# Improving fisheries management through spatio-temporal analysis of catches, discards, fishing effort and selectivity, across different métiers

Monika Jadwiga Szynaka

Thesis submitted for the degree of Doctor of Philosophy (Marine Sciences)
Doctoral program in Marine, Earth and Environmental Science
Specialty in Fisheries and Aquaculture

Orientadores:
UAlg-CCMAR - Dr. Karim Ezini
UAlg-CCMAR - Dr. Jorge Gonçalves
IPMA - Dr. Aida Campos

**Faro 2023**

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## Declaration of authorship

This work has not previously been submitted for a degree in any university. To the best of my knowledge and belief, the thesis contains no material previously published or written by another person except where due reference is made in the thesis itself.

### 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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Monika Jadwiga Szynaka

## Support

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## Apoio

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# Short abstract

Fishers in the Southern Portuguese multi-gear coastal fleet own licenses for a variety of fishing gears including static nets, longlines, and traps, and dredges. Information on the fishing gear being actively used is scarce and most vessels are not required to report geographic location, making the impact of the local environment difficult to evaluate. The first and main objective of this thesis was to identify métiers in the multi-gear coastal fisheries operating in the Portuguese south coast, including the type of gear being used to target specific species or assemblages in certain areas during a specific time of year in a three-step process. The first step was a review to understand the definition of fisheries métiers using static longlines due to their well-defined target species, little environmental impacts, and various characteristics that can be modified for improved fishing. This was followed by a cluster analysis on landing profiles for the fleet (2012-2016), followed by the second and third step in which validations using questionnaires and onboard observations, respectively. The main finding was the application of a low-cost analysis to identify métiers within a multi-gear fleet with limited data, and specific to this fleet, an increasing number of vessels active within the octopus (*Octopus vulgaris*) trap métier. The second objective was to assess a proposed raised trammel net (by insertion of a section referred to as "aranha") to reduce by-catch and habitat impacts in the cuttlefish (*Sepia officinalis*) trammel net fishery. The results were promising as the modified net caught significantly less habitat forming organisms and similar target species' amounts as the standard net. The results presented in this thesis can contribute to the management of this multi-gear fleet by presenting the necessary information to make decisions, especially for métiers with high number of vessels, and effort in highlighting the necessity for gear modifications in areas where the habitat is impacted.

**Key words:** fishing métiers; landing profiles; multi-gear fleet; coastal fleet; fisheries management; trammel nets

# Resumo

As embarcações da frota costeira polivalente que opera na costa sul portuguesa possuem geralmente várias licenças de pesca, incluindo redes de emalhar e de tresmalho, armadilhas, potes (alcatruzes), palangres de deriva e de fundo, e dragas. A informação existente sobre as artes efetivamente utilizadas e as áreas de operação é escassa, pois só um número muito reduzido de embarcações nesta frota está equipada com o sistema de monitorização das pescas (MONICAP e diários eletrónicos de pesca). Uma vez que a utilização de artes distintas resulta em grandes diferenças quer na composição das capturas, quer nos efeitos sobre os diferentes habitats, é difícil avaliar o impacte desta frota sobre o ecossistema onde opera.

O primeiro e principal objetivo desta tese foi identificar os métiers desta frota, incluindo as artes de pesca utilizadas em determinadas áreas ao longo do ano e as espécies capturadas por estas artes. Para responder a este objetivo foi adotada uma abordagem em quatro etapas sequenciais (**Capítulos 2 a 6**). A primeira etapa visou melhorar a compreensão sobre o conceito de métier, através da revisão bibliográfica sobre os principais parâmetros operacionais que podem afetar as capturas em palangres de fundo e semi-pelágicos, artes de pesca consideradas altamente seletivas, ambas utilizadas pela frota polivalente costeira. A revisão bibliográfica (**Capítulo 2**) resultou na definição das características destas artes (tipo e tamanho do de anzol) e estratégias de pesca (tipo de isco e tempo de imersão) associadas a diversos métiers. Concluiu-se que a utilização de anzóis circulares melhora a seletividade e a eficiência de captura em diversas pescarias com esta arte, enquanto que o tempo de imersão não afetará de modo significativo estas características, embora isso possivelmente se deva ao fato de ser um parâmetro mascarado por outros parâmetros. Os resultados contribuem para futuros estudos que tenham como objetivo otimizar as estratégias de pesca com esta arte e melhorar a eficiência de captura. A segunda etapa (**Capítulo 3**) envolveu a utilização de técnicas de análise multivariada (*Clustering Large Aplications*, CLARA) com o objetivo de definir os perfis de desembarque para esta frota entre 2012 e 2016, identificando as principais espécies-alvo, bem como possíveis alterações sazonais na composição das capturas e ainda propondo, com base em conhecimento prévio, as artes de pesca utilizadas. A terceira etapa (**Capítulo 4**) foi dedicada à validação dos métiers propostos por meio de inquéritos/entrevistas nos portos, utilizando dois questionários, o primeiro contendo questões abertas sobre as características da viagem e das artes de pesca utilizadas, incluindo perguntas sobre as espécies-alvo, enquanto que o segundo visou a associação entre espécies-alvo e operações de pesca em perguntas fechadas. A comparação das respostas nos dois questionários permitiu avançar na identificação dos métiers. Na quarta etapa (**Capítulo 5**) procedeu-se a uma validação adicional dos métiers através de observações a bordo, onde foi registada a composição das capturas, juntamente com os detalhes e a localização geográfica das operações de pesca nos métiers amostrados.

Os resultados dos **Capítulos 3 a 5** apontam para a relevância de uma pescaria dirigida ao polvo (*Octopus vulgaris*) com alcatruzes e armadilhas, durante todo o ano, a profundidades até aos 100 metros, tendo sido definido um conjunto de espécies acessórias numa pescaria anteriormente conhecida como sendo mono-específica. Outros métiers importantes são a pescaria do tamboril (*Lophius* spp.) com redes de emalhar, no período do inverno ao verão, a profundidades até 400 metros; e da pescada branca (*Merluccius merluccius*) e a azevia (*Microchirus* spp.), também com redes de emalhar, durante todo o ano, a profundidades até 100 e 50 metros, respetivamente, com capturas acessórias mais reduzidas quando comparadas com as capturas reportadas em estudos anteriores sobre estes métiers. Os bivalves, incluindo o pé-de-burrinho (*Chamelea gallina*), a amêijoa-branca (*Spisula solida*) e as conquilhas *Donax* spp, são capturados com ganchorras, durante todo o ano. Por fim, o choco (*Sepia oficinallis*) e a canilha (*Bolinus brandaris*) são capturados com tresmalhos, o primeiro no inverno e na primavera e a segunda durante todo o ano. Estes resultados permitiram validar métiers propostos em estudos anteriores, embora os nossos resultados indiquem que mais de metade das embarcações se encontram envolvidas na captura de polvo, tendo alterado as suas licenças de pesca para incluir alcatruzes e armadilhas durante o período em análise. De um modo geral, as embarcações que operam redes alternam sazonalmente entre tresmalhos e redes de emalhar. No **Capítulo 5**, procedeu-se a uma caracterização mais aprofundada de alguns dos métiers propostos, tendo sido identificados alguns métiers adicionais envolvendo um número reduzido de embarcações. Um segundo objetivo desta tese (**Capítulo 6**) foi propor e testar modificações às artes para reduzir capturas acessórias e impactes negativos no ecossistema, concretamente na pesca de choco (*Sepia officinalis*) com redes de tresmalho, em áreas com fundos rochosos, onde as capturas acessórias de invertebrados são elevadas. As alterações à rede tradicionalmente utilizada consistiram na introdução de uma secção entre os panos de rede e o cabo dos chumbos, à qual os pescadores chamaram "aranha", e que permitiu levantar a rede do fundo. Os resultados apontam para uma redução dos principais invertebrados (incluindo esponjas, corais, pepinos-do-mar e estrelas-do-mar), com alterações não significativas na captura das duas principais espécies-alvo, o choco e a azevia. As entrevistas que foram feitas após a análise permitiram recolher opiniões dos pescadores sobre a utilidade de uma futura implementação das alterações propostas, tendo oferecido uma solução que poderá ser testada no futuro.

Os resultados apresentados nesta tese fornecem uma base para a identificação de métiers através de uma abordagem que envolve três etapas sequenciais. A informação obtida com a análise das atividades desta frota pode ser utilizada para avaliar o impacte no meio ambiente local de acordo com as artes de pesca efetivamente utilizadas. Os diferentes métodos de entrevista devem também ser considerados e, para fins futuros, os dois formulários utilizados podem ser reunidos num único formato. No entanto, reconheceu-se que a segunda rodada de questionários foi mais útil, pois forneceu respostas mais diretas às questões colocadas aos pescadores. Curiosamente, os resultados obtidos relativamente às rejeições ao mar foram diferentes daqueles esperados para as embarcações que operam com armadilhas e redes. Os resultados apresentados nesta tese podem ser utilizados na gestão desta frota polivalente, voltando potencialmente a atenção para o segmento da frota que visa o polvo, uma vez que este métier envolve mais de metade das embarcações ativas desta frota. Além disso, os ensaios de pesca experimental podem ajudar a gestão a avaliar os impactos das artes estáticas nas espécies formadoras de habitat e, ao apoiar futuros estudos com foco na captura acidental desses organismos, reduzir os impactos negativos da atividade da pesca.

**Palavras – chave:** métiers; perfis de desembarque; frota polivalente; frota costeira; gestão das pescarias; redes de tresmalho

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## Abbreviations

| Analyses | |
|---|---|
| ANOVA | Analysis of Variance |
| ASW | Average Silhouette Width |
| CCA | Canonical-correlation analysis |
| CLARA | Clustering Larger Applications |
| CPUE | Catch per Unit Effort |
| E | Fishing Effort |
| F | Fishing Mortality |
| HAC | Hierarchical Agglomerative Clustering |
| HCA | Hierarchical Clustering Analysis |
| MRT | Multivariate Regression Tree |
| NMDS | Non-Metric Multidimensional Scaling |
| PAM | Partitioning Around Medoids |
| PCA | Principal component analysis |
| SIMPER | Similarity Percentage |

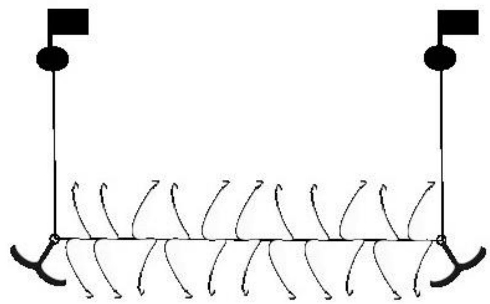
| Fishing Gear Codes | |
|---|---|
| DRB | Dredge |
| FIX | Traps |
| FPO | Pots |
| GNS | Gillnets |
| GTR | Trammel nets |
| LHP | Pelagic Longlines |
| LLD | Drift Longlines |
| LLS | Bottom Longlines |

| General | |
|---|---|
| AIS | Automatic Identification System |
| DCF | Data Collection Framework |
| DGRM | Direção-Geral de Recursos Naturais, Segurança e Serviços Marítimos<br>Directorate-General for Natural Resources, Safety and Marine Services |
| FAO | Food and Agriculture Organization |
| FAOCOD | Food and Agriculture Organization Codes |
| GDPR | General Data Protection Regulation |
| GPS | Global Positioning System |
| ICES | International Council for the Exploration of the Sea |
| IMO | International Marine Organization |

| | |
|---|---|
| LEK | Local Ecological Knowledge |
| INE | Institute of Statistics (Portugal) |
| LOA | Length Overall |
| LP | Landing Profiles |
| MLRS | Minimum Landing Reference Size |
| TAC | Total allowable catch |
| VME | Vulnerable Marine Ecosystem |
| VMS | Vessel Monitoring System |

| Species FAO Codes | Species | Common |
|---|---|---|
| ANK | *Lophius budegassa* | Blackbellied Angler |
| BIB | *Trisopterus luscus* | Pouting |
| BON | *Sarda sarda* | Atlantic bonito |
| BOY | *Bolinus brandaris* | Purple dye murex |
| BRB | *Spondyliosoma cantharus* | Black seabream |
| BRF | *Helicolenus dactylopterus* | Blackbelly rosefish |
| BGR | *Pomadasys incisus* | Bastard grunt |
| BSS | *Dicentrarchus labrax* | European seabass |
| COE | *Conger conger* | Conger eel |
| CRE | *Cancer pagurus* | Edible crab |
| CTB | *Diplodus vulgaris* | Common two-banded seabream |
| CTC | *Sepia officinalis* | Common cuttlefish |
| DEL | *Dentex macrophthalmus* | Large-eye dentex |
| DON | *Donax* spp. | Donax clams |
| FOR | *Phycis phycis* | Forkbeard |
| GUR | *Aspitrigla cuculus* | Red gurnard |
| HKE | *Merluccius merluccius* | European hake |
| HOM | *Trachurus trachurus* | Atlantic horse mackerel |
| JOD | *Zeus faber* | John dory |
| KRJ | *Charonia lampas* | Knobbed triton |
| MAS | *Scomber colias* | Atlantic Chub mackerel |
| MGR | *Argyrosomus regius* | Meagre |
| MKG | *Microchirus variegatus* | Thickback sole |
| MNZ | *Lophius* spp. | Monkfishes |
| MON | *Lophius piscatorius* | Monkfish |
| MUR | *Mullus surmuletus* | Surmullet |
| NEP | *Nephrops norvegicus* | Norway lobster |
| OCC | *Octopus vulgaris* | Common octopus |
| PAC | *Pagellus erythrinus* | Common pandora |

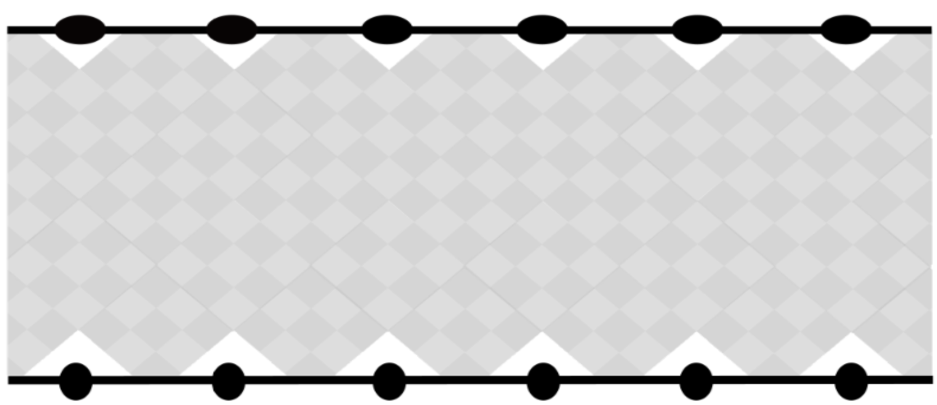
| | | |
|---|---|---|
| RJC | *Raja clavata* | Thornback ray |
| RJI | *Raja circularis* | Sandy ray |
| RPG | *Pagrus pagrus* | Red porgy |
| SBA | *Pagellus acarne* | Axillary seabream |
| SBG | *Sparus aurata* | Gilthead seabream |
| SBR | *Pagellus bogaraveo* | Blackspot seabream |
| SBZ | *Diplodus cervinus* | Zebra seabream |
| SCL | *Scyliorhinus* spp. | Catsharks |
| SCS | *Scorpaena* spp. | Scorpianfishes |
| SKA | *Raja* spp. | Raja rays nei |
| SLO | *Palinurus elephas* | Common spiny lobster |
| SOL | *Solea solea* | Common sole |
| SOO | *Solea* spp. | Soles nei |
| SVE | *Chamelea gallina* | Striped venus |
| SWA | *Diplodus sargus* | White seabream |
| SYT | *Scyliorhinus stellaris* | Nursehound |
| THS | *Microchirus* spp. | Bastard soles |
| TOE | *Torpedo* spp. | Torpedo rays |
| ULO | *Spisula solida* | Surf clam |
| WRF | *Polyprion americanus* | Wreckfish |

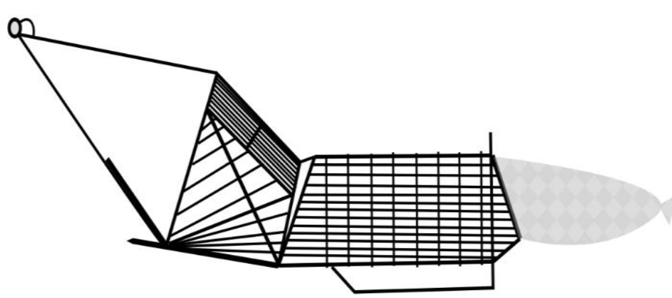


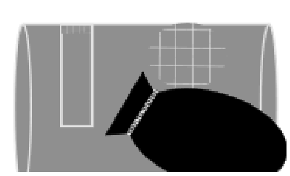
# Chapter 1

# Introduction

Multi-Gear Coastal Fishing Fleet in Portugal







# 1. General Introduction

### *1.1 What are métiers?*

Fisheries management has been traditionally based on single species approaches such as Total Allowable Catches (TAC) or regulation of fishing effort (E). However, in multi-gear, multi-species fisheries, TAC-based management often leads to misreporting (Bastardie et al. 2010a), and it can also lead to the situation where the so-called "choke" species (species for which the fishing quotas become exhausted), are discarded until the quota for the "primary" species being targeted is attained. Some examples are cod (*Gadus morhua*) in the North Sea or saithe (*Pollachius virens*) in a Danish demersal trawl fishery (Ulrich et al. 2012, Hatcher 2014, Baudron and Fernandes 2015, Mortensen et al. 2018). An alternative to single species management is the adoption of fleet-based management measures, calling for the definition of métiers. Métiers are defined as directed fisheries, in which vessels are targeting similar species using the same type of gear in the same area and time of year, following a similar exploitation pattern (ICES 2012). Some examples of these métiers are the cuttlefish (*Sepia officinalis*) fishery in spring with trammel nets in Mallorca (Palmer et al. 2017); the hake (*Merluccius merluccius*) fishery all year round with gillnets in Greece (Tzanatos et al. 2006), or the year-round octopus (*Octopus vulgaris*) fishery with pots and traps in the Algarve (Szynaka et al. 2021).

Different methods are used to define métiers, commonly starting with the analysis of catch data available in sales notes or logbooks, often using multivariate statistical techniques in order to define landing profiles (LP), or groups of species, to which fishing gear types are then associated. In previous studies, métiers have been defined even within fleets, for example the coastal bottom pair trawl fleet and set-longline fleet, of vessels using a single type of gear (Castro et al. 2010, Castro et al. 2011). Ultimately, the identification of métiers is the first step towards better management for multi-gear/multi-species fleets. However, this also requires further validation and continuous observation as métiers are not fixed, shifting in time due to economic reasons or fluctuations in the availability of the main target species, and sometimes driven by habit and risk-aversion, or in other words due to either environmental, socioeconomic, or fisheries-related reasons (Roditi et al. 2018, Schadeberg et al. 2021, Szynaka et al. 2021).

### *1.2 Landing Profiles and Métiers*

Many métiers have been previously described through onboard data collection and analysis (e.g., Erzini et al. 1996, 1998, 1999, 2001, 2003, 2010 and Borges et al. 2001 in Southern Portugal). However, in most cases this is not possible since it is extremely costly and time-consuming. Thus, métiers have been commonly addressed through the analysis of daily auction records (data on species landing weight and first sale value by vessel) that allow to define landing profiles (LP), or groups of species, which are then associated to a gear type. Various studies have approached the identification of LP through multivariate analyses using different methods. In the Mediterranean, daily auction records consisting of data on species landing weight and first sale value, by vessel, have been used to identify métiers using multivariate techniques, specifically cluster analysis, nMDS and SIMPER, to determine catch profiles, catch composition among samples, identifying the main species by weight and value (Samy-Kamal et al. 2014). Katsanevakis et al. (2010a) used landing profiles of Greek longliners to describe métiers using factorial analysis of the landing profiles and hierarchical dendrograms. Common longline métiers found included white sea bream (*Diplodus sargus*), hake, common sea bream (*Pagrus pagrus*), and common pandora (*Pagellus erythrinus*) in bottom longlines and hake in semi-pelagic longlines. Cardoso et al. (2015) used CLARA (CLustering LArge Applications) to characterize métiers in Portugal using logbooks, finding that the main métiers included octopus caught with traps, the black scabbard (*Aphanopus carbo*) caught with bottom longlines, and hake caught with gillnets. By predicting métiers, it is also possible to describe temporal (normally seasonal) trends as was done by Palmer et al. (2017) for small-scale fisheries in Mallorca (cuttlefish in spring and spiny lobster (*Palinurus elephas*) in summer using bottom trammel nets and dolphinfish (*Coryphaena hippurus*) in autumn and transparent goby (*Aphia minuta*) in winter using special surrounding nets).

Katsanevakis et al. (2010b) described a total of nine métiers in Greek seiners using a PCA (Principal Component Analysis), followed by a HAC (Hierarchical Agglomerative Cluster). The main métier was found to target picarel (*Spicara smaris*) and bogue (*Boops boops*), in both the Aegean and Ionian Seas, using 16 mm mesh size codends. Other métiers included the fishery for red mullet (*Mullus barbatus*) in the Argosaronikos area, with less than 16 mm codend mesh size.

When identifying métiers in a Spanish set-longline fleet from logbooks, Castro et al. (2011) combined spatio-temporal patterns of fishing activity, surveys conducted with fishermen and clustering of landing profiles using CLARA. In other studies, the identification of métiers was carried out with support of the software VMStools (Hintzen 2012), matching the catch information in vessels' logbooks with VMS (Vessel Monitoring System) data, in order to map the landings spatio-temporal heterogeneity.

### *1.3. What we know about Portuguese Métiers*

The definition of métiers in the Portuguese multi-gear coastal fleet was previously addressed by Duarte et al (2009); an update was provided by Campos et al. (2021), in which some métiers have been defined and assigned to fleet components. However, little is known about the impact of these métiers on the living resources and the state of the species exploited by these fishing fleets. Each vessel owns licenses for different fishing gears, and fleets targeting a single species are exceptions, such as the octopus fleet in Southern Portugal, targeting the species with pots and traps (Szynaka et al. 2021), or the black scabbard deep-sea longline fleet (Campos et al. 2021) operating off the west continental coast. Borges et al. (2001) described multiple métiers in the Algarve, including the crustacean trawl fishery targeting the rose shrimp (*Parapenaeus longirostris*) and the Norway lobster (*Nephrops norvegicus*); the demersal purse seine targeting sea breams (*Diplodus*, *Pagellus*, *Pagrus* and *Sparus species*) and sea bass (*Dicentrarchus labrax*); the pelagic purse seining targeting small pelagic species such as sardines (*Sardina pilchardus*), and the trammel net fishery targeting cuttlefish.

The Southern Portuguese coastal multi-gear fleet, comprising vessels ranging from 9 to 23 m in length, operates off the south coast of Algarve. These fishers own licenses for a variety of static and mobile fishing gears including pots and traps, bottom longlines, dredges, and trammel nets and gillnets (Figure 1.1). Duarte et al. (2009) described this fleet as using passive gears including gillnets, trammel nets, lines and hooks, and traps and pots. Furthermore, métiers are described by the time of year that certain species are targeted, as some species are caught year-round while others are targeted during a specific season. Cuttlefish and sole species, for example, are targeted during late autumn and winter with trammel nets (Szynaka et al. 2018). Monkfish (*Lophius* spp.) are also targeted in deepwater trammel nets, around 200 m (Erzini 2001, Santos et al. 2003a). As mentioned previously, the gear characteristics are very important for establishing métiers; in this case the mesh size is chosen specifically for a target species. One experimental study in the Algarve found that cuttlefish are generally targeted with 140mm mesh size nets; the

Senegalese sole (*Solea senegalensis*) with 120mm nets and the bastard sole (*Microchirus azevia*) with 100mm nets in autumn and winter (Stergiou et al. 2006).

Gillnets of 220mm mesh size are also used to specifically target monkfish (*Lophius piscatorius*) in Portuguese fisheries, often in deep waters (Cardoso et al. 2015), whereas smaller mesh gillnets less than 100 mm (Fonseca et al. 2005) are commonly used in Southern Portugal to target hake. This species is also targeted by bottom longlines (Santos et al.2002, Santos et al.2003b) often in the summer and fall seasons. Erzini et al. (2003), found that the gillnets used in Portuguese fisheries primarily catch common two-banded seabream (*Diplodus vulgaris*), axillary seabream, common pandora, and black seabream (*Spondyliosoma cantharus*); many *Sparidae* are also caught in bottom longlines although these tend to catch larger individuals.

Bottom longlines and traps are static gears that use bait, commonly sardine and mackerel (Erzini et al., 1998, 1999, 2000, 2001). In terms of longlines, the main targeted species include white sea bream and common two-banded seabream inshore, at a depth less than 30m, and red sea breams (including common pandora and axillary seabream) between 40 – 60m, using small hooks. Larger hooks are used for demersal species such as common seabream and conger eel (*Conger conger*). Semi-pelagic longlines that are used to target hake at depths between 200 – 700 m, with hook sizes ranging from 10 to 5 (Erzini et al.1998, 1999, 2001). Octopus traps and pots are used in the Algarve to target octopus (*Octopus vulgaris*), while fish traps are used to target Sparidae, including common pandora, axillary seabream and annular seabream (*Diplodus annularis*) (Erzini et al. 2008). There is a lack of seasonality in the octopus' métier and octopus is generally caught year-round.

In comparison to the previous types of gears referred, that are passive, dredges are active gears used for bivalves. Bivalve dredging is common in Portugal with three main species targeted in the Algarve region: the surf clam (*Spisula solida*) and the striped venus (*Chamelea gallina*) with the "SDredge", and *Donax trunculus* with the "DDredge" (Gaspar et al.2015). Dredges for these species operate year-round except for a seasonal closure between May 1st and June 15th due to spawning and larval settlement (Anjos et al.2018).

According to the DGRM licensing information for all vessels operating in the Algarve region in the period from 2012 to 2016, there was a decrease in the number of fishing licenses for fishing gears referred to as "Anzol" (hooks) (140 licenses less in 2016 compared to 2012), and a decrease in "Redes", or nets, (58 less in 2016 compared to 2012), while for "Armadilhas" or traps an increase of 18 licenses was recorded. For vessels between 10 and 15 meters, there was an increase in the number of licenses for *Anzol* and *Armadilhas* by 9 and 11 respectively, and a decrease in Redes by two in 2016. Despite fishers having licenses to more than a single gear, they often do not use all the licenses; rather owning those licenses is a preference to have all the options available to them. Thus, to improve knowledge on the impacts on the environment of these multi-gear fleets, the fishing gears actively used must be identified along with the main targeted species and the fishing patterns, including gear shifts due to seasonal changes in the abundance of these species. It is also important to note that, as previously stated, certain species are targeted with more than a single gear type, making it difficult to define a métier.

**Figure 1.1.** An Atlantic bonito (or sarrajão in Portuguese; *Sarda sarda*) caught in a gillnet (upper left); a monkfish (*Lophius* spp.) caught in a large mesh trammel net (upper right); a moray eel (*Muraena helena*) in an octopus trap (lower left); a square iron trap (Photos by M. Szynaka).

### *1.3.1. Fishing gears, selectivity and fishing regulations*

#### *1.3.1.1. Gillnets*

Gillnets are static nets made of a single net panel and are generally not species selective, catching a wide range of vertebrates and invertebrates through a variety of catching mechanisms, including gilling, wedging, and entangling. Mesh size is an important factor affecting size selectivity (Erzini et al. 2003), smaller mesh sizes resulting in higher quantities of undersized individuals (Fonseca et al. 2005) while an increase in mesh size is associated with decrease in catches of some target species (Santos et al. 2003a). However, other net characteristics can also affect selectivity to a high extent, including twine type, hanging coefficient and others (Hamley 1975, Erzini et al. 2003, Gladston et al. 2017). The current regulations for gillnet fisheries in Portugal allow a length range for a single net of 2000 to 15000 meters and height range from 3.5 to 10 meters. In terms of the trip characteristics, vessels cannot keep their nets in the water for longer than 24 hours unless at depths of 300 meters or deeper when using nets with a mesh size larger than 100mm, in which case they are allowed to keep their nets in the water for a maximum of 72 hours and must fish further than one mile from the coastline.

#### *1.3.1.2. Trammel nets*

Trammel nets are static nets made of three mesh panels, two large mesh size outer panels and one small mesh inner panel. These are less species selective due to their unique catch mechanism known as pocketing or trammeling (Santos et al. 2002, Erzini et al. 2006), related to the inner net characteristics, creating a vertical slack that highly increases gear efficiency, resulting in the catch of a wider range of fish sizes (Salvanes, 1991, Losanes, 1992a, b). The fish length frequency distributions in trammel nets are also generally wider than those observed in gillnets for the same species, and, according to some studies, they are more likely to catch larger fish (Akiyama et al. 2004, Karakulak and Erk 2008, Park et al. 2011).

According to the Portuguese fisheries regulations, the length range for trammel nets must be between 4000 and 20000 meters, depending upon fishing vessel size, with a maximum of five meters in height. Similarly to gillnets, vessels are permitted to soak their nets for a maximum of 72 hours if they are fishing at depths of 300 meters or deeper, with an inner mesh size larger than 100mm, and are required to fish further than one mile from the coastline.

#### *1.3.1.3. Longlines*

In longlines, gear characteristics such as hook model and size, along with bait type, can be adjusted to in order to increase species and size selectivity (Løkkeborg and Bjordal, 1992, Erzini et al. 1997). Therefore, many métiers can be considered within longlines as there are many characteristics that can be changed in order to catch a given target species. This makes this gear type interesting to use as a baseline when understanding how a métier is defined.

Bait and hook type both are reported to affect species selectivity, with a few studies showing that larger bait and larger hooks can result in catches of larger individuals (Otway and Craig 1993, Erzini et al. 1996, Sousa et al.1999, Huse and Soldal, 2000, Ingólfsson et al.2017), while in other studies the use of alternative hooks such as circle hooks, and of alternative baits increased efficiency in the respective fisheries (Chapter 2).

#### *1.3.1.4. Traps*

Traps and pots appear to be increasingly popular in Portuguese fisheries. Most of the pots that are currently used are made of plastic coated with a layer of cement on the bottom, when previously they were entirely made of clay. They are more species selective than the previously mentioned gear types. Pots, also known as shelter traps, are highly species selective as they are used by octopus for shelter, especially during spawning periods (Sonderblohm et al.2017), and although sometimes used by other species, they do not have any mechanism that prevents escape. Traps, made with wire and/or plastic, use bait specific to the targeted species and have an inverted funnel-shaped entrance that prevents escape. Regulations in force (Table 1.1) allow vessels to own up to 3000 pots and 1000 baited traps for vessels between 9 and 12 meters in length and 1250 baited traps for vessels over 12 meters in length or over (DGRM). The mesh sizes for these traps are generally between 30 and 50 mm and are used to target octopus and fish. In terms of trip characteristics, coastal vessels, or vessels larger than 9 meters in length, fishing with traps or pots are required to fish at least 1 mile off the shoreline.

**Table 1.1.** Portuguese regulations (Portarias) on the gear and trip characteristics according to gear type

| Gear type | Gear characteristics | Trip characteristics |
|---|---|---|
| **Gill- & Trammel nets** | No. 1102-H/2000, 22/11<br>*Recent Amendment:*<br>*No. 594/2010, 29/07* | No. 296/94, 17/05 |
| **Cage Traps** | No. 1102-D/2000, 22/11<br>*Recent Amendment:* | No. 296/94, 17/05 |

| | | |
|---|---|---|
| | *No. 255/2019, 12/08* | |
| **Shelter Traps (Pots)** | No. 1102-D/2000, 22/11<br>*Recent Amendment:*<br>*No. 230/2012, 03/08* | No. 296/94, 17/05 |
| **Longlines** | NO. 1102-C/2000, 22/11 | NO. 296/94, 17/05 |

### *1.4 Fishing for answers: Gears and Trends*

While it is possible to define métiers for a fleet using landing profiles, there are still many issues associated with this approach. One of these relates to the fact that the type of fishing gear being used is only available through logbooks, when available and correctly filled in. In a project aiming to find an approach to identifying métiers conducted on Spanish fisheries, Castro et al. (2011) used results obtained through a multivariate CLARA analysis of catch data along with fishing intention from interviews carried out at port, as fishers' behaviors cannot be determined solely from logbook data (Ulrich et al. 2012). To obtain missing information for a finer definition of métiers, questionnaires have been used to gather information on fishing activities including area, depth, duration, gear characteristics and target species (Machado et al. 2004); to collect landings information at port, as well as information regarding by-catch, such as seabird or cetacean interactions with fishing gear (Wise et al. 2007, Oliveira et al. 2015, Alexandre et al. 2022); to understand fishers' perceptions on trends of their target species (Gamito et al. 2016); and to collect local ecological knowledge, LEK, and attitudes towards conservation or management efforts of important commercial species (Braga et al. 2017, Silva et al. 2019).

Questionnaires can be used in fisheries to study the trends in catches over time, especially with the older fishers who have been fishing for multiple generations. Veneroni and Fernandes (2021) provide an example, where older fishers indicated changes in the seascape in waters (in the Northern Italian Ports: Cattolica, Rimini and Cesenatico) previously full of sea life, whereas this lack of abundance is all the younger fishers have come to know. This is an example of the "shifting baselines" phenomenon (Pauly 1995). This could be the result of overfishing, and fishing down the food chain, that then reduces the population as undersized individuals are caught (possibly prior to first maturity or during the recruitment phase) to compensate for loss of money (Garcia and Newton, 1994, Gladston et al. 2017). Interviews can also be carried out to understand the trends in fishing gear over time which could potentially be related to trends in target species. In some studies, it was concluded that fishers tend to switch gears either through the year or over many years not due to economic reasons, but rather species availability (Maynou et al. 2011, Roditi et al. 2018). If the abundance of a main target species is starting to decrease, the fishers in a multi-gear fleet have the opportunity to change gears at any given time, making it difficult to define métiers, unless this information is obtained directly from the fishers themselves, through questionnaires valuable to understand the impact of fisheries on the local environment.

The utility of the questionnaires as a validation method highly depends on how the interviews or questionnaires are conducted, which in turn depends on the relationship between the interviewer and the interviewee (Marchal 2008). A good relationship with the local fishers is a fundamental requirement; however, it is important to note that the fishers may answer questions according to what they know they are permitted to do by law, rather than how they are fishing at sea, which is why it is necessary to assure them that the information collected and analyzed is anonymized. These questionnaires can be differently structured, with open-ended or closed-ended questions, and both styles or methods have their pros and cons. Open ended questions can result in many answers and additional information, being thus necessary to define them within the scope of the needed data.

## *1.5 Let's go to Sea: Sampling onboard*

### *1.5.1 Mapping the Métier: Depth and Sediment*

Another issue when relying only on landing profiles and even on logbooks to define métiers, is the lack of GPS (Global Positioning System) information on fishing activities. GPS information is vital to understand the movements of fishing vessels, estimate fishing effort, identify the location, depth, and bottom types of fishing grounds, calculate the fishing pressure and the ecological impact of different fishing gears. Both AIS (Automatic Identification System) and VMS (Vessel Monitoring System) are currently used to track the vessel activity; however, georeferenced data is recorded only for larger vessels; in the case of VMS, only vessels above 15 meters (or 12 meters if undertaking trips of more than 24 h) are recorded; furthermore, the European Union has set 2h as the minimum frequency for VMS data, which makes it difficult or impossible to identify the different phases of a fishing trip, namely steaming, gear setting and gear hauling (Natale et al. 2015, Russo et al. 2016). Some vessels haul a single long net for hours, during which the VMS would gather some information on hauling; however, others have multiple small nets that only require 30 minutes to an hour of hauling time and even less time to set, resulting in no VMS data coverage. This is a concern because it is difficult to determine where the actual fishing is occurring based on such widespread data points. Without information on the precise location of the fishing operation, the depth, as well as the bottom type being impacted, is unknown. The bottom type in particular is an important information as it is known that gear impacts depend to a high extent of the seabed composition. For example, nets (gillnets and trammel nets) are known to cause disturbances when fishing on rocky bottom areas which serve as important habitats, with high biodiversity, pulling out corals and sponges (Fosså et al. 2022).

For smaller vessels without VMS or AIS, georeferenced data can be collected at sea during onboard sampling to track fishing events by means of a handheld GPS, marking the waypoints of navigation, setting, and hauling. This also allows the collection of more detailed information on events, namely the gear used and details on operations, that are not possible when using only VMS system. As previously mentioned, VMS data are collected at a low frequency, thus missing many fishing events. While VMS was created for fisheries control purposes by the control regulation (Council Regulation (EC) No. 1224/2009), AIS is a safety system created to prevent collisions by allowing for real time exchange of position and introduced by the International Maritime Organization (IMO), and is capable of transmitting at a rate ranging from 2 seconds to 3 minutes. However, this system must be turned on by the fishers, which they may not always do. Some of the pros include good fleet coverage and anti-tampering system in the VMS versus the high frequency of data of AIS (Russo et al. 2016).

