model deviance, strongly reinforcing the existence of a fleet component dedicated to catch cephalopods. However, time also explains much of the variation found in the data.

Seasonal alternation between landings of octopodidae and cuttlefish was observed within a small group of old trawlers operating mainly off the south coast, following the abundance cycles of these species. For a larger group of more modern trawlers, operating off the western coast, inter-annual shift between octopus and squid was found, together with a well marked seasonal pattern between the catches of cephalopods and horse mackerel.

Spatial patterns of activity were identified using vessel monitoring system (VMS) data available for trawlers in Portugal, demonstrating the existence of cephalopod targeting strategies in Portuguese fish trawling activities.

Keywords: Landing profiles; Bottom trawl fisheries; Vessel monitoring systems; Octopus; Cuttlefish; Squid

1. Introduction

Cephalopod landings by trawlers in European waters are generally attributed to incidental catches while fishing for finfish and crustacean species (Arvanitidis et al., 2002; Chen et al., 2006; Fonseca et al., 2002; Lourenço and Pereira, 2006; Moreno et al., 2002; Young et al., 2004). Although directed trawl fisheries for different species of cephalopods do exist (Wang et al., 2003; Young et al., 2006) they are not the rule. Additionally cephalopods seem to be one of the remaining marine resources, in some areas, that still experience an increase in landings (Caddy and Rodhouse, 1998). In Portugal there is no official recognition of a trawling fleet targeting cephalopods, despite the substantial proportion of the total mainland landings that can be attributed to coastal trawling: 14% in 2002, 10% in 2003 and 13% in 2004, according to the official statistics (INE, 2003, 2004, 2005). Cephalopod fisheries assessments in European waters generally assume landings per unit of effort to constitute a good index of abundance for many species, based on the supposition that there are few discards and virtually no directed fishing effort (Pierce and Boyle, 2003).

A previous study on the Portuguese trawl fleet allowed the identification of different fleet components associated with landing profiles (LP), that were defined by the relative importance of their target and by-catch species (Campos et al., 2007). Within the fish trawlers, a group of vessels targeting cephalopods emerged, thus evidencing the previously unsuspected importance of this taxonomic group as a targeted resource for this fleet. Octopus and cuttlefish accounted for a high proportion of the total landings of these vessels (Campos et al., 2007).

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In the present work, the importance of octopus, squid, and cuttlefish landings is addressed. Analyses of the landings were restricted to the fish trawling fleet operating within the depth range of distribution of these cephalopods, extending up to 200 m (Boyle, 1983; Guerra, 2006; Mangold, 1983; Moreno et al., 2002). Within this fleet, homogeneous groups in terms of landings composition were defined in spatial and temporal terms by using the Portuguese vessel monitoring system (VMS) data. The identification of differences in the fishing activities and in the landing dynamics of specific groups of vessels demonstrates the existence of cephalopod targeting strategies. Ultimately, we expect that the results from this study may improve the cephalopod assessment methodologies.

2. Methods

2.1. Data sources

In Portugal, the bottom trawl fisheries can broadly be divided into two components according to the target species, crustacean and fish trawl fisheries. Cephalopods landings by the crustacean trawl fleet are negligible. Therefore the current work is focused on the so-called fish trawl fleet, which was responsible for 95% of the cephalopods landed by all trawlers between 2002 and 2004. This fleet is defined as an assemblage of vessels holding fishing licenses for 65 mm mesh size cod-ends.

This study aims to increase the level of detail in the analysis in relation to a previous study (Campos et al., 2007), thus providing more information about cephalopod catches made by the fish trawl fleet. In this study, LP were defined over a landings matrix composed of 1618 observations (rows), corresponding to monthly fishing trips for a 3-year period, for fish trawlers that landed at least 9 months each year. For this analysis 31 species were considered (columns), accounting for approximately 98.3% of the total landings of the 48 selected trawlers.

Landings data used in the analysis were available to the Portuguese Institute for Fisheries and Sea Research (IPIMAR) through the Portuguese General-Directorate for Fisheries and Aquaculture (DGPA), following a protocol between the two institutions.

Cephalopod landings data in the DGPA database appear under 11 designations, eight of which used for local catches: *Loligo* spp., *Loligo forbesi*, *Loligo vulgaris*, Octopodidae, *Octopus vulgaris*, *Eledone cirrhosa*, *Sepia officinalis*, and Ommastrephidae. Only the octopodidae (*Octopus vulgaris* and *Eledone cirrhosa*), the cuttlefish (*Sepia officinalis*) and loliginid squid (*Loligo* spp.) data were selected.

The catches of longfin squid in Portugal potentially combine three different species not distinguished commercially: *L. vulgaris*, *L. forbesi* and *Alloteuthis subulata*. However, there is a minimum landing size for *L. vulgaris* of 10 cm mantle length (ML) which effectively covers the three species, since they are not distinguished commercially. In 1990s only *L. vulgaris* entered the market because *L. forbesi* was not available in any significant numbers (Chen et al., 2006) and *A. subulata* is a small species that is almost always under the minimum landing size. Therefore our classification of Loliginid landings as squid (*Loligo* spp.) represents mainly, if not exclusively *L. vulgaris*.

The octopodidae present in landings are *Octopus vulgaris* and *Eledone cirrhosa*. The family designation is frequently used in data recording at fish auction sites because there is no obligation to record the exact species name. Although these two species are landed together and no separation is made in the landing statistics, the two species are never sold together because *O. vulgaris* fetches a higher price than *E. cirrhosa.* For this analysis all octopodidae data were grouped under the common name, octopus, since the species identification was not relevant to our objectives.

The Sepiidae were grouped under the designation cuttlefish (*Sepia officinalis*) because most of the catches are in fact *S. officinalis*. There is a small percentage of other Sepiidae that

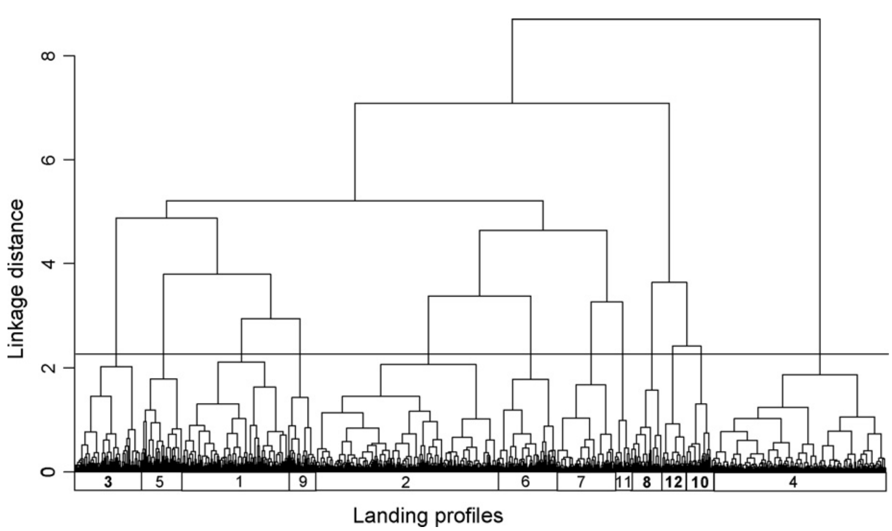

Fig. 1. Results from HCA undertaken in a matrix of 1618 rows (monthly landings) × 31 columns (species) comprising the period 2002–2004 for the 48 vessels selected from the fish trawling fleet. The number of cases in the *xx* axis was grouped by landing profiles (LP) defined in Table 1. The horizontal line at linkage distance 2 allowed the identification of 12 separate clusters corresponding to different LP. Four of the identified clusters correspond to LPs (3, 8, 10 and 12) associated with cephalopods.

occasional are landed together with *S. officinalis* but their quantities are unquantifiable and possibly insignificant.

Fleet spatial dynamics was analysed using GeoCrust, a dedicated computer application for integrating VMS, logbook and landings data (Afonso-Dias et al., 2004). The Portuguese VMS ("MONICAP") is now fully operational for vessels greater than 15 m of overall length, which is the case of all trawlers in this study. The GPS positions and speed of each vessel under VMS control are recorded every 10 min and transmitted via satellite to the "Inspecção-Geral das Pescas" (IGP), the Portuguese authority responsible for fisheries surveillance. A full analysis of the data provided by this system enabled us to map the fish trawlers activity off the Portuguese coast.

2.2. Data analysis

Hierarchical clustering analyses (HCA) were applied to the data matrix (1618 × 31) in order to define the landing profiles that are relatively homogeneous with respect to species composition. HCA was run using Ward's minimum variance clustering algorithm (Ward, 1963) based on the Euclidean distances matrix.

Generalized linear models (GLM) were used with the logit link function to model the relationships between monthly landings (for each taxon: octopus, cuttlefish and squid) and the explanatory variables, year, season, vessel and vessel characteristics (gross tonnage, GT and horse power, HP). Year, Season and Vessel were adjusted as factors (3, 4 and 48 levels respectively), while GT and HP were adjusted as continuous variables. Due to the particular nature of the response variable (landings percentages), a quasi-likelihood approach was adopted (Venables and Ripley, 2002) to allow for a less restricted characterisation of the error structure.

The statistical analyses were carried out using S-Plus 2000 (Insightful Corp., 1999).

VMS data were combined by vessel and month and mapped using GeoCrust 2.0, the most recent version of the software GeoCrust (Afonso-Dias et al., 2004) to visually display fishing operations by LP, in order to better define the geographic pattern of the fishing activity of this fleet.

3. Results

3.1. Landing profiles

HCA allowed us to classify the data in three major groups (Fig. 1), considering a linkage distance around six: one small cluster quite dissimilar from the others grouping vessels that landed horse mackerel as the main species (LP4); a second cluster grouping vessels that landed octopus and/or cuttlefish as the main species (LP8, LP10 and LP12) and a third assemblage of vessels that landed a large number of species, including horse mackerel and squid, grouping together the remaining landing profiles (Fig. 1 and Table 1).

Considering a smaller linkage distance (2) it is possible to separate the data in 12 different clusters (Fig. 1) of which four are associated with vessels that landed cephalopods as the main

Table 1
Definition of landing profiles in terms of species composition, landed weight, landed value and number of monthly trips (2002–2004)

Landing profile	Species composition (%)				No. of monthly trips	% of total trips	Landed weight (*t*)	% of total landings	Landed value (10^3 Euros)
1	*T. trachurus* (26.9)	*S. scombrus* (14.4)	*S. japonicus* (8.7)	*M. poutassou* (8.5)	210	13.0	6057	14.8	9571
2	*T. trachurus* (43.4)	*T. luscus* (7.7)	*S. scombrus* (6.6)	*S. japonicus* (6.6)	360	22.2	8769	21.4	16045
3	*L.vulgaris* (29.2)	*T. trachurus* (19.7)	*T. luscus* (13.8)	*Octopodidae* (10.8)	132	8.2	1503	3.7	4162
4	*T. trachurus* (64.4)	*S. scombrus* (6.6)	*M. poutassou* (5.5)		349	21.6	11573	28.3	16943
5	*M.merluccius* (27.7)	*N. norvegicus* (9.0)			82	5.1	382	0.9	2589
6	*T. trachurus* (27.6)	*T. luscus* (22.6)	*Octopodidae* (13.5)		118	7.3	1668	4.1	3307
7	*T. trachurus* (49.0)	*M. poutassou* (28.1)			118	7.3	5846	14.3	6058
8	*Octopodidae* (44.8)	*T. luscus* (16.0)	*T. trachurus* (12.6)		63	3.9	651	1.6	1863
9	*S.japonicus* (33.4)	*M. poutassou* (19.9)	*T. trachurus* (13.2)	*T. picturatus* (9.7)	57	3.5	2294	5.6	2418
10	*Octopodidae* (28.6)	*Bothidae* (17.7)	*Microchirus* spp. (11.0)	*Rajidae* (10.2)	50	3.1	164	0.4	670
11	*M.poutassou* (62.1)	*T. trachurus* (13.7)			30	1.9	1826	4.5	2014
12	*S. officinalis* (38.6)	*Microchirus* spp. (17.3)	*Octopodidae* (17.0)		49	3.0	208	0.5	881
					1618	100.0	40940	100.0	66522

species (LP3, LP8, LP12 and LP10; see Table 1). Octopus was the most important species in two of the four LPs dedicated to cephalopods, LP8 and LP10 (Table 1). Vessels with LP8 landed octopus together with pouting and horse mackerel, whereas vessels with LP10 landed octopus associated with other demersal species such as flounders (*Bothidae*), soles (*Microchirus* spp.) and rays (*Rajidae*). The third cluster, LP 12, groups vessels that landed cuttlefish as the main species combined with soles and octopus. The vessels whose landings were grouped in LP 3, landed squid as the main species, along with horse mackerel, pouting and octopus. The remaining clusters include five LPs in which horse mackerel is the main landed species, though in different proportions and with different associated species (LP1, LP2, LP4, LP6 and LP7); and three others containing vessels that landed blue whiting (LP11), hake (LP5) and chub mackerel (LP9).

Although 31 species were selected for this study, representing about 98.3% of the total landings, only 13 species (86.6%) were considered to account for the differences between LPs (Table 2). Regarding the landings of cephalopods, the vessels that landed cuttlefish (about 52%) were associated with LP12 whereas the vessels that landed squid (about 46%) were related to LP3. A considerable proportion of the squid (about 27%) was also landed by vessels associated with LP2 (Table 2). Although octopus landings were scattered throughout the different LPs (Table 2), it is possible to observe that the vessels associated with LP2 and LP8 captured higher quantities of these species (19.8% and 18.5%, respectively). Vessels related to LP4 (targeting horse mackerel) also landed a considerable amount of cephalopods, 16.3% octopus, 11.5% squid and 6.1% cuttlefish).

Although cephalopods only represented 6% of the total landings in weight (Table 2), their importance in value was more than double (16%), showing the high commercial value of these species when compared with species that are landed in higher quantities, such as horse mackerel (41% in weight and 36% in value), blue whiting, mackerel and pouting.

Cephalopod landings showed some monthly variations during the studied period (2002–2004) as shown in Fig. 2. Despite the small period in analysis, there seems to be some evidence of inter-annual variation in the landings of squid with much higher landing levels in 2002 and 2004 than in 2003. Inter-annual variation was also observed for octopus, with higher landing levels in 2003. The landings of cuttlefish also showed some fluctuations, but clearly related to seasonal changes rather than annual variations (Fig. 2). In fact, the data suggest that the fishery for these species of cephalopods has a clear seasonal pattern. The quantity of squid landed during the first two quarters was low, increasing from August until the end of the year, while the quantity of cuttlefish landed was lower during the second and third quarters, from April to September. In contrast the landings of octopus showed an opposite trend, as the one described for the cuttlefish landings, suggesting a seasonal alternation between octopus and cuttlefish as the target species.

Vessels fishing activities showed a seasonal trend in the cephalopod landings, clearly related to the target species (Fig. 3).

Table 2
Landings composition for the main species in each landing profile (2002–2004)

Species	Landing profile												Landings (tons)	% of total landings	Landings (10^3 Euros)	% of total landings (value)	Total average price (Euro/kg)
	1	2	3	4	5	6	7	8	9	10	11	12					
Octopodidae	8.6	19.8	10.2	16.3	1.6	14.4	2.4	18.5	2.4	2.9	0.6	2.3	1527	3.7	5044	7.6	3.30
L.vulgaris	6.1	26.6	46.0	11.5	0.1	3.8	2.0	1.4	0.6	0.2	1.1	0.6	918	2.2	4985	7.5	5.43
S.officinalis	4.1	12.3	3.6	6.1	4.8	4.7	0.9	0.9	2.0	7.7	0.5	52.4	150	0.4	568	0.9	3.77
Bothidae	16.1	19.9	1.2	7.4	5.3	1.1	1.3	0.7	5.9	25.7	1.8	13.8	107	0.3	273	0.4	2.56
Rajidae	21.6	31.4	3.2	19.5	2.3	6.1	5.1	1.7	3.5	2.2	2.2	1.2	722	1.8	1737	2.6	2.41
Microchirus spp.	6.0	12.9	1.9	4.1	8.3	15.0	0.8	1.3	2.5	15.2	0.6	31.5	112	0.3	813	1.2	7.24
T. trachurus	9.5	22.0	1.7	43.5	0.2	2.6	16.8	0.5	1.8	<0.1	1.5	<0.1	16921	41.3	23622	35.5	1.40
T. picturatus	42.4	16.3	0.1	8.8	<0.1	0.1	2.3	<0.1	23.8	<0.1	6.1	<0.1	928	2.3	348	0.5	0.38
S. scombrus	30.2	20.1	4.3	26.9	0.1	2.1	8.9	1.3	5.0	<0.1	1.1	<0.1	2825	6.9	1476	2.2	0.52
S. japonicus	18.7	20.6	0.8	16.5	<0.1	1.1	10.1	0.1	27.5	<0.1	4.7	<0.1	2760	6.7	823	1.2	0.30
T. luscus	12.5	30.4	9.2	20.4	0.6	16.9	4.3	4.7	0.5	<0.1	0.4	<0.1	2172	5.3	2965	4.5	1.37
M. merluccius	26.3	28.4	0.8	20.4	6.2	2.8	4.6	1.0	5.7	0.5	3.1	0.2	1533	3.7	5900	8.9	3.85
M. poutassou	10.5	6.2	0.4	13.2	0.2	2.0	34.2	0.2	9.5	<0.1	23.6	<0.1	4769	11.6	2269	3.4	0.48
Total (13 species)													35445	86.6	50823	76.4	1.43
Total (31 species)													40261	98.3	63224	95.0	1.57
Total													40940		66522		1.62

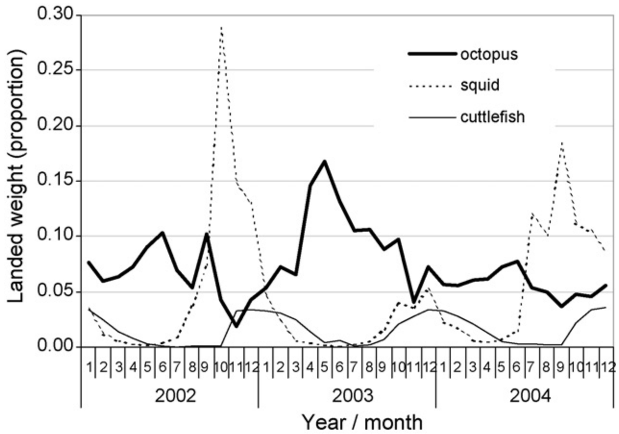

Fig. 2. Mean monthly landings of octopus, squid and cuttlefish associated to the selected 48 vessels of the fish trawl fleet from 2002 to 2004.

A small group of trawlers (three in the analysis) shifted the target species between octopus and cuttlefish, according to the abundance of the species confirming the seasonal trend observed in the landings (Fig. 2). Cuttlefish was mainly targeted by these vessels in the autumn and winter, whereas octopus was captured during spring and summer months (Fig. 4).

A substantial number of other vessels (eight vessels in the analysis) was found to target octopus seasonally, particularly evident during 2003, from April to September (Fig. 3). In 2002 and 2004 these vessels shifted target species, landing squid instead of octopus, particularly between July and December (Fig. 5).

3.2. GLM

GLM adjusted to the data available described quite accurately the relationships between the different variables (Table 3). For the three studied taxa, the factor "vessel" explained most of the model deviance, strongly reinforcing the existence of a fleet component dedicated to cephalopods. On the other hand, the factor "season" played a relatively important role for cuttlefish, but was particularly marked for squid, supporting the idea that cephalopod fisheries are based upon each species seasonal recruitment.

The inclusion in GLM, of a technical characteristic of vessels (GT) adjusted as a third variable, together with year and season, contributed to explain a higher percentage of the deviance but only for cuttlefish and octopus (65% and 32% of deviance explained, respectively) while it was non-significant (1%) in the model adjusted for squid.

For octopus monthly landings, the model adjusted explains up to 64% of the deviance, using a combination of three variables, year, season and vessel (Table 3), against 38% and 39% when the variable vessel was replaced by HP and GT, respectively. The variable vessel explained about 57% of the model deviance, strongly suggesting the existence of a fleet component dedicated to this species, while season and year only explained 4% and 3% of the deviance, respectively.

For cuttlefish monthly landings, the model adjusted explained 93% of the deviance, of which 81% was explained by the variable vessel and 12% by season. Year only explained 0.1% of the deviance and was found to be statistically non-significant

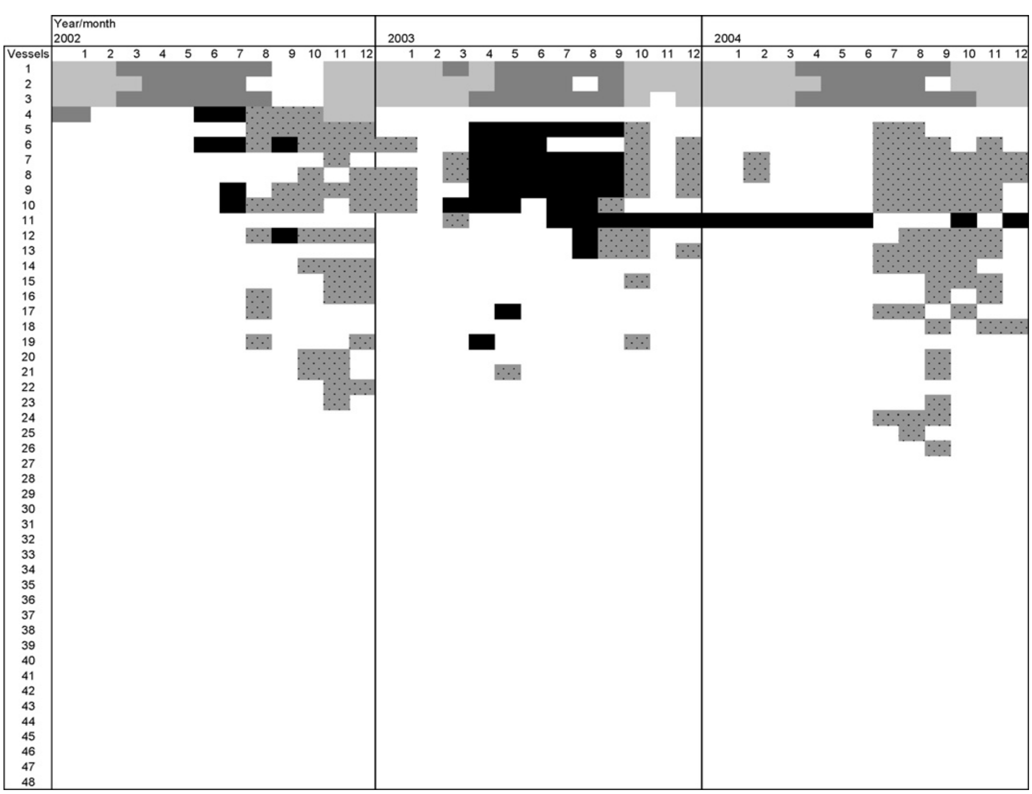

Fig. 3. Patterns of monthly fishing activity (landing profiles' temporal distribution) displayed by the 48 vessels (rows) selected from the fish trawling fleet from 2002 to 2004. Light grey: LP12; Dark grey, LP10; Black, LP8; Dotted, LP3; White, non-cephalopod targeting LPs.

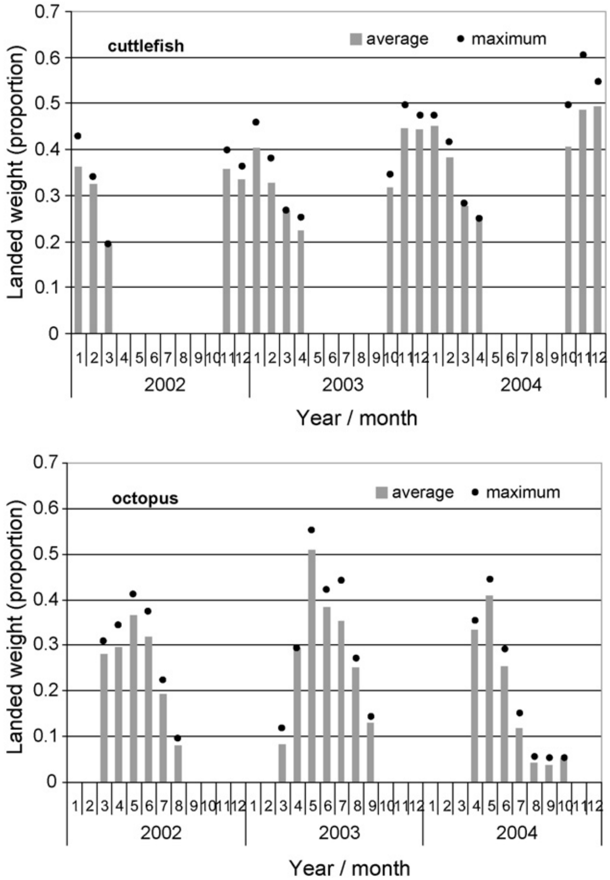

Fig. 4. Cuttlefish and octopus monthly landings made by the small group of vessels permanently targeting cephalopods, from 2002 to 2004.

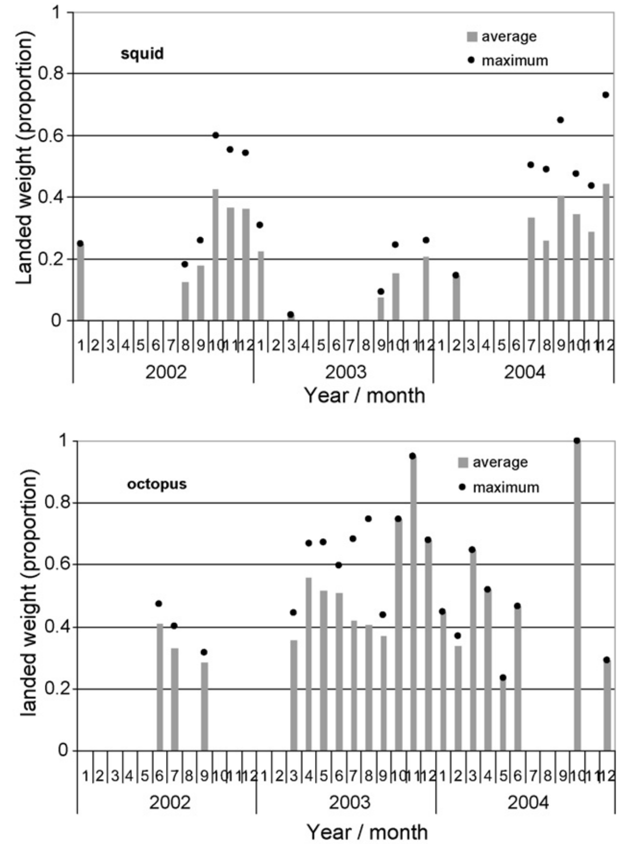

Fig. 5. Monthly landings of squid and octopus from 2002 to 2004, made by the group of fish trawlers associated with LP3 (squid) and LP8 (octopus).

Table 3
Analysis of deviance for GLM (quasi-likelihood) fitted to cephalopods monthly landing proportions (2002–2004)

Cephalopod taxa	Model	Residual		Percentage (cumulative) of deviance explained	Test d.f.	Deviance	$P(X^2)$
		d.f.	Deviance				
Octopus	Null	1617	209.27	–			–
	Year	1615	202.51	3.23	2	6.76	0.034
	Year + Season	1612	194.09	7.25	3	8.42	0.038
	Year + Season + Vessel	1565	74.97	64.17	47	119.12	< 0.001
	Year + Season + GT	1611	127.16	39.23	1	66.93	< 0.001
	Year + Season + HP	1611	128.99	38.36	1	65.10	< 0.001
Cuttlefish	Null	1617	135.92	–			–
	Year	1615	135.74	0.13	2	0.18	0.916
	Year + Season	1612	119.25	12.26	3	16.49	0.001
	Year + Season + Vessel	1565	9.80	92.79	47	109.45	< 0.001
	Year + Season + GT	1611	30.78	77.35	1	88.47	< 0.001
	Year + Season + HP	1611	29.82	78.06	1	89.43	< 0.001
Squid	Null	1617	210.48	–			–
	Year	1615	195.51	7.11	2	14.97	0.001
	Year + Season	1612	139.41	33.76	3	56.09	< 0.001
	Year + Season + Vessel	1565	62.05	70.52	47	77.36	0.003
	Year + Season + GT	1611	136.54	35.13	1	2.87	0.090
	Year + Season + HP	1611	133.54	36.55	1	5.87	0.015

d.f., degrees of freedom.

