Dinâmica das Pescas e Gestão Participativa do polvo vulgar (*Octopus vulgaris*) capturado pela frota de covos e alcatruzes no Sul de Portugal

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Tese para a obtenção do grau de doutor

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Fishery dynamics and Participatory management of the Common octopus (*Octopus vulgaris*) pot and trap fishery in southern Portugal

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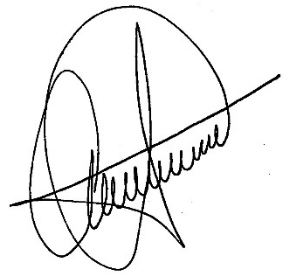
Declaração de autoria de trabalho

Tese: **Fishery dynamics and Participatory management of the *Octopus vulgaris* pot and trap fishery in southern Portugal**

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



Apoio

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The stone that the builder refuse
Will always be the head cornerstone
Psalm 18:22

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Abstract

The following PhD dissertation presents information on biological, ecological, socio-economical and governmental aspects of the fishery of the common octopus (*Octopus vulgaris*), captured by pot and trap fishing fleets in the region of Algarve (Portugal), in the southwest of the Iberian Peninsula. The thesis work has been divided into two parts, Part One and Part Two. Part One addresses the fishery dynamics of the common octopus and its relationship with the life cycle of the species, especially those aspects concerning key reproductive stages such as spawning, para-larvae and fishing recruitment, and also its relationship with the environment. Part Two analyses the management of the fishery of the common octopus currently in force in Portugal, particularly in the Algarvian region. A series of workshops were held with stakeholders from this fishery, such as fishermen, scientists and government officials, with the purpose of discussing management approaches aimed to improve this fishery, for example the implementation of a seasonal closure in order to protect the reproduction of the species.

Part One is sub-divided into two chapters, Chapter Two and Chapter Three, which precede the introduction or Chapter One. Chapter One gives an overview of the octopus fisheries around the world, the life cycle of the species and how it affects the management of the fishery, and challenges faced by the fishers and industry. Chapter Two emerges from the necessity of the fishermen to establish the time of the year that is deemed most suitable for implementing a ban on the fishery of the common octopus, in order to protect its reproduction and recruitment. This chapter aims to explain the relationship between the dynamics of the fishery and the octopus's life cycle. By means of multivariate statistical analysis of the last 25 years of data from fishing landing records at 12 main ports of the region, the most important factors linking the fishery dynamics of the octopus and its biology were identified. The results were used to construct an life cycle figure that can be used by fishermen, scientists, students, government officials, among others as a quick reference guide.

Chapter Three investigate fishing landing data from the Port of Santa Luzia, one of the most important octopus ports in the Algarvian region. The use of statistical techniques such as Dynamic Factor Analyses (DFA) specifically intended for the analysis of time series including local oceanographic and environmental data is explored in order to find common trends and its

relationship with environmental variables relevant to the selected fishing area. The results of these analyses reveal factors that affect the recruitment of the species in the Algarve.

Part Two is sub-divided also into two chapters, Chapter Four and Chapter Five. Chapter Four begins with a description of the current socio-economic situation and governance model of the pot and trap octopus fisheries in the country. Using a time line approach, a retrospective of the evolution of this fishery during the last 50 years was developed. Common challenges associated with the steady increase of this fishery were identified. Chapter Five analyses ideas debated at seven participatory workshops, held between 2014 and 2015, on the management of the pot and trap octopus fishery in the Algarvian region. In these meetings, stakeholders (fishermen, marine biology researchers, scientists, representatives of government bodies and public institution, university students, among others) discussed proposals aimed to address current challenges, improve the management of the fishery of this resource, and develop a co-management model that benefits all parties involved in the activity. These proposals were summarized in a handbook that is included as an annex at the end of this PhD dissertation. This paper concludes in Chapter Six with a general discussion about previous chapters and future research that are considered necessary as a result of this work.

Main results

Common octopus life cycle

The pot and trap fishery of the common octopus in the Algarvian region, in the south of Portugal, revealed a distinct seasonal landing pattern both at windward and leeward ports. Two annual peaks of landing were identified for a time period spanning from 1990 up to 2014. Leeward ports displayed maximum average landings in November, while windward ports did it between February and March. These months are considered to be the periods when the fishing recruitment of the species is at its maximum. The landing data is coherent with the reproductive biology described for the area, confirming a life cycle with two main spawning periods, one in spring and one in late summer. Octopus para-larvae need around seven to nine months since spawning to reach a size that is deemed suitable for commercial fishery. Leeward young recruits caught in autumn may belong to the spring spawning event, while windward young recruits may belong to the late summer spawning event.

The abundance of the common octopus in the Algarvian region seems to be influenced by the effects of the hydrologic process of the fishing area: upwelling and river runoff. At leeward ports, the common trends inferred from the time series analyses show significant correlation with autumn rainfall from the previous year, in particular for the October, November and December time series. At windward ports the spawning and hatching may be synchronized with an upwelling and relaxation system occurring more intensely in early summer, during which intermittent filaments of upwelled water penetrates the south coast of Portugal.

Common octopus fishery management

The study of the current management system of the common octopus fishery in Portugal, and particularly in the Algarvian region, revealed that it is a top-down process, where Fishermen demand policy changes and the authorities take the decisions after consultation. The fishing legislation comes exclusively from the central government, under the direct responsibility of the General Directorate for Marine Resources and Maritime Services and Safety (DGRM), a branch of the Ministry of Agriculture and Sea. Fishing regulations are supported by scientific and technical advice provided by the National Institute of Sea and Atmosphere (IPMA by its Portuguese acronym) and higher education institutions. Local government bodies, and since 2010 fishermen (called upon by the Secretary of State for Fisheries), also collaborate in the development of policies and rules for the fishery of the common octopus.

The current management plan of the octopus fishery consists of 15 regulations that coordinate the exploitation of the resource. The legislation addresses basically three aspects: Minimum weight of the individuals, fishing gear and fishing areas. Out of these 15 regulations, eight of them are exclusively enforced in the Algarvian region, giving an idea of the importance of the region's fishing activity at a national scale. The fundamental drawbacks of the legal framework are the limited understanding of the common octopus's biology and ecology, mostly by the authorities, and the insufficient and ineffective communication among the stakeholders, especially between the originators of the legislation at the top level and the fishermen at the bottom. Drastic fluctuations of the fishing landings of the species in the past 15 years, as confirmed by the first part of this PhD dissertation, have repeatedly triggered demands from the fishing associations for changes in the regulations. Some demands have resulted in ordinances that have palliated specific issues, sometimes over a short term, sometimes over a longer period. But the impact and effectiveness of these measures are deemed to be reduced when they are not part of a comprehensive fishery management plan.

Controversial subject matters were identified in the process of learning and understanding the legislation currently in effect, for example regulations on bait type and limits on the maximum number of pots and traps. Bearing current fishing issues in mind, and trying to foresee needs in the management of the common octopus fishery, seven participatory workshops were organized and held between April 2014 and April 2015. Overall, up to 60 participants from 10 octopus fishing associations and 16 entities, including regulatory bodies and higher education institutions, attended the events. The brainstorming and discussions that took place in the workshops produced 52 proposals on regulation and management. The proposals were incorporated, utilizing a SWOT analysis, as the backbone of a seven-section management strategy. Condensed in a convenient handbook format (see annex), the strategy aims at educating the stakeholders involved in this economic activity, and promoting and encouraging best practices in the sustainable exploitation of this important resource. Overall, the objective of this investigative work was to understand the relationship and interdependency between life cycle and fishery management, and by receiving input from stakeholders of the fishery, a co-management model was devised in which fishermen and scientists have a leading role to develop an ecosystem approach for the sustainability of the octopus fishery in the Algarve.

Keywords: *Octopus vulgaris*, common octopus, pot and trap fishery, Portugal, Algarve, fishery dynamics, fishing landing, multivariate statistical analysis, time series analysis, life cycle, spawning, para-larvae, recruitment, windward, leeward, fishery co-management model, participatory workshop, regulations, fishing associations, sustainable exploitation.

Sumário estendido

A presente dissertação de doutoramento foca aspetos biológicos, ecológicos, socioeconómicos e governamentais da pesca do polvo comum (*Octopus vulgaris*), capturado por covos e alcatruzes pela frota pesqueira da região do Algarve, no Sul de Portugal. Este trabalho está dividido em duas partes principais: a primeira (1) descreve a dinâmica pesqueira deste cefalópode e a sua relação com o ciclo de vida da espécie, especialmente os aspetos relacionados com etapas chave como desova, para-larva e recrutamento e o impacto das condições ambientais. A segunda parte do trabalho (2) analisa a gestão da pesca do polvo em Portugal, particularmente na costa Algarvia. Esta análise considera as propostas de gestão definidas pelas principais partes envolvidas: pescadores, entidades governamentais, entre outros; com a finalidade de avaliar as vantagens e desvantagens de cada medida, como por exemplo a implementação duma época de defeso para proteger a reprodução desta espécie no âmbito de um futuro plano de gestão.

Ao nível estrutural, a primeira parte é dividida em três capítulos. O primeiro capítulo é uma introdução geral à pesca do polvo ao nível mundial, nomeadamente sobre as dificuldades na sua gestão e relação entre a biologia da espécie e condições ambientais. O segundo capítulo pretende explicar a relação entre a dinâmica da pesca e o ciclo de vida do polvo. Através de uma análise estatística multivariada dos desembarques mensais em cada porto nos últimos 25 anos (1990-2014), são identificados os padrões mais importantes na dinâmica da pesca e relação com a reprodução da espécie. A partir dos resultados desta análise foi construído um diagrama do ciclo de vida que pode ser útil para pescadores, cientistas, estudantes, gestores e público em geral, como um guia de referência para a gestão desta pescaria.

No capítulo três, técnicas estatísticas mais avançadas especificas para a análise de séries temporais são utilizadas para analisar os dados de desembarques do Porto de Santa Luzia, um dos portos mais importantes da região algarvia, de forma a identificar padrões comuns nos desembarques mensais. O crescente acesso gratuito a grandes bases de dados oceanográficos e ambientais, permite explorar os padrões de desembarque e a relação com as variáveis ambientais com maior impacto nos pesqueiros da região. Os resultados destas análises revelam os principais fatores que afetam o recrutamento desta espécie no Algarve.

A segunda parte da dissertação está dividida em dois capítulos. O capítulo quatro descreve da situação atual da gestão da pesca do polvo por covos e alcatruzes ao nível nacional, com ênfase no sistema legislativo, tal como alguns aspetos socioeconómicos. Seguidamente, é descrita a evolução da pescaria nos últimos 50 anos, de forma a apresentar uma análise retrospetiva. Como principais resultados desta análise, são identificadas as principais questões associadas ao aumento constante do esforço de pesca.

O capítulo cinco discute as medidas de gestão proposta pelos agentes interessados e analisadas pelos mesmos ao longo de sete tertúlias sobre a gestão da pesca do polvo por covos e alcatruzes na região algarvia, entre Abril 2014 e Abril 2015. Os intervenientes (pescadores, investigadores, representantes da entidades governamentais de gestão da pescaria, estudantes universitários, entre outros) discutiram propostas para solucionar problemas correntes, de forma a melhorar a gestão da pesca deste recurso e desenvolver um modelo de cogestão que beneficie todas as partes envolvidas na atividade. Os resultados deste processo são descritos neste capítulo. Em anexo encontra-se uma publicação de apoio à gestão desenvolvida ao longo deste trabalho que resume informação relevante para os pescadores e gestores da pesca do polvo no Algarve. Este artigo conclui no Capítulo Seis com uma discussão geral sobre os capítulos anteriores e futuras pesquisas que são consideradas necessárias como resultado deste trabalho.

Resultados principais

Ciclo de vida do polvo comum

A pesca por covos e alcatruzes na região do Algarve, no Sul de Portugal, revelou um padrão sazonal distinto nos desembarques entre os portos do Barlavento e Sotavento. Dois picos foram identificados entre 1990 até 2014. Os portos de Sotavento obtiveram desembarques médios máximos em Novembro, enquanto que nos portos de Barlavento a ocorrência deu-se entre Fevereiro e Março. Estes meses são considerados como os períodos em que o recrutamento à pesca atinge o seu máximo. Os dados de desembarque analisados são coerentes com a biologia reprodutiva descrita para a área, confirmando um ciclo inferior a um ano com dois períodos de desova, um pico durante a Primavera e outro no final do Verão. As paralarvas do polvo necessitam entre sete a nove meses desde a desova para serem recrutadas à pesca comercial.

Os recrutas de polvo do Sotavento a ser capturados no Outono poderão pertencer ao período de desova da Primavera, enquanto os recrutas do Barlavento capturados durante a Primavera poderão pertencer ao período de desova do final do Verão.

A abundância do polvo comum na região algarvia poderá estar a ser regulada entre outras causas pela hidrologia do sistema onde se desenvolve esta pescaria. Na zona de Sotavento, o padrão comum inferido através da análise de séries temporais tem uma correlação significativa com a precipitação outonal do ano anterior, particularmente as séries temporais de Outubro, Novembro e Dezembro, que corresponde ao período de maior recrutamento à pesca. Entretanto, nos portos do Barlavento, a desova e a eclosão podem estar sincronizados com o sistema de afloramento costeiro que ocorre mais intensamente no início do Verão sobretudo na costa ocidental, conhecidos como períodos intermitentes de afloramento de águas profundas da costa oeste que interatuam com as águas quentes do Mediterrâneo provenientes do Golfo de Cádis.

Gestão da pesqueira

O estudo do atual sistema de gestão da pesca do polvo comum em Portugal, e em particular na região Algarvia, revelou ser um sistema de gestão descendente (conhecido como "*top-down*"). Existe uma interação nos últimos 15 anos que pode ser designada como ação-resposta, onde os pescadores da região algarvia solicitam alterações na legislação como consequência de temporadas de pesca desfavoráveis. A legislação pesqueira é definida ao nível do governo central, sob a responsabilidade direta da Direção Geral dos Recursos Naturais, Segurança e Recursos Marítimos (DGRM), uma ramificação do Ministério da Agricultura e do Mar (MAM). Os regulamentos pesqueiros são apoiados cientificamente pelo Instituto do Mar e Atmosfera (IPMA) e algumas outras instituições universitárias. A gestão atual da pesca do polvo comum consiste em 15 portarias que regulam a exploração deste recurso. Esta legislação foca basicamente três aspetos: peso mínimo de captura, limitação de artes e métodos de pesca (controlo do esforço). Destas 15 leis, 8 são exclusivas à região algarvia, o que enfatiza a importância desta região na atividade pesqueira do polvo à escala nacional. O conhecimento limitado da ecologia do polvo comum, e a inexistência de uma estratégia de gestão definida num plano de pesca para a região encontraram-se entre as falhas mas importantes nesta pescaria.

No processo de aprendizagem e compreensão da legislação em vigor nesta pescaria, foram identificados temas controverso, como exemplo as disputas sobre o regulamento em relação ao tipo de isco a usar nas armadilhas e as limitações desatualizadas do número máximo de artes por embarcação. De forma a fomentar a discussão alargada da gestão da pesca do polvo na região, foram organizadas no âmbito deste trabalho sete reuniões participativas, designadas tertúlias, entre Abril 2014 e Abril 2015. No total, cerca de 60 participantes de 10 associações de pesca do polvo e de 16 instituições participaram nestes eventos. Como parte dos resultados destas tertúlias, foram coletadas, analisadas e discutidas 52 propostas de gestão para a pesca do polvo no Algarve. Estas propostas foram analisadas utilizando uma análise SWOT, condensando a informação discutida entre os intervenientes ao longo das reuniões. Esta informação foi compilada num documento de apoio à gestão (anexo), com a finalidade de transmitir aos intervenientes desta pescaria o conhecimento científico disponível sobre o ciclo de vida da espécie na região e implicações na gestão, de forma de encorajar os pescadores a participar ativamente no desenvolvimento de melhores práticas na exploração sustentável deste importante recurso.

No geral, esta tese deu uma visão detalhada sobre a dinâmica do recurso ao nível regional e regulamentação existente. Parte desta contribuição visa incorporar questões essenciais relacionadas com a biologia e ecologia do recurso e dinâmica pesqueira, de forma a estas serem consideradas num possível plano de cogestão para a pesca do polvo na região do Algarve onde é considerado que os pescadores e investigadores têm um papel de fundamental.

Palavras-chave: *Octopus vulgaris*, polvo vulgar, covo e alcatruz, Portugal, Algarve, dinâmica de pesca, desembarques, análise estatística multivariada, análise de séries temporais, ciclo de vida, desova, para-larvas, recrutamento, Barlavento, Sotavento, cogestão das pescas, reuniões participativas, medidas de gestão, associações de pesca, exploração sustentável.

Structure of the thesis

The following PhD thesis consists of two parts and three annexes, with each part containing three chapters. The chapters were written following the format of a scientific paper, and can be read independently from each other. The information about the author(s) and the status of the publication is given on the first page of the chapter. Part One discusses the relationship between the lifecycle of the common octopus (*Octopus vulgaris*) and the dynamics of its fishery. Chapter One discusses worldwide octopus fisheries and provides information on the ecology of the common octopus and the fishery management. Chapter Two discusses findings on the reproduction cycle of the species resulting from the analysis of commercial fishing landing data obtained from the main ports of the region. Chapter Three is about the times series analyses of landings, where results revealed first, that fishing recruitment is largely affected by the environment conditions and second that resource biomass is largely driven by the fishery. Results of both chapters provide relevant information to underpin ecosystem based management of this important fishing resource in the Algarve region.

Part Two discusses the management of the common octopus pot and trap fishery in Portugal, including references to the contemporary history of this activity in the country and strategies originating from consultations with stakeholders that are oriented to improve and make sustainable the exploitation of this important resource. Chapter Four discusses the current situation of the octopus fishery in Portugal, focusing on the management and governance models. Then, Chapter Five analyses proposals made by stakeholders during seven participatory workshops held in Faro between 2014 and 2015, aimed to improve the fishery management model of the common octopus. Chapter Six encompasses a general discussion of the results presented in this thesis about the common octopus, which highlights the importance of understanding the effects of fisheries on the ecosystem. The chapter ends with recommendations on lines of investigation that are possibly worth researching in the future. There are three annexes attached at the end of the thesis. Annex (1) is a booklet titled "The green paper of the octopus fisheries", that condenses information from the participatory workshops held with the stakeholders of the octopus fishery. Annex (2) is a brief report titled "EcoFishMan MP0", prepared prior to holding the workshops, that describes the octopus fishery in the port of Santa Luzia, one of the most important ports of the Algarvian region, nicknamed "The Octopus Capital" of Portugal. Annex (3) is a brochure that was developed in collaboration with the municipality of the city of Tavira with the purpose of promoting tourism activities around the octopus fishery in Tavira and the port of Santa Luzia.

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Part One

Fishery Dynamic, Life Cycle and Environment

Chapter 1.

Introduction

1.1. World Octopus Fisheries

Cephalopods are considered one of the most valuable fishery resources throughout the world (Jereb et al., 2014). The declining trends in many traditional fisheries, such as cods, hakes and haddock, have resulted in increased pressure on cephalopods to meet the ever-increasing demand for high-quality protein (Caddy, 1983). Global fishing landings of cephalopods have increased sevenfold since 1950, reaching a maximum in 2012 (4,449,322 tonnes; FAO 2014; Figure 1.1). These are mainly composed by members of the families: Loliginidae (squid); Ommastrepidae (squid); Sepiidae (cuttlefish); and Octopodidae (octopus). Among them, benthic octopuses of the family Octopodidae constituted around 7% of the world landings while the rest is dominated (75% Loliginidae and Ommastrepidae) by squid (Oosthuizen, 2003).