### *1.5.2 Validation and Catch Composition*

Onboard observation is the ultimate step in the validation of métiers. Validation of the main target species, the fishing gear being used (fishing gear type, mesh size, gear length), and details on operations, including speeds and geographic location, can all be done through onboard observations. Onboard observation not only helps with métier validation but also gives a view of the fisheries impacts on the local environment. While the catch composition is generally recorded by onboard observers, including data on commercial by-catch, discards and reasons for discards, this is usually carried out in studies addressing a single métier, for instance within the framework of selectivity trials, and not to characterize fleet segments or métiers (Borges et al. 2001). Onboard observations are also especially important to understand local multi-gear fleet gear impacts such as habitat destruction, resulting from the removal of habitat-forming species such as corals and sponges (Figure 1.2).

**Figure 1.2.** A large piece of the coral *Dendrophyllia ramea* (left) and sponge *Axinella polypoides* (middle) and sponge *Cliona celata* (right) commonly caught in a small mesh gillnets and trammel nets (Photos by M. Szynaka).

### *1.6 Trammel Nets and By-catch*

Finally, with the métiers defined and some understanding about their impacts on the local environment, it will be possible to address by-catch and discard issues and propose solutions. Discards correspond to the catch fraction that is thrown back into the sea, generally comprising of undersized individuals (juveniles) of targeted species, as well as species with little to no economic value that live in the same environment as target species (Kelleher, 2005). Other discarding practices result from quota limitations, sex (e.g., female crustaceans during spawning season), and existence of body damage or parasites (Alverson et al. 1994, Hall et al. 2000, Catanese et al. 2018). The European Union (CEC 2007) and United Nations Sustainability Goals 2030 (RES/70/1) call for action to decrease by-catch and discarding practices, increasing public awareness for overfishing, as well as for the need to monitor fishing pressure and bottom impacts. Concerns are also raised regarding fishers working conditions, e.g. relating to the time spent on detangling nets and repairing damages (Metin et al. 2009, Gelcich et al. 2014, Szynaka et al. 2018).

Another issue that requires attention is habitat degradation resulting from the use of bottom-contact gear such as gillnets, trammel nets and traps. Previous studies report overfishing and by-catch with gillnets, with decrease of important species' populations, and negative impacts on coral ecosystems or the coral itself (Giraldes et al. 2015, Dias et al. 2020), proposing gear modifications (e.g., brindle lines with strapping bands) to reduce coral by-catch by reducing the contact of the gear with the corals (Paransa et al. 2017). When these habitats are negatively impacted by anthropogenic activities, the populations of the species that rely on these habitats are impacted as well, limiting the area in which they can live in and food availability (Dayton et al. 1995, Auster et al. 1996, Fogarty and Murawski, 1998). However, not all habitat-forming structures such as corals receive attention by policy makers, most likely due to the lack of information on the anthropogenic impact on these species.

Trammel nets in particular, are a type of fishing gear that is not species selective (Erzini et al. 2006), due to their particular design with three mesh panels instead of a single panel-(Gonçalves et al. 2007, 2008). Previous studies have attempted to decrease discards in trammel nets, involving the testing of inner panels of different mesh sizes (Olguner and Deval 2013); or the use of greca, which is a single panel net inserted between the leadline and the net panels (Metin et al. 2009, Aydin et al. 2013). This latter option was tested with good results in the Algarve within the framework of the MINOUW project in the cuttlefish trammel net métier, allowing by-catch reduction with significant decrease in the catch rates for sole when compared to the standard net (Szynaka et al. 2018). However, the catch rates of cuttlefish were not significantly affected, thus making it a workable solution for decreasing by-catch and discarding in this métier.

### 1.7 Main Objectives and structure of the thesis

The main objectives are:

Objective 1: Identifying fishing métiers.

- 1.1 To review the factors that can be helpful in identifying longline métiers.
- 1.2 To identify and characterize the different métiers of the multi-gear coastal fishery in the Algarve, Southern Portugal, based on vessel landing profiles.
- 1.3 To validate the métiers defined and describe the fishing operations through structured questionnaires with the fishers of this fleet at the ports in Southern Portugal.
- 1.4 To further validate this segmentation through onboard observation of fishing operations, catches and catch processing (i.e., landings and discarding), including the reasons for discarding, thereby contributing to improved assessment.

Objective 2: Mitigation of bycatch and impacts on benthic habitats.

- 2.1 To decrease invertebrate by-catch and reduce the impacts on the local habitat of trammel nets operated by this fleet, using a novel modified trammel net raised off the seabed.

## 1.8 Study Area

The study area includes a coastal area off the Algarve coast, Southern Portugal, comprising a total of eight fishing ports, where fishing generally occurs between approximately 50 and 400 m. The bottom type varies greatly, being coarser and rockier in the west area by comparison to the east, with higher fraction of sand and mud (Figure 1.3). The data available within the scope of the TECPESCAS project, provided by DGRM (*Direcção Geral de Recursos Naturais, Segurança e Serviços Marítimos*), includes landing sales and fleet characteristics for all the coastal vessels from the multi-gear fleet, including the ports of Sagres, Portimão, Albufeira, Lagos, Quarteira, Olhão, Sta. Luzia, and Tavira. The interviews were conducted in Sagres, Lagos, Portimão, Quarteira, Olhão, Sta. Luzia, and Tavira with various coastal fishers whose vessels are registered in these ports. The onboard sampling was carried out in Sagres, Portimão, Quarteira, Olhão, and Tavira. Finally, the selectivity experiments with the trammel net were carried out with a vessel registered and landing in Portimão.

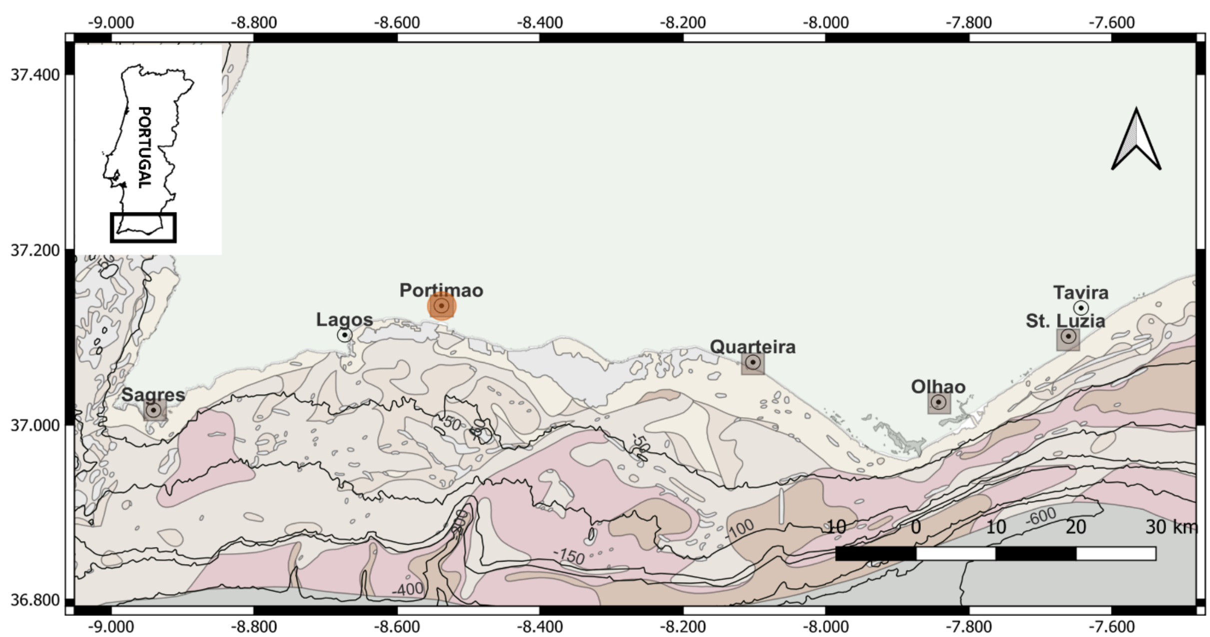



**Figure 1.3. Figure 1.3.** Map of the Algarve with areas in which interviews (black circles), onboard sampling (grey squares), and trammel net study (orange circle) occurred.

## 1.9 Thesis Structure

In **Chapter 1**, a general introduction is provided with the topics including the current definition of métiers and the methods used to describe them; what is known about métiers in the Portuguese fleet, the fishing gears, and regulations; and previous modifications in trammel nets.

In **Chapter 2**, objective 1.1, a review is presented to understand the concept of métier using longlines, which are relatively selective fishing gears and often used to target only a single species at a time. Furthermore, the review focuses on how certain fishing characteristics and operations will affect the target catch.

In **Chapter 3**, objective 1.2, was addressed: to identify and characterize the different fleet components (métiers) of the multi-gear coastal fishery in the Algarve, Southern Portuguese region based on vessel landing profiles. This was carried out through multivariate analysis, including clustering analysis and multivariate regression trees using the software R. A total of 11 métiers were described, describing the seasonal patterns and assumed fishing gears according to past studies.

In **Chapter 4**, objective 1.3, was to validate métiers previously identified and describe the fishing operations through structured questionnaires/interviews with the fishers of this fleet at the ports in Southern Portugal. The interviews were conducted in various ports during their respective auction hours by interviewing fishers, first with open ended questionnaires, that were used to validate gear type, fishing depth, and better understand the fishing operations, while a second round with close ended questions was carried out to validate the gear types and the fishing seasons.

**Chapter 5**, objective 1.4, was to further validate métiers through onboard observation of fishing operations, catches, landings and discards. This was carried out by charting six vessels from the multi-gear fleet willing to take observers onboard. Three trips were conducted in each of the vessels, during which all the catch was recorded and waypoints for fishing were noted on a GPS.

In **Chapter 6**, objective 2.1, of decreasing invertebrate by-catch and reducing the impacts on the local habitat in the trammel net segment of this fleet was addressed, using a new modified trammel net that is raised off the seafloor. Fishing was conducted off Portimão in the course of 16 fishing trips. Each individual caught was identified taxonomically, measured, and categorized as commercial or discard. The differences between the two nets were assessed with regards to commercial catch and discards/by-catch.

In **Chapter 7,** the segmentation and validation of métiers in this multi-gear fleet and their usefulness in fisheries management are discussed, as well as gear modifications and their importance in decreasing by-catch and protecting habitat loss.

In the final chapter, **Chapter 8**, conclusions for the entire thesis are presented and suggestions for future work made.

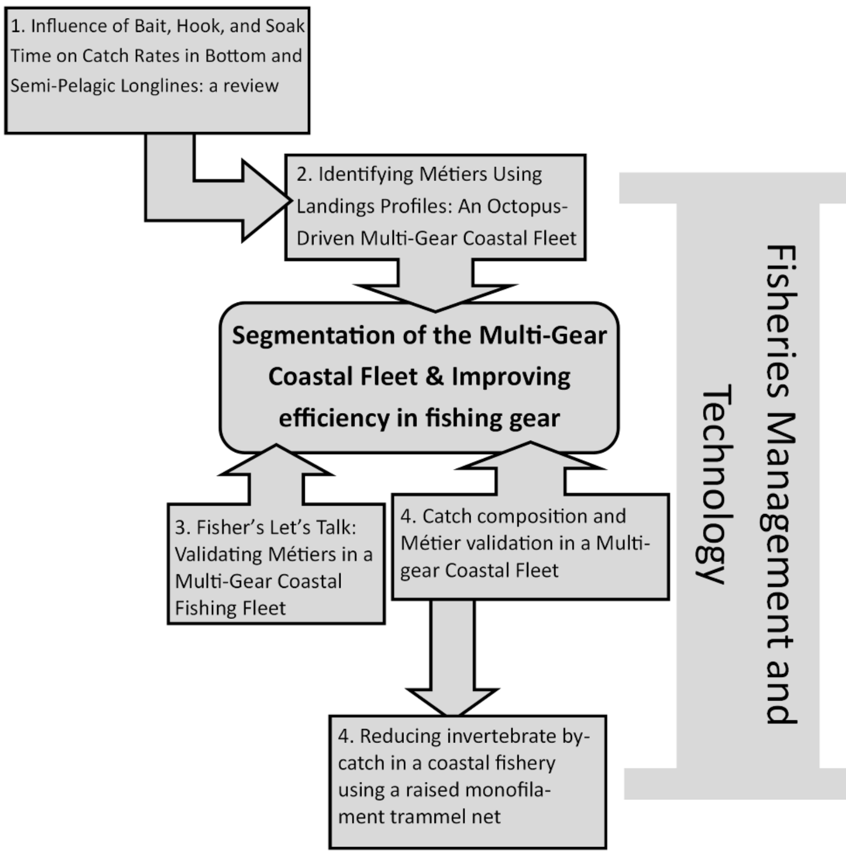



**Figure 1.4.** A schematic of the thesis structure.

**Chapter 2– A Review**

# Factors contributing to the identification of bottom and semi-pelagic longline métiers: a review.

Szynaka MJ, Erzini K, Løkkeborg, S. Factors contributing to the identification of bottom and semi-pelagic longline métiers: a review (In Prep for resubmission)

**2.1. Abstract:** A review was carried out with the aim of improving our understanding of factors that can be used to identify demersal and semi-pelagic longline métiers. The parameters discussed include bait (type and size), hook (type and size), and soak time. The review revealed that various longline métiers would benefit from using a) circle hooks, as the studies showed this hook type resulted in higher CPUE and catchability of targeted species in their respective fisheries, and b) larger hook sizes, which caught larger individuals. In general, alternative baits compared to those traditionally used resulted in higher CPUE, but there was no significant effect of bait type on size selectivity. The few studies that have been conducted on bait size showed that larger bait size would result in larger individuals. Studies reveal little to no effect of soak time in bottom longlines. This review contributes to future studies that aim to optimize longlining strategies and improve catch efficiency.

**Keywords:** longline efficiency, bait characteristics, hook characteristic, size selectivity, catch rates

## 2.2. Introduction

Catch efficiency, sometimes referred to as gear efficiency or catch power, is the probability of catching a specific species with a particular fishing gear within a certain area. It stands as an essential factor in sustainable fisheries management, involving both changes in stock and fishing gear evolution through the observation of catch rates (*CPUE* - or catch per unit effort, which is the catch divided by the total fishing effort in a given period), size and species selectivity (Arreguín-Sánchez 1996). Catch efficiency increases with improvements in fishing strategy and gear parameters as they relate to a specific métier; in longlines this includes the style of longline (demersal, semi-pelagic, etc.), setting and hauling time, soak time, the bait type and size, the depth, the number, shape and size of hooks, the use of mono- or multi-filament material, and the length of the snood or gangion.

There are many longline métiers (gear type used to target a specific species) globally, with varying gear characteristics adapted to the catch of specific target species. When operating semi-pelagic longlines, some common target species include hake (*Merluccius merluccius*), the black spot sea bream (*Pagellus bogaraveo*) and the bluemouth rockfish (*Helicolenus dactylopterus*) (Sousa et al. 1999, Erzini et al. 2001). Demersal longlines are commonly used to target a wide range of species including Atlantic cod (*Gadus morhua*), Patagonian toothfish (*Dissostichus eleginoides*), sablefish (*Anoplopoma fimbria*), Pacific halibut (*Hippoglossus stenolepis*), haddock (*Melanogrammus aeglefinus*), ling (*Molva Molva*), tusk (*Brosme brosme*) and various Sparids (Skeide et al. 1986, Bjordal 1987, Erzini et al. 1999, Erickson et al. 2000, Willis and Millar, 2001, Laptikhovsky and Brickle 2005, Milliken et al. 2009, Ingólfsson et al. 2017). Within the different types of longline, not all gear characteristics and strategies are standardized and therefore experimental trials can be used to evaluate gear modifications in order to improve catch rates and selectivity.

While longlines are less size selective than fishing gears like gillnets in that they tend to catch a larger size range of individuals, they are more likely to catch larger individuals and a lower species diversity (Bjordal, 1984, Engås et al. 1996, Huse and Soldal, 2000, Stergiou et al. 2002, Stergiou and Erzini, 2002, Erzini et al. 2003). Suuronen et al. (2012) reported a substantial number of advantages in longlines when compared to other gear types, including greater species selectivity and less impact on the environment. Depending on the characteristics of the longline, there is still the potential risk of catching protected species or important megafauna such as elasmobranchs, turtles and seabirds that can suffer from drowning or internal and external injuries, as well as cause damage to fragile seafloor fauna such as corals and sponges (Robertson et al.2006, Edinger et al. 2007, Parker and Bowden, 2010, Coelho et al. 2012, Peckham et al.2007).

The primary focus of this review will be on evaluating the hook and bait characteristics and soak time effects on catch efficiency, based on experimental fishing trials carried out globally on various longline métiers. Hooks and bait are the two most important parameters of longlines; the goal of the bait is to serve as an attractant and stimulate feeding behavior, causing the fish to ingest the bait, while the hook characteristics are responsible for the probability of hooking and preventing escape (Bjordal and Løkkeborg, 1996). Theoretically, an optimized soak time can result in higher catch rates and less by-catch and discarding. It is thus important to evaluate this effect in longlines and discuss the current state of knowledge based on previous studies. The review will cover by-catch reduction studies and how overall catch efficiency is affected in two different types of longlines, demersal and semi-pelagic. Furthermore, based on the current knowledge, possible improvements in longlines and their role in improving sustainability in these fisheries will be discussed.

## 2.3. Methodology

Studies that either focus on one of the characteristics or pairing two of the characteristics and their effects on catch rates and/or size selectivity were selected. Papers were searched for in various search engines including google scholar, science direct, web of science, followed by a snowball search in which reference lists of the articles found were reviewed. It was required that the article referenced one of the characteristics specified; that a field study was carried out; that the results yielded were regarding either size selectivity or catch rates, preferably both; and that they were within marine commercial (including artisanal) longline fisheries (thus not including recreational fisheries). The studies were grouped by location of fishing, the type of longline (semi-pelagic and bottom), and finally by target species. All of these contribute to a better understanding of the results if they were to be compared to one another as there is a higher likelihood of the gear being similar according to these characteristics and fishing practices. However, this review was not conducted to compare but rather to gather information.

The sections regarding hook type, hook and bait size are displayed in tables with seven columns: the area in which the study was carried out in, the respective characteristic, the métier (type of longline and the target species as stated by the authors), catch rates, size selectivity and the reference corresponding to the study. For the parameter bait type, an additional column was added to describe type of bait comparison (species, combination, artificial or manufactured). The tables were prepared in such a way as to simplify the compiled results of each study with a more in-depth explanation of the study and the important results regarding selectivity in the text. The section regarding soak time included a brief introduction of the importance of the fishing method regarding catch efficiency as few reviews have discussed this. Finally, the section regarding by-catch included some of the issues faced regarding the main characteristics, how they affect by-catch, and some current solutions including meta-analyses and reviews that go into greater detail regarding the subject.

A total of 31 publications regarding the characteristics of longlines were found in the global literature review for approximately 25 of commercial species conducted in various parts of the Atlantic, Pacific and Indian Oceans and a total of 12 seas, bays, and gulfs. The commercial species primarily focused on in the studies include various demersal fishes (such as Sparidae spp. and hakes (*Merluccius* spp.)

## 2.4. Hooks

Hook design is a key parameter in longline catch efficiency. In its most basic function, the hook holds the bait, penetrates the mouth of the individual, and ensures capture (Thomas et al. 2007). The hooking mechanism is studied to understand which characteristics of the hooks affect catch rates, species selectivity, and size selectivity (Huse and Fernö, 1990, Løkkeborg 1991, Woll et al.2001). The probability of hooking is correlated to the offset and the position of the point on the hook in relation to the snood or shank, which is either parallel or towards it (Huse and Fernö, 1990). The two factors that show strong effects on the catchability of certain species include the size and the shape of the hook, of which there is a great variety, including wide gap or round bent, EZ baiter, and "Rush" which evolved from the J hooks and Japanese tuna hooks.

### *2.4.1. Hook Shape*

Hooks come in a variety of shapes; hook shape strongly determines which species are caught and the sizes of the individuals (Figure 2. 1). Some of the standard hook shapes include circle hooks, that were developed in the Pacific and have a circular or oval shape with the point perpendicular to the shank and curving inwards (Hurum 1977; Johannes 1981). Circle hooks have been used as an alternative to the traditional J-hooks, that have a more exposed point that is parallel to the shank. The increase in hooking probability of circle hooks is due to their shape which causes a more effective transfer of energy from the snood to the point of the hook. This led to a general shift from J-hooks to circle hooks in the mid-1980s (Bjordal and Løkkeborg, 1996).

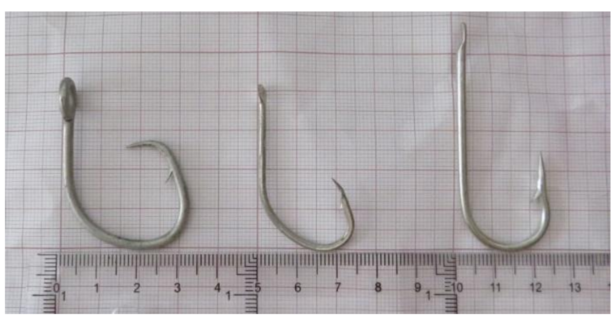



**Figure 2. 1** A circle hook, round hook, and a J-hook.

A review of studies comparing the influence of different hook types on the catch efficiency of different métiers is given in Table 2.1.

No significant differences were found in catch rates between circle and J-hooks among the dominant commercial catch *Lethrinidae* species in a bottom longline fishery off the Ra's Abu

Rasas, South of Masirah Island (Al-Qartoubi et al. 2019), while Moreno (1991) found that circle hooks were more efficient in retaining fish than the J-hook in a Chilean Patagonian toothfish fishery. In a bottom longline fishery targeting white grouper (*Epinephelus aeneus)*, results showed significantly higher catch rates with circle hooks than J-hooks (11.03: 8.51) (Echwikhi et al. 2015).

Another type of hook that has been tested is the EZ-baiter hook (Figure 2.2), which is in between circle and J-hooks and was created not only for efficiency but also to be used in mechanized handling. The EZ-baiter outperformed the Mustad Kirby for haddock (32: 14) and cod (168: 128) and Mustad Norway for haddock (21.0: 11.0) and cod (178.0: 146.0) in a bottom longline fishery (Skeide et al.1986). The EZ-Baiter hook also outperformed the Kirby Sea, J-hook with significantly higher CPUE of ling (63.0: 48.0) and tusk (90.0: 71.0); EZ-baiter also showed higher catch rates of ling (65.0: 42.0) in comparison to the tuna circle hook (Bjordal 1987).

Woll et al. (2001) found that when comparing the EZ to three versions of circle hooks in a Greenland halibut (*Reinhardtius hippoglossoides*) bottom longline, the EZ hook resulted in a CPUE of 281 kg/1000 hooks in comparison to the best performing circle hook which resulted in a CPUE of 435 kg/1000 hooks. Wide-gap hooks (a circular hook) and Rush hooks (where the shank is bent at an angle) had higher catch rates of cod and haddock in comparison to the Mustad Norway hook (J-hook) in a bottom longline fishery in Norway (Huse and Fernö, 1990).

Bjordal (1987) reported smaller individuals of ling and tusk with EZ-baiter compared to standard J-hooks and tuna hooks, respectively. Skeide et al. (1986) found no significant differences in size selectivity between the Mustad Norway and EZ baiter hooks in one experiment but, in another, larger individuals of cod were caught with the Mustad Kirby. Woll et al. (2001) found that the mean length of the halibut was significantly larger for circle hooks when comparing to the EZ hook. Echwikhi et al. (2015) found that circle hooks resulted in larger individuals of white grouper being caught in comparison to J-hooks. In the case of *Lethrinidae*, fewer smaller individuals were caught on J-hooks (Al-Qartoubi et al. 2019).

**Table 2.1.** Summary of studies describing influence of hook type on the catch efficiency of target species in various longline métiers.

| Area | Métier Type | Longline Target Spp. | Hook size | Catch rates | Size selectivity | Reference |
|---|---|---|---|---|---|---|
| Arabian Sea | Bottom | Smalltooth emperor (*L. microdon*), Spangled emperor (*L. nebulosus*), and Pink ear emperor (*L. lentjan*) (Dominant) | Circle hook 6/0 vs J-hook No. 6 | No significant difference between hook types | Larger Lethrinidae caught on J-hook | Al-Qartoubi et al. (2019) |
| Southern Pacific Ocean | Bottom | Patagonian toothfish (*D. eleginoides*) | Circle hook 14/0, J-hook No. 4 | Catch rates were higher with circle hooks | N.A. | Moreno et al. (1991) |
| Mediterranean Sea | Bottom | Grouper: Epinephelinae subfamily | Circle hook 12/0 vs J-hook 9/0 (0 ° offset both) | Catch rates of *E. aeneus* were higher with circle hooks | Larger Epinephelinae caught on circle hooks | Echwikhi et al. (2015) |
| Northern Atlantic Ocean | Bottom | Greenland halibut (*R. hippoglossoides*) | Circle hook 14/0, EZ hook 12/0 | Catch rates were higher with circle hooks | Larger *R. hippoglossoides* on circle hooks | Woll et al. (2001) |
| Barents Sea | Bottom | Cod (*G. morhua*), Haddock (*M. aeglefinus*) | [1] EZ-baiter 12/0, Mustad Kirby No.4; [2] Ez-baiter 12/0, Mustad Norway No.8 | [1,2] Catch rates of *G. morhua* and *M. aeglefinus* were higher with the EZ-baiter | [1] Larger *G. morhua* caught on Mustad Kirby [2] No significant differences between hook type | Skeide et al. (1986) |
| Norwegian & Barents Sea | Bottom | Cod (*G. morhua*); Haddock (*M.aeglefinus*) | [1, 2, 3] Wide gap 5/0, (J) Norway No. 6; [3] Rush; (J) Norway No. 6 | N.A. ([1] Catch rates of *G. morhua* were higher with wide gap [2] No significant differences between hook types [3] Catch rates of *G. morhua* and *M. aeglefinus* were higher with rush and wide gap hooks | N.A. | Huse and Fernö, (1990) |
| Norwegian Sea | Bottom | Ling (*M. molva*) and Tusk (*B. brosme*) | [1]EZ-Baiter Circle Hook 12/0, Kirby Sea, J-hook No 6; [2] EZ-Baiter Circle Hook 12/0,Tuna Circle Hook 11/0; [3]EZ-Baiter Circle Hook 12/0, Tuna Circle Hook 13/0 | [1] Catch rates of *M. molva* and *B. brosme* were higher with EZ baiters [2] No significant difference between hook types [3] Catch rates of *M. molva* were higher with EZ baiter | [1] Larger *M. molva* caught on J-hook[2] Larger B. bromse on Tuna circle hook [3] No significant differences between hook type | Bjordal (1987) |

*2.4.2. Hook Size*

Generally, the higher the number of the hook, the smaller it is in size (e.g., a No. 9 hook is smaller than a No. 5 hook, as seen in Figure 2.2b). Hook size varies widely across the many longline fisheries and the effects on catch rate varies by métier (Figure 2.2a). In general, smaller hooks are associated with higher catch rates and there is no clear effect on size selectivity (Bjordal 1989, Bertrand 1988), as seen in Table 2.2.

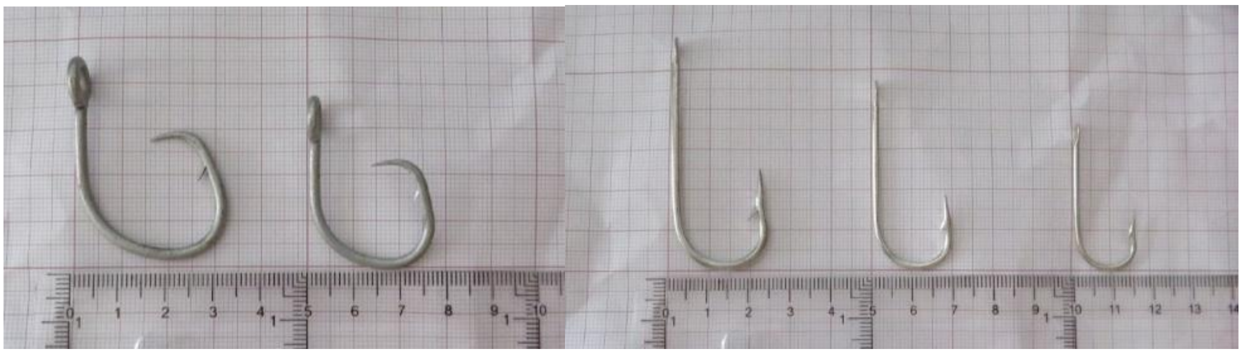


**Figure 2. 2 a.** 10/0 and 8/0 Mustad circle hooks. **2.2b.** Roundbent SIAPAL J-hooks No. 5, 7, and 9 (left to right).

Experimental hook size studies carried out in three different longline fisheries (two bottom longlines targeting white sea bream (*Diplodus sargus*, *Diplodus vulgaris*, *Lithognathus mormyrus, and Spondyliosoma cantharus*) and red sea bream (*Pagellus acarne* and *Pagellus erythrinus*), and one semi-pelagic longline targeting European hake in the Algarve region of Portugal (Figure 2. 3), resulted in a general decrease in catch rates with increase of hook size across the three different métiers (Erzini et al.1999, Erzini et al. 2001). Öztekin et al. (2020) found that the second smallest hook size (No. 8) was the most efficient, resulting in higher catch rates of hake. In the multi-species bottom longline fishery in the Southern Portuguese coast, the catch rates were significantly lower for the largest hook (No.11 – 109% larger than the No. 15 hook, the smallest hook) (Erzini et al.1996).

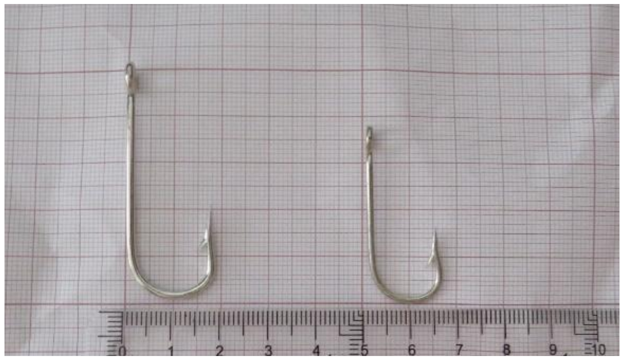


**Figure 2. 3** No. 7 and 9 (left to right) SIAPAL J-hooks used in Semi-pelagic longlines.

There were significant differences in catch rates for black spot sea bream, with the lowest catch rates on the smallest hook (Stella 2335 No. 12). In comparison, the bluemouth rockfish exhibited the highest catch rates with the No. 9 (second to smallest) hook compared to the No. 4 hook, or the largest hook (Sousa et al. 1999). McCracken et al. (1963) found that there were no significant differences in catch rates among hook size for cod, however haddock had the highest catch rates on the largest hook (No. 11). Ingólfsson et al. (2017) compared five sizes of EZ baiter hooks (ranging from 10/0 to 14/0, with the larger hooks 1.15, 1.33, 1.39, and 1.73 times greater in total length than the smallest hook 14/0) in the multi-species Icelandic long-line fishery and found that the smallest hook resulted in the highest catch rates of all the species (cod, haddock, tusk, ling, wolffish (*Anarhichas lupus*)). In the Southeastern Black Sea, the catch rates of whiting (*Merlangius merlangus*) increased with increasing hook size (Ari and Balik, 2021). In the Yucatan Peninsula, there were also no significant differences in catch rates of red grouper (*Epinephelus morio*) between hook sizes (Brulé et al. 2015).

Mongeon et al. (2013) found that the No. 10 hook had the highest catch rate of Spotted Rose Snapper (*Latjanus gattatus*) (6.43), compared to both the No. 6 and No. 8 hooks (116% and 41% larger than No.10) with catch rates of 1.86 and 4.66. In an Alaskan halibut fishery, it was found the smallest hook size (13/0) resulted in the highest catch rates (Leaman et al. 2012). Higher catch rates of larger individuals of Australasian snapper (*Pagrus auratus*) were obtained with the larger No. 8 hook, 64% larger than the No.12 hook (Otway and Craig, 1993). Xu et al. (2021) found that catch rates of red tilefish (*Branchiostegus japonicus*) were highest with the smallest hook size and the middle-sized hook for yellowback seabream (*Dentex tumifrons*).

Hook size can also influence size selectivity. Otway and Craig (1993) found that the No.10 Mustad tuna hook (larger by 26.5%; using absolute size or product of the length and width of the hook) resulted in less undersized individuals (27% of total catch) than the smallest hook used, No.12 Mustad tuna hook, (42% of total catch) for Australasian snapper (*Pagrus auratus*). Öztekin et al. (2020) also found that the largest hook (No. 6) resulted in the largest individual optimum catch lengths. The largest individuals of red grouper (*Epinephelus morio*)were caught on hook No. 13/0 (the largest hook which is 54.1% larger than the smallest hook: No. 11) (Brulé et al. 2015).

In the Azores semi-pelagic longline fishery, the largest individuals of black spot sea bream and the bluemouth rockfish were caught on the No. 6 and No. 4 hooks, respectively, in comparison to the smaller No. 12 and 9 (Sousa et al. 1999).

Mongeon et al. (2013) reported that the Mustad J-style No. 6 hook resulted in an increase in size (mean total length) of spotted rose snapper individuals in comparison to the No.10 (the smallest hook tested). Ingólfsson et al. (2017) reported that the mean length increased for wolffish and cod with hook size (although for cod this effect was in combination with increased bait size). McCracken et al. (1963) also found that both cod and haddock were larger when caught on the largest hook (No. 11). The size of whiting also increased with hook size in a Black Sea bottom longline (Ari and Balik, 2021). Lastly, Xu et al. (2021) reported that the largest red tilefish and yellowback seabream were caught on the largest hook. There was also little evidence of the effect of hook size on minimum size at capture in the multi-species bottom longline fishery in Southern Portugal (Erzini et al. 1996, Erzini et al. 1999, Erzini et al. 2001). There were also no differences in size of halibut and Patagonian toothfish in two bottom longline fisheries in the northeast Pacific and Chile (Moreno 1991, Leaman et al. 2012).

**Table 2.2.** Summary of the studies describing influence of hook size on the selectivity of target species in various longline métiers.

| Area | Métier Longline Type | Target Spp. | Hook size | Catch rates | Size selectivity | Reference |
|---|---|---|---|---|---|---|
| North-Eastern Atlantic Ocean | Semi-pelagic | Hake (*M. merluccius*) | No. 10, 9, 7, 5 | Catch rates were higher with No. 10 | No significant differences between hook size | Erzini et al. (2001) |
| Mediterranean Sea | Bottom | Hake (*M. merluccius*) | No. 9, 8 , 7, 6 | Catch rates were higher with No. 8 | Larger *M. merluccius* individuals caught on No. 6 | Öztekin et al. (2020) |
| Northern Atlantic Ocean | Semi-pelagic | Black spot sea bream (*P. bogaraveo*), Bluemouth rockfish (*H. dactylopterus*) | No. 12, 9, 6, 4 | Catch rates of *P. bogaraveo* were lower with No. 12; Catch rates of *H. dactylopterus* were higher with No. 9 | Larger *P. bogaraveo* caught on No. 6. Larger *H. dactylopterus* caught on No. 4 | Sousa et al. (1999) |
| North-Eastern Atlantic Ocean | [1,2] Bottom; [3] Semi-Pelagic | [1, 2] White and Red Seabream (Sparidae); [3] Hake (*M. merluccius*) | [1,2] No. 15, 13, 11; [3] No. 10, 9, 7, 5 | [1,2] Catch rates were higher with No. 15 [3] Catch rates were higher with No. 10 | No significant differences between hook size | Erzini et al. (1999) |
| North-Eastern Atlantic Ocean | Bottom | White Seabream (Sparidae) | No. 15, 13, 11 | Catch rates were lower with No. 11 | No significant differences between hook size | Erzini et al. (1996) |
| North-Western Atlantic Ocean | Bottom | Cod (*G. morhua*), Haddock (*M. aeglefinus*) | No. 17, 15, 14, 11 | No significant differences between hook sizes (*G. morhua*); Catch rates for *M. aeglefinus* were lower with No. 11 | Larger *G. morhua* and *M. aeglefinus* were caught with No. 11 | McCracken (1963) |
| Northern Atlantic Ocean | Bottom | Cod (*G. morhua*), Haddock (*M. aeglefinus*), Tusk (*B. brosme*), Ling (*M. molva*), Wolffish (*A. lupus*) | No. 10/0, 11/0, 12/0, 13/0, 14/0 | Catch rates for all species were higher with 10/0 | Larger *G. morhua* and *A. lupus* with hook size | Ingólfsson et al. (2017) |
| South-Eastern Black Sea | Bottom | Whiting (*M. merlangus*) | No. 10, 8, 6, 4, 2 | Catch rates of *M. merlangus* were higher with no. 2 | Larger *M. merlangus* with No. 2 | Ari and Balik (2021) |
| Gulf of Mexico | Bottom | Red Grouper (*E. morio*) | 11/0, 12/0, 13/0 | No significant differences between hook sizes | Larger *E. morio* caught on No. 13/0 | Brulé et al. (2015) |
| Northern Pacific Ocean | Bottom | Spotted Rose Snapper (*L. guttatus*) | No. 10, 8, 6 | Catch rates were higher with No. 10 | Slight increase in mean total length for No.6 | Mongeon et al. (2013) |

| | | | | | | |
|---|---|---|---|---|---|---|
| Southern Pacific Ocean | Bottom | Patagonian toothfish (*D. eleginoides*) | No. 4,3 | N.A. | No significant differences between hook size | Moreno et al. (1991) |
| Tasman Sea | Bottom | Snapper (*P. auratus*) | No. 12, 10, 8 | Catch rates of legal size were higher with Hook No. 8 & 10 | Larger *P. auratus* individuals caught on No. 8 | Otway and Craig (1993) |
| Eastern China sea | Bottom | Red tilefish (*B. japonicus*), Yellowback seabream (*D. tumifrons*) | No. 15, 13, 11 | Catch rates of *B. japonicus* were higher with No. 15, Catch rates of *D. tumifrons* were higher with No.13 | Larger *B. japonicus* and *D. tumifrons* with No.11 | Zu et al. (2021) |

## 2.5 Bait

Bait varies globally across specific longline fisheries with the most important characteristics being smell, taste and physical strength. Løkkeborg et al. (2014) previously noted that the bait needs to release an odor or attractant to induce food searching behavior over several hours, and the taste, texture, and size are key in luring the fish and result in it being hooked. Commonly used teleost bait species include mackerel (e.g. Atlantic Chub mackerel (*Scomber japonicus* Atlantic mackerel- (*Scomber scombrus*) and sardinellas and sardines (e.g. Round sardinella - *Sardinella aurita,* European pilchard - *Sardina pilchardus*). Bivalves such as razor shell clam (*Ensis siliqua*) are also used in some longline fisheries for demersal species (Erzini et al. 1996, Coelho et al. 2003, Barcelona et al. 2010).