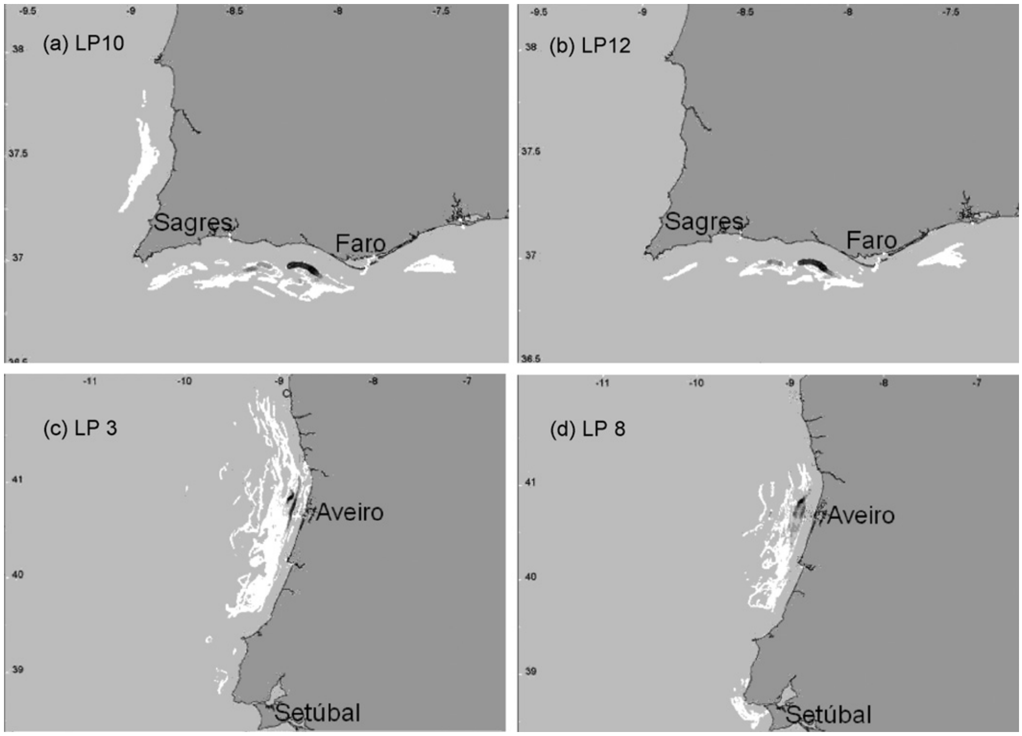

Fig. 6. Visual display of trawling operation associated with cephalopod landings (effort distribution) from 2002 to 2004 obtained by using GeoCrust 2.0 software. (a) LP10-Octopus and (b) LP12-cuttlefish, associated with fish trawlers targeting octopus and cuttlefish off the southern coast; (c) LP3-Squid and (d) LP8-Octopus, associated with trawlers targeting octopus and squid off the west coast. Each map presents VMS data individually filtered by trawler after excluding the navigation routes. Trawling intensity (10 classes) is represented as the number of points by square (in this case 0.3 nm × 0.3 nm) where the minimum corresponds to white colour and the maximum to black colour (grey scale). Maximum number of points per square (0.3 nm × 0.3 nm) differs from (a) to (d).

(Table 3). When the variable GT was adjusted instead of the variable vessel the model adjusted only explained 77% of the deviance.

The model fitted for squid monthly landings accounted for 71% of the deviance, 37% of which were explained by the variable vessel, 27% by season and 7% by year (Table 3).

For the three species in study, the best model was always the one adjusted using individual vessel as a factor instead of vessel quantitative continuous characteristics such as the GT or HP.

3.3. Spatial patterns of fishing activity

Fishing activity spatial patterns of the vessels associated with cephalopod LP are displayed in Fig. 6. Two distinct fishing grounds are perceptible, one describing the fishing activities of vessels that permanently targeted octopus and cuttlefish (LP10 and LP12). These vessels extended their fishing activity over approximately 50 nautical miles (Fig. 6a and b) in coastal areas of the south and southwest coast of Portugal. A second fishing ground was depicted for vessels that alternate their target species between octopus, squid, and other species of fish such as horse mackerel (LP3 and LP8). These vessels' main fishing areas are located in the coastal areas off Aveiro, on the west coast of Portugal (Fig. 6c and d).

The spatial pattern of the fish trawling activity off the Portuguese coast is displayed in Fig. 7, showing that this fleet operates in a wide area. However, the trawlers that target cephalopods both occasionally and almost exclusively, operate in the west coast of Portugal off the trawling exclusion zone (6 nautical miles off the coast line) in front of the mouth of "Ria de Aveiro" and on a small area to the south of the Setúbal canyon. On the south coast of Portugal, most of the fishing activity takes place in the eastern half of the Sagres to Faro basin.

4. Discussion

The existence of a small number of fish trawlers (three vessels) exclusively targeting cephalopods was detected in a previous study made by Campos et al. (2007). These vessels operating off the south coast are old and technologically less advanced units when compared with the other fish trawlers. They were also identified in this study to target octopus and cuttlefish. However, during this study a second group of fish trawlers was identified operating mainly off the west coast of Portugal. These trawlers are better equipped and targeted octopus and squid seasonally along with non-cephalopod species.

Temporal and spatial patterns of fishing activities have emerged for this fish fleet regarding the capture of cephalopods. A seasonal alternation between octopus and cuttlefish was observed for the small trawlers that almost exclusively target these two species. The observed alternation between them seems to follow the abundance cycles of the target species, which in turn matches their life-cycles. The landings of octopus in the Algarve increased substantially during the second quarter of the year due to an important increase in the number of these specimens above the minimum landing weight (750 g) which were present in this

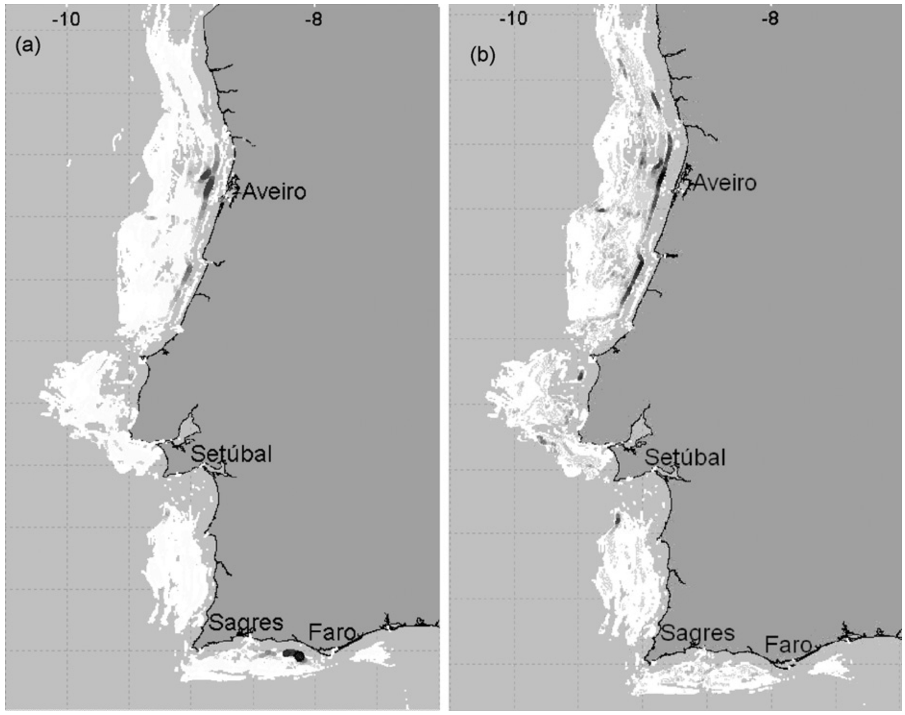

Fig. 7. Visual display of trawling operations (effort distribution) by (a) the 48 selected fish trawlers and (b) excluding the trawlers associated with the four cephalopods landings profiles, from 2002 to 2004, obtained by using GeoCrust 2.0 software. Maximum number of points per square (0.3 nm × 0.3 nm) differs between (a) and (b).

area and available to the fishery after the spawning peak period in April (Pereira, unpublished data). Likewise the increase in the landings of cuttlefish is also probably related to its reproductive strategy. This species assembles in coastal areas outside Ria Formosa, off Faro, from about October onwards, before they enter the lagoon to spawn (Coelho and Martins, 1991). For these trawlers, operating almost at all times in sheltered areas off the south coast, it is likely that their technical characteristics (small size, low HP) are a limiting factor restricting their choice of target species to octopus and cuttlefish.

In contrast, the vessels operating on the west coast, off Aveiro, show inter-annual shifts between octopus and squid and seasonal shifts between cephalopods and other species (mainly horse mackerel). These vessels are larger trawlers, technologically more advanced, and for which landings of cephalopods seem to be associated to a well defined fishing strategy. These vessels target mainly horse mackerel during the winter, changing their target species in the spring/summer and autumn to take advantage of the higher abundance of octopus or squid, depending on the yearly recruitment of these species. The observed inter-annual alternation in the proportion of the landings of octopus and squid along the 3-year period can be partially explained, by the observed variations in the abundance of these two species. Both *O. vulgaris* and *L. vulgaris* are short-lived species with fast growth rates and high reproductive potential (Rocha et al., 2001; Moreno et al., 2007). These species are highly prone to inter-annual fluctuations in abundance, caused by environmental change (e.g. Sobriño et al., 2002; Erzini, 2005), and high levels of mortality in the life-cycle takes place at pre-recruitment life-stages (e.g. Boyle and Rodhouse, 2005; Mangold, 1983; Roberts, 2005; Worms, 1983). It has been suggested that octopus abundance off the Portuguese coast is positively correlated to temperature at a relatively short time-lag (2–3 months) (Lourenço and Pereira, unpublished data), but the greatest changes in abundance are not solely related to temperature.

During the period analyzed, abundance indices from research cruises showed similar fluctuations in the relative abundance of octopus and squid (Pereira, unpublished data) throughout the year. Squids were more abundant than octopus between July and October 2002 and in November of 2003 and 2004. Conversely, octopus landings in Portugal in 2002 were particularly low in relation to the abundance series recorded (the second lowest landing since 1987), while in 2003 they were the third highest (INE, 2003, 2004, 2005). These observations confirm the variability in the abundance of both species which suggests that the alternation in the target species between squid and octopus may, to some extent, reflect species availability.

However, alternation between fish and cephalopods or between cephalopod species cannot simply reflect abundance or the chance of an occasional by-catch, since not all vessels operating simultaneously in the same area present the same landing patterns. A group of vessels appear to display a clear targeting behaviour shifting from fish to cephalopods and between cephalopod species. This can be achieved by changing trawl gears or trawling speed, as well as by using more appropriate trawl nets (several models of trawl nets can be carried simultaneously by a vessel).

The results from this study indicate that landings of octopus and cuttlefish are related to vessel size, which was also observed by Campos et al. (2007). Both species are coastal epibenthic, characterised by low sustainable swimming speeds. Although bursts of high speed jet propulsion are used in short distance escape movements and high speed travel may also be possible (Stark et al., 2005), they are generally slow species. However, gross tonnage (GP) was not found to be a significant variable to explain the variability in the model adjusted for squid landings, suggesting that vessel size was not a limiting factor to its capture.

The fact that the qualitative individual vessel characteristics explained a higher percentage of the deviance of the adjusted model than the technical characteristics of the vessel suggests that the vessel factor may include an ensemble of qualitative characteristics related to the skills of the skippers, effectively exceeding the importance of size (GP) and power (HP) of the vessel. The choice of fishing grounds and fishing techniques such as the use of more advanced tracking devices, the existence of fuel-saving strategies, associated to lower towing speeds necessary to the capture of some cephalopod species, are possibly more relevant than vessel characteristics such as HP and GP.

The high market value that some cephalopods may fetch, coupled with the commercial importance of other demersal species associated with them, may also contribute to explain the shift between target species.

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Paper 3

ACTIVITY PATTERNS FOR PORTUGUESE FISH TRAWLERS BASED ON A 13-YEAR TIME-SERIES OF TRIP LANDINGS

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ABSTRACT

In this study, the activity of Portuguese fish trawlers operating in western Iberian waters is analysed using a 13-year time-series of trip landings from 1995 to 2007. A total of six landing profiles (LP) differing in species composition were defined, using the classification method Clustering Large Applications (CLARA) applied to species proportions, in weight and value. Two distinct LP were defined in weight, exclusively targeting pelagic horse mackerel (*Trachurus trachurus*) and blue whiting (*Micromesistius poutassou*). The remaining four LP corresponded to mixed fisheries, where squid (*Loligo spp*.), horse mackerel and octopuses (Octopodidae) were identified as main targets. Three fleet components (FC) are identified, targeting distinct ecological groups and differing in their technical characteristics, LP stability and polyvalence, and fidelity to a geographic region. Large vessels, targeting mainly pelagic, were found to be active along the entire coast. Average powered units concentrate their activity in the Centre of the country, landing a diversified catch, including horse mackerel and benthic species. These vessels were observed to frequently change their fishing tactics, switching between LP on a trip basis. Low-powered and old vessels, target cephalopods and benthic species off the south coast. Quarterly estimates of species-directed landings per unit of effort (Landings per Trip) are presented.

Keywords: bottom trawling, fleet segmentation, landing profiles, mixed fisheries, Portuguese waters, landings per trip

INTRODUCTION

As a first step in the progression towards an Ecosystem Approach to Fisheries Management (EAFM), in 2008 the European Commission altered the former Data Collection Regulation (now Data Collection Framework, DCF, EC, 2008).Changes resulted from the acknowledgement that the single-stock approach to stock assessment and management has proven inadequate to achieve management goals, encouraging overfishing and discarding (COM, 2001; Baudron et al., 2010). This is particularly true for mixed fisheries targeting a large number species belonging to different ecological groups, and usually impacting many more non-commercial species. Consequently, the scope of data collection programmes was expanded, calling for a deeper insight into the various components of the ecosystem and the resulting impacts of fishing fleets activity.

Data for EAFM require detailed information at fleet/fishery-level, namely species-specific fishing effort (Ratz et al., 2007), implying the need for the definition of the different segments of the fishing fleets, in order to identify métiers and highlight their short and long-term dynamics. In effect, the importance of fleet dynamics in fisheries management models has been increasingly emphasized, especially for mixed fisheries (Ulrich and Andersen, 2004; Andersen et al., 2010).

Portuguese coastal fisheries in mainland waters are carried out by 3 distinct segments: trawl, seine and polyvalent fleet, operating in Western Iberian waters (Northeast Atlantic, ICES division IXa), off the Portuguese continental coast (36º to 42ºN and 7º to 9ºW) along an extension of approximately 950 km, corresponding to an Exclusive Economic Zone (EEZ) of about 320 thousand km2. In 2009, this fleet accounted for 12 and 17% approximately of the total national landings in weight and value, respectively. The remaining segments, the so-called “polyvalent fisheries” (longliners, gillnetters and trap vessels) and the purse seining represent 43 and 45% in weight, and 65 and 18% in value, respectively (DGPA, 2010).

The coastal trawl fleet included approximately one hundred vessels at the end of 1999 (DGPA, 2000), but this number has progressively decreased to a total of about 80 units in 2009, corresponding to approximately fourteen thousand gross tonnage (GT) (DGPA, 2010). It is constituted by two distinct groups of trawlers, one licenced for the simultaneous use of 55 and 70 mm minimum mesh sizes, targeting crustaceans (the crustacean fleet), and the other, licenced for

65 mm, mostly directed to fish and cephalopod species (the 'fish' fleet), (Diário da República, 2000; 2002). The former is constituted by approximately 30 vessels targeting mainly rose shrimp (*Parapenaeus longirostris*) and Norway lobster (*Nephrops norvegicus*), in the continental slope off the southwest and southern coasts (36º to 37ºN and 7º to 9ºW), while the remaining fleet operates off the entire Portuguese continental coast, landing a large number of fish and cephalopod species. These include pelagic species such as horse mackerel (*Trachurus trachurus*), blue whiting (*Micromesistius poutassou*), mackerels (*Scomber colias* and *S. scombrus*), and squid (*Loligo spp.*), as well as benthic species such as octopuses (*Octopus vulgaris* and *Eledone cirrhosa*), hake, flatfishes and several seabreams (DGPA, 2010).

Quantification of discard rates for fish trawlers working off the south coast have been carried out by Borges et al. (2001), while Fernandes et al. (2008) reported the frequency of discards for a number of species in vessels operating along the entire coast. A high number of species is listed in the latter study, with small pelagic or benthopelagic fish such as the longspine snipefish (Macroramphosus scolopax), the blue whiting and the scabbardfish (*Lepidopus caudatus*) among those most frequently discarded. Taking into account the number of fish trawlers, the coastal extension in which they operate and the fact that they exploit different fish assemblages (Sousa et al., 2005), adequate management for this fleet requires knowledge about fleet short- and long-term dynamics; i.e., fishing tactics and strategies. The definition of target fisheries based on the historical analysis of the fleet catches and the spatial distribution of its activity (effort allocation) has been assuming an increasing relevance in the last decade, as new, integrated approaches to fisheries management are being adopted (i.e., EAFM).

In previous studies, Campos et al. (2007) based in a 3-year (2002-2004) of monthly landings for the entire coastal trawl (crustaceans and 'fish') fleet, identified six landing profiles (LP) by their specific composition in terms of target and by-catch species. These LP were associated to species abundance and distribution, as well as to technological characteristics of vessels, forming three distinct fleet components (FC): fish (with three distinct LP), cephalopod (one LP) and crustaceans (two LP) trawlers. In Pilar-Fonseca et al. (2008) the scope of this study was narrowed, comprising the two last FC targeting fish and cephalopods. LP were addressed in more detail and the spatial and temporal (aggregated landing data by month) alternation of LP was characterized for cephalopod species: squid, octopus and cuttlefish. Fleet spatial dynamics was illustrated using geo-referenced vessel monitoring system (VMS) data from 2003.

The objective of the present study is to investigate the dynamics of the 'fish' trawlers fleet in Pilar-Fonseca et al. (2008), based on a 13-year time-series of landings per trip (from 1995 to 2007). The existence of a number of different fishing strategies or tactics directed to specific target species is investigated and related to potential specific FC. Species landing per trip (kg/trip) was estimated selecting the corresponding LP. LP stability, polyvalence and fidelity to region were also quantified.

DATA ANALYSIS

Data collection and selection

The data set is constituted of trip landings registered from the first sales at the auction market, obtained from the Portuguese Directorate for Fisheries and Aquaculture (DGPA). The data in weight and value, is aggregated by species/taxa, vessel, date, and landing port in the period 1995-2007. It was assumed that the analysis of this 13-year period would cover possible inter-annual fluctuations in species abundance, without excessively restricting the number of active vessels during the period in study.

From the initial data (88 trawlers x 190 species/groups), only vessels with more than 20 fishing trips per year and at least three years of activity were selected, where fishing trips (FT) is defined as any voyage by a fishing vessel from a land location to a landing event (EC, 2010). A total of 17 taxa were chosen as the most representative for the fishery, representing 90% and 91% of the total weight and value of the total daily landings, respectively. The remaining taxa were grouped as "Others", a diversified number of fish and crustacean species that are mainly captured in other fisheries.

The final 13-year data matrix included data for 74 trawlers, consisting of a total of 103693 landings, each corresponding to one FT, and 18 groups (species). Both the landings data and the technical characteristics of the trawlers under study were obtained from the Portuguese General Directorate for Marine Resources (DGRM). The vessel characteristics for the 74 trawlers in study are in Table 1, in a total of 9 and 51 vessels belonged to the <18 m and 24-40 m LOA class segments, respectively.

Table 1. Vessel characteristics for the 74 units analysed. LOA (Length over-all), HP (Horse power) and GT (Gross tonnage). min. (minimum), max. (maximum) and c.v. (coefficient of variation). All correlations were considered significant (p-value < 2.2e-16)

Characteristics	Min. – Max.	Average (c.v.)	Median	Correlations		
				LOA	HP	GT
LOA (m)	15 - 35	27.2 (21.3)	28.1	1	0.85	0.87
HP	150 - 1455	713.6 (40.2)	720.0		1	0.85
GT (ton)	22 - 275	183.9 (39.6)	197.5			1

Vessel activity, landing profiles and fleet components

A description of vessel activity (by region and port) is given for the selected fleet.

Definition of landing profiles (LP) was carried out for the fish trawl fleet, based on the relative importance of the target and by-catch species landed. Due to the high volume of data, a non-hierarchical classification technique was applied Clustering LARge Application (CLARA), consisting of a partitioning algorithm (partitioning around medoids) that divides the dataset into k clusters, where k needs to be specified a priori. This method deals with large datasets by considering data subsets, avoiding the need to store the dissimilarity matrix of the entire dataset. The algorithm was run a number of times allowing k to vary between 2 and 20. To define the ideal number of groups, k was chosen based on a quality index provided by the algorithm, the Overall Average Silhouette Width (OASW, Struyf et al., 1997). Average silhouette width (ASW) is used to define the importance of each group, where values of this parameter between 0.51-0.71 and above 0.71 define "reasonable" and "strong" quality groupings, while values from 0.26 to 0.50 and below 0.26 define "weak" and "non-existent" group structure, respectively (Struyf et al., 1997).

Clustering analysis was run over the two separate datasets, with landings in weight and in value expressed as a percentage of the total daily trip landings. The first type of analysis evidences biological aspects of fisheries related to species abundance, while the analysis in value takes into consideration the economical dimension of this activity.

Time distribution of LP dynamics was analysed at quarterly and yearly scales. Yearly patterns of LP activity were investigated by analysing separate data matrices of daily landings, for this time-series, in weight and value, in order to confirm LP stability over time. Spatial activity was also investigated, using both region and landing port as spatial indicators.

To define fleet components (FC), LP previously defined were assigned to trawlers through correspondence analysis (CA). The relationship between LP in weight and the 74 trawlers included in this study was analysed using a (6×74) frequency matrix of the 103693 FT.

The status (target or by-catch) of each species in the fishery was determined by their relative importance in the LP where that particular species was caught. Their importance as target species was then examined along the period in study according to Biseau (1998), by plotting the cumulative proportion of daily fishing trips against the landing proportion. This determines to what extent the fishing effort is directed to each particular species, i.e., the importance of specialized trips in terms of landings. The relationship between the species percentages in weight and value was examined.

Patterns of vessel LP activity

Fishing vessels are able to switch between fisheries (i.e. LP). In this study, description of vessel activity by LP is characterized through the use of two different metrics. The "polyvalence index" (Ulrich and Andersen, 2004) measures the relative importance of the LP and a "stability index", which quantifies the percentage ratio of consecutive FT with the same classified LP. The two indices provide an insight into individual short-term fishermen behaviour, in particular the tactical patterns associated to the FT. These estimates can be helpful in understanding which vessels would most likely be affected by changes in resource availability and/or management decisions.

The polyvalence LP index, H, is based on the index by Shannon (1948) and was later adopted by Ulrich and Andersen (2004):

$$H_v = -\sum_{i=1}^{nLP} p_{i,v} * \log p_{i,v}$$

where $p_{i,v}$ is the proportion of trips spent by vessel v in LP i and nLP is the total number of LP. According to Ulrich and Andersen (2004), the polyvalence index reflects the relative importance of the main LP to the remaining LP, low and high index values indicating specialized and polyvalent vessels, respectively.

The index of LP stability, *S*, was estimated as the proportion of consecutive *FT* with the same classified LP according to each vessel:

$$S_v = \frac{\sum_{i=1}^{t-1} f(i,v)}{(nFT_v - 1)} \quad \text{with} \quad f(i,v) = \begin{cases} 1, LP_{i,v} = LP_{i+1,v} \\ 0, LP_{i,v} \neq LP_{i+1,v} \end{cases}$$

where *i* is instant time (the first FT of a certain vessel); *t* is final time (last FT); *LPi,v* is LP of vessel *v* at instant *i* and *nFTv* is the total number of FT for vessel *v*. “Zero” LP vessel stability means that the vessel always changed LP between FT, while “1” means that the vessel had landings in only one LP. Average indices (vessel LP stability and polyvalence) were estimated by FC. The two indices defined above were also estimated for the fishing port (instead of LP).

A third index denoted as fidelity, F_v, was estimated for region. The index of fidelity for region was estimated as:

$$F_v = \max \mathrm{p}_{r,v}$$

where $p_{r,v}$ is the proportion of trips spent by vessel *v* in region *r*.

Species-directed quarterly landings per unit effort: LpT (landings per trip)

A first approach was carried out to the estimation of the landings per unit effort (LPUE), fishery-dependent catch per unit effort (CPUE). Starting with landed quantities per trip (LpT, kg/trip) and using the LP defined, average quarterly LPUE estimates were obtained in kg/trip by LP and vessel for some of the most landed species/groups.

All statistical analyses were performed in the R environment (R-Development Core Team, 2009), using several different specialized packages, including ca and cluster (Maechler et al., 2005; Greenacre and Nenadic, 2007).

RESULTS

Vessel activity

Only 25 vessels were active during the entire thirteen year period. Both the number of active vessels and corresponding FT slowly increased until 2004 (approximately 60 vessels and 800 FT), after which a 21.8% decline was observed in fishing activity during a 3-year period, 2004 to 2007.

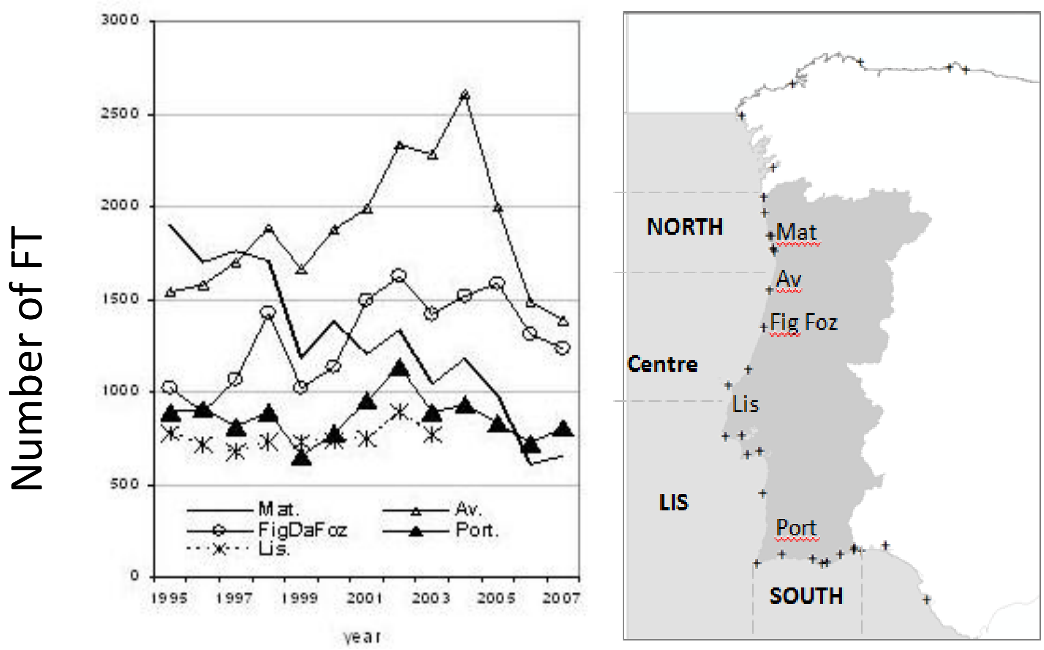

Figure 1. Left – Number of fishing events (fishing trip landings) by fishing port and year. Fishing ports represented are Matosinhos (Mat), Aveiro (Av), Figueira da Foz (FigDaFoz), Lisboa (Lis), and Portimão (Port), and were chosen according to the importance of the number of fishing trips during the time-period in analysis. Right – Map of Portuguese coastline, including ICES subdivision IXa (limits are 36 to 43ºN and 5º to 12ºW, shaded in light grey), with geographical location of main fishing ports, represented by dots. Four regions (North, Centre, Lisbon and South) are also indicated, with fishing ports in the latter region on the south coast, while the remaining three regions are located on the West coast.

Relatively to the landings activity by region (Figure 1), the Centre region, with four main fishing ports, corresponds to the region with highest proportion of landings. In this region the activity has progressively increased along the time-series considered, representing in 2007 over 50% of the total landing activity. Inversely, Lisbon and South (Algarve) regions, corresponding to south-west and southern coasts, were those with the lowest (stable) landings proportion during this entire period (due to the closure of the port of Lisbon and the diversion of trawlers landings from

Cascais). Finally, in the northern region, with only one important fishing port (Matosinhos), the proportion of fishing trips decreased along the time period in analysis.