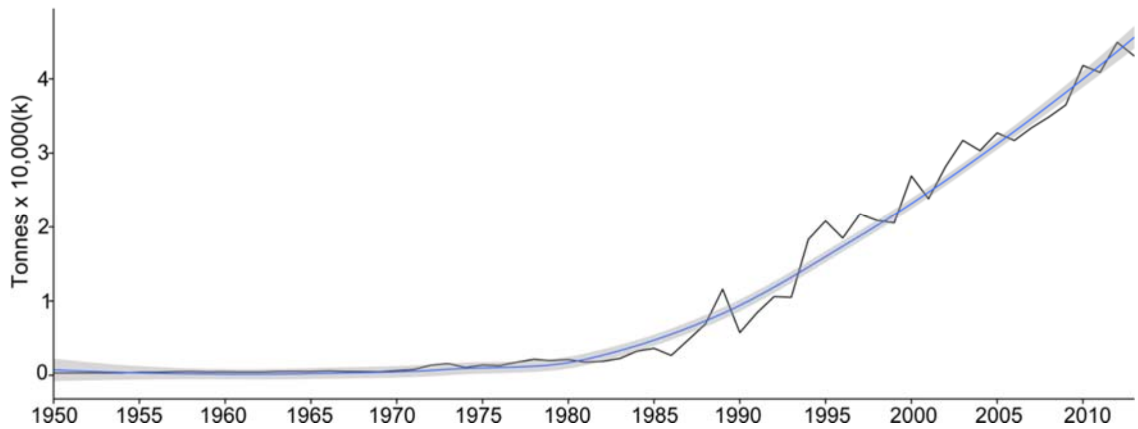

Figure 1.1. World cephalopod global landings from 1950 to 2013 with LOESS smoothing line (Local Polynomial Regression Fitting) (data source: FishStat dataset, FAO 2014)

In 2011, octopus exports (frozen and fresh) recorded 142,748 tonnes, representing an average price of 6.9 €/kg (frozen) and 5.8 €/kg (fresh), and accounting for close to one billion euros (964,898,089 €; FAO 2014). In many regions, the price and landings of cephalopods were much greater than many valuable finfish fisheries; for example the export value of fresh tuna, bonito and billfish was 3.16€/kg in 2011 (FAO 2014). Frozen octopus is the main commodity traded in the global market of this taxa group. Since the early nineties, the exports of frozen octopus have increased over five times, with Europe and Africa accounting for more than 70% of the global exports. Principal destination markets for frozen octopus are Europe and Asia, where more than 90% of this commodity is traded (FAO 2014).

During the last decade, several aquaculture trials for octopuses have been undertaken in different parts of the world: China (Liao et al. 2006; Lv et al., 2007, Cai et al, 2009); Spain (Vas-Peres et al. 2004); Chile (Perez et al. 2006); and Mexico (FIS, 2009), although none have reached commercial operation. On the other hand, octopus ongrowing, where wild caught small animals are fed in captivity until they reach profitable sizes, has been tested (Rodriguez el at. 2006; Pham and Isidro, 2009) but there is still uncertainty about its economic viability.

Figure 1.2 shows the total reported global octopus production over the past 6 decades, exhibiting a steady increase from 32,144 tonnes in 1950 to nine times greater at 298,093 tonnes in 2013 (FAO 2014). Around 15% of this data corresponds to landings of *Octopus vulgaris* (FAO 2014). However, fishery statistics from FAO have classified this important group of cephalopods as Octopuses nei ("not elsewhere included") where only a few countries discriminate landings to the species level and the total global production may actually include four main species: common octopus (*O. vulgaris*); Mexican four-eyed octopus (*Octopus maya*); horned octopus (*Eledone cirrhosa*); and, musky octopus (*Eledone moschata*) (Norman et al. 2000). The recent inclusion of fishery statistics from China since 1987 have shown increases in the global octopus trend to current levels, whereas the exclusion of the Chinese data makes the global trend appear less sustained (Figure 1.2).

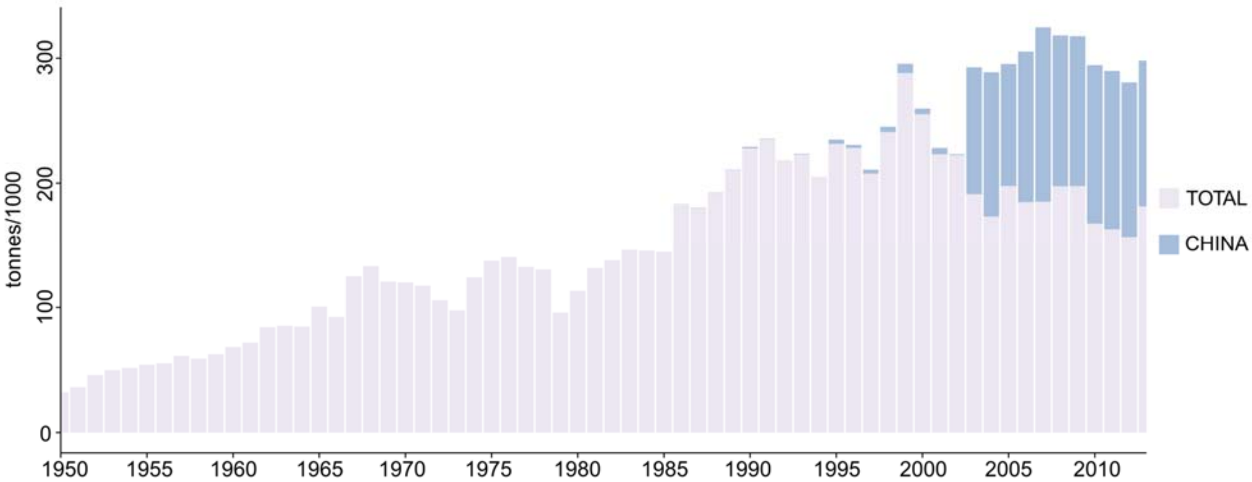

Figure 1.2. Octopuses ("Octopuses nei") global landings from 1950 to 2013 with China declared landings (data source: FishStat dataset, FAO 2014).

2.1.1. Common Octopus

World landings of common octopus *O. vulgaris* reached a maximum in 1975 (109,216 tonnes; Figure 1.3; FAO 2014), declining steadily since. The most recent values at the time of this study recorded 42,217 tonnes for 2013 (FAO 2014). European fisheries accounted for 58% of global landings, with the Atlantic northeast primarily dominating this figure (17,503 tonnes; 71%) and represented by the Iberian north and western shelves and gulf of Cadiz fishing ground regions divided between Portugal and Spain. The Mediterranean region, split between southern European countries and Africa also presents vast fisheries for cephalopods, with southern Spain, Italy, France and Greece being the largest producers from the European side.

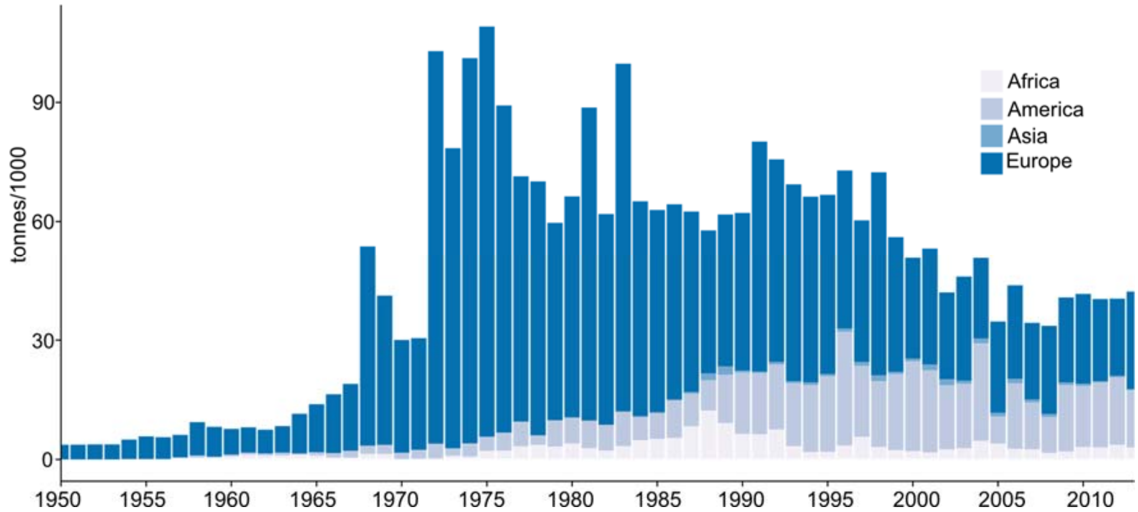

Figure 1.3. Common octopus *O. vulgaris* global landings by continent from 1950 to 2013 (data source: FishStat dataset, FAO 2014).

America is the second largest region for *O. vulgaris* fishing, accounting for 14,406 tonnes (34%). Here, the largest producers are Mexico, Brazil, Chile, Peru and Venezuela (FAO 2014). Africa is ranked third with 7% of the global *O. vulgaris* production. However, this value is believed to be underestimated due to a lack of species discrimination, where *O. vulgaris* may be grouped under the category *octopueses nei*, with countries like Morocco, Mauritania, Tunisia and Senegal accounting for important landings of this species. Asia only recorded 308 tonnes for 2013, with Japan as the main producer, while the rest of the Asian harvest is mainly based on other octopus genera (Jereb et al., 2014).

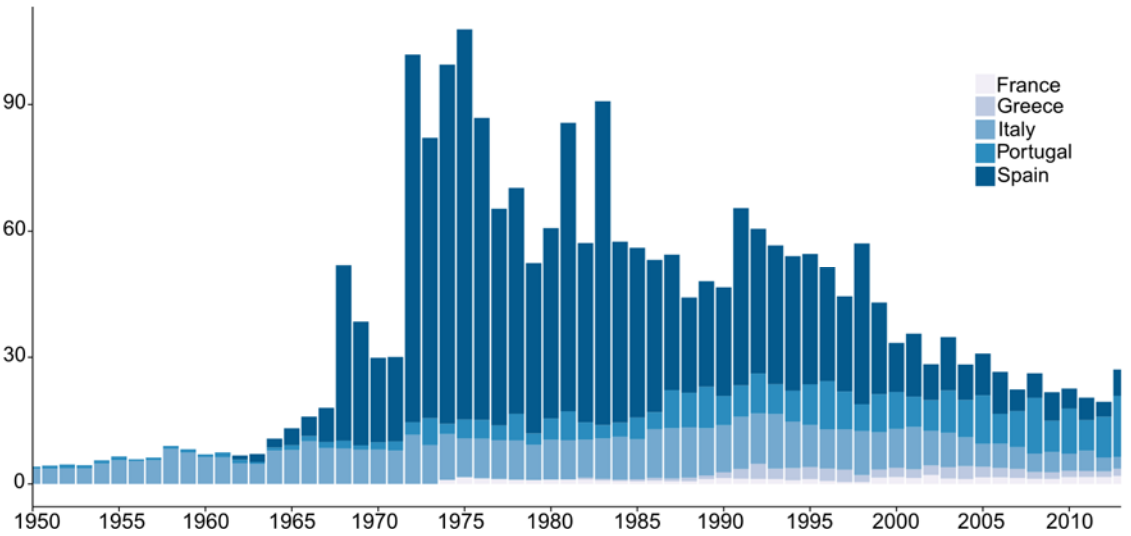

Figure 1.4. Common octopus O. vulgaris landings by country in Europe from 1950 to 2013 (data source: FishStat dataset, FAO 2014).

Portugal is currently the largest European producer of *O. vulgaris*, accounting for approximately 42% (54,317 tonnes) of production in the last six years (2008-2013) (Figure 1.4; FAO 2014). Before this period, Spain was ranked first for almost 40 years (1968-1999), recording more than 90% of the *O. vulgaris* landings. High values (max. 92,362 tonnes in 1975) followed by marked drops, may relate to the Spanish trawler fleet operating in North African countries. Italy has recorded values between 2,787 tonnes and 12,910 during the last six decades, with a maximum in 1993 (12,910 tonnes) and a steady decline since 2000. France and Greece have remained more stable with annual averages of 1,800 tonnes and 1,177 tonnes respectively (FAO 2014).

1.2. Main Fishing grounds

Several fishing grounds on the continental shelf of many countries have been intensively fished for octopus during the last six decades. Octopus fisheries can be classified into three main groups according to the method of fishing: (1) large trawlers mostly operating in foreign countries; (2) small scale boats using pots, traps, nets, jigging hooks or baited lines; and (3) coastal fishing using mostly scuba diving, spearfishing and hooking (with or without boats). The following paragraphs give an overview of some of the major fishing grounds for octopus in the world.

1.2.1. Northwest Africa

The largest *Octopus vulgaris* trawl fishery has been based in the north-western African upwelling system (also known as the Sahara Bank) where octopus has been the target of an international trawling fleet in the waters of Senegal, Mauritania and Morocco. This fishery has been widely described and analysed since 1960, when traditional finfish landings started to decline (Hatanaka, 1979, Sato and Hatanaka, 1983, Balguerías et al., 2000; Caverivière, 2002; Gascuel et al. 2007; Yagi et al. 2009). Around 300 freezer trawlers between 30-40 m in length from Spain, Italy, Korea, Morocco and Mauritania have been sharing the harvest. Products have been primarily exported as frozen octopus to Japan (Guerra, 2010). Due to large variations in fishing effort during the past 40 years, *O. vulgaris* landings have shown great variability. During the late 1990´s this fishery was diagnosed as overexploited and landings decreased from 106,671 tonnes in 1991 to 55,508 tonnes in 1997 (FAO 2014).

Since 2000, the artisanal fleet in this area has become an important component of the fishery when the EU-Morocco fishing treaties ended (Peiro, 2014). A large heterogeneous fleet of vessels including small canoes and larger boats using more sophisticated fishing gear (pots and jiggers) from Morocco, Senegal and Mauritania flourished. Important changes in management schemes were also implemented during this period. The most important change is a biological rest season to conserve the reproductive success of *O. vulgaris* (two months in autumn and two in spring). Currently, landings between Morocco, Mauritania and Senegal account for 85,568 tonnes and the latest assessment dating back to 2007 indicates that the stock is still overfished (FAO 2014).

1.2.2. Japan

Another important fishery for *O. vulgaris* has been identified in Japan (Asada et al., 1983). Most of the landings came from pot fishing and bottom trawling which together accounted for around 10-15% of the world’s production (FAO 2014). However, landings have decreased steadily from 14,166 tonnes during the 1960's to 6,422 during the 1980's, when a five year plan to protect and enhance spawning and nursery areas was implemented (Oosthuizen, 2003). Among the measures to safeguard recruitment, around 12,000 to 17,000 pots are laid out annually to provide shelter and enhance egg production (Asada et al., 1983). Despite this, reported landings of octopus for 2013 (not only *O. vulgaris*) still show a declining trend, reducing by almost half during the last ten-year period (2003-2013; FAO 2014). This fishery is concentrated in the South-western region of Japan, around the Seto Sea, where islands like Amakusa have been using pots since the beginning of the twenty century (Asada et al., 1983; Okutani et al., 1987).

1.2.3. Latin America and the Caribbean

Latin America and the Caribbean have reported cephalopod landings of four different species: *O.vulgaris*, *Octopus maya*, *Octopus mimus* and *Octopus insularis* (Jereb et al., 2014). Mexico is the largest producer, with most of its catch from the Yucatan peninsula in the Caribbean Sea. This fishery uses unique method of baited lines without hooks (drift lines) by a large artisanal fleet focussing on two main species involved *O. maya* and *O. vulgaris*. Landings of *O. vulgaris* have exhibited an increasing pattern since the early 1970's, with a peak during 1996 (28,572 tonnes), showing great variability in the later years. The latest landings recorded 16,919 tonnes in 2013 (FAO 2014). Among the management measures implemented are: (1) a six-month period where fishing is closed; and (2) harvesting by hooking and spearing has been banned (Jurado-Molina, 2010). Other producers of *O. vulgaris* in the region are Brazil (1,869 tonnes), Chile (1,796 tonnes), Peru (1318 tonnes) and Venezuela (270 tonnes) which use both traps and bottom trawling (Archidiacono and Tomás, 2009; Arocha, 1989; Leite et al., 2009).

1.2.4. The Mediterranean

The Mediterranean pot fisheries have existed since ancient times and the Mediterranean is nowadays one of the four FAO marine statistical areas with the highest octopus landings as a proportion of the total catch of all octopus species (Tsangridis et al., 2002). This region’s latest catch totalled around 9,953 tonnes in 2013, with a peak of 26,033 tonnes in 1988 (FAO 2014). Here, pots and traps are not the only fishing method used, but also bottom trawling and other gears are involved, including beach seines, trammel nets and fyke nets (Belcari et al., 2007; Garofalo et al., 2010; Gonzalez et al., 2011; Sánchez, P. and Obarti, R., 1993; Tsangridis et al., 2002). Every country and region promotes its own management scheme. However, a minimum landing weight and seasonal closures to protect reproduction is widely implemented throughout the Mediterranean. The largest five producers are Italy, Greece, France, Tunisia and Spain, together accounting for around 40% of the European harvest (FAO 2014).

1.2.5. The Iberian Atlantic coast

The Iberian-Atlantic coastal region is divided in three primary areas for octopus fisheries: 1) northern Spain including Galiza, Asturias, Cantabria and the Basque country (Fernández-Rueda and García-Flórez, 2007; Otero et al., 2005); (2) the west coast of Portugal, from Galiza to cape São Vicent in the south (Cunha and Moreno, 1994; Fonseca et al., 2008; Lourenço and Pereira, 2006); and (3) one third of the Gulf of Cadiz system, including the Algarve Region (Portugal) and Andalusia (South Spain) (Borges, T., 2001; Sobrino et al., 2011). This region is responsible for more than 40% of the global declared landings of *O. vulgaris* in recent years (FAO 2014) and represents one of the largest trap and pot fisheries in the world. The main fisheries management is carried out by yearly regional harvesting plans targeting *O. vulgaris* fisheries in Galiza, Asturias and Cadiz.

1.2.6. Portugal

Since 1970 *O. vulgaris* has become one of the most important target species in Portugal. This fishery takes place mainly in the south where, after the Bluefin Tuna trap fishery collapsed (Fromentin, 2009) and finfish fisheries has shown a declining trend (Erzini, 2005), fisheries have been re-directed to search for alternative resources (Pereira, João, 1999; Pita et al., 2015). Thus, Figure 1.5 shows a steady increase in *O. vulgaris* fishing through this period (1970-2014), where landings have recorded strong inter-annual differences of more than 50% between consecutive years. Pita et al. (2015) in a temporal analysis of the octopus fishery in Portugal identified three major periods relating to significant changes in fishing effort: (1) a period of steady landings only in the South (Algarve) using clay pots hauled manually (1920-1970); (2) a period of steep increase due the introduction of mechanical winches (in the early 1970's); and (3) a period of rapid expansion following the use of baited traps to the west and north-western coast of the Portugal (mid 1980's). In recent years, the interruption of the EU-Morocco fishing agreement in the Western Sahara grounds and some other African countries have increased the of demand on *O. vulgaris* in European countries including Portugal (Peiro, 2014). This situation can be considered as a fourth period in this retrospective timeline, where attractive prices of *O.vulgaris* in foreign markets have pushed Portuguese fishers to increase their effort on this resource. Moreover, recent declines of Iberian sardine landings since 2006 (Santos et al., 2012) have lifted the *O. vulgaris* to first place in the rank order of total value at national level, accounting for 44 million euros (2014), representing around 15% of the total revenue by all fisheries (DGRM, 2014).

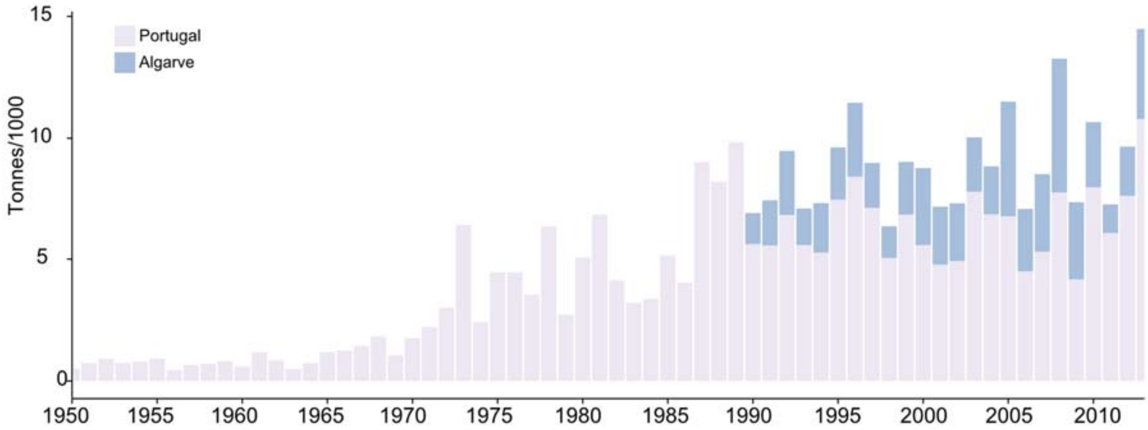

Figure 1.5. Common octopus *O. vulgaris* landings in Portugal from 1950 to 2014 and Algarve contribution since 1990 (data source: Directorate General for Marine Resources and Maritime Services and Safety-DGRM, 2015).