The use of alternative species, different sizes, and manufactured baits are beginning to improve catch efficiency and provide cost effective solutions for bait issues in various longline métiers (Table 2.3). Species such as the European sardine are not only caught for consumption but also for bait and despite fisheries regulations, sardines are still exploited at levels beyond their maximum sustainable yield (Monteiro 2017). Other common baits that are also consumed by humans include mackerel and squid, and thus prices continue to increase, making manufactured or alternative bait ever more necessary and desirable (Løkkeborg et al. 2014).

### *2.5.1. Bait Type*

#### *2.5.1.1. Alternative Species and Combination*

A non-significant loss in efficiency was observed when using chopped Atlantic herring compared to the traditional whole European sardine, when targeting European hake in the Gran Sole banks (Sistiaga et al. 2018). Combining common bait types has resulted in increased catch rates in some fisheries. Franco et al. (1987) reported higher catch rates of hake using a combination of filleted mackerel and whole sardine and higher catch rates of cod when using a combination of mackerel and squid, instead of using the traditional baits. On the west coast of Norway, fishers stated that a combination of mackerel and squid when targeting tusk and ling was more effective in comparison to either one used alone, although Bjordal (1983a) reported that squid was in fact the most effective bait in terms of catch rates. In a deep sea demersal longline fishery, a 25%

increase of CPUE for Greenland halibut occurred when using grenadier bait instead of squid (Woll et al. 2001).

Soykan et al. (2016) reported that when compared to the traditional sardine, a discarded cephalopod species *(Sepietta* spp.*)* resulted in increase of 45% of the total catch in weight and of 50% in numbers of *Sparidae* caught in the longline fishery in the Aegean Sea. Ari and Balik (2021) found that using squid increased catch rates of whiting in a bottom longline fishery in the South-eastern Black Sea. There were no significant differences in catch rates among bait types in a Chilean Patagonian toothfish fishery (Moreno 1991).

Larger halibut were caught with the fish bait in a demersal fishery as opposed to squid (Woll et al. 2001). Four of the aforementioned studies found that there were no significant differences in size of target species among bait types (Bjordal 1983a, Franco et al. 1987, Soykan et al. 2016, Ari and Balik, 2021).

*2.5.1.2 Alternative Bait: Manufactured and Artificial*

A form of alternative bait has included the use of by-products of a certain fishery. When comparing herring to manufactured bait made of pollack waste and herring, the manufactured bait resulted in the highest catch rates for sablefish and Pacific halibut in an Alaskan demersal longline fishery (Erickson et al.2000). In another study, Løkkeborg (1991) observed that when compared to natural bait, an alternative bait made from minced herring (*Clupea harengus*) in nylon bags resulted in higher catch rates of haddock (58%), tusk and ling, but had a negative effect on catch rates of cod. Løkkeborg (1990) found that the smallest-sized artificial bait (polyurethane foam impregnated with shrimp flavor) produced similar catch rates to natural bait of shrimp in a Northern Norwegian Atlantic cod fishery. In the Commonwealth of Massachusetts Cod Conservation Zone (CCZ), there were no significant differences in catch rates of haddock in bottom longlines among between baits including Norbait 700E (a binder added to fish and fish offal in a case), food grade herring, and clams (Pol et al. 2008).

While there was no significant difference in size for sablefish between bait types (herring and pollack waste variations), herring resulted in the capture of larger Pacific halibut (Erickson et al. 2000). In the cod fishery, Løkkeborg (1990) observed that larger artificial bait resulted in catches of significantly larger cod. In the multi-species demersal fishery, Løkkeborg (1991) observed larger individuals of cod were caught with hooks baited with herring in a nylon bag due to the clip used to close the bag increasing the general size of the bait. Pol et al. (2008) found that clams resulted in the highest catch rates of legal sized haddock in comparison to food grade herring and Norbait 700 E (a gelling agent/binder added to fish and fish offal extruded into a casing).

**Table 2.3.** Summary of the studies describing influence of bait type on the selectivity of target species in various longline métiers.

| **Area** | **Métier**<br>**Longline Type** | **Target Spp.** | **Bait Type** | **Bait Species** | **Catch Rates** | **Size selectivity** | **Reference** |
|---|---|---|---|---|---|---|---|
| Northern Atlantic Ocean | Bottom | Hake (*M. merluccius*) | Species | Sardine; Herring ; Pacific Saury; Squid; Mackerel | Catch rates for *M. merluccius* were higher using sardine and herring | N.A. | Sistiaga et al. (2018) |
| [1] Bay of Biscay ; [2] North Sea | [1] Semi-pelagic; [2] Bottom | [1]Hake (*M. merluccius*); [2] Tusk (*B. brosme*) | Combination | [1]Sardine; Sardine and Mackerel; [2] Mackerel; Squid; Mackerel and Squid | Catch rates for [1] *M. merluccius* and [2] *B. brosme* were higher using combination baits | [1] N.A. [2] No significant differences between bait type | Franco et al. (1987) |
| Norwegian Sea | Bottom | Tusk (*B. brosme*) & Ling (*M. molva*) | Combination | Mackerel; Squid; Mackerel and Squid(4:1) | Catch rates for *M. molva* and *B. brosme* were higher using squid | No significant differences between bait type | Bjordal (1983a) |
| Northern Atlantic Ocean | Bottom | Greenland halibut (*R. hippoglossoides*) | Species | Squid; Grenadier | Catch rates for *R. hippoglossoides* were higher using grenadier bait | Larger *R. hippoglossoides* caught with grenadier | Woll et al. (2001) |
| Aegean Sea | Bottom | Serranidae and Sparidae | Discard Species | Sardine; European razor clam; Cuttlefish | Sepietta spp account for half total Sparidae catch | No significant differences between bait type | Soykan et al. (2016) |
| South-Eastern Black Sea | Bottom | Whiting (*M. merlangus*) | Species | Squid, hose mackerel, chicken breast, whiting | Catch rates for *M. merlangus* were higher with squid | No significant differences between bait type | Ari and Balik (2021) |
| South-Eastern Pacific Ocean | Bottom | Patagonian toothfish (*D. eleginoides*) | Species | Salted common sardines, mackerel | No significant differences between bait types | N.A. | Moreno et al. (1991) |
| | | | | | | | |
| North-Western Atlantic Ocean | Bottom | Haddock (*M. aeglefinus*) | Manufacture d | Norbait 700E; Food grade Herring; Clams | No significant differences between bait types | Highest amount of legal sized *M. aeglefinus* caught with clams | Pol et al. (2008) |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Norwegian & Barents Sea | Bottom | [1]Tusk (*B. brosme*), Ling (*M. molva*), [2] Cod (*G. morhua*), Haddock (*M. aeglefinus*) | Manufactured | [1] Mackerel, Squid, Minced Herring in Nylon Bags; [2] Squid, Minced Herring in Nylon Bags | Catch rates for *B. brosme*, *M. molva*, and *M. aeglefinus* were higher with minced herring in nylon bag | Larger *G. morhua* were caught on bait in a nylon bag | Løkkeborg (1991) |
| Norwegian Sea | Bottom | Cod (*G. morhua*) | Artificial | Shrimp; Polyurethane foam impregnated with shrimp flavor | No significant differences between bait types | Larger *G. morhua* caught with larger artificial bait | Løkkeborg (1990) |
| Aialik & Resurrection Bay | Bottom | Sablefish (*A. fimbria*); Pacific Halibut (*H. stenolepis*) | Manufactured | Herring; Pollack Waste (1-5) | Catch rates were higher or similar with final waste manufactured bait | No significant differences between bait type for *A. fimbria*; Larger *H. stenolepis* caught with herring | Erickson et al. (2000) |

### *2.5.2. Bait Size*

The size of bait plays an important role in catch efficiency and size selectivity and is suggested to have an effect on species selectivity (Løkkeborg et al. 1989, Løkkeborg and Bjordal 1992, Johannessen et al. 1993), as seen in Table 2.4.

No difference in catch rates of tusk, ling, haddock, and most importantly cod, (Bjordal 1983b) were recorded when bait was reduced by 40-50%. Ingólfsson et al. (2017) reported that the larger bait (30 g versus 10 g of Pacific saury) resulted in higher catch rates of larger sized cod, tusk, ling and wolfish. However, it also resulted in 57% fewer haddock caught compared to the smaller bait. When using a plastic body on the hook to enhance the size of the bait, Løkkeborg and Bjordal (1995) found that there was no significant difference in catch rates of tusk and ling but, a decrease in catch rates of haddock. In the North Sea, it was found that using whole bait as opposed to chopped (specifically the sardine) resulted in higher catch rates of hake (Sistiaga et al. 2018).

Løkkeborg and Bjordal (1995) used a plastic body attached to the hook in order to increase the size of the bait; this resulted in less undersized haddock in comparison to hooks with just bait. Ingólfsson et al. (2017) reported that the larger bait resulted in larger individuals of all the species (cod, tusk, and wolfish) except for ling. Sistiaga et al. (2018) also found that larger bait, whole sardines, are more efficient for capturing larger sized hake than pieces of sardine.

**Table 2.4.** Summary of the studies describing influence of hook size on the selectivity of target species in various longline métiers.

| Area | Métier<br>Longline Type | Target Spp. | Bait Size | Catch Rates | Size Differences (Length) | Reference |
|---|---|---|---|---|---|---|
| Norwegian Sea | Bottom | Tusk (*B. brosme*), Ling (*M. molva*), Haddock (*M. aeglefinus*), Cod (*G. morhua*) | Reduced bait 40-50% | No significant differences between bait size | N.A. | Bjordal (1983b) |
| Barents Sea | Bottom | Tusk (*B. brosme*), Ling (*M. molva*) | Mackerel Bait, Hook with plastic body | No significant differences between bait size | No significant differences between bait size | Løkkeborg and Bjordal(1995) |
| North Atlantic Ocean | Bottom | Cod (*G. morhua*), Haddock (*M. aeglefinus*), Tusk (*B. brosme*), Ling (*M. molva*), Wolffish (*A. lupus*) | 10 g & 30 g Pacific saury | Catch rates were higher with larger bait (except *M. aeglefinus*) | Larger *G. morhua*, *A. lupus*, and *B. brosme* with 30 g bait | Ingólfsson et al. (2017) |
| North Atlantic Ocean | Bottom | Hake (*M. merluccius*) | Whole baits vs chopped baits (Sardine) | Catch rates for *M. merluccius* were higher with whole sardine | Largest *M. merluccius* caught with whole sardine | Sistiaga et al. (2018) |

## 2.6. Soak time

Woll et al. (2001) noted that there was no significant effect of soak time on CPUE of the Greenland halibut. In Tromsøflaket, Norway, results for soak time were similar, suggesting that other factors have a more important effect on catch and possibly mask the effects of soak time (Løkkeborg and Pina, 1997). A study in Sagami Bay, Japan, allowed to conclude that shorter soak times resulted in higher catch rates in bottom longlines and after two hours a decline in catch was observed (Ogura et al. 1980). Additionally, a research group in the Gulf of Mexico observed that in a commercial bottom longline fishery targeting red grouper, a soak time of less than one hour would result in minimal to no reduction in the target species catch rates (Foster et al. 2017).

## 2.7. Discussion

The review describes some key parameters that affect catch rates in semi-pelagic and bottom/demersal longline métiers targeting a variety of species worldwide. Choosing the longline type is an important step in the fishing strategy as it will determine the target species and their catch rates. Besides the main type of longline, other important aspects of longlining include choosing the appropriate bait, hook and soak time. The bait serves the purpose of attracting the targeted species, the soak time affects the strength of the baits' attractant potential over a certain period of time or loss of bait as well as the time for which deterioration or loss of the individual, and finally the hook serves the purpose of penetrating the targeted individual in a way that will hold the individual on the line until it is retrieved by the fishers.

As opposed to earlier studies, more recent studies have focused on multiple factors influencing catch rates, combining characteristics of hooks with characteristics of baits as well as varying soak times. These combinations of hook shape, hook size, bait type, bait size, and soak time can help identify métiers, reveal ways of improving species selectivity, size selectivity, and catch rates as well as ultimately contribute to better fisheries management (e.g., Woll et al. 2001, Ingólfsson et al. 2017, Sistiaga et al. 2018). It appears, however, that improvements are more likely to be fishery-specific rather than generalized, with changes succeeding in one fishery while failing in others.

The most important factor determining fishing operations among longlines is the target species, which will determine the type of longline used, the fishing depth, the fishing area, the best setting and hauling times, and the soaking time, among others. Some target species vary by area like cod and haddock (in the Northern seas of Europe) or sablefish and Pacific halibut (in the Northern Pacific), and despite being targeted by longlines, gear configurations will vary based on the fishing area and the fishing operations will vary as well (Løkkeborg 1991, Erickson et al. 2000). Erzini et al. (1996, 1999) exemplifies that even in a similar area (Southern Portugal), different longline configurations are necessary to target demersal species, Sparids, being targeted with bottom longlines, while hake are targeted by semi-pelagic longlines where the hooks are raised slightly off the bottom.

### *2.7.1 Catch rates*

According to the 7 articles, 12 experimental trials that were reviewed comparing the efficiency of hook type. There is evidence that the J-hook is less efficient than circle hooks, with higher reported catch rates with circle hooks, three of which were in longlines targeting groupers, emperors, halibut and the Patagonian toothfish, while in one study non-significant differences were reported. This is a result of the position of the point of the circle hook in relation to the line resulting in a stronger force by the hook point and thus an increase in hooking probability (Bjordal and Løkkeborg, 1996). Four of the studies resulted in higher catch rates of EZ-baiter hooks, and one study in which the Wide gap hook and Rush hook resulted in higher catch rates compared to tuna hooks and J-style hook, targeting cod, haddock, ling and tusk, and two of the publications showing no difference among hook types in one of the trials.

Of the 13 articles reviewed, totaling 15 experimental trials, regarding the effect of hook size on catch rates, in 11 studies it was concluded that smaller hooks resulted in higher catch rates, while two studies stated higher catch rates with the larger hook sizes, one study stated that larger hook sizes resulted in more legal sized target catch and one resulted in non-significant differences among the hook sizes. Smaller hooks in general have the potential to catch more individuals, with thinner wire that requires less force to penetrate the mouth cavity (Bjordal and Løkkeborg, 1996).

Studies conducted on the feeding ecology and stimulatory responses of target species can be used to find alternative baits that can be compared to traditional baits, potentially resulting in an increase in efficiency and a decrease in negative impacts. In the 11 reviewed research studies, totaling 12 experimental trials, while seven of the articles concluded that the alternative bait (be it another species e.g., grenadier for halibut, a new species combined with the traditional, e.g. sardine and mackerel for hake, or discards as bait) resulted in increased catch rates, and three studies reported no significant differences. There are a limited number of studies exploring the effects of bait size on catch rates. Four studies were reviewed, where two resulted in better catch rates using larger bait and two with non-significant differences among baits of different sizes.

The limitations of altering soak time do exist as some longline fisheries such as semi-pelagic longlines start hauling from the beginning of the line as soon as the fishers are done setting it. This does not prevent researchers from sectioning off the longline and observing the differences of the soak time on the species caught. Furthermore, hook timers can be useful in observing how long it takes for fish to begin interacting with the hooks and at what hour this would occur (Kerstetter and Graves, 2006). Soak time studies are still limited compared to bait and hook selectivity comparison studies but, as in all fishing gears, this parameter shows some apparent effects on catch efficiency. Both in pelagic and demersal longline fisheries there is an apparent peak time after which catch rates slow down, and therefore it would be important to conduct studies in longline fisheries where there is a possibility of changing the soak time. Soak time also serves as an important factor in assessing bait efficiency as the strength and rate at which bait releases its' attractant will depend on the soak duration (Erickson et al.2000).

*2.7.2 Size selectivity*

Optimizing the hook and bait will also be necessary to catch legal sized or larger individuals of the target species. Out of the five articles, or eight reviewed studies for hook type, three studies reported an increase in size of individuals with circle hooks, primarily larger grouper, and two of the studies resulted in no significant differences among hook type, with two experiments showing that J-hooks catch more individuals. One of the studies showed that larger individuals were caught when using the Mustad Kirby hook. In terms of hook size, six studies in this review described little to no size selection related to this parameter, while 10 articles concluded that larger hooks resulted in larger individuals. This would make sense as a larger hook would require the mouth gape of the individual to bite down on the hook and not eat around it.

Of the nine studies reviewed for bait type, two of the studies resulted in larger individuals with the traditional bait type while three of the studies resulted in larger individuals caught on the alternative bait and four studies showed no significant difference. A decrease in bait size can be positive both for the populations of the bait species as well as for the fishermen by decreasing costs, but it has the potential to increase undersized catch. Of the four studies reviewed, two resulted in the capture of larger individuals of target species with larger bait size. This may not always be the case, as Ménard et al. (2006) found that in nature, the maximum size of prey preferred was smaller than those predicted. If more undersized individuals are not caught with a decrease in bait size, then it could be considered an optimization of bait. Increasing the bait size resulted not only in increased catch rates but also in increased size selectivity in the reviewed articles.

## 2.8. Conclusion

In summary, this review described multiple semi-pelagic and demersal longline métiers and the parameters characterizing them. Hook and bait type have received more attention while others such as bait size and soak time, with effects in species and size selectivity as well as in catch rates, are not yet well studied in experimental fishing trials. While the individual characteristics of longlines have been shown to have an impact on catch efficiency, some of the studies reviewed focused on more than one parameter, often evaluating characteristics of the hook and the bait simultaneously, which is important for optimizing efficiency. Ultimately, researchers along with fishers will need to work together to decide if the positive effects of changing baits, hooks, and soak time would outweigh the negative implications for their respective longline métiers.

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# Chapter 3

## Identifying Métiers Using Landings Profiles: An Octopus-Driven Multi-Gear Coastal Fleet

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**Abstract:** The multi-gear coastal vessels in the Algarve (South Portugal) own licenses for various fishing gears. However, it is generally uncertain what gears they use, which is problematic as each individual gear is responsible for unique impacts on the resources and the environment. In this study, landing profiles identified for the multi-gear coastal fleet (2012–2016) were used as support in defining potential métiers using k-mean clustering analysis (CLARA) along with information from past studies on métiers. The results showed that more than 50% of the vessels were engaged in the octopus fishery year-round, using traps, while a small percentage (~13%) were entirely dedicated to clam dredging. In general, gillnets (21%) were used to target monkfish, hake and bastard soles, while trammel nets (6%) were used to target cuttlefish, with some vessels alternating the fishing gears (either seasonally or annually) according to target species. The method for the initial characterization of this fleet's métiers and its efficiency with limited data is discussed, as well as the utility of this segmentation in support of management advice.

**Keywords:** fishing métiers; landing profiles; multi-gear fleet; coastal fleet; fisheries management; Portugal

## 1. Introduction

The current European Common Fisheries Policy, which became effective from 1 January 2014, focuses on long-term sustainability. Emphasis is placed on a regionalized approach to fisheries management, with the establishment of fishery-based plans tailored to specific fisheries. Fisheries management using the single stock management approach is thus being progressively replaced by a fleet-based management approach, particularly important for multi-gear and multi-species fleets (CEC 2007). In mixed fisheries in particular, management decisions based on fleets and métiers can be more effective than using approaches designed for single-species stocks, such as Total Allowable Catches. The study of mixed-species fisheries' métiers is especially important for management when there are temporal changes in landing composition and abundances of commercial species due to environmental and fisheries-related factors (Erzini et al. 2005). In fact, the latter requires accurate tracking of stock fluctuations and reported landings and can lead to the well-known problem of "choke" species, when quotas for some species are exhausted quicker than for others, resulting in an increase in discards and incentivizing underreporting (Bastardie et al. 2008, Ulrich et al. 2001). Fleet-based management requires fleet segmentation, aiming at the definition of métiers, i.e., fishing operations characterized by similar exploitation patterns, targeting similar species using similar gear during the same time of year and/or area. The characterization of the different métiers, as well as of their impact on both the living resources and the ecosystems exploited (ICES 2017), is an important tool in assisting appropriate management decisions, contributing to the economic sustainability of the fisheries (Salas & Gaertner, 2004, Castro et al. 2011). In the Southern Portuguese multi-gear coastal fishing fleet, comprising vessels from 9 to 23 m in length, each vessel owns licenses for more than one gear, making it difficult to identify particular métiers within the fleet and assess biological and environmental fishing impacts. A high number of commercial species are landed by this fleet, from which only some are subject to formal assessment, resulting in TACs and quotas. The number of vessels and trips sampled by the National Biological Sampling Plan is very low, resulting in poor knowledge of the fleet dynamics, namely the existence of métiers and the fishing gear used. For this fleet, fisheries-dependent data are an important, alternative source of information in support of fisheries management. While fishing logbooks can potentially assist in the identification of métiers, they are mandatory only for vessels equal to or above 10 m in length, and they are not readily available for analysis (EC 2009). Electronic logbooks, on the other hand, are required for vessels equal to or above 12 m in length; however, vessels between 12 and 15 m absent from the port for less than 24 h are exempt from this obligation, which is the case for all vessels in this fleet belonging to this length interval (EC 2009). With logbooks available only for a limited number of vessels, most of the information on the stocks comes from landings and respective sales at auction.

Segmentation of this fleet requires an appropriate method based on the definition of landing profiles, corresponding to groups of landings with similar composition of target and by-catch species. In previous studies, métiers were identified through the definition of landing profiles, such as in the Western Mediterranean, where daily auction records (data on species landing weight and first sale value by vessel) have been analyzed through multivariate analysis for this purpose (Samy-Kamal et al. 2014, Katsanevakis et al. 2010a). Métiers can be time-limited, having a seasonal pattern related to the abundance of the target species, as was found by Palmer et al. (2017) within small-scale fisheries in Mallorca, with transparent goby (*Aphia minuta*) targeted in winter, cuttlefish (*Sepia officinalis*) in spring, spiny lobster (*Palinurus elephas*) in summer and dolphinfish (*Coryphaena hippurus*) in fall. When identifying métiers in Patraikos Gulf in Greece, Tzanatos et al. (2006) found that only two out of the 12 different métiers identified (one of which is considered the most important métier, targeting hake with gillnets), were active during most of the year, while the remainder were seasonal.

In the Algarve region, South Portugal, Borges et al. 2001 analyzed the catch composition onboard vessels of the coastal fleet, identifying multiple métiers, including the crustacean trawl fishery, targeting shrimps and Norway lobster (*Nephrops norvegicus*), the demersal purse seine fishery targeting sea breams (*Diplodus* spp. and *Pagellus* spp) and seabass (*Dicentrarchus labrax*), the pelagic purse seine fishery targeting small pelagics such as sardines (*Sardina pilchardus*) and the trammel net fishery targeting cuttlefish. Despite a considerable amount of existing knowledge for the multi-gear fleet derived from shortterm (1 to 2 years) gear selectivity and by-catch and discards projects, involving high costs (interviews of vessels' skippers and onboard observations), no studies are available aiming at the identification of métiers through fleet segmentation and identification of landing profiles. In fact, within this fleet, most vessels alternate between gears along fishing trips or even in the same trip, and gear changes occur over the years, adding complexity to the analysis.

In this study, landing profiles, along with knowledge from previous studies on defined métiers and fishing licenses, are used for the first time to identify potential métiers and their temporal dynamics in a multi-gear coastal fleet operating in southwestern Iberian waters, in the Algarve, South Portugal. The temporal fishing patterns are identified for the main species, followed by an attempt to assign fishing gears to the vessels in the study. The results are expected to contribute to improving the fleet-based, regional management of the multi-species coastal fisheries while using an effective and low-cost approach.

## 2. Materials and Methods

### *2.1. Data Collection*

The information analyzed included vessels' daily sales, fishing gear licenses and vessel characteristics from a total of 163 vessels of the coastal multi-gear fishing fleet, including 39 vessels below 10 m, 59 between 10 and 12 m, 49 between 12 and 15 m and 16 equal to or above 15 m in length, landing in the Algarve (South of Portugal). The data were provided by the Portuguese fisheries administration (Directorate-General for Natural Resources, Safety and Maritime Services—DGRM) for the period of 2012–2016, within the framework of the project

Mar2020 TecPescas (Tecnologia da Pesca e Seletividade, MAR2020 16-01-04- FMP-0010). All data were provided in an anonymized format, i.e., each vessel was assigned a code and no vessel names were included.

Logbooks obtained for 25 vessels included data on fishing gear, spatial information through the Vessel Monitoring System (VMS) data (coordinates for beginning and end of hauling), species landed and the respective biomass (in kg) and temporal information by date and hour.

*2.2. Data Analysis*

The analysis included 163 vessels using 50 pre-selected species that accounted for approximately 99% of the total weight in the original dataset, comprising a total of 297 species. The first step in the analysis was to identify landing profiles (LP) based on daily landing species composition. Landing profiles were identified by multivariate analysis (clustering of vessels based on their landings) (Katsanevakis et al. 2010a, Katsanevakis et al. 2010b, Hintzen et al. 2010]. A non-hierarchical classification technique, Clustering LARge Applications (CLARA— Kaufman & Rousseeuw, 1990), was applied, consisting of a partitioning algorithm (partitioning around medoids or PAM) that divides the dataset into k clusters, where k needs to be specified a priori. The K-means clustering algorithm is a method using random probability distribution by repeating clustering, allowing for a specific métier to be identified and assigned to a trip (Hartigan & Wong, 1979, Bastardie et al. 2010). 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 many times for optimal search, allowing k to vary between 2 and 30, using Euclidean distance. To define the ideal number of groups or clusters, k was chosen based on a quality index provided by the algorithm, the Average Silhouette Width (ASW, (Struyf et al. 1997); Table S1 in the Annex defines four different cluster categories based on ASW: strong, reasonable, weak, and unstructured.

The CLARA method was applied to analyze variations in the targeted species/métiers across the years and seasons, with each season being designated according to months (e.g., Spring–Month 3–5). The top three species and the percentage that they contributed in weight and value (kg and €) for each LP were defined, as well as the number of vessels and individual landings/trips, and the ASW and Silhouette class were identified for each cluster. Unstructured and weakly structured clusters were not considered as landing profiles in this study.

E-logbooks were examined in order to check for consistency regarding the number of trips and haul registered per vessel and the associated fishing gears, in order to decide whether they could be used in support of métier identification, as well as checking for missing data (e.g., hauling coordinates).

Multivariate regression tree (MRT) analysis implemented in the archived R package ‘mvpart 1.6.20 was used to evaluate the importance of different factors on the species caught (De’Ath, 2002). Each leaf was analyzed by the main factor and indicator species. The factors used for the analysis included Gear (FPO = trap, GTR = trammel net, GNS = gillnet, LLS = bottom longline and DRB = dredge), season (Fall, Spring, Summer and Winter) and Year (2012, 2013, 2014, 2015 and 2016). This resulted in a total of 2174 data points in the MRT analysis.

## 3. Results

### *3.1. Logbooks*

After analyzing the e-logbooks, the information was found to be very inconsistent. A single vessel accounted for most of the data inputs during several years, whereas other vessels only occasionally recorded the information from their landings, with as little as seven landings registered by one vessel. Furthermore, the quantity and quality of the information varied, with “0s” for the starting and finishing coordinates of the hauls, trip departure data and times, trip return data and times, port of departure and port of return.

### *3.2. Target Species*

A total of 9,423,901 kg in landings from 163 vessels and 50 species contributed to defining the nine k-mean clusters (CLARA) in Table 1. Four of the clusters were strongly structured, three were reasonably structured, and two were unstructured according to their SilClass (Annex Table S1). The number of vessels contributing to the clusters ranged between 14 and 113 and the number of trips (landings) between 1763 and 22,798.

**Table 1.** Cluster analysis in weight (Annex Figure S1) with the cluster ID, average silhouette width of the cluster (ASW), the silhouette class (SC; S = strong, in bold; R = reasonable; W = weak; U = unstructured), number of vessels (No. V), number of trips (No. T), total weight (in tonnes), average price (AP) in Euros, total value in Euros, the three top species (Spp) and the percentage (Spp%) that each species represented in total landings. (FAO Codes: BRB = Black seabream; COE = Conger eel; CTC = Cuttlefish; DON = Donax clams; FOR = Forkbeard; HKE = Hake; MKG = Thickback sole; MON = Monkfish; OCC = Octopus; RJC = Thornback ray; THS = Bastard soles; SBA = Axillary seabream; SCL = Catshark; SOL = Common sole; SVE = Striped venus clam; ULO = Surf clam).

| Clust ID | ASW | SC | No. V | No. T | Wt(t) | AP(€) | Value ($10^5$ €) | Spp 1 | Spp%1 | Spp 2 | Spp% 2 | Spp 3 | Spp% 3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1** | **0.85** | **S** | **31** | **2233** | **224** | **6.35** | **10.13** | **CTC** | **66** | **RJC** | **7** | **SOL** | **4** |
| 2 | −0.02 | U | 110 | 17,578 | 2288 | 6.05 | 128.3 | COE | 10 | HKE | 7 | FOR | 7 |
| 3 | 0.57 | R | 49 | 2477 | 575 | 4.52 | 18.46 | HKE | 74 | MKG | 5 | SCL | 5 |
| **4** | **0.79** | **S** | **34** | **2985** | **637** | **5.65** | **34.36** | **MON** | **75** | **RJC** | **3** | **HKE** | **3** |
| **5** | **0.95** | **S** | **113** | **27,798** | **4061** | **4.65** | **187.85** | **OCC** | **98** | **COE** | **1** | **BRB** | **0** |
| 6 | 0.68 | R | 27 | 1938 | 237 | 4.96 | 14.35 | THS | 45 | SBA | 8 | RJC | 7 |
| 7 | 0.68 | R | 20 | 4506 | 649 | 1.45 | 9.52 | SVE | 89 | ULO | 8 | DON | 3 |
| 8 | 0 | U | 14 | 1763 | 346 | 1.13 | 3.35 | ULO | 75 | SVE | 22 | DON | 3 |
| **9** | **1** | **S** | **18** | **2618** | **205** | **2.33** | **4.93** | **DON** | **93** | **SVE** | **4** | **ULO** | **2** |

Target species in strong clusters (ASW with 0.71 or above) were octopus (*Octopus vulgaris*: OCC), representing 98% of the total landings in cluster 5, with 113 vessels involved and a total of 27,798 trips; Donax clam (*Donax* spp.: DON), 93% in cluster 9, with 18 vessels and 2618 trips; monkfish (*Lophius piscatorius*; MON), representing 75% of the total landings in cluster 4, with 34 vessels and 2985 trips, and cuttlefish (CTC), for which 31 vessels contributed with a total of 2233 trips (cluster 1).

Reasonable clusters (ASW of 0.51–0.70) related to the striped venus (*Chamelea gallina*: SVE), representing 89% of the landings in weight in cluster 7, with 20 vessels and 4506 trips; to hake (cluster 3), with 49 vessels and 2477 trips, and to bastard soles (*Microchirus* spp.: THS), representing 45% of the landings in cluster 6, with 27 vessels and 1938 trips.

### *3.3. Yearly Trends*

Octopus (caught in traps) and the bivalve species Donax clams or wedge clams (caught with dredges) were the main species represented in strongly structured clusters for all five years (Table 2). Regarding octopus, over the five years, the number of vessels for this fleet rose from 64 to a maximum of 92 in 2015, while its average price dropped in 2013.

The number of trips and weight landed of octopus, however, decreased with each year following. The number of clam dredgers was stable and so was the average price. The striped venus clam, caught with dredges, was represented in strongly structured clusters from 2012 to

2015. Hake and monkfish, caught with gillnets, were represented in strongly structured clusters: hake in 2012 and 2013 with a decrease in the number of vessels, while monkfish was the main species represented in 2014 and 2015, with similar numbers of vessels in both years. The conger eel (*Conger conger*), caught with longlines, was the main species represented in strongly or reasonably structured clusters from 2012 to 2014, while the surf clam (*Spisula solida*), caught with dredges, and cuttlefish, caught with trammel nets, were the main species in similarly structured clusters in 2015–2016 and 2014–2015, respectively. Some of the target species were only present in reasonably and strongly structured clusters in a single year, such as the thickback sole (*Microchirus variegatus*) and the bastard sole, caught with gillnets in 2012.

**Table 2.** Outputs for yearly clusters (Annex Figure S2) with the cluster ID, average silhouette width of the cluster (ASW), the silhouette class (SC; S = strong, in bold; R = reasonable), number of vessels (No. V), number of trips (No. T), total weight in tonnes (in tonnes), average price (AP) in Euros, total value in Euros, the three top species (Spp) and the percentage (Spp%) that each species represented within the species (in quantity). (FAO Codes of primary species for reasonable and strongly structured clusters (Annex Table S2): BRB = Black seabream; COE = Conger eel; CTC = Cuttlefish; DON = Donax clam; HKE = Hake; MON = Monkfish; OCC = Octopus; RPG = Red porgy; SVE = Striped venus clam).

| Clust ID/Year | ASW | Sil Class | No. V | No. T | Wt(t) | AP(€) | Value ($10^5$ €) | Spp 1 | Spp% 1 | Spp 2 | Spp% 2 | Spp 3 | Spp% 3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2012 | | | | | | | | | | | | | |
| 2 | 0.51 | R | 28 | 822 | 76 | 4.35 | 3.94 | MKG | 40 | HKE | 25 | MAS | 4 |
| **4** | **0.73** | **S** | **30** | **476** | **103** | **4.20** | **2.84** | **HKE** | **81** | **SCL** | **4** | **MON** | **3** |
| **6** | **0.91** | **S** | **34** | **228** | **22** | **4.53** | **0.83** | **COE** | **45** | **OCC** | **36** | **BRB** | **7** |
| **10** | **0.97** | **S** | **64** | **4709** | **610** | **4.55** | **27.55** | **OCC** | **98** | **COE** | **1** | **FOR** | **0** |
| **11** | **0.76** | **S** | **13** | **250** | **20** | **4.56** | **1.23** | **THS** | **63** | **RJC** | **6** | **HKE** | **5** |
| **12** | **1.00** | **S** | **16** | **627** | **90** | **1.47** | **1.33** | **SVE** | **93** | **ULO** | **5** | **DON** | **2** |
| **13** | **1.00** | **S** | **13** | **482** | **29** | **2.38** | **0.70** | **DON** | **96** | **SVE** | **3** | **ULO** | **1** |
| 2013 | | | | | | | | | | | | | |
| **3** | **0.76** | **S** | **24** | **454** | **107** | **4.17** | **2.86** | **HKE** | **84** | **SCL** | **3** | **MKG** | **3** |
| **5** | **0.96** | **S** | **74** | **5370** | **1154** | **3.34** | **37.46** | **OCC** | **98** | **COE** | **1** | **BRB** | **1** |
| 7 | 0.58 | R | 20 | 571 | 115 | 5.85 | 5.76 | COE | 32 | BRF | 23 | FOR | 17 |
| **8** | **0.88** | **S** | **15** | **1015** | **128** | **1.49** | **1.89** | **SVE** | **86** | **ULO** | **10** | **DON** | **5** |
| **9** | **1.00** | **S** | **11** | **732** | **62** | **2.22** | **1.46** | **DON** | **89** | **SVE** | **6** | **ULO** | **5** |
| 2014 | | | | | | | | | | | | | |
| **2** | **0.79** | **S** | **15** | **414** | **58** | **6.10** | **2.30** | **CTC** | **77** | **RJC** | **6** | **OCC** | **3** |
| **4** | **0.91** | **S** | **17** | **729** | **161** | **5.63** | **8.60** | **MON** | **74** | **RJI** | **4** | **RJC** | **3** |
| 5 | 0.64 | R | 28 | 547 | 104 | 6.20 | 4.27 | COE | 44 | FOR | 24 | BRF | 14 |
| **6** | **0.92** | **S** | **79** | **6146** | **891** | **4.92** | **45.88** | **OCC** | **98** | **COE** | **1** | **FOR** | **0** |
| **7** | **0.84** | **S** | **16** | **1372** | **172** | **1.41** | **2.47** | **SVE** | **90** | **ULO** | **9** | **DON** | **1** |
| **8** | **1.00** | **S** | **16** | **410** | **34** | **2.37** | **0.83** | **DON** | **97** | **SVE** | **2** | **ULO** | **1** |
| 2015 | | | | | | | | | | | | | |
| 3 | 0.66 | R | 13 | 340 | 30 | 6.43 | 1.38 | CTC | 71 | SOL | 6 | RJC | 5 |
| **4** | **0.75** | **S** | **18** | **687** | **146** | **5.75** | **8.46** | **MON** | **74** | **JOD** | **3** | **HKE** | **3** |
| **5** | **0.96** | **S** | **92** | **6003** | **723** | **5.11** | **39.23** | **OCC** | **98** | **COE** | **1** | **FOR** | **0** |
| 7 | 0.60 | R | 14 | 695 | 160 | 1.10 | 1.76 | ULO | 55 | SVE | 45 | DON | 0 |
| **8** | **1.00** | **S** | **18** | **869** | **158** | **1.45** | **2.34** | **SVE** | **98** | **ULO** | **2** | **DON** | **0** |
| **9** | **1.00** | **S** | **16** | **432** | **38** | **2.47** | **0.95** | **DON** | **99** | **ULO** | **0** | **SVE** | **0** |
| 2016 | | | | | | | | | | | | | |
| **2** | **0.95** | **S** | **89** | **5439** | **666** | **5.23** | **37.07** | **OCC** | **97** | **COE** | **2** | **FOR** | **0** |
| **3** | **0.78** | **S** | **11** | **851** | **154** | **1.04** | **1.27** | **ULO** | **92** | **SVE** | **7** | **DON** | **1** |
| **5** | **1** | **S** | **15** | **499** | **32** | **2.46** | **0.80** | **DON** | **99** | **ULO** | **1** | **SVE** | **0** |

*3.4. Seasonal Trends*

Octopus, along with striped venus and Donax clams, were the main species represented in strongly structured clusters all year round (Table 3). Monkfish was the main species represented in either strongly or reasonably structured clusters in winter, spring and summer, hake in spring, summer and fall, and the surf clam in fall, winter and spring. The bastard sole and thickback sole were the main species represented in reasonably structured clusters in fall and winter, and the cuttlefish in winter and spring. The purple dye murex (*Bolinus brandaris*) and Norway lobster were the main species represented in strongly structured clusters in spring.