In general, vessels concentrate most of their landings, displaying a high fidelity to region (0.86 ± 0.17, mean ± s.d.) and fishing port (0.70 ± 0.20). Landings occurred in a total of 21 different ports; however, continuous landing activity across the entire 13-year period in study was observed only in ten ports. Four out of these ten ports (Matosinhos, Aveiro, Figueira da Foz and Nazaré) accounted for two thirds (66%) of the total number of FT.

Species composition and landings

The main different species (or groups of species), landed by the 74 trawlers under analysis, are listed in Table 2, along with their percentages, in weight and value (ranked by weight) of the total catch. Data are also presented on the percentage of FT in which they were landed, as well as on their abundance (kg/trip). The species were classified according to their ecological characteristics (benthic, benthopelagic or pelagic) and priority level, as presented in EC, 2008.

Five groups (horse mackerel, blue whiting, Octopodidae, hake and squid) were chosen for the analysis on the basis of their importance in landings, both in weight and value. Horse mackerel is by far the most landed species, representing almost half of the landings, being landed in almost 90% of the FT with an average landing weight of over 500 kg per trip. It was followed by blue whiting, with 12% of the landing in weight, while the remaining three groups are among the most important regarding commercial value.

Plots of the cumulative proportion of FT versus the species proportion in landings are indicative of the extent to which fishing effort is directed at the species/groups in study (Figure 2), by showing whether a particular species is landed in a high or low proportion of FT. Three distinct patterns are evidenced. The first corresponds to horse mackerel, landed in the vast majority of FT, its importance as a target species being highly variable. By contrast, blue whiting and squid were landed in a much lower proportion of FT (0.4 to 0.5). Octopodidae and hake were landed in the majority of FT, but only in few of them they constituted a significant proportion of the landings. Significant inter-annual variability can be observed for horse mackerel and octopus (and, to a certain extent, squid). As an example, high proportions for Octopodidae and horse mackerel were observed in 1996 and 2006, respectively. Inversely, landings for squid were particularly low in 2006 when compared to other years. Blue whiting and hake seem to have maintained their importance along the time period analysed.

Table 2. General information for the different species (or group of species) in analysis. P – Pelagic (P), bentho-pelagic (BP), and benthic (B). Priority group (G1 – Top 1 priority; G2 – 2nd priority). Rv – rank of value. Species ordered by importance of landings in weight. Last three columns are statistics relative to the FT with positive landings of the respective species (or group of species): FTwpL – fishing trips with positive landings and corresponding median landings by trip (Landed weight per Trip, LpT in kg/trip and Landed value per Trip, LvPT in Eur/trip).

Species group	English	Ecology	Priority	%			FT with	Landing
(Latin name)	common name		Group*1	weight	value	FTwpL	LpT*4	LvpT*4,5
Trachurus trachurus	Horse mackerel	P	G2	45.5	33.8	89.8	541.2	812.63
Micromesistius poutassou	Blue whiting	P	G1	12.1	4.3	35.7	160.7	51.70
Scomber scombrus	Mackerel	P	G1	5.6	2.1	70.2	47.5	30.75
Trisopterus luscus	Pouting	BP	G2 *2	4.2	4.5	76.7	51.7	69.23
Scomber colias	Spanish mackerel	P	G1	4.2	0.9	39.4	84.0	25.68
Octopodidae	Octopus	B	G2 *3	3.9	7.8	78.6	43.5	88.42
Merluccius merluccius	Hake	BP	G1	3.7	9.5	81.6	52.9	260.87
Sparidae	Sea breams	BP	G2	3.4	8.6	80.9	23.4	107.78
Loligo spp	Squid	P	G2 *3	2.1	7.5	48.8	22.0	102.91
Scyliorhinus spp	catsharks	B		1.7	0.7	72.0	30.0	21.93
Raja spp	Rays and skates	B	G1	1.6	2.5	81.8	19.0	55.04
Zeus faber	John Dory	BP	G2	0.7	3.2	65.5	8.3	55.80
Sepia officinalis	Cuttlefish	BP	G2	0.4	1.0	30.8	5.0	28.71
Microchirus spp	Thickback soles	B	G2 *3	0.3	1.2	22.8	6.6	23.91
Lophius spp	Monkfish	B	G2 *3	0.3	1.0	36.9	6.4	40.96
Mullus spp	Mullets	B	G2 *3	0.3	1.2	58.0	3.7	39.02
Solea spp	Flatfishes	B	G1 *3	0.2	1.4	52.8	3.5	36.31
Others				9.9	8.9	97.6	103.5	155.65

***1– "Each species within a region is classified within a group according to the following rules: — Group 1 (G1): Species that drive the international management process including species under EU management plans or EU recovery plans or EU long term multiannual plans or EU action plans for conservation and management; Group 2 (G2): Other internationally regulated species and major non-internationally regulated by-catch species" (EC, 2008). *2– more general, ie spp (*Trisopterus spp*); *3 – more specific/taxonomic (ie *Octopus vulgaris*; *Loligo vulgaris*; *Microchirus variegatus*; *Lophius budegassa* and *L. piscatorius*; *Mullus surmuletus*; *Solea solea* VIIbc/VIIhjk/IXa); *4– median values; 5– values corresponding to year 2007.**

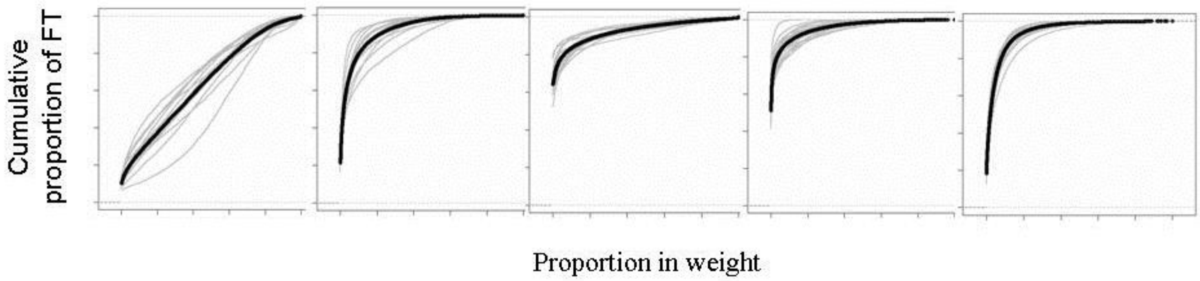

Figure 2. Empirical cumulative proportions of fishing trips (y-axis) vs. species proportion in weight (x-axis). Black and grey lines correspond to the entire time-series and yearly data, respectively. From left to right, horse mackerel (*Trachurus trachurus*), octopuses (Octopodidae), blue whiting (*Micromesistius poutassou*), squid (*Loligo spp.*) and hake (*Merluccius merluccius*). Information from 103693 daily fishing trips of fish trawlers in the period 1995-2007.

Landing profiles

Landing profiles (LP) are presented in Table 3 using the percentages (in value and weight) of species or groups of species. Each LP is characterized in terms of target and by-catch species, as well as its contribution to the total landings in value, weight and in number of fishing trips. A total of eight and six groups corresponding to the highest values of OASW index (0.35 and 0.29) were obtained respectively. When considering the analysis in weight, six groups (LP) were identified. Stronger groupings correspond to LP5 and LP6 (ASW 0.59 and 0.57), where horse mackerel and blue whiting are the main targets, contributing with 76% and 59% to the total landed weight for the LP. In LP4, squid was the main species with 45% of the landed weight. LP1 to LP3, where benthic species and horse mackerel are targeted, did not present any group structure.

When percentages in value were analysed, horse mackerel and Octopodidae were the main target species in the LPs for which higher ASW values were obtained. LPv2 and LPv8, with squid and blue whiting as the main targets respectively, were classified as weak groupings. The remaining four LP, with horse mackerel, hake, mackerel and Others (benthic fish species, Norway lobster and shrimps) as target species, presented asw values below 0.2. In both analyses two different LP were defined having horse mackerel as the main target species. The main difference between LP5 (and LPv6) and LP3 (and LPv4) is that the former two represent a directed fishery, while in the latter considerable by-catches are landed together with horse mackerel (Table 3).

Table 3. Fleet segmentation: definition of landing profiles (LP) based on 17 species and a total of 103693 fishing trips conducted by Portuguese fish trawlers in the period 1995-2007. LPv and LPw are defined according to target and by-catch species (only species with percentage above 10% are represented) having been used data corresponding to percentages of value and weight, respectively. Average price (Eur/kg) and importance of landings (% according to number of fishing trips, FT, weight and value) by LP are also shown. Overall average silhouette width as o.a.s.w.

	LP	Target species (%)	By-catch species (%)	% FTs	% weight	% value	average price	(oasw) asw
$LP_{\%w}$		% weight						(0.29)
	1	Octopodidae (26.3)	*T. luscus* (22.4), Others (17), *T. trachurus* (12.8)	22.3	11.5	18.6	2.59	0.09
	2	Others (54)	*S. colias* (19.6)	9.1	7.2	7.4	3.24	0.20
	3	*T. trachurus* (44.9)	*T. luscus* (10.3)	32.1	28.1	33.7	1.92	0.16
	4	*Loligo spp*. (44.9)	*T. trachurus* (25.7), *T. luscus* (11.3)	4.8	2.3	4.3	2.92	0.40
	5	*T. trachurus* (75.9)		23.5	37.2	28.0	1.37	0.59
	6	*M. poutassou* (58.7)	*S. colias* (19.6)	8.2	13.5	8.0	1.01	0.57
$LP_{\%v}$		% value						(0.35)
	1	Octopodidae (61.8)	*Loligo spp.* (12.8), *T. trachurus* (10.5)	7.4	4.0	6.4	2.55	0.50
	2	*Loligo spp*. (47.2)	Octopodidae (23.2)	12.3	7.2	11.6	2.60	0.42
	3	*M. merluccius* (29.4)	*T. trachurus* (14.8), *Sparidae* (14.3), Others (13.5)	18.6	12.3	16.3	2.26	0.14
	4	*T. trachurus* (30.6)	Others (15.3), *M. merluccius* (14.3), *Sparidae* (12.3)	31.7	29.7	31.8	1.76	0.18
	6	*T. trachurus* (75.9)	*M. merluccius* (11.6)	22.8	36.8	27.0	1.37	0.53
	8	*M. poutassou* (45.5)	*Z. faber* (14.0), Others (11.7)	4.2	8.4	4.4	0.80	0.35
	5	Others (83)		2.7	1.2	2.4	7.52	0.00
	7	*S. scombrus* (100)		0.3	0.3	0.1	0.42	0.00

*** Total weight, value and average (first sale) price are in 103 tonnes, 106 Euros and Euros/kg, respectively.**

Differences in total landings in weight between LP were observed (p-value <0.05), with LP1 and

LP4 totalling lower weights. However, non-significant differences could be observed when considering total landings in value ($p>0.05$).

Similarity in terms of number of groupings and basic species composition was observed between LP identified in value and weight, with two additional LP for the former dataset (Table 3). However, a close correspondence between FT within LP defined in weight and value was not observed, except for the pelagic species. As an example, about 80% of the trips from the horse mackerel LP in weight (LP3 and LP5) were identified as horse mackerel trips in value (LPv4 and LPv6), and vice versa (Table 4).

Table 4. Correspondence between the number of fishing trips by LP In weight and in value.

		$LP_{\%w}$					
		1	2	3	4	5	6
$LP_{\%v}$	1	6672	116	658	0	153	21
	2	4708	465	2213	4662	564	186
	3	7423	2769	7451	27	531	1065
	4	4078	3255	17733	29	5901	1856
	5	161	2336	41	0	10	222
	6	6	335	5155	5	17223	923
	7	55	12	22	206	3	47
	8	16	124	45	0	13	4200

Considering the results above, where the importance of the main target species in LP definition is higher for LP defined in weight, and the fact that the additional LP in value are grouped at a very weak level of asw, the analysis will henceforward refer to the LP in weight.

The distribution of proportions in weight for the five main groups across LP is evidenced in Figure 3A, confirming the results above. Horse mackerel is landed in all LP with particular relevance to LP5 and LP3, while Octopodidae, squid and blue whiting are species characteristic of LP1, LP4 and LP6, respectively. Hake is not landed in any of the LP with any particular relevance. However, in LP1 to LP3 higher average percentages were observed (overall average

6.9%) in comparison to LP4 to LP6 (2.5%), although the differences were not statistically significant (p-value>0.05). Proportions in weight are also shown by LP for the two ecological groups considered (Figure 3B), pelagic and demersal (benthic and benthopelagic). LP1 and LP2 are characterised by relatively low (but variable) proportions of pelagics while in LP4 to LP6 pelagic species clearly dominate. LP3 combines pelagic with benthic species.

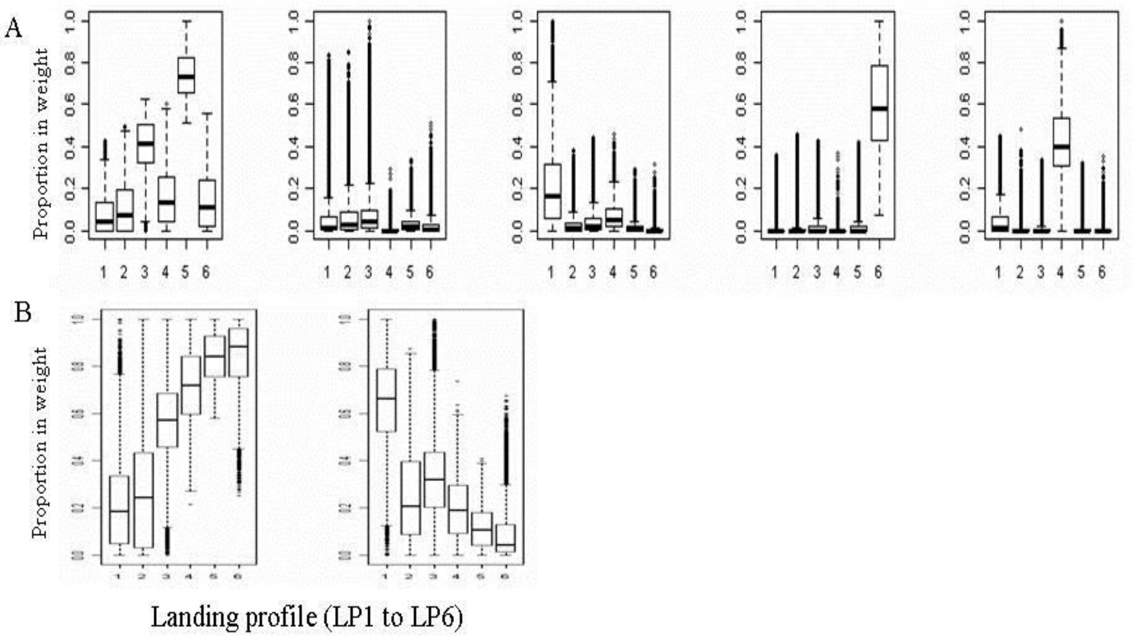

Figure 3. Boxplots showing the distribution of proportions in weight (y-axis) by LP (x-axis, 1 to 6). Box, horizontal line, whiskers and dots correspond to the interquartile range, median, most extreme value within 1.5 times the interquartile range and outliers. A – species proportion corresponding to the following species/groups, from left to right: horse mackerel (*Trachurus trachurus*), hake (*Merluccius merluccius*), octopuses (Octopodidae), blue whiting (*Micromesistius poutassou*) and squid (*Loligo spp*). B – proportions in weight of two main ecological groups. Left, pelagic species are: horse mackerel, blue whiting, mackerel (*Scomber scombrus*), Spanish mackerel (*Scomber colias*), and squid; right, benthic and benthopelagic: pouting (*Trisopterus luscus*), sea breams (*Sparidae*), John Dory (*Zeus faber*); octopus (Octopodidae), hake, catsharks (*Scyliorhinus spp*), cuttlefish (*Sepia officinalis*), mullets (*Mullus spp*); rays and skates (*Raja spp*), thickback soles (*Microchirus spp*), monkfish (*Lophius spp*), flatfishes (*Solea spp.*). Data consists of the 103693 fishing trips for the fish trawlers in the period 1995-2007.

Time and regional patterns of LP

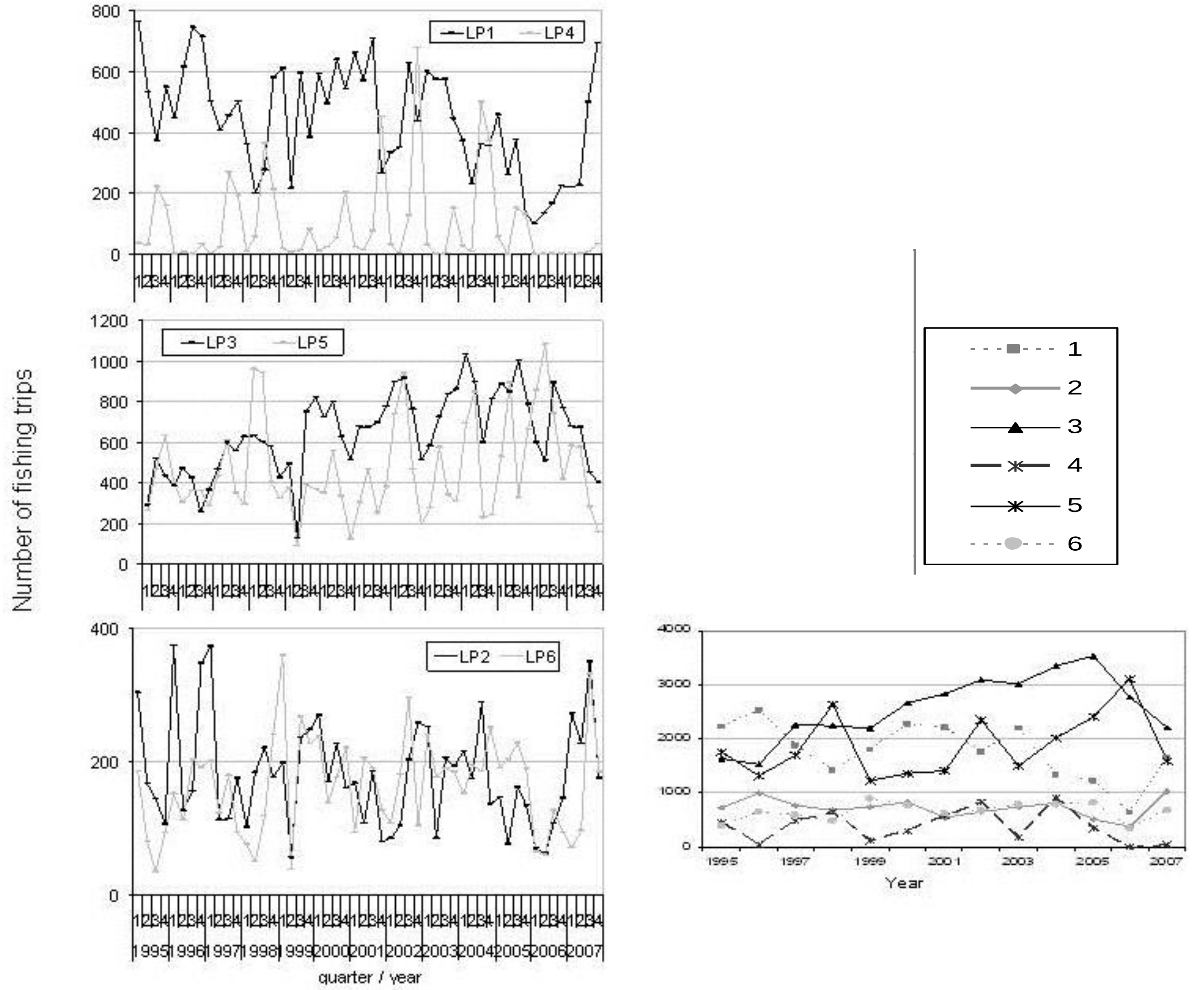

Figure 4. Quarterly and yearly distribution (x-axis) of the number of fishing trips by LP. LP1: octopus (Octopodidae); LP4: squid (*Loligo spp*); LP3 and LP5: horse mackerel (*Trachurus trachurus*), LP6: blue whiting (*Micromesistius poutassou*); and LP2: Others. Bottom right figure corresponds to yearly data. Data from 1995 to 2007. The following symbols 1 2 3 4 5 6 **represent LP1 to LP6, respectively.**

Quarterly distributions of FT frequencies by LP in weight are shown in Figure 4. Time patterns were not evident for LP6 (blue whiting) or LP2 (Others). On the other hand, seasonal fluctuations were marked mainly for LP5 (targeting horse mackerel) and LP4 (squid) and, to a lesser extent, LP3 (horse mackerel) and LP1 (Octopodidae). Differences in the number of FT by semester was observed in LP5 and LP4 (prop.test, p-value<0.05), higher number of trips for horse mackerel in LP5 were recorded during the first semester, while squid was landed mainly in the second semester. Progressive annual increase in the number of FT in LP3 has been registered along the time-series, while marked inter-annual fluctuations were observed mostly in LP4 and LP5. Highest (negative) significant correlation observed (p-value<0.05) for the number of FT by LP was between LP1 and LP5 at the various time scales chosen, i.e. correlations relative to year, quarter and month resolutions were -0.846, -0.59, and -0.57, respectively (Table 2).

Table 2. Correlation between number of fishing trips by LP (lower and upper triangle with yearly and monthly data, respectively).

		Month					
		LP1	LP2	LP3	LP4	LP5	LP6
Year	LP1		0.335	-0.2891	-0.1058	-0.5657	0.3779
	LP2	0.5519		-0.1529	0.0431	-0.4243	0.2755
	LP3	-0.4747	-0.5046		-0.0349	0.3125	0.1543
	LP4	-0.0579	-0.1551	0.3971		-0.3183	0.0091
	LP5	-0.8460	-0.6430	0.3796	0.2170		-0.3067
	LP6	0.2477	0.3402	0.3885	0.0143	-0.5268	

All LP had landings in the four regions (North, Centre, Lisbon and South), with the exception of LP4 targeting squid, for which landings were almost entirely in the Centre (83% of the FTs) and North regions. For LP6 (targeting blue whiting), almost 80% of the FT are from the North and Centre, similarly, for LP2 (Others) 60% are from the southwest and South regions, suggesting regional patterns of activity. For LP1 (targeting octopus) and LP3 and LP5 (horse mackerel) a wide geographical distribution was recorded, LP5 with a higher activity in the North when compared to the other two.

Species-directed landings per unit effort: Landings per Trip (LpT)

Quarterly estimation of species abundance (species-directed LpT, landings per trip) is presented in Figure 5. For horse mackerel, decrease in LpT was observed from averages varying between 2000 and 3000 kg/trip in the first years analysed until values around 1000 kg/trip from 2002 onwards. For the remaining species, inter-annual variations were observed. Seasonal variations can also be noticed for all species, with the exception of blue whiting (LP6).

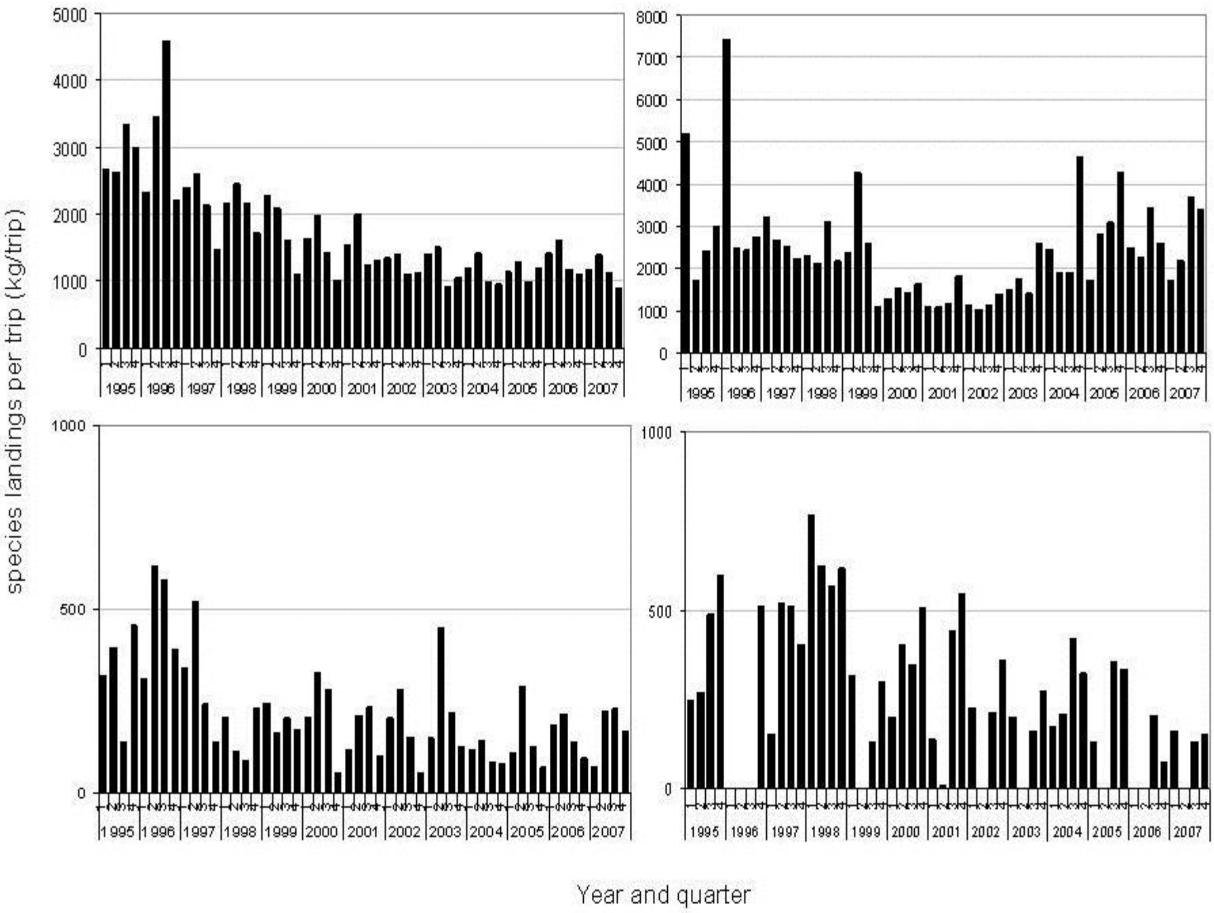

Figure 5. Quarterly mean species landings per trip, LpT (kg/trip, y-axis) for (top left) horse mackerel, *Trachurus trachurus* (LP3 and LP5), (bottom left) Octopuses, Octopodidae (LP1), (top right) blue whiting, *Micromesistius poutassou* (LP6) and (bottom right) squid, *Loligo spp* (LP4) from 1995 to 2007.