The frozen octopus exportation value in Portugal was recorded at 81,510,000 € for 2014, which represents around 10% of total exports of fishing products and an average price of 5.25€/kg, 40% more than 2013 (3.8€/kg) (INE, 2015). However, a significant part of the national exports of octopus commodities does not originate from national fisheries, where national landings only reached 10,661 tonnes in 2014 against 15,523 tonnes of frozen octopus exported. This difference might be represented by the imports of the product from elsewhere, then resell it in other markets The main destination of octopus exports from Portugal is Spain, where more than 90% of national production is traded (INE, 2015).

1.2.7. Algarve

The South of Portugal contributes around 30% of the country's total *Octopus vulgaris* landings, due to having the largest fleet in the country (765 fishing boats for the year 2014, DGRM, 2014). Between 1990 and 2014, octopus landings in the Algarve region have been highly variable, ranging from a minimum of 1,193 tons to a maximum of nearly 5,500 tons per year (Figure 1.5). Most of the landings are caught using pots and traps, with only around 10% attributed to bottom trawling (Fonseca et al., 2008; Pilar-Fonseca et al., 2014). The total fishing ground area for the octopus pot and trap fishery in Algarve is around 2016 km^2, divided into two sub-regions, leeward and windward, with 10 registration ports in operation (Figure 1.6).

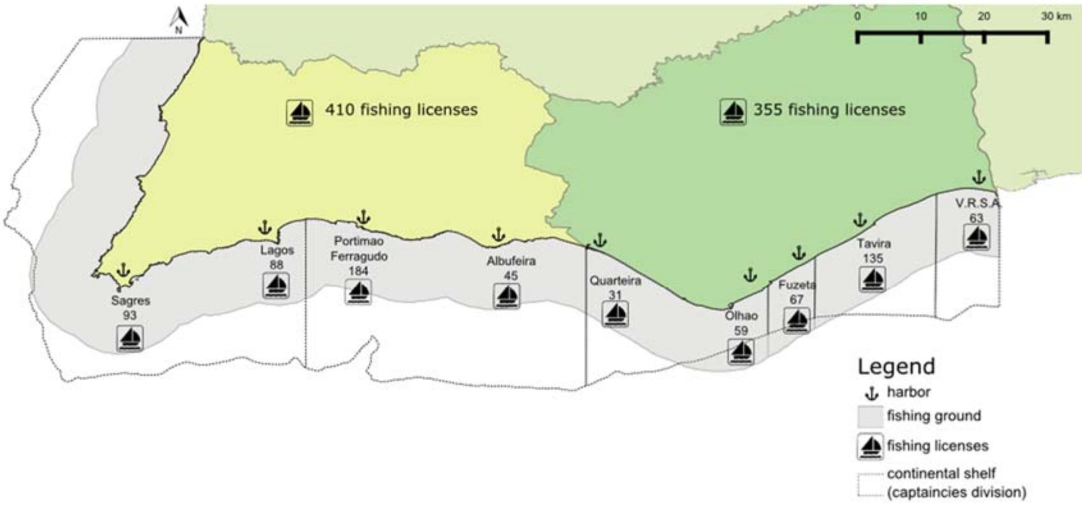

Figure 1.6. Fishing ground area for the Octopus pot and trap fishery in Algarve and its main fishing ports. Numbers correspond to total number of fishing licences approved for 2014 (Data source: Directorate General for Marine Resources and Maritime Services and Safety-DGRM, 2015).

1.3 Life cycle implications for management

The increasing fishing pressure on cephalopod species in many coastal communities has led to several challenges in fisheries management and traditional approaches, mostly developed for finfish that may not be appropriate for the ecology of many octopus species. The short life cycle and semelparity of this group results in rapid changes in population size (Boyle and Rodhouse, 2005). Thus, a broad understanding of the octopus life cycle, including reproductive output (recruitment) and breeding success (mating and spawning) is crucial. These are essential processes to underpin successful management strategies for this group of marine invertebrates (Jereb et al., 2014).

The life cycle of cephalopods has been extensively described and reviewed (Boyle, 1987, 1983; Boyle and Rodhouse, 2005; Robin et al., 2014). *O. vulgaris* fisheries depend on this short-lived species, with a cycle of around 12–14 months characterized by only one or two cohorts present in the fishery at any time. The sensitivity of early life stages to changes in environmental conditions drive drastic changes in population biomass, increasing uncertainty in stock assessment and consequent management (Guerra et al., 2010). Although the *O. vulgaris* life cycle has been largely described in the main fishing areas of the species, there is no comprehensive study compiling all this information. For the northwest coast of Africa, also known as the Sahara bank, most of the data comes from a single trawl fishery (Balguerías et al., 2002, 2000; Caverivière, 2002; Faraj and Bez, 2007; Guerra, 1981; Hatanaka, 1979). Likewise, in the Mediterranean, the species has been broadly studied from both small-scale fishing, using traps and pots, and bottom trawling (Belcari et al., 2007; Cuccu et al., 2013; Garofalo et al., 2010; Gonzalez et al., 2011; Mangold and Boletzky, 1973; Quetglas et al., 1998; Sánchez, P. and Obarti, R., 1993; Tsangridis et al., 2002). On the northeast Atlantic coast, between western Iberia and Gulf of Cadiz, the reproduction and landings have also been largely analysed (Cunha and Moreno, 1994; Lourenço et al., 2012; Lourenço and Pereira, 2006; Otero et al., 2007, 2005; Pilar-Fonseca et al., 2014; Silva et al., 2002; Sobrino et al., 2011; Sonderblohm et al., 2014). Most of these studies have reported year-around reproduction in the presence of one or two main reproductive seasons, addressing the relationships between environmental factors and early life stages of this resource.

1.3.1. Environment-recruitment

Probably one of the first studies of the relationships between environment and recruitment for *O. vulgaris* was carried out by Kubo (1935) who found that rainfall during the breeding season of a certain year influenced the size of the following year's catch in octopus fisheries around southern Japan. Sobrino et al., (2002) also demonstrated a negative correlation between rainfall and *O. vulgaris* abundance in the Gulf of Cadiz. Otero et al., (2009) have suggested that the reproductive cycle of *O.vulgaris* is coupled with the coastal upwelling system in north-western Spain where more than 80% of the variability in octopus landings depends on coastal wind patterns. Recently, Pierce et al. (2008) complied an in-depth review of these cephalopod-environment interactions with particular attention on the European Seas, addressing both large-scale atmospheric and oceanic processes; and local-scale environmental variation on principal fisheries across the continent and in other important areas. These authors highlighted the importance of identifying and including these variables in future fisheries models to forecast recruitment. Despite the current knowledge of environment-recruitment interactions for this species, climate change is expected to increase the complexity of early life stages dynamics and interactions with the environment, where its impacts are still largely unknown.

1.3.2 Mating and Spawning

A minimum spawning stock is necessary to ensure a sufficient supply of eggs and larvae to provide for the annual population recruitment (Boyle and Rodhouse, 2005). It is therefore a valid objective of management to ensure that this minimum spawning stock is protected. However, the unpredictability of the environmental conditions to which the output of that breeding stock will be subjected provides strong reasons for setting a minimum estimate of spawning biomass sufficiently high to allow for unfavourable conditions (Boyle and Rodhouse, 2005).

Some fisheries have reported problems of overexploitation when targeting octopus during breeding aggregations, like the case of *O. minor* on the Peng-hu Island of Taiwan (Jereb et al., 2014). High demand of this species during the breeding seasons led to intensive fishing, resulting in dramatic declines in landings. A one-month seasonal closure each year was then implemented to protect spawning. Other examples on the effects of fishing targeting inshore spawning aggregations of cephalopods are documented for neritic species of loliginid squid, both for the northeast and northwest Atlantic region (Hanlon, 1998). These examples show the effects of fishing gear selectivity on the spawning stock, where targeting high proportions of females has resulted in insufficient escapement of pre-spawning individuals, leading to large decline in landings.

1.4. Management examples

Most octopus fisheries worldwide have been managed by input controls such as closed areas, closed seasons and effort limitation (Asada et al., 1983; Augustyn et al., 1992; Fernández-Rueda and García-Flórez, 2007; Pereira, João, 1999; Pita et al., 2015). The main advantages of these input controls are that they do not require detailed quantitative assessment of the population dynamic. However, the most common criteria used for its definition have been based on expert opinions rather than scientific results, where political lobbies based on fisher’s demands have often been driving management decisions.

On the other hand, output measures like definition of catch quotas and minimum landing weight depend on expensive sampling and monitoring programs to generate detailed data for stock assessment. Moreover, these sampling efforts and assessments must be performed on a regular basis (e.g. annually) due the short life cycle of this species, showing great uncertainty related with environmental variability (Pierce et al., 2008). Among the most common output measures identified for management of octopus fisheries in the world is the minimum landing weight. However, its biological value estimation has been employed as a reference point, but its definition is not only based upon biological measurements, but also socio-economic interests of the fishery.

There is a lack of published work on assessment of management measures for octopus fisheries worldwide. The lack of common references points to assess their effectiveness implies the review of scattered published results from different fisheries, where the catching method and habitat differences do not allow quantitative comparisons. Boyle and Rodhouse, (2005) provide an in-depth review of cephalopod fishery management strategies around the world, concluding that worldwide efforts show no consensus in either management objectives or assessment methods. Pierce et al., (2010) presents an overview of cephalopods fishery management for four European countries, showing part of the complex interactions among public bodies in the policy-making process.

1.4.1. Octopus management In Europe

In European waters, there is no quota-management for any cephalopod fishery, and most of the management is based on gear restrictions and number of licenses (Pierce et al., 2010). Regarding the small scale fisheries (traps and pots) for octopus, the most common regulations have been: maximum number of traps and minimum landing size, seasonal closures and minimum fishing depth/distance limitation. Most of these regulations have been implemented through the publication of laws in each country or region official codes, where the access to fishing grounds is still being regulated through a top-down approach by centralized institutions, namely ministries or governmental bodies. However, the absence of European quota has promoted the development of country or region independent management plans, where consultation process and proposals via participation of the fishing sector have been a common factor in recent years (Pierce et al., 2010). The most representative example is from Galiza, where the fishery has been regionally managed for over 20 years through a participatory process between fishers and regional authorities, providing a reference point for the development of a co-management framework in Europe and across the world.

1.4.2. Octopus management In Galiza

One of the most developed management schemes of an octopus trap fishery in Europe is found in Galiza, in the northwestern Iberian Peninsula. Its management plan is based on a series of regulations: maximum number of traps, daily catch quota, fishing schedule, seasonal closures, minimum landing size, among others (Otero et al., 2005). Since the early nineties, the regional government of Galizia started promoting a co-management system between local fisher agencies, the so-called cofradías, and the fisheries administration (Macho et al., 2013). This process has resulted in the publication of several experimental management plans for the *O. vulgaris* trap fishery in the region, and most of them were developed with the participation of public bodies, fisheries agencies and marine researchers (Resolución do 30 de maio, 2014). Other regions in Spain, such as Asturias, have followed this initiative with different levels of participation from the fishing sector (Fernández-Rueda and García-Flórez, 2007) and the Gulf of Cadiz (Sobrino et al., 2011).

1.4.3. Octopus management in other regions

In Japan, a small-scale octopus fishery has been managed for over a century within cooperative arrangements between fishers. Here, fishing grounds were subdivided in small local areas within a rotating closing system, including the protection of reproduction grounds and artificial substrate enhancement for spawning (Asada et al., 1983). Rotational closures for octopus fishing have also been implemented and assessed in some small fishing communities across the Indian Ocean, achieving positive results (Benbow et al., 2014; Oliver et al., 2015). Watanuki, (2008) analyzed minimum landing size and closed seasons for *Octopus sp*. in Senegalese waters, while Narvarte et al., (2006) compared *O. tehuelchus* abundance in open areas and marine protected areas in northern Patagonia (Argentina). Leite et al. (2009) described the ecology of *O. insularis* and its implications for management in north-east Brazil, results from that study have been used to propose a management plan for the species in the area.

1.4.4. Octopus management in Portugal

In Portugal there have been several attempts since the late nineties to regulate the small scale pot and trap fishery fleet, with the publication of several ordinances in the national legislation code as a result of a top-down consultation process based on fishers demands (Pereira, 1999), mostly in the southern region, where this fishery is very important. Pita et al. (2015) described this process, which consists essentially of regulations defining a minimum landing weight and the gear used.

Most of the examples referred above agree in protection of the reproduction season to guarantee spawning and recruitment, as a key point to support fisheries. By other hand, most of these studies showed different levels of fisher participation during the management process, in which social dimensions of fishery management must be considered. After all, for any regulation to be effective it must be properly enforced, and all concerned groups should be familiar with the reasons of its implementation. If the majority of users of a fishing resource support the aims of the regulation, peer pressure becomes a strong deterrent to those disregarding the law (King, 2013).

The octopus fishery in the Algarve is moving towards implementation of new management regulations, where detailed information at local scale on the reproductive biology and recruitment is essential. The large amount of existing literature on the biology and ecology of the species has been increasing rapidly in recent years, however much of it is not incorporated in the management of the resource. Among the main reasons for the poor linkage between scientific research and fishery management is the lack of common spaces for building cooperation, in order to translate this knowledge to optimize the exploitation of the resource and its ecosystem. The fishers-scientists interaction can generate interesting practical knowledege to develop new models of exploitation of the fishing resources. Thus, the main aim of this thesis is provide a groundwork to develop a co-management framework for the octopus pot and trap fishery in the Algarve. By understanding the relationship between fisheries, biology and resource management, this PhD contribution tries to cover essential questions related to the biology of the resource and its fishery dynamics, where the incorporation of this information in the existing management is carried by the establishment of a new processes of co-management, where fishermen and researchers have a leading role.

1.5. Objectives

The structure of this PhD thesis consists of two parts, Part One and Part Two. Part One is sub-divided into two chapters, Chapter Two and Chapter Three, which precede the introduction or Chapter One. This first part addresses the fishery dynamics of the common octopus and its relationship with the life cycle of the species, especially those aspects concerning key reproductive stages such as spawning, para-larvae and fishing recruitment, and also its relationship with the environment. Part Two, containing chapters Four and Five, addresses governance and management of the octopus fisheries in Portugal. In this section a bottom-up process between fishers and authorities is developed. At the end, Chapter Six concludes with a general discussion about previous chapters and future research that are considered necessary as a result of this work.

Chapter Two objective is to understand the strong variability present in the landings time series and its relation with the life cycle at regional scale. For this purpose, landings statistics by port have been analysed from 1990 up to 2014. In addition, the fisheries data is analysed in relation to existing information on the reproduction of *O. vulgaris*, in order to better understand the link between the lifecycle, the fishing dynamics and the habitat. Overall, the first chapter intends to summarize this information in a clear and understandable way so that it can be used to facilitate the subsequent development of an ecosystem-based management process.

Chapter Three objective is to analyse the recruitment pattern of the *O. vulgaris* pot and trap fishery in one of the most representative fishing ports of the country for this cephalopod, located in the leeward Algarvian region, in the south of Portugal. Whereas other octopus recruitment studies are based on catching paralarvae or other small stages, usually involving long term sampling surveys, this study employs a time series analysis of fishery data to understand the population dynamics. A Dynamic Factor Analysis (DFA) is used to identify common trends in the *O. vulgaris* landing time series in order to investigate the effects of local environmental variables, and consequentially to gain insight on octopus recruitment.

Chapter Four objective is to examine the governability of the traditional small-scale fishery of the common octopus. This chapter intends to describe the natural and socio-economic systems in which this fishery operates, and the governing body regulating it. By means of surveys conducted among 18 representatives of fishery-related stakeholders such as fishing associations, producer organizations and traders, information is systematically collected and analyzed. Finally, this information is used to suggest the most appropriate management measures for small-scale fisheries, the best practices to increase the value of the catch, and how participation in the decision-making process can be enhanced.

Chapter Five's objective is to develop a participatory methodology to support octopus fishermen from the region in developing a fishery management plan. For this purpose, a bottom-up process among fishermen, management authorities and researchers is initiated in order to identify management strategies and implement a co-management process. One of the outcomes of this chapter is a small book describing and analysing every management regulation proposed during these meetings.

Through analyzing the different dimensions of the octopus fishery in the region, the contribution herein attempts to provide a consistent foundation to develop a management plan for this resource, where fishermen's involvement and ecosystem knowledge is considered fundamental.

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Chapter 2.

Relationship between the *Octopus vulgaris* life cycle and its exploitation patterns by the trap fishery in the southern coast of Portugal

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Abstract

Fishers of the *Octopus vulgaris* trap fishery from the south coast of Portugal have proposed a seasonal closure of the fishery in order to protect its reproduction and recruitment. In order to implement this management strategy, information based on the scientific knowledge for defining the length and timing of such closure has been requested. For this purpose official landing data from the last 25 years (1990 – 2014) of the commercial trap fishery of *O. vulgaris* along the southern coast of continental Portugal have been analysed to delve into the life cycle of this cephalopod. A seasonal pattern of landings has been observed: average landings during the seasons of autumn and winter have been higher than those during the rest of the year indicating the existence of two main fishing recruitment periods. Lower landings during summer may be related to mating and spawning. The landing data is coherent with the reproductive biology described for the area, confirming an annual cycle with two main spawning periods, in spring and late summer. Non-Metric Multi-Dimensional Scaling (NMDS) applied to 12 monthly time series of landings per port exhibited a clustering pattern among them. Leeward ports had larger landings during autumn, especially in November, according to a common pattern described for the Mediterranean Sea and Gulf of Cadiz waters while windward ports had larger landings during spring, suggesting that this area to be more like the western Iberia Atlantic coast. Understanding the life cycle of *O. vulgaris* and its exploitation patterns by means of analysing landing data may contribute to support the management of its fishery in the Algarve.

Keywords: *Octopus vulgaris*, fishery, reproductive cycle, recruitment, fishery management, Algarve

2.1. Introduction

The life cycle of cephalopods has been extensively described and reviewed (Boyle, 1987, 1983; Boyle and Rodhouse, 2005; Robin et al., 2014), leading to the conclusion that their fisheries are intrinsically difficult to assess and manage. These authors attribute this fact to the short life cycle and rapid growth of this group of species, which results in little overlap between generations, with most of the commercial fisheries depending on young animals, probably recruited earlier in the same year. Thus, the timing of the reproduction events, such as mating, spawning, hatching and subsequent recruitment may regulate fishing dynamics, resulting in a strong seasonal pattern in landings.

Although the *Octopus vulgaris* life cycle has been largely described in the main fishing areas of the species, there is no comprehensive study compiling all of this information. For the northwest coast of Africa, also known as the Sahara bank, most of the data come from an important trawl fishery (Balguerías et al., 2002, 2000; Caverivière, 2002; Faraj and Bez, 2007; Guerra, 1981; Hatanaka, 1979). Likewise in the Mediterranean the species has been extensively studied (Belcari et al., 2007; Cuccu et al., 2013; Garofalo et al., 2010; Gonzalez et al., 2011; Mangold and Boletzky, 1973; Quetglas et al., 1998; Sánchez, P. and Obarti, R., 1993; Tsangridis et al., 2002). In the northeast Atlantic coast, between western Iberia and Gulf of Cadiz, the reproduction and landings also have been largely analyzed (Cunha and Moreno, 1994; Lourenço et al., 2012; Lourenço and Pereira, 2006; Otero et al., 2007, 2005; Pilar-Fonseca et al., 2014; Silva et al., 2002; Sobrino et al., 2011; Sonderblohm et al., 2014). Most of these studies reported year around reproduction with the presence of one or two main reproduction seasons, and addressed the relationships between the environmental factors and the early life stages of this resource. However, the link between the life cycle and fishing dynamics is not very clear. Furthermore, life cycle dynamics in the different habitats for *O. vulgaris* across the fishing grounds is not well understood, where management measures may consider ecosystem interactions within other species for maintaining productivity of the fishery resources (Witherell et al., 2000).