**Table 3.** Outputs for seasonal clusters (Annex Figure S3) with the cluster ID, average silhouette width of the cluster (ASW), the silhouette class (SC; S = strong, in bold; R = reasonable), number of vessels (No. V), number of trips (No. T), total weight (in tonnes), average price (AP) in Euros, total value in Euros, the three top species (Spp) and the percentage (Spp%) that each species represented within the species (in quantity). (FAO Codes of primary species for reasonable and strongly structured clusters (Annex Table S3): BOY= Spiny-dye murex; COE= Conger eel; CTC = Cuttlefish; DON = Donax clam; HKE = Hake; MKG = Thickback sole; MON = Monkfish; OCC = Octopus; THS = Bastard sole; SBG = Gilt-head seabream; SVE = Striped venus clam; ULO = Surf clam).

| Clust ID/Season | ASW | Sil Class | No. V | No. T | Wt(t) | AP(€) | Value ($10^5$ €) | Spp 1 | Spp% 1 | Spp 2 | Spp% 2 | Spp 3 | Spp% 3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Winter** | | | | | | | | | | | | | |
| 1 | 0.58 | R | 29 | 1133 | 121.69 | 6.17 | 6 | CTC | 61 | RJC | 9 | SOL | 7 |
| **4** | **0.95** | **S** | **15** | **186** | **48.80** | **5.04** | **3** | **MON** | **72** | **RJI** | **5** | **JOD** | **2** |
| 5 | 0.53 | R | 34 | 936 | 134.40 | 5.03 | 8 | THS | 49 | RJC | 9 | HKE | 6 |
| **6** | **1.00** | **S** | **88** | **6290** | **1090.88** | **4.66** | **49** | **OCC** | **98** | **COE** | **1** | **BRB** | **0** |
| **7** | **1.00** | **S** | **12** | **483** | **93.08** | **1.09** | **1** | **ULO** | **87** | **SVE** | **10** | **DON** | **3** |
| **8** | **1.00** | **S** | **16** | **545** | **69.83** | **1.50** | **1** | **SVE** | **81** | **ULO** | **12** | **DON** | **6** |
| **9** | **1.00** | **S** | **18** | **979** | **78.42** | **2.31** | **2** | **DON** | **92** | **SVE** | **5** | **ULO** | **3** |
| **Spring** | | | | | | | | | | | | | |
| 1 | 0.56 | R | 24 | 1016 | 103.83 | 6.42 | 4.39 | CTC | 68 | RJC | 8 | OCC | 4 |
| 3 | 0.69 | R | 25 | 1122 | 277.09 | 5.71 | 13.30 | MON | 81 | RJC | 3 | RJI | 3 |
| **6** | **0.75** | **S** | **30** | **464** | **93.47** | **4.67** | **2.90** | **HKE** | **68** | **SCL** | **9** | **MON** | **5** |
| **10** | **1.00** | **S** | **6** | **47** | **1.94** | **45.94** | **0.93** | **NEP** | **100** | | | | |
| **11** | **0.78** | **S** | **7** | **164** | **4.20** | **9.26** | **0.46** | **BOY** | **69** | **CTC** | **7** | **TOE** | **7** |
| **14** | **0.98** | **S** | **99** | **7580** | **1148.61** | **4.87** | **54.65** | **OCC** | **98** | **COE** | **1** | **BRB** | **0** |
| **17** | **0.85** | **S** | **10** | **187** | **34.91** | **1.15** | **0.31** | **ULO** | **87** | **SVE** | **11** | **DON** | **2** |
| **18** | **1.00** | **S** | **16** | **568** | **67.88** | **1.47** | **1.01** | **SVE** | **97** | **ULO** | **3** | **DON** | **1** |
| **19** | **0.79** | **S** | **17** | **599** | **39.29** | **2.38** | **0.97** | **DON** | **97** | **SVE** | **2** | **ULO** | **1** |
| **Summer** | | | | | | | | | | | | | |
| 2 | 0.67 | R | 29 | 1091 | 180.98 | 6.17 | 11.12 | MON | 64 | HKE | 6 | RJC | 4 |
| **3** | **0.99** | **S** | **99** | **7660** | **1020.07** | **4.61** | **47.93** | **OCC** | **97** | **COE** | **2** | **BRB** | **0** |
| 4 | 0.63 | R | 29 | 898 | 273.38 | 4.36 | 7.74 | HKE | 83 | MON | 4 | SCL | 4 |
| **6** | **1.00** | **S** | **20** | **1992** | **292.67** | **1.51** | **4.41** | **SVE** | **97** | **DON** | **2** | **ULO** | **2** |
| **7** | **0.75** | **S** | **18** | **368** | **32.34** | **2.32** | **0.78** | **DON** | **93** | **SVE** | **4** | **ULO** | **2** |
| **Fall** | | | | | | | | | | | | | |
| **4** | **0.84** | **S** | **38** | **436** | **117.42** | **4.17** | **3.59** | **HKE** | **72** | **MON** | **4** | **SCL** | **4** |
| 5 | 0.57 | R | 22 | 683 | 64.01 | 4.46 | 3.92 | MKG | 45 | HKE | 24 | SBA | 4 |
| **9** | **0.98** | **S** | **99** | **6240** | **794.96** | **4.45** | **36.19** | **OCC** | **98** | **COE** | **1** | **FOR** | **0** |
| 10 | 0.66 | R | 11 | 346 | 70.19 | 1.20 | 0.82 | ULO | 50 | SVE | 45 | DON | 4 |
| **11** | **1.00** | **S** | **18** | **911** | **111.29** | **1.47** | **1.65** | **SVE** | **93** | **ULO** | **5** | **DON** | **2** |
| **12** | **0.91** | **S** | **12** | **334** | **55.64** | **0.98** | **0.45** | **ULO** | **94** | **SVE** | **5** | **DON** | **1** |
| **13** | **1.00** | **S** | **18** | **648** | **51.27** | **2.38** | **1.25** | **DON** | **95** | **SVE** | **4** | **ULO** | **1** |

*3.5. Factors Influencing Landings*

Figure 1 shows the results of the MRT analysis conducted with the commercial species biomass (kg), which confirmed that "Gear" was the main variable explaining the landings. The best MRT had three splits. Landed species composition varied strongly across the four leaves, with octopus defining the first split against the remaining species, while in the second split, the bivalves were separated from fish species, and in the last split, different fish species were separated according to different fishing gears. In terms of fishing gears, the left leaf on the initial split was explained by octopus traps (FPO), with 52% of the points. The remainder of the gears were represented (dredges, gillnets, trammel nets and longlines) on the right-hand side of the initial split, for which hake, the thornback ray and forkbeard were the indicator species. The third split was between dredges, on one hand, and nets and longlines, on the other. Dredges were represented on the left-hand side, for which the three main clams were the indicator species, while on the right-hand side, the nets and longlines were represented, with the indicator species being hake, forkbeard and thornback ray. In the final split below, the left-hand side corresponds to trammel nets and longlines, with the indicator species being conger eel, forkbeard and cuttlefish, while on the right-hand side, gillnets are represented, associated with hake, axillary seabream and monkfish.

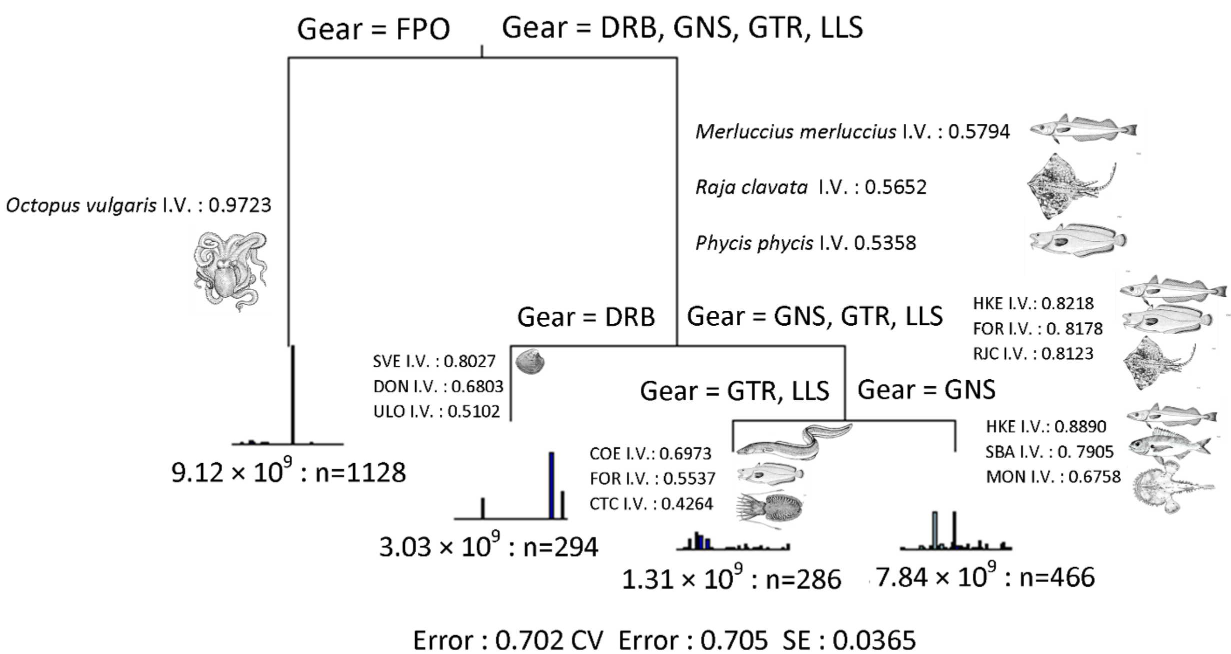


**Figure 1.** Multivariate regression tree (MRT) with 3 splits and 4 leaves, where gear type is the strongest factor, with the indicator species (I.V. indicator values), the percentage of deviance explained and the number of vessels representing each node. (FPO = Traps; DRB = Dredges; GTR = Trammel nets; GNS = Gillnets; LLS = Longlines)

*3.6. Métiers*

When cross-referencing all the results and previous studies in order to propose the métiers (Table 4), it was found that: (a) cuttlefish is targeted with trammel nets specifically in winter and spring (Erzini et al. 2001, Erzini et al. 2006, Guerra 2006, Szynaka et al. 2018), (b) hake with gillnets (80 mm mesh size) from spring through fall (Fonseca et al. 2005); (c) monkfish with gillnets (100 mm and higher) from winter through summer (Azevedo 2995), (d) bastard soles with gillnets usually in winter, (e) octopus with traps (including pots) all year round (Cardoso et al. 2015), and (f) the striped venus clam and Donax clams with dredges also all year round, while the surf clam is targeted from fall through spring (Gaspar et al. 2015).

**Table 4.** Métiers proposed including the main species, the gear type and the season in which they are targeted.

| Métiers | Fall | Winter | Spring | Summer |
|---|---|---|---|---|
| Monkfish gillnet (MONGNS) | | ■ | ■ | ■ |
| Hake gillnet (HKEGNS) | ■ | | ■ | ■ |
| Octopus traps (OCCFPO) | ■ | ■ | ■ | ■ |
| Striped venus dredge (SVEDRB) | ■ | ■ | ■ | ■ |
| Donax clam dredge (DONDRB) | ■ | ■ | ■ | ■ |
| Surf clam dredge (ULODRB) | ■ | ■ | ■ | |
| Cuttlefish trammel net (CTCGTR) | | ■ | ■ | |
| Norway lobster traps (NEPFPO) | | | ■ | |
| Purple-dye murex trammel net (BOYGTR) | | | ■ | |
| Bastard sole gillnet (THSGNS) | | ■ | | |
| Thickback sole gillnet (MKGGNS) | ■ | | | |

"Lesser" yearly and seasonal métiers were identified, representing possible shifts in gears. Despite fishers having licenses for more than a single gear, they often do not use all the gears; rather, owning these licenses makes all fishing options available, allowing them to switch gears according to resource availability or seasonally. Four main species were represented in yearly and seasonal clusters, including the conger eel targeted with longlines, the thickback sole, which was present in both yearly and seasonal clusters, targeted with gillnets in fall (Table 4), the purple dye murex targeted with trammel nets and the Norway lobster targeted with traps, both in spring.

## 4. Discussion

Single-species or single-stock management based on Total Allowable Catches (TACs) and regulation of fishing mortality (F) has, in many cases, failed to achieve the intended management goals and conservation benefits, mainly because of the multi-species nature of most fisheries, where it is difficult to control total catches and constrain fishing mortality (Rätz et al. 2007, Ulrich et al. 2012) Discarding and misreporting of landings when TAC allocations are exceeded are problems associated with TAC-based management (Rätz et al. 2007). Fleet- or métier-based management is a better way of controlling fishing effort and fishing mortality, reducing discards and is a pathway to multi-species and ecosystem-based fisheries management (Ulrich et al. 2012, Gascuel et al.2012). Furthermore, fleet or métier-based management is a means of promoting the use of more selective fishing gear (Rätz et al. 2007), such as the use of creels rather than trawls to target high-value crustaceans such as Norway lobster, and improved management through the reallocation of fishing effort (Leocádio et al. 2012). The implementation of fleet-based or métier-based management is contingent upon the correct identification of the different fleet or métier components. In this study, we focused on the identification of métiers in the multi-species, multi-gear coastal fisheries of the south of Portugal.

This study was carried out on a selected group of vessels fishing species that fall under Category 5 (stocks with only landings data provided by the national auction network/ DGRM) (ICES 2012). As only fishing licenses were provided, there was little or no information on which gears were actually used to target the different species, as well as on the fishing strategy or the métier. Previous studies have used principal component analysis (PCA), hierarchical agglomerative clustering (HAC), hierarchical clustering analysis (HCA) and other multivariate methods. The CLARA method applied in this study was purposely developed to analyze large datasets, as is the case in the present study (Kaufman & Rousseeuw, 1990), resulting in significant and consistent clusters in terms of target species and landing composition (Castro et al. 2011, Deporte et al. 2012).

Métiers can be used as a baseline in our understanding of fishers' behavior through the characterization of individual trips and fishing pressure on certain species, giving fisheries managers additional insight for informed advice (Parsa et al. 2020). In the present study, the initial cluster analysis resulted in the definition of seven strongly or reasonably structured clusters, providing the foundation to define potential métiers using gear type, which was found to be the strongest explanatory variable for these métiers. Clusters classified as unstructured comprised two métiers, characterized by having a "mixed" composition, with no clear target species.

Seven of the 11 métiers exhibited seasonality, including the four gillnet métiers targeting hake, monkfish, bastard soles and the thickback sole, two trammel net métiers targeting cuttlefish and the purple dye murex and one métier targeting Norway lobster with traps. Yearly shifts are apparent within this fleet, with some vessels switching between hake and monkfish as target species caught with gillnets. In 2012 and 2013, hake was the main species in strongly structured clusters and landed by 30 and 24 vessels, respectively. Moreover, 14 of the forementioned vessels made a switch and were landing monkfish in 2014 and 2015, years in which hake was not a main species in a strongly or reasonably structured cluster. This could be a result of the implementation of the southern hake and Norway lobster recovery plan in 2008 (Council Regulation (EC) No 2166/2005), with the progressive reduction of the fishing effort and temporary cessation of the activity for vessels affected by this plan. Cuttlefish also appeared to be an important species in the same year as monkfish, being targeted seasonally by this fleet in winter and spring. Interestingly, nearly 50% of the vessels that were targeting hake in 2012 were targeting monkfish and cuttlefish in 2014, with approximately 30% of these vessels targeting both species, possibly indicating seasonal gear switching. Cuttlefish are usually targeted in fall and winter with trammel nets, as well as in spring (Guerra 2006, Szynaka et al. 2018), while monkfish are targeted mostly year-round with gillnets, with the exception of January and February, months during which monkfish can represent only a small percentage of the total catch (Ordinance 315/2011).

The number of vessels operating with dredges remained similar across the years and seasons. It is clearly a very strong fishery, which was further confirmed by the MRT, targeting exclusively bivalve species including the striped venus, surf clam and Donax species, which are targeted year-round, with the exception of a closure that occurs between May 1 and June 15. However, one of the identified clusters was classified as unstructured, dominated by *Spisula solida* with a relatively high percentage of *Chamelea gallina*. This is most likely due to the fact that the two species are sympatric and therefore neither of them is considered the main target species [36].

Octopus was consistently in strong clusters among the years and seasons as well as being the only species clearly separated from the remaining based on the gear used, since it is exclusively targeted with traps. However, the number of vessels dedicated to the octopus fishery has increased over the years. It is clear that these vessels were in fact actively using traps to target octopus, with increasing effort. This is one reason for monitoring these shifts over time and understanding how they are impacting these populations. Octopus is an extremely important species in economic terms

(Sonderblohm et al. 2017), with large quantities landed and a generally high first sale price. Setting, baiting and hauling traps requires less effort, as opposed to longlines and nets, and the individuals are more easily retrieved, as opposed to nets, where fish and invertebrates either need to be untangled, which is time consuming, or ripped out, which implies costly repair to nets. Therefore, it seems reasonable that more vessels are leaning towards the use of traps. The octopus fishery in Portugal is highly regulated (DGRM, (Pita et al. 2015, Sonderblohm et al. 2016)), including a fishing ban during weekends, minimum distance of at least one mile from the coast for vessels larger than 9 m, maximum number of traps per vessel and a minimum landing weight requirement of 750 g. Despite these restrictions, there is a high abundance of octopus in the Algarve, making it a preferential target species for a large part of the fleet and thus resulting in an increase in effort.

Several studies have evaluated the relationships between landings, landings per unit effort, species composition and environmental and fisheries-related explanatory variables in Portugal (Erzini 2005, Correia & Smith 2003, Teixeira & Cabral, 2009, Teixeira et al. 2014, Teixeira et al. 2016, Gamito et al. 2013, Gamito et al. 2015 and Bueno-Pardo et al. 2020). While fishing effort was found to be one of the most important factors (Erzini 2005, Gamito et al. 2020), combinations of regional environmental variables associated with global change, including sea surface temperature (SST) and river runoff, were also found to be associated with the main trends (Erzini 2005,Teixeira & Cabral, 2009, Teixeira et al. 2014, Teixeira et al. 2016, Gamito et al. 2013, and Gamito et al. 2015). Thus, the shift in fishing effort towards the octopus might be influenced by alterations in environmental conditions, or most probably by the decreasing abundance of many commercial fish species. Indeed, since the late 1990s, total Algarve landings for all species (DGRM official auction data) have decreased steadily from a maximum of 37,414 t in 1998 to 11,846 t in 2017. During this period, while finfish landings have been in decline, octopus landings have increased in importance from 3.6% (1341 t) of the total biomass landed in 1998 to a maximum of 18.4% (3702 t) in 2013. Changes in the abundance of commercial finfish species and in species composition lead to changes in fishing strategies, highlighting the importance of the study of temporal changes in métiers for the improved conservation and management of coastal resources.

The eleven métiers defined in this study in terms of target species, gear type and season can be used in different ways to support fisheries management. Compliance with fishing regulations can be checked for species such as the monkfish, which defines a strong cluster in winter despite only being allowed to represent 3% of the total catch during this period. Implementing a sampling program for this fleet is of the utmost importance, allowing us to monitor fishing activities over time and create a management plan including time or depth restrictions, or gear replacement. Using smaller mesh trammel nets to target cuttlefish and bastard soles, which are generally targeted during winter, can be a useful measure in such a management plan. It is recommended that there should be greater awareness, demand and enforcement regarding the effective and rigorous completion of logbooks by the fishing captains, particularly with regard to the métier used in each fishing trip.

## 5. Conclusions and Further Developments

This study contributed to the definition of métiers, necessary for fleet-based management, when only landings data are available and logbook information is limited due to a portion of the fleet not meeting the necessary length or trip requirements. It also contributed with a less costly methodology in time and money and covered a longer time period compared to previous studies that were conducted through interviews with skippers and onboard observations. The analysis of the landings data was found to be a good alternative to detect fishing métiers and their dynamics over time. This information is of great utility in improving the design of sampling schemes in this fleet as well as in similar multi-gear fleets, which is the case of many Southern European fleets in the Mediterranean, where the number of vessels and trips sampled is very low and the exploited stocks are not subject to a formal assessment. The methods used here can contribute to improving fisheries management for the populations of the main species/stocks that are being targeted and possibly overexploited, when using these types of gears.

Due to the lack of information from logbooks, regular questionnaire surveys and onboard observations are recommended in the future, at the scope of a sampling program, using surveys and Local Ecological Knowledge (LEK) (González-Álvarez et al. 2016, Falsone et al. 2020).

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**Supplementary Materials:** The following are available online at https://www.mdpi.com/article/10.3390/jmse9091022/s1, Table S1. Range Silhouette Class (SC) and the interpretation, Figure S1. Clusters using quantity (kg) from landings data for the Algarve coastal multi-gear fishing fleet. FAO codes are defined in Annex Table S2, Figure S2. Clusters using quantity (kg) from landings data for the Algarve coastal multi-gear fishing fleet per year from 2012 to 2016. FAO codes are defined in Annex Table S2. The class, family, species (SPP), FAO codes (CodFAO) and the quantity (t) and value (10 5 €) per year, Figure S3. Clusters using quantity (kg) from landings data for the Algarve coastal multi-gear fishing fleet per year for winter, spring, summer and fall. FAO codes are defined in Annex Table S3. The class, family, species (SPP), FAO codes (CodFAO) and the quantity (q) and value (v) per season. (Win = winter; Spr = spring; Sum = summer; fall).

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J.M.S.G.; project administration, A.C., M.J.S. and J.M.S.G.; funding acquisition, A.C., M.J.S. and K.E. All authors have read and agreed to the published version of the manuscript.

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**Chapter 4**

# Fishers, Let Us Talk: Validating Métiers in a Multi-Gear Coastal Fishing Fleet

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**Abstract:** In the multi-gear coastal fleet in the Algarve (South Portugal), fishers own licenses for various fishing gears. However, they generally do not use all these licenses, and therefore, it is difficult to estimate the impacts this fleet has on the local environment. In this study, two types of questionnaires were used directed to the local fishers from the multi-gear fleet during interviews carried out between November 2019 and July 2021 with the objective to validate the métiers proposed for this fleet in a previous study using multivariate analysis on past landing profiles. A total of 10 out of the 11 proposed métiers were validated, including four métiers with gillnets, three with dredges, two with trammel nets, and one with traps. Additional métiers were identified not found in the previous study. The results obtained with the two types of questionnaires are presented, and their usefulness in validating the gear used and the seasonality of fishing activities are discussed, as well as their contribution to a clearer distinction between target species and commercial by-catch.

**Keywords:** fishing métiers; fisher questionnaires; multi-gear fleet; coastal fleet; fleet-based management

## 1. Introduction

In the Portuguese multi-gear coastal fishing fleet, the fishers have multiple licenses for different gear types, often varying in their characteristics, such as mesh size and dimensions, giving them the possibility for alternating gear use according to species availability and abundance. This means that the environmental impacts of the fishing activity can vary by vessel throughout the year. The characterization of the different métiers, as well as of the evaluation of their impact on both the living resources and the ecosystems exploited, are important tools in assisting management decisions in fisheries, as they describe the fishing operations with similar exploitation patterns and target species using similar gear during the same time and location (ICES 2017). In the DCF (European data collection framework) and the EU-MAP (EU-MAP (EC 2017)), six levels are considered when describing métiers, with level 1 corresponding to the activity (fishing versus non-fishing), levels 2 through 4 to gear category, group, and type, respectively, level 5 to the main species type in terms of target assemblages (e.g., demersal fish, crustaceans), and level 6 to fishing gear details, such as mesh size or hook size. Deporte et al. (2012) discuss a seventh level that is more specific and based on the target species or species at which the fishing effort is directed (EC

2017). In a previous study, fleet segmentation based on multivariate analysis of the landing profiles of the coastal multi-gear fleet in Southern Portugal resulted in 11 proposed métiers where a correspondence was established between various gears and particular target species (Szynaka et al. 2021). These gears included gillnets and trammel nets, traps and pots, longlines, and dredges, differing in their impacts on the local environment. A total of six métiers were identified using nets, with gillnets used in four different métiers having as target species the monkfishes (*Lophius piscatorius* and *Lophius budegassa*); the European hake (*Merluccius merluccius*); the bastard sole; and the thickback sole (Microchirus spp.), while trammel nets were found to be used in two métiers, targeting cuttlefish (Sepia officinalis); and murex (*Bolinus brandaris*). Traps were used in two métiers, one targeting octopus (*Octopus vulgaris*) and the other Norway lobster (*Nephrops norvegicus*); the remaining three métiers were related to the use of dredges for bivalve fishing (*Donax* spp., *Spisula solida*, *Chamelea gallina*). All these were observed to be seasonal métiers except for the bivalve and octopus métiers.

The clustering of landing profiles, an output-based method in métier identification, is commonly used to observe trends in catch across years and seasons, as well as in the main target species. However, this type of analysis can have some limitations, as the métiers defined are not always indicative of "true" or intended targeted species (Marchal et al. 2008). One possible way to identify the true targeted species is by analyzing logbooks (records of catch and effort at the fishing operations level), which are mandatory for vessels above 10 m in length. More recently, e-logbooks containing detailed georeferenced information are also available, mandatory for all vessels above 15 m (or above 12 m if absent from port for periods longer than 24 h).

For vessels under 10 m, information on landings can be obtained from auction sales slips. However, this information does not provide details on fishing operations and gear characteristics. It is, therefore, necessary to find additional ways to complement and build on the information provided by the landings to evaluate the potential environmental impacts of specific fleets. One possibility is to discover the fishing strategy with the help of direct knowledge from the local fishers themselves. This can be done by developing structured questionnaires with the purpose of collecting information on fishing trips, gear characteristics, and species captured, that can validate previously identified métiers resulting from fleet segmentation. It also allows the possibility to address the fishers' current perceptions on trends in the fishing activity, including landings. However, few studies have focused on métier identification using LEK (local ecological knowledge) in support of the analysis of landing profiles. In a few cases, questionnaires were carried out to assess fishing intentions, as well as to obtain technical information on fishing strategies and gear design regarding métiers (Castro et al. 2010, 2011, Palmer et al. 2017). In other studies, they were used to observe fishing trends and fluctuations, often focusing on particular species (Bender et al. 2014). The perception of older fishers with many years of experience has proven to be particularly important because they can identify trends, whereas younger fishers are unable to detect long-term changes or overexploited species (Bender et al. 2014, Veneroni et al. 2021).

In Portugal, interviews with fishers using structured questionnaires have become a commonly used method to provide information to understand fishers' perceptions on landings, as well as on the ecology and biology of the species they are targeting (Machado et al. 2004, Wise et al. 2007, Oliveira et al. 2015, Gamito et al. 2016, Goetz et al. 2015, Braga et al. 2017, and Silva et al. 2019). Through questionnaires, information can also be collected on fishing operations and gear characteristics, on the effects of fisheries on megafauna, and on how different local fishing activities affect stocks, many of which are not assessed and are considered by the International Council for Exploration of the Sea, ICES 2012, as category 5 (only landings data is available) and category 6 (negligible landings stocks and stocks caught in minor amounts as by-catch). Finally, questionnaires allow scientists to collect fishers' suggestions and LEK that may be potentially useful for improving advice to fisheries.

The main objective of this study is to compare the utilities of two types of questionnaires to explore the possibility of validating previously identified métiers (Szynaka et al. 2021) and to add further information to promote efficient management; to investigate changes in licenses from 2012 to 2016; to observe license trends from 2012–2016 and 2019–2020; and to detect shifts in fishing operations.

## 2. Materials and Methods

### *2.1. Study Area*

Two surveys were carried out during this study, corresponding to the use of two differently structured questionnaires, carried out at seven fishing ports along the south coast of Portugal (Figure 1). The first round of questionnaires was conducted from November 2019 to February 2020 and the second round in July 2021. The vessels selected for the study belong to the multi-gear coastal fleet, with length overall (LOA) of 9 m or more, holding licenses for more than a single gear type.

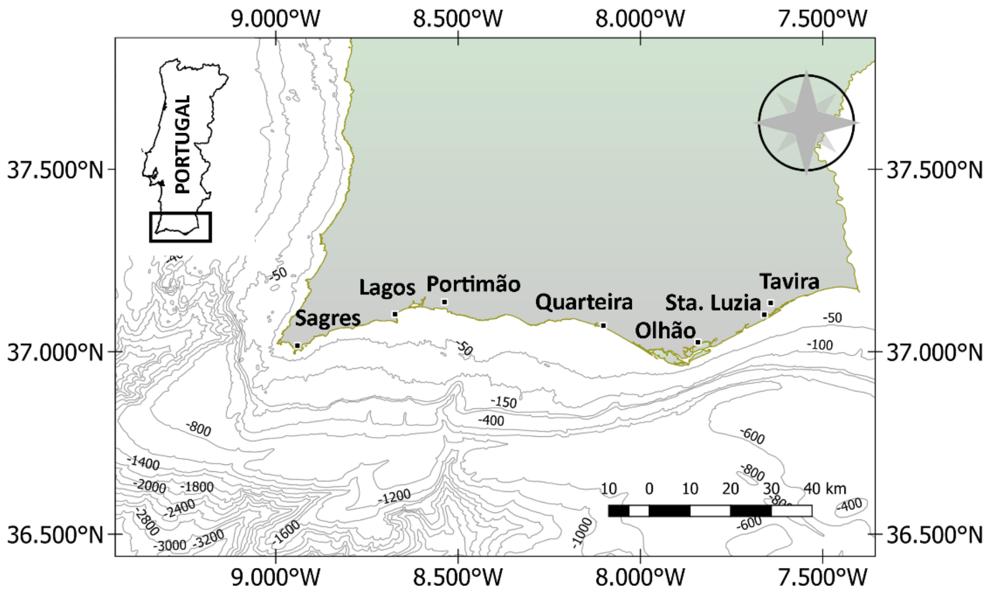



**Figure 1.** Map of the Algarve with all the ports where questionnaires were conducted.

*2.2. Questionnaires*

The first questionnaire focused on trip characteristics and details of fishing operations, while the second questionnaire aimed to provide clarification on target species and seasonality. The questionnaires were prepared within the framework of the project, TECPESCAS, and the interviews were carried out with professional fishers by experienced interviewers, including masters’ students and one PhD student. The choice to conduct questionnaires with the skippers rather than the crew was made because they are generally more knowledgeable regarding the species names and ecology or the gears’ technical characteristics and are the ones responsible for filling in fishing logbooks or landing declarations. The questionnaires were conducted without considering skippers’ age, using three methods: (a) in situ search, where fishers were met at the landing dock during regular auction hours when most of the vessels arrive from fishing; (b) obtaining a prepared list of vessels by asking the local auction for names of vessels greater than 9 m in length and licensed for more than a single gear type; (c) using the “snowball effect” during which skippers introduced or provided contacts of other active skippers from this fleet.

The first type of questionnaire (first round) with open ended questions is often used for initiating a discussion. It can take longer to respond in comparison to the one with close ended questions that can be answered in a shorter time span, but on the other hand, it leaves room for discussion and can result in collecting extra, potentially useful information. This type comprised two main sections: 1. vessel and contact information; 2. fishing activity—2.1 trip characteristics and 2.2 fishing gear characteristics. The questions related to fishing trip characteristics addressed the number of trips and their duration, hours and port of departure, average number of trips per week, number of gears regularly used, gear loss, and soak time. Questions on fishing operations addressed any license changes from the period of 2012–2016, setting and hauling speed, total length of the gear, total number of traps and pots, mesh size for nets and hook size for the longlines, and the species being targeted (including commercial by-catch).

A second set of questionnaires was conducted using a similar method (second round). This questionnaire differs from the former one in that it contained close-ended questions and was constructed with the top six species per cluster, representing a minimum of 73% of the cluster in landings. This group included those species that were present in the yearly and seasonal trend clusters from the original multivariate analysis conducted on the fleet-landing profiles from 2012–2016 [4]. Each skipper was given a list of species and the percentage of each species represented in the cluster and were asked to identify the gear, gear characteristics, fishing season, and depth based on their experience and knowledge.

All the information was treated anonymously and is protected (Article 89 of the GDPR) under the personal data protection regulation of Portugal. Responses to all questions within the questionnaires were optional, and each skipper gave verbal consent to use the information for the study.

### *2.3. Analysis*

The tables and figures are presented for the different gear types with details on: (a) fishing trips, operations, and gear characteristics; (b) gear type comparisons between 2012–2016 and late 2019–early 2020 (the first questionnaire time period), and (c) the existing métiers. The primary and secondary gears found for each vessel in the EU fleet register were compared to the gears currently in use to search for and identify trends in gear use along time. The data from the questionnaires were cross checked with the previously identified métiers [4] in the first round by gear type and in the second by both gear type and season with the purpose of validating the métiers. The two questionnaire forms are compared by species, fishing gears, gear characteristics, depth, and season. The consistency of responses among vessels, as well as the skipper's confidence in answering the questions, were noted. The responses to the second round of questionnaires regarding depth, season, gear characteristics, and gear type by target species were compared with similar information in the proposed métiers.

## 3. Results

### *3.1. Interviews: First Round Using Questionnaire 1*

A total of 40 vessels (skippers) were interviewed in the various ports, corresponding to 66 gear licenses being actively used (Table 1), with 15 vessels (37.5%) between 9 and 11.99 m in total length, while 25 (62.5%) were equal to or more than 12 m in total length. A total of 10 different métiers were identified through the questionnaires, comprising vessels operating a similar type of gear, including the same mesh or hook size, and targeting similar species. A total of 31 out of the 40 vessels (77.5%) were operating a single gear type per trip, while the remaining vessels operated two different gear types, mostly gillnets and trammel nets.