Fleet components

The existence of fleet components, i.e. groups of trawlers involved in specific LP, was investigated by relating the individual vessels to the different LP based on percentages of species landings in weight (Figure 6). The first axis explained 54.8% of the total variance for these data, differentiating between LP1 and LP4, associated to a group of trawlers identified as FC1 (27 vessels, with mean estimates of 25m LOA and 602 HP), targeting mostly cephalopods (Octopus and squid), and the remaining LP (LP3 to LP6), aggregating those vessels targeting horse mackerel and blue whiting in FC2. These FCs differ essentially in their size (more than one third and one half of the vessels in analysis in FC1 and FC2 respectively), as well as in their mean size

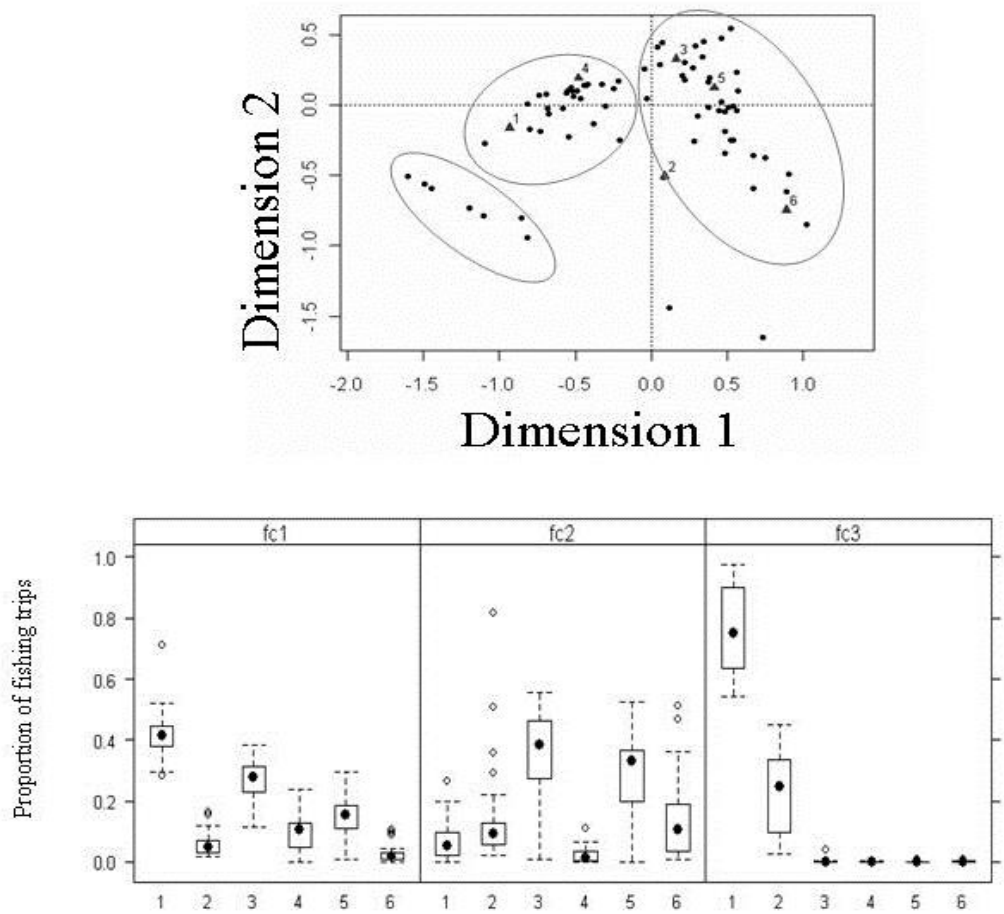

Figure 6. Fleet components (FC) defined by CA (correspondence analysis) of six landing profiles (LP based on proportion of species landings in weight) and vessels for the Portuguese fish trawl fleet in the period 1995-2007. A - Along the first axis (Dimension 1), the cephalopod trawlers engaged in LP1 and LP4 are separated from vessels targeting horse mackerel (LP3 and LP5) and blue whiting (LP6). A number of trawlers are plotted along the second axis (Dimension 2) landing mostly cephalopods and benthic species. Dots and triangles represent vessels and LP, respectively. Centre, right and left circles contain vessels belonging to FC1, FC2 and FC3, respectively. B – Boxplot of proportion of fishing trips by LP (x-axis, 1 to 6), grouped by FC.

and engine power (p-value<0.05), which are larger for FC2 (average LOA and HP are 30.4m and 868.5 HP, respectively), targeting pelagic fish. LP2 (others: including mainly benthic species), as well as LP6, are well individualized in the second axis, explaining 19.7% of the total variance; however, they were not found to be the core for distinct fleet components. In fact, a small number of trawlers was observed to scatter between LP1 and LP2, indicating mixed landings composed by octopus and benthic species. This corresponds to a third, well-individualized group of vessels, composed by a small number of much older (more than 30 years) and less powered vessels (17m and 259HP). Finally, two vessels are observed which could not be considered as a different LP, being included in FC2.

Figure 7 shows the distribution of FT by FC, region and LP. FC1 vessels are mainly active in the Centre (78% of FT). Vessels belonging to FC2 present a wider geographical activity, landing along the entire coastline. However, the Centre region is also the one with higher importance in terms of FT (43%). FC3 vessels, a small number of older, less powered and less active trawlers, operate exclusively in the south.

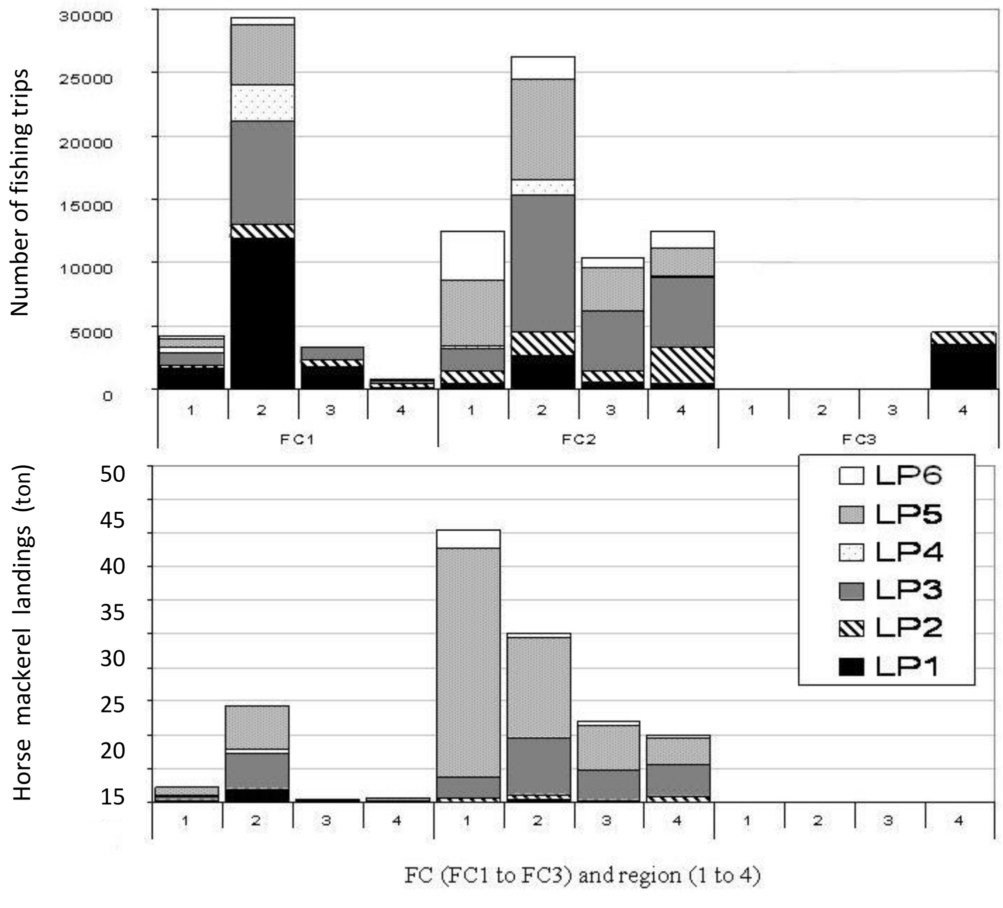

Figure 7. Number of fishing trips and horse mackerel landings in tonnes (y-axis) by landing profile (LP), grouped according to (x-axis) region and fleet component (FC) for the 74 vessels. Regions 1 to 4 correspond to North, Centre, Lisbon and South respectively.

Octopus and squid (LP1 and LP4) are mainly targeted by FC1, and blue whiting (LP6) by FC2. On the other hand, horse mackerel (LP3 and LP5) is targeted by FC1 in the Centre and FC2 along the entire coast. FC vessels present mixed landings composed of octopus and benthic species (Figure 7).

Despite the much higher importance of the Centre ports, mainly Aveiro, in terms of FT for horse mackerel, the landings for this species attain higher values per trip in the north, where horse mackerel is almost exclusively targeted in LP5.

Vessel LP stability, polyvalence and fidelity to region

Differences of LP stability and polyvalence were observed between the three FC (p-value<0.05), with higher LP stability (median 0.88) and lower LP polyvalence (0.58) observed for vessels belonging to FC3 (Table 6) when compared to the remaining. Only five vessels, all belonging to FC3, registered 100% LP stability in different years, with total fidelity to LP1. For vessels belonging to FC1 and FC2, stability was 0.54 and 0.53, and polyvalence 0.61 and 0.58, respectively. As for the vessel behaviour in relation to the fishing port, stability remained relatively constant between FC (varying between 0.82 and 0.85 on average), and polyvalence ranged between 0.21 (FC3) and 0.30 (FC2). Regarding fidelity to region by FC, mean values varied between 0.81 (FC2) and 1.00 (FC3).

Table 6. Statistics of vessel index of stability (S), polyvalence (H) and fidelity (F) by fleet component (FC) between 1995 and 2007. Indices were estimated according to landing profile (LP), fishing port (landing port) and region, respectively. Mean and standard deviations (s.d., in brackets) are shown.

FC	LP		Fishing Port		Region
	S	H	S	H	F
FC1	0.543	0.605	0.842	0.285	0.893
	(0.053)	(0.068)	(0.099)	(0.176)	(0.140)
FC2	0.525	0.577	0.846	0.301	0.805
	(0.065)	(0.083)	(0.102)	(0.193)	(0.176)
FC3	0.860	0.224	0.829	0.213	0.997
	(0.079)	(0.117)	(0.110)	(0.121)	(0.000)

DISCUSSION

Results from finfish fleet segmentation in the present study point out to a total of six LP using the landings percentage in weight. LP having as main targets pelagic such as horse mackerel and blue whiting (LP5 and LP6 respectively) were identified as stronger groupings. The remaining (LP1 to LP4) did not show a clear dominance of a particular species, being therefore classified as weaker groupings. For LP defined in value, stronger groupings were composed by commercially valuable species such as the Octopodidae and squid. From all the groupings defined, close correspondence between results in weight and value could be observed between LPw5 and LPv6, where horse mackerel is the main target and, to a lesser extent, between LPw6 and LPv8, for blue whiting.

Three main fishing effort patterns were evidenced for the species in study, by showing the cumulative FT proportion versus the landings proportions in the fishing trips. The first corresponded to horse mackerel, the second to Octopodidae and hake and a last one, to squid and blue whiting. Horse mackerel was landed in almost all FT although in variable proportions, suggesting its importance as a target species with high abundance and wide geographical distribution. Octopodidae and hake were landed in the vast majority of trips, denoting wide distribution, but with very low proportions in many of the FT. By contrast, squid and blue whiting were landed in a much lower proportion of FT, which suggests a timely and/or spatially located distribution, for both species. However, for blue whiting the results obtained by analysing landings data should be carefully interpreted since this is a frequently discarded species, mainly in the centre and southern coasts (Borges et al., 2001; Fernandes et al., 2007).

Seasonal fluctuations in LP activity were recorded for LP5 (targeting horse mackerel) and LP4 (squid), with higher number of trips for the former during the first two quarters, while squid was landed mainly in the last two. This is in accordance with the life cycle for both species (Moreno et al., 2007). A progressive annual increase in LP3 has been registered, while marked inter-annual fluctuations were observed for LP4 and LP5, suggesting shifts in vessel strategy that can be environmentally-driven, market-driven, or both.

Distribution of FT by ports revealed regional patterns of activity. Horse mackerel (LP3 and LP5) is landed along the whole coastal extension by a high number of trawlers with different characteristics. On the other hand, cephalopods (octopus and squid) are targeted, together with horse mackerel, mainly in the north and centre (ports of Matosinhos, Aveiro and Figueira da Foz). This is in accordance with data in Pilar-Fonseca et al. (2008), in a spatial analysis using VMS data from 2003. Cephalopods are also landed as target species of the trawl fleet at the south coast, but at much lower quantities.

For these vessels belonging to the finfish trawl fleet, constituting a diversified group in terms of vessel's technical characteristics and LP, evidence is given of the existence of three FC addressing different ecological groups and differing in their fishing strategies, namely the area of operation. Apparently, vessel tonnage, and consequently vessel power and trawling speed, are the main factors explaining these differences. FC3 corresponds to a small number of old and low powered vessels, previously defined and characterised by Campos et al. (2007), operating off the south coast, targeting mostly Octopodidae and benthic species and with only one vessel landing more than 100 times per year. Large vessels (FC2), operating along the entire coast from Region 1 to 4, target mainly fast-swimming species such as horse mackerel and blue whiting in LP5 and LP6. Average powered units belonging to FC1 operate almost exclusively in the centre (Region 2), targeting a diversified number of species, including horse mackerel and benthic groups in which octopus dominates landings (LP3 and LP1 respectively). These two different patterns of activity are possibly related to higher trawling speeds in FC2 when compared to FC1, which makes these latter vessels behave as "active predators". The FC results obtained with the LP defined by percentages in value were not found to differ much from these.

Inter-annual variability in the landings proportion suggests changes in the importance of these species as targets. This is possibly associated to fluctuations in species abundances due to shifts in environmental conditions. It is the case of horse mackerel, for which strong LP were defined from 2005 to 2007. Inversely, for squid, in the last three years of this analysis no LP was identified, contrasting with previous high abundance years (1998, 2002 and 2004), while octopus was an important LP in 2003. Finally, two LP were identified with mackerel (*Scomber scombrus*) and pouting (*Trisopterus luscus*) as important targeted species in 2006 and 2001, respectively.

Notwithstanding, results obtained at the scope of a year by year analysis showed that a number of vessels changed their fishing strategy across the study period, switching between distinct LP with more frequency than others. This was particularly observed between LP1 and LP3, sharing common species, and can possibly contribute to explain why these two groupings were defined as weak ones in the cluster analysis using proportions in weight.

A shift of vessel behaviour in terms of main landing port was also observed during the period in analysis, with landings gradually increasing in the centre and decreasing in the northern region. This may be due to economic reasons and operational improvements in the main port of region 2, Aveiro.

The results of fleet segmentation for the time series analysed are consistent with those obtained in previous studies for the period between 2002 and 2004, based on the analysis of monthly aggregated landings for the entire coastal trawl fleet (Campos et al., 2007) and for the finfish fleet (Pilar-Fonseca et al., 2008). In this study, further knowledge is gained regarding time and regional patterns of activity for the different LP.

It must be noted that the patterns above may reflect fish abundance for pelagic, such as horse mackerel, blue whiting and squid, which are mostly targeted by trawl fisheries. However, that is not the case for benthic species such as hake and particularly the octopuses, for which trawl landings represent less than 50% and 10% of total landings, respectively (DGPA, 2008). These groups are targeted with different types of gear, including traps, gillnets and longlines. As such, technical interactions have to be taken into account.

The indices estimated allowed an insight into individual short-term fishermen behaviour, in particular the tactical patterns associated to the vessel LP stability and polyvalence. According to Ulrich (et al., 2004), the polyvalent index reflects the relative importance of the main LP to the other LP, low and high index values indicating specialized and polyvalent vessels, respectively. These estimates can be helpful to understand which vessels would most likely be affected with changes in resources availability and/or management decisions (i.e. decrease in TAC). The importance of fleet dynamics in fisheries management models has been emphasized in various works, including Anderson et al. (2010). High stability and low polyvalence (as it is the case of FC3 vessels in this study) may indicate vessel specialization, but also higher dependency towards certain stocks and probably lower ability to changes in fishing tactics/strategies if necessary.

Conversely, low stability and high polyvalence in terms of LP may reflect vessels with a more opportunistic behaviour and more prepared for unexpected changes.

This study completes previous work by Campos et al. (2007), based on the analysis of three years (2002-2004) of monthly landings for the entire coastal trawl fleet, where three distinct fleet components have been identified: crustacean, finfish and small cephalopods trawlers. From these, crustacean vessels were found to be a distinct fleet in terms of target species, area of operation and type of fishing licence and therefore, this segment of the trawl fleet will be separately addressed. Here, the objective was to examine in more detail fleet segmentation and dynamics for finfish trawlers (licensed for 65 mm mesh size), based on a 13-year time series of daily landings information. Together with the identification of trawl fisheries for the Cantabrian Sea by Punzón et al. (2010), using similar methods over a similar time series, and with the study by Jiménez et al. (2004) in the southern Spanish waters of the Gulf of Cadiz, this completes the description of trawl fisheries for the Atlantic waters of the Iberian Peninsula.

Punzón et al. (2010) identified a total of four different fishing tactics, targeting mackerel, horse mackerel, blue whiting and a mixture of species, and two different fleet components associated to eastern and western Cantabrian Sea. Two of these tactics, horse mackerel and blue whiting, coincided with LP defined in this study, while the remaining corresponded to benthic species (e.g. Octopus) with southern distribution. On the other hand, Jiménez et al. (2004) identified, for the trawl fleet of the southern Spanish waters of the Gulf of Cadiz (ICES Subdivision IXa South), a total of 22 types of trips using information from a one-year period (1993). A total of thirteen fisheries were defined having one single species as target, some of them coinciding with the LP defined here, such as horse-mackerel, common octopus (*Octopus vulgaris*), blue whiting and hake, or in Campos et al. (2007): Norway lobster, *Nephrops norvegicus*, and rose shrimp, *Parapenaeus longirostris*. The higher number of trip types defined by Jiménez et al. (2004), with monkfish, *Lophius budegassa*, *Solea spp.*, *Engraulis encrasicholus*, *Lithognatus mormyrus*, *S.officinalis*, *Dicologoglossa cuneata* and *Penaeus kerathurus* reflect higher biodiversity typical of Mediterranean waters.

The existence of LP targeting pelagic and benthic fish, within fish trawlers, can constitute the basis for improving adequate sampling programmes in order to critically address by-catch and discards in the different components of the fleet. It also comes in support of the idea of having technical management measures, including gear-based measures, specifically directed to each LP. In Cantabrian waters, for instance, blue whiting is not targeted with otter trawls but instead with pair-trawls, which was found to be a more efficient method (Punzón et al., 2010) and besides it is a much less invasive one in terms of the impact at the bottom.

The implementation of a management network based on real-time closures requires, on the other hand, further analysis of spatial patterns of activity using VMS data for these distinct FC vessels, in order to confirm the relationships between fishing effort, catchability and habitat properties. All these features have to be considered in order to enhance fisheries management in the framework of the ecosystem approach to fisheries management.

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Paper 4

Maritime Engineering and Technology – Guedes Soares et al.

The importance of satellite-based vessel monitoring system (VMS) for fisheries management: A case study in the Portuguese trawl fleet

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ABSTRACT: Satellite-based Vessel Monitoring System (VMS) data, consisting of vessel location and speed, have been used for fisheries control. However, the usefulness of these data can be extended to fisheries research, as the outputs provided by this system make it possible to map and quantify the fishing activity. One possible application is the estimation of effective fishing effort. Moreover, the cross analysis of effort with the corresponding vessel landings, allows the estimation of landings per unit effort (LPUE), used as a proxy of stock abundance in fisheries management. VMS data with 10-minute interval was processed for a Portuguese coastal trawler operating off the west coast, using GeoCrust 2.0, a geographical information system which identifies fishing trips and towing events (hauls) within trips. This information was then used to characterize vessel activity. It is demonstrated how high-resolution VMS data allows to understanding fishing tactics and derive more precise series of effort estimates.

1 VMS IN PORTUGUESE FISHERIES

The Portuguese vessel monitoring system (MONICAP), created in 1987, was the first implemented in Europe, being presently operating in vessels with length overall (LOA) higher than 15 meters (EC, 2003). Global Positioning System (GPS) data for each vessel, consisting of a succession of geographical locations (latitude, longitude), dates, times, speed and course, are received by a 'blue-box' (satellite-tracking device installed on board Community fishing vessels), recorded and automatically transmitted via satellite (Loran-C) to the Portuguese Fishery Directorate (DGPA/IGP), the national monitoring authority responsible for marine surveillance. Until 2004, records were obtained each 10 minutes, but since then, according to European Union (EU) regulations the frequency of data transmission may be at least once every two hours, if the national Fisheries Monitoring Center (FMC) has the possibility of polling the actual position of the fishing vessels (EC, 2003), which is the case of Portugal.

These geo-referenced data have been exclusively used with the purpose of fisheries control, in particular to check whether vessels are operating outside the six nautical miles line off the coast as required by law. However, the usefulness of MONICAP data can be extended to fisheries research purposes, as the analyses of data provided by this system makes it possible to map and quantify the fishing activity. One possible application is the estimation of series of effective fishing effort. Moreover, the cross analysis of effort with the corresponding catches from vessel logbook, or with vessel landings, allows the estimation of landings per unit effort (LPUE), often used as a proxy of stock abundance in fisheries management.

For each vessel, a series of trajectories can be produced by mapping the geo-referenced information, each defining a fishing trip, starting at a fishing port and ending at the same or in other port. These trajectories will tend to form patterns consisting in a succession of points, closer or more distant according to the slower or faster vessel speed. In addition to providing geographical location of the fishing activity, depending on the amount of data, these patterns can also identify and characterize the main operational phases of a trip.

Satellite-based VMS information is available for all Portuguese coastal trawlers operating mostly in Western Iberian waters, ICES division IXa (DGPA, 2010), with occasional trips in divisions VIIIc and IXb. A total of 83 vessels were active at the end of 2009, corresponding to 15385 GT (gross tonnage) and 69737 of engine power (kw). During this year, this fleet accounted for 12 and 17% approximately of the total national landings in weight and value, respectively. Fishing pressure is high, the fishing activity taking place all year round and exploiting a large number of fish, cephalopods and crustaceans. These include pelagics such as horse mackerel (*Trachurus trachurus*), mackerels (*Scomber scombrus* and *Scomber japonicus*), and blue whiting (*Micromesistius poutassou*), demersal species such as octopuses (*Octopus vulgaris* and *Eledone cirrhosa*) and European hake

(*Merluccius merluccius*). A different fleet component exploits deepwater crustaceans including the rose shrimp (*Parapenaeus longirostris*) and the Norway lobster (*Nephrops norvegicus*).

Herein, we demonstrate the utility of satellite-based VMS information to map the activity of a Portuguese coastal fish trawler mainly involved in the capture of horse mackerel and cephalopods, identify fishing tactics and estimate effective effort.

2 DATA ANALYSIS

A collection of unprocessed VMS data corresponding to a 12-month period of activity (2003) was selected for this trawler. The spatial pattern of the vessel activity is displayed in Figure 1, showing that the vessel operated over approximately 193 nautical miles in the western coastal area between Matosinhos and Figueira, between 40.0° and 41.6°N in latitude and 8.7° and 9.5°W in longitude, with only a few trips south of this area. Operational fishing depth was between 30 and 200 m.

Criteria for filtering these data for effort estimation purposes are primarily based on the separation between fishing from non-fishing points, according to each vessel speed profiles. The speed-frequency histogram for trawlers typically displays the trimodal pattern in Figure 2, where the speed profile for the vessel in study is shown using the raw data corresponding to 2003. The second low speed peak will correspond to fishing activity (trawling), in this case between 3 and 5 knots approximately, while the third peak corresponds to faster movements (e.g., steaming, 9 to 11 knots). Low speeds of pre-processed data can also correspond, for instance, to steaming near port or shooting the trawl.

The geo-referenced information, consisting of trajectories with 10-minute intervals between records, each corresponding to one fishing trip (FT), was then processed using GeoCrust 2.0 (Afonso-Dias et al., 2004). This dedicated geographical information system (GIS) was designed to analyze fleet spatial dynamics through semi-automatic identification of the fishing trips and trawl hauls, thus requiring expertise and time from an operator.

Once the identification process by GeoCrust is complete at the haul level, the haul characteristics (i.e. duration, distance, and geographical location) are defined. The operator classifies each trip with a two-level quality index, indicating if the original data consists of high/low quality data regarding completeness. Fishing trips with incomplete VMS data are considered of "low" quality (partially valid fishing trip) since this can affect haul identification, and therefore, the effective effort estimates.

GeoCrust identified a total of 849 hauls (corresponding to 11563 points) within 128 high-quality FT (21270 points). These FT are analyzed and interpreted to identify the main operating phases: steaming from port to fishing ground; towing; steaming between fishing grounds; and steaming back to the port. For practical purposes, only two main activities were considered, trawling and steaming. Accurate computation of fishing effort estimates were obtained from the system including trip and hauls duration, as well as distances trawled (nautical miles, nm).

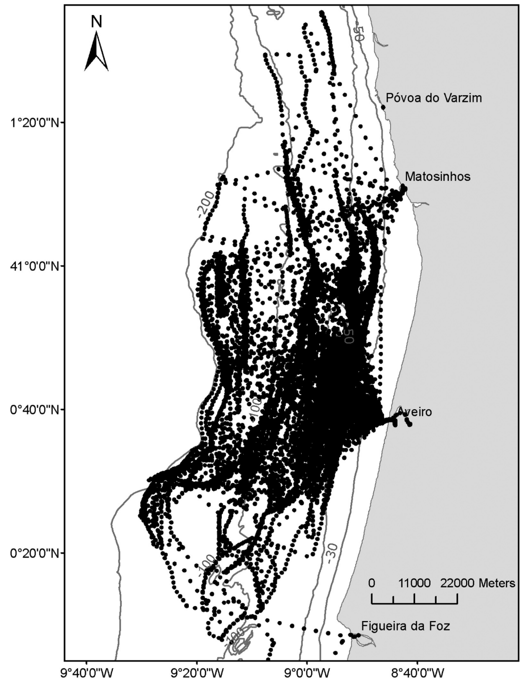


Figure 1. Map of the geographical distribution of vessel activity (unprocessed data). Each point represents a position of the vessel during 2003. Approximately 25000 VMS points (with 10-minute interval) were used.

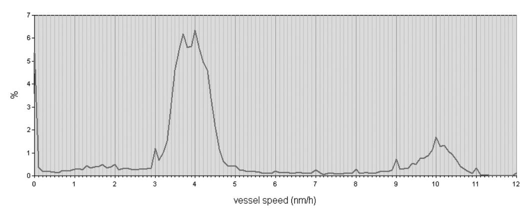
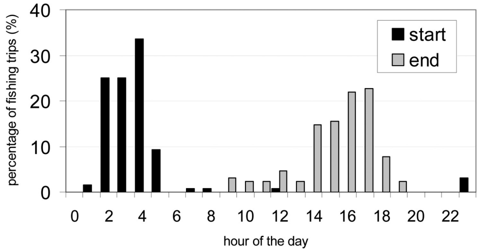
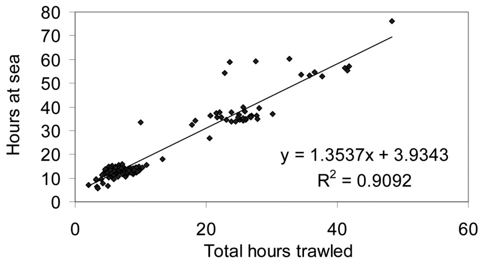


Figure 2. Speed profile (nautical miles/hour, x-axis) for the vessel in study using pre-processed VMS information for 2003.

Within this fishery, a number of different species can be targeted by the same vessel. The methodology to estimate species directed effort involved the cross analysis of effort with landings from individual fishing trips. The trips were previously classified (Pilar-Fonseca et al., 2009), in a number of distinct groups (landing profiles, LP) according to the main target species landed. Effort and abundance indices (landings per unit effort, LPUE) by LP could then be obtained for fisheries management purposes.



a)



b)

Figure 3. a) Frequency distribution of starting and ending time (black and gray, respectively) of trips by hour (x-axis). b) Relationship between trip and haul duration (total hours trawled and hours at sea) for the vessel in study during 2003. Total number of trips identified: 128.

3 RESULTS

During 2003, the trawler in study presented relevant activity for three distinct LP, one of them targeting exclusively horse mackerel (LP5), a second one where horse mackerel is targeted along with bentho-pelagic species (LP3), and a remaining one targeting benthic species, with relevance to the Octopodidae (LP1).

Trips usually start before dawn, and the vessel steam offshore for a variable period, depending on the distance to fishing grounds (Figure 3). When reaching the fishing area, speed is reduced and the trawl is set at low speeds. Setting, as well as hauling-back, are operations limited in time. However, these operations could be identified in this case (Figure 4) due to the high data quality and completeness.

Total hours trawled by trip varied between 2 and 48 hours, with mean haul duration of 125 minutes (s.d. = 54 minutes). For this vessel, trawling speeds (at the trip level) varied between 3.3 and 4.4 knots depending on the target species, after which haul-back is initiated with the vessel stopped. The number of hauls per trip varied between 1 and 21, with average number of 7. Hours at sea (trip duration) varied between 5.6 and 76.1 (average = 22.7 hours) with average steaming and trawling speeds estimates around 6.4 and 4.0 knots (Table 1).

For the vessel in study, geographical location of fishing activity was not found to differ much between LP. However, differences in trip duration are evident, with longer trips when benthic species are targeted (LP1), progressively reducing towards LP5 and LP3, where the main target is horse mackerel (Table 1). This is possibly related to higher catches in the latter, leading to more frequent landings. The proportion of hours trawled by trip was found to be related with trip duration, with about 65% of the time spent trawling in LP1 versus around 50% in the remaining LP. Haul duration was found to be longer in LP1 targeting octopuses when compared to those targeting pelagic fish.