The Algarve region, located in the southeast corner of the Iberian Peninsula, supports one of the most important octopus fisheries in Europe, with annual landings averaging around 2500 tonnes/year (DATAPESCAS, 2014). The fishing is practiced with two main gears: shelter pots and traps, with the latter the most important gear in the region. There is also a significant bottom trawling fleet which in late years has been targeted *O. vulgaris* (Fonseca et al., 2008). Recently, the management of this fishery in the region has been reviewed and discussed among stakeholders, with bottom-up management proposals collected from fishers and analysed by scientists (unpublished data). Among the measures proposed, seasonal closures for the protection of the reproduction and recruitment of *O. vulgaris* have been selected for implementation. Regarding this strategy, scientific knowledge on the life cycle of *O. vulgaris* has been requested by the sector to inform the definition of the length and timing for its implementation.

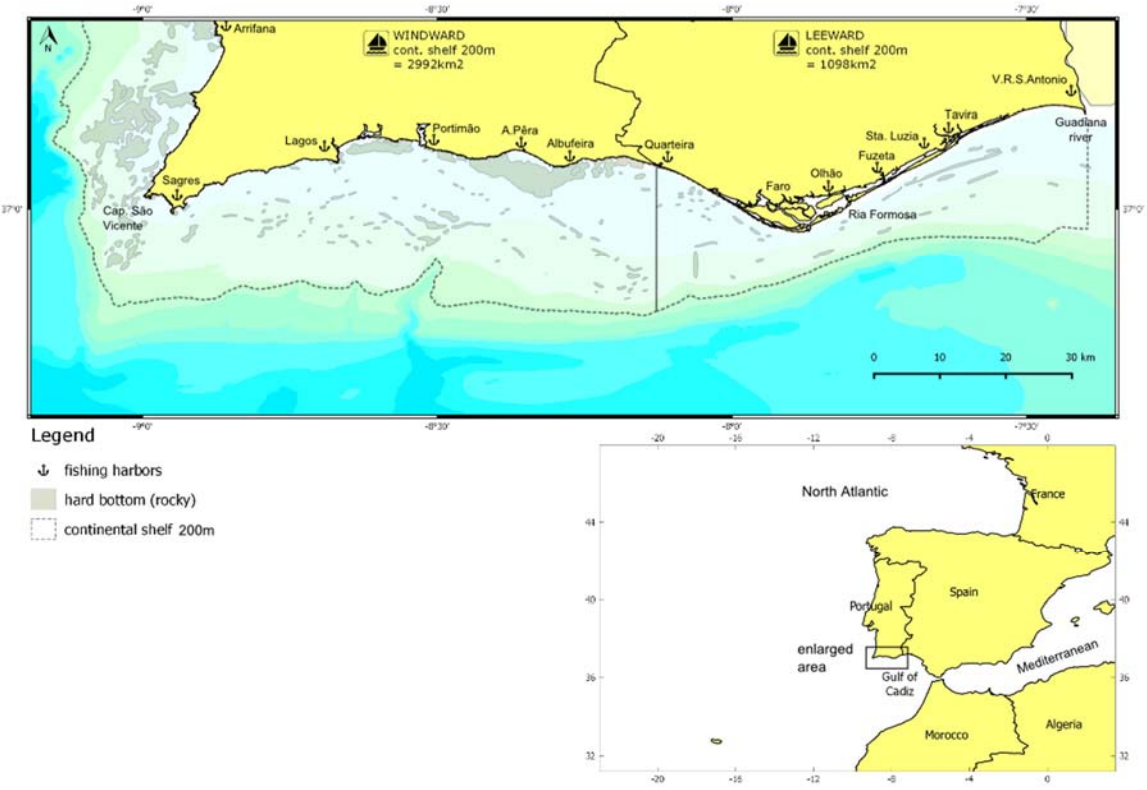
Despite the literature cited above, there is no clear identification of the two main landing cycles present in the region and understanding of how they are related with the reproduction cycle, with most of the information coming from expert opinion. Moreover, landing pattern differences between ports related to fishing ground habitats is not well understood. In response to this situation, the seasonal pattern of landings by port has been analysed along with existing research in order to describe the main life cycle events related to the octopus fishery in the Algarve region. By compiling the published research on *O. vulgaris* reproduction for this area, a closer picture of the link between the life cycle in relation with the fishing dynamic and local constraints has been addressed, where landings data in combination with existing research may provide relevant information to underpin ecosystem based management of this fishery.

2.2. Methodology

2.2.1. Description of the Fishing Grounds

This area covers the western border of the Gulf of Cadiz up to the southwest edge of the Iberian Peninsula (North Atlantic coast) (Fig. 2.1). It is divided in two main sub-regions: leeward and windward. The windward sub-region is the most westerly zone, more exposed to the prevailing swells from the north and northeast Atlantic. At the same time this area is sub-divided into two coastlines by the São Vicente cape, where the western and southern coasts intersect at almost right angles. The shelf off the west coast of windward Algarve is steep and only ≈10 km wide (Relvas, 2002), mostly consisting of rocky bottom, while in the south side it is wider and extends up to 20 km, where the largest rocky substrate formation of the region has been described (Gonçalves et al., 2008). In contrast, the leeward shelf is narrower showing width values ranging from 5 km off Faro to 20 km off the Guadiana River, mostly composed of fine sediments (Lobo et al., 2004). This area presents a large barrier island-lagoon system (Ria Formosa) extending 55 km along the eastern part of the south coast of the Algarve (E–W) (Newton and Mudge, 2003). On the east border, this fishing ground receives the outflow of the 4th longest river of the Iberian Peninsula, the Guadiana River, and some other small rivers flowing from Portugal and Spain.

Figure 2.1. *O. vulgaris* fishing grounds of the south coast of Portugal with details of the continental shelf (200m) and main fishing ports.



The total continental shelf area of Algarve (200m) is around 4994 km2 divided into 1698km2 (leeward) and 3296km^2 (windward), where around 11 main fishing ports distributed among 6 captaincies exist (Fig. 2.1). For analysis purposes in this work, the names are abbreviated as follows, from windward (west) to leeward (east): Arrifana (ARR), Lagos (LGS), Pera (PER), Albufeira (ABF), Sagres (SGS), Portimão (PMO), Quarteira (QRA), Fuzeta (FUZ), Olhão (OHA), Tavira (TAV), Santa Luzia (SZA) and Vila Real de Sto. Antonio (VSA). Outside boundaries of the fishing ground is 6nm off the coast, where the crustacean bottom trawling fleet operates. More close to the coast, the inshore limit is between ¼ to 1 nm depending on the time of the year, boat size and type of gear. The total fishing ground area according to current policies is 2569km^2 (51% of the continental shelf). However, most of the octopus trap fishing in the region is carried out between 20 to 80 meters depth only on soft bottoms over the continental shelf.

2.2.2. Life cycle and fisheries

Based on published research and exploration of landings data, the life cycle of *Octopus vulgaris* was drawn for the south coast of Portugal. Three main events in the *O. vulgaris* cycle were identified, namely: spawning, hatching and recruitment. Data on landings for *O. vulgaris* during the period from 1990 to 2014 were compiled from the Directorate General for Marine Resources and Maritime Services and Safety (DGRM by its Portuguese acronym). This dataset contains monthly landings of *O. vulgaris* recorded at the 'first sale' for every port in the Algarve region. Three variables were obtained from this dataset: landings (tonnes), price at first sale (€/kg) and number of boats. Averages were estimated for every month and season of the year. Autumn corresponds to October-December; winter to January-March; spring to April-June and summer to July-September. Analyses of variance was applied to compare mean landings between seasons of the year for every port.

2.2.3. Non-Metric Multidimensional Scaling

The goal of NMDS is to collapse information from multiple dimensions (into two or three, so that they can be visualized and interpreted. Unlike Principal Coordinates Analysis, NMDS uses rank orders instead of eigenvalues, and thus is an extremely flexible technique that can accommodate a variety of different kinds of data (Zuur et al., 2007). This technique has been used widely in ecological research mostly for comparing species composition and diversity among different sites and communities (Duffy et al., 2015). In the analyses herein, octopus monthly landings by ports have been transformed into a matrix of similarities using the Bray-Curtis index applying the *metaMDS* function from the *vegan* package in the R statistics software. The main advantage of choosing the Bray-Curtis index instead of raw Euclidean distances is that the latter are sensitive to total abundances, so may treat common months between ports with large differences in landings as non-similar, even though the landings seasonal pattern is much the same. Thus too large or too small landings during specific months are not driving the distances among ports. A square root transformation of the dataset was automatically applied.

2.3. Results

Figure 2.2 represents the main *O. vulgaris* life cycle stages in relation to the trap fishery exploitation pattern over the last 25 years in the south coast of Portugal. Six main rings were plotted, representing from inside to outside: 1) month of the year; 2) and 3) first and second cohort life cycle (spawning, larval stage and recruitment to the fishery) and 4), 5) and 6) fishing dynamics averages (landings, prices and effort - number of boats). Regarding the fishing dynamic, the 4th ring exhibits two major peaks in landings: one during winter months (February mean value =244.5±149.5 ton) and a second, more abrupt one in autumn (November: 244±180.2 tonnes) (Fig. 2.3). Minimum landings were recorded during late summer (September: 123.7±35.3 tonnes). The maximum average price (5th ring) was identified during both May (4.35€/kg) and August (4.35€/kg); while the price was lowest during November (3.75€/kg) and January (3.78€/kg). In agreement to published research, the reproductive biology of this species for the Algarve is represented by two major spawning events: early spring (March-April) and late summer (August-September) (Table 2.2). Moreover, two major para-larvae abundance peaks were also identified from published data, listed in descending order of importance: October-November and June-July (Table 2.2). Consequently, two main fishing recruitment seasons were identified: one during November and the second during February- March.

Monthly average landings for each port analysed displayed two common main peaks during the year: November and February-March (Fig. 2.3). Leeward ports such as Tavira, Santa Luzia and Fuzeta registered larger landings especially during November, while highest landings of the windward fleets from Quarteira, Albufeira, Portimão and Lagos were during spring months, namely February and March. However, the pattern is less clear for other ports from the west coast like Sagres, Arrifana, where a single peak in summer months has been detected. V.R.S. Antonio also presented a single peak in summer. A. Pera from the windward Algarve exhibited a unique pattern with a single peak in May. On the other hand, averaging landings by windward and leeward ports enhanced these two peaks, with spring months prevailing for the windward Algarve, while leeward has more similar peaks for both seasons, where autumn months have higher landings than spring, especially November.

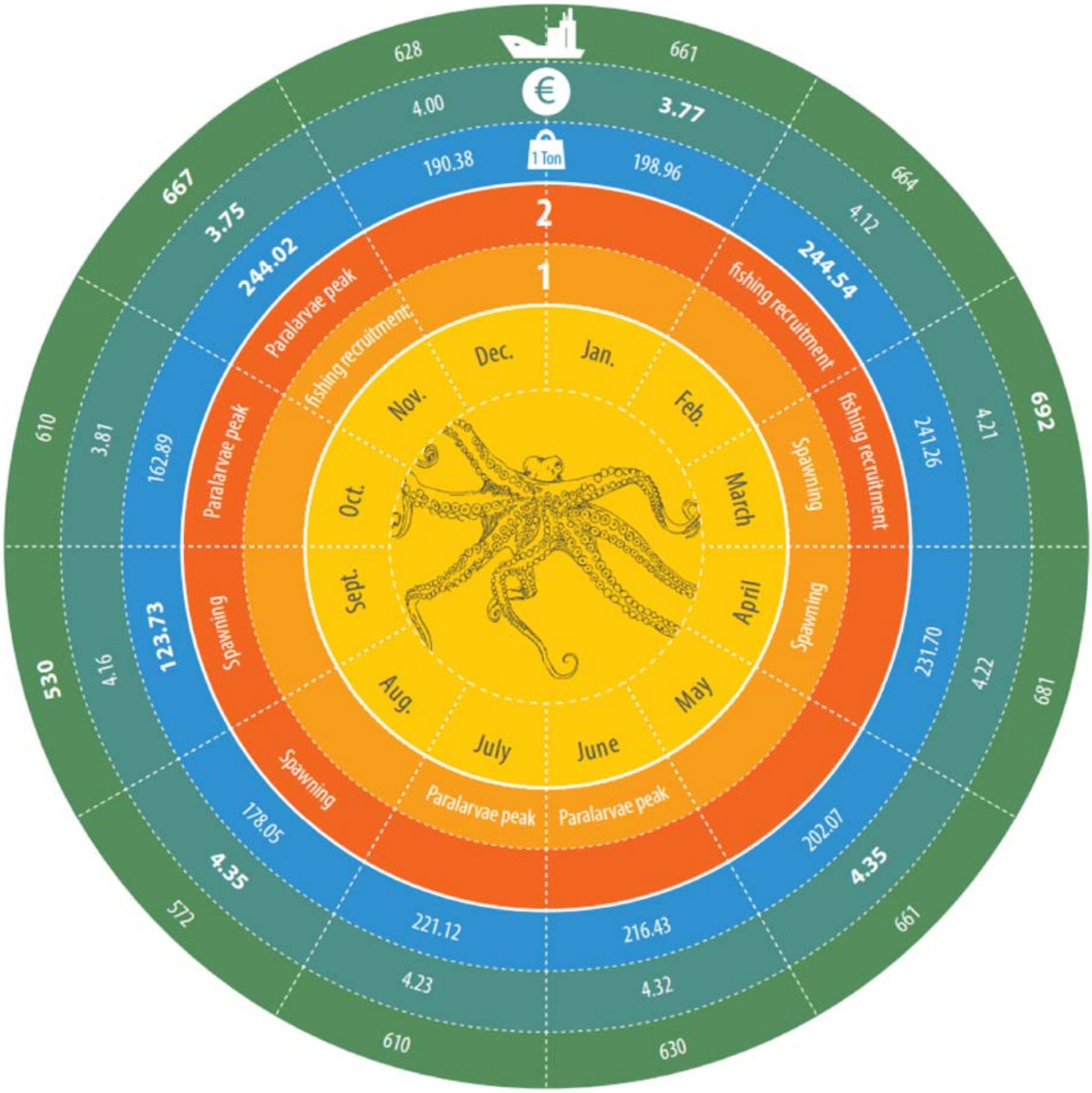


Figure 2.2. Life cycle of *O. vulgaris* for the south coast of Portugal based on exploration of landings data and published research The six circles, representing from inside to outside: 1) month of the year; 2) and 3) first and second cohort life cycle (spawning, larval stage and recruitment to the fishery) and 4), 5) and 6) fishing dynamics averages (landings, prices and effort - number of boats). Numbers inside the boxes correspond to averages from 1990 to 2014.

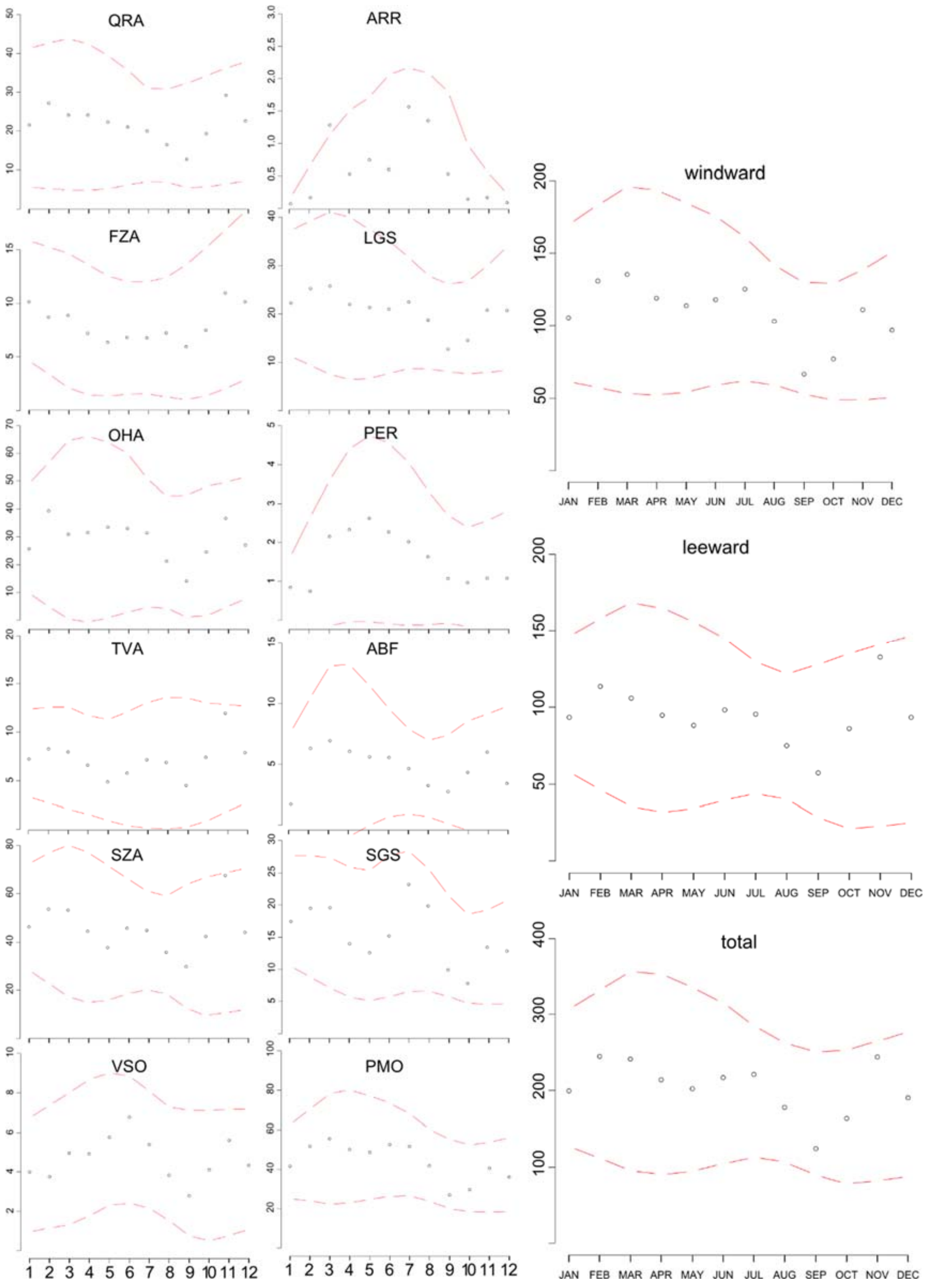


Figure 2.3. *O. vulgaris* monthly mean landings by port from 1990-2014 in southern Portugal. Right side of the figure shows the port data aggregated by: windward, leeward and total. Left side column are leeward ports, middle column are windward. Red dashed lines represent the standard deviation. All y axis represent tonnes.

The NMDS bi-plot shows that some ports are clustered together, namely Lagos, Sagres and Portimão. Also Olhão and Quarteira were grouped together, while other ports were separate (Fig. 2.4). Arrifana and A. Pera were plotted on the top left hand corner, suggesting that there is some sort of similarity shared between these two ports. Other ports like V.R.S.Antonio, Tavira and Fuzeta also exhibit some proximity. The scatter plot between the interpoint distances and their original similarities (Shepard plot) showed small scatter around the line (not included), suggesting that the original similarities estimated are well preserved in the reduced number of dimensions. NMDS using landings separated by season of the year exhibit the same pattern, where windward ports such as Portimão, Sagres, Lagos and Albufeira are plotted together, while Arrifana and A.Pera are isolated from the rest.