**Table 1.** Average trip and gear characteristics by gear type of the interviewed vessels, number of crew per vessel, number of trips per week, setting and hauling speed, time of departure from port, net length, number of traps or hooks, mesh size (mm) or hook number, setting and soaking time (h), and trip duration

| Gear | No. of Crew | Trips per Week | Setting Speed (kn) | Hauling Speed (kn) | Time of Departure | Net (m)/No. of Traps/No. of Hooks | Mesh Size (mm)/Hook No | Setting Time (h) | Soak Time (h) | Duration of Trip (h) |
|---|---|---|---|---|---|---|---|---|---|---|
| Trammel nets | 3.0–7.0 | 3.0–6.0 | 3.0–7.0 | 0.5–3.0 | 01:00–06:00 | 500–6000 | 100–120 * | 0.5–2.5 | 1.0–24.0 | 7.5–15 |
| Bottom Gillnets | 3.0–5.0 | 2.0–6.0 | 1.0–5.0 | 1.0–2.0 | 4:00–17:00 | 4000–6000 | 35–40 | 0.5–1.5 | 24.0 | 8.0–12.0 |
| Bottom Gillnets | 3.0–5.0 | 3.0–4.0 | 5.0–7.0 | 2.0–3.0 | 00:00–01:00 | 9000–13,000 | 60–79 | 1.0 | 2.0–24.0 | 11.0–15.0 |
| Bottom Gillnets | 3.0–5.0 | 2.0–6.0 | 3.0–5.0 | 0.5–2.0 | 02:00–14:00 | 600–10,000 | 80–99 | 0.5–1.0 | 0.5–24.0 | 7.5–16.0 |
| Bottom Gillnets | 3.0–5.0 | 3.0–4.0 | 6.5 | 1.0 | 14:00–22:00 | 600 | 100–150 | 0.5 | 0.5–12.0 | 7.0–16.0 |
| Bottom Gillnets | 5.0 | 6.0 | 5.0–8.0 | 0.5–3.0 | 01:00–04:00 | 4500–10,000 | 200–220 | 0.5–1.0 | 0.5–24.0 | 7.0–10.0 |
| Pots | 3.0–4.0 | 2.0–5.0 | 2.0–8.0 | 1.5–3.0 | 14:00–22:00 | 1000–2500 | NA | 2.0–8.0 | 24.0–72.0 | 8.0–12.0 |
| Traps | 2.0–5.0 | 2.0–5.0 | 2.5–8.0 | 1.0–4.0 | 14:00–07:00 | 750–2400 | 30–50 mm | 0.5–3.0 | 5.0–168.0 | 7.0–48.0 |
| Bottom Longlines | 4.0 | 1.0–4.0 | 3.0–5.0 | 1.0–5.0 | 17:00–23:00 | 3000–5000 | 5–8 | 3.0–5.0 | 24.0 | 36.0 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Bottom Longlines | 3.0–4.0 | 1.0–5.0 | 1.5–4.0 | 1.0–1.5 | 22:00–23:00 | 900–2000 | 9–13 | 1.0–3.0 | 2.0–24.0 | 11.0–48.0 |

* inner mesh size for trammel nets.

In general, the crews in this fleet are between two and five fishers, not including the skipper. For trammel nets and gillnets, the fishers stated they go out to sea up to six days a week with the majority carrying out three to five fishing trips a week. The fishers using pots and traps stated that they carry out between three and five trips weekly and those using longlines between one and four trips. The setting and hauling speeds reported are similar for trammel nets, gillnets, pots, and traps and higher than those reported for longlines. Vessels operating nets leave early in the morning, and those using pots, traps, and longlines leave in the afternoon or late in the evening. The longest soak times reported are for pots and traps, varying from 5 h to an entire week, while for longlines and nets they are up to 24 h. The longest trip duration was found to be for longlines, around 36 h from departure to arrival at port, while for trammel nets, gillnets, and pots, fishing trips take up to 16 h and for traps up to 48 h. While bottom gillnets and longlines were used for various métiers, differing in fishing depth, mesh size, and hook size, the vessels using trammel nets stated their main target species was cuttlefish. For those using traps and pots, octopus was the target species.

The comparisons of the responses of the first interviewing period (2019–2020) and the period of the landing profiles from the multi-variate analysis (2012–2016) show an increase in the number of vessels using traps/pots (Figure 2). From a total of fourteen gear license combinations, eight combinations were found to be no longer used by the interviewed vessels, including combinations of traps; traps and longlines, gillnets and longlines, and traps and trammel nets. A decrease was found in two license combinations, (i) only gillnets and (ii) a combination of gillnets and trammel nets; a single license combination was found to persist (gillnets and traps); one new license combination was identified (gillnets, traps, and longlines). Two license combinations (one including traps and pots, and the other including also longlines) were more represented in 2019–2020. A total of nine vessels indicated changes in their licenses, eight of which added trap licenses, and one added a gillnet license.

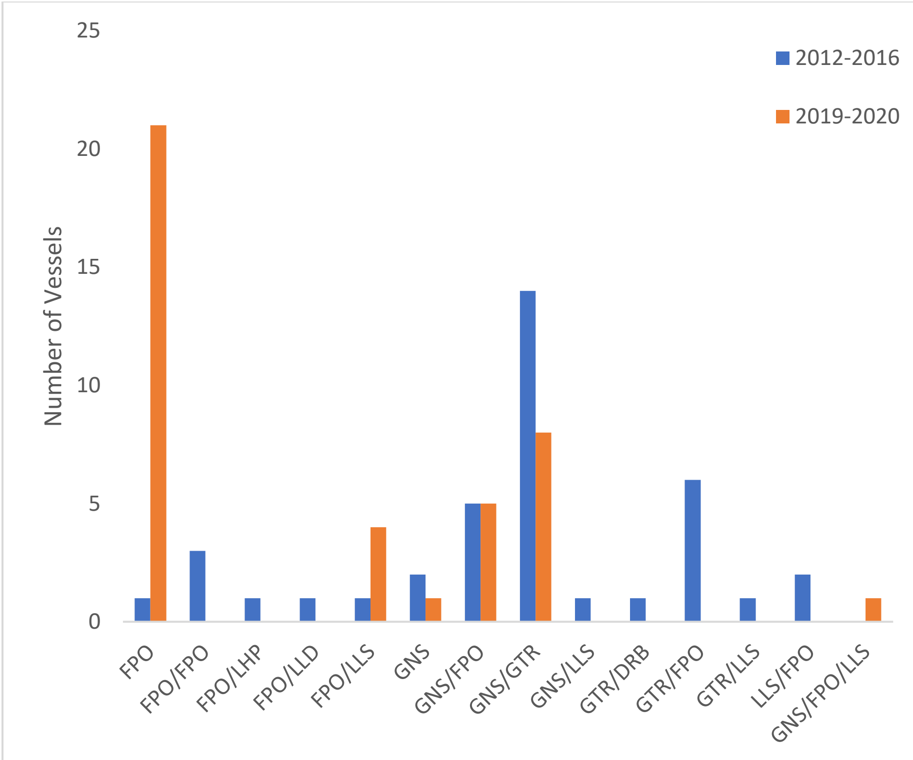



**Figure 2.** Comparison of gear license combinations (actively used) between 2012–2016 and 2019–2020 complementing Appendices A and B and Tables A1 and A2 [FPO = pots and traps; LLD/LLS = drifting/set longlines; GNS = gillnets; GTR = trammel nets; DRB = dredge]

The ten métiers identified in this study are defined in Table 2, from which six had been already proposed by Szynaka et al. (2021). Two longline métiers were identified, with three vessels operating with small hook sizes (numbers 9, 10, 12, and 13) and two with large hooks (numbers 5 to 8). The blackbelly rosefish (*Helicolenus dactylopterus*), forkbeard (*Phycis phycis*), conger eel (*Conger conger*), and wreckfish (*Polyprion americanus*) were targeted with large hook size ranges, while for the red porgy (*Pagrus pagrus*), axillary seabream (*Pagellus acarne*), common pandora (*Pagellus erythrinus*), forkbeard, blackbelly rosefish, and common two-banded seabream (*Diplodus vulgaris*), hook sizes 9–13 were used.

**Table 2.** Gear type with mesh size or hook number, the targeted species and the number of vessels operating with the métier and the validated potential métiers [FAO Code: ANK = blackbelly angler; BIB = pouting; BRF = blackbelly rosefish; BSS = European seabass; COE = conger eel; CTB = common Two-banded seabream; CTC = cuttlefish; FOR = forkbeard; HKE = hake; JOD = john dory; MGR = meagre; MKG = thickback sole; MON = monkfish; MNZ = Lophius spp, MUR = red mullet; OCC = octopus; PAC = common pandora; RJC = thornback ray; RPG = red porgy; THS = bastard soles; SBA = axillary seabream; SBG = gilthead seabream; SBR = blackspot seabream; SOO = sole; SWA = white seabream; WRF = wreckfish].

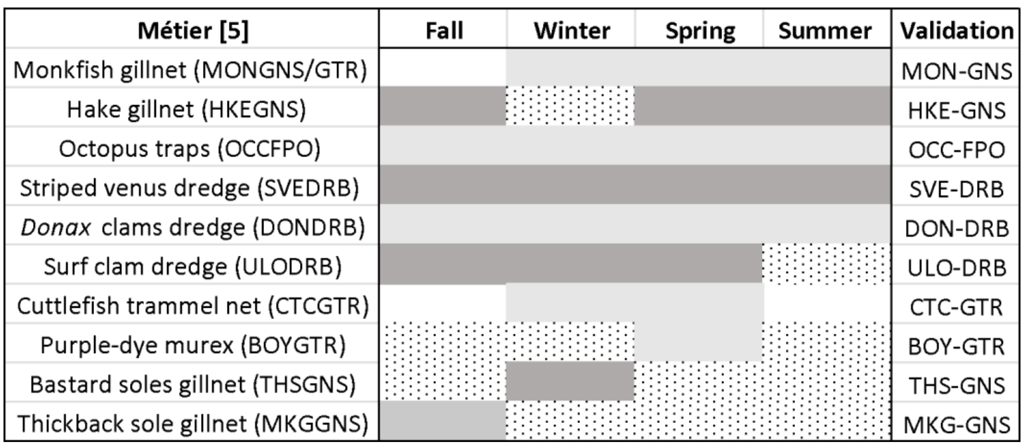
| Gear Type | Mesh Size/ Hook Number | Species | No. Vessels Targeted | Validated Potential Métiers |
|---|---|---|---|---|
| LLS | H 5–8 | BRF, COE, FOR, WRF | 2 | - |
| LLS | H 9–13 | BRF, CTB, FOR, PAC, SBA, RPG | 3 | - |
| GNS | 35–40 mm | BIB, HKE, THS, SBA | 2 | HKE-GNS, THS-GNS |
| GNS | 60–79 mm | BIB, HKE, PAC, MKG, MUR, THS, SBA | 3 | HKE-GNS, MKG-GNS |
| GNS | 80–99 mm | BSS, HKE, MKG, MUR, RJC, RPG, SBA, SOO, THS | 8 | HKE-GNS, MKG-GNS, THS-GNS |
| GNS | 100–200 mm | BSS, MUR, RPG, SBA, SBG | 3 | - |
| GNS | 200+ mm | ANK, JOD, MNZ, MON | 3 | MON-GNS |
| GTR | 100+ mm | BRF, BSS, CTC, MGR, MKG, SOO, SWA, THS | 8 | CTC-GTR |
| FPO | Traps | OCC, CTB, SBR | 27 | OCC-FPO |
| FIX | Pots | OCC | 8 | - |

Small mesh gillnets (35–40 mm and 60–79 mm) were operated by two and three vessels, respectively, targeting pouting (*Trisopterus luscus*), hake, thickback sole (*Microchirus variegatus*), axillary seabream, common pandora, bastard soles, and red mullet (*Mullus surmuletus*). Eight vessels fished with 80–99 mm mesh size gill nets, targeting European bass (*Dicentrarchus labrax*), hake, thickback sole, red mullet, thornback ray (*Raja clavata*), red porgy, axillary seabream, sole (*Solea solea*), and bastard soles. Three vessels were operating with gillnets of mesh sizes between 100 and 200 mm, targeting European seabass, red mullet, red porgy, axillary seabream, and gilt-head seabream (*Sparus aurata*), and three more vessels used mesh sizes of 200 mm or greater to target blackbellied angler (*Lophius budegassa*), john dory (*Zeus faber*), monkfish, and *Lophius* spp. (the blackbellied angler and monkfish). Eight vessels operated with 100 mm or greater mesh-size trammel nets, targeting blackbelly rosefish, European seabass, cuttlefish, meagre (*Argyrosomus regius*), thickback sole, soles, white seabream (*Diplodus sargus*), and bastard soles. Pots and traps were used by a total of eight and twenty-seven vessels, respectively, to target octopus, with some traps used to target finfish, such as the common two-banded seabream and the blackspot seabream (*Pagellus bogaraveo*).

A total of six métiers proposed by Szynaka et al. [4] were validated by the skippers in this round of interviews, including four gillnet métiers and a trammel net métier targeting a variety of species and a métier using traps [4].

### *3.2. Interviews: Second Round Using Questionnaire 2*

A total of 48 vessels were interviewed, totaling 71 gear licenses being used. Twenty-eight vessels were between 9 and 11.99 m (58.3%), and 20 were 12 m or larger (41.7%). Thirty-six use traps to target octopus, four target clams with two types of dredges, one vessel targets hake with bottom longlines, and 14 vessels target hake, cuttlefish, monkfish, and bastard soles with gillnets and trammel nets. 10 of the 11 métiers proposed by Szynaka et al. (2021) based on the multivariate analysis of landing profiles were validated by the questionnaire used (Figure 3).



| Métier [5] | Fall | Winter | Spring | Summer | Validation |
|---|---|---|---|---|---|
| Monkfish gillnet (MONGNS/GTR) | | | | | MON-GNS |
| Hake gillnet (HKEGNS) | | | | | HKE-GNS |
| Octopus traps (OCCFPO) | | | | | OCC-FPO |
| Striped venus dredge (SVEDRB) | | | | | SVE-DRB |
| *Donax* clams dredge (DONDRB) | | | | | DON-DRB |
| Surf clam dredge (ULODRB) | | | | | ULO-DRB |
| Cuttlefish trammel net (CTCGTR) | | | | | CTC-GTR |
| Purple-dye murex (BOYGTR) | | | | | BOY-GTR |
| Bastard soles gillnet (THSGNS) | | | | | THS-GNS |
| Thickback sole gillnet (MKGGNS) | | | | | MKG-GNS |

**Figure 3.** Métiers (common name, gear type, FAO code, and DGRM gear abbreviations) with the characteristic season (in which the highlighted seasons represents an overlap with the landing profile potential métiers from 2012–2016 and the dotted pattern solely represents the questionnaire responses), and validated métiers.

The 10 métiers validated were: monkfish targeted with both 200 mm year-rounder gillnets and trammel nets from winter through summer in areas up to 400 m deep; hake and bastard soles (including thickback soles) targeted with 80–99 mm mesh gillnets year round at depths up to 200 m; octopus targeted with traps (mesh size 30–50 mm) and pots year round at depths up to 400 m; the striped venus, *Donax* clams and surf clams targeted with dredges year round; cuttlefish targeted with 100–120 mm mesh size trammel nets in winter and spring at depths up to 100 m; and purple-dye murex targeted by trammel nets (of varying mesh sizes) year round at depths up to 200 m. A total of 21 skippers operated various other gears along with the gears they are currently using.

## 4. Discussion

As previously mentioned, many fisheries in Portugal are considered as stock category 5 and 6 by ICES 2012, as is the case for fisheries by the multi-gear coastal fleet in Southern Portugal, making it difficult to understand what species are actually being targeted. A total of 11 métiers could be defined through the analysis of species composition associated to gear licenses (Szynaka et al. 2021). However, a few questions remained concerning validation of métiers, as well as their persistence in time. According to previous studies, landings information can be gathered using fishers' knowledge, and their knowledge can also be used for the validation of potential métiers by collecting information on catch data (catch composition and catch rates), fishing operations, and gear technical characteristics (Castro et al. 2010, 2011, González-Álvarez et al. 2016, Falsone et al. 2020). LEK was used in this study to validate the previous multivariate analysis (Szynaka et al. 2021).

### *4.1. Methods*

Open- and closed-ended questionnaires were used during interviews, and nearly every skipper answered the questions with confidence. One of the challenges faced was not to overwhelm the fishers with too many questions, especially after they had just come back from sea. While some were initially hesitant to answer the questionnaires, they realized the format was not too long (especially the second-round format), and thus, encouraged their colleagues to answer as well. This contributed to strengthening the relationship between those issuing the questions and the respondents, positively influencing the willingness to respond (Marchal et al. 2008).

In terms of the first round of questionnaires, the open-ended questions and the variety of questions resulted in an in-depth characterization of the fishing trips and gear types. On the other hand, the second round of questionnaires, with close ended questions, where target species were defined a priori, resulted, as previously expected, in the definition of specific métiers. While the majority of the respondents answered that they only switch between fishing gears when one of the species they are targeting is less available, very few indicated that this switch is related to closures for certain species, such as the monkfish in January and February (Ordinance 315/2011).

### *4.2. Trip Characteristics*

Most vessels are between 9 and 15 m, resulting in the use of increasing gear numbers and dimensions, crew, and, thus, higher catches and potentially longer trips compared to small-scale or artisanal vessels (<9 m). In the first round of questionnaires, most skippers reported that they operate with a single gear type during each fishing trip, with only a few reporting the use of two different gear types. In terms of legal issues, many of the vessels appear to be fishing within regulations set by the Portuguese national fishing authority, DGRM, (Directorate General for Natural Resources, Security, and Maritime Services), except for those targeting octopus with traps. These vessels are allowed to operate with 1000 or 1250 baited traps based on vessel size. However, some own up to 2400 baited traps and are exceeding the amount allowed on a daily basis.

### *4.3. Changes in Gear and Target Species*

The observed shift in gears towards traps can suggest either that the fish stocks targeted with longlines and nets are in decline and/or that the use of traps is economically more profitable, justifying the effort and costs associated with the change. This highlights the importance of using questionnaires to investigate fleet dynamics over the study period, either over the course of a year or over a longer, multi-year period (Maynou et al. 2011, Tzanatos et al. 2006, and Monroy et al. 2010). Part of the vessels present seasonal shifts from one net type to another (e.g., targeting monkfish and hake in summer and fall with gillnets and cuttlefish and soles in winter and spring with trammel nets). Some of the vessels that target clams with dredges stated that they change to octopus traps during harmful algal bloom events affecting the clams. However, the majority stated that their shifts in fishing gears is due to shifts in the availability of the main target species, similar to what was reported in previous studies (Maynou et al. 2011, Roditi et al. 2018).

In previous studies, it was found that trends in gear shifts can be identified by properly structured questionnaires. There has been a considerable shift towards landing octopus with traps, as demonstrated in the previous study on landing profiles (Szynaka et al. 2021), and by comparing the results of the questionnaire with the public fleet data. This can either be a result of the depletion of many finfish stocks, of the abundance and high first sale price of octopus, or both (Moreno et al. 2014, Pita et al. 2015, Sonderblohm et al. 2016). Some fishers stated during the informal discussion part of the questionnaire that there is a decline in the willingness of young workers to become fishers, with some skippers going as far as having to sell their coastal category boats due to lack of labor force available, which could be another reason for a shift to "easier" fishing gear (i.e., fewer hours on the vessel and less effort in retrieval of individuals from the fishing gear, as appears to be the case with octopus traps). This lack of information, especially regarding the rapid development of the octopus fleet segment, decreases the possibility of effective management. Acknowledging the continuous increase in vessels targeting octopus with traps and pots should shift the focus of management from the entire fleet to this specific segment, reformulating the existing regulations based on fishers' suggestions. The current octopus fishery regulations may need to be addressed and restructured, with the main problem being the very high number of traps being set, leading to excessive occupation of fishing grounds and competition among vessels, originating conflicts. Previously proposed management measures included establishing a fishing schedule, setting seasonal closures and a maximum allowable catch, and increasing the minimum landing weight DGRM (Sonderblohm et al. 2016, 2017] of which only the closure of fishing on weekends was implemented.

### *4.4. New Information*

As previously mentioned, questionnaires can help gather information to fill in gaps on seasonality in fishing activities, as well as on target and by-catch species not identified in landing profiles analyses due to their low-catch rates. Although hake, surf clam, and bastard soles appeared to be seasonally targeted, according to Szynaka et al. (2021), the answers to the questionnaires indicated that these species are being targeted year-round. Inversely, species that were indicated as "target catch" by the fishers in the first round of questionnaires are most likely commercial by-catch, which is either a result of poor phrasing, misunderstanding by the fishers, or as previously mentioned, simply the lack of a clear distinction between target species and commercial by-catch.

Some bottom longline métiers reported here were not identified in the previous study (Szynaka et al. 2021), most likely due to the small number of vessels still operating with longlines. However, these métiers can still be important due to the large areas that these longlines can cover (Erzini et al. 2001). Again, the results of the surveys confirm the decline in the use of longlines, especially for hake (Erzini et al. 1999, 2001), with longliners now mainly targeting wreckfish, forkbeard, and conger eel at greater depths. This confirms the results of previous studies where a clear shift to fishing deeper is reported in Portugal starting in the early 1980s (Villasante et al. 2012).

### *4.5. Validation of Métiers*

A total of 10 out of the 11 métiers proposed by Szynaka et al. (2021), were validated during the two rounds of interviews with respect to gear type. According to the first round using the open-ended questionnaire, the majority of the vessels do not engage in seasonal activity but instead land most species year-round. However, this round of interviews resulted in the validation of only six out of the 11 métiers identified. By comparison, the second round was formatted to validate métiers by species rather than by gear type. This resulted not only in the validation of target species and the respective gear types, but also of season. During this round, 10 of the 11 métiers were validated, with the inclusion of the clam species targeted with dredges. In future studies it will be important to address the definition of target species and what this means to the fishers, as it often appears to correspond to the species that they retain to sell. A further question deserving some attention concerns the seasonal character of some fisheries and the number of gears used, as fishers may bias their answers towards what they know they are allowed to do according to the regulations.

## 5. Conclusions

The current study addresses the specific fishing operations, the métiers, the variables affecting landings, and finally, the trends in fishing gear use between 2012 and 2016, prior to the questionnaire surveys (2019–2021). All this information adds to the previous knowledge on potential métiers, allowing the observation, to some extent, of the impact of these coastal fisheries on the exploited stocks, including the fishing effort and how it changed over time based on shifts in fishing gears used. An example is the increase in fishing effort for octopus with the shift towards traps.

It is, thus, important to describe the different fleets, especially in countries, such as Portugal, where the fishing sector has a high socio-economic importance in the local communities, not only in terms of direct employment but also along the entire value chain. The present study resulted in the validation of 10 of the 11 métiers that were identified by a previous study that conducted cluster analysis on landings data from 2012–2016, providing evidence that these métiers are current and that the method of analysis of landing profiles successfully identified métiers within this multi-gear, multispecies fleet. The next step to further validate the métiers, as well as to describe the fishing operations, is to develop an onboard observation program to record fishing locations, depths, bottom type, and information on the entire catch.

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## Appendix A

**Table A1.** The original ordinances used to describe gear and trip characteristics including the most recent amended ordinance (where applicable) per gear type.

| GEAR TYPE | GEAR CHARACTERISTICS | TRIP CHARACTERISTICS |
|---|---|---|
| **GILL- & TRAMMEL NETS** | No. 1102-H/2000, 22/11<br>*Recent Amendment:*<br>*No. 594/2010, 29/07* | No. 296/94, 17/05 |
| **CAGE TRAPS** | No. 1102-D/2000, 22/11<br>*Recent Amendment:*<br>*No. 255/2019, 12/08* | No. 296/94, 17/05 |
| **SHELTER TRAPS (POTS)** | No. 1102-D/2000, 22/11<br>*Recent Amendment:*<br>*No. 230/2012, 03/08* | No. 296/94, 17/05 |
| **LONGLINES** | No. 1102-C/2000, 22/11 | No. 296/94, 17/05 |

## Appendix B

**Table A2.** Primary and secondary gears in EU Fishing Fleet data (2012–2016) and presently used (2019–2020) per vessel questionnaireed and the number of vessels per trend. [FPO = traps (in bold); LHP/LLD/LLS = longlines (pelagic/drift/bottom); GNS = Gillnets; GTR = traps; DRB = dredges]. The first vessel in the table was under a different name and the fishing crew was different between 2012–2016.

| Primary/Secondary Gear (2012–2016) | Gear Type (2019–2020) | N° of Vessels |
|---|---|---|
| (Change of fishers/name) | **FPO** | 1 |
| **FPO** | **FPO** | 1 |
| **FPO**/**FPO** | **FPO** | 3 |
| **FPO**/LHP | **FPO** | 1 |
| **FPO**/LLD | **FPO**/LLS | 1 |
| **FPO**/LLS | **FPO**/LLS | 1 |
| GNS | **FPO** | 1 |
| GNS | GNS/**FPO** | 1 |
| GNS/**FPO** | **FPO** | 1 |
| GNS/**FPO** | GNS/**FPO**/LLS | 1 |
| GNS/**FPO** | GNS/GTR | 1 |

| | | |
|---|---|---|
| GNS/**FPO** | GNS/**FPO** | 2 |
| GNS/GTR | **FPO** | 5 |
| GNS/GTR | GNS | 1 |
| GNS/GTR | GNS/GTR | 7 |
| GNS/GTR | GNS/**FPO** | 1 |
| GNS/LLS | GNS/**FPO** | 1 |
| GTR/DRB | **FPO** | 1 |
| GTR/**FPO** | **FPO**/LLS | 2 |
| GTR/**FPO** | **FPO** | 4 |
| GTR/LLS | **FPO** | 1 |
| LLS/**FPO** | **FPO** | 1 |
| LLS/**FPO** | **FPO** | 1 |
| | **Total** | **40** |

**Chapter 5**

# Catch composition and Métier validation in a Multi-gear Coastal Fleet

## 5.1. Abstract

In the multi-gear coastal fleet in the Algarve (South Portugal), previous studies have identified métiers that continue to be active. However, it is particularly difficult to define target and by-catch species. In this study, onboard observations were carried out on six local vessels from the multi-gear fleet between June and December 2021 with the objective to validate métiers previously identified and go a step further by defining the catch composition per métier, including target species, by-catch, and the fishing areas. A total of seven out of the 15 proposed métiers were validated, including a trammel net, three gill net, one pot, and two trap métiers. Furthermore, by-catch and non-target commercial catch were described per métier. The results obtained from the onboard observation are presented, and their usefulness in describing the areas of fishing, specifically depth, is discussed.

## 5.2. Introduction

A key issue in multi-gear and multi-species fisheries management is the adoption of a fleet and métier-based approach. The identification of métiers in which target species and associated fishing gear are defined and related to exploitation patterns, including the spatial and temporal components, has attracted considerable attention during the last two decades (ICES 2012). A few studies used landings composition to define landing profiles (Katsanevakis et al. 2010a, b, Castro et al. 2012, Samy-Kamal et al. 2014), whereas in others fishing logbooks have been used to determine the main target species and associated gears, especially when attempting to map fishing areas, either in single gear fleets or in multi-gear fleets (Bastardie et al. 2010c, Cardoso et al. 2015, Natale et al. 2015). While some studies were successful in proposing métiers, there is always the need to validate them and, more importantly, to describe any shifts in the métiers proposed (Tzanatos et al. 2006, Castro et al. 2010, 2011, González-Álvarez et al. 2016, Palmer et al. 2017). In the previous study (Chapter 4), one issue that arose was that from the 11 métiers that were initially proposed in Chapter 3, the Norway lobster (*Nephrops norvegicus*) fishery with traps was difficult to validate due to the extremely low number of vessels operating within this specific fishery. Another key issue found in the definition of métiers was the lack of a clear definition of target species by the fishers, and the distinction between target and by-catch species (Szynaka et al. 2022). This may be due to discrepancies between the FAO's and the fishers' definitions, in other words a communication issues, e.g., target species or by-catch (Borges et al. 2001).

One of the difficulties in defining métiers stems from the fact that catch composition can greatly vary for similar gear, depending upon several factors including gear characteristics such as mesh size or hook size and finally, on the fishing strategies adopted, including location of fishing grounds, bottom type, depth, setting time and soak time (Halliday, 2002, Stergiou et al. 2006, Batista et al. 2009). In general, there is an optimal soak time for each gear/métier corresponding to a peak in the capture of target species, after which there are increases in unwanted by-catch with corresponding increase in discards (Ogura et al. 1980, Acosta 1994, Gonçalves et al. 2007, 2008). As fishing area and bottom type also affect catch, understanding the relationships between species and their habitats is important in their exploitation (Wearmouth et al. 2003).

Almost all gears are responsible for by-catch and discarding to some extent. In the Algarve, Southern Portugal, while the information regarding by-catch and discards is scarce for the multi-gear coastal fleet as a whole, many studies have focused on catch composition of particular gears or métiers (Borges at al. 2001, Erzini et al. 2002, Santos et al. 2002, Coelho et al. 2003, 2005, Gonçalves et al. 2007, 2008b, Anjos et al. 2018). For trammel nets targeting soles and cuttlefish, up to 105 discarded species have been reported (Gonçalves et al. 2007) and approximately half of the species were discards species, mostly invertebrates (Erzini et al. 2002, Gonçalves et al. 2008, Szynaka et al. 2018), while Santos et al. (2003a) reported 25 species, 11 of which were discarded, in the hake fishery using gillnets.

In this study, validation of the proposed métiers was conducted on board six vessels representing the majority of the Southern Portuguese multi-gear coastal fishing fleet in terms of the fishing gear actively used according to the questionnaires, namely trammel nets, gillnets, pots and traps, in order to further validate the métiers proposed in previous studies (Szynaka et al. 2021, 2022). The fishing trip characteristics that were identified in the questionnaires (Chapter 4) are compared with the results obtained here and followed by a description of the catch composition, focusing primarily on the target species but, also on by-catch and discards per métier, in order to complete the definition of some of the métiers that currently exist within this fleet.

## 5.3. Materials and Methods

### *5.3.1. Field work*

A general agreement was set between skippers and observers that all the data gathered onboard would remain anonymous. Observations took place onboard six vessels between 12 and 17 meters in length, three of which operate with traps and pots and the remaining with gillnets and trammel nets. The vessels departed and landed in Sagres, Portimão, Quarteira, Olhão and Tavira (Figure 5.1). A total of 18 trips (three trips with each of the six boats) were conducted between June December 2021.

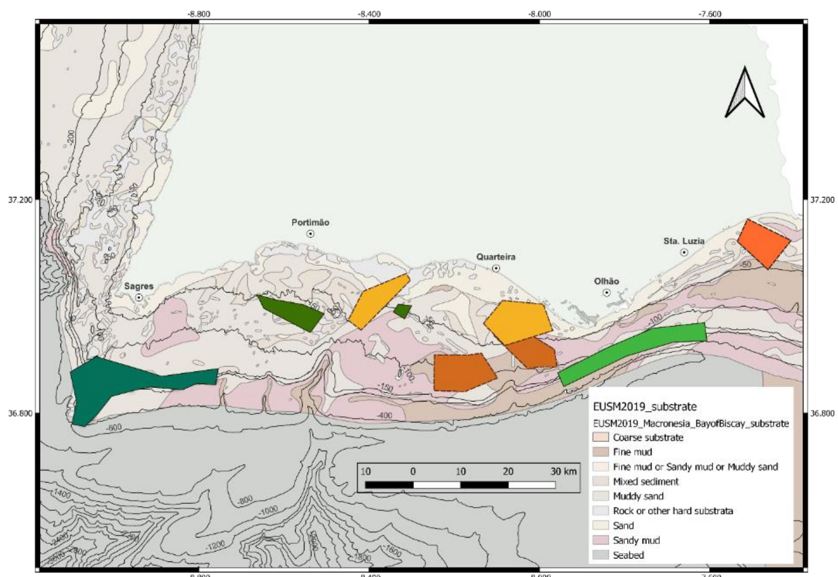



**Figure 5.1.** Map with the fishing grounds of all the trips conducted between June and December 2020 and the main ports in the Southern Portugal region. [Each color represents a different vessel; green colors represent vessels operating with nets, while oranges represent vessels operating with traps and pots].

Data was gathered on gear technical characteristics, including mesh size and overall gear dimensions in meters or number of traps. Operational data were also collected including GPS trajectories, setting and hauling points (including the time it took to complete these operations), operational speeds (hauling, setting, searching (or in other terms using the GPS to 'find' and approach the fishing set intended on hauling), and navigation), and soak time for the different gears being used in a single trip. Each individual fish brought on the deck was identified to the species (whenever possible) and classified as target species, commercial by-catch or discard/unwanted catch, as indicated by the fisher sorting the catch, and the given reason for discarding was noted.

The landings record with the weight of each species sold at auction was requested after each trip and provided for a total of 17 of the 18 trips.

### *5.3.2 Data Analysis*

Métiers were identified *in situ* and described according to the fishing gear characteristics and target species in order to validate previously proposed métiers, either according to landing profiles or through interviews with structured questionnaires (Szynaka et al. 2021, Szynaka et al. 2022). The trip characteristics were condensed into a single table per métier. The CPUE (catch per unit effort) was calculated for each species as the landed weight in kilograms per 1000 meters of net or 1000 traps. The number of individuals either of target or by-catch species were recorded per métier. The GPS information was used to characterize and map the vessels' activity in terms of fishing operations (hauling and setting) and linked to the bathymetry and bottom substrates in which fishing occurred (as seen in Figure 5.1).

The commercial catch and by-catch were separated, and the species were grouped by the taxonomic rank of class due to the low number of individuals for each species or, in some cases, difficulties in their identification. To evaluate which factors best explain the taxonomic composition of the catch, a Multivariate regression tree (MRT) analysis was conducted using the archived R package 'mvpart 1.6.2' (De'Ath 2002). The CP, or complexity parameter of the tree is the number of branches that is plotted against the relative error to obtain the optimal number of leaves. Each leaf was analyzed by the main factor and indicator classes (which are also separated by whether they were discarded or retained) and their explanatory percentage of deviance. The factors used for the analysis included gear type [nets: GNS, gillnet, and GTR, trammel net; FPO for traps and FIX for pots]; gear characteristics: mesh size [60-79mm, 80mm, and 200mm, O for octopus traps and F for fish traps). Each data point is a unique combination of these factors. A canonical correspondence analysis (CCA) was run using the R package "vegan", (Oksanen et al. 2022), to evaluate the effect of each of the main variables indicated by the MRT on the catch and an ANOVA was run to test the significance of the correlations. The variables were labeled the same as in the MRT.

## 5.4. Results

Seven out of a total of 17 métiers proposed, 11 in the first and six in the second (chapters 3 and 4; Szynaka et al. 2021, Szynaka et al. 2022) were validated, including various gillnets métiers targeting monkfish and hake with different mesh sizes, and traps being used to target octopus. Of the métiers proposed further through interviews conducted with structured questionnaires (Szynaka et al. 2022), an additional monkfish trammel net métier was validated, as well as pots to target octopus, a mixed seabream trap and a gillnet métier (Table 5.1).

**Table 5.1.** First validation and additional métiers from questionnaires (Szynaka et al. 2021) and the seven métiers validated through onboard observation, including the assigned *métier* ID. (FAO Codes: MON – monkfish, HKE – hakes, OCC – octopus, SVE – striped venus clam, DON – *Donax* spp. clams, ULO – surf clam, CTC – cuttlefish, BOY- purple-dye murex, THS – bastard soles, MKG – thickback sole; DGRM fishing gear codes: GNS – gillnets, FPO – traps, FIX – pots, DRB – dredges, GTR – trammel nets, LLS – bottom longlines; additional codes: MIX – mixed species; SBr – various seabreams).

| | Metier | Validated (Szynaka et al. 2022) | Validation (onboard) |
|---|---|---|---|
| Metiers proposed (Szynaka et al. 2021) | **Monkfish gillnet (MONGNS)** | MON-GNS | **MON-GNS** |
| | **Hake gillnet (HKEGNS)** | HKE-GNS | **HKE-GNS** |
| | **Octopus trap (OCCFPO)** | OCC-FPO | **OCC-FPO** |
| | Norway lobster trap (NEPFPO) | | |
| | Striped venus dredge (SVEDRB) | SVE-DRB | |
| | Donax clams dredge (DONDRB) | DON-DRB | |
| | Surf clam dredge (ULODRB) | ULO-DRB | |
| | Cuttlefish trammel net (CTCGTR) | CTC-GTR | |
| | Purple-murex trammel net (BOYGTR) | BOY-GTR | |
| | Bastard soles gillnet (THSGNS) | THS-GNS | |
| | Thickback sole (MKGGNS) | MKG-GNS | |
| Additional (Szynaka et al. 2022) | **Seabream traps (SBrFPO)** | - | **SBr-FPO** |
| | **Octopus pot (OCCFIX)** | - | **OCC-FIX** |
| | **Monkfish gillnet (MONGTR)** | - | **MON-GTR** |
| | **Seabream gillnet (SBrGNS)** | - | **SBR-GNS** |
| | Blackbelly rosefish longlines (BRFLLS) | - | |
| | Seabream longlines (SBrLLS) | - | |

*5.4.1. Net métiers*

The first métier to be validated during the onboard trips was the monkfish fishery with trammel nets, described through the questionnaire surveys, differing from the original proposed métier (Chapter 3) using gillnets. This métier was validated in only one vessel using multiple short trammel nets of about 1500 meters in length, made in large mesh (220 mm). These nets took the least amount of time to haul in (30 minutes) by comparison to the other net sets, placed in various locations at depths ranging from 150 to 400 meters off the coast of Sagres (Figure 5.1).