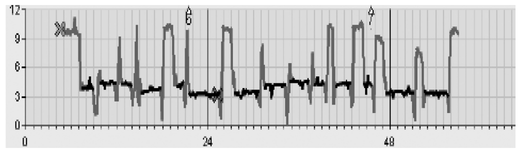


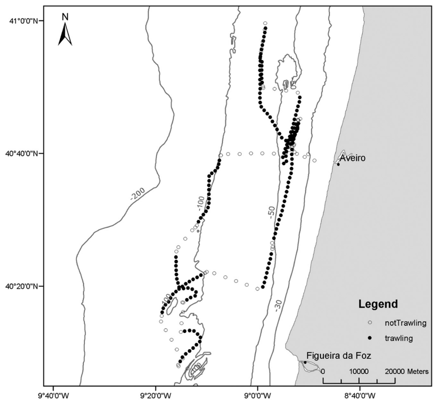
Figure 4. Speed profile (y-axis) along time (x-axis) for one fishing trip obtained from the GeoCrust system. Trawling activity correspond to low speed, identified in black. This 54-hour trip started at around 5 am and ended at around 10 am of the third day.

Table 1. VMS-based effort and landing per unit effort (LPUE) estimates by landing profiles (LP) for the vessel in study high quality data processed by GeoCrust 2.0. LP named according to Pilar-Fonseca et al. (2009). LPUE is kg landed/hour. Standard deviations in parenthesis.

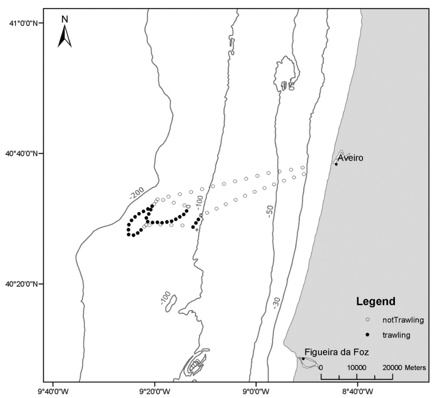
	LP1	LP3	LP5	Total
Effort and operational parameters				
Total number of FT	53	35	26	128
Number of hauls*	8	5	6	7
Trip duration (h)*	28.1 (14.9)	15.7 (9.3)	22.4 (18.9)	23 (15.0)
Number of hours trawled per trip*	18.9 (10.9)	8.1 (5.5)	12.5 (12.4)	14.0 (11.0)
Number of hours in navigation*	9.2	7.6	9.9	9.0
Speed in navigation* (kt)	5.9	7.0	6.6	6.0
Trawling speed* (kt)	3.8	4.1	4.0	4.0
Total trip duration (h)	1488	549	582	2899
Total number of hours trawled	1001	282	326	1770
Total number of hauls	430	172	168	849
Proportion of trawling time within trips*	0.65	0.50	0.53	
LPUE				
Octopodidae LPUE* (kg/h)	10.9	5.6	4.7	7.0
Horse mackerel LPUE* (kg/h)	6.2	61.8	130.3	49.0
Total landings in weight per trip* (kg/trip)	886	866	1660	1034
Total landings in value per trip* (Euros/trip)	2376	1849	3170	2364
Total landings in value per hours trawled* (Euro/h)	58	140	170	108

*Average estimates.

Trip 1 (LP1)



Trip 2 (LP3)



Trip 3 (LP5)

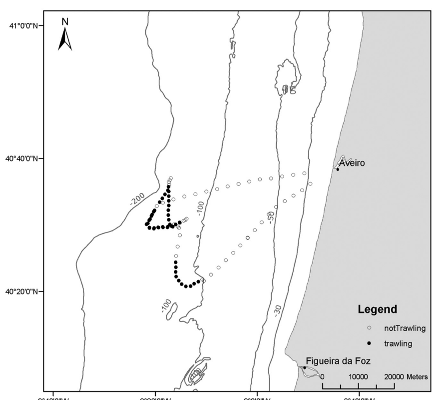


Figure 5. Map of the VMS information (trajectories) processed by GeoCrust at the trip level for three FT corresponding to the three main different LP. For trip 1, 2 and 3 targets are: octopuses and benthic species; horse mackerel and bentho-pelagic; horse mackerel. Trip duration: 38.1 h; 11.1 h; 14.9 h. Hours trawled; 25.8 h (68% of trip); 4.1 h (76%); 7.0 h (47%). Trawling speed: 3.9 kt; 4.33 kt; 4.22 kt. Navigation speed: 6.6 kt; 8.5 kt; 7.8 kt. A total of 12, 3 and 4 hauls were identified. Black dots correspond to trawling activity. All trips began and ended in the fishing port of Aveiro.

Differences in trawling speed are also noticed between LP targeting pelagic and benthic species, although the magnitude of these differences is less than 0.5 knots. Average trawling speed was found to be around 4.0 knots for pelagic, while for benthic fish it corresponded to 3.8 knots (Table 1).

Three different FT considered as representative of the three LP above (LP1, LP3 and LP5), for which observed effort approached the average LP effort estimates, were chosen (Figure 5). The figure illustrates the existence of different fishing tactics. The vessel activity in the first trip (LP1), where benthic species were targeted, extends over a wide geographical area, with a large number of hauls carried out at two different sites following distinct isobaths. The remaining trips, directed to pelagic species (LP3 and LP5), are shorter with lower number of hauls, and spatially located in fishing grounds at higher depths, being more distant from the coast. Short duration hauls were carried out at a higher trawling speed, which is directly related to horse mackerel behavioral characteristics.

4 FINAL CONSIDERATIONS

By providing a more reliable account of effective towing time, the use of VMS data allows for a precise estimation of fishing effort, and therefore of LPUE, thus contributing for better resource management. Even considering the major step arising from the use of VMS-derived effort data, reliability of LPUE estimates could be further improved if a trustworthy relationship between catch and individual hauls were established. However, at present time, the accuracy of the information contained in logbooks is, at the least, questionable. The future adoption, within the EU, of electronic logbooks, may contribute to partially solve this problem, although the "human–factor" – the correctness of entries by the skipper – will persist.

The use of geo-referenced data can be extended to address fishermen behaviour and fishing impacts on the ecosystem, allowing for the integration of spatial planning in fisheries management schemes. However, the financial constraints related to data transmission (satellite communication fare) that led to the adjustment of transmission rate from 10-minute to 2-hour interval, will compromise the use of more recent VMS data for the above purposes. In this fishery, where mean tow duration is, as it was stated above, of 125 minutes, a 2-hour-interval between the consecutive reception of VMS data points will preclude the correct identification of single tows.

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Technologies” (MARE, FEDER, QCA-III, 22-05-01-FDR-00114: 2000-2007).

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Paper 5

Exploitation patterns and size composition of *Octopus vulgaris* in Portuguese waters (Northeast Atlantic) derived from fine-scale geo-referenced bottom-trawl commercial catches

(accepted for publication in Fisheries research)

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Abstract

Octopus vulgaris is the most important target species in Portuguese fisheries in terms of economic value, when all official and non-declared landings are considered. Around 10% of the landings in national waters come from the trawl fleet, which is both the least selective and the best documented *métier* in the fishery, allowing the simultaneous assessment of distribution and population structure. This study represents a first attempt to integrate different sources of information obtained at commercial trip-level, with the objective of providing a perspective of octopus population structure and relative distribution, together with information on the exploitation pattern in 2003. High-quality resolution of sequential geo-referenced data were obtained from the Portuguese Vessel Monitoring System for the fishing trips targeting octopus. Intensive fishing activity is observed inshore of two regions, one to the north of Peniche (from Cape Carvoeiro to Portuguese border) and the other between Cape St. Vicente (Sagres) and Cape St. Maria (Faro) in the South coast.

Fishing trips undertaken between 39.5 and 42ºN were used to provide information on volume and size distribution of landings. These show that smaller individuals (=<12 cm ML) are mainly concentrated between 40.5 and 41.5 ºN, whereas larger individuals (>12 cm ML) concentrate south of 41.5 and north of 40.5 ºN.

Keywords: fishing intensity; population structure; *Octopus vulgaris*; Portuguese Iberian Northeast Atlantic waters.

1. Introduction

The European Marine Strategy Framework Directive (MSFD; EC, 2008, 2010) established the need for reference points (benchmarking) of population characteristics, in order to assess the impact of exploitation pressures, species spatial distribution and structure, as well as the dynamic interactions between the several components of the ecosystem.

Cephalopods are regarded as key ecosystem components, as they are simultaneously important predators and prey, highly sensitive to ecosystem change, with short life cycles and high generation turnover (e.g. Boyle and Rodhouse, 2006). Thus, they constitute potential community-level indicators to monitor and assess marine environmental status, including biodiversity. However, in order to be able to identify ecosystem change, it is necessary to first describe the ecosystem status at least at some point in a time-series.

The octopod cephalopod *Octopus vulgaris* (Cuvier, 1797) ranks as the second to fourth most important fisheries resource in Portugal in terms of the quantities landed in almost every year since records in weight began in 1927 (National Statistics Institute, databases, "Estatísticas da Pesca", available online at http://www.ine.pt/xportal/xmain?xpid=INE&xpgid=ine_publicacoes&xlang=en for most recent years). Statistics indicate that there has been a general tendency for an increased volume of landings marked by three relatively stable periods (1927-1970, 1975-1986 and 1988-present) in-between which there were rapid rises.

More than 90% of the landings in the Portuguese mainland coast are from the artisanal fishery using traps. Bottom-trawling for demersal communities accounts for the remaining, and while this is therefore not the most important source of fishing mortality, it is arguably both the least selective and the best documented of all of the fishing métiers employed in the fishery, allowing the simultaneous assessment of distribution and population structure.

Officially, the species is also the second most important target in Portuguese fisheries in value (INE, 2011), and is estimated to rank first when all official and non-declared landings are considered (IPMA, unpublished data), which makes it a prime candidate for dedicated monitoring and control activities.

Research surveys conducted by the Portuguese public research laboratory (IPMA) between 1989 and the present (unpublished data), indicate that the species is widespread throughout the coast, presenting concentration hotspots especially in the northwest coast (near Aveiro) and in the Algarve (south coast). These areas roughly coincide with hotspots for pre-recruits in the same seasons (Moreno *et al*., this volume), indicating that most of the population biomass is based on newly recruited individuals, as a consequence of the one-year life cycle.

Cephalopod assessments in European waters generally assume that there is no directed fishing effort (Pierce and Boyle, 2003). However, previous studies on trawl fleet segmentation by

Campos *et al*. (2007) identified the existence of landing profiles (fishing trip types) where cephalopods are target species. In a latter study, Fonseca *et al*. (2008) identified spatial and temporal patterns of cephalopods landings in this fleet, with a number of larger vessels, operating on the west coast and targeting horse mackerel during the winter, and shifting target species in the Spring/Summer and Autumn to take advantage of the higher abundance of octopus and squid respectively, depending on the yearly recruitment of these species.

Portuguese bottom trawling fisheries spatial activities have been monitored by a dedicated Vessel Monitoring System (VMS) created in 1987 (the first to be implemented in Europe). Until 2004, information was collected every 10 minutes, but since then, according to European Union (EU) regulations, the frequency of data transmission has been decreased to once every two hours (EC, 2003; Pilar-Fonseca *et al.*, 2011).

Spatial patterns of fishing activity were mapped for this fleet using VMS data from 2002 to 2004, with landings mainly in the ports of Aveiro (central west Portuguese coast; Fonseca *et al.*, 2008). Further analysis on the evolution of fishery dynamics for Portuguese finfish trawlers, using daily landings for the period 1995-2007 (Pilar-Fonseca *et al.*, 2009), has shown results that are consistent with the former.

Taking advantage of statistical multivariate techniques, developed for the determination of target species of specific fleet components, trawl fishery-dependent data from 2003 were analysed (Campos et al., 2007; Pilar-Fonseca *et al.*, 2009). The choice of the reference year (2003) is due to an advantageous combination of high-resolution spatial data and a distance in the past that may allow comparisons with the present situation. In addition, landing patterns and volumes have also been shown to be similar to those in a wider time-series (1995-2007 – Pilar-Fonseca et al., 2009).

This study represents a first attempt to integrate different sources of information obtained at the commercial trip-level. Our objective is to provide a perspective of octopus population structure and relative distribution, together with information on the effective fishing pressure and specific exploitation pattern, in order to contribute for a decision support system to the design of an ecosystem management.

2. Material and Methods

The geographical area for this study is the Portuguese mainland waters (including the Exclusive Economic Zone) corresponding to a total of 326362 km^2 in the Iberian waters of the Northeast Atlantic Ocean. This area covers 20 rectangles (0.5º x 1º in latitude and longitude respectively) belonging to the International Council for the Exploration of the Sea (ICES) spatial grid in the ICES division IXa (Figure 1). Located in a transition zone between temperate and tropical ecosystems, the whole area is characterized by high biodiversity and relatively low abundance of commercially exploited marine species.

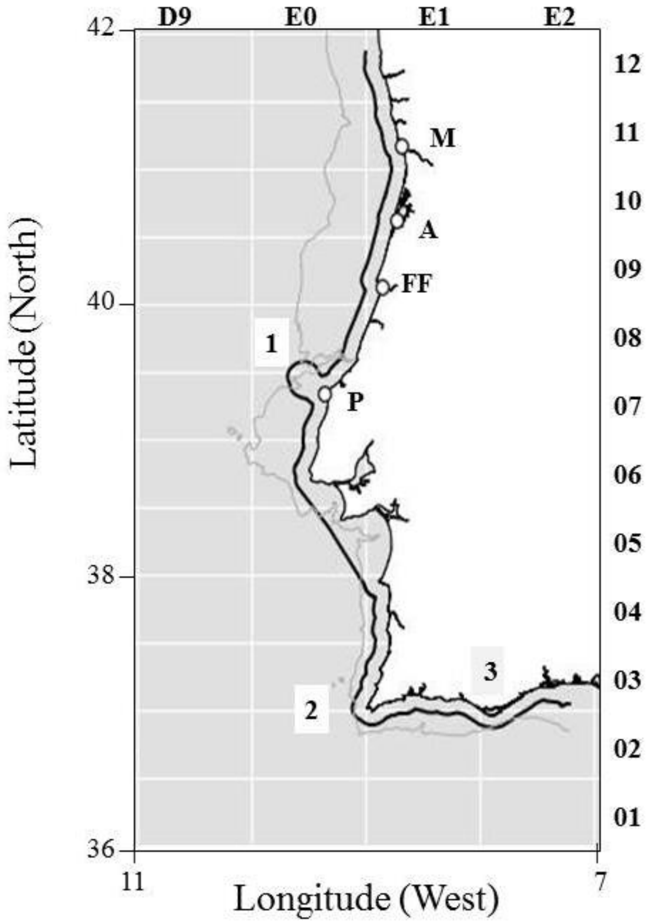

Figure 1. Study area. Portuguese mainland waters of the Iberian Peninsula, Northeast Atlantic ocean. The International Council for the Exploration of the Sea (ICES) rectangles nested within the ICES subdivision IXa are shown (rectangles identified from top and right axes). The 6-mile limit from the baseline (black line), and the 200 m depth bathymetric (light grey line) are identified. The ports of Aveiro (A), Figueira da Foz (FF), Matosinhos (M) and Peniche (P), are identified. Cape Carvoeiro (1), and Cape St. Vicente/ Sagres (2) are located on the west coast; Cape Sta. Maria/Faro, Algarve (3) is located on the south coast.

The bottom trawl fleet licensed for 65 mm mesh size codend operates off the entire continental shelf beyond a 6-mile distance line from the coast, over different fish assemblages, landing a diversified amount of fish and cephalopods. Within this multispecies fleet, segmentation was carried out by Pilar-Fonseca et al. (2009), based on the analysis of a time series of daily landings for the period 1995-2007. Landing profiles were defined according to the relative importance of target and by-catch species, using non-hierarchical classification techniques (Clustering Large Applications - CLARA) suitable to large data sets.

The fishing trips analyzed here are from a landing profile where octopus was identified as the target species in the former study, consisting of over 20 000 fishing trips during the period 1995-2007. From these, a total of 2 200 trips carried out by 53 trawlers (vessel length varying between 15 and 34 m), were selected for 2003. This is considered a reference year since it was the most recent year for which high quality fisheries-dependent data was available, with a complete and regular set of processed geo-referenced data of vessel activity.

VMS records provided fleet activity data at 10-minute intervals. Presently the system operates in vessels with length overall above 15 meters. Global Positioning System data for each vessel consist of a succession of geographical locations, dates, times, speed and course, recorded and automatically transmitted via satellite to the Portuguese Fishery Directorate, the national monitoring authority responsible for marine surveillance.

This high-quality resolution of sequential geo-referenced data provides high discrimination patterns on the spatial fishing activity of the individual vessels, in order to characterize the distinct operational phases within a fishing trip, e.g. departure from the fishing port; travel to the fishing ground(s) and between fishing grounds (if more than one haul is carried out); trawling trajectories, which represent the effective fishing effort; and return to fishing port where the trip ends (not necessarily the same as the initial fishing port).

Trip- and haul-level VMS data were processed by GeoCrust 2.0 (Afonso-Dias *et al.*, 2004; Afonso-Dias and Pinto, 2008) before further analyses. Trajectories associated to fishing activity were identified for 2003 based on a speed rule and location. By analyzing these geo-referenced fishery data, high-resolution effective fishing effort (hours trawled and distance) could thus be estimated for a total of 755 fishing trips targeting octopus (corresponding to a sub-set of 43 vessels). The length of the vessels selected varied between 15 and 34 m (median 28 m), with horse power between 150 and 1455 (median 630).

Fishing intensity was then mapped by allocating VMS records associated to fishing to a grid corresponding to the ICES geographical rectangles for the period in study (2003). Within each rectangle, the number of VMS fishing records was summed (points per grid cell, according to Lee *et al.*, 2010 and Afonso-Dias *et al.*, 2004), defining fishing intensity as the time spent fishing.

Of the initial 755 fishing trips, spatial distribution of the population in terms of individual sizes was determined from first sale point (fish auction site) port-side size sampling for octopus. Available data corresponded to a sub-set of 42 fishing trips from 18 trawlers varying between 20 and 34 m (median 24 m), with horse power between 424 and 1000 (median 600).

All catches were landed in the fishing ports of Matosinhos (41.18ºN, 8.70ºW) (11 fishing trips), Aveiro (40.63ºN, 8.73ºW) (19 trips) and Figueira da Foz (40.14ºN, 8.86ºW) (12 trips).

Octopus was measured within commercial categories as classified at the auction site: large, medium and small or T0 to T4, depending on the auction site. When it was not possible to measure the entire landing, a sample was taken by commercial category. The respective category was then weighed to calculate the scaling factor and this value was used to estimate the number of individuals per category and fishing trip.

In this study, two new size categories were defined for ease of analysis: octopus with length above and below 12 cm. This limit corresponds to the first length class after the minimum landing weight of 750g (National Regulation "Portaria" Nº 281-C/97 of 30 April) regardless of sex and geographic origin, and it corresponds to an early maturation developmental stage, under which very few individuals are fully mature (Lourenço *et al*., 2012).

After the selection of all available combinations of octopus-directed fishing trips with corresponding catch analysis and size-samples, only 42 trips conducted in 2003 in the northwest coast area provided estimations of size-dependent effort as well as analysis of geographical patterns of population structure.

Fishing trip was the sampling unit selected, as landings and length sampling are aggregated at the trip-level. However, as trips were not all undertaken within a single rectangle, effort and abundance-based data were allocated to each ICES rectangle according to the proportion of the number of VMS points identified by trip in each rectangle, and their landings partitioned accordingly (Lee *et al*., 2010). ICES rectangle 7E0 was excluded from further analyses due to the low number of points (10).

Differences in the distribution of fishing intensity among ICES rectangles were tested using the G statistic for the log-likelihood ratio goodness of fit test (Zar 1999).

To evaluate the null hypothesis that the ratio of individuals below and above 12cm was the same in all grid cells (ie size distribution is independent of ICES rectangle), a log-likelihood ratio for contingency tables was performed (Zar, 1999). A contingency table consisting of frequencies observed by size distribution and ICES grid were analysed: two size classes by 9 grid cells. Further analysis on every combination of two grid cells (2x2 contingency tables) was carried out to identify significant differences between rectangles.

To determine if fishing intensity was significantly different between areas of high proportions of individuals under 12cm, an analysis of variance (ANOVA) was applied assuming two groups of ICES rectangles defined *a priori* based on the results of the previous test.

3. Results

Fishing trips classified as octopus-directed represented approximately 26% of the total number of trips, in which octopus contributed to 26% and 32% of the average landed weight and value, respectively. The corresponding observed average landings were 238 kg/trip (827 Euros/trip first sale value). Octopus directed fishing trips existed in every month (varied between 5% of the trips occurring in December and 11% in May).

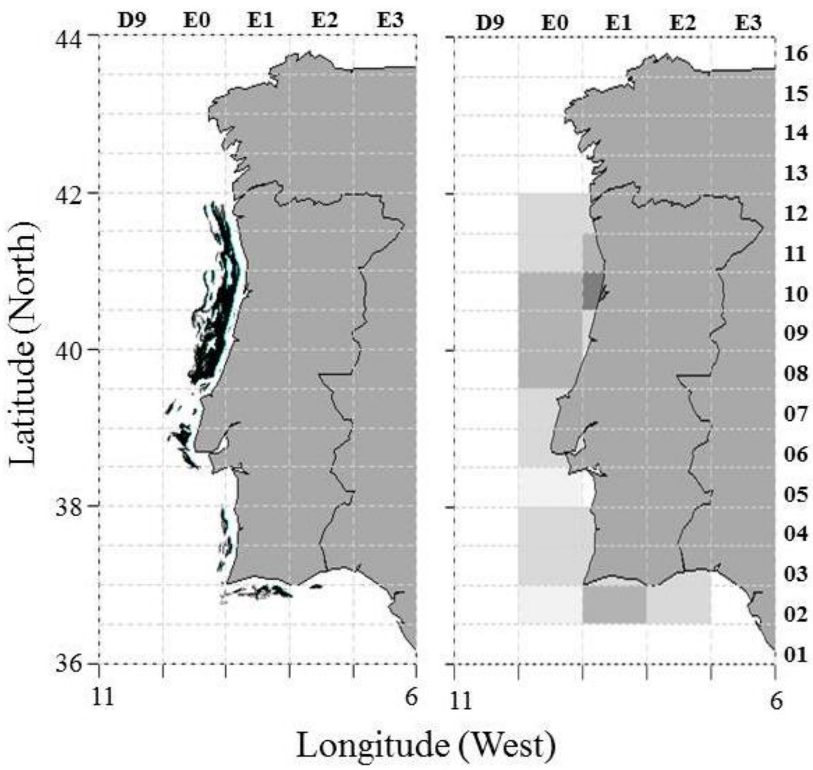

Figure 2. Map of distribution of fishing intensity by the Portuguese trawl fleet (755 fishing trips from 43 trawlers) in fishing trips targeting octopus. In the left panel a plot of all of the Vessel Monitoring System (VMS) fishing points; in the right panel the number of VMS points aggregated by International Council for the Exploration of the Sea (ICES) rectangles (0.5º latitude x 1º longitude). Classified (0-50, 50-4000, 4000-15000, above 15000) from light gray to dark gray. See also Table 1 for results by ICES rectangles.

The spatial distribution of octopus fishing intensity for 2003 is shown in Figure 2 and Table 1. Results indicate significant differences among the ICES rectangles (G=178123, p<0.001, Chi-square$_{(0.001,19)}$=43.82). Intensive fishing for octopus is observed inshore up to 200 m depth in two regions, one to the north of Peniche (from Cape Carvoeiro to the Portuguese border) and the other between Cape St. Vicente (Sagres) and Cape St. Maria (Faro) in the South coast. Fishing intensity was highest in ICES rectangle 10E1, with approximately 38% of activity identified in this grid.

From the octopus-directed fishing trips defined above, port-based sampling size information of the 42 trips correspond to 992 hours of effective fishing effort, varying between 24 and 51 hours trawled per trip, with an average and median value of 24 and 24.6 hours, respectively. The 42 trips totaled 64.1 days at sea, with trip duration varying between 6 and 112 hours at sea (average of 36.2 hours). A total distance of 6330 and 3667 n.m. was estimated at the trip (travelling parameter) and haul (effort-parameter) level, respectively. On average, distances travelled and trawled by an octopus-targeting vessel were 151 and 87 n.m. per trip, respectively. Distance trawled per trip varied between 15.8 and 178 n.m..

Table 1. Number of Vessel Monitoring System (VMS) points by rectangle of the International Council for the Exploration of the Sea (2 to 12 in latitude, E0 to E2 in longitude). VMS fishing trips targeting octopus (n=755) and highly detailed fishing trips (with size-based information, n=42).

	755FT			42FT	
	E0	E1	E2	E0	E1
12	1376	291		608	187
11	1234	4889		194	765
10	8605	32962		554	2212
9	14102	3386		938	257
8	8142			664	
7	801			10	
6	1893				
5	7				
4	182	198			
3	123	138	59		
2	21	7788	242		

Octopus were caught along the coastline from 40.5 to 42º N (6 ICES rectangles, 10E0 to 12E1) for those sampled in the port of Matosinhos, 39.5 to 41.5º N for Aveiro (5 rectangles, 8E0 to 11E1) and between 39 and 41ºN for Figueira da Foz (6 rectangles, 7E0 to 10E1). From the 42 fishing trips analyzed, only 3 operated exclusively in one ICES rectangle, 10E1, East of Aveiro, which corresponded to the area with the highest fishing intensity (Fig. 3, Table 1) with a number of VMS points larger than the average plus twice the standard deviation.

For this subset of data, octopus mantle length (ML) ranged between 10 and 25 cm, weighing on average 1000 g (median 1200, varying between 636 and 3250 g). The number of octopus caught varied between 0.1 and 39 individuals/hour, averaging 8. Landings in weight per hour trawled varied between 0.2 and 37 kg/hour, with average and median values of 9 and 5.6 kg/hour, respectively. At the trip level (regardless of ICES rectangle effort attribution), the proportion of juveniles in the landings varied between 0 and 70%, with a median value of 19%.

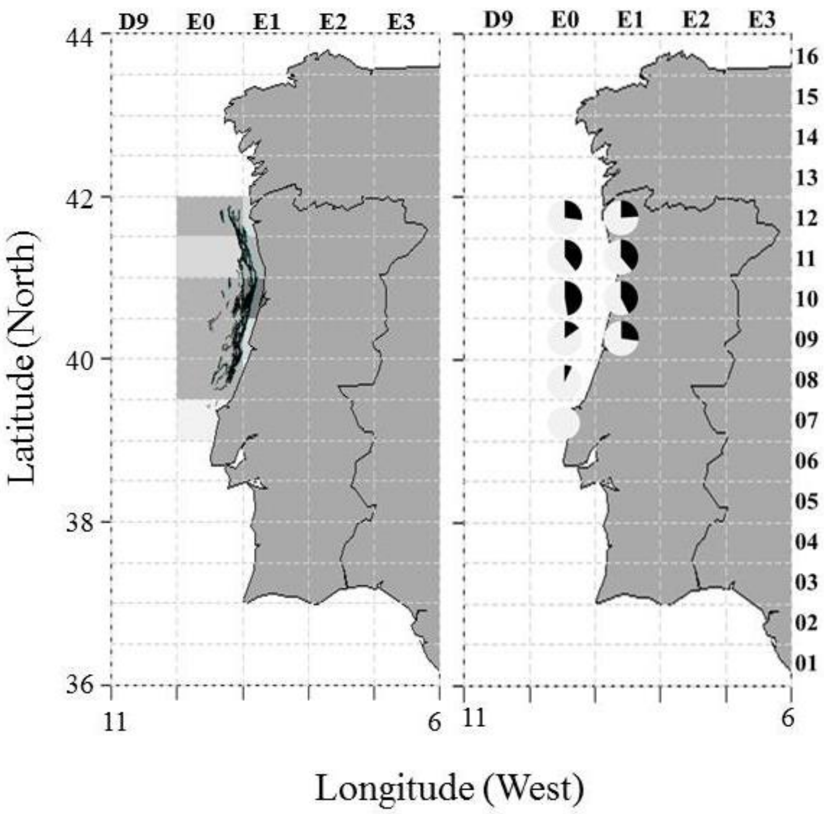

Figure 3. Map of Vessel Monitoring System-based fishing intensity (left panel) belonging to fishing trips (n=42) which contain length data distributed by International Council for the Exploration of the Sea (ICES) rectangles (n=20), in the north coast of Portugal (Northeast Atlantic Iberian Waters) between 39 and 42º N, and 8.5 and 10º W (ICES Division IXa). Fishing intensity (number of VMS points) decreases from dark to light gray. See also Table 1 for results by ICES rectangles. Octopus size structure by ICES rectangle (right panel). Pie diagrams represent proportions of the total number of individuals caught in each rectangle grouped into two size classes (under 12cm ML in black, and over 12cm ML in grey).