Landings of *O. vulgaris* by season of the year exhibit larger averages during winter, while the second largest mean was found in spring (Fig. 2.5). When landings are separated by fishing ground area, winter means are larger for both windward and leeward ports. Leeward ports showed the second largest mean during autumn (128.73 tonnes/month; s.d.: 98.63; Fig. 2.5), while for windward ports the second largest landings on average were in spring (92.7), follow by summer landings (79.8 tonnes/month; s.d.: 39.44; Fig. 2.5). Analysis of variance revealed significant differences among seasons for ten out of the twelve ports analysed (Table 2.2). Seasonal differences in landings of Fuzeta and Albufeira ports were not statistically significant.

2.4. Discussion

The octopus fishery in southern Portugal shows a strong seasonal landing pattern which reflects its short life cycle, within two main landing peaks: one during November and another one in February. The presence of these two main peaks in landings appears to correspond to the presence of two main spawning events reported for this area (Lourenço et al., 2012; Moreno et al., 2008) and more directly with two peaks in recruitment, consistent with what is expected of a recruitment fishery. However, when looking at each port individually the two main cycles exhibit different patterns, which may be related to fishing ground hydrography and oceanography, as well as habitat type and possibly prey-type availability, among other factors.

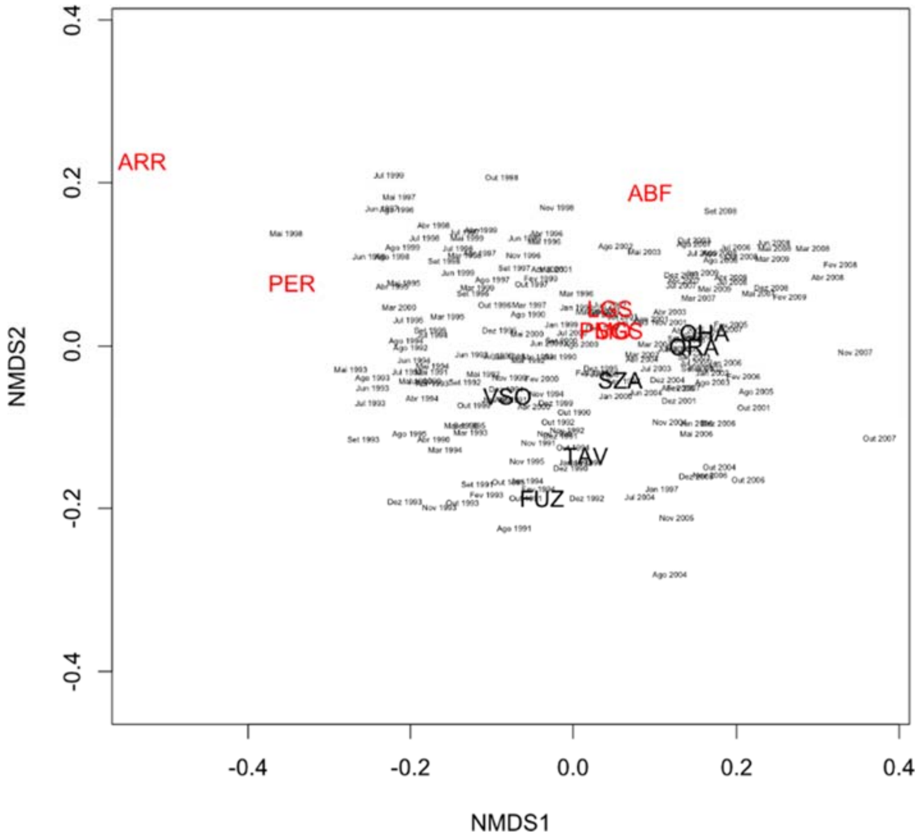


Figure 2.4. Non Metrical Dimensional Scaling (NMDS) using Bray and Curtis similarity matrix applied to *O. vulgaris* monthly landings by port. (stress 0.18).

Generally, leeward ports displayed maximum average landings during the months of November, considered to be the main fishing recruitment period for this area (Sonderblohm et al., 2014); while windward ports exhibit maximum landings during February-March. These two peaks in landings reported herein have previously been identified by Cunha and Moreno (1994) from different landing ports along the Portuguese coast. Those authors also described two peaks in CPUE, one in spring and a minor peak in late summer consistent with increasing resource abundance. In neighbouring waters of the Gulf of Cadiz, Silva et al., (2002) and Sobrino et al., (2011) have reported similar seasonal trends in landings of *O. vulgaris* caught by shelter pots, where the fishing season starts in October, with the largest recorded annual landings. For the Saharan bank (Northwest Africa), Spanish freezer trawlers fishing for cephalopods recorded largest catches of *O. vulgaris* during September-October, with a second peak during March and April (Balguerías et al., 2000; Hatanaka, 1979). Moreover, these studies showed that the largest part of the catches correspond to juvenile octopus, an early indication that the fishery strongly depends on the contribution of seasonal recruitment booms.

Table 2.1. *Octopus vulgaris* spawning, hatching, recruitment and abundance (LPUE) patterns in 12 different regions based on published research.

Region	Spawning	Hatching (*paralarvae*)	Recruitment	Abundance (LPUE)	References
South Portugal – Algarve (north-eastern Atlantic Ocean – Gulf of Cadiz)	Two peaks: August-September / March-April	Two peaks: October-November / June-July	Two peaks: November – February (Fishing recruitment)	Maximum = January-March; Min.= September	Lourenço et al., 2012; Moreno et al., 2008, Sonderblohm et al., 2014
Portuguese West Coast (Iberian Peninsula; North-Eastern Atlantic Ocean)	February to July with two peaks: February-April / June- July	June-July / October-November	N.R.	Tow peaks: Spring and Late Summer	Lourenço et al., 2012 ; Moreno et al., 2008; (Cunha and Moreno, 1994)
Eastern Mediterranean Sea	Two peaks: Late winter-spring / Late summer-early autumn (August-September)	2-3 months to hatch for first spawning peak (May-June), second only 1 month to hatch (November)	Benthic recruitment: two peaks: late spring - summer and late autumn	N.R.	Katsanevakis and Verriopoulos, 2006
Gulf of Cadiz System (North-Eastern Atlantic Ocean)	Two peaks: April-May / August -September	N.R.	N.R.	Maximum October-November (fishing season is October to May)	Silva et al., 2002; Sobrino et al., 2002
Galiza, north-eastern Atlantic Ocean	single peak: spring months	end of summer- autumn (end of upwelling season)	N.R.	Maximum during Winter	Otero et al., 2007; Otero et al., 2005
Saharan bank (North West Africa)	two peaks: Spring (February-May) / Autumn (October-December)	N.R.	Two main peaks = September-November; and March-April (or May-June)	Two maximum= September-November; and March-April	Hatanaka, 1979; Balguerías et al., 2002, Faraj and Bez, 2007, Caverivière, 2002
Moroccan Waters	Two peaks:March-April / September-October	Two peaks: May / November	Two peaks: main recruitment is autumn (October) secondary during spring (April)	N.R.	Robert et al., 2010
Western Mediterranean	N.R.	January to August	Two peaks: September / April	minimum= August September/ max= Spring	Quetglas et al., 1998
South African West coast	two peaks: spring / summer	N.R.	N.R.	N.R.	Smith and Griffiths, 2006
South African East coast	two peaks: intense summer spawning	N.R.	N.R.	N.R.	Osthuizen and Smale, 2003
Central East Atlantic (Canary Island)	two peaks: April-may / September-November	N.R.	N.R.	two peaks: April-may / September-November; lowest = July-August	Hernández-García, 2002)
Strait of Sicily, Central Mediterranean	Two peaks (Spring/Summer): April-May / August -September	N.R.	Autumn months	N.R.	Garofalo et al., 2010

Table 2.2. Mean landings (tonnes) of *O. vulgaris* grouped by season for the 12 ports analysed. P-values derived from ANOVA tests.

	Harbor	Autumn	Spring	Summer	Winter	p value
Leeward	*VSO*	3.52	4.86	3.44	3.17	**0.0082**
	TAV	8.17	5.03	5.8	7.65	**0.0066**
	SZA	52.14	40.13	35.46	52.11	**0.0017**
	FZA	7.5	6.31	5.87	8.37	0.0669
	OHA	31.41	33.16	23.45	37.01	**0.0427**
	QRA	25.98	22.78	16.3	28.23	**0.0003**
	Leeward	128.73	112.75	90.91	136.56	**0.0028**
Windward	*ABF*	7.59	7.19	5.01	7.54	0.1530
	PER	0.77	2.16	1.42	0.9	**0.0000**
	PMO	33.45	48.95	38.64	45.78	**0.0001**
	LGS	17.16	20.41	16.93	21.58	**0.0500**
	SGS	11.66	13.71	17.83	16.94	**0.0002**
	ARR	0.13	0.66	1.15	0.55	**0.0101**
	Windward	75.7	95.09	81.92	101.28	**0.0356**
	Total	202.19	211.7	175.43	230.99	0.1510

Personal observations during on-board fishing trips in leeward Algarve during 2011-2014 confirmed these findings, as most of the commercial catch during autumn landing peaks, especially during October and November are composed of juvenile octopuses hardly over the 750 g minimum landing weight allowed for the country. Moreno et al. (2014) described high concentrations of juvenile octopus (pre-recruits) in the south-east coast during autumn-winter, identifying this period as the main yearly recruitment season for *O. vulgaris*. Other regions exhibiting high abundance in landings during autumn months include: Canary Islands in the Central East Atlantic (Hernández-García et al., 2002); Strait of Sicily in the Central Mediterranean (Garofalo et al., 2010), Baleares Sea, western Mediterranean (Quetglas et al., 1998), Thracian Sea, Eastern Mediterranean (Tsangridis et al., 2002), among others.

In contrast, some important windward ports of this study, like Albufeira, Portimão and Lagos, showed highest average landings during spring months, especially during March, coinciding with a second peak found by Balguerías et al. (2002) for the Saharan Bank in North-West Africa. Otherwise, there is a third peak in landings during July-August only for the two ports located on the west coast, Sagres and Arrifana, when most of the other ports remain with very low averages. However, these large summer landings in the west coast of Algarve probably reflect calmer seas and thus better fishing conditions in summer, combined with the species reproductive cycle. In this area access to fishing grounds is very limited during most of the year due to strong north winds and swells, with fishing close inshore shallow rocky reefs often only possible in summer. This is when high numbers of big mature females (spawners) are expected near the coast during the reproduction season, and might contribute to greater landings during these months. Such high concentrations of *O. vulgaris* near the coast during the spawning season were also reported by Quetglas et al., (1998).

In general, with the exception of Sagres and Arrifana, there seems to be a trend in that ports on the windward south and the western Portuguese coast present stronger recruitment fisheries in spring, whereas the leeward south Portuguese coast, the Mediterranean and Northern Africa present stronger recruitment fisheries in autumn. It was possible to relate this port-specific seasonality of *O. vulgaris* landings for the region directly to existing published research on the reproductive biology. Lourenço et al. (2012) defined three different spawning seasons for the Portuguese coast in relation to two main oceanographic regimes: the western Iberian upwelling system and the Gulf of Cadiz system. For the latter region an intense spawning period was recorded during August and September, benefiting from warmer temperatures during this time of the year, which resulted in high paralarvae abundance during November (Moreno et al., 2008). The second spawning season as reported by Lourenço et al. (2012) for the south is described as being less intense and only occurring occasionally during early spring months, due to variable favourable environmental conditions.

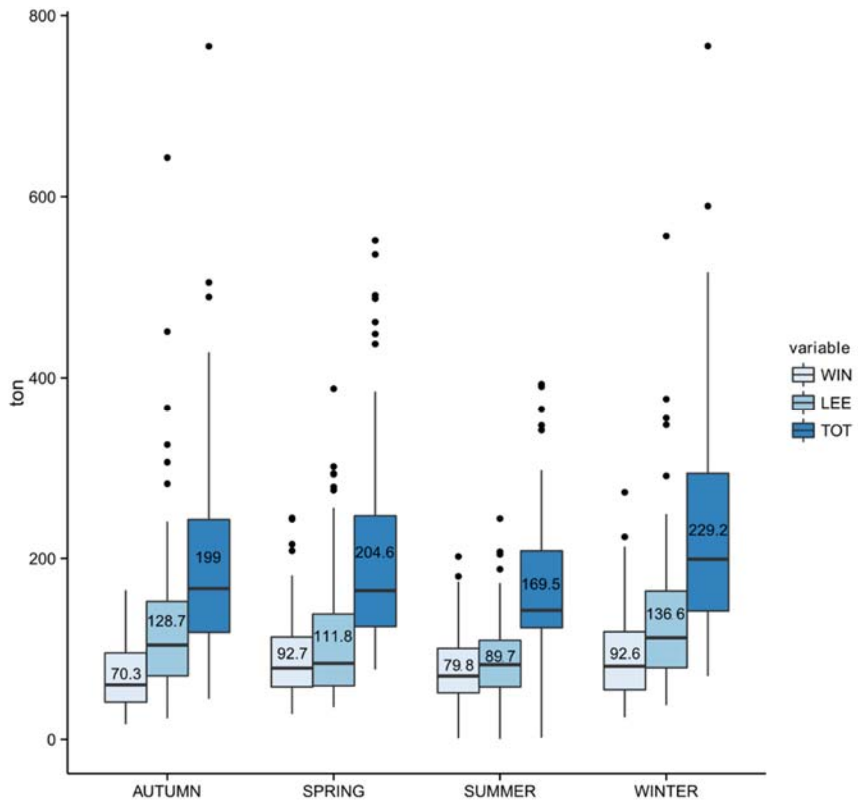


Figure 2.5. Box plot of *O. vulgaris* landings by season averaged for: a) Total ports (TOT); b) leeward (LEE) and c) windward (WIN) region between 1990 and 2014. Autumn corresponds to: October-December; winter: January-March; spring: April-June and summer: July-September. Numbers inside the box represent mean values.

These two main spawning seasons, in contrast with the commercial landings, can be linked to the two main recruitment periods hypothesized herein: November and February-March. For Leeward ports, the November recruitment seems to be extremely important for the period analyzed; young recruits caught during this season might belong to the early spring spawning event, and so hatching might coincide with the local hydrology. In spring the natural peak of the Guadiana river runoff occurs, which is one of the most important sources of nutrients for plankton communities in this oligotrophic area (Faria et al., 2006). This spawning-hatching strategy during spring has been reported in previous research by Erzini (2005) for most of the commercial fish species landed in the region, with the main spawning periods following maximum river runoff, commonly during January until March (Kilsby et al., 2007). Thus, hypothetical recruitment to the fishery from the early spring spawning event might take place approximately 9 month later, mostly during November. Rapid growth of this species has been reported in captivity experiments, with juveniles reaching 0.5-0.6 Kg within six months of hatching (Iglesias et al., 2004).

On the other hand, windward landing peaks during spring might belong to the second spawning event during late summer (August-September), when young individuals could be available to the commercial fisheries within 7 months, approximately from February and March, due to warmer temperatures at hatching and consequently faster growth. This second spawning strategy and the resulting hatching could be synchronized with the upwelling and relaxation system (and thus the greater similarities with the West coast). A filament of upwelling waters, more intense during early summer penetrates the south coast from the west which is followed by higher primary productivity in this area (Relvas, 2002), possibly enhancing larval growth for *O. vulgaris*. A synchronization of hatching with upwelling has been described for north-western Spain with only one spawning season during spring (González, 2005).

Temporal variation of the two main landings is to be expected, due to the dynamics of the environmental factors, namely hydrology (river runoff and rainfall) and oceanographic processes (upwelling-relaxation), which might drive octopus life cycle processes for this area, but more importantly modulate abundance. Therefore, among some of the factors to consider that may regulate the timing and strength of the *O. vulgaris* annual recruitment in the region include: rainfall intensity and seasonality, gulf of Cadiz inflow-outflow hydrology and west coast upwelling intensity and timing (interestingly, this also hints on the strong possibility that among other factors, an anthropogenic impact can be expected through the regulation of the Guadiana river outflow by the Alqueva dam - at the limit, some form of fisheries management might be achieved that way). Conversely, a variable timing of the reproduction cycle can also be expected considering the adaptability of a species of very-wide geographic distribution, and this has been recognized as a key strategy for the species survival in highly variable environments (Boyle and Rodhouse, 2005).

In the analyses herein, besides the environmental variation and its effects on timing of the life cycle of this species, the physical nature of the bottom is also hypothesized to be an important factor regarding the abundance and distribution of *O. vulgaris*. The Algarve coast consist of two main types of substrates: soft or sandy/muddy substrate and hard or rocky substrate; the first mostly covering the leeward area and the second being more abundant on the windward area (Gonçalves et al., 2008). Both types of substrate define the density and biodiversity of the benthic communities associated to each region, with octopus exhibiting highly adaptive occupation of these habitats (Boyle and Rodhouse, 2005). *O. vulgaris* reproduction and diet, among other processes might change according to habitat type. Moreno et al., (2014) identified important benthic-recruitment grounds near two important estuaries in the leeward area of the Algarve region, and found that coarse sediment with large mollusk shell fragments is important for the distribution of pre-recruit octopus, since young octopus were observed to use these shell fragments as shelters . In another study from the coast of Greece, in the Central Mediterranean, artificial dens of human origin were found to be the main constraint for the distribution of *O. vulgaris* on soft sediment (Katsanevakis and Verriopoulos, 2004). Curiously, for the Algarve region it was estimated that more than 50 thousand octopus traps are lost during a year, with higher losses in the leeward area (Erzini, 2007). Thus, habitat characteristics and fishing impacts on the ecosystem should be considered as possible modulators in the life cycle. Knowledge on habitat differences across the fishing grounds for this area may therefore also be essential for the management of this species.

Results from an intensive mapping project of the biodiversity of the coastal shallow areas of central Algarve (windward) show a clear separation between the two main substrates, where rocky bottoms were characterized by higher biodiversity and densities of organism than soft bottoms (Gonçalves et al., 2008). Moreover, the authors described that the relationship between the hydrodynamics and the temperature affects the annual life cycle of many benthic species. Curiously, a unique pattern in the monthly average landings has been observed in only one port which is located close to the reefs described in the report mentioned above, where *O. vulgaris* catches peaked during May and the lowest value occurred during February. Thus, it is reasonable to think that site specific landing patterns might be related to habitat differences in fishing grounds, as *O. vulgaris* might exhibit different reproduction strategies adapted to local conditions. According to Faraj and Bez (2007) a clear distinction between spatial areas of spawning and recruitment of *O. vulgaris* exist in the Dakhla area in Northwest Africa. Recent research from mark and recapture experiments and visual census showed high site fidelity to rocky substrate, referred by the authors as preferred spawning and recruitment areas (Garofalo et al., 2010; Guerra et al., 2015; Mereu et al., 2015).

However, it is important to recognize the noise associated to the landing data, because although most of the landings are expected to originate from nearby areas, fishing vessels can move across different ports and fishing grounds. Fishers from the region know the seasonality of the fishing grounds very well, and some of them move their boats across different ports or fishing grounds between seasons,. For example, during spring months, when the leeward fleet has fished the autumn-winter harvestable surplus intensively, some boats move westwards to benefit from a second more intense fishing recruitment peak in the area of the windward ports. This fishing vessel interchange between leeward and windward was observed personally, but only for the larger coastal category vessels (>12m in length as determined by law) and interchange occurred mostly between the two most important ports: Santa Luzia (leeward) to Portimão (windward), where landings take place in the nearby fish auction site.

2.5. Recommendations

The landing pattern described herein shows the importance of physical differences in the fishing grounds on the resource dynamics in this area. Knowledge of the spatial characteristics of the habitats of important fishing resources is a fundamental step to provide managers with a broader picture of resource dynamics at local level. From an ecological perspective, the implementation of a closure for this fishery should consider these habitat differences, where the two sub-regions exhibit port-specific dynamics according to the two main life cycle patterns identified. Moreover, the plasticity of the resource related to environmental factors adds an extra challenge to the implementation of seasonal closures, where timing of spawning and recruitment is not fixed. Weighting this scenario, a more local-scale management scheme based on rotational closures might be considered, where recent analyses from octopus fisheries in the Indian Ocean shows interesting findings (Benbow et al., 2014; Oliver et al., 2015; Raberinary and Benbow, 2012).