The second métier to be validated was one of the originally proposed métiers, the hake fishery targeted with gillnets. Two vessels were sampled participating in this métier, including the previous one engaged in the trammel net monkfish métier, and another vessel fishing off the coast of Olhão. Both vessels used a long (up to 6400 m) gillnet with a mesh size of 80 mm, at depths ranging between 100 and 400 meters. The trip and soak time duration were reported in the questionnaires to be 8 to 10 hours and 24 hours respectively, but during the experimental trips, the trip duration ranged between 9.5 and 16 hours and the soak time ranged between 5 and 12 hours (Table 5.2).

The third métier validated was the monkfish fishery with gillnets, also one of the original proposed métiers. The vessel from Olhão from the aforementioned métier, participated in this monkfish métier, using a large mesh size gillnet of 220 mm, with approximately 6400 meters length, at depths between 150 and 400 meters. Compared to the results of the questionnaire surveys, where the reported soak time was 24 hours, the soak time from the onboard observations was greater, ranging between 48 and 72 hours (Table 5.2). This vessel had the shortest trip duration of all net vessels sampled, with the maximum duration being 10.5 hours.

Finally, the last net métier to be validated, described in the interviews, was the small mesh gillnet (ranging between 60 and 79 mm) used to target various seabreams at depths ranging between 50 and 100 meters off the coast of Portimão. This vessel used the longest net, with 13000 meters length, had the shortest soak period of a maximum of three hours, and the longest haul time of seven hours for the set.

### *5.4.2. Trap métiers*

The first originally proposed métier to be validated was the trap fishery for octopus at a depth range between 50 and 100 meters, with mesh ranging between 30-50 mm (Table 5.2). Two vessels were sampled in this métier; one that fished off the coast of Olhão and the other one off the coast of Santa Luzia/Tavira. The length of the sets varied, one vessel using sets of 200 traps while the other used sets of 1000 traps, which was the longest set of traps during the onboard observations. These traps were soaked for the longest time period, ranging from 72 to 84 hours; however, the soak time varied from the responses given during the inquiries, in which the vessels claimed the soak times were between 6 and 72 hours. The trip durations also varied from the responses as they ranged between 11.5 and 22 hours, with 22 hours being the longest trip for all the métiers during this study.

The other trap métier to be validated, from the inquiries, was the pot fishery for octopus, in the same vessel that fishes off the coast of Olhão. Sets of 250 pots were used, differing from the number of pots per set stated in the inquiries, which was 200. Similar to the traps, these pots are soaked for the longest time period, up to 84 hours, at depths ranging between 50 and 100 meters and the trips also ranged between 11.5 and 22 hours.

Finally, the last trap métier described in the interviews to be validated, was the seabream fishery with traps, targeting various seabreams. One vessel was sampled at depths ranging between 50 and 100 meters off the coast of Quarteira, using the smallest number of traps, ranging between 30 and 60. The shortest trip duration was recorded in this vessel, with a maximum of eight hours , as well as the shortest haul back time of all the fishing gears in this study, no more than one hour per set.

**Table 5.2.** Characterization of the fishing activity of the seven different métiers, including the *métier* ID, the vessel length, the gear characteristics (including the length of the gear in meters if net or number of traps per set, the mesh size in millimeters, and the number of gears used during one trip) and the trip characteristics (including the depth ranges in meters, the duration of the trip, soak, and haul durations in hours, and the speeds including navigational, setting, search and hauling in knots).

| | | Gear Characteristics | | | Trip Characteristics | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Métier ID** | **Vessel length** | **Gear len./No traps per set** | **Mesh size** | **No of gear used** | **Depth** | **Trip duration** | **Soak duration** | **Haul duration** | **Nav. Speed** | **Set. Speed** | **Search Speed** | **Haul. Speed** |
| **GTR-MON** | 17 | **1500** | **220** | 2 | 100-400 | **13-16** | 17 - 72 | 1.5-2 | 9-10 | 7-9 | 7-8 | **1-2** |
| **GNS-HKE** | 13.5&17.0 | **4800** | **80** | 2 | 100-400 | **9.5-16** | **5-12** | 2-3 | 8-10 | **4.5-5** | 7-8 | **1-2** |
| **GNS-MON** | 13.5 | **6400** | **220** | 2 | 150-400 | **7-10.5** | 48 - 72 | 2-3 | 8 | **4.5-5** | 7-8 | **1-2** |
| **GNS-SBr** | 11.6 | **13000** | **60-79** | 1 | 50-100 | **10.5-12** | **1.5 - 3** | 5-7 | 7-8 | **4-5** | 5-6 | **0-2** |
| **FIX-OCC** | 16.5 | 200-1000 | **30-50** | 2 | 50-100 | 11.5-22 | 72 - 84 | 1.5-2 | 8.6-9 | **6-8** | 7.5-8 | 2-3 |
| **FPO-OCC** | 11.9&16.5 | 250 | | 2 | 50-100 | **11.5-22** | **24 - 84** | 1.5-3 | 7-9 | **6-8** | 7.5-8 | 0-3 |
| **FPO-SBr** | 12.9 | 30-60 | | 2 | 50 | **7-8** | **22 - 46** | 0.5-1 | 8-8.5 | **3-4** | 7-8 | 0-2 |

**Table 5.3.** CPUE (in kg per 1000 meters of net or per 1000 traps) per vessel, for a total of 32 commercial taxa, along with class, family, species, and FAO code of each target species and commercial by-catch species per vessel. [Landed weight according to DOCAPESCA].

| **Class**<br>Family | **Species** | **Cod FAO** | **GTR & GNS kg/ 1000m** | **GNS kg/ 1000m** | **GNS kg/ 1000m** | **FPO & FIX kg/ 1000** | **FPO_Sbr kg/ 1000** | **FPO_OCC kg/ 1000** |
|---|---|---|---|---|---|---|---|---|
| **Actinopterygii** | | | | | | | | |
| Carangidae | *Trachurus trachurus* | HOM | | | 0.23 | | | |
| Congridae | *Conger conger* | COE | | | | | 171.03 | |
| Gadidae | *Trisopterus luscus* | BIB | 0.20 | 3.05 | | | | |
| Lophidae | *Lophius budegassa* | ANK | 11.71 | | 8.87 | | | |
| | *Lophius piscatorius* | MON | 4.49 | | | | | |
| Merlucciidae | *Merluccius merluccius* | HKE | 2.52 | 0.97 | 5.80 | | | |
| Mullidae | *Mullus surmuletus* | MUR | 0.16 | 1.35 | | | | |
| Phycidae | *Phycis phycis* | FOR | 0.60 | 1.02 | | | 15.38 | |
| Polyprionidae | *Polyprion americanus* | WRF | 4.50 | | | | | |
| Scombridae | *Sarda sarda* | BON | | 0.32 | | | | |
| Scorpaenidae | *Scorpaena* spp. | SCS | 0.04 | | | | | |
| | *Sebastes* spp. | RED | 0.45 | | | | | |
| Sebastidae | *Helicolenus dactylopterus* | BRF | 0.18 | | | | | |
| Soleidae | *Microchirus* spp. | THS | | 0.18 | | | | |
| Sparidae | *Dentex macrophthalmus* | DEL | 0.08 | | | | | |
| | *Diplodus cervinus* | SBZ | | | | | 2.56 | |
| | *Diplodus sargus* | SWA | | | | | 46.92 | |
| | *Diplodus vulgaris* | CTB | | 0.53 | | | 5.90 | |
| | *Pagellus acarne* | SBA | 0.78 | 2.10 | | | | |
| | *Pagellus erythrinus* | PAC | | 0.55 | | | | |
| | *Pagrus pagrus* | RPG | 0.03 | | | | | |
| | *Sparus aurata* | SBG | | | | | 43.08 | |
| | *Spondyliosoma cantharus* | BRB | | | | | 565.13 | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Triglidae | *Aspitrigla cuculus* | GUR | 0.32 | | | | | |
| Zeidae | *Zeus faber* | JOD | 0.20 | 0.04 | | | | |
| **Cephalopoda** | | | | | | | | |
| Octopodidae | *Octopus vulgaris* | OCC | | | | 47.14 | 71.54 | 111.17 |
| **Elasmobranchii** | | | | | | | | |
| Rajidae | *Raja* spp. | SKA | 2.02 | 0.19 | | | | |
| Scyliorhinidae | *Scyliorhinus stellaris* | SYT | 12.72 | | 0.26 | | | |
| Torpedinidae | *Torpedo* spp. | TOE | | | 0.07 | | | |
| **Gastropoda** | | | | | | | | |
| Charoniidae | *Charonia lampas* | KRJ | 0.50 | | | | | |
| **Malacostraca** | | | | | | | | |
| Cancridae | *Cancer pagurus* | CRE | 0.31 | | | | | |
| Palinuridae | *Palinurus elephas* | SLO | 0.04 | | | | | |

A total of 58 taxa, 32 of which were considered commercial by the fishers sorting the catches, and 5 genus (individuals that were difficult to identify to the species) representing 47 families were recorded during the 18 trips, accounting for 3148 kg in total over the course of 17 trips (Table 5.3). A total of 78% of the species in weight (kg) were caught in nets and 32% in traps. The highest CPUEs in fish traps (kg/1000 traps) were for conger eel (Conger conger) and black seabream (*Spondyliosoma canthurus*), and octopus (the only species landed) in octopus traps. In nets, either in trammel nets or gillnets of 80 mm or larger mesh size, the highest CPUE (kg/1000 m of net) was for the black-bellied angler, while the axillary seabream (*Pagellus acarne*) presented the highest CPUE in small mesh gillnets.

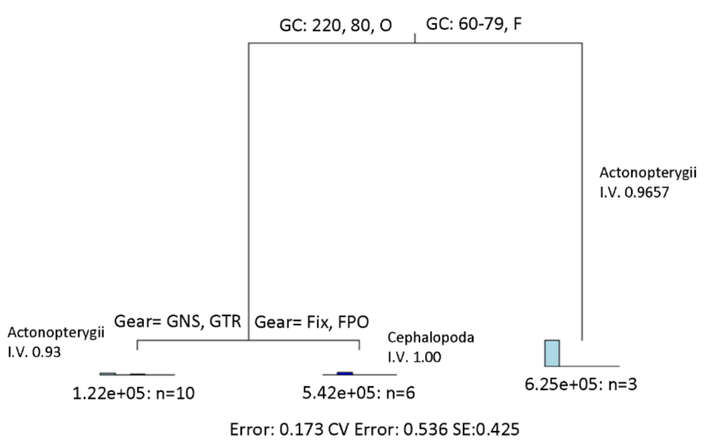
The majority of the catch was represented by the class Actinopterygii, in both the commercial catch and by-catch, and was the discriminant class and the indicator class for the first split in the MRT. The second split had two discriminant classes, Actinopterygii and Cephalopoda. In terms of fishing gears, on the second node, the left leaf was explained by nets (gillnets and trammel nets) and the right leaf was explained by pots and traps (Figure 5.1A). A canonical correspondence analysis (CCA) conducted on the commercial catch presented a total variance of 3.5 with 1.312 constrained (37.48% of the x axis) and 2.188 unconstrained (62.52% of the y axis), which means there is some structure to the data by the response data (Figure 5.2B).

The gillnets with a mesh size of 80mm are correlated with Elasmobranchii (Figure 5.2. B, 1st quadrant,). The 80 mm gillnets are used to target hake, and during the trips 32 species were caught, with 22 species being discarded. The correlation could be explained by the high quantities of the nurse hound (*Scyliorhinus stellaris*), which is a commercial species.

Actinopterygii is strongly correlated with fish (F) traps (FPO) and to a lesser extent nets (in this case gillnet) of 60-79 mm mesh gillnets, both of which were targeting various seabreams (2nd quadrant). The GNS-Sbr and FPO-Sbr caught a total of 29 and 21 species and discarded individuals from 22 and 15 species, respectively. Species recognized as vulnerable according to the IUCN classification system (IUCN 2022) include grey triggerfish (*Balistes capriscus*) caught by fish traps and Atlantic horse mackerel (*Trachurus trachurus*) and the near threatened thornback ray (*Raja clavata*) in gillnets (annex Table 5I).

Cephalopoda is strongly correlated with pots (FIX) and octopus (O) traps (FPO) (3rd quadrant). Only one species was caught with pots (FIX-OCC), while 20 species were caught in the traps (FPO-OCC), of which 12 were discarded. The main discards were various undersized Sparidae species in the octopus traps and a dead leatherback turtle (*Dermochelys coriacea*) caught in the main line of an octopus trap set.

Malacostraca and Gastropoda are correlated with trammel nets and nets of 220 mm mesh size (4th quadrant). In trammel nets and gillnets targeting monkfish with a mesh size of 220 mm, a total of 28 species and seven species were caught of which 26 and six were discarded (either due to being an unwanted individual or an individual of no value). This vessel was targeting crabs (*Cancer pagurus*) and lobsters (*Palinurus elephas*), which are considered vulnerable according to the IUCN.



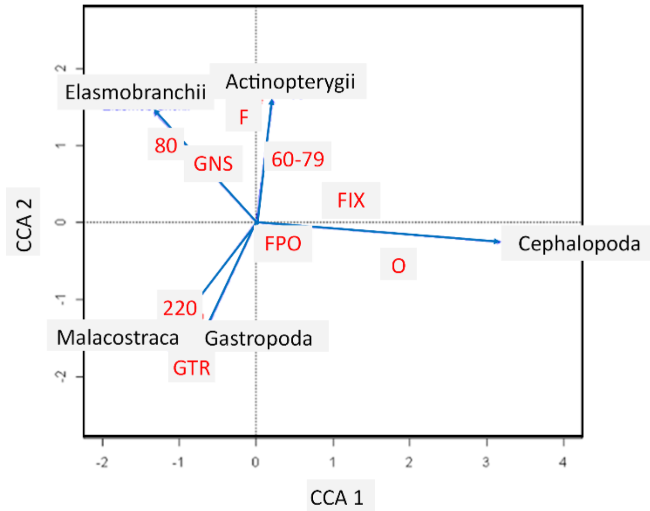



**Figure 5.2.** Top: Multivariate regression tree (MRT) with two nodes and three leaves where gear characteristic is the strongest factor with the indicator class (I.V. indicator values), the percentage of deviance explained, and the number of commercial individuals by class representing each node Bottom: CCA (canonical correspondence analysis) regarding commercial individuals by class and the explanatory variables gear. [Gear: FPO = Traps, FIX = Pots, GTR = Trammel nets, GNS = Gillnets; Characteristics: O = octopus trap, F = fish trap, mesh sizes = 60-79 mm, 80mm, and 220 mm]

### 5.5. Discussion

In this study, observations of fishing characteristics and operations collected onboard vessels of the multi-gear coastal fishing fleet were used to validate previously proposed métiers (Szynaka et al. 2021, 2022). Gear and trip characteristics gathered from the interviews were also validated through this onboard observational study. This study described the in-depth fishing operations and catch composition of six vessels that use nets and traps, which represent 81% of the fishing gear licenses owned by the fishers in the multi-gear coastal fleet operating in the Algarve. Similarly, Leitão et al. (2022) also found that the most important fishing gears included nets and pots, as well as longlines, in the overall Portuguese multi-gear fishing fleet. Three of the original métiers from Szynaka et al. (2021) were validated in this study, as well as four other métiers: the monkfish fishery with trammel nets, the octopus fishery with pots, and two other métiers, previously identified in the inquiries (Szynaka et al. 2022), in which seabreams were targeted with traps and small mesh gillnets, which were most likely not observed in the clustering analysis due to the few boats involved.

Depth is an important variable to consider when targeting species such as *Lophius* spp., as they are caught in the deepest waters ranging from 100 up to 400 meters; the same vessels targeting hake will do so at shallower depths of less than 100 meters (Azevedo and Pereda, 1994, Santos et al. 2003a). On the other hand, mesh size and distance to the coast are important when targeting species such as seabreams, with small mesh gillnets and closer inshore and at depths of 50 m. The vessel targeting seabream with traps also operates at similar depths, around 50 meters, and on rocky bottoms. Soak time also varied according to target species, with a maximum of three hours in small mesh gillnets targeting seabream, while gillnets used to target hake are set for a maximum of 12 hours. Time of fishing is associated with the activity periods of the target species as the fishers operating with nets targeting seabreams and hake commonly begin hauling at sunrise (Batista et al. 2009, Baeta et al. 2010). Among the net métiers, gillnets and trammel nets used to target monkfish are left in the water for longer periods. One of the vessels targeting both monkfish and hake at similar depths was observed to discard hake mostly in hauls where gillnets were left in the water for long periods (up to 72 hours). Actually, hake are less likely to be hauled in alive after long soak time periods; this explains the maximum soak time adopted by vessels targeting hake with gillnets, varying between 3 and a maximum of 24 hours (Santos et al. 2003a, Fonseca et al. 2005).

Notably, the monkfish was considered to be the main target species in large mesh gillnets and trammel nets. However, this study showed that it was mainly the black-bellied angler that was caught in higher amounts. Since the 1980s, there has been a shift towards fishing at higher depths in Portuguese waters off the continental coast, due to diminishing shallow depth resources and an increase in demand and consumption of these two species of anglers (Maguire et al. 2008, Azevedo 1995). Interestingly, according to the analysis of landings, few black-bellied anglers were caught compared to the monkfish (Szynaka et al. 2021). Although this is a one-off study, it raises questions regarding a possible shift in availability of the two species of monkfish.

Soak time surpasses 24 hours when targeting octopus with traps and the number of traps in sets are lower compared to the numbers recorded during the inquiries (Szynaka et al. 2022). This is interesting, allowing the fishers to spread their gears out and haul the legal amount of traps allowed for their sizes (1250 traps for vessels 12 m and over) in a wider area compared to the fishers that have one or two sets maximum (Pita et al. 2015, Sonderblohm et al. 2016, 2017). Going onboard also gave extra information regarding the trip characteristics such as navigational, setting, and searching speeds, which are all important for mapping impacts on the bottom habitat and in which particular areas, and is considered more reliable information (Natale et al. 2015).

There was some spatial overlap of species caught between the different gear types and in one case, the fishing area was overlapped by a vessel using traps for octopus and another using the same gear to target seabream, which is a much larger trap and usually round with a 1.2 m diameter. The intensity of the overlap of fishing activity in a given area is an important factor when considering the changes in availability of certain species. Without the spatial information (distance from shore, depth, and sediment type) and knowledge of the species being targeted, often several species as opposed to targeting single species, it is difficult to understand the fishing pressure on the local waters. It is necessary to observe any ecological interactions and thus create spatial management strategies (Punt, 2006). Overfishing is a problem that can be tackled only if the decision makers are aware of the operations of all the fishing vessels belonging to the local fleets, including those that can switch among gears when they feel it is necessary and those underrepresented in the data, such as the various seabream targeting fish trap vessels.

The thornback ray and grey triggerfish were also caught in nets and landed; however, they are considered to be near-threatened and vulnerable according to the IUCN; this will represent a challenge for the future if these two species fall into worse IUCN categories as they continue to be fished. Furthermore, the CCA showed an interesting correlation between the trammel net used for monkfish and the spiny lobster, suggesting that the fishers were actually trying to target lobster by leaving the nets in the water for a long period in certain areas, with the purpose to attract crustaceans to the deteriorating catch. However, the spiny lobster is a vulnerable species according to the IUCN classification, which again will pose an issue in the future as it continues to be targeted by certain fishers.

Contrary to previously assumed lack of by-catch in octopus traps, three of the trips resulted in many species being caught including undersized Sparids, *H. didactylus*, and *S. granularis*, with these species being recorded in another study in the Portuguese octopus fisheries (Almeida et al. 2022). A possible explanation for this is the fishing location of these trips, closer to shore when compared to others and in mixed substrate closer to nurseries, attracting invertebrates (Vinagre et al. 2010). In one of the trips, a leatherback sea turtle (*Dermochelys coriacea*) was tangled in the mainline of a trap set that used live green crab (*Carcinus maenas*) as bait (which is still not legal in the Algarve); perhaps it was the bait that attracted this individual (Pita et al. 2021). These turtles are known to be caught in longlines, along with other by-catch such as elasmobranchs (Coelho et al., 2012, Santos et al., 2002, Baeta et al., 2010). The CCA highlighted an important correlation between the 80 mm gillnets and the high catch rates of the small-spotted catshark, which although a commercial species is not considered a target species, and in fact the fishers shared their catch with another boat and it is assumed it is for the other boat to sell.

Seven of 15 métiers were validated including gillnets, trammel nets, pots, and traps for their respective species. Some of the métiers were not included in the validation due to various reasons, for example dredgers, as vessels from this particular fleet tend to solely use dredges, except when toxic algal blooms occur, at which point they change to octopus traps, according to the questionnaire surveys (Gaspar et al. 2015, Anjos et al. 2018, Szynaka et al. 2022). From the original proposed métiers, the Norway lobster (*Nephrops norvegicus*) trap vessels were not possible to interview due to the small number of vessels that operate within this métier, and therefore they were also excluded from this study. Similarly, there are few vessels targeting the purple-dye murex (*Bolinus brandaris*) with trammel nets, and also few vessels fishing with longline métiers. Furthermore, longline vessels are difficult to sample due to long trip duration, often exceeding 24 hours, thus preventing on-board sampling by observers (Szynaka et al. 2022). None of the vessels fished inshore, in areas characterized by soft sediment, making it difficult to validate the two bastard sole gillnet métiers. Due to the fact that there is a higher chance of encountering a vessel operating with traps or gillnets, the chance of validating the other métiers described is reduced.

## 5.6. Conclusion

The fishers in this fleet prefer to have as many gear options as possible in the case of low abundance of the main target species. Considering the growing numbers of traps in use from 2012 to 2016 and even more since 2016, future onboard sampling should be conducted to observe the probability of by-catch by these trap métiers to fully grasp the ecological impacts of these traps. Similar fisheries exist that are and can follow the same, or similar approaches taken in this study, including the analysis of landing profiles and logbooks, the organization of port interviews and the implementation of onboard observation programs, in order to obtain a better picture of existing métiers as well as trends in their relative importance. There is also a need to look at the species that are being targeted in Portuguese waters, that are listed by the IUCN (vulnerable and endangered, as well as data deficient). Future work can include seeking out the métiers that were difficult to validate through either inquiry, onboard observation or both, including but not limited to the various trammel nets and longliners in this fleet.

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## Appendix A

**Table A.1**. Number of individuals on by-catch species and their respective families, number per métier ID. The species in bold in are either near threatened[1] and vulnerable[2] according to the IUCN.

| | | | Discard | | | | | | | Commercial | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Class** | **Family** | **Species** | **GNS-MIX** | **GNS-MNZ** | **GNS-HKE** | **GTR-MNZ** | **FPO-MIX** | **FIX-OCC** | **FPO-OCC** | **GNS-MIX** | **GNS-MNZ** | **GNS-HKE** | **GTR-MNZ** | **FPO-MIX** | **FIX-OCC** | **FPO-OCC** |
| **Actinopterygii** | Balistidae | *Balistes capriscus*[2] | | | | | | | | | | | | 3 | | 1 |
| | Batrachoididae | *Halobatrachus didactylus* | 3 | | | | | | 93 | | | | | | | |
| | Carangidae | *Trachurus trachurus*[2] | 198 | | 10 | | | | | | | 15 | | | | |
| | Congridae | *Conger conger* | 1 | | | | 4 | | | 1 | | | | 24 | | 3 |
| | Gadidae | *Trisopterus luscus* | 17 | | | | | | | 485 | | 3 | | 2 | | 14 |
| | Lophidae | *Lophius* spp. | | 24 | 1 | 19 | | | | | 119 | 15 | 103 | | | |
| | Merlucciidae | *Merluccius merluccius* | 11 | 87 | 74 | 13 | | | | 85 | 24 | 203 | 12 | | | |
| | Molidae | *Mola mola*[2] | | | | 1 | | | | | | | | | | |
| | Mullidae | *Mullus surmuletus* | 4 | | 1 | | | | | 148 | | 15 | | | | |
| | Muraenidae | *Muraena helena* | | | | | | | 1 | | | | | | | |
| | Perciformes | *Argyrosomus regius* | | | | | | | | | | | | | | |
| | Phycidae | *Phycis phycis* | | | 3 | 1 | | | | 100 | | 22 | | 6 | | 9 |
| | Polyprionidae | *Polyprion americanus* | | | | | | | | | | 1 | 13 | | | |
| | Sarranidae | *Serranus cabrilla* | 15 | | 5 | | 6 | | | | | | | | | |
| | Scombridae | *Scomber colias* | 174 | 6 | 124 | 325 | | | | 334 | | 2 | 12 | | | |
| | Scorpaenidae | *Scorpaena scrofa* | 64 | | | | 4 | | 62 | | | | | | | |
| | Sebastidae | *Helicolenus dactylopterus* | | | 3 | 13 | | | | | | 25 | 12 | | | |
| | Soleidae | *Microchirus* spp. | | | | | | | | 32 | | | | | | |
| | | *Solea* spp. | 44 | | 27 | 2 | | | | | | | | | | |
| | Sparidae | *Dentex macrophthalmus* | | | | | | | | | | 3 | | | | |
| | | *Diplodus cervinus* | | | | | | | | | | | | 3 | | |
| | | *Diplodus sargus* | | | | | 1 | | | | | | | 19 | | |
| | | *Diplodus vulgaris* | 6 | | | | 4 | | | 141 | | | | 7 | | 1 |

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *Pagellus acarne* | 4 | | | | | | | 319 | | 51 | | | | |
| | | *Pagellus bogaraveo*[1] | | | | 12 | | | | | | | | | | |
| | | *Pagellus erythrinus* | 3 | | | | | | | 127 | | 2 | | | | 1 |
| | | *Pagrus pagrus* | | | | 1 | | | | | | 1 | | 4 | | |
| | | *Sparidae* | | | | | | | 111 | | | | | 107 | | |
| | | *Sparus aurata* | | | | | | 23 | | | | | | | | |
| | | *Spondyliosoma cantharus* | | 2 | 9 | | 6 | | | 19 | | 3 | | 1707 | | 1 |
| | Trigildae | *Lepidotrigla cavillone* | 40 | | 26 | 1 | | | | 60 | | 40 | | | | |
| | Zeidae | *Zeus faber* | | | | 1 | | | | 2 | | 6 | | | | |
| **Anthozoa** | Hormathiidae | *Adamsia palliata* | | | 6 | 2 | | | | | | | | | | |
| | Gorgonia | *Alcyonacea* | 3 | | | 6 | | | | | | | | | | |
| **Asteroidea** | Astropectinidae | *Astropecten aranciacus* | | 2 | 2 | | 1 | | 74 | | | | | | | |
| **Bivalvia** | Ostreidae | *Ostreidae* | | | 2 | | | | | | | | | | | |
| **Cephalopoda** | Loliginidae | *Loligo vulgaris* | 1 | | 4 | | | | | | | | | | | |
| | Octopodidae | *Octopus vulgaris* | | | | 1 | 2 | | 85 | | | | | 23 | 163 | 733 |
| **Echinoidea** | Echinidae | *Echinus acutus* | | | 5 | 21 | | | | | | | | | | |
| | Toxopneustidae | *Sphaerechinus granularis* | | | | 2 | | | 96 | | | | | | | |
| | Cidaridae | *Cidaris cidaris* | | | 17 | 10 | | | 4 | | | | | | | |
| | Echinodermata nid | | | | | 9999 | | | | | | | | | | |
| **Elasmobranchii** | Scyliorhinidae | *Scyliorhinus stellaris* | | | 16 | 6 | | | | 3 | | 471 | | | | |
| | Rajidae | *Raja clavata*[1] | | | | 8 | | | | 14 | | 3 | 1 | | | |
| | Rajidae | *Raja miraletus* | | | 5 | 7 | | | | | | 1 | 4 | | | |
| | Torpedinidae | *Torpedo* spp. | | | | | | | | | 2 | | | | | |
| **Gastropoda** | | | 6 | | | | | | | | | | | | | |
| | Aplysiida | *Aplysia fasciata* | | | | | | | 59 | | | | | | | |
| | Charoniidae | *Charonia lampas* | | | | 6 | 1 | | | 2 | | 5 | 18 | | | 6 |
| | Muricidae | *Bolinus brandaris* | | | | | | | 16 | | | | | | | |
| **Holothuroidea** | | | 5 | 2 | | | 1 | | | | | | | | | |
| | Synallactida | *Stichopus regalis* | | | 3 | | | | | | | | | | | |

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Malacostraca** | Cancridae | *Cancer pagurus* | | | | 3 | | | | | | 4 | 12 | | | |
| | Diogenidae | *Dardanus arrosor* | 2 | | | | 5 | | 26 | | | | | | | |
| | Galatheidae | *Galathea strigosa* | | | | | 1 | | | | | | | | | |
| | Homolidae | *Homola barbata* | | | | 5 | 18 | | | | | | | | | |
| | Palinuridae | *Palinurus elephas*[2] | | | | | | | | | | | 10 | | | |
| | Parthenopidae | *Parthenope macrochelos* | | | 2 | 4 | | | | | | | | | | |
| **Ophiuroidea** | Gorgonocephalidae | | 46 | | | | 2 | | | | | | | | | |
| **Porifera** | | | 18 | | | 36 | | | | | | | | | | |
| **Reptilia** | Testudines | *Dermochelys coriacea*[2] | | | | | | | 1 | | | | | | | |
| **UID** | | | 8 | | 5 | 27 | | | | | | | | | | |
| | | **Total: 58** | **673** | **123** | **350** | **533** | **56** | **23** | **628** | **1872** | **145** | **891** | **197** | **1905** | **163** | **769** |

## Chapter 6

# Reducing invertebrate by-catch in a coastal fishery using a raised monofilament trammel net.

## 6.1. Abstract

Trammel nets are one of the least selective fishing gears and are known to catch a variety of species, many of which are discarded, including important invertebrates that are considered habitat-forming species. These habitat-forming species include corals and sponges that are vulnerable to disturbances from fishing activities using bottom contact gear, although there are few studies focusing on this type of by-catch. Experimental fishing was conducted off the port of Portimão (southern Portugal) from November 2021 to April 2022 using standard and modified trammel nets rigged to be lifted off the bottom with the objectives of reducing invertebrate by-catch and impacts on the bottom habitat. The modified lifted net caught 39% less by-catch of invertebrates in numbers than the standard net. There was no significant decrease of catch rates of target species in the modified net. The results obtained with the two types of nets are discussed, as well as the necessity for good video recording equipment that can improve sampling accuracy, and the usefulness of interviewing the fishers on net performance after experimental fishing was conducted.

## 6.2. Introduction

Commercial fishing activities contribute to the degradation of seabed habitats due to the by-catch of invertebrates that serve as habitat-forming structures and ecosystem engineers. Organisms including corals, sponges, and kelp promote species' recruitment, foraging areas, and reproductive grounds, with various species living in and around them, but they are vulnerable to crushing, severing, or getting buried by fishing gear (Sainsbury et al. 1997, Bell 2008, Fuller et al. 2008). Few studies have focused on the by-catch of these species, especially in static gears. The use of gillnets appeared to result in some of the highest bycatch rates of habitat-forming structures, with up to 85% of gillnet deployments in the south of Portugal catching corals, and 45% of the corals consisting of entire colonies (Dias et al. 2020). In another study in Piedra de Layo and Piedra Zúñiga, Costa Rica, set gillnets were responsible for the highest percentages of kelp (*Eisenia arborea*) and gorgonian corals by-catch compared to lobster traps, drift gillnets, and fish traps (Shester and Micheli 2011). In one previous study on trammel nets in the Mediterranean, Catanese et al. (2018) found that discards contained many habitat-forming structures including seagrass, kelp, sponges, and hard corals, as well as a calcareous alga (*Lithothamnion* spp.).

Trammel nets consist of three panels, two outer large mesh size panels and a single inner mesh size panel, and are less species and size-selective than gillnets (Fabi et al. 2002, Erzini et al. 2006, Karakulak and Erk 2008). Individuals can be caught similarly to gillnets, in which they are wedged, gilled or entangled, but in addition, they can also be caught through pocketing or trammeling (Fabi et al. 2002, Erzini et al. 2006). Gonçalves et al. (2007, 2008) reported that discards can be up to 50% in numbers in trammel nets due to their low selectivity properties, making these nets one of the main fishing gears negatively impacting coastal benthic communities.

A guarding net, sometimes referred to as a "greca" net, which includes a single large mesh panel net up to 30 cm in height placed between the standard net and leadline, has been used to reduce by-catch when targeting various species including the prawn (*Penaeus kerathurus*), *Mullus* spp., and the spiny lobster (*Palinurus elephas*) (Metin et al. 2009, Aydin et al. 2013, Catanese et al. 2018). These studies have resulted in either no or non-significant decreases in commercial catch, and between 17 to 63% reduction in discard rates of by-catch species. However, in other studies where guarding nets were tested, a decrease in commercial catch of target species including cuttlefish (*Sepia officinalis*), green tiger prawn (*Penaeus semisulcatus*), and caramote prawn (*Penaeus kerathurus*) was recorded with the use of modified nets, preventing their acceptance by fishers (Gökçe et al. 2016, Sartor et al. 2018, Szynaka et al. 2018). In only one study was there a significant decrease in discards, mainly invertebrates, and a significant increase in the catch rates of the target species, cuttlefish (Martínez-Baños and Maynou 2018).

The present study was carried out in order to evaluate the potential of a new, modified raised trammel net designed to reduce by-catch, focusing on the cuttlefish (*Sepia officinalis*) trammel net métier in southern Portugal. The objective was to compare a standard and a modified net in terms of the catch composition (commercial, by-catch and discards), the economic yield, the amount of invertebrates captured, as well as the associated ecological impacts.

## 6.3. Materials and methods

### *6.3.1. Net design*

Two types of net were rigged: a standard trammel net (SN) and a modified net (AN), raised from the seabed by means of a net panel that is placed between the net and the leadline, made of a thin line diagonal pattern that the fishers call "spider" ("aranha," Fig. 6.1A). In the experimental sets a total of 15 net panels per net type (length 45-m, each) were used, with three standard and three modified nets alternating five times, giving a total of ten sections (e.g., SN1…SN3, AN1…AN3, SN4…SN6, etc.). Between each section a two-meter gap was used to reduce bias due to fish guidance effect, (Holst et al. 1998) for a total of approximately 1.5 kilometers of net.

Both the standard and the modified nets were entirely made of polyamide (PA) for both inner and outer panels. The inner mesh panel was made of PA monofilament of 0.35 mm twine diameter, 50 meshes high and 1000 meshes long, and the two large mesh outer panels of monofilament of 0.60 mm twine diameter, 4.5 meshes high and 200 meshes long. The modified net section was 20 cm in height, made of 6 mm polyethylene cable inserted between the net and the leadline (Fig. 6.1B). The raised net differed from the standard net in that there are ropes every two *aranha* meshes. The vertical slack for all the nets, or the inner panel stretched mesh height/outer panel stretched mesh height, was 1.96.

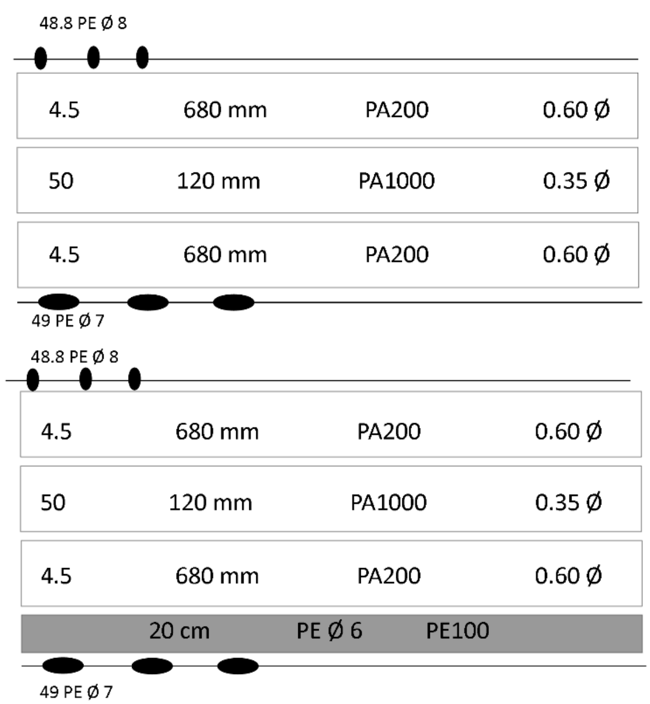


**Figure 6. 1.** Technical drawings of the two net types, the standard (top) and the modified net (bottom).

### *6.3.2. Experimental Fishing*

Experimental fishing took place off the coast of Algarve (southern Portugal), onboard a commercial fishing vessel belonging to the coastal multi-gear fleet registered in the port of Portimão (37.1362° N, 8.5377° W) (Fig. 6.2). A total of 16 experimental fishing trials were conducted from November 2021 to April 2022 at depths around 50 m in mixed sediment (various percentages of mud and sand) near to rocky bottoms. The nets were usually set and hauled back during the same morning, before sunrise, with few exceptions. Two HD cameras, GoPro Hero 7 and 6, filming cameras were set up on board to record any overlooked individuals in the net, specifically the invertebrate discards, in order to allow the validation of the by-catch abundance. This was done as the hauling speed is increased when the nets are free of any commercial individuals, and this increase makes it difficult to properly record all individuals caught. Each video was slowed down to observe any individual from the classes indicated, counting each severed piece of the sponges as individuals, and in which net type the individual were caught in. A total of 10 videos were watched out of the 16 trips due to poor footage quality or technical issues with the GoPros.