The size distribution composition of landings between 39.5 and 42ºN is displayed in Figure 3 (left panel). Results of the overall G statistic indicate significant differences in the proportions of individuals between rectangles (G=668.97, d.f.=8, p-value<0.001). The plots show that smaller individuals (=<12 cm ML) are mainly concentrated between 40.5 and 41.5 ºN (with proportions of 40 to 48%), whereas larger individuals (over 12 cm ML) concentrate south of 40.5 ºN and north 41.5ºN (with proportions over 70%). However, pairwise comparison results are ambiguous for rectangle 11E0 (Table 2).

Table 2. Results of pairwise comparisons of the octopus population structure (ratio of individuals below and above 12cm) log-likelihood ratio for contingency tables: two size classes by nine rectangles (International Council for the Exploration of the Sea 08E0 to 12E1). *** p<0.001; ** p<0.01; * p<0.05; NS – Not Significant.

	12E0	12E1	11E0	11E1	10E0	10E1	09E0	09E1
12E0								
12E1	NS							
11E0	NS	NS						
11E1	*	*	NS					
10E0	***	**	NS	*				
10E1	***	**	NS	NS	*			
09E0	**	NS	***	***	***	***		
09E1	NS	NS	*	***	***	***	***	
08E0	***	***	***	***	***	***	***	***

Fishing intensity in those rectangles with the highest proportions of individuals under 12 cm (11E1, 10E0 and 10E1) tends to be larger than in the remaining rectangles but is not significantly different (ANOVA, df=8, F=4.617, p-value=0.069).

4. Discussion

The EU Common Fisheries Policy (CEC, 2009) recently recognized the importance of shifting from individual fish stocks management towards fleets management, particularly in mixed fisheries. Inside a given fleet segment, specific activities in time and space can occur as an adaptation to fluctuations in fishing opportunities and stock availability. These activities can constitute potential management units, calling for an accurate description of spatial and seasonal distribution of the fishing effort and landings within them (Bastardie *et al.*, 2010). The linkage of VMS with logbooks or landing declarations constitutes valuable information for mapping the catch per unit of effort, or specific fishing mortality, as the basis for more elaborate management decisions including the establishment of marine protected areas, fishing closures, etc.

Within this study, we have demonstrated how different sources of fisheries dependent data obtained at the trip level can be integrated with the objective of providing a perspective of population structure and relative distribution. Starting with previous knowledge about segmentation in the trawl fishery, with a particular fishing trip type where octopus is the main target, and adding geo-referenced information processed for a high number of these fishing trips (Pilar-Fonseca *et al.*, 2009), we have mapped fishing effort for octopus. The effort could be tracked at a high spatial resolution, in a haul-by-haul basis, using data from the Portuguese

Vessel Monitoring System, MONICAP, with a high frequency of signals, enabling us to obtain fishing trajectories associated with the total number of hours trawled. Furthermore we linked effort at the trip level to the size composition of octopus landings, therefore integrating biological data from size-sampling with fisheries effort data, geo-referencing the location of different developmental stages of octopus from a non-scientific data source. These data (effort and size distribution) were then aggregated within ICES geographical rectangles using spatial gridding algorithms, so they could be displayed through a standard grid map that permits ready comparisons between population structure and the structure of the fleet fishing effort.

Our results show that most of the fishing intensity was directed at the rectangles off the region of Aveiro on the west coast, where the smaller octopus are found. This is an area where important fish nurseries are also located (e.g. Cabral et al., 2007), and coincides with the largest concentration of octopus biomass that was determined by research surveys conducted along the years over the entire Portuguese coast (IPMA, unpublished data).

In the area between 40.5 and 41.0ºN (ICES rectangles 10E0 and 10E1), a significant fishing intensity (the highest is in 10E1) exists over the smallest individuals, and is only matched by that deployed in rectangle 9E0, where larger octopus are caught. The fact that most effort is directed at the smallest individuals in a one-year life-cycle species, is a possible reflection of the population structure, which is based upon each years recruitment. In octopus from the West Portuguese coast, there are two main spawning seasons each year (Lourenço *et al*., 2012) that produce two main pulses of recruitment, the most important of which is the one that occurs in autumn. The area near the Aveiro lagoon is also within easy reach of some of the most important fishing ports in Portugal, particularly the port of Aveiro itself. Thus the combination of these two situations favors the catch of individuals recruiting to the area, and suggests that the existence of the octopus landing profile is both a cause for the landing of the recruiting octopus and a consequence of the overlap of the distribution of this particular stage of the species ontogeny, with fishing activities already taking place in the area. The same conclusion can also be deduced from the seasonal nature of some of the landing profiles, in which target species alternate in alternating seasons (Fonseca *et al.*, 2008). The selectivity for the 65mm codend mesh size commercially used (L50% = 97mm ML, Fonseca *et al*., 2002) results in commercial catches of underweight individuals. The intensive effort directed at recruiting octopus may potentially be a reason for concern, as it may result in detrimental growth overfishing with putative negative impacts in future fishing success. On the contrary, in the neighbouring 9E0 rectangle it is the larger octopus that are particularly targeted in a region where the fishing grounds lie close to rocky outcrops (IH-IPIMAR, 2008), suggesting this to be one of the possible areas where adults concentrate prior to spawning.

The most significant difficulty when analysing and combining different levels of data is the often reduced overlap between each layer that reduces the number of data points available for analysis. The fact that most of the size-sampled fishing trips did not belong to the octopus landing profile has contributed to greatly reducing the amount of data analyzed. In this particular case, only the west coast catches could be analysed to the extent that octopus size could be matched back to catch location. This may mean that the choice of vessels from which size sampling is carried out should be improved. The real importance of octopus in priority (level 2) given by the EU Data Collection Framework (EC, 2009) also contributes to poor port-based sampling.

Whatever management objectives may be determined, high-resolution spatial data derived from fisheries can help pinpoint action. Although not the most important octopus fishing métier, trawling has proven particularly useful in determining the location of specific catches and as a tool for the continuous sampling of the population, something that is not easily achievable by dedicated research surveys due to the costs involved. In this study we highlight the key role of data which is already being collected (i.e. the EU Data Collection Framework) in delivering the objectives of the EU Common Fisheries Policy, Biodiversity Policy and the Marine Strategy Framework Directive. In other words, this study examines octopus exploitation patterns and simple population structure parameters obtained from the daily activities of the fishing fleet by making use of data already being gathered for other purposes. Detailing an example of trawl tracking data and highlighting the importance of the integration of landings, VMS and biological data, the analysis provides results that can go far beyond monitoring and control. The estimations carried out within this study were possible due to the high-quality of the then available VMS data. The shift from 10 minutes to 2 hours interval between points means that the detail will be lost.

EU member states are obliged to monitor and assess the state of their marine waters, including biodiversity, the ecosystem, the commercial species and the food web, to fulfill the EU MSFD. Techniques and studies that characterize spatial distributions of species and habitats and the production of maps from surveys and fisheries activities are keys to identify changes over time. The integration of a directed octopus fishery at a national level was thus carried out to obtain a 2003 (historic) snapshot of fishing effort distribution, identifying areas of high fishing intensity. However potentially restricted in geographic coverage, this snapshot is a valuable reference for future assessments of a similar nature, and can thus be used within the current MSFD monitoring programme of the EU regarding the evolution of the fishery for *Octopus vulgaris*.

In summary, we have shown how the use of fisheries dependent data collected in a well documented fishery was maximized to improve scientific knowledge, and provide useful tools for demographic analysis of the population structure while assessing the state of exploitation of this important resource, helping to contribute to the objectives of the Common Fisheries Policy and the implementation of the MSFD for a better and more sustainable governance of resources in a competitive and limited space. Although octopus itself may not be considered a “species of special interest" according to the interpretation of the EU Scientific and Technical Committee for Fisheries, as these have to be covered by habitat directives and international conventions, the Committee considers that the data requirement to sample benthos means the identification and monitoring of benthic communities particularly affected by fishing activities is necessary (CEC, 2005).

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Paper 6

VMS-based Fishing Effort and Population Demographics for the European squid (*Loligo vulgaris*) off the Portuguese Coast

(accepted for publication in Hydrobiologia)

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Abstract

This study presents a one-year synopsis of the trawl fishery for the European squid *Loligo vulgaris* (Lamarck, 1798) in Portuguese waters, integrating length-structured landings with corresponding geo-referenced fishing activities. From Vessel Monitoring System (VMS) data, landings and biological sampling, a “status-report” was obtained for 2003.

Fishing pressure was found to be most intense in inshore areas of the northwest and the south coasts. Population size structure, classified into 3 categories, was not uniform throughout the fishing areas. Larger squid are found offshore in the northwest (International Council for the Exploration of the Sea – ICES rectangle 10E0) and in the south (rectangles 2E1 and 3E1), whereas all inshore western coast rectangles showed larger proportions of small squid relative to the southern rectangles.

The analysis carried out in this study provides an insight into the possible impact of the fishing intensity pattern on the population structure in various zones. The results demonstrate the benefits of combining geo-referenced fisheries information with landings and size data, to produce explicit spatio-temporal information that can contribute to integrated planning and management, in accordance with the objectives of the Common Fisheries Policy and Marine Strategy Framework Directive.

Keywords

Loligo vulgaris; Portuguese coast; bottom trawling; Vessel Monitoring System; fishing effort; size structure

Introduction

The ecosystem-based approach to fisheries management in the European Union's Common Fisheries Policy (CFP; EC, 2002) implies switching from a single species-based assessment to an integrated holistic approach, in order to ensure the sustainability of marine activities and the protection of marine species and habitats. Furthermore, the European Marine Strategy Framework Directive (MSFD; EC, 2008) and the need to obtain Good Environmental Status in marine waters require the establishment of reference points and call for in-depth information at a species level, including population structure. It is therefore paramount that the state of the marine environment is assessed by reporting species distribution and identifying areas of highest fishing impacts.

The loliginid squid *Loligo vulgaris* Lamarck, 1798 is one of the cephalopod species that is most exploited in Portuguese fisheries [together with the octopod *Octopus vulgaris* Cuvier, 1797, the sepiid *Sepia officinalis* Linnaeus, 1758, and the ommastrephids *Illex coindetii* (Verany, 1839) and *Todaropsis eblanae* (Ball, 1841)], ranking third in volume after *O. vulgaris* and *S. officinalis* (INE, 2011).

As important predator and prey species, many cephalopods are key ecosystem components, and therefore some of the most important elements to consider for maritime spatial planning and management. The European squid has approximately a one year lifespan. After hatching, paralarvae are at first planktonic then becoming epi-benthic or semi-pelagic, spending most of the day near the bottom and part of the night in the water column (Worms 1983; Moreno et al., 2009). In Portuguese waters, the species presents multiple age and length micro-cohorts at any time (Bettencourt et al., 1996; Moreno et al., 2005) as a result of the near-continuous breeding cycle, marked nevertheless by two peaks on the northwest coast (Moreno et al., 2002) and only one peak on the south coast (Coelho et al., 1994). Thus each year the population is comprised of multiple batches of animals hatched at different times, without overlap between parents and their progeny. At a given time, the population is made up of the same year's recruitment stock. Micro-cohorts arise and merge as a consequence of the developmental plasticity of the species and the environmental conditions to which each individual is subjected (Rocha and Guerra, 1999; Moreno et al., 2007), producing a complicated pattern of individuals of different sizes and ages that make up the populations at any given time (Smith et al., 2011). The species is widespread along the Portuguese coast and single-haul catches tend to be comprised of individuals of various sizes (IPMA, unpublished data), as also observed in the Gulf of Cadiz (Vila et al., 2010).

In Portugal approximately 75% of the landings are from commercial catches of the bottom trawl fleet (Cunha and Moreno, 1994; INE, 2011), taking advantage of the day-time behaviour of the species. Squid are also exploited by hand-jigging and a variety of other gear, the former being used mostly during the night, when the animals surface. Portuguese regulations impose a minimum landing-size of 100 mm mantle length (ML) (Portaria 27/2001), which is close to the length of recruitment (120 mm, Moreno et al., 2002), as well as a minimum codend mesh size of 65 mm. Selectivity experiments by Fonseca et al. (2002) in commercial vessels operating near 40ºN on the Portuguese coast have shown that catches consisted almost entirely of individuals close to or above 100 mm ML.

Landings statistics for the species date back to the beginning of the second quarter of the 20th century, providing a time-series of exploitation that is presently ca. 85 years long (Figure 1). This history shows an increasing trend between 1928 and 1965, followed thereafter by a decreasing trend with both periods marked by fluctuations, which are more noticeable in the second period. The particular features of the landing series have not been interpreted in a way that can fully explain the trends observed. It is also not clear whether they reflect features of the dynamics of the ecosystem, the physical environment, the exploitation patterns or a combination of various factors.

The species has been studied extensively in Europe both from a biological and an exploitation perspective, and attempts have been made at describing time-series of catch and landing data as proxies of abundance and distribution (Sanchez & Martin, 1993; Guerra et al., 1994; Tsangridis et al., 1998). It has been said that in Europe, loliginids are generally a by-catch (Pierce & Guerra, 1994; Pereira et al., 1998), i.e. that they are not targeted by commercial trawlers, although they are subject to direct fishing in specific areas and periods (Fonseca et al., 2008; Hastie et al., 2009).

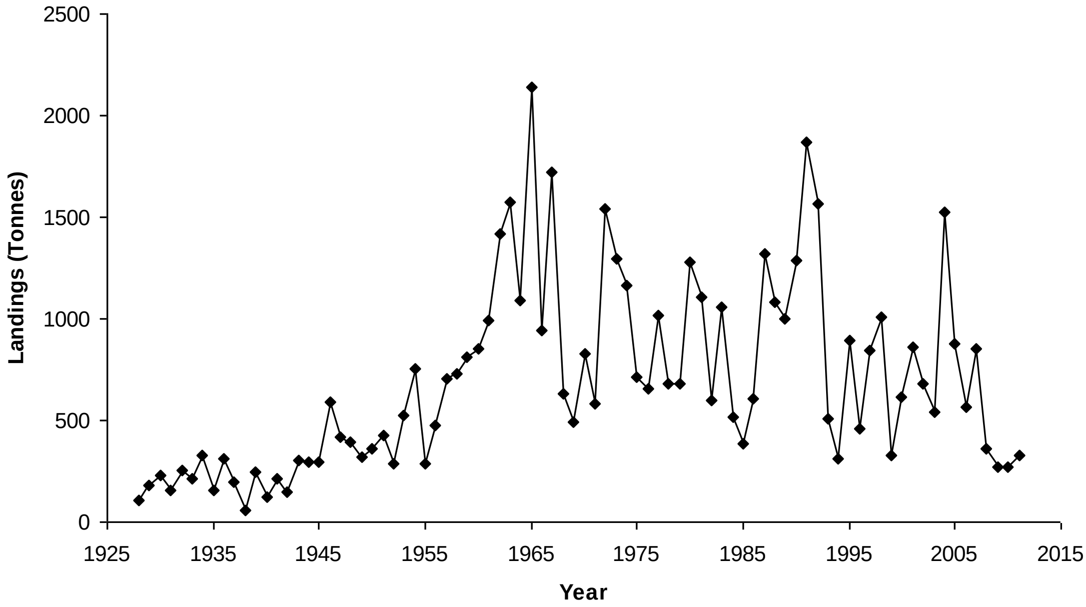

Figure 1 - Landing statistics (tonnes) of European squid (*Loligo vulgaris)* caught and landed in Portugal from 1928 to 2011 (data from Portuguese Statistics Institute, INE).

Even though catches and landings of *L. vulgaris* in Portugal are primarily carried out by trawling, their nature as target or by-catch species is less clear. The existence of landing profiles (LPs), corresponding to fishing trip types where cephalopods are target species has however been demonstrated by Campos et al. (2007), in a study on fleet segmentation in multi-species bottom trawling operating in the North-east Atlantic Ocean off the Portuguese coast. Fonseca et al. (2008) identified squid (mainly *L. vulgaris*) as the target for a significant proportion of a seasonal trawl fishery taking place during the second semester. Spatial activity was mapped for this fleet using Vessel Monitoring System (VMS) data from 2002 to 2004, with landings occurring mainly in the ports of Aveiro and Figueira da Foz (west Portuguese coast).

Further analysis on the evolution of fishery dynamics for Portuguese finfish trawlers, using daily landings for the period 1995-2007 (Pilar-Fonseca et al., 2009) showed results consistent with those obtained in previous studies, providing additional information regarding temporal and regional patterns of activity for the different LPs. Fishing trips (FTs) targeting squid represented approximately 5% of the total number of trips, with squid contributing to 42% of the average landed weight, averaging 409 kg/trip. However, squid were also found to represent a substantial proportion of the total landed weight in FTs targeting octopus and horse mackerel (where average squid landings were 60 and 28 kg/trip respectively).

This study integrates landings and port-side biological sampling data with corresponding geo-referenced fishing activities (VMS) for *L. vulgaris* where this species was a significant component of the landings, either as a target or as an important by-catch in FTs directed at octopus and horse mackerel.

Squid spatial distribution patterns may already have been changed by the current and previous spatial distribution of fishing pressure, partially hampering the establishment of a reference situation, and emphasizing the importance of analysing historical fishery-dependent data (OSPAR Commission, 2011).

A nation-wide squid “status-report” for 2003 is presented in order to: 1) characterize squid fishing intensity pattern on the Portuguese coast (ICES Division IXa); and 2) examine the geographical distribution of the squid population structure; with the objective of gaining insight into the fishing pressure induced by the exploitation pattern.

Methods

A dataset consisting of 1110 FTs was used in the analysis. Data used are daily landings, spatial information from VMS (obtained from the Directorate General of Natural Resources - DGRM) and port-based length sampling for 2003 (obtained under the EU Data Collection Framework).

The reference year (2003) was chosen as the last year with a complete and regular set of 10-minute interval VMS data for the fleet, providing high discrimination patterns of the spatial fishing activity of the individual vessels at a trip and haul level. In addition and within the MSFD context, these data can be regarded as historical. In this case study, the FT is the sampling unit selected, since landings, length sampling and processed VMS are aggregated at the trip level.

The FTs selected, identified from commercial landings data by Pilar-Fonseca et al. (2009), comprise the largest component of the directed fishing effort for squid in 2003 from three distinct LPs out of a total of six identified for the period 1995-2007. Squid was the target species in a single LP, whereas in the remaining two (targeting octopus and horse mackerel) it was found to be an important by-catch.

VMS data processed by GeoCrust 2.0 (Afonso-Dias and Pinto, 2008) were used, in which trajectories associated with effective fishing activity (hauls), were identified based on a speed rule and vessel location. All of the points not identified as trawling were excluded from the dataset. High-resolution estimates of fishing intensity associated with squid landings could thus be obtained for the selected trips within each LP. VMS records associated with fishing, during the period in study (2003) were then allocated to a grid corresponding to ICES geographical rectangles (0.5 latitude * 1º longitude). Within each rectangle, the number of VMS fishing records was summed (points per grid cell) according to Afonso-Dias and Pinto (2008) and Lee et al. (2010), providing a measure of fishing intensity which may be viewed as a proxy of fishing effort. This was done for each LP.

Finally, to analyse geographical patterns of population structure for squid landed by the trawl fleet, fishing trips with corresponding port-sampling squid length data were selected and analysed. The data were collected from a total of 40 FTs carried out by 18 different trawlers.

Species categories are established by weight or by number per kilogram, according to Council Regulation 2406/1996 (EC 1996) however no common marketing standards exist for squid. In Portugal, auction supervising company "DocaPesca" establishes four commercial size categories, T1 to T4 from larger to smaller individuals, variably defined according to daily landings at each port. A length overlap was observed between categories, for example squid ranging in length from 22 to 26 cm were found in three categories (T2, T3 and T4). This led to the adoption of three distinct size classes (10-15, 16-21, and >21 cm), with the 10-15 cm category (comprising the average length of recruitment) being considered as sub-adults (Moreno et al., 2002).

The number of individuals by size category was then allocated to each ICES rectangle according to the proportion of number of VMS points identified by trip (Lee et al., 2010). There was a relatively low number of fishing trips (40 FTs) that combined all of the necessary sources of data. Additionally there was a great similarity in size classes observed between LPs for the same geographic areas. Therefore squid size data in the three LPs were pooled.

Results

Fishing trips targeting squid represented only approximately 2% of the total number of trips in 2003. These FTs contributed to 39% of the average total landed squid weight, compared to 4% and 1% in the LPs targeting octopus and horse mackerel, respectively. The corresponding observed average landings per trip in the three LPs were 256, 28 and 15 kg/trip.

Within the time-series, 2003 was a low squid abundance year, comparable only to 1999, while in 2006 and 2007 there were almost no landings (Figure 2). The time-series shows the relative importance of squid landings in the three LPs and the seasonal importance of the LP targeting squid. For this study, the effects of the seasonality of the squid-targeting LP on data availability were reduced by including squid landed as bycatch in FTs targeting octopus and horse mackerel.

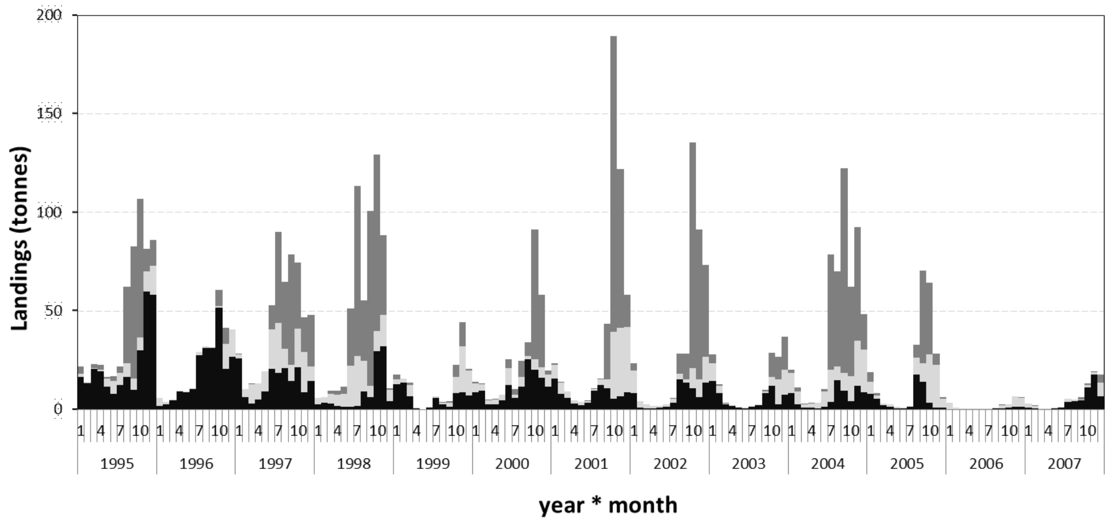

Figure 2 - Monthly squid landings (tonnes) from fishing trips of the three Landing Profiles (LP) selected for this study during the period 1995 to 2007. LP targeting octopus, horse mackerel and squid are shown in black, light grey and dark grey, respectively.

In Figure 3, fishing intensity is shown as the number of VMS points, proportional to fishing effort, aggregated by ICES rectangle for the three LPs. The fishing activity was distributed along the entire continental shelf of the ICES division IXa (between 36.5 and 41.5º N and 7 and 10º W). However, fishing intensity was variable along the coast, being most intense in inshore areas of the west coast between the ports of Aveiro (10E1) and Peniche (7E0), and off the south coast between 8 and 9º W.

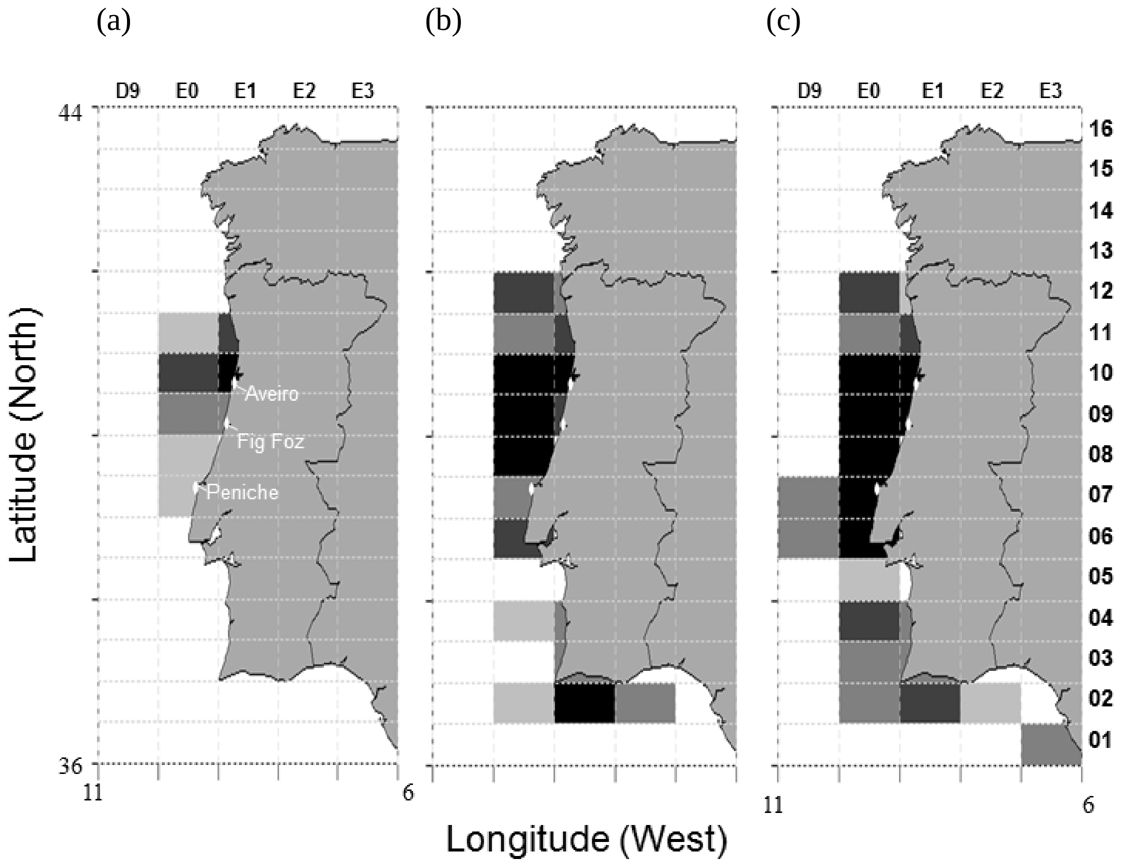

Figure 3 - Map of trawling intensity in number of VMS points (specified in Table 1) for 2003 in ICES division IXa (rectangles identified from top and right axes). Fishing trips identified by Landing Profile (LP): (a) targeting squid, (b) with squid as by-catch while targeting octopus; and (c) with squid as by-catch while targeting horse mackerel. Fishing intensity decreases from dark to light grey. Three fishing ports are indicated: Aveiro, Fig. Foz (Figueira da Foz) and Peniche.

Fishing directed at squid was distributed across a total of eight ICES rectangles in northern waters adjacent to Aveiro. From 39 to 41.5º N the fleet operated in a shallow area from the 6 nautical miles (legal limit for trawling), to the 200 m isobath. Squid fishing activity belonging to FTs targeting octopus covered a wider area, including the north coast above 38.5ºN and ICES rectangles 2E1 and 2E2 in the south. The remaining FTs targeting horse mackerel covered the entire Portuguese coast, with higher intensity between 38.5 and 41º N in latitude and 10 and 9º W in longitude.

Table 1. Fishing effort in number of VMS points (6 points correspond approximately to 1 hour trawled, using 10-minute frequency VMS data) by Landing Profile (LP) and ICES rectangle (2 to 12 in latitude, E0 to E2 in longitude) for Portuguese bottom trawl fleet in 2003. Study area between 36.5 and 42ºN and 6 and 11ºW. Squid fishing trips (FT) from 3 LPs targeting: squid (95 FT), octopus (584 FT) and horse mackerel (431 FT).