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Chapter 3.

Environmental and fishery driven dynamics of the common octopus (*Octopus vulgaris*) based on time series analyses from leeward Algarve, southern Portugal.

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Abstract

Dynamic Factor analysis (DFA) was used to explore monthly LPUE series of *Octopus vulgaris* and environmental variables recorded in the south west Iberian Peninsula, south Portugal. In spite of the large fluctuations in the octopus abundance series, results showed a strong aggregation pattern for the last three months of the year (October to September), possibly related with the input of new recruits to the fishery. The calculated common trend for the 12 months' time series presented significant correlations with autumn rainfall of the previous year (lag-1), particularly for the October, November and December series. Other important correlations were found for Western Mediterranean Oscillation index (WeMOi) (lag-1), Ekman transport, summer River runoff (lag-1), horizontal and vertical component of wind stress, among others. The main trend describes a moderate steady increase in LPUE during the last 10 years, suggesting that octopus abundance has increased from 1990 to 2010. The strong correlations of the monthly octopus LPUE series, together with the annual life cycle suggest that after environmentally controlled recruitment, population dynamics is largely fishery driven, resulting in strong seasonality in the landings.

Keywords: environment, *Octopus vulgaris*, Portugal, recruitment, time series, trap fishing, trends.

3.1. Introduction

Cephalopod populations are well known to exhibit wide fluctuations in abundance, mainly due to the presence of a planktonic larval stage particularly sensitive to environmental factors (Pierce *et al.*, 2010). Among them, *Octopus vulgaris* is a short-lived species, with a cycle of around 12-14 months characterized by non-overlapping generations, with only one or two cohort's presents in the fishery at any time, and a very rapid growth with high fecundity rates (Pierce and Guerra, 1994). The success of mating, incubation, spawning, paralarval stage and recruitment to the benthic life are key processes of the octopus life cycle. Identification of the spatio-temporal scale of these events and their relationships with the environment has been the pursuit of many scientists attempting to understand the dynamics of this important mollusc (Payne *et al.*, 2006).

Several studies have tried to identify possible mechanisms that could explain the variability of recruitment of short lived marine species in relation to the environment using time series analyses. Recently, Santos *et al.* (2012) analysed recruitment variability of the Iberian sardine (*Sardina pilchardus*) in relation to environmental parameters using dynamic factor analysis (DFA) and Generalized Additive Modelling (GAM). Another interesting approach was carried out by Lloret *et al.* (2001) who found links between recruitment of Mediterranean species and local and global environmental conditions based on analyses of CPUE data. Thus, the use of environmental variables to examine trends in abundance of certain cephalopods has received increased interest over the past few years. Robin and Denis (1999), explored the relationships between water temperature and squid abundance in the English Channel using time series analyses. Agnew *et al.* (2000) reported effects of sea surface temperature on recruitment of *Loligo gahi* around the Falkland Islands. Zuur and Pierce (2004); Chen *et al.* (2006) and Chen (2010) investigated common trends in north east Atlantic squid series using DFA.

Studies on recruitment of *O. vulgaris* based on fishery data are scarce. Sobrino *et al.* (2002) analyzed landings per unit effort (LPUE) of *Sepia officialis* and *O. vulgaris* in the Gulf of Cadiz using multivariate analyses, showing the influence of rainfall, river discharges and temperature on the LPUE series. Faure *et al.* (2000) applied linear regression and generalized additive models (GAM) to relate recruitment indices and environmental conditions in Mauritanian waters, while Otero *et al.* (2008) inferred the influence of upwelling events on recruitment of *O. vulgaris* based on octopus fishery and environmental data.

Santa Luzia, located in the Algarve region (south Portugal), is the most important octopus fishing harbour for the area, yielding an average annual catch of 1300 t during the past two decades (1990-2010). Its fishing fleet has been using a single octopus gear, the octopus trap, for more than 20 years, and landings are sold at auction in the village. Discards represent less than 16 % of the catches in weight for this fishery, consisting mainly of small individuals (Baeta, 2009). Hence, as fishing effort is known, LPUE can be estimated from octopus landings recorded in the auction and can be considered a good proxy of the abundance of *O. vulgaris* for the area. Whereas other octopus recruitment studies are based on catching paralarvae or collecting data on very small individuals (Moreno *et al.*, 2008), usually involving long term sampling surveys, time series analysis of fisheries data is an alternative approach that could shed light on the population dynamics of this valuable resource in budget limited conditions.

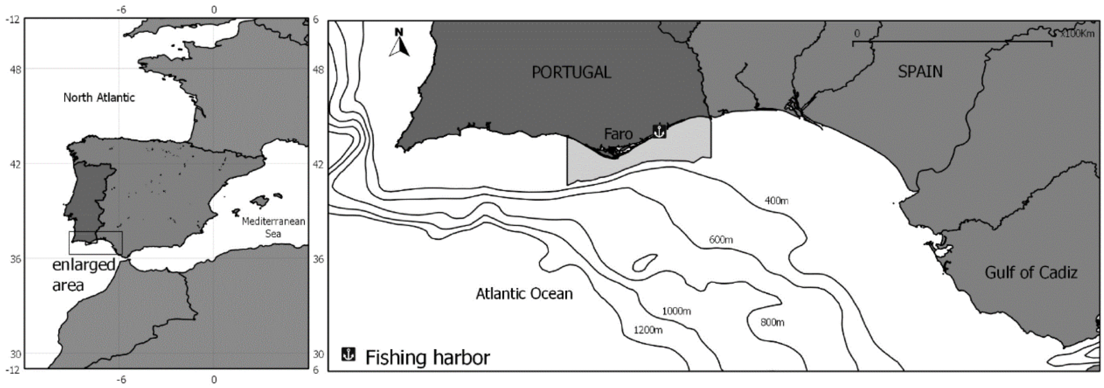
Statistical tools developed for short, non-stationary time series were used to study the variations in abundance of *O. vulgaris* and the recruitment dynamics in the south of Portugal. DFA has been successfully applied to fisheries data in recent years (Devine and Haedrich, 2011; Erzini, 2005; Erzini *et al.*, 2005; Zuur and Pierce, 2004; Zuur *et al.*, 2003) with the main goal of finding common trends within the multiple time series and to explore the relationships and interactions of these trends with explanatory environmental and fisheries variables. This technique, which is basically a smoothing method, can provide key information hidden within time-series and can incorporate explanatory variables. In spite of the large fluctuations in the octopus abundance series, where a smoothing technique might not be considered appropriate, the use of DFA as an exploratory technique presents consistent results confirmed by other multivariate techniques, such as Principal Component Analysis (PCoA), clustering and Non-Metrical Multidimensional Scaling (NMDS). Here, DFA was used to estimate common trends for *O. vulgaris* LPUE time series in the leeward Algarve region (southern Portugal), explore the effects of local environmental variables and their different seasonal combinations on the LPUE time series, and to gain insight on octopus recruitment.

3.2. Materials and Methods

3.2.1. Fishing grounds

The fishing grounds cover an area of about 750Km^2, mostly composed of soft bottoms (sandy and sandy gravel) off the Algarve leeward coast, the northwest boundary of the Gulf of Cadiz (Fig. 3.1). This transition zone, between the Atlantic and Mediterranean, receives the outflow of the 4th longest river of the Iberian Peninsula, the Guadiana River, and some other small rivers flowing from Portugal and Spain. The fleet operates between 1 and 6 nm from the coast most of the year, most of the catches are still landed in the Santa Luzia Fish Auction of Docapesca, inside the Ria Formosa lagoon, where the local harbour is located.

Figure 3.1. Location of the fishing ground (gray filled rectangle). (GCS WGS84, projection transv. Mercator).



3.2.2. Local climate

The Algarve region is characterised by a Mediterranean climate (Csb or Csa according to Köppen's classification; Arnaud-Fassetta *et al.*, 2006). The Hydrological year starts in October, with most of the rainfall occurring during autumn (average 129 mm).The most intense and frequent winds in the area come from the west and south-west, especially during the winter months. East and south-east winds are also quite frequent, especially in summer when the *Levante* blows (Newton and Mudge, 2003). The physical oceanography of this part of the Atlantic is dominated mostly by the Gulf of Cadiz system, where the Mediterranean inflow-outflow plays a strong role (Peliz *et al.*, 2009), but the influence of Atlantic waters from the west persists during the whole year, with intermittent upwelling and relaxation episodes, especially for summer months, when these events became more intense and frequent (Relvas, 2002).

3.2.3. Response variable

Official landings statistics for the period 1990 to 2010 were compiled from the Portuguese Institute for The Sea and Atmosphere (Portuguese acronym: IPMA). This dataset contains monthly landings of *O. vulgaris* by boat from 1990 to 2010, recorded at the 'first sale' in the fish auction for every harbour in the Algarve region. In order to analyze octopus abundance, LPUE was calculated for Santa Luzia, under the assumption that each fishing landing event at the fishing auction represents a fishing day, where LPUE is a simple division of the total landed in a month by boat (Kilograms) by the number of days recorded at auction per month (Days):

$$\text{LPUE} = \frac{\text{Kg (total of kilos landed by boat in a month)}}{\text{Days (total of auction days per boat in a month)}}$$

According to Pierce and Guerra (1994) examination of the correlation between landings, overall effort (landing fishing days) and the resulting LPUE is a useful tool to examine the reliability of LPUE as an abundance measurement. Correlations between landings, effort and LPUE were analyzed and a monthly LPUE time series dataset was built for the Santa Luzia fleet.

3.2.4. Explanatory variables

A total of 9 environmental variables were collected for use in the analysis (Table 3.1). Following the protocol proposed by Zuur *et al.* (2010), these variables were explored for colinearity, outliers and missing data before their use in the analysis and modelling. Relationships between the response, LPUE and the explanatory variables were studied using the Pearson correlation and cross correlations (CC) at different time lags (1,2 yr), given that *O. vulgaris* has a short life cycle (~1yr), with only 1-2 generations generally present in the fishery at any time (Mangold and Von Boletzky, 1973). In order to explore seasonal variability, 14 combinations for each explanatory variables were created according to the season of the year and its 1 year lagged value (Table 3.2). These categorical groupings for each variable were based on monthly averages, except for rainfall, where the sums of the values of each month per season were calculated.

Table 3.1. Explanatory variables names, abbreviations, units and sources used in the analyses.

abbrevia-tion	variable name	description	unit	source
Rain	RainFall	total precipitation by year	mm	http://snirh.pt/index.php/
River	River Discharge	Guadiana River Flow measured at Pulo de Lobo Station	cm^3	CIMA Algarve University
SST	Sea Surface Temperature	Sea Surface temperature year average from AVHRR	°C	http://oceanwatch.pfeg.noaa.gov
Ekman	Ekman transport	East-west component of Ekman Transport	kg/m	http://www.pfeg.noaa.gov
WS_u	Wind Stress u component	u-component of pseudostress at 10 meters	m^2/s^{-1}	http://podaac.jpl.nasa.gov
WS_v	Wind Stress v component	v-component of pseudostress at 10 meters	m^2/s^{-1}	http://podaac.jpl.nasa.gov
GC_z	Zonal Geo-Currurrent	z-component of geostrofic current	m^2/s^{-1}	http://oceanwatch.pfeg.noaa.gov
GC_m	Meridional Geo-Currurrent	m-component of geostrofic current	m/s^{-1}	http://oceanwatch.pfeg.noaa.gov
WeMOi	Western Mediterranean Oscilation Index	di erence between the surface pressures at Cadiz and Padua.	atm	http://www.ub.edu

3.2.5. Data analysis

LPUE data were log transformed as suggested by the analysis of the QQ-plots of the original data. To facilitate visualization and interpretation, the twelve LPUE time series and the explanatory variables were standardized (difference from the mean divided by the corresponding standard deviation). Analysis of variance (ANOVA) was used to test for differences between seasons in effort (landings events), LPUE and landings, using monthly data grouped into spring, summer, autumn and winter. A second classification according to the beginning of the hydrological year (October), into rainy and dry seasons was also considered.

Table 3.2. Different variable combinations and nomenclature used in the analyses (combinations were based on averages by season, except for rainfall, where sums were estimated).

N	combination	description	nomenclature
1	normal	normal time series	var.name
2	lagged^{-1}	lagged one year	var.name
3	spring	january, february, march	spr_var.name
4	summer	april, may, june	sum_var.name
5	autumn	july, august, september	aut_var.name
6	winter	october, november, december	win_var.name
7	rainy season	october to march	rai_var.name
8	drought season	april to september	dro_var.name
9	spring^{-1}	lagged one year	spr_var.name^{-1}
10	summer^{-1}	lagged one year	sum_var.name^{-1}
11	fall^{-1}	lagged one year	aut_var.name^{-1}
12	winter^{-1}	lagged one year	win_var.name^{-1}
13	rainy season^{-1}	lagged one year	rai_var.name^{-1}
14	drought season^{-1}	lagged one year	dro_var.name^{-1}

Three multivariate techniques were used to explore the 12 monthly LPUE time series: Non Metric Dimensional Scaling (NMDS), with the Euclidean distance to measure the association between the variables and build the distance matrix D, hierarchical clustering, and Principal Component Analysis (PCoA) using the covariance matrix and the distance biplot.

Dynamic Factor Analysis is a method to estimate common trends (Zuur *et al.*, 2007), and to investigate which of the monthly time series follow a common pattern over time, that allows incorporation of explanatory variables. A detailed statistical description of DFA is given in (Zuur *et al.*, 2003). The approach proposed by Zuur and Pierce (2004) was followed, where LPUE data were grouped into twelve time series, one for each month of the year and modelled as a function of linear combinations of common trends, a constant level parameter, one or more explanatory variables and a noise term :

N time series = constant + linear combination of M common trends + explanatory variables + noise

Three sets of DFA models were fitted in a stepwise method, using symmetric non-diagonal and diagonal matrices (Table 3.3). Akaike's information criterion (AIC) was used as a measure of goodness of fit to compare the models (Zuur *et al.*, 2003), while factor loadings and canonical correlations were used to measure the relation of a particular trend with the time series. For the first group, the N time series were modelled as a linear combination of M common trends, without explanatory variables.

In the second set, explanatory variables and their combinations were added one by one to the best models obtained from the first set for both types of error covariance matrices. This stepwise procedure allowed the relative importance of each variable to be identified based on the AIC criterion, as well as the t-values for the individual regressions for each time series. For the third set, the best model from the first set with one common trend (symmetric non-diagonal matrix) was selected and the most important explanatory variable combinations obtained from the second set were incorporated. Models with two and three explanatory variables were fitted.

Table 3.3. Dynamic factor models (DFA) set used in the analyses.

Set	Model	Covariance matrix R
1	12 time series = constant + M common trend + noise	Diagonal
	12 time series = constant + M common trend + noise	Non Diagonal
2	12 time series = constant + M common trend + one explan. var.+ noise	Diagonal
	12 time series = constant + M common trend + one explan. var.+ noise	Non Diagonal
3	12 time series = constant + M common trend + two or three explan. var.+ noise	Non Diagonal

3.3. Results

Octopus landings showed great variability and seasonality, oscillating between 7 tonnes in September 1990 and 250 tonnes in November 2007 (Fig. 3.2), with an average of 45 tonnes (s.d. = 35) per month. A strong relationship was found between landings and the estimated LPUE (Pearson correlation = 0.90). Since there were no landings in August 2005 due to a voluntary fishing ban, the missing value in the time series was replaced by the mean LPUE of the months of August (46.3 Kg/day/vessel).

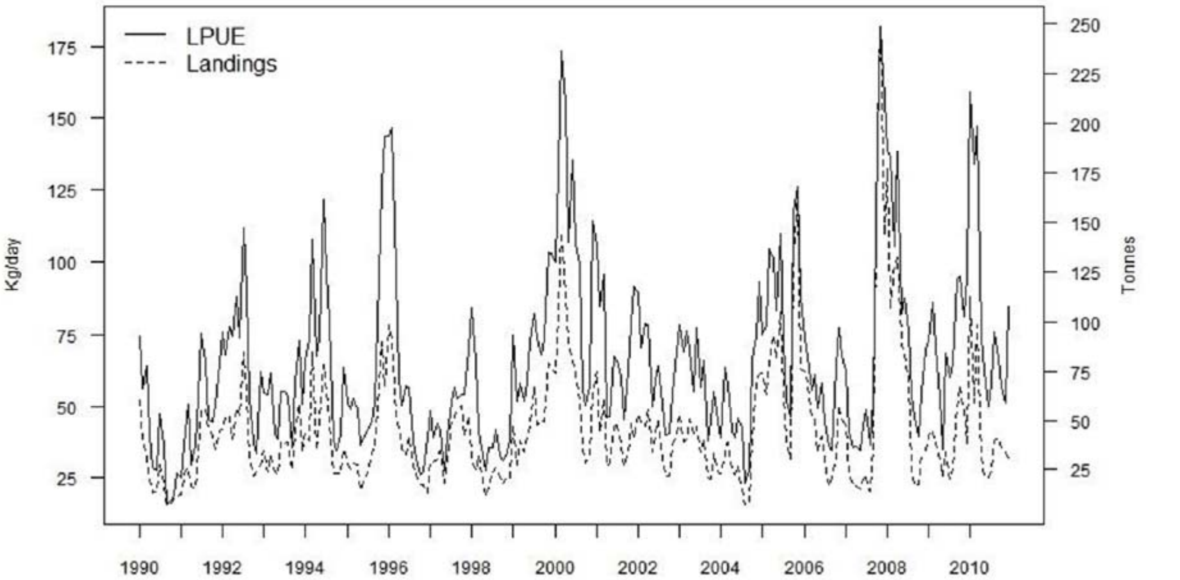


Figure 3.2. Octopus vulgaris monthly landings (tonnes) and estimated LPUE (Kg/day) from Santa Luzia harbour between 1990 and 2010. Data compiled from the Portuguese Institute for The Sea and Atmosphere (IPMA) recorded at the 'first sale' in the fish auction.

LPUE by season of the year shows evidence of differences in relative abundance, with Winter (January to March) having the highest mean LPUE (78.6 Kg/day/vessel; s.d. = 33.5; $p < 0.05$; Fig. 2.3). Based on the hydrological classification, LPUE in the rainy period (73.6 kg/day/vessel; s.d. = 34) is higher than in the dry period (58.4 kg/day/vessel; s.d. = 24; $p < 0.001$; Fig. 2.3). Furthermore, LPUE has increased over the years, from an average of 56 kg/day/vessel (s.d. = 26) for the first half of the series (1990 to 1999) to a significantly higher average 74 kg/day/vessel (s.d. = 33) for the second half (2000 to 2010) ($p < 0.05$) Moreover, landings events (considered as the effort measurement for LPUE) showed no differences by season or year ($p > 0.05$).