The net was hauled in with a hydraulic hauler; upon arrival on board, each individual was removed manually, assigned the net type it was caught, and identified to the lowest possible taxonomic level. Individual size of ray-finned and cartilaginous fishes was measured as the total length, while for crustaceans the carapace width, and for cuttlefish (*Sepia officinalis*), the mantle length. Each individual was registered as 'discard' (including by-catch of unwanted species and undersized or predated or scavenged commercial species) or 'commercial' according to the fishers sorting the catch. Invertebrate by-catch species individuals were noted only by observation.

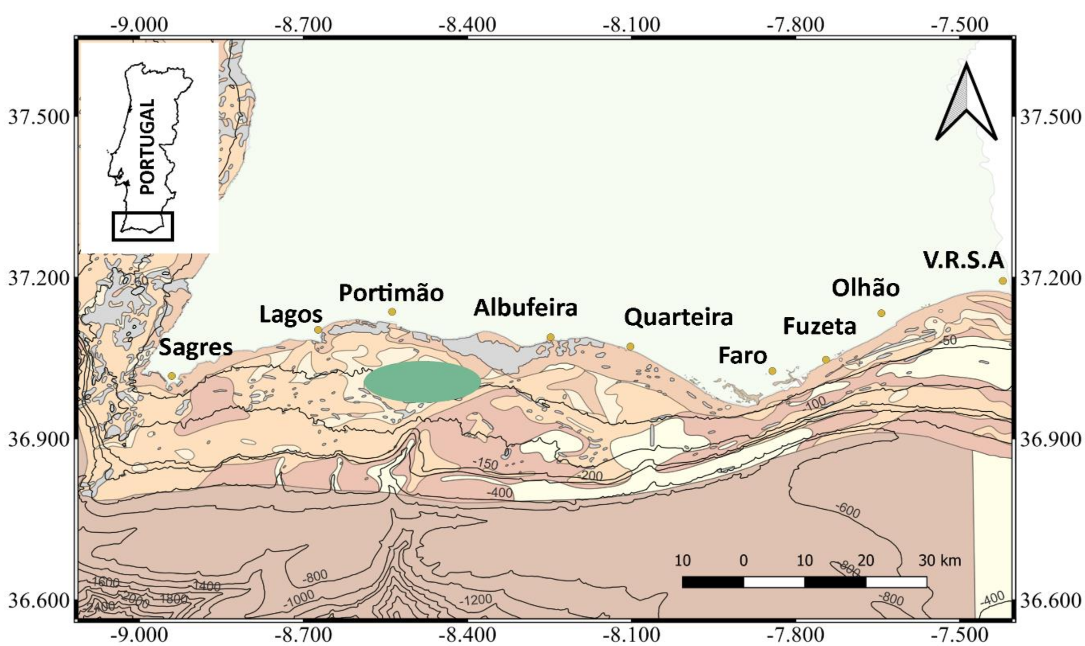


**Figure 6. 2.** Map of the Algarve coast with the ellipse representing the general location of all the fishing trips.

*6.3.3. Data Analysis*

Using weight-length relationships parameters, biomass in grams and length in cm, in which a and b are provided by FishBase, $Froese\ and\ Pauly\ (2022),$ the weights of each individual fish were estimated:

$$Biomass\ =\ a\ *\ Length^{b}$$

The total catch (kg) of each species was converted into euros using the average price per kg obtained from the first auction sale (Report of DGRM 2020). The weight of by-catch species individuals was recorded for all hauls in the two net types SN (standard) and AN (“Aranha” - modified) (DGRM ‘Recursos da Pesca 2020). CPUE was calculated for the effort in numbers and in biomass, along with the mean value (euros) per 1000 m of trammel net and the respective standard deviation. A paired t-test (Stats package R Core Team, 2022) was used, for both the real time data and the video validation analysis (of the habitat forming invertebrates only), to evaluate significant in differences in CPUEs between the two net types:

$$CPUE = \left(\frac{number\ of\ individuals}{total\ length\ of\ net}\right) * 1000\ m$$

The length distribution of the species with over 100 individuals caught in total over the course of the 16 trips, was calculated and a two-sample Kolmogorov-Smirnov test, using the Stats package in R, was used to evaluate possible differences in size frequency distributions between the net types. Furthermore, a nMDS (Nonmetric multidimensional scaling) was used to model the response variables (commercial species CPUE and discard species CPUE) as a function of net type (AN = experimental net and SN = standard net), Season (Fall, Winter, Spring), and trip number (T1…T16) in the program PAST 4.03.

*6.3.4. Interviews*

Following the trials, preliminary results with CPUEn and CPUEkg of the total commercial catch, the total discard catch, and the cuttlefish and flatfish of the two net types were presented to 16 fishers operating trammel nets, which represent approximately 23% of the fleet using trammel nets in the Algarve. The fishers were asked to give their opinions on the nets performance (standard vs. modified net), which one they believe would be more useful and would be more likely to operate with in the future. They were also asked about the inner mesh size in the trammel nets they use and the cost per panel of a standard net (for comparative purposes). Finally, the fishers were also asked for any practical modifications that could potentially be tested in the future.

## 6.4. Results

### *6.4.1. Commercial catch*

A total of 418 commercially valuable individuals were caught over the course of 16 trips, with a total weight of 358kg, and value of €1870. The standardized values of commercial species caught in each net type are shown in Table 6.1. A total of 237 individuals (188 kg and €1003) were caught in the standard net (SN) and 181 individuals (170 kg and €866) in the modified "aranha" net (AN). The CPUE for the standard net was 17.41 kg per 1000 m of net, corresponding to 22 individuals, and the VPUE (value per unit of effort) € 92.91; for the modified net, the CPUE was 15.74 kg per 1000 m of net (17 individuals) and the VPUE €80.24. The ratios (SN:AN) for the CPUE/VPUE (abundance, biomass, and value) are 1:0.76, 1:0.90, and 1:0.86. According to paired t-test carried out on each of the CPUE/VPUE of the observed onboard results, there were no significant differences between the two net types ($p > 0.05$).

A total of 114 commercial-sized individuals of cuttlefish (above the minimum landing reference size MLRS, >10 cm) were caught, totaling 159.44 kg and sold for €795.66. The standard net accounted for 52.6% of the number of individuals caught, and 46. 8% of the biomass and value. The overall catch value ratio (SN:AN) was 1:1.38, with larger, higher valued individuals being caught in the modified net. A total of 140 commercial-sized individuals of the bastard sole (*Microchirus azevia*), with an MLRS of >=18 cm, were caught, totaling 25.62 kg and €263.89. The standard net accounted for 57.86% of the individuals caught, 64.36% of the biomass and value. According to the paired t-test carried out on the combined CPUEs of cuttlefish and the bastard sole, there were no significant differences between the two net types ($p > 0.05$).

**Table 6.1.** Mean commercial catch per 1000 m of trammel net in numbers (CPUEn) and biomass (CPUEkg), and value (VPUE€) and associated standard deviations (sd) for the modified trammel net (AN) and the standard trammel net (SN). The main target species are in bold.

| Class | Species | CPUEn (AN) | sd | CPUEkg (AN) | sd | VPUE € A (AN) | sd | CPUE n (SN) | sd | CPUEk g (SN) | sd | VPUE € (S (SN) | sd |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Actinopterigii | *Balistes capriscus* | 0.185 | 0.500 | 0.124 | 0.338 | 0.531 | 1.433 | 0.833 | 1.031 | 0.582 | 0.669 | 2.489 | 2.864 |
| | *Dentex canariensis* | (-) | (-) | (-) | (-) | (-) | (-) | 0.093 | 0.250 | 0.201 | 0.543 | 3.376 | 9.116 |
| | *Diplodus sargus* | 0.093 | 0.250 | 0.153 | 0.414 | 1.222 | 3.300 | (-) | (-) | (-) | (-) | (-) | (-) |
| | *Diplodus vulgaris* | 0.093 | 0.250 | 0.010 | 0.027 | 0.024 | 0.064 | 0.278 | 0.403 | 0.064 | 0.126 | 0.151 | 0.297 |
| | *Merluccius merluccius* | 0.370 | 0.447 | 0.162 | 0.294 | 0.347 | 0.628 | 0.278 | 0.750 | 0.049 | (-) | 0.105 | 0.282 |
| | ***Microchirus azevia*** | **5.278** | **4.885** | **0.721** | **0.653** | **9.269** | **8.385** | **6.667** | **5.888** | **0.945** | **0.817** | **12.145** | **10.503** |
| | *Mullus surmuletus* | 0.185 | 0.342 | 0.056 | 0.113 | 1.034 | 2.077 | 0.185 | 0.342 | 0.093 | 0.187 | 1.716 | 3.440 |
| | *Pagellus acarne* | 0.648 | 0.892 | 0.180 | 0.290 | 0.926 | 1.493 | 0.463 | 0.602 | 0.150 | 0.248 | 0.774 | 1.275 |
| | *Pagellus bogaraveo* | (-) | (-) | (-) | (-) | (-) | (-) | 0.648 | 1.504 | 0.184 | 0.468 | 3.091 | 7.863 |
| | *Pagellus erythrinus* | 0.833 | 0.814 | 0.318 | 0.349 | 2.548 | 2.802 | 0.833 | 1.094 | 0.631 | 0.975 | 5.062 | 7.818 |
| | *Pagrus auriga* | 0.093 | 0.250 | 0.210 | 0.597 | 2.802 | 7.566 | 0.185 | 0.342 | 0.214 | 0.444 | 2.851 | 5.921 |
| | *Pagrus pagrus* | 0.093 | 0.250 | 0.064 | 0.173 | 0.857 | 2.314 | (-) | (-) | (-) | (-) | (-) | (-) |
| | *Phycis phycis* | (-) | (-) | (-) | (-) | (-) | (-) | 0.370 | 0.775 | 0.099 | 0.217 | 0.253 | 0.557 |
| | *Sarda sarda* | 0.093 | 0.250 | 0.037 | 0.100 | 0.297 | 0.801 | (-) | (-) | (-) | (-) | (-) | (-) |
| | *Scophthalmus rhombus* | 0.093 | 0.250 | 0.072 | 0.195 | 0.927 | 2.502 | (-) | (-) | (-) | (-) | (-) | (-) |
| | *Solea senegalensis* | 0.185 | 0.500 | 0.119 | 0.321 | 1.528 | 4.125 | 0.370 | 0.775 | 0.219 | 0.469 | 2.819 | 6.033 |
| | *Solea solea* | 0.463 | 1.014 | 0.079 | 0.183 | 1.021 | 2.346 | 0.370 | 0.775 | 0.057 | 0.114 | 0.732 | 1.464 |
| | *Sparus aurata* | 0.093 | 0.250 | 0.070 | 0.189 | 0.722 | 1.950 | 0.370 | 0.775 | 0.227 | 0.468 | 2.338 | 4.824 |
| | *Trisopterus luscus* | (-) | (-) | (-) | (-) | (-) | (-) | 0.093 | 0.577 | 0.028 | 0.075 | 0.080 | 0.215 |
| | *Uranoscopus scaber* | (-) | (-) | (-) | (-) | (-) | (-) | 0.370 | 0.342 | 0.161 | 0.243 | 0.688 | 1.039 |
| | *Zeus faber* | (-) | (-) | (-) | (-) | (-) | (-) | 0.185 | 0.342 | 0.095 | 0.175 | 0.405 | 0.748 |
| Cephalopoda | *Octopus vulgaris* | 0.185 | 0.342 | (-) | (-) | (-) | (-) | 0.185 | (-) | (-) | (-) | (-) | (-) |
| | ***Sepia officinalis*** | **4.722** | **2.105** | **7.858** | **4.424** | **39.212** | **(-)** | **5.093** | **2.683** | **6.906** | **3.867** | **34.460** | **(-)** |
| Elasmobranchii | *Dipturus oxyrinchus* | (-) | (-) | (-) | (-) | (-) | (-) | 0.185 | 0.342 | 0.718 | 1.762 | 2.096 | 18.397 |
| | *Raja brachyura* | 0.556 | 0.806 | 0.984 | 1.287 | 2.873 | 3.758 | 0.833 | 0.964 | 1.178 | 1.349 | 3.441 | 3.940 |
| | *Raja clavata* | 0.556 | 0.619 | 1.544 | 1.954 | 4.508 | 5.651 | 0.463 | 0.793 | 1.219 | 2.089 | 3.558 | 6.100 |
| | *Raja montagui* | 0.556 | 0.619 | 0.678 | 0.756 | 1.980 | 2.208 | 0.648 | 0.727 | 0.668 | 0.830 | 1.951 | 2.424 |
| | *Raja undulata* | 0.185 | 0.342 | 0.709 | 1.359 | 2.071 | 3.968 | 0.093 | 0.250 | 0.328 | 0.885 | 0.957 | 2.583 |
| | *Rostroraja alba* | 0.185 | 0.500 | 0.509 | 1.373 | 1.485 | 4.009 | 0.278 | 0.544 | 1.462 | 3.063 | 4.269 | 8.943 |
| | *Torpedo marmorata* | 0.741 | 0.966 | 0.896 | 1.169 | 2.617 | 3.413 | 0.556 | 0.806 | 0.485 | 0.822 | 1.417 | 2.400 |
| | *Torpedo torpedo* | 0.093 | 0.250 | 0.124 | 0.335 | 0.362 | 0.978 | 0 | (-) | (-) | (-) | (-) | (-) |
| Gastropoda | *Bolinus brandaris* | (-) | (-) | (-) | (-) | (-) | (-) | 0.093 | 0.250 | (-) | (-) | (-) | (-) |
| | *Charonia lampas* | 0.093 | 0.250 | (-) | (-) | (-) | (-) | 0.648 | 0.630 | (-) | (-) | (-) | (-) |
| Malacostraca | *Maja squinado* | 0.093 | 0.250 | 0.064 | 0.173 | 0.242 | 0.654 | 0.278 | 0.544 | 0.448 | 1.040 | 1.690 | 3.921 |

According to the nMDS of commercial CPUE, using season and net type as variables in figure 6.3, there is some similarity among the trips regardless of the net type or the season, which some exceptions like the standard net catch during trip 5, 9, 11 and 14 or the catch of the modified net during trip 5 and 9. When looking into the data, it appears that the CPUE of bastard soles is relatively high compared to many of the other trips with three to four other species beign caught resulting in small CPUEs. This nDMS resulted in a stress value of 0.07714, or less than 0.1, indicating a fair fit, meaning that the interpretation does not require caution.

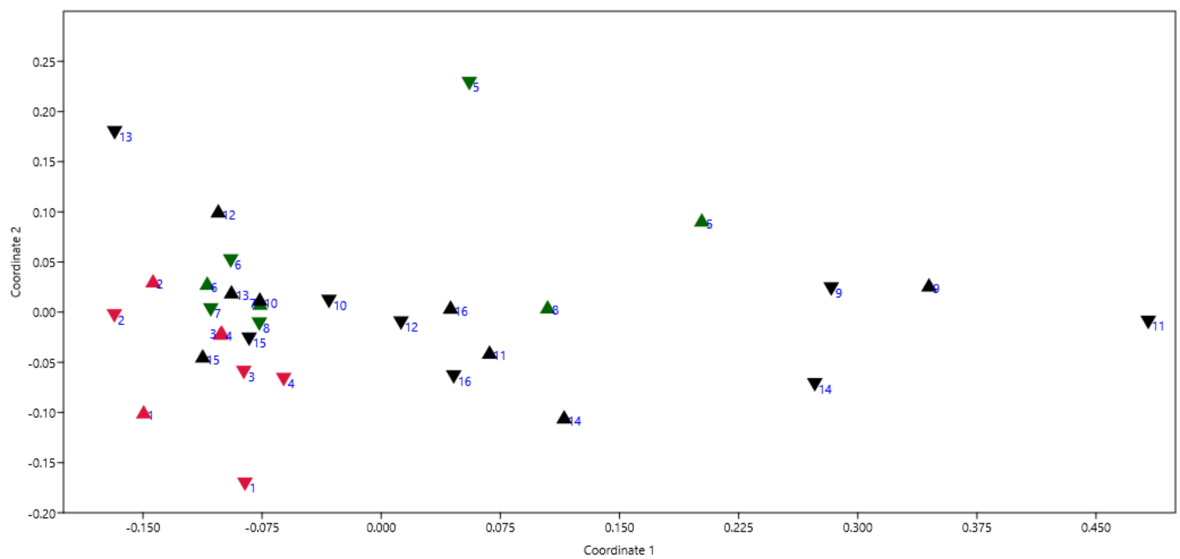


**Figure 6.3.** A Nonmetric multidimensional scaling (nMDS) of the commercial CPUE (catch per unit effort) per gear type (triangle – modified net, upside down triangle – standard) and season (red – fall, green – spring, and black – winter) in 16 trips.

*6.4.2. Discarded catch*

A total of 1459 individuals were discarded in 16 trips. The primary reason for discarding was the lack of commercial value of the species, with the majority of by-catch being made up of the classes Anthozoa, Demospongiae and Gymnolaemata, and therefore no weight was assigned to the individuals. The individuals of species with commercial value, were primarily discarded due to damage, caused by predation/scavenging. The standardized values of the discarded species caught in each net type are shown in Table 6.2. The commercial individuals that were discarded were from the taxonomic classes Actinopterygii, Cephalopoda, Elasmobranchii, and Malacostraca and totaled 81.53 kg. The standard net represented 52.09% and 53.35% of the abundance and biomass of discards, respectively. The main discarded species included *Axinella polypoides*, *Desmacidon fruticosum*, *Parazoanthus axinellae*, and *Scomber scombrus*. According to paired t-test carried out on each of the CPUEs from the onboard observations, concerning the discards, there were no significant differences between the two net types ($p > 0.05$).

**Table 6.2.** Discards per 1000 m of trammel net in, according to the onboard observations, numbers (CPUEn) and biomass (CPUEkg) and associated standard deviations (sd) for the modified trammel net (AN) and the standard trammel net (SN). Species with a (V) vulnerablem, (NT) near threatened, CR (Critically endangered) in Europe according to the IUCN. The main discarded species are in bold.

| Class | Species | CPUEn (AN) | Sd | CPUE kg (AN) | sd | CPUEn (SN) | sd | CPUEkg (SN) | sd |
|---|---|---|---|---|---|---|---|---|---|
| **Actinopteri** | *Boops boops* | 0.370 | 0.447 | 0.026 | 0.045 | 0.185 | 0.500 | 0.008 | 0.023 |
| | *Chelidonichthys lastoviza* | 0.648 | 0.727 | 0.097 | 0.117 | 1.852 | 1.653 | 0.197 | 0.173 |
| | *Chelidonichthys lucerna* | 0.093 | 0.250 | 0.022 | 0.059 | 0.278 | 0.544 | 0.015 | 0.034 |
| | *Chelidonichthys obscurus* | 2.037 | 1.544 | 0.338 | 0.316 | 2.685 | 1.905 | 0.436 | 0.320 |
| | *Dicentrarchus labrax* | 0.093 | 0.250 | 0.131 | 0.354 | (-) | (-) | (-) | (-) |
| | *Diplodus vulgaris* | 0.093 | 0.250 | (-) | (-) | 0.093 | 0.250 | 0.009 | 0.025 |
| | *Fish n.i.d.* | 1.204 | 1.223 | (-) | (-) | 0.648 | 0.727 | (-) | (-) |
| | *Labrus mixtus* | 0.093 | 0.250 | 0.011 | 0.029 | 0.185 | 0.500 | 0.016 | 0.044 |
| | *Merluccius merluccius* | (-) | (-) | (-) | (-) | 0.093 | 0.250 | 0.014 | 0.041 |
| | *Microchirus azevia* | 1.759 | 3.016 | 0.170 | 0.329 | 2.037 | 3.519 | 0.170 | 0.351 |
| | *Mola mola* | 0.185 | 0.500 | 0.460 | 1.242 | (-) | (-) | (-) | (-) |
| | *Mullus surmuletus* | 0.185 | 0.342 | (-) | (-) | (-) | (-) | (-) | (-) |
| | *Pagellus acarne* | 0.463 | 0.873 | 0.069 | 0.137 | 0.185 | 0.500 | (-) | (-) |
| | *Pagellus bogaraveo (NT)* | (-) | (-) | (-) | (-) | 0.185 | 0.500 | 0.057 | 0.155 |
| | *Pagellus erythrinus* | 0.185 | 0.342 | 0.015 | 0.041 | 0.185 | 0.500 | 0.017 | 0.043 |
| | *Sardina pilchardus* | 0.185 | 0.342 | 0.010 | 0.020 | (-) | (-) | (-) | (-) |
| | *Scomber colias* | 0.741 | 1.265 | 0.057 | 0.084 | 0.833 | 1.788 | 0.031 | 0.075 |
| | ***Scomber scombrus*** | **8.148** | **21.469** | **0.752** | **1.993** | **4.907** | **13.250** | **0.449** | **1.213** |
| | *Scorpaena notata* | 0.185 | 0.342 | 0.011 | 0.022 | 0.556 | 0.719 | 0.056 | 0.075 |
| | *Serranus cabrilla* | 1.204 | 1.276 | 0.138 | 0.158 | 1.111 | 1.125 | 0.136 | 0.138 |
| | *Solea senegalensis* | 0.093 | 0.250 | 0.048 | 0.130 | (-) | (-) | (-) | (-) |
| | *Spicara maena* | 0.093 | 0.250 | 0.012 | 0.031 | (-) | (-) | (-) | (-) |
| | *Trachinus draco* | 1.019 | 1.352 | 0.039 | 0.049 | 0.741 | 1.033 | 0.049 | 0.081 |
| | *Trachurus trachurus* | 0.648 | 1.088 | 0.057 | 0.134 | 0.278 | 0.544 | 0.019 | 0.197 |
| | *Trisopterus luscus* | 0.093 | 0.250 | 0.021 | 0.057 | 0.370 | 0.775 | 0.089 | 0.071 |
| | *Zeus faber* | (-) | (-) | (-) | (-) | 0.093 | 0.250 | 0.026 | (-) |
| **Anthozoa** | *Coral n.i.d.* | (-) | (-) | (-) | (-) | 0.093 | 0.250 | (-) | (-) |
| | *Dendrophyllia ramea* | 0.185 | 0.500 | (-) | (-) | 0.278 | 0.544 | (-) | (-) |
| | *Eunicella verrucosa (Vu)* | 0.185 | 0.500 | (-) | (-) | 0.648 | 0.892 | (-) | (-) |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | *Leptogorgia sarmentosa* | 2.963 | 3.559 | (-) | (-) | 3.796 | 3.540 | (-) | (-) |
| | *Paramuricea* cf. *grayi* | 1.852 | 2.887 | (-) | (-) | 2.407 | 3.900 | (-) | (-) |
| | ***Parazoanthus axinellae*** | **13.796** | **12.877** | **(-)** | **(-)** | **11.759** | **14.125** | **(-)** | **(-)** |
| **Ascidiacea** | *Ascidia n.i.d.* | 0.093 | 0.250 | (-) | (-) | (-) | (-) | (-) | (-) |
| | *Phallusia mammillata* | 0.093 | 0.250 | (-) | (-) | (-) | (-) | (-) | (-) |
| | *Synoicum blochmanni* | 0.093 | 0.250 | (-) | (-) | 0.185 | 0.342 | (-) | (-) |
| **Asteroidea** | *Astropecten aranciacus* | 0.093 | 0.250 | (-) | (-) | 0.556 | 0.719 | (-) | (-) |
| | *Ophidiaster ophidianus* | 0.185 | 0.500 | (-) | (-) | 0.185 | 0.342 | (-) | (-) |
| **Cephalopoda** | *Octopus vulgaris* | (-) | (-) | (-) | (-) | 0.185 | 0.342 | (-) | (-) |
| | *Sepia officinalis* | 0.278 | 0.403 | 0.158 | 0.426 | 0.463 | 0.793 | 0.853 | 1.813 |
| **Demospongiae** | ***Axinella polypoides*** | **8.148** | **4.747** | **(-)** | **(-)** | **8.148** | **3.981** | **(-)** | **(-)** |
| | *Cliona celata* | 0.370 | 0.447 | (-) | (-) | 1.667 | 2.066 | (-) | (-) |
| | *Demospongie* | 0.556 | 0.814 | (-) | (-) | 0.370 | 0.450 | (-) | (-) |
| | ***Desmacidon fruticosum*** | **4.352** | **3.549** | **(-)** | **(-)** | **5.648** | **3.125** | **(-)** | **(-)** |
| | *Porifera n.i.d.* | 0.185 | 0.500 | (-) | (-) | 0.093 | 0.250 | (-) | (-) |
| **Echinoidea** | *Paracentrotus lividus* | (-) | (-) | (-) | (-) | 0.093 | 0.250 | (-) | (-) |
| **Elasmobranchii** | *Dipturus oxyrinchus* | (-) | (-) | (-) | (-) | 0.185 | 0.500 | 0.046 | 0.124 |
| | *Myliobatis aquila (VU)* | 0.278 | 0.403 | 0.162 | 0.322 | 0.093 | 0.250 | 0.122 | 0.329 |
| | *Raja brachyura (NT)* | 0.278 | 0.750 | (-) | 0.523 | 0.185 | 0.342 | (-) | 0.580 |
| | *Raja microocellata* | (-) | (-) | (-) | (-) | 0.093 | 0.250 | (-) | (-) |
| | *Raja miraletus* | 0.093 | 0.250 | 0.025 | 0.067 | (-) | (-) | (-) | (-) |
| | *Raja montagui* | 0.370 | 0.775 | 0.230 | 0.543 | 0.278 | 0.544 | 0.214 | 0.464 |
| | *Raja undulata (NT)* | 0.093 | 0.250 | 0.228 | 0.614 | 0.093 | 0.250 | 0.250 | 0.674 |
| | *Rostroraja alba (CR)* | (-) | (-) | (-) | (-) | 0.093 | 0.250 | 0.230 | 0.621 |
| | *Torpedo marmorata* | (-) | (-) | (-) | (-) | 0.093 | 0.250 | 0.210 | 0.566 |
| **Rajiformes** | *Leucoraja naevus* | (-) | (-) | (-) | (-) | 0.093 | 0.250 | (-) | (-) |
| **Gastropoda** | *Cymbium olla* | 0.093 | 0.250 | (-) | (-) | 0.370 | 0.577 | (-) | (-) |
| **Gymnolaemata** | *Adeonella calveti* | 1.944 | 1.870 | (-) | (-) | 2.500 | 3.030 | (-) | (-) |
| | *Myriapora truncata* | 0.648 | 1.153 | (-) | (-) | 1.296 | 2.971 | (-) | (-) |
| | *Pentapora fascialis* | 0.463 | 0.793 | (-) | (-) | 0.648 | 0.892 | (-) | (-) |
| **Holothuroidea** | *Holothuria arguinensis* | (-) | (-) | (-) | (-) | 0.093 | 0.250 | (-) | (-) |
| | *Holothuria forskali* | 0.278 | 0.775 | (-) | (-) | 0.463 | 0.806 | (-) | (-) |
| | *Parastichopus regalis* | 0.093 | 0.250 | (-) | (-) | 0.463 | 0.602 | (-) | (-) |
| **Hydrozoa** | *Hydrozoa n.i.d.* | 0.093 | 0.250 | (-) | (-) | 0.185 | 0.342 | (-) | (-) |
| **Malacostraca** | *Calappa granulata* | 0.278 | 0.544 | (-) | (-) | 0.185 | 0.342 | (-) | (-) |
| | *Dardanus arrosor* | 0.741 | 1.095 | (-) | (-) | 1.667 | 1.204 | (-) | (-) |
| | *Homola barbata* | (-) | (-) | (-) | (-) | 0.093 | 0.250 | (-) | (-) |
| | *Maja squinado* | (-) | (-) | (-) | (-) | 0.093 | 0.250 | 0.035 | 0.094 |
| **n.i.d.** | *Bryzoa n.i.d.* | 0.278 | 0.750 | (-) | (-) | 0.278 | 0.750 | (-) | (-) |
| **Ophiuroidea** | *Astrospartus mediterraneus* | 3.426 | 2.469 | (-) | (-) | 5.556 | 5.222 | (-) | (-) |
| **Sabellida** | *Filograna implexa* | 0.185 | 0.342 | (-) | (-) | 0.093 | 0.250 | (-) | (-) |
| **Scyphozoa** | *Rhizostoma pulmo* | 0.833 | 1.360 | (-) | (-) | 0.463 | 0.630 | (-) | (-) |
| **Thaliacea** | *Pyrosoma atlanticum* | 0.278 | 0.544 | (-) | (-) | 0.185 | 0.500 | (-) | (-) |

According to the nMDS of commercial CPUE, using season and net type as variables in figure 6.4, there is some similarity among the trips regardless of the net type or the season, with the exception of trip 2 with both net types. Looking into the data, it appears that there was a relatively high CPUE of the by-catch species *Scomber scombrus*. This nMDS shows a stress value of 0.113, indicating that this is not a good fit.

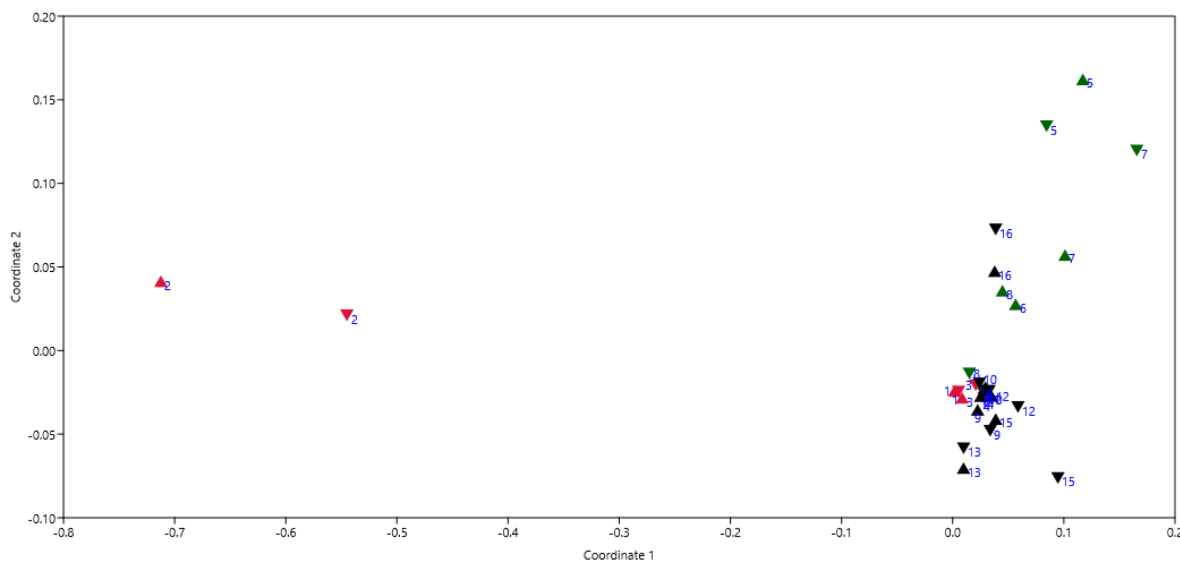


**Figure 6.4.** A Nonmetric multidimensional scaling (nMDS) of the discarded CPUE (catch per unit effort) per gear type (triangle – modified net, upside down triangle – standard) and season (red – fall, green – spring, and black – winter) in 16 trips.

### *6.4.2.1. Video analysis*

According to the video analysis, a total of 1260 individuals from the classes Anthozoa, Demospongie, Gymnolaemata were discarded in 10 trips. Approximately 61% of the total number of these individuals was caught in the standard net. Discards included some important species such as *Dendrophylia ramea* and *Paramuricea clavata* which are protected under Portuguese Law. The paired t-test showed a significant difference between the two net types ($p < 0.05$).

### *6.4.3. Length Distributions*

The length frequency distributions of the four most abundant species caught are shown in Figure 6.5. The bastard sole had the widest length range, from 12.0 cm to 37.0 cm. The mantle length frequency distributions of cuttlefish (Fig. 3b) ranged from 17.5 cm to 41.0 cm, followed by the longfin gurnard (*Chelidonichthys obscurus*) with a length frequency of 18.0 to 28.0 cm. The Atlantic mackerel had the smallest length range of the three species, from 21.2 cm to 28.0 cm. The size distributions of the two net types overlapped for all four species and the K–S two-sample test showed no significant differences ($p > 0.05$).

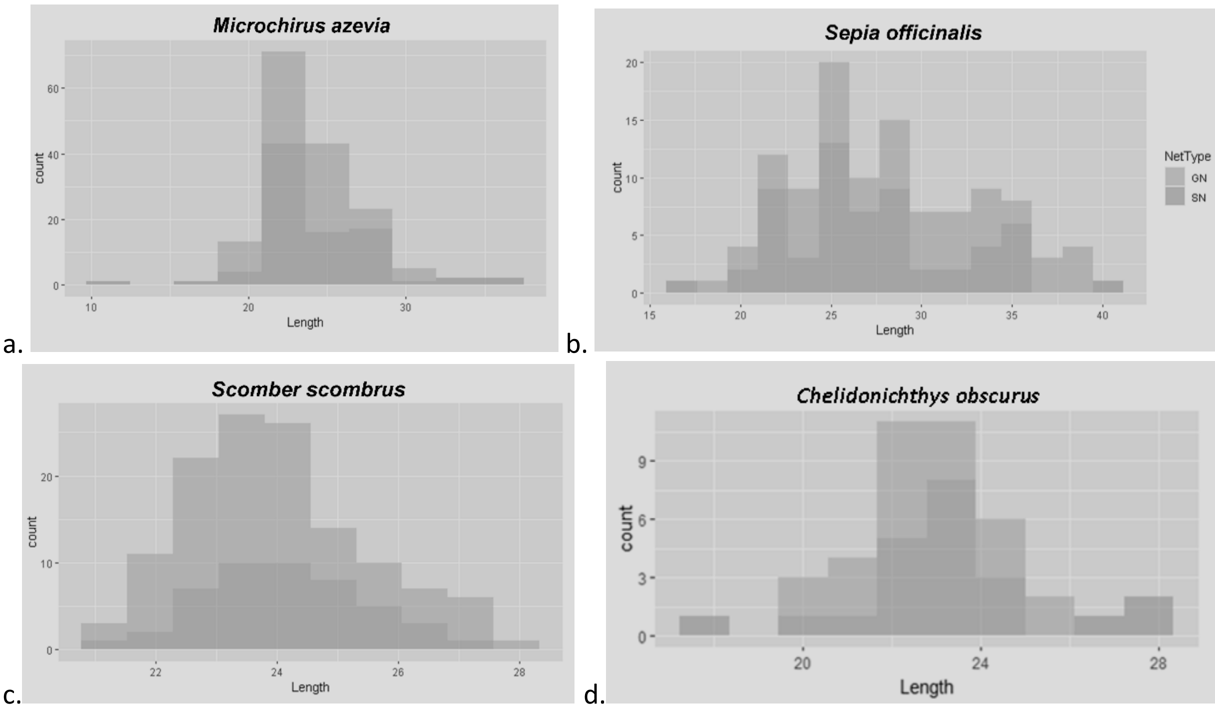


**Figure 6. 5.** The length distributions of the four species with the highest abundance; a. bastard sole, b. cuttlefish and c. Atlantic mackerel, d. longfin gurnard [AN = experimental net and SN = standard net).

### *6.4.4. Fishers' perceptions*

A total of 16 interviews were conducted in five ports in Southern Portugal with both coastal and artisanal (vessels with an overall length, LOA, above and under 9 m, respectively) fishers who use trammel nets. A total of seven different trammel net configurations were reported by fishers (Table 6.3). Two vessels in Sagres used trammel nets to catch other species (*Lophius* spp. and *Zeus faber*) with the remainder of the vessels targeting cuttlefish during some part of the year. Métiers 4, 6, 7 were represented by two vessels each. The inner mesh size used to target cuttlefish and sole varied between 33 mm (used inside the Ria Formosa, a coastal lagoon) and 120 mm (used off the coast), with prices per panel ranging between €15 to €26 (just the panel without the bouys, leadlines, etc.) and €60 to €120 (with the leadline, buoys and weights). The fishers' opinion on the performance of the modified nets were noted, with 10 of the fishers not being convinced or stating that they already attempted a similar design, and it did not function. Some fishers were interested or stated that they would use the modification if it provided good results. One fisher proposed a gear alteration, in which the leadline would be replaced with weights so that the bottom line had greater flexibility for draping over the rockier parts of the bottom.