	Squid			Octopus			Horse mackerel			
	E0	E1	E2	E0	E1	E2	D9	E0	E1	E2
13								1		
12				687	148			358	11	
11	20	685		430	3088			230	658	
10	339	1065 4		6052	30889			3799	10498	
9	171			10680	3504			8871	1700	
8	8	200		5301				4967	1	
7	37			373			247	3471		
6				720			157	2750		
5				1				29		
4				21	74			292	142	
3					115			132	50	
2				15	7421	170		44	945	8

Exploratory analyses revealed a high similarity between the proportions of squid belonging to each of the three size categories that were attributed to each of the LPs. The subsequent analyses therefore combined all of the data in one group.

The geographical patterns of the population structure of the squid exploited by the trawl fleet are shown in Figure 4. Sampled squid varied between 9 and 48 cm ML. Similar length distributions have been shown to be entirely retained in commercial codends (Fonseca et al., 2002). A geographic assessment of variations in the population structure is shown in Figure 4, using the proportion of squid belonging to each of the three size classes (10-15, 16-21, and >21 cm) in each ICES rectangle.

The squid population structure was not uniform throughout the fishing areas. Larger squid were found in ICES rectangles 10E0 (north) and 2E1 and 3E1 (south). A larger proportion of sub-adults was exploited in 9E1 (>90% under 16 cm), but all other west coast rectangles showed larger proportions of small squid relative to the south.

A comparison between the geographical patterns of fishing intensity and population structure for squid off the Portuguese coast shows that a higher proportion of small squid can be found in ICES rectangles where fishing pressure is the highest, particularly in rectangles 9E0, 9E1 and in 10E1, for fishing trips where squid are specifically targeted.

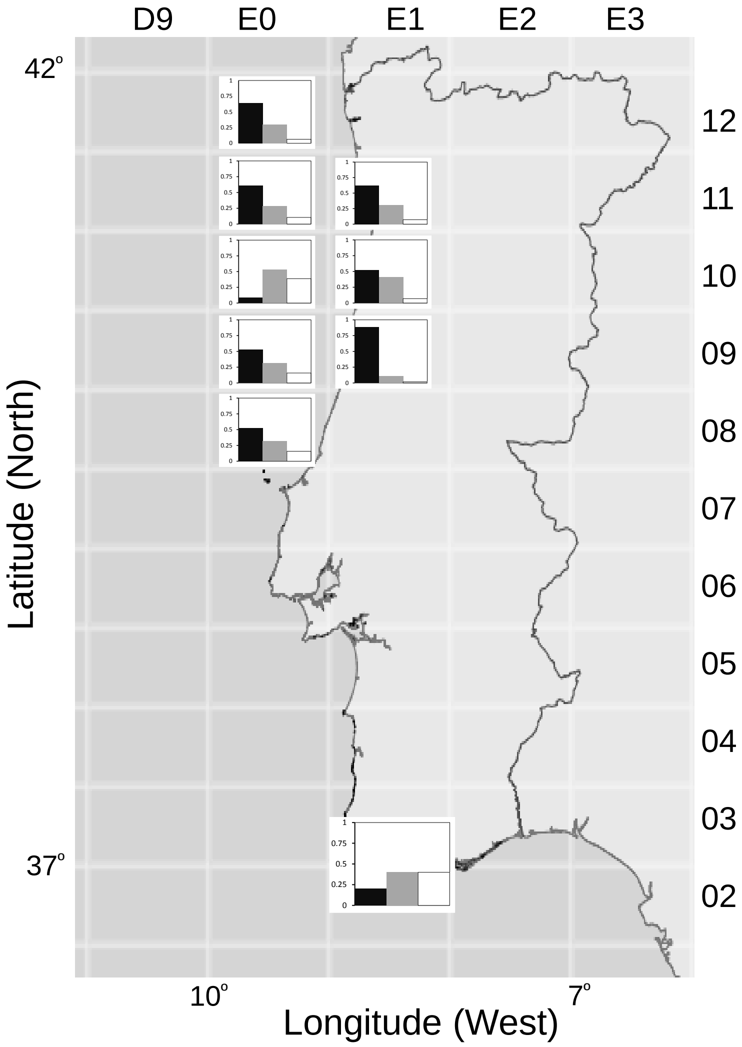

Figure 4 - Squid size structure by ICES rectangle (south coast plot corresponds to 2E1 and 3E1) using VMS and port-based length data for 2003, corresponding to a total of 40 Fishing Trips (FT) carried out by 18 trawlers. Squid were grouped into three size classes (under 16; between 16 and 21; and over 21 cm, in black, grey and white, respectively) shown as proportions (0 to 1, y-axis of the barplots).

Discussion

Fishing is one of the main activities that directly affect marine resource populations, a situation which calls for continuous monitoring of abundances and population structure at various spatial scales. In a previous study by Fonseca et al. (2008), the spatial fishing activity for the trawl fleet targeting cephalopods was mapped. Overall fishing intensity in trips targeting squid was highest in a coastal area between the fishing ports of Aveiro and Figueira da Foz. In the present study, the integration with data on population structure has allowed mapping of the distribution of the squid population exploited by coastal trawlers. The year 2003 was chosen as a reference year, due to the availability of high-quality fishery-dependent data, including haul-level geo-referenced effort data and population structure data from squid landings in a number of ports. A status report is provided for this year characterizing squid fishing patterns and relating them to the population structure.

Loligo vulgaris is a short-lived species with fast growth rates and high reproductive potential (Rocha et al., 2001; Moreno et al., 2007). It is therefore highly prone to inter-annual fluctuations in abundance, believed to be caused mainly by environmental variation (Chen et al., 2006; Pierce et al., 2008). Its population structure is however relatively stable over time with respect to location of concentrations of particular life-stages (Cunha et al., 1995).

Fishing activity for squid in 2003 was mainly exerted in areas around Aveiro where higher concentrations of sub-adults occurred in that year, which coincide with important recruitment areas (Cunha et al., 1995). In fact, an important spawning season is known to occur on the northwest coast in December/January (Moreno et al., 2002) followed by an embryonic development period of 40–47 days on average (Villanueva et al., 2003). This results in a peak of paralarval abundance in March (Moreno et al., 2009). At this time, specific oceanographic conditions near Figueira da Foz favour the formation of coastal gyres (Relvas et al., 2007) which, combined with diel vertical migrations, retain zooplankton (Cunha, 2001) including squid paralarvae in the area, until the latter become nektonic juveniles around June (Moreno et al., 2012). Eventually these squid recruit to the fishery as sub-adults in the same area from September/October (Cunha et al., 1995). It is therefore on this important recruitment area and at the time young squid begin to appear in greater numbers that most squid-directed fishing effort is exerted. At other times in the year, when squid throughout the entire coast tend to be larger in size, fishing effort is not directed at squid and is widespread along the coast.

Depending on the temperatures to which they are exposed prior to hatching, at a time when environmental conditions are the most variable (Relvas et al., 2007), young squid may belong to either of two temperature cohorts (warm or cold cohorts, WC and CC) that include most of the squid hatched in this region (Moreno et al., 2005, 2007, 2012; Boavida-Portugal et al., 2010). Those of the CC will attain a larger size than those of the WC. For adult squid of the same weight, WC individuals are more fecund and produce smaller eggs with less yolk (Boavida-Portugal et al., 2010) which will develop into smaller paralarvae with lower individual fitness and lower survival rate resulting from a reduced starvation endurance (Steer et al., 2003).

Within gyres it is predictable that survival rates of different sized paralarvae will not differ as much, due to a higher prey aggregation. If individuals of the WC (generally smaller at maturity) are being culled out of the population, this may effectively reduce the reproductive potential of the whole population considering the within-gyre relatively higher survival rates of WC-descended paralarvae. Therefore, by targeting smaller individuals in this region there may be a selective pressure against the offspring of WC squid, potentially inducing a negative feed-back cycle on population abundance (completely unrelated to the environmental circumstances which generally influence abundance).

In the south coast, trawling activity is being directed almost exclusively at larger individuals, so no impact on juveniles is to be expected.

Within the time period of a year, all sizes of squid occur in the same geographical areas. Squid migrations in Portuguese waters have been suggested, some of which are possibly ontogenic between the paralarval and juvenile stages (Moreno et al., 2002). Other evidence shows non-directed movements between areas, which results in aggregations of juveniles or adults in specific areas at different times (Coelho et al., 1994; Moreno et al., 1994). Strong recruitment pulses appear annually in the area of the Aveiro lagoon (Moreno et al., 2002), a possible indication of good feeding conditions for young squid. However, a large numbers of small squid of which some may not be juveniles, may also reflect geographical variation in population structure that are a result of previous differences in fishing pressure on the squid population, or the current biological characteristics of the species in the north-west coastal region may already reflect former exploitation history. Such complex open questions illustrate the relevance of this type of analysis, as well as the importance of longer data collection periods of fishery-dependent data and different spatial resolutions. The ICES statistical grid may not be the most appropriate for the current analysis, but it continues to be the spatial resolution chosen by ICES for fisheries assessment. Thus even though squid are not currently assessed, it was adopted as an appropriate spatial unit for this analysis.

Initially the idea for this study was to use only data from fishing trips targeting squid, arguably those that more closely reflect the influences of fisheries on squid populations. This squid targeting landing profile however shows a marked seasonality and spatial fidelity which reflects the recruitment pattern. Therefore, to reduce the effect of the main recruitment season in the overall size distribution and to enable a wider geographic analysis, we opted for the inclusion of trips where squid represented a significant part of the catches when targeting other species (mostly octopus and horse mackerel). This effectively permitted a reflection of the annual size distribution present in the population.

This study shows how fishery-dependent information from existing data collections can be combined and optimized to analyse commercial species distribution and demographics. In 2012 the status of the squid was reported in the Portuguese MSFD. This type of analysis provides key contributions towards the objectives and potential future targets of the Common Fisheries Policy in general and the Marine Strategy Framework Directive in particular, by providing opportunities for better spatial planning and ecosystem management in the Atlantic Ocean, and contributing towards the knowledge of one of the hinge components of the ecosystem.

Acknowledgements

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Paper 7

SPECIES-DIRECTED EFFORT AND LPUE INDICATORS USING FISHERY-DEPENDENT INFORMATION

ABSTRACT

This study extends previous work on fleet segmentation and the analysis of fleet dynamics, using fishery-dependent information to estimate species-specific fishing effort and landings per unit effort (LPUE) for commercial species. Landings from individual fishing trips were combined with geo-referenced data from the vessel monitoring system (VMS), for the Portuguese finfish coastal trawlers. VMS data from a five-year period (2000 to 2004) were processed by software GeoCrust 2.0 to define fishing trips and individual hauls. The fishing effort derived were trip duration (TD) and the number of hours trawled (HT), i.e., the effective effort. Landings per day at sea (LPDAS) and landings per hour trawled (LPHT) were estimated by fishing trip, representing an increase in the accuracy of landings per unit of effort (LPUE) previously estimated from landings per trip (LPT). Species-directed effort and LPUE indicators were then estimated for the different landing profiles (LPs) targeting homogeneous groups in terms of species composition. A number of vessels were chosen as representative of the different LPs defined for this fleet in previous studies. Fishing effort (in number of hours trawled per trip and trip duration) and LPUEs were computed for this group of vessels. These estimators were then compared with those obtained for the remaining fleet within the different LPs analysed, and validated by comparing them with those obtained for the entire fleet within the 2000-2004 period. The results suggest that this sample fleet is a good candidate to adequately sample horse mackerel, while for cephalopods, in particular Octopodidae, LPUE were underestimated, suggesting that there is the need for increasing the sampling effort.

Keywords: Landing profiles; Fishery-dependent data, Vessel Monitoring System (VMS); Species-directed effort; landings per unit effort; Bottom trawling; sample fleet; Portuguese coast.

1. INTRODUCTION

Analysis of geo-referenced information has been widely used, including in Portuguese waters, to understand fishing patterns and improve the accuracy of fishery-based effort data and landing per unit effort as a proxy of abundance (Afonso-Dias et al., 2004; Bordalo-Machado, 2006). This is particularly relevant in a multispecies context, where these indicators are influenced by the high number of different target species and subsequent varying effort allocation (Bordalo-Machado, 2006; Bastardie et al., 2010).

This is the case for the Portuguese multispecies bottom trawl fish fleet operating off the continental shelf in the Western Iberian Sea. According to Afonso-Dias and Pinto (2008), a total of 190 *taxa* (species or group of species) were landed by this fish trawl fleet in 2003. The high biodiversity of trawl catches was confirmed by other studies, Costa et al. (2008) identified over 200 species that are vulnerable or exploited by the bottom trawl fleet in the south coast. Despite this high biodiversity, in the latter study ten species represented about 85% and 76% of the total landings in weight and value, respectively. Horse mackerel (*Trachurus trachurus)* was the most represented species, followed by blue whiting (*Micromesistius poutassou*), Spanish mackerel (*Scomber colias*), European hake (*Merluccius merluccius*) and octopus (*Octopus vulgaris)*.

Geo-referenced data obtained from vessel monitoring system (VMS), available for 75 trawlers operating in 2003 (Afonso-Dias and Pinto, 2008) showed that the fleet operates off the entire Portuguese coast (36.5 to 42ºN, 7 to 10.5ºW). This study also observed that the vessel activity concentrates mainly between the 6-mile limit and the 200m isobath, with average haul duration corresponded to 2 hours, with average vessel trawl speed varying between 2.1 and 4.9knots.

Currently, species-based effort and LPUE estimates used in the stock assessments do not take into account the existence of distinct landing profiles (LP) differing in their composition in terms of target and (non-targeted) by-catch species (see Campos et al., 2007; Paper 1 in this thesis). Such estimates are thus likely to be biased, particularly for those species targeted in lower quantities and/or in a lower number of fishing trips (FT). Paper 3 in this thesis identifies six landing profiles (LPs) based on different specific composition of target and non-target species (from daily 1995-2007 landings. Horse mackerel, Octopodidae, squid (*Loligo vulgaris*) and blue whiting were identified as target species in five of the six LPs defined.

In the present study, spatial information from the Portuguese VMS system was combined with landings by fishing trip (FT), for the previously defined LPs, with the objective to estimate species-directed effort and LPUE, for a number of commercial species caught by the coastal trawl fleet, based on the period 1995-2007. The methodology developed herein consists in the identification of a number of vessels with high VMS coverage and regular landings that could be considered representative of the fishing activity for this fleet.

2. METHODS - DATA ANALYSIS

2.1 Fishing effort data extraction

To obtain an estimation of fishing effort GeoCrust 2.0 application was used to process the VMS tracking data for 2003 (Afonso-Dias et al., 2002, 2004; Afonso-Dias and Pinto, 2008). This system initially identifies fishing trips (FT) by a semi-automatic procedure which uses a buffer (radius of 0.1º WGS84) around the fishing port to identify the beginning and the end of each trip. The algorithm then assigns each FT to a corresponding landing event. Each FT is classified according to a two-level quality index, indicating if the original data consists of high/low quality spatial data regarding completeness. FT with consistent 10-minute interval VMS data are classified as valid fishing trips, whereas incomplete VMS data are categorized as partially valid FT. This classification is an important step since this may affect haul identification to a high extent and, consequently, the precision of effective effort estimates by haul, and consequently by trip. Within each FT, fishing hauls are detected and marked using a semi-automatic identification procedure based on the analysis of the monthly speed profile for each vessel. The fishery-dependent initial VMS processed data included, at trip level: time of beginning and end of fishing trip, distance trawled during the fishing trip (in nautical miles, nm); and at the haul level: start and end time of each haul, and distance trawled (nm). From these parameters, total distance trawled during the fishing trip (in nm),average speed trawled and proportion of time spent trawling within a trip were estimated along with fishing effort metrics, time spent at sea (trip duration, TD) and total hours trawled (HT, e.g. total duration of fishing activity during the trip).

Given the 2003 dataset, average fishing indicators (trip duration, TD, and hours trawled, HT) was estimated by LP, and differences between LP were examined. As the variable trip duration does not follow a normal distribution for the 2003 high-quality data, (Shapiro-Wilk test W=0.7593, p-value<2.2e-16), the Kruskal-Wallis test were applied to test for differences in trip duration between LP. This analysis was repeated with the total hours trawled dataset (n=2292 FT).

2.2 Effort estimators LPT, LPDAS and LPHT

To compute species Landings Per Days At Sea (LPDAS) for each trip, species landings in weight was divided by the corresponding trip duration (TD, time spent at sea, in days):

$$LPDAS_{si} = L_{si} / TD_i$$

where L_{si} is the landings (in weight) for species *s* in fishing trip *i* and TD*i* is the trip duration in fishing trip *i*.

Subsequently, the higher-quality index Landings Per Hour Trawled (LPHT) was estimated from those trips where all hauls were identified, as follows:

$$LPHT_{si} = L_{si} / HT_i$$

with L_{si} as above and HT_i the total number of hours trawled in trip *i*.

Species-specific Landings per unit of effort estimates could be obtained for the four main target species, by using the fishing effort estimates, i.e. trip duration and hours trawled. The species selected were those identified as target species in the following LPs – horse mackerel (associated to LP3 and LP5), Octopodidae (LP1), squid (LP4) and blue whiting (LP6). Fishing trips from LP2 were eliminated from subsequent analysis, including the estimation of LPUE as no target species was identified in this LP.

2.3 Sample fleet

Raw VMS records for the entire fleet were also available during the period 2000-2004. The investment in time and human effort needed for processing all this information and the existence of a high number of trips with incomplete data implied the selection of a small group of vessels as representative of the previously defined LPs. This group of vessels, henceforth referred to as a "sample fleet", was defined for this fishery to estimate species-directed fishing effort and abundance. In order to identify potential candidate vessels for this fleet, data concerning landings (1995 to 2007), VMS (2000 – 2004) and logbooks (2000 – 2004) were analyzed on the adequacy of the information (quantitatively and qualitatively) for each vessel. The chosen vessels were among those with regular landings for the entire 13-year period or at least in most of this period, and good VMS coverage for the five-year period in study. Six vessels were thus selected as representative of the distinct LP defined in Campos et al. (2007) (Paper 1 in this thesis), and expected to provide reliable indicators of the fishing regime: trip duration, number of hours trawled.

To assess if the reduced fleet had been active in the same geographical area in comparison to the remaining fleet activity (using VMS "fishing" points) was then mapped and compared by LP for both fleets. Fishing effort indicators (time spent at sea and number of hours trawled) were computed for each trip, and landings per unit effort (LPT, LPDAS and LPHT) were then obtained for the selected fleet, by LP, for 2000-2004.

2.4 Sample fleet evaluation

To assess whether this six-vessel fleet could be used as a sample fleet for the purpose of estimating species-specific effort and LPUE a number of analyses were carried out.

First, fishing effort mean estimates (trip duration, TD and total hours trawled by trip, HT) were computed by LP using the high quality 2003 data from the sample fleet:

$$TD_{l,s2003} = \sum \left(\text{time spent at sea}_{i,l,R2003} / \sum n_{l,R2003}\right)$$

and

$$HT_{l,s2003} = \sum \left(\text{total hours fishing during fishing trip}_{i,l,R2003} / \sum n_{l,s2003}\right)$$

where n_{lr2003} is the number of fishing trips in landing profile *l* belonging to the sample fleet in 2003. *s2003* corresponds to the 2003 data from the sample fleet, *l* is the LP (1 to 5) and *i* is the fishing trip (1 to n=total number of fishing trips).

These fishing indicators by LP (trip duration and total hours trawled) were then once again estimated using the data from 2000 to 2004 for the reduced fleet ($TD_{l,s2000-2004}$ and $HT_{l,s2000-2004}$). For each LP, comparison of fishing effort and species-specific LPUE estimates between the group of six vessels and the remaining fleet with high-quality data was carried out for 2003 data. Differences in the effort data (trip duration and hours trawled) between the sample fleet and the remaining fleet in 2003 were examined (p-value=0.8242 and p-value=0.4318, Wilcoxon rank sum test, respectively). Indicators of fishing effort by LP ($TD_{l,R2003}$ and $HT_{l,R2003}$) from this sample fleet could then be used to estimate the corresponding LPDAS and LPHT, under the assumption that fleet behaviour (trip and haul duration) has remained constant over time for each LP during the period in study (2003).

The quarterly (*qy*) estimates of LPUE (LPDAS and LPHT) were quantified for the four species/*taxa(s)*, using the landings per trip and corresponding fishing effort indicator (TD*l* or HD*l*, respectively). For example, to estimate LPDAS: $LPDAS_{sqy,TD2003} = \sum (LPT_{sjlqy}) / \sum TD_{l,2003}$.

These observed mean quarterly LPDAS values for the reduced fleet were compared with the corresponding estimates using the LPT and fishing effort indicators for the same dataset. Both observed and estimated values were compared with those for the entire fleet in 2003. In other words, the validation of this fleet was carried out by comparing these fishery-based indicators (TD, HT, LPT, LPDAS and LPHT) with those obtained for the remaining fleet in 2003.

For each LP, comparison of the overall fishing effort estimate (TD and HT) between 2003 and the remaining years (2000 to 2004) was carried out for the reduced fleet. For each species (and selecting the corresponding LP of the reduced fleet), LPDAS and LPHT were then estimated by quarter using the landings and the corresponding trip duration and hours trawled indicators, respectively, for the reduced fleet in the period 2000 - 2004. For example, $LPHT_{sqyl}$ was estimated as: $LPHT_{sqyl,HT2000\text{-}2004} = \sum (LPT_{sjlqy}) / \sum HT_{l2000\text{-}2004}$

Quarterly species-directed for the target species between 1996 and 2007 were estimated by dividing the mean quarterly LPT (estimates from Paper 3) by the respective fishing effort indicator. The observed average quarterly LPHT values for the reduced fleet were compared with the corresponding estimates using the fishing effort indicators for the same dataset. Both observed and estimated values are provided together with the corresponding estimates for the entire fleet (13-year time series) in 2000-2004.

The above analyses were carried out in the application GeoCrust 2.0 (Afonso-Dias et al., 2004) and the statistical open-source software R® (version 2.9.0, R Development Core Team, 2009).

3. RESULTS

3.1 Fishing effort and landings per unit efffort

A total of 10568 FTs and 40192 fishing hauls (corresponding to a total of 81574 hours trawling from 66 vessels) were identified from the processed VMS data between 2000 and 2004.

Four main fishing areas were identified (Figure 1), in accordance with Afonso-Dias and Pinto (2008), with their boundaries corresponding to geographical discontinuities (canyons) from north to south: 1) the first fishing area extends from the northern borderline (42ºN) to the north of the Nazaré canyon (39.5ºN, 9.5ºW); 2) between Nazaré and Setúbal canyons (38.3ºN, 9.2ºW); 3) southwest coast between the Setubal and São Vicente canyons (37.1ºN, 9.3ºW); and 4) the south coast (between 36.6 and 37.1ºN, 7.4 and 9ºW). The figure illustrates how vessels in the northern waters are engaged in fishing activity only up to depths of 200m, whereas on the southwest and south coasts, vessels may operate at higher depths. There are small patches where no fishing activity was detected; these areas coincide with the rough and rocky seafloors and steep slopes (Figure 1). The different areas are not submitted to the same fishing activity which is more intense in the northern area. The latter comprises the north and Center regions, as defined in Paper 3, accounting for a much higher proportions of FT and landings when compared to the remaining areas.

A total of 80% of the fishing trips started in the first five hours of the day, with 21% of FT starting between 2 and 3 a.m. A reduced number of trips (4.6%) began between 7 a.m. and 6 p.m. (12-hour time frame). Average (and median) trip duration was 28 (and 17) hours at sea, the average trip duration by vessel varied between 16 and 60 hours. By cross-combining these (10568) FTs with the landings from Paper 3 (103693 landings, 13-year time series), for the same time interval (2000-2004) a total of 9507 FT were retained. From the 2003 data, a total of 5003 FT were identified with a corresponding LP, with a final selection of 2922 FT (from 52 vessels) as the dataset of high-quality data (with all trawl hauls identified and valid trips). These represent 35.5% of the number of 2003 fishing trips referred in Paper 3 in this thesis.

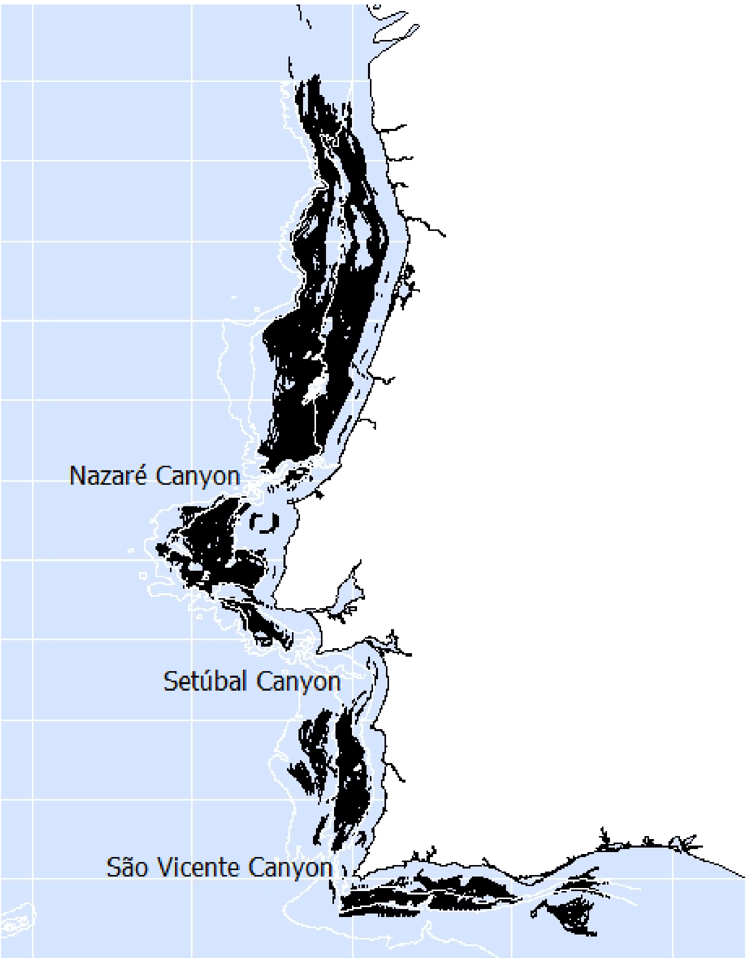


Figure 1. Map with the location of the four main fishing areas of activity for the Portuguese trawl fish fleet (66 vessels): north, central (between the Nazaré and Setúbal canyons), southwest and the south coast. From left to right, white contours correspond to the 1000, 200 and 100 m isobaths, respectively. ICES rectangles are shown in the background.

Average total distance trawled within a trip was 48.17 n.m., varying between 3.0 and 318.8 n.m. The minimum total distance travelled by trip was 20 n.m. For each trip, the total trawled distance was divided by the total number of hours trawled to calculate fishing speed (knots). Five out of the 52 vessels trawled at speeds under 3.0 nm/h (knots) in at least one fishing trip, and 8 vessels operated over 5.0 knots. In a small number of trips (n = 5) belonging to two vessels, trawling speeds were below 2.0 knots (1.882 – 1.995).

Estimates of FT duration (days) and total number of hours trawled by FT are presented for 2003 data corresponding to the valid fishing trips, for each LP in Table 1. Trip duration (hours at sea) varied by LP for both the (valid) high quality and the entire datasets. Both trip duration and hours trawled datasets for the 2003 data (n=2922FT) have a non-normal distribution according to the

Shapiro-Wilk test (hours trawled, W=0.7593, p-value<2.2e-16; trip duration, W=0.73, p-value <2.2e-16). Significant differences in trip duration were observed between LP (Kruskal-Wallis chi-squared=143.52, df=5, p-value<2.2e-16), as with the total number of hours trawled by fishing trip (Kruskal-Wallis chi-squared=560.40, df=5, p-value<2.2e-16). In LPs targeting cephalopods (LP4 and LP1 targeting squid and Octopodidae, respectively) fishing trips were longer and vessels spent more hours trawling (average 27.4 and 25.7 hours at sea; 19.4 and 17.3 total hours trawling), when compared to those targeting horse mackerel (LP3, LP5) and blue whiting (LP6, with an average of 8.1 total hours trawling and 18.5 hours at sea per trip) (Table 1). The average percentage of time spent fishing relative to the total hours at sea was also higher in trips targeting Octopodidae (66%) and squid (70%). LP2 was removed from further analysis since it was not associated to any particular species (Paper 3).