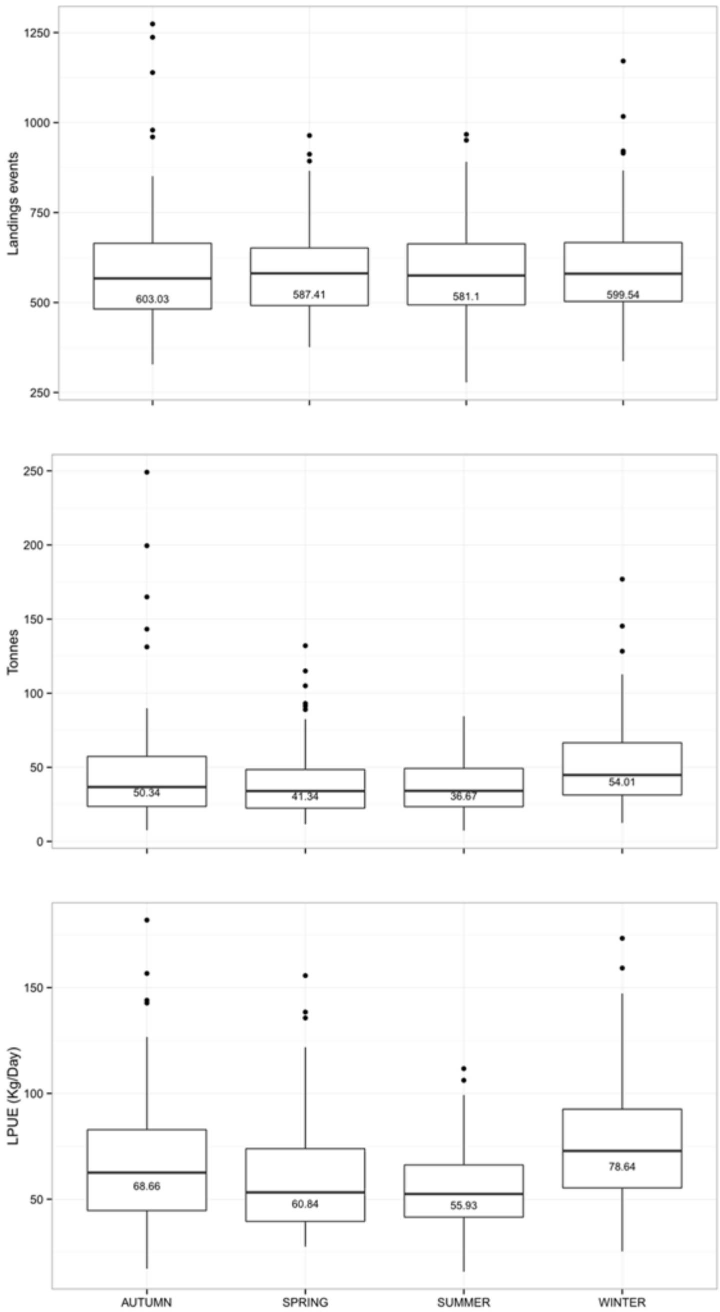


Figure 3.3. Box plots of Effort (fishing landings events), Landings (tonnes) and LPUE of Octopus vulgaris by season (spring, summer, winter and autumn). Numbers in the box represent averages, and the horizontal line is the median. The hydrological year start in autumn (October), which is the beginning of the rainy season.

The log-transformed and standardized LPUE monthly time series are shown in Figure 3.4 Principal component analysis, hierarchical clustering and MDS (not shown) gave similar results, with a clear separation of the autumn months (October, November and December) from the other months. Principal component analysis of the monthly LPUE data, based on the covariance matrix, explained 76 % of the variability, where the first axis seems to be determined by the first seven months of the year, and the second axis by the autumn months (October, November and December). The sequential arrangement of the variables on the biplot suggests a monthly correlation, where LPUEs of consecutive months tend to be strongly correlated (Pearson correlation = 0.80). However, within the 20 years sampled, these correlations between the LPUE monthly vectors are less well represented in some years (e.g: 1990, 1991, 1993, 1997, 1998).

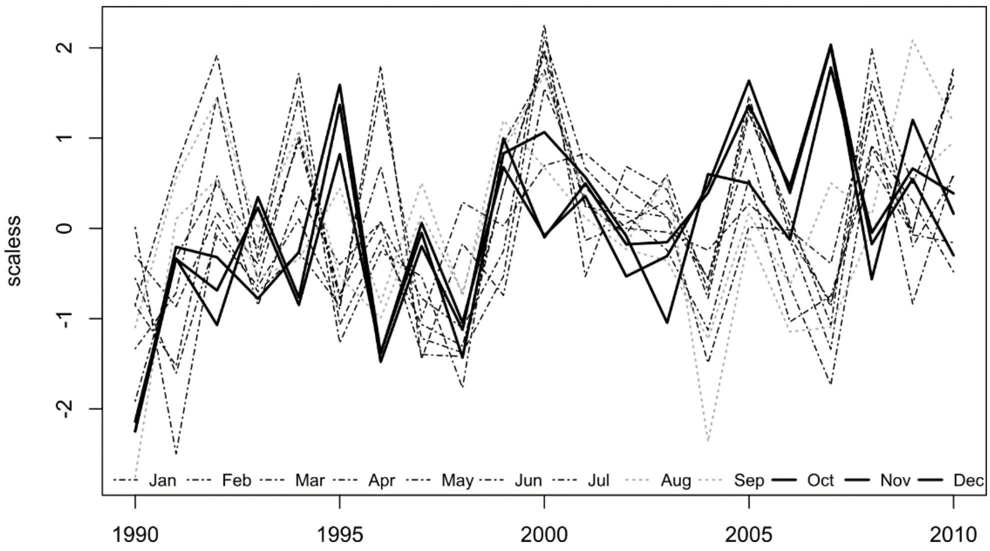


Figure 3.4. Log-transformed and standardized series of the 12 months LPUE between 1990 to 2010. October, November and December represented in bold line.

For the first set of DFA models, without explanatory variables the best fit was for model 4a with 4 common trends plus noise with a symmetrical non-diagonal matrix (Table 3.4). However, model 1b with 1 common trend and a non-diagonal symmetric matrix had a lower AIC value (AIC = 448), but higher diagonal elements of the error covariance matrix (average error = 0.80). The plot of the observed versus fitted values of the 12 LPUE time series for model 1b showed poor fits for the first 8 months, improving for September, October, November and December. The inspection of the diagonal elements of the error covariance matrix showed that model 4a had very small values for months 2, 5, 7, 9, 10 and 11, especially for months 2 and 9, which resulted in perfect fits, whereas model 1b registered larger values (Table 3.5).

Table 3.4 Akaike's information criterion (AIC) values for the first set of dynamic factor analysis (DFA) models with one to five trends and diagonal or symmetric non-diagonal matrix.

DIAGONAL			NON-DIAGONAL (symmetric)		
model	trends	AIC	model	trends	AIC
1a	1	624.24	1b	1	448.21
2a	2	551.36	2b	2	455.08
3a	3	519.83	3b	3	472.70
4a	4	500.58	4b	4	492.08
5a	5	506.03	5b	5	508.98

For the second set of models, with one explanatory variable included, one common trend and a non-diagonal matrix, the autumn Rainfall (lag -1) resulted in a smaller AIC (AIC = 403; model 1b; Table 3.6), improving the fit of the model by reducing the diagonal elements of the error covariance matrix, especially for autumn months (Table 3.5). Arranged by AIC value (increasing order), the 5 most important variables after rainfall, were: rainy season WeMOI (lag -1) with AIC = 429, rainy season Ekman transport with no lags (AIC = 432), horizontal and vertical component of wind stress for rainy season (lag -1) with AIC = 435 and AIC = 437, respectively, and summer River runoff (lag -1) with AIC = 438.

Table 3.5. Diagonal elements of the error covariance matrix comparison of the different DFA's set.

	1st set		2nd set	3rd set
	Diag.	No Diag.	No Diag.	No Diag.
Time series	M 4a	M 1b	M 1b*	M 40
1	0.31	0.82	0.79	0.67
2	0.00	0.84	0.84	0.59
3	0.08	0.95	0.90	0.64
4	0.20	0.84	0.77	0.64
5	0.09	0.93	0.64	0.59
6	0.08	0.88	0.57	0.49
7	0.08	0.92	0.46	0.44
8	0.09	0.91	0.48	0.43
9	0.00	0.75	0.26	0.25
10	0.04	0.60	0.42	0.33
11	0.03	0.61	0.45	0.36
12	0.19	0.70	0.42	0.29

Table 3.6. Akaike's information criterion (AIC) values for the second set of dynamic factor analysis (DFA) models with explanatory variables (4 trend diagonal and 1 trend symmetric non-diagonal matrix). Bold values represent the lower AIC for each variable combination.

Variable	Error	N	Year (t)	t^{-1}	Wi	Sp	Su	Au	Ra	Dr	Wi t^{-1}	Sp t^{-1}	Su t^{-1}	Au t^{-1}	Ra t^{-1}	Dr t^{-1}
RainFall	diag.	4	486.9	479.3	505.9	507.9	504.4	503.4	492.6	502.9	505.3	495.1	505.5	462.2	486.2	497.3
	no diag.	1	430.1	436.5	446.4	444.1	453.5	441.1	426.1	440.3	449.5	445.1	455.2	403.3	432.9	444.1
River Runo	diag.	4	508.1	500.6	511.3	515.3	503.8	513.7	620.9	1188.6	504.9	515.8	503.9	503.9	500.2	517.0
	no diag.	1	458.7	446.3	454.4	450.4	438.1	458.5	446.6	446.8	451.7	450.4	438.0	446.3	446.1	450.5
SST	diag.	4	504.6	507.9	491.7	512.5	513.5	509.3	513.5	512.7	502.5	512.0	498.4	506.2	512.6	504.1
	no diag.	1	447.1	454.1	443.9	457.5	458.6	445.4	453.0	457.7	451.1	452.1	454.2	454.7	454.0	438.4
Ekman	diag.	4	505.5	708.6	496.7	510.6	500.0	496.7	480.4	512.4	863.6	662.4	745.5	750.2	696.0	904.1
	no diag.	1	457.3	448.5	453.0	452.1	436.5	449.6	432.5	450.9	448.7	448.6	448.7	448.6	448.5	448.7
WS_u	diag.	4	510.2	515.4	504.5	509.8	507.7	508.7	500.8	507.3	500.1	501.1	505.0	499.9	495.4	500.6
	no diag.	1	448.2	460.9	448.5	445.5	439.4	449.0	436.0	447.7	449.8	445.6	447.4	442.0	435.1	441.6
WS_v	diag.	4	514.9	504.8	500.0	517.8	494.4	506.0	492.7	519.7	481.7	503.7	510.4	500.9	485.9	504.9
	no diag.	1	462.0	442.5	450.3	464.3	464.3	454.1	444.2	466.8	451.9	453.0	455.6	441.7	436.6	446.1
$GeoCURR_m$	diag.	4	821.5	761.3	979.8	800.8	989.8	775.1	764.8	599.0	800.8	800.9	800.8	800.7	800.7	800.9
	no diag.	1	459.1	445.1	445.0	445.1	452.9	456.0	459.1	445.1	439.3	438.7	438.7	445.1	445.0	438.8
$GeoCURR_z$	diag.	4	1005.0	800.7	800.7	800.7	1422.1	900.4	1057.3	800.9	800.9	930.1	800.7	1245.3	795.4	800.9
	no diag.	1	459.2	445.1	445.0	445.1	453.0	456.0	459.1	445.1	438.8	439.6	438.8	445.0	445.0	438.8
WeMOi	diag.	4	502.4	501.6	497.9	493.0	506.1	511.7	509.8	499.8	501.9	501.0	518.1	489.6	487.1	510.1
	no diag.	1	442.1	450.6	442.8	431.8	456.3	452.1	452.6	442.9	442.2	438.9	464.6	437.2	429.1	455.0

For the third set of models, with one common trend and more than one explanatory variable, model nº 40 was chosen as the best model. This model had the lowest AIC (AIC = 335; Table 3.7), resulting from the combination of the rainy season value of Rainfall (lag -1) and WeMOi (lag -1) with the summer River Runoff (lag -1). Among the 10 environmental indices used, 9 resulted in marked drops in AIC when included in the analyses; with 8 of the variables associated with important decreases in AIC when lagged 1 year (lag -1), and 5 of them were variables corresponding to rainy months.

The calculated t-values for the individual regressions for each LPUE series with the environmental variables showed Autumn Rainfall (lag-1) had high negative t-values for the last 8 months of the year (May to December), with the largest value for September (t = -7.2). The rainy season average of vertical component of Wind stress (lag-1) and WeMOi (lag -1) indicated large absolute t-values for months 8 to 12, with a positive relationship between WeMOi and the LPUE series. The dry season average Sea Surface Temperature (lag -1) had the largest negative values for spring months.

The factor loadings for DFA model nº 40 show significant positive correlations for 8 months, with negative correlations only for July and August. Months from September to January recorded the highest correlations with the common trend, with the highest values for October and November (canonical correlation > 0.5; Fig. 3.5).

Table 3.7. Akaike's information criterion (AIC) values for the third set of dynamic factor analysis (DFA) models with explanatory variables combination (just for 1 trend symmetric non-diagonal matrix).

ID	combination	AIC	ID	combination	AIC
1	rai_Rain^{-1} + rai_WeMOi^{-1}	367.15	27	rai_WS$_v$$^{-1}$ + sum_River^{-1}	423.18
2	rai_Rain^{-1} + rai_Ekman	375.80	28	rai_WS$_v$$^{-1}$ + W_SST	417.97
3	rai_Rain^{-1} + rai_WS$_u$$^{-1}$	388.80	29	rai_WS$_v$$^{-1}$ + sum_GC$_m$$^{-1}$	423.15
4	rai_Rain^{-1} + rai_WS$_v$$^{-1}$	409.53	30	rai_WS$_v$$^{-1}$ + sum_GC$_z$$^{-1}$	423.08
5	rai_Rain^{-1} + sum_River^{-1}	393.16	31	sum_River^{-1} + W_SST	418.25
6	rai_Rain^{-1} + W_SST	390.03	32	sum_River^{-1} + sum_GC$_m$$^{-1}$	423.77
7	rai_Rain^{-1} + sum_GC$_m$$^{-1}$	392.25	33	sum_River^{-1} + sum_GC$_z$$^{-1}$	423.75
8	rai_Rain^{-1} + sum_GC$_z$$^{-1}$	393.00	34	spr_SST^{-1} + sum_GC$_m$$^{-1}$	421.78
9	rai_WeMOi^{-1} + rai_Ekman	404.48	35	spr_SST^{-1} + sum_GC$_z$$^{-1}$	422.03
10	rai_WeMOi^{-1} + rai_WS$_u$$^{-1}$	415.89	36	sum_GC$_m$$^{-1}$ + sum_GC$_z$$^{-1}$	430.17
11	rai_WeMOi^{-1} + rai_WS$_v$$^{-1}$	417.27	37	rai_Rain^{-1} + rai_WeMOi^{-1} + rai_WS$_v$$^{-1}$	373.53
12	rai_WeMOi^{-1} + sum_River^{-1}	409.63	38	rai_Rain^{-1} + rai_WeMOi^{-1} + rai_Ekman	340.47
13	rai_WeMOi^{-1} + W_SST	408.98	39	rai_Rain^{-1} + rai_WeMOi^{-1} + rai_WS$_u$$^{-1}$	355.36
14	rai_WeMOi^{-1} + sum_GC$_m$$^{-1}$	422.01	40	rai_Rain^{-1} + rai_WeMOi^{-1} + sum_River^{-1}	334.57
15	rai_WeMOi^{-1} + sum_GC$_z$$^{-1}$	422.20	41	rai_Rain^{-1} + rai_WeMOi^{-1} + W_SST	348.61
16	rai_Ekman + rai_WS$_u$$^{-1}$	414.48	42	rai_Rain^{-1} + rai_Ekman + rai_WS$_v$$^{-1}$	375.54
17	rai_Ekman + rai_WS$_v$$^{-1}$	411.30	43	rai_Rain^{-1} + rai_Ekman + rai_WS$_u$$^{-1}$	354.55
18	rai_Ekman + sum_River^{-1}	421.75	44	rai_Rain^{-1} + rai_Ekman + sum_River^{-1}	367.01
19	rai_Ekman + W_SST	417.93	45	rai_Rain^{-1} + rai_Ekman + W_SST	359.73
20	rai_Ekman + sum_GC$_m$$^{-1}$	424.28	46	rai_Rain^{-1} + rai_WS$_v$$^{-1}$ + rai_WS$_u$$^{-1}$	381.65
21	rai_Ekman + sum_GC$_z$$^{-1}$	424.29	47	rai_Rain^{-1} + rai_WS$_v$$^{-1}$ + sum_River^{-1}	396.35
22	rai_WS$_u$$^{-1}$ + rai_WS$_v$$^{-1}$	411.22	48	rai_Rain^{-1} + rai_WS$_v$$^{-1}$ + W_SST	387.34
23	rai_WS$_u$$^{-1}$ + sum_River^{-1}	430.40	49	rai_Rain^{-1} + rai_WS$_u$$^{-1}$ + sum_River^{-1}	377.97
24	rai_WS$_u$$^{-1}$ + W_SST	428.70	50	rai_Rain^{-1} + rai_WS$_u$$^{-1}$ + W_SST	375.42
25	rai_WS$_u$$^{-1}$ + sum_GC$_m$$^{-1}$	460.40	51	rai_Rain^{-1} + sum_River^{-1} + W_SST	370.27
26	rai_WS$_u$$^{-1}$ + sum_GC$_z$$^{-1}$	445.22			

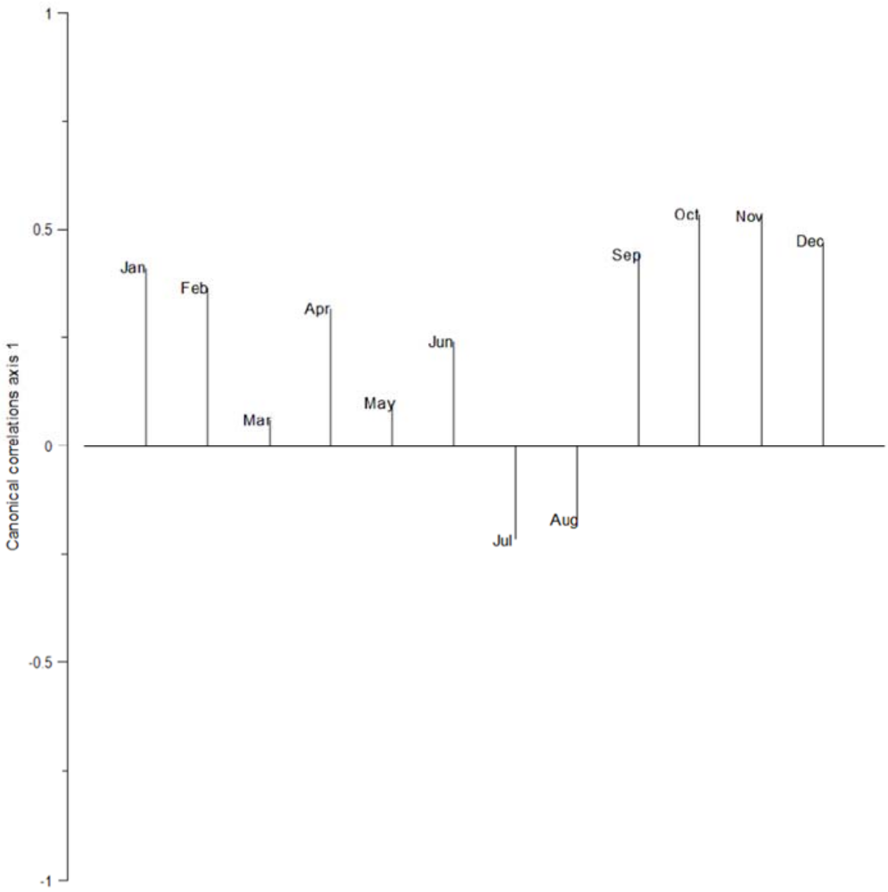


Figure 3.5. Canonical correlations for the DFA model nº 40 (third set). Correlations > -0.5 or > 0.5 are significant ($p < 0.05$).

Figure 3.6 shows the observed and fitted LPUE series for model nº 40. For all months, the model adequately fits the data, despite strong inter annual variability. Residuals were evenly distributed for all months, except August and September, where a strong oscillating pattern was found. Figure 3.7 shows the MDS ordination of the error covariance matrix R for model nº 40 after transformation into a dissimilarity matrix by using absolute correlations. The first axis shows the differences between months, separating them into three main groups: January to August, September and October to December. Within the first group it is possible to identify a small subgroup with two months: July and August. The trend calculated for model nº 40 is given in Figure 3.8.