**Table 6.3.** Results from the interviews including the métier, the port, the category of boat, the inner mesh side of the respective trammel net, the coast of the panel, and the response (negative or positive) the vessels of each métier per vessel, with * representing the single fisher who made a modification suggestion, and the total number of vessels participating in the métier.

| MÉTIER | PORT | BOAT CAT. | INNER MESH USED (MM) | NET PANEL COST (€) | FISHERS' OPINION | | NO. OF VESSELS |
|---|---|---|---|---|---|---|---|
| | | | | | - | + | |
| 1 | Olhão | Artisanal | 33 | 100 | | 2 | 2 |
| 2 | Olhão, Quarteira | Artisanal | 80 | 25-100 | 1 | 2 | 3 |
| 3 | Quarteira, Sagres | Artisanal, Coastal | 100 | 66-120 | 3 | *1 | 4 |
| 4 | Quarteira, Tavira | Artisanal | 110 | 26-75 | 1 | | 2 |
| 5 | Olhão,Portimão, Sagres | Coastal | 120 | 15-70 | 3 | 1 | 3 |
| 6 | Sagres | Coastal | 200 | 80 | | 1 | 1 |
| 7 | Sagres | Coastal | 240 | N.A. | | 1 | 1 |

## 6.5. Discussion

### *6.5.1. Do the raised nets work?*

By-catch reduction is often focused on megafauna such as seabirds, marine mammals, and sea turtles caught in fishing gear and often resulting in their death (Lewison et al. 2004, Alexandre et al. 2022). Studies regarding by-catch reduction of invertebrates are not as common, even though invertebrates such as corals and sponges provide architectural complexity and shelter for many species (e.g., Moore et al. 2009, Grabowski et al. 2014, Brownell et al. 2019). They are often referred to as "animal forests" which influence hydrodynamics and release nutrients and promote particle retention and carbon fixation (Rossi et al. 2017). Studies regarding by-catch of corals are more common regarding deep-sea fishing, including gillnets and trawls which tend to strip coral coverage (Clark and O'Driscoll, 2003, Dias et al, 2020). While some studies on gillnets were carried out, there are few that highlight the incidental capture of habitat-forming structure species in trammel nets, which are even more harmful than gillnets towards these species (Gonçalves et al. 2008, Karakulak and Erk, 2008, Shester and Micheli, 2011, Catanese et al. 2018, Dias et al. 2020). The environmental impact of removing these species is either direct or indirect, including the reduction of species that filter the water, reducing habitat, and food sources for other organisms that rely on these structure species, increasing competition among those species. There is a necessity for better understanding of the ecological roles of the local species (Wulff 2001, Fuller et al. 2008) and the results of the impacts of extractive activities on them and on the health of the associated ecosystems.

Similarly to previous studies, specifically those in which guarding nets have been used to reduce by-catch (Metin et al. 2009, Aydin et al. 2013, Catanese et al. 2018), the results of this study show that lifting the standard trammel net off the seabed tends to reduce non-commercial invertebrate by-catch, while maintaining the catch rates of demersal target species such as the cuttlefish, with a tendency (non-insignificant),to reduce the catch rates of other commercial benthic species such as various species of soles.

In the present study, results of the t-test showed there was a non-significant increase in the catch of cuttlefish by weight, and thereby value. A corresponding non-significant decrease was also recorded for flatfish, specifically the bastard sole (*M. azevia*). While this was predictable due to the nature of the net, as it was lifted from the seabed and flatfish are more likely to be entangled near the bottom of a trammel net, it was a smaller difference when compared to that previously observed by Szynaka et al. (2018) when using a trammel net modified with a guarding net between the leadline and the trammel net. The reason may be either due to the difference in height in the net bottom section, 30 cm versus 20 cm in the current study, or perhaps due to the net standing differently in the water column than the net used in previous studies. However, the net behavior could not be compared due to the lack of underwater footage data of the previously modified net. Interestingly, the slack was more taunt in the current study (calculated vertical slack from the previous net was 2.04 vs 1.96 in the current study), which could also affect catch rates.

In regard to commercial catch, it appears that some seabream and sole species were caught during specific trips. Other species were not strongly related to any trips, seasons, or net type. The ratios in CPUE of cuttlefish and bastard sole of the standard net to the modified net were 1:0.93 and 1:0.79, respectively, which indicates that the raised modified net was successful in maintaining acceptable catch rates of these commercial species, while in Martínez-Baños and Maynou (2018) more cuttlefish was caught in the modified net with the greca. Size differences were found to be non-significant between the two nets types regarding cuttlefish, although the modified raised net could have caught larger individuals due to their movement patterns as they are more likely to move further up the water column than smaller individuals as they move vertically to hunt during the night (Castro & Guerra, 1989, Quintela and Andrade, 2002).

In regard to discarded catch, it appears that some sea sponges, corals, and sea fans were caught during specific trips. Other species were not strongly related to any trips, seasons, or net type. The main discards were sponges and one fish species, the Atlantic mackerel (*Scomber scombrus*). The Atlantic mackerel is sometimes sold as a commercial species when caught with other types of gears in large quantities but, usually discarded when caught in relatively small numbers by static gears, as it was in the present case. The two most discarded species were the sponges *Axinella polypoides* and *Desmacidon fruticosum*, representing 19.74% of the total discards in numbers. Destroying these types of habitat structures can be problematic for the local environment and the species that depend on them as sponges fill many ecological niches.

While the IUCN (International Union for Conservation of Nature) classifies the Atlantic mackerel as a species of least concern (LC), species of sponges are classified as “not evaluated”, which means that not only are the impacts of fishing activities on these species poorly known, but also that there is no information on whether these species are vulnerable or threatened by other anthropogenic activities. A sign of concern should be pointed out here, as it is known that sponge aggregations are an important marine habitat, being currently protected in the deep sea, as part of the Vulnerable Marine Ecosystems (VME; Thompson et al. 2016). However, some other invertebrate species that were caught in these nets are now protected by the Portuguese law and under VME in the deep sea, including species that are pulled up alongside the two species, including the coral *Dendrophyllia ramea*, and gorgonians, or soft corals, *Eunicella verrucosa, and Paramuricea clavata*. Though the catch rates of these vulnerable corals were relatively low over the course of 16 trips, the nets were relatively short compared to the longest possible trammel nets, which can be as long as 20000 m (according to the Directorate-General for Natural Resources, Safety and Maritime Services, or DGRM) or approximately 13.5 times as long as the net in this study, meaning that large quantities can be caught over a short time period. This clearly requires a need for by-catch and discards management to extend beyond vertebrates. In general, this also produces a positive outcome for the fishers as the reduced catch of such organisms reduces the sorting costs and net damages associated with the catch of these species (Martínez-Baños and Maynou, 2018).

### *6.5.2. Video Analysis*

It is easier to observe commercial catch, as each individual is retrieved from the net and measured. However, depending on the hauling speed, and due to the fishers rarely remove the invertebrate by-catch during hauling, but rather at a later date, it is more difficult to assess by-catch efficiently. Despite only being able to rewatch 10 of the 16 trips due to technical issues with the GoPros, it was possible to improve the accuracy of the invertebrate by-catch analysis. The by-catch of invertebrates was actually significantly different among the two net types, with the modified lifted net catching 36% less invertebrates of the main by-catch classes.

### *6.5.3. Interviews*

By-catch can make the work harder for the fishers during hauling periods. Cleaning operations, whether they be onboard or following a trip, can be tedious and time consuming. The presence of by-catch also often results in net damage, reducing the efficiency over time, or the lifespan of the fishing gear. Sartor et al. (2018) report that the fishers in Ligurian Sea (western Mediterranean) caramote prawn fishery discussed how by-catch is a limiting factor to net efficiency, taking up to two days to clean nets, which resulted in an increase of fishers relying on guarding nets. Szynaka et al. (2018) recognized that the results need to be convincing in order to persuade fishers to adopt a new gear or fishing practice. Despite the promising results achieved in the present study, the fishers' perception towards the performance of the modified net, expressed in the interviews, was not positive. Most fishers were concerned about the reduction in catch of various sole species; despite showing them that this reduction was not significant, any decrease in earnings is found to be unacceptable by fishers. The economic benefits of using these nets were not estimated since damage assessment could not be carried out following the onboard experiments. However, taking both cuttlefish and the bastard sole into consideration, the ratio of the landed value of the standard net to the modified net is 1:1.04, and the results of the video analysis point out to a significant decrease in the capture of species that require net cleaning. These results are found to be important for the future adoption of such a modified net. The difference in price between the two types of nets is approximately 22 euros, however we do not know if there would be an economic benefit regarding the use of the modified net considering the reduction in net damage compared to the standard net, as this is often what is associated with high costs of fixing or replacing entire panels of the net.

## 6.6. Conclusions

Using the modified net did not result in a significant decrease of commercial catch, showing even slightly higher sales values for the two target species, cuttlefish and bastard sole, when combined. On the other hand, *Aranha* successfully contributed to reducing the discards of habitat-forming or bioengineering species, such as corals, gorgonians and bryozoans, thereby contributing to ecosystem protection. In future studies, it is suggested to use close up images onboard to better evaluate the true difference in by-catch if the individuals are not retrieved by the fishers during hauling. They should also include the evaluation of the net damage as it is crucial to understand if there is a difference in durability between the two new types. Finally, interactions with fishers to discuss results and concerns related to the use of the modified net can facilitate the effective adoption of such net modifications and lead to further improvements in fishing gears that can ensure the future of fisheries activity minimizing environmental impacts.

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## Chapter 7: General discussion

The present study aimed at improving the methodology of identifying métiers in multi-gear fisheries in situations with limited resources and time, as well as reducing their negative impacts on the marine ecosystem through alterations to the gears used. The main objectives were i) to have a concise understanding of what a métier is, and to propose métiers based on landing profiles, as well as on additional information provided by the local administration authorities (the General Directorate of Natural Resources, Safety and Maritime Services; DGRM), and the fish auction (Docapesca – Portos e Lotas); ii) validate and update the métiers proposed through interviews in ports, comparing interviewing methods in the collection of necessary data; iii) further validating, and describing the catch composition in the métiers proposed, through onboard observations; and iv) reducing the environmental impact in one of the most important métiers through experimental fishing trials with modified fishing gear with a particular focus on reducing the by-catch of habitat-forming species.

Each fishing gear type results in specific by-catch and discards composition, as well as in particular environmental impacts. Knowledge on the fleet's métiers is thus essential to a proper assessment of fisheries impacts. The research in this thesis was carried out to complement previous step-by-step processes in other studies regarding the identification of métiers in order to provide updated and accurate information in support of fisheries management and advice (Castro et al. 2007, Duarte et al. 2009; Campos et al. 2021).

This knowledge is particularly important in countries such as Portugal, with a strong economic, social, and cultural connection to its surrounding seas, with many people employed in different jobs related to the fisheries' value chain, from the sea (fishers) to the plate (consumers). The studies in this thesis focused on the Algarve coastal multi-gear fleet, as most of its métiers were previously poorly known. Considering the Algarve has important commercial fishing ports and many of the registered vessels own multiple licenses to have all the fishing possibilities available, it is difficult to know which gears are being operated through time and thus difficult to inform local fisheries authorities, managers, and stakeholders of the impacts of this fleet on the local resources and the environment. In **Chapter 2**, objective 1.1, a literature review was conducted on static longline highly selective fisheries, and the variables that contribute to defining and characterizing longline métiers. There are two types of static longlines, semi-pelagic and bottom, both operated in the Algarve. The importance of characterizing fishing operations per métier and understanding how these operations affect gear efficiency towards target species, as well as size selectivity, was explored. Having to define a métier for each study made it easier to understand the main goal of the project, regarding the definition of métiers and how certain characteristics of fishing gear play a role in this definition.

In **chapter 3**, objective 1.2, the sales notes from auctions in each port, from 2012 to 2016 made available to the project TECPESCAS by DGRM, the General Directorate of Natural Resources, Safety and Maritime Services, were analyzed, giving us an important insight on catch trends within this fleet. These trends varied not only between seasons, but between years as well. From 2012 to 2016 a shift was noticed towards targeting octopus; given that this is a specific fishery in the Algarve in which the fishers use only traps and pots, it was clear that they were changing their fishing gear from nets to traps.

Seasonal shifts were observed, such as changing from gillnets in spring and summer to trammel nets during fall and winter. However, there was a progressive decrease in the number of vessels operating with nets during the period in study. There is a strong likelihood that this is due to 1) the populations of species that are caught with nets are decreasing, and the amount of effort and investment to operate these gears is not economically worthwhile; and 2) the high value of the octopus and reduced logistics, including physical effort, of retrieving the individuals from traps and pots compensates economically this shift. According to the INE (National Institute of Statistics for Portugal) report in 2021, octopus landings rose by 37.9% (in weight) from 2020 to 2021 in the Portuguese multi-gear fleet. Even though there are many restrictions when fishing for octopus, the fishers clearly find fishing this species to be economically worthwhile (Pita et al. 2015, 2021, Sonderblohm 2016, 2017). Given that this requires a change in the boat's structure as well, specifically adding railing to the side and back of the boat to stack the traps when transporting and hauling, it appears to be more of a permanent change for the vessel. A positive reaction to this increase has been the pressure from the fishers towards better management; this involved effective participation of the fishers themselves, especially during the assessment of management measures in which many issues were tackled by all stakeholders involved in the octopus' fishery in the Algarve, within the framework of the "Tertulia do Polvo" project (Rangel et al. 2019). Currently, there is an ongoing project regarding the fisheries regulations, co-management, and the octopus' fishery in the Algarve, Participesca, and the results of the work in this project will be of great value as this fleet segment continues to grow in the Algarve. It seems that fishers in this fleet are slowly abandoning nets. The same is true for longlines, which have been operated by a decreasing number of vessels in the last few decades, with very few remaining in the Algarve. This is evident as the number of licenses allowed for longlines has been continuously decreasing (INE annual reports). Previous studies have also shown that fishers were beginning to prefer targeting hake with gillnets, rather than longlines, due to the ease of operations (Santos et al. 2003a, b).

In **chapter 4**, objective 1.3, interviews were conducted through questionnaires, resulting in more fishers having been interviewed who operate with pots and traps rather than nets, and even less who operate with dredges and longlines in this fleet. These questionnaires were important given that much of the information that was collected, from fishing trip characteristics to target species for longlines, was not available from the initial datasets provided and would be otherwise inaccessible. Interviews were found to be an important step in métier identification, as well as in understanding the impact of this fleet on the local environment, by providing information on depth, fishing areas and habitats.  Regarding the comparison between the questionnaire methods, it became clear that the type of questions asked must be well defined for the fishers to be able to answer; for example, being able to define target species versus commercial species. Having specific data in mind assists in creating the appropriate questions for fishers to be encouraged to answer while reducing additional data of which particular information is not necessary.

To observe the fishing composition and validate the information on fishing operations collected during the work in chapter 4, six different vessels in five ports participated voluntarily during the work described in **chapter 5**, objective 1.4. The main results of this chapter were the validation of the métiers previously proposed, allowing to link fishing gears and target species, as well as providing information on the maximum fishing depths in some of the métiers identified both in the first study addressing landing profiles (Szynaka et al. 2021) and in the second study where questionnaires were issued (Szynaka et al. 2022). The métiers that were validated included octopus pot and trap fishery and the maximum depth for fishing this species is about 100 meters for the vessels that were boarded. For monkfish, it was common for the vessels to go much deeper, up to 400 meters, which also gave the fishers the added benefit of being able to keep their gear in the water for up to 72 hours. Hake was also caught around 100 m and interestingly, this species was one of the main discards associated with the monkfish gillnet fishing. Fish traps were generally used in depths of about 50 meters, targeting various seabream species and catching relatively larger individuals than small mesh gillnets fishing at a similar depth. One interesting result was related to the amount of discarding: there were significantly less individuals than expected being discarded from the nets, while the opposite was true for the traps. One of the vessels targeting monkfish using gillnets caught very little by-catch and discarded mostly rotting hake, while one of the vessels targeting octopus, which previously was suggested to be a fishery with little or insignificant by-catch in the Algarve (Almeida et al. 2022), caught various species including undersized seabreams and many invertebrates. With this knowledge, it would be interesting to know how the increase in the octopus' segment of this fleet will impact, in the long term, the invertebrates and juvenile fish living closer to the coast on rocky bottoms or nearby.

In both vessels mentioned results were obtained that contradict those in previous studies in terms of catch composition. It appears the areas in which nets are regularly set have been disturbed to a high extent by previous fishing activity, leading to decrease in biodiversity; this was confirmed through anecdotal evidence by fishers, who stated that when they were growing up, their fathers would catch a much greater variety of fish. In other words, there is a shift in baselines as described by Pauly (1995, 2019). However, some métiers still produced considerable amount of by-catch, including the large mesh trammel net targeting monkfish, in which many invertebrates were caught which can be particularly impactful given the deeper ecosystems these species live in (Braga-Henriques et al. 2013, Dias et al. 2020).

To reduce the by-catch of habitat-forming, noncommercial invertebrates, a modified trammel net was tested. The results are presented as the final research chapter, **chapter 6**, objective 2.1. These results point out the need to continue studying the possibilities of reducing important by-catch species, such as corals and sponges which serve as habitats, food sources, and filtering organisms. There is little to no formal protection of these species, most likely due to the lack of knowledge on the time periods and amounts in which they are by-caught; and when this knowledge exists, the enforcement of the protection is difficult due to this by-catch being discarded at sea and not reported. Gear modifications such as the one tested here should be considered as the first step in by-catch reduction methods, as they can require little additional effort from the fishers. Instead, these modifications can ease their work as there can be a reduction of "trash" in the net that can require hours of cleaning, as well as reduce the catch of dangerous species as was the case in previous work in which the greater weever (*Trachinus draco*) catch was reduced in the modified net (Szynaka et al. 2018). However, it would be interesting to see if the fishers now keep these species, as there is an indication of this previously undervalued species becoming a popular dish sold in restaurants and in markets, both locally and in other countries. As the results achieved were promising and we were motivated by some positive responses from the fishers, we have applied and won an international grant to continue this work (Schmidt Family Foundation, G-22-64372).

Finally, regarding the thesis, it is necessary to address the positive aspects and the negative ones as there is always room for improvement. As the work was well structured, in that there was a clear starting point and end point of the research (specifically regarding chapters 3 through 5), it made it easier to plan the work, despite the covid interruptions. Carrying out onboard observations also permits to closely follow the fishing operations, what they are catching, how they sort the fish, and how much is kept for personal consumption, which helps us gauge how much of the catch is actually being landed and the impact on the seabed habitats by these métiers. Creating positive relationships with the fishers gave us the ability to have honest discussions with them regarding the future of their jobs, allowing us to collect many elements central to supporting management and advice. Finally, during the experimental trials, we were also able to witness in real-time the reactions of the fishers to the fishing operations with the two net types and to discuss their willingness to use the modified nets.

However, some issues arose related to communicating with the fishers, including some unwillingness from their side to talk to us during the questionnaires. We also faced a potential problem during the questionnaire study (chapter 4), as the fishers did not know how to properly answer the question regarding target species, as to them, target species are all the commercial species. We also experienced the potential shortcoming that some fishers will answer questions based on what they know they are allowed to do, rather how they operate during fishing, such as telling us they do not target monkfish in winter (as they are not allowed to do so in January and February). There is also the possibility, during onboard observations, that the fishers choose different fishing areas to operate when compared to usual areas, potentially biasing the information on which areas are being affected by their day-to-day fishing activities. A problem onboard included the loss of GPS data due to malfunctioning GPS or loss of important footage due to the GoPro cameras malfunctioning. Finally, there was some sort of miscommunication or misunderstanding with the fishers as they continued to use the experimental net when we were not onboard and thus made it impossible to perform a net damage assessment.

## Chapter 8. Conclusions

- The review highlights the importance of identifying the characteristics and variables that define longline métiers, allowing us to understand which factors influence species and size selectivity of static longline gear and the potential impact of different longline métiers in terms of by-catch and discards.
- It seems as though the approach taken in this study, initiating with a) multivariate analysis of landing profiles to first describe the main target species and the use of literature to associate the fishing gears to these landing profiles, followed by b) validation of these proposed métiers through questionnaires at ports, and finally by c) validation of either the métiers proposed or the additional ones described through the interviews, through onboard experiments, was indeed successful. Shifts in métiers were identified, with some métiers progressively decreasing in importance, including those that involve longlines and certain net types (those targeting soles and hake). It is important to continue following these vessels and their shifts in fishing operations given their multiple licenses, which translate into different environmental impacts.
- Regarding the ever-growing octopus fishery segment, even though the lifespan of the common octopus is short (believed to be usually about one to two years), we cannot be sure that such fast and continuous increase in effort of targeting them will not produce a substantial reduction in their population. One problem with this fleet is the quick shifts in fishing activity, and thus we suggest a statistical analysis every 5 years at minimum to observe the trends within those years.
- Additionally, a proper observer program in which observers board vessels twice a year, as there does not seem to be much seasonal variation among targeted species but rather between fall and winter when compared to spring and summer, should be implemented, followed by the statistical analysis to validate the métiers observed in the data analyzed.
- Regarding trammel nets, future studies can focus on other modifications or variations of the previously studied ones in trammel nets, with video recording of the activity with cameras to properly validate the results, specifically the by-catch.
- The coastal multi-gear fishing fleet is dynamic and provides employment to many people from the boat crew to the retailers and everyone in between, as well as providing large quantities of species that are economically and culturally important. Thus, this is a fleet

that needs to have its place secured in the future through proper management using the best information available.

### *8.1. Recommendations for future work*

Some future recommendations include the use of incentives to catch self-reporting, at a haul level, by the fishers in this fleet, in order that the information collected can be used in future métier validation. A way to achieve this is by developing monitoring devices to be used in smaller vessels and creating economic incentives in order to widen their use among this fleet. Furthermore, extending the participatory approach that already exists in the octopus' fleet (co-management) to other métiers is recommended, as it is apparent that when fishers are involved in the process, more effective management is possible. Also including fishers in the process of gear modifications to mitigate negative effects on by-catch species and bottom habitat would result in a better chance of adoption of these modifications in other fishing gears. Economic incentives, such as financial assistance of the initially purchased modified nets for a group of fishers that are willing to self-report any noticed differences (regarding not only catch but, how often the net sections need to be fixed or replaced), should also be promoted. It is important to note however, that in this study the economic benefits of using modified nets were not estimated since damage assessment was not carried out and that this evaluation is crucial for future work. And finally, the fishing activity should be mapped to the best of our ability, so that possible impacts could be assessed for vulnerable/threatened species and habitats, and Vulnerable Marine Ecosystems (VMEs).

## 9. General References


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# Annex

**PROJECTO TECPESCA**

1. ***Informações sobre a embarcação*** *(Information on vessel's characteristics)*

| | |
|---|---|
| **Port + Interview # (Letter - #)** | |
| **Mestre** *(Skipper)* | |
| **Contacto** *(Contact)* | |
| **Nom & Matrícula** *(Vessel name & registration)* | - - C |
| **Tamanho (9m+) [se mais de XX potencia]** | |
| **Licenças de Pesca** *(Fishing licenses)* | Palagre/Anzol/Linha Armadilhas [Covos / Alcatruzes] Emalhar Tresmalhar |
| **Alterações a Licenças** *(Changes to fishing licenses)* | Sim/Não |
| **Especificar Alterações** *(Specify changes)* | |

2. **Actividade de pesca** *(Fishing activity)*
   2.1. ***Caracterização da viagem*** *(Trip characteristics)*

| | |
|---|---|
| **Porto de Saída** *(Depart port)* | |
| **Porto(s) de desembarques** (landings ports) | Usually in: Sometimes in: |
| **Hora de Saida & Chegado** | |
| **Duração da viagem** (Trip duration) | |
| **Nº de homens na tripulação** | |
| **Nº médio de viagens por semana** | |
| **Uso de várias artes durante a viagem** | Sim/Não – quais? |
| **Veloc. Navegação** *(Navigation speed)* | |
| **Perda de Aparelhos** *(Lost gears)* | Sim/Não |
| **Período de Largada** *(set period)* | Gear 1: h Gear 2: h Gear 3: h |
| **Nº Artes Largadas** *(Nº gears set in a single trip)* | 1 / 2 / 3 |
| **Duração da Largada** *(Time it takes to Set)* | Gear 1: h Gear 2: h Gear 3: h |

| | |
|---|---|
| **Nº Horas de Imersão da Arte** (*Gear soaking time*) | Gear 1: h Gear 2: h Gear 3: h |
| **Why are gears switched? (Seasonal? Depth? Lack of main species?)** | |

2.3. ***Características da arte de pesca*** (*Fishing gear characteristics*)

| | |
|---|---|
| **Armadilhas** | |
| **Espécies Alvo** | |
| **Nº de caçadas/Armadilhas** (*Nº of fleets/traps*) | |
| **Tipo de Armadilhas** (*Traps type*) | covos / alcatruzes |
| **Velocidade de largada das artes** (*setti. speed*) | |
| **Velocidade de alagem** (*Hauling speed*) | |
| **Espaçamento entre Armadilhas** (*Traps spacing*) | m |
| **Comprimento da Madre** (*Main line length*) | m |
| **Tipo de Isco** (*Bait*) | |
| **Palangre** (*Longline*) | |
| **Espécies Alvo** (*Target species*) | Espécies alvo (sazonalmente)- usar códigos das espécies |
| **Nº de caçadas/Anzóis** (*Nº of fleets/hooks*) | |
| **Velocidade de largada das artes** (*setti. speed*) | |
| **Velocidade de alagem** (*Hauling speed*) | |
| **Tipo de Palangre** (*Longline type*) | Superfície / Demersal / Fundo |
| **Espaçamento entre Anzóis** (*Hooks spacing*) | cm |
| **Comprimento da Madre & [gangion]** (*Length of main line & gangion*) | m |
| **Tipos; Tamanhos;** | |

| | |
|---|---|
| *(Hooks types; sizes)* | |
| **Tipos de Isco** (*Bait type*) | |
| | |
| **<u>Redes de emalhar</u>** | |
| **Espécies Alvo** (*Target species*) | Espécies alvo (sazonalmente)- usar códigos das espécies |
| **Nº de Redes na Caçada** (*Nº of nets on fleet*) | |
| **Velocidade de largada** (*setti. speed*) | |
| **Velocidade de alagem** (*Hauling speed*) | |
| **Comprimento de Rede** (em metros) | |
| **Malhagem** (*Mesh*) | mm |
| **<u>Tresmalho</u>** | |
| **Espécies Alvo** (*Target species*) | Espécies alvo (sazonalmente)- usar códigos das espécies |
| **Nº de Redes na Caçada** (*Nº of nets on fleet*) | |
| **Velocidade de largada** (*setti. speed*) | |
| **Velocidade de alagem** (*Hauling speed*) | |
| **Comprimento de Rede** (em metros) | |
| **Malhagem** (*Mesh*) | mm |

**Figure I.** The first set of questionnaires

## TecPescas Interviews R2

Interview No. ____ Port: **Sagres** **Lagos** **Portimão** **Olhão** **Quarteira** **Fuzeta** **Tavira**
Vessel length: ______m
When did the vessel change to traps/OCC & Why (only occ vessels)? ________________________
All gear types of the Captain worked with in his life time: **Tres** **Emal** **Arma** **Gancho** **Anzois**
Current gears being used: **Tres** **Emal** **Arma** **Gancho** **Anzois**

| | |
|---|---|
| Choco | 66 |
| Raia lenga | 7 |
| Linguado legítimo | 4 |
| Polvo | 4 |
| Azevia raiada | 3 |
| Tremelgas | 2 |

Esta.: Inverno Primavera Verão Outono Todo Ano
Arte: Tresmalho Emalhar Armadilhas Ganchorra Anzois
Cara1.: 60 – 79 mm 80 – 99 mm 100 - 120 mm 200 mm +
Cara2: 13 12 11 10 9 8 7 6 5 4 3 2 1
Profun.: 0 – 50 m 50 – 100 m 100 – 200 m 200 – 400 m
Outro:

| | |
|---|---|
| Tamboril | 75 |
| Raia lenga | 3 |
| Pescada branca | 3 |
| Raia de S. Pedro | 3 |
| Buzina | 2 |
| Galo negro | 2 |

Esta.: Inverno Primavera Verão Outono Todo Ano
Arte: Tresmalho Emalhar Armadilhas Ganchorra Anzois
Cara1.: 60 – 79 mm 80 – 99 mm 100 - 120 mm 200 mm +
Cara2: 13 12 11 10 9 8 7 6 5 4 3 2 1
Profun.: 0 – 50 m 50 – 100 m 100 – 200 m 200 – 400 m
Outro:

| | |
|---|---|
| Azevia | 54 |
| Pescada branca | 17 |
| Besugo | 3 |
| Choupa | 3 |
| Raia lenga | 3 |
| Ruivo | 2 |

Esta.: Inverno Primavera Verão Outono Todo Ano
Arte: Tresmalho Emalhar Armadilhas Ganchorra Anzois
Cara1.: 60 – 79 mm 80 – 99 mm 100 - 120 mm 200 mm +
Cara2: 13 12 11 10 9 8 7 6 5 4 3 2 1
Profun.: 0 – 50 m 50 – 100 m 100 – 200 m 200 – 400 m
Outro:

| | |
|---|---|
| Cherne | 58 |
| Safio | 13 |
| Cantarilho | 9 |
| Abrotea | 5 |
| Goraz | 4 |
| Pata roxa | 2 |

Esta.: Inverno Primavera Verão Outono Todo Ano
Arte: Tresmalho Emalhar Armadilhas Ganchorra Anzois
Cara1.: 60 – 79 mm 80 – 99 mm 100 - 120 mm 200 mm +
Cara2: 13 12 11 10 9 8 7 6 5 4 3 2 1
Profun.: 0 – 50 m 50 – 100 m 100 – 200 m 200 – 400 m
Outro:

| | |
|---|---|
| Safio | 63 |
| Abrotea | 13 |
| Cantarilho | 7 |
| Raia | 3 |
| Polvo | 3 |
| Cherne | 2 |

Esta.: Inverno Primavera Verão Outono Todo Ano
Arte: Tresmalho Emalhar Armadilhas Ganchorra Anzois
Cara1.: 60 – 79 mm 80 – 99 mm 100 - 120 mm 200 mm +
Cara2: 13 12 11 10 9 8 7 6 5 4 3 2 1
Profun.: 0 – 50 m 50 – 100 m 100 – 200 m 200 – 400 m
Outro:

| | |
|---|---|
| Pescada branca | 74 |
| Azevia raiada | 5 |
| Pata roxe | 7 |
| Tamboril | 4 |
| Carapau | 2 |
| Besugo | 1 |

Esta.: Inverno Primavera Verão Outono Todo Ano

Arte: Tresmalho Emalhar Armadilhas Ganchorra Anzois

Cara1.: 60 – 79 mm 80 – 99 mm 100 - 120 mm 200 mm +

Cara2: 13 12 11 10 9 8 7 6 5 4 3 2 1

Profun.: 0 – 50 m 50 – 100 m 100 – 200 m 200 – 400 m

Outro:

---

| | |
|---|---|
| Lagostim | 100 |

Esta.: Inverno Primavera Verão Outono Todo Ano

Arte: Tresmalho Emalhar Armadilhas Ganchorra Anzois

Cara1.: 60 – 79 mm 80 – 99 mm 100 - 120 mm 200 mm +

Cara2: 13 12 11 10 9 8 7 6 5 4 3 2 1

Profun.: 0 – 50 m 50 – 100 m 100 – 200 m 200 – 400 m

Outro:

---

| | |
|---|---|
| Buzio | 57 |
| Tremelgas | 11 |
| Linguado | 7 |
| Choco | 5 |
| Raia lenga | 5 |
| Azevia | 4 |

Esta.: Inverno Primavera Verão Outono Todo Ano

Arte: Tresmalho Emalhar Armadilhas Ganchorra Anzois

Cara1.: 60 – 79 mm 80 – 99 mm 100 - 120 mm 200 mm +

Cara2: 13 12 11 10 9 8 7 6 5 4 3 2 1

Profun.: 0 – 50 m 50 – 100 m 100 – 200 m 200 – 400 m

Outro:

---

| | |
|---|---|
| Dourada | 67 |
| Corvina | 7 |
| Safia | 6 |
| Bica | 5 |
| Pargo | 4 |
| Sargo | 4 |

Esta.: Inverno Primavera Verão Outono Todo Ano

Arte: Tresmalho Emalhar Armadilhas Ganchorra Anzois

Cara1.: 60 – 79 mm 80 – 99 mm 100 - 120 mm 200 mm +

Cara2: 13 12 11 10 9 8 7 6 5 4 3 2 1

Profun.: 0 – 50 m 50 – 100 m 100 – 200 m 200 – 400 m

Outro:

---

| | |
|---|---|
| Raia lenga | 49 |
| Choco | 8 |
| Linguado | 6 |
| Safio | 5 |
| Azevia | 4 |
| Tremelgas | 3 |

Esta.: Inverno Primavera Verão Outono Todo Ano

Arte: Tresmalho Emalhar Armadilhas Ganchorra Anzois

Cara1.: 60 – 79 mm 80 – 99 mm 100 - 120 mm 200 mm +

Cara2: 13 12 11 10 9 8 7 6 5 4 3 2 1

Profun.: 0 – 50 m 50 – 100 m 100 – 200 m 200 – 400 m

Outro:

| | |
|---|---|
| Raia pontuada | 59 |
| Choco | 11 |
| Tremelgas | 7 |
| Linguado do ariea | 5 |
| Linguado | 3 |
| Buzio | 3 |

Esta.: Inverno Primavera Verão Outono Todo Ano

Arte: Tresmalho Emalhar Armadilhas Ganchorra Anzois

Cara1.: 60 – 79 mm 80 – 99 mm 100 - 120 mm 200 mm +

Cara2: 13 12 11 10 9 8 7 6 5 4 3 2 1

Profun.: 0 – 50 m 50 – 100 m 100 – 200 m 200 – 400 m

Outro:

---

| | |
|---|---|
| Salmonete | 75 |
| Besugo | 4 |
| Choco | 3 |
| Bica | 3 |
| Safia | 2 |
| Polvo | 1.9 |

Esta.: Inverno Primavera Verão Outono Todo Ano

Arte: Tresmalho Emalhar Armadilhas Ganchorra Anzois

Cara1.: 60 – 79 mm 80 – 99 mm 100 - 120 mm 200 mm +

Cara2: 13 12 11 10 9 8 7 6 5 4 3 2 1

Profun.: 0 – 50 m 50 – 100 m 100 – 200 m 200 – 400 m

Outro:

---

| | |
|---|---|
| Choupa | 49 |
| Polvo | 14 |
| Safio | 13 |
| Sargo | 11 |
| Safia | 7 |
| Besugo | 2 |

Esta.: Inverno Primavera Verão Outono Todo Ano

Arte: Tresmalho Emalhar Armadilhas Draga Linha

Cara.: 60 – 79 mm 80 – 99 mm 100 - 120 mm 200 mm +

Profun.: 0 – 50 m 50 – 100 m 100 – 200 m 200 – 400 m

Outro:

---

| | |
|---|---|
| Polvo | 98 |
| Safio | 1 |

Esta.: Inverno Primavera Verão Outono Todo Ano

Arte: Tresmalho Emalhar Armadilhas Ganchorra Anzois

Cara1.: 60 – 79 mm 80 – 99 mm 100 - 120 mm 200 mm +

Cara2: 13 12 11 10 9 8 7 6 5 4 3 2 1

Profun.: 0 – 50 m 50 – 100 m 100 – 200 m 200 – 400 m

Outro:

---

| | |
|---|---|
| Pé de burrinho | 89 |
| Amêijoa branca | 8 |
| Cadelinhas | 3 |

Esta.: Inverno Primavera Verão Outono Todo Ano

Arte: Tresmalho Emalhar Armadilhas Ganchorra Anzois

Cara1.: 60 – 79 mm 80 – 99 mm 100 - 120 mm 200 mm +

Cara2: 13 12 11 10 9 8 7 6 5 4 3 2 1

Profun.: 0 – 50 m 50 – 100 m 100 – 200 m 200 – 400 m

Outro:

---

| | |
|---|---|
| Cadelinhas | 93 |
| Pé de burrinho | 4 |
| Amêijoa branca | 2 |

Esta.: Inverno Primavera Verão Outono Todo Ano

Arte: Tresmalho Emalhar Armadilhas Ganchorra Anzois

Cara1.: 60 – 79 mm 80 – 99 mm 100 - 120 mm 200 mm +

Cara2: 13 12 11 10 9 8 7 6 5 4 3 2 1

Profun.: 0 – 50 m 50 – 100 m 100 – 200 m 200 – 400 m

Outro:

**Figure II.** The second set of questionnaires.

**ANNEX II**

**Outreach**

During this thesis, outreach efforts were made in order to help school children and adults who do not work in fisheries to understand the basics of fisheries related information. In 2019 and 2022, I attended the annual school science fair in the Lisbon school 'Grémio Instrução Liberal Campo de Ourique' to present general information regarding marine biology and then worked with school children of various ages on projects including to learn about microalgae identification, fish anatomy through dissection, touch tank in which local invertebrate species were presented, and finally a fisheries related project regarding catch composition and variations among fishing gears (Figure III). The project was expanded on with collaborating with the communications office of CCMAR in which larger gears were made with larger species of local commercial catch and discard species (including undersized commercial individuals that were measured using a ruler). The project was further expanded to work with older children in which they were given one role from the process of seafood going from the sea to the plate including: fishers, fisheries observers, Docapesca workers, store and restaurant owners and consumers.


**Figure III.** Children learning about passive fishing gear (nets and longlines) and the various catch compositions, tags for role play, large versions of gillnet and longline.