Table 1. Fishing effort estimates from VMS processed data for 2003 (2922 fishing trips from 52 vessels). Average and total fishing trip duration (total hours at sea) and hours trawled (total hours trawled) in the six LPs (landing profiles). Numbers of fishing trips and distinct vessels (in brackets) are also shown by LP, as well as percentage of time at sea engaged in fishing activity (%TF).

		LP1	LP2	LP3	LP4	LP5	LP6	All
FT (Vessels)		695 (43)	176 (28)	1050 (47)	92 (23)	555 (41)	354 (38)	2922 (52)
Trip	Average	25.7 (25.8)	23.0	22.0	27.4	18.9	18.5	22.1
	Min-Max	4.8 – 90.0	5.8 – 86.5	5.4 – 116.7	6.8 – 64.3	5.6 – 117.8	6.9 – 84.6	4.8-86.5
	Total	17835	4045	23131	2520	10503	6540	
Hauls	Average	17.3 (17.6)	11.7	11.7	19.4	9.0	8.1	
	Min - Max	1.8- 68.6	1.8-75.4	0.8-82.2	4.6-48.8	0.8-48.8	0.7-99.2	
	Total	12037	2067	12274	1787	4982	2874	
% TF	Average	65.8	49.3	52.5	70.2	47.4	43.2	53.9

The 2003 high-quality data used in subsequent analyses corresponds to a total of 4574 hours at sea (36021 hours trawling). The remaining data (e.g. partially valid trips) was removed as hauls were not always identified, due to data gaps from partially valid trips.

3.2 Species-specific LPUE: LPT, LPHT and LPDAS for 2003

Species-specific LPUE estimates for 2003 considering the entire fleet with VMS-based data are presented in Table 2. Landings per unit effort for small pelagic such as blue whiting and horse mackerel, attaining higher yields of 271kg/hour trawled in the first quarter of 2003, highly contrast with those for cephalopods with LPHT not exceeding one tenth of the former values. Correlations between the three LPUE indices and the two fishing effort estimates are shown in Table 3 for the four species/taxa in high-quality 2003 trips. The highest correlation between LPT and LPDAS was observed in fishing trips targeting octopus (0.73), whereas the lowest correlation was observed in trips targeting squid (0.39). High correlations were observed between LPDAS and LPHT for all five LPs, varying between 0.90 (LP5) and 0.97 (LP1).

Table 2. Species-directed landings per unit effort by quarter (Q) and LP (landing profiles) in 2003 using high-quality fishery-dependent data. Landings per trip (LPT), LPDAS and LPHT are in kg/trip, kg/days at sea and kg/hours trawled.

		Octopodidae	Squid	Horse	Mackerel	Blue whiting
LPUE	Q	LP1	LP4	LP3	LP5	LP6
LPT	1	141.6	219.5	670.9	2119.5	1522.0
	2	364.6		710.1	1717.5	1615.1
	3	193.3	186.4	540.4	1022.4	1648.5
	4	119.5	283.6	604.7	1424.8	2030.1
LPDAS	1	152.2	203.0	864.8	2567.0	2235.8
	2	383.6		913.5	2614.6	2387.0
	3	175.2	138.4	653.3	1624.1	2231.2
	4	113.8	269.5	648.4	1696.4	2252.0
LPHT	1	10.6	12.8	82.9	270.5	233.4
	2	23.2		81.8	266.9	253.2
	3	10.8	9.1	58.1	166.5	253.2
	4	7.3	16.0	51.3	156.3	241.0

Table 3. Correlations between the three observed landings per unit effort (LPUE) for each species (selecting corresponding landing profile, LP) considering high-quality trip data from 2003. LPUE: LPT, LPDAS and LPHT. Correlation between the fishing effort estimates trip duration (TD) and hours trawled (HT) are also shown. All correlations are statistically different.

		LPUE			Effort (in time)
Species landings	LP	LPT – LPDAS	LPT – LPHT	LPDAS - LPHT	TD - HT
Octopodidae	LP1	0.74	0.68	0.96	0.97
Squid	LP4	0.39	0.32	0.97	0.97
Horse mackerel	LP3	0.71	0.64	0.93	0.88
Horse mackerel	LP5	0.62	0.63	0.90	0.87
Blue whiting	LP6	0.66	0.61	0.92	0.69

3.3 Sample fleet (six vessels)

In Table 4, information is presented regarding the activity and technical characteristics for the six vessels selected to be representative of the entire fleet. All six vessels had activity in all LPs between 2000 and 2004, with main landing activity in the central and northern ports of Aveiro, Nazaré and Peniche. Only two of these vessels landed over 50 times in the fishing ports of the south coast (Table 4).

A total of 4053 FT (with corresponding LP and VMS processed data) were identified for these six vessels within the five-year period 2000-2004. The number of FTs by month and vessel for this fleet varied between 73 and 179.

Comparison of the geographical activity between the six-vessel fleet and the remaining fleet is in Figure 2, depicted by LP and as a whole. The bottom right maps, where all LPs are mapped, shows that the activity of this reduced vessel fleet covered the four main fishing areas. From exploratory analysis (not shown herein), it was observed that these fishing areas differ in terms of the relative importance of fishing activity, with the lowest intensities in the southwest area, reflecting the existence of spatial and temporal restrictions to fishing (boxes).It was also observed that only one of these vessels presented fishing activity along the entire coast. Likewise, one vessel had fishing activity restricted to the northern area in the proximity of Aveiro. The remaining trawlers operated along most of the western coast.

All LPs covered the four fishing areas with the exception of LP4, which was geographically restricted to the area in the vicinity of Aveiro. Similarity is also observed between the two fleets in what concerns their geographical activity by landing profile. LP1, targeting Octopodidae, was the only one for which differences in geographical coverage are apparent, with no activity identified in the southwest coast for the sample fleet.

Table 4. Vessel and activity information on the reduced fleet (six vessels, V1 to V6). Vessels characteristics include length overall (LOA), gross tonnage (GT), and power (kilowatts, kW). Total number of fishing trips between 2000 and 2004 by LP and fishing port are shown for each vessel.

	V1	V2	V3	V4	V5	V6
Vessel characteristics						
LOA (m)	24 - <40	24 - <40	24 - <40	24 - <40	24 - <40	24 - <40
GT	243	216	172	249	249	217
Power (kW)	699	633	441	588	588	588
Fishing Ports						
Matosinhos	37		48		11	2
Aveiro	894	257	793	44	310	20
Figueira Da Foz	23	239	6	136		523
Nazaré + Peniche	154+60	460+42	8+1	166+41	610+117	87+253
Cascais+Lisboa		9+61	35+31	42	14	1+49
Sesimbra+Setúbal+Sines		0+0+0	6+0+3	0+1+0	0+0+9	3+1+4
Sagres+Olhão+Portimão		0+0+3	1+2+62	3+36+464	0+4	0+1
Landing Profiles						
LP1	26	70	254	59	71	186
LP2	44	36	38	125	63	22
LP3	486	461	317	535	471	486
LP4	48	37	153	47	94	24
LP5	471	308	222	124	250	218
LP6	93	163	12	43	126	8

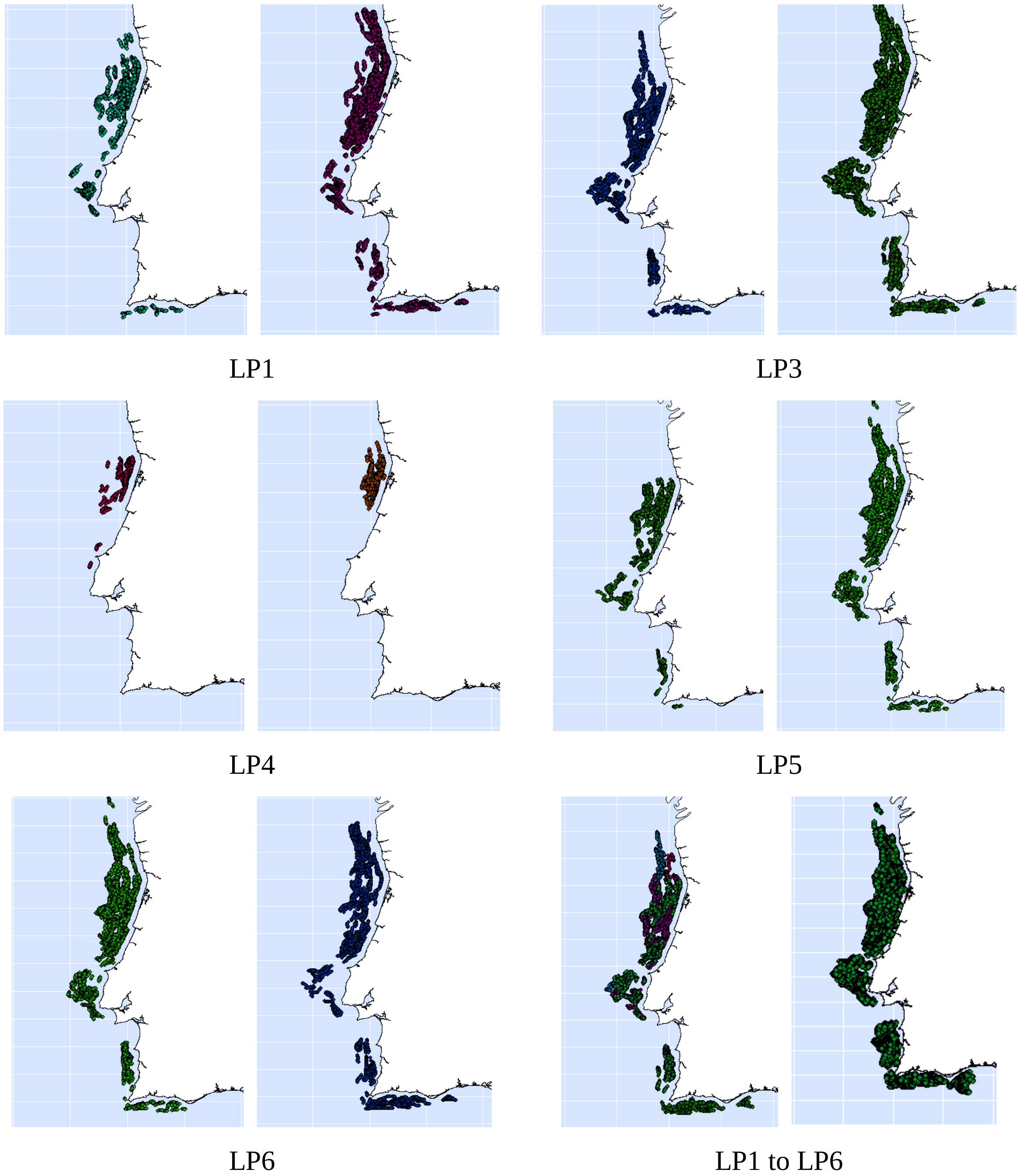


Figure 2. Map with the distribution of fishing activity by LP and group of vessels (six vessel fleet – left - and remaining fleet - right). Points correspond to VMS data from hauls identified by GeoCrust with high-quality data, from 2000 to 2004. Bottom right trips from all LPs are aggregated by fleet. ICES rectangles are shown in the background.

3.3.1 Fishing effort estimates for sample fleet

Average fishing estimates (trip duration and hours trawled) by LP for the six vessels selected are presented in Table 5. The five-year average trip duration was maximum when targeting Octopodidae (LP1, 28.9 hours) attaining a minimum of 17.6 hours blue whiting (LP6). When comparing the sample fleet with the remaining 2003 fleet, the only statistically significant difference was found for the number of hours trawled in LP5, horse mackerel (p-value=0.006). No significant differences between the sample and the remaining fleet were observed, either in the overall average 2003 effort data (trip duration and hours trawled) or when effort was analyzed in trip duration by LP (p-values varied between 0.23 and 0.93 in LP1 and LP3, Table 6). For the total hours trawled (HT) by trip (Table 6), significant differences between the sample fleet and the remaining vessels were only observed in trips targeting mainly horse mackerel (LP5, with W=30203 and corresponding p-value=0.006).

Table 5. Fishing effort estimates (trip duration and hours trawled in hours) and number of fishing trips (FT) by LP using high-quality data (year 2003; 2000 to 2004) for the six-vessel sample fleet.

		LP1	LP2	LP3	LP4	LP5	LP6
2003	FT	82	32	213	22	119	39
	Trip duration	28.5	23.7	23.5	27.9	21.0	18.6
	Hours trawled	18.1	8.6	11.6	18.2	10.6	7.9
2000-2004	FT	375	122	1163	188	676	239
	Trip duration	28.9	27.6	25.2	22.4	19.0	17.7
	Hours trawled	18.7	12.8	13.1	15.9	9.9	8.3

On the other hand, when the 2003 data for the same sample fleet was compared with the same fleet, for years 2000-2002 and 2004, hours trawled for LP3 were significantly different and so were both trip duration and trawl hours for squids, LP4 (Table 8, B). High-quality VMS data from the sample fleet for 2000 to 2004 (n=2763FT) was selected and effort estimates for 2003 (507 FT) were compared with the remaining years within this period (2256 FT). No significant differences in trip duration by LP between the two time periods (Wilcoxon-test results shown in Table 6) were observed, with the exception of trips targeting squid, with marginally significant differences. Conversely, for hours trawled (Shapiro-Wilk normality test W=0.8192, p-value<2.2e-16), significant differences were observed in LP3 and LP4, targeting horse mackerel and squid, respectively.

Table 6. Comparison of species-specific fishing effort and LPUEs for four species. The effort estimates are trip duration and hours trawled LPUE estimates are Landing per trip (LPT), landings per days at sea (LPDAS) and landings per hour trawled (LPHT). Two datasets were tested: A – data from the sample fleet was compared with the remaining fleet for 2003. B – data from 2003 was compared with data from 2000 to 2002 and 2004 for the sample fleet. Results of Wilcoxon tests (p-value, in brackets are the corresponding statistical significance). Statistical significance in brackets: NS – Not Significant; *<0.001; ** <0.01; * <0.05**

Data set	estimates	LP1	LP3	LP4	LP5	LP6
A	Trip duration	0.234 (NS)	0.926 (NS)	0.826 (NS)	0.811 (NS)	0.621 (NS)
	Hours trawled	0.892 (NS)	0.330 (NS)	0.461 (NS)	0.006 (**)	0.484 (NS)
	(species)	OCT	HOM	SQC	HOM	WHB
	LPT	0.13 (NS)	0.003 (**)	0.251 (NS)	0.727 (NS)	0.001 (**)
	LPDAS	0.008 (**)	0.026 (*)	0.139 (NS)	0.617 (NS)	0.000 (***)
	LPHT	0.197 (*)	0.000 (***)	0.021 (*)	0.128 (NS)	0.000 (***)
B	Trip duration	0.738 (NS)	0.070 (NS)	0.024 (*)	0.794 (NS)	0.052 (NS)
	Hours trawled	0.355 (NS)	0.001 (**)	0.003 (**)	0.261 (NS)	0.977 (NS)

3.3.2 Species-specific LPUEs for sample fleet

Landings per trip (LPT) from the sample fleet were found to be good estimators for blue whiting, horse mackerel from LP5 and cephalopods (Octopodidae and squid), as differences in LPT between the six-vessel fleet and the remaining fleet vessels were not statistically significant (p-values of 0.12, 0.25 and 0.72, respectively). Inversely, LPT for horse mackerel in LP3 significantly differed between the two fleets (p=0.003). Landings per day at sea estimates, however, could only be considered as good estimators for horse mackerel in LP5 and squid. Finally, concerning Landing per Hour Trawled (LPHT), only for horse mackerel in LP5 this could be considered as a good estimator.

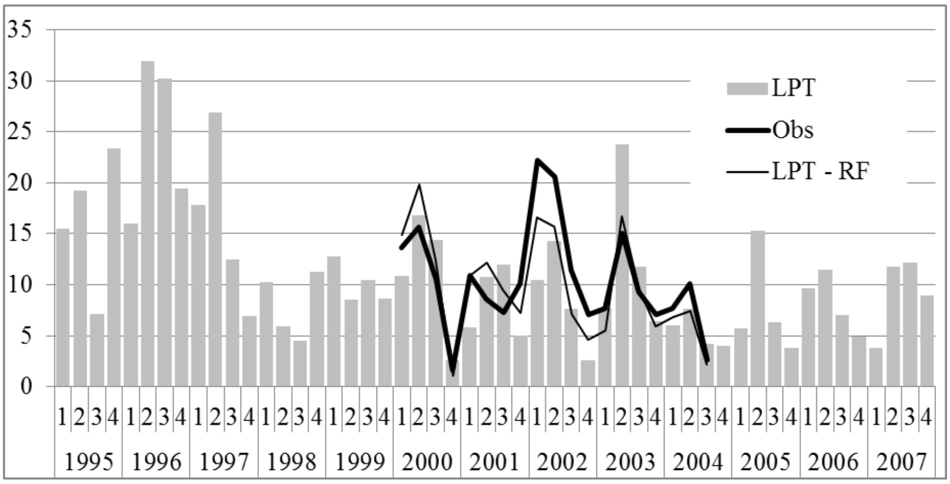
3.4 Species-specific LPUE

The quarterly LPHT for target species/taxa (Octopodidae, horse mackerel, squid and blue whiting) are shown in Figure 3. Three different series for LPHT are provided: a) average observed values from the sample fleet (Obs); b) values estimated using LPT and the corresponding effort indicator for the sample fleet with VMS fishing trips (LPT – RF, using the same trips as in Obs);

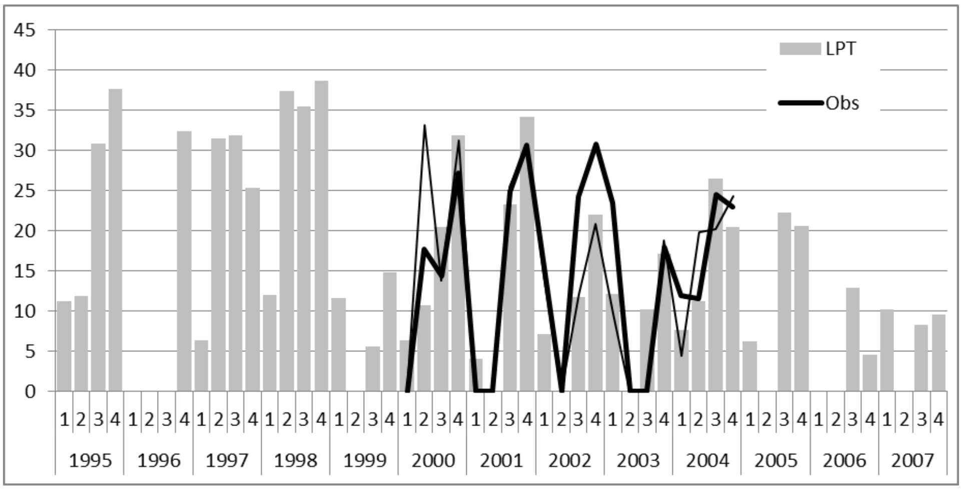
and c) values for the 13-year time series using the same indicator as in b. The first two estimates are only shown for the five-year period, as this is the period for which VMS data were processed. The 13-year LPHT estimates assume that the fishing effort indicator for the reduced fleet in 2000-2004 remains constant for the 13-year period and can be applied for the remaining fleet.

LPHT figures for pelagic fish, horse mackerel and blue whiting were found to be higher (within the same order of magnitude), decreasing for squid and Octopodidae. Seasonal patterns are evident for Octopodidae, with higher values usually in the 2nd and 3rd quarters; for squid in the last semester; and for LP3 horse mackerel in the first semester.

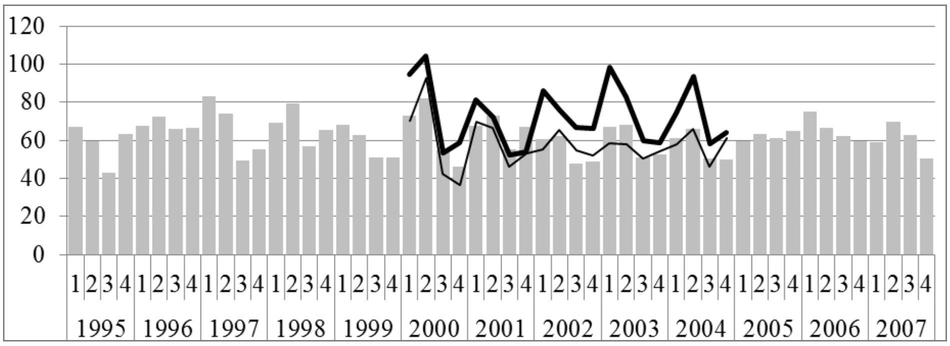
Generally, within the 5-year period, sample fleet indicators using the effort estimates (b) displays a trend that follows closely that of the 13-year series (c), with the exception of horse mackerel in LP3 (Figure 3).



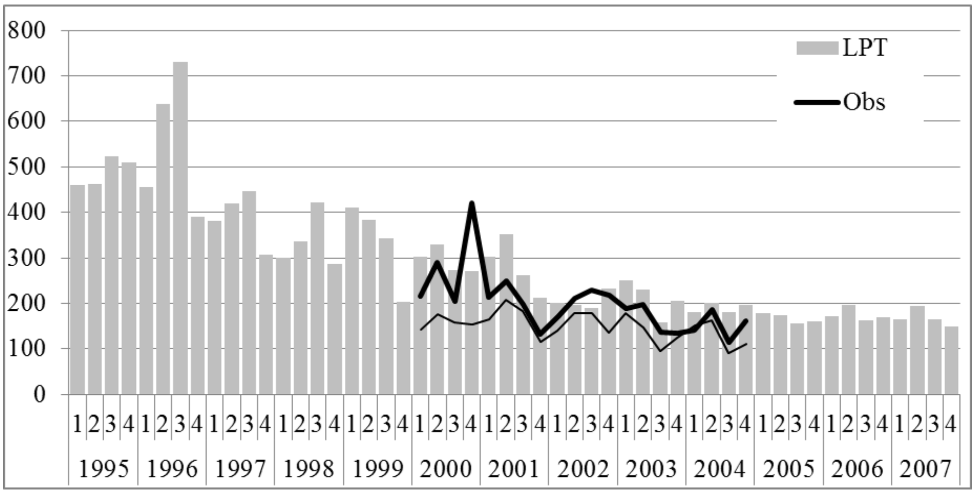
OCT – LP1



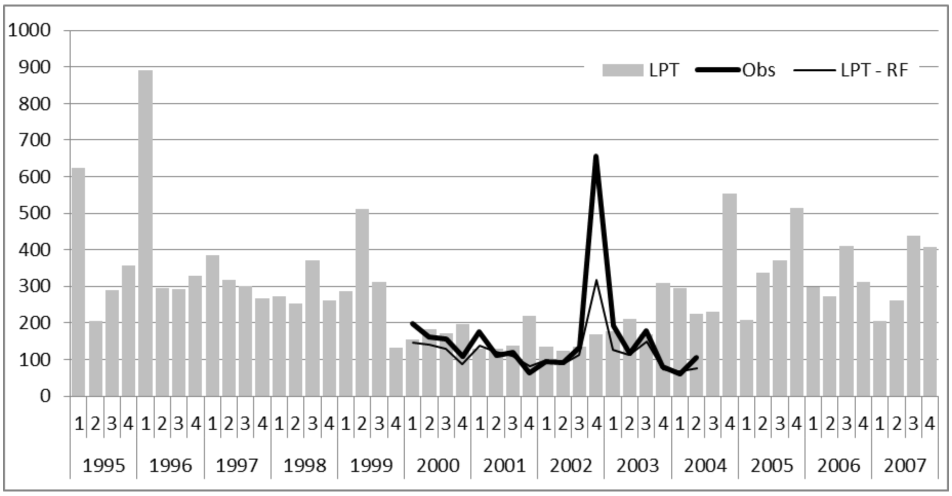
SQC – LP4



HOM – LP3



HOM – LP5



WHB – LP6

Figure 3. **Quarterly LPHT (kg/hours trawled, y-axis) are shown for four species by LP. From top to bottom: octopus (OCT), squid (SQC), horse mackerel (HOM - LP3 and LP5) and blue whiting (WHB). Three datasets are shown. a) Obs-sf (bold line) and b) l-sf (thin line) correspond to the same fishing trips from the sample fleet (sf) with VMS processed data; c) correspond to the initial 13-year time series (1995 to 2007 - bars). LPTs were used in b and c. Fishing effort indicators (hours trawled) used for b and c are found in table 5.**

4. DISCUSSION

First rough estimates of species-directed effort and LPUE (i.e., landings per trip, LPT) had already been obtained in Campos et al. (2007) (Paper 1 in this thesis) for horse mackerel, Octopodidae, blue whiting and squid during the 1995-2007 period. Herein, we extend the previous work with the purpose to obtaining more indicators for fishing effort by using the identification of the effective fishing time from high-quality VMS data.

Differences in fishing effort (total hours trawling and trip duration) between LPs were evident. Longer trips and higher number of total hours trawled were observed in LP1 and LP4 targeting octopuses and squid respectively, when compared to those targeting horse mackerel and blue whiting. This is possibly related to higher catches in LPs targeting small pelagic, schooling fish, forcing the vessels to carry out daily landings in these trips, while in many fishing trips targeting cephalopods, vessels are landing every other day.

In this study hours fishing and time at sea was examined, as well as the proportion of time actually spent fishing, also identified in Piet et al. (2007) as fishing effort parameters. The high correlation observed between LPDAS and LPHT can possibly suggest the use of the first estimator as a proxy of fishing effort.

For the purpose to obtain indicators of species-specific effort and LPUE, a number of vessels were chosen to be representative, of the different LP previously defined for this fleet in Campos et al. (2007) (Paper 1 in this thesis). Fishery-based effort and abundance estimators were then computed for this group of vessels. These estimators were first compared, for the main species of each LP, with those obtained for the entire fleet within the year of 2003. Results suggest that this "reference" fleet may not be the ideal to capture the LPUE trends for all the main species. It may be adequate for horse mackerel and for squid, but having more difficulty for the Octopodidae. For blue whiting the yearly and quarterly variability is also a factor thwarting the ability to obtain precise estimates of LPHT.

These results may be related to the process of vessel selection. Ideally, vessels would have been chosen based on the adequate information (landings and VMS data). However, only five vessels fulfilled both these requirements and, when assessing the quality of the VMS data, three of the vessels were eliminated from the list due to the gaps in the various sources of information. As such, the initial minimum requirements were modified in order to admit as potential candidates for this "reference" fleet, other vessels for which data quality was not so good but could still be considered as appropriate at the spatial and temporal scale.

Spatial patterns of activity were already analyzed for the entire fleet by Afonso-Dias and Pinto (2008) using VMS data, by Pilar-Fonseca et al. (2008, Paper 2 in this thesis) for trips associated to cephalopods landings, and for the entire fleet in Paper 3 region and landing port as spatial indicators were used. This study analyses data by landing profile (species-specific trips) confirming previous observations on the seasonal-related LPUE for cephalopods (and, to a certain extent, horse mackerel), as well as spatially located distribution for squid.

Even for vessels with high quality VMS information, data processing was frequently challenging. For example, when two hauls identified by GeoCrust occur within a small time frame (i.e., difference between end of one haul and beginning of the next is short), there is uncertainty if they should be identified separately or classified as the same haul. Furthermore, this may also cause some bias in the estimation of the time spent trawling (effective fishing activity). Logbooks could be useful for validating VMS information, but misreporting was observed with the effort information. As an example, the number of hauls reported by a given vessel was always four per trip, even when it was obvious from VMS data that fishing patterns had changed from one trip to another. Logbooks data is not used in some area of research at IPMA due to this type of constraints.

Throughout Geocrust project (Afonso-Dias and Pinto, 2008), although similar frequency distribution in trip duration and hours trawled by trip were observed between VMS-processed data (GeoCrust estimates) and logbook data, the number of hauls within a trip varied significantly between both datasets, with a higher number of hauls identified using the GeoCrust. The number of hauls and the criteria used to identify the beginning and the end of a haul should be validated, for example by using observers onboard to detect the limits of the haul activity within a fishing trip or using additional information e.g. from aerial surveillance.

The increase in electronic tracking systems and the information are gaining an increased importance and are an auxiliary tool for the monitoring of this activity. However, there is a need to identify and define standardized methodologies and procedure to analyse the high quantity of information (both high and low quality data), which is an important and essential step to assess the pressure and state of the marine resources and ecosystem, in accordance with the Common Fishery Policy and the Marine Strategy Framework Directive.

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