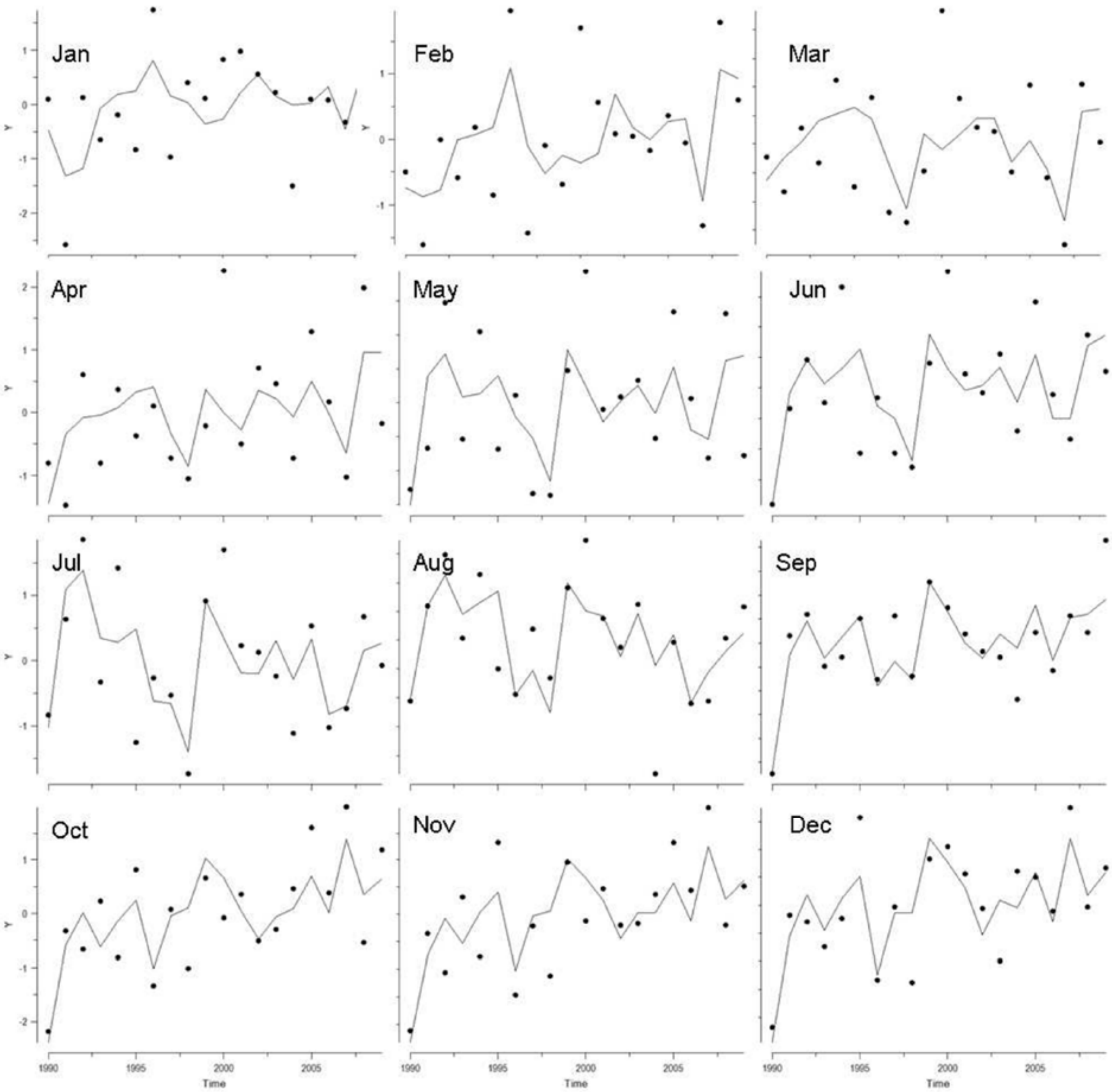


Figure 3.6. Observed (filled circles) and fitted (lines) LPUE series from the dynamic factor analysis model nº 40 with one common trend and three explanatory variables (rainy season value of RainFall lag -1, WeMOi lag -1 and summer River Runoff lag -1) and positive non-diagonal matrix. Y axis are standardized. Months are represented by its initials (JAN = January, FEB = February, and so on) and refer to LPUE time series.

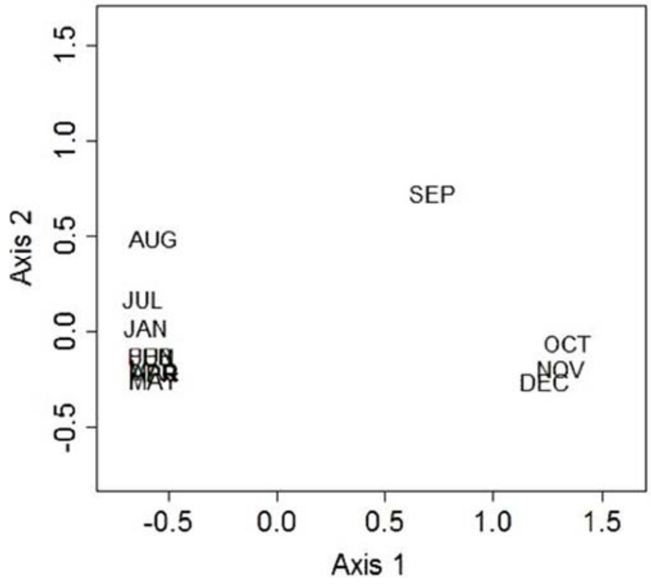


Figure 3.7. Multidimensional scaling applied on the error covariance matrix from model nº40. Months are represented by its initials (JAN = January, FEB = February, and so on) and refer to LPUE time series.

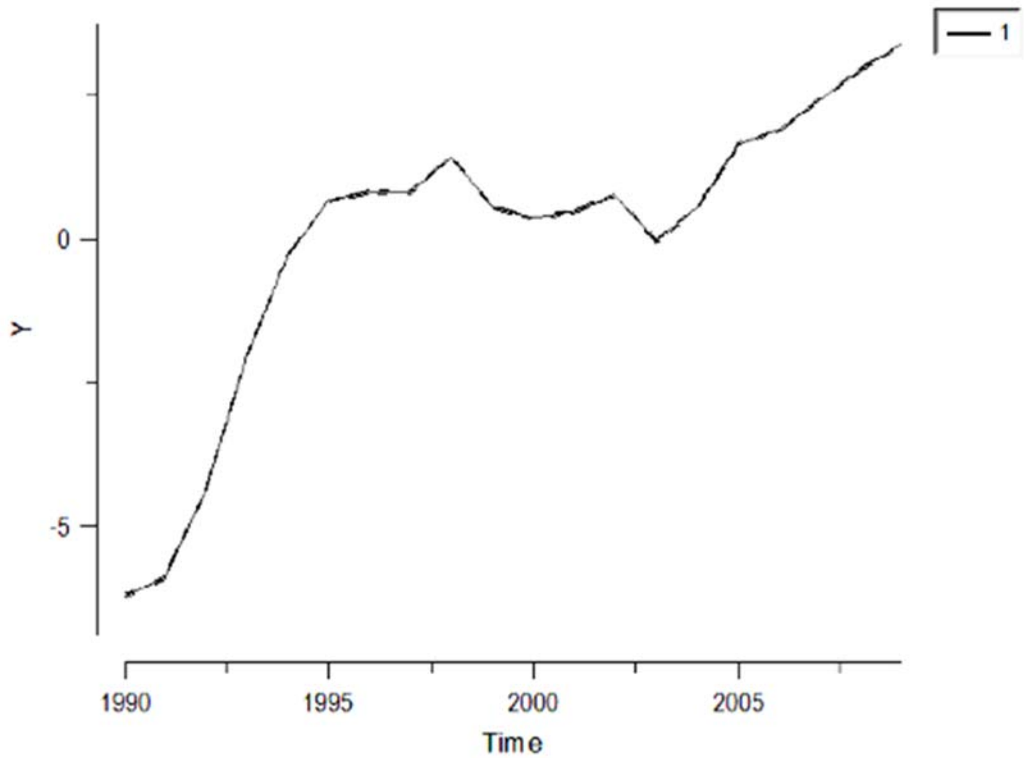


Figure 3.8. The estimated common trend by model nº40 (standardized).

2.4. Discussion

In spite of the large fluctuations in the octopus abundance series, where a smoothing technique might perhaps not be considered appropriate, the use of DFA as an exploratory technique gave consistent results confirmed by other multivariate techniques, such as Principal Component Analysis (PCoA), hierarchical clustering and Non-Metrical Multidimensional Scaling (NMDS). The three multivariate techniques along with DFA showed the same aggregation pattern for the last three months of the year and the fits of the DFA models are quite good, especially for October, November and December. The analyses of the canonical correlations, as a measure of association between the original time series and the estimated trend, indicated that the estimated trend is significant for the last three series, October, November and December. Inspection of the off-diagonal elements of the covariance matrix R, confirms this clear grouping (Zuur *et al.*, 2003), indicating two joint interactions: autumn months and winter-spring months. These groups share a certain amount of information which is partially explained by this common trend, whereas August and September are less clear.

The main trend describes a steep rise in LPUE for the first quarter of the series, followed by a short drop for a couple of years and then a moderate and steady increase to the end of the series (Fig. 3.8). In a global analysis, Caddy and Rodhouse (1998) reported that cephalopod landings had increased in recent years in contrast with decreasing ground fish abundance. They argued that fishing pressure has changed ecological conditions in the fishing grounds, where predatory fish have declined and cephalopod stocks have increased. Erzini (2005) also described declines in common trends for at least four of the main commercial fin fish species for South Portugal (Algarve) over the past several decades. The rapid stock turnover of *O. vulgaris,* considered an opportunistic species, together with a decline in large predatory demersal fish could be one of the factors contributing to the observed trends in octopus landings. In the report of the Working Group on Cephalopod Fisheries for the Gulf of Cadiz area (ICES, 2012), CPUE of *O. vulgaris* presented a very similar trend for some years (1993-2010), with coinciding maxima and minima, except for the last 2 years, where they reported an important drop, especially for 2010. However, the WGCEPH has warned about spatial and temporal constraints of these data that may potentially bias the comparison.

The increasing trend obtained by the DFA could also be explained, in part, by the increasing numbers of octopus traps. For south Portugal, the number of traps per set increased from 600 units in 2003 (Fonseca, 2003) to 1200 in 2013 (personal observation). This increase has led to double the amount of bait used, mainly consisting of small pelagics (e.g. *Scombrus japonicus* and *Trachrus trachurus*). Interestingly, studies on lobster traps carried out in the Gulf of Maine (east coast of north America) conducted by Grabowski *et al.* (2010) and Saila *et al.* (2002), and in western Australia by Waddington and Meeuwig (2009) concluded that lobster trap bait, mostly constituted by pelagic fishes such as herring, represented a significant food subsidy which contributed to unprecedented increases in lobster abundance. On the other hand, trap losses could also be considered as important substrates for octopus egg-laying and as shelter, and large numbers of lost traps and pots of different sizes and materials are known to litter the bottom in this area (Erzini, 2007). Furthermore, the existence of a bottom trawling exclusion zone, up to 6 nm off the coast where octopus fishing takes place, also provides additional shelter for octopus, thereby enhancing the natural carrying capacity of the ecosystem.

It is well known by the fishermen that *O. vulgaris* landings for this area have a marked seasonality, with highest landings generally in winter months and lowest in summer months, in agreement with the two joint interactions found by the DFA (autumn months and winter-spring months). Sobrino *et al.* (2011) suggested that the octopus presents an annual lifecycle in the nearby Gulf of Cadiz, with recruitment in late autumn and early spring and the reproduction season between July and October. Therefore, we hypothesize that the peak in octopus abundance in winter, from October to December, represents the main recruitment to the fishery, whereas the landings in the consecutive months (January to March) correspond to a second recruitment peak, some late developing individuals, and remaining biomass not fished from previous months. However, the magnitude and timing of the recruitment is highly dependent on external factors, mostly environmental conditions during the paralarval stage.

Moreno *et al.* (2008) found that there are two main *O. vulgaris* paralarvae peaks, in autumn and spring, in the Portuguese south coast, with the most important peak corresponding to eggs laid at the end of the summer spawning season. The different environmental conditions and geographical features between the northwest coast and the south coast (Algarve) of Portugal result in different timings for spawning peaks of *O. vulgaris*. The northwest population spawns from March to July, in synchrony with the northwest coast upwelling season, whereas the south coast population spawns mainly in summer, between August and September (Lourenço *et al.*, 2012). This spawning pattern is similar to that off NW Africa, in the Arguin Bank and the south Senegalese coast (Demarcq and Faure, 2000). There is however no evidence of a genetic structure suggestive of different stocks for this area of the Atlantic (Cabranes *et al.*, 2008).

Among the environmental factors examined, rainfall in late summer and in autumn, is one of the most important variables influencing octopus recruitment. It is well documented worldwide that river runoff and rainfall have detrimental effects on the survival of *O. vulgaris* paralarvae (Pierce *et al.*, 2010). In the neighbouring Gulf of Cadiz, Sobrino *et al.* (2002) reported a significant negative correlation between octopus landings and rainfall from the previous hydrological year. In the present study models with autumn rainfall (beginning of the hydrological year), had the lowest AIC value in the common trend analyses, suggesting a strong correlation between precipitation during the months of October to December and LPUE. Hence, assuming that autumn LPUE is a proxy for recruitment, autumn rainfall from the previous hydrological year is likely the most important factor driving octopus landings in the south of Portugal.

Under the assumption that rainfall affects the survival of paralarvae, the autumn hatching peak found by Moreno *et al.*, (2008) is synchronized with the beginning of the rainy season. Based on data available from studies of development in captivity (Cabranes *et al.*, 2008), paralarvae will stay in the plankton for approximately 40 days, after which they will settle to the bottom and grow to 750g in 4 months more. Under captive conditions, peak recruitment in October consisting of 600-750g individuals might stem from spawning having taken place in April of the same year. This could indicate that the secondary maturity peak of March/April in the Algarve and/or the paralarval peak recorded soon thereafter, are actually responsible for the vast majority of the landings in the region. However, captive conditions could shorten development significantly, as octopus are very adaptable, and culture conditions may improve the feeding regime and provide more stable and relatively higher than natural temperatures for development. We therefore contrarily propose that the paralarvae of the autumn peak recruit to the fishery approximately one year later, during the next autumn. This is supported by the good fits obtained using environmental variables lagged by one year.

Other than rainfall, strong negative correlations were also found between LPUE and summer river runoff lagged 1 year, especially for spring and summer. Erzini (2005) also found that the most important variable affecting trends of 12 landings time series of important fisheries resources in the same area was the Guadiana river runoff. Sea surface temperature (dry season average: April to September) lagged 1 year was also significantly negatively correlated with LPUE, especially for spring and early summer months. A similar pattern was reported by Chédia *et al.*, (2010) in the Mediterranean (Tunisia) who found a negative correlation between SST and CPUE of *O. vulgaris* with a 4 to 6 month lag, corresponding to the preceding paralarval period. Our results suggests that warmer waters during spring, especially in April, seem to be detrimental to the LPUE of the next year, especially for the recruitment months. Another variable which presented lower AIC was the horizontal component of wind stress lagged 1 year (rainy season average). In Galicia, Gonzalez (2005), found that wind stress structure during the spring–summer (prior to the hatching peak) and autumn–winter (during the planktonic stage) explained up to 85% of the total variance of the adult catch. Moreover, Otero *et al.* (2008) in the same area proposed that *O. vulgaris* spawning is synchronized with upwelling-relaxation events, with a single peak in spring.

Recently, Roura (2013) proposed an oceanic life cycle for *O. vulgaris* during its planktonic phase in upwelling areas (Ria de Vigo, northwest Spain), presenting evidence that *O. vulgaris* paralarvae are washed offshore during upwelling events, despite the coastal distribution of juveniles and adults. Weighing the latter facts, and considering that Algarve fishing grounds display different hydrodynamic and meteorological conditions, there may be a different early life history strategy in the south of Portugal. However, the upwelling-relaxation coupling system in South Portugal which extends to leeward Algarve plays an important role in the cephalopod plankton community in the area (Moreno *et al.*, 2008), with some similarities with Ria the Vigo.

In any attempt to evaluate the underlying relationships between octopus reproductive biology, recruitment and fishery dynamics, interpretations based on LPUE-environment interactions should be considered with care. Knowledge of the most relevant processes, both oceanographic and biological is essential. The effects of rainfall and the other environmental variables analyzed on *O. vulgaris* LPUE should not only be considered during the sensitive planktonic cycle, but also at important stages, such as mating and spawning. In terms of fisheries biology, the octopus life cycle in the region is still not entirely clear, with detailed information on reproductive timing still lacking. There is also a need for information on age and growth, in order to back-calculate age and identify specific cohorts, thereby contributing to a better understanding of octopus dynamics in relation to fishing and environmental variability.

Notwithstanding, the results of this study have shed light on the octopus population and fishery dynamics at the regional scale, identifying the most important environmental variables influencing recruitment, and helping to explain the observed patterns in LPUE.

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Part Two

Fishery Management and Stakeholder Involvement

Chapter 4.

The Traditional Small-Scale Octopus Fishery in Portugal: Framing its Governability

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Abstract

The common octopus (*Octopus vulgaris*) fishery is of substantial importance in southern Europe. This is the case in Portugal where the octopus fishery has considerable social and economic value, with small-scale fishing being increasingly economically dependent on this resource. The octopus fishery in the European Union is excluded from quota regulations under the Common Fisheries Policy, and hence Portugal is responsible for managing its own fishery. This chapter describes the current status of the small-scale octopus fishery in Portugal, its governing system, challenges faced by the fishery and implications of these challenges for the governability of the fishery. The Portuguese octopus fishery faces several challenges including those inherent to the biological features of the species and its sensitivity to environmental influences. Limited understanding about the resource has led to inappropriate monitoring and assessment, and a lack of intervention by authorities in the management of octopus. Although formal participation of fishers in the decision-making process for octopus management is a recent phenomenon, the management measures implemented over the years were the result of pressure from fishers worried about decreasing economic returns. However, poor organization, lack of trust and little cooperation between fishers results in them having little influence in the decision-making process. Several recent developments aimed at improving the governance framework and increasing the profitability of the octopus fishery, however, have the potential to improve the current management system and increase sustainability.

Keywords: Cephalopods, Europe, Governability, Governance, Octopus, *Octopus vulgaris*, Portugal.

4.1. Introduction

The common octopus (*O. vulgaris*) is the most important commercially harvested octopus species worldwide. In Europe, the common octopus is fished in both the northeast Atlantic and the Mediterranean Sea, mainly by small-scale fishing fleets using hand-jigs, pots, traps, fyke-nets, trammel nets and bottom trawls (Lefkaditou et al. 2002; Tsangridis et al. 2002; Pierce et al. 2010; Sobrino et al. 2011).

In Portugal, the common octopus has long been an important target species for small-scale fishers. Nowadays, it is an increasingly important fishery resource in terms of quantities landed and particularly in terms of commercial value. The small-scale fishing fleets targeting octopus in Portugal, as well as in other southern European countries, are of considerable socio-economic importance, as the octopus fishery plays a major role in providing employment and income to coastal fishing communities.

The common octopus fishery, like other European Union (EU) cephalopod fisheries, is excluded from quota regulations under the Common Fisheries Policy (CFP) and hence management of this fishery has evolved under the tutelage of national and/or local governments. In Portugal, fisheries management is carried out through a top-down system based on a series of input and output control measures, with little participation from the fishing industry in the decision-making process.

In this chapter we examine the governability of the traditional small-scale common octopus fishery in Portugal using the governability assessment framework, as originally put forward by Kooiman et al. (2005; 2008) and further developed by Bavinck et al. (2013). As such, we describe the natural and socio-economic systems in which the fishery operates, and follow that with a description of the governing system for the common octopus fishery and governing interactions. We then highlight the key challenges these pose to the system-to-be-governed. Finally, we discuss the implications of these challenges to the governability of the octopus fishery and provide some concluding remarks.

4.2. Methodology

The data presented in the chapter is based on information elicited through semi-structured questionnaires administered to eighteen representatives of fisher associations, Producer Organizations and traders of fishery products, as well as from participant observation in official governmental and non-governmental meetings and workshops about the octopus fishery. Some authors, as members of task-forces organized for the octopus fishery, were also privy to discussions in these committee meetings. Questionnaires were administered between May 2013 and September 2014, in mainland Portugal. They solicited information about interviewees' opinions pertaining to the main challenges and opportunities for the small-scale fishing sector in Portugal, the most appropriate management measures for small-scale fisheries, the best measures to increase the value of the catch, and how best to increase participation in the decision-making process. Data was also collected from official national statistics on landings, fleets and fishers. Figure 4.1 shows the location of the study site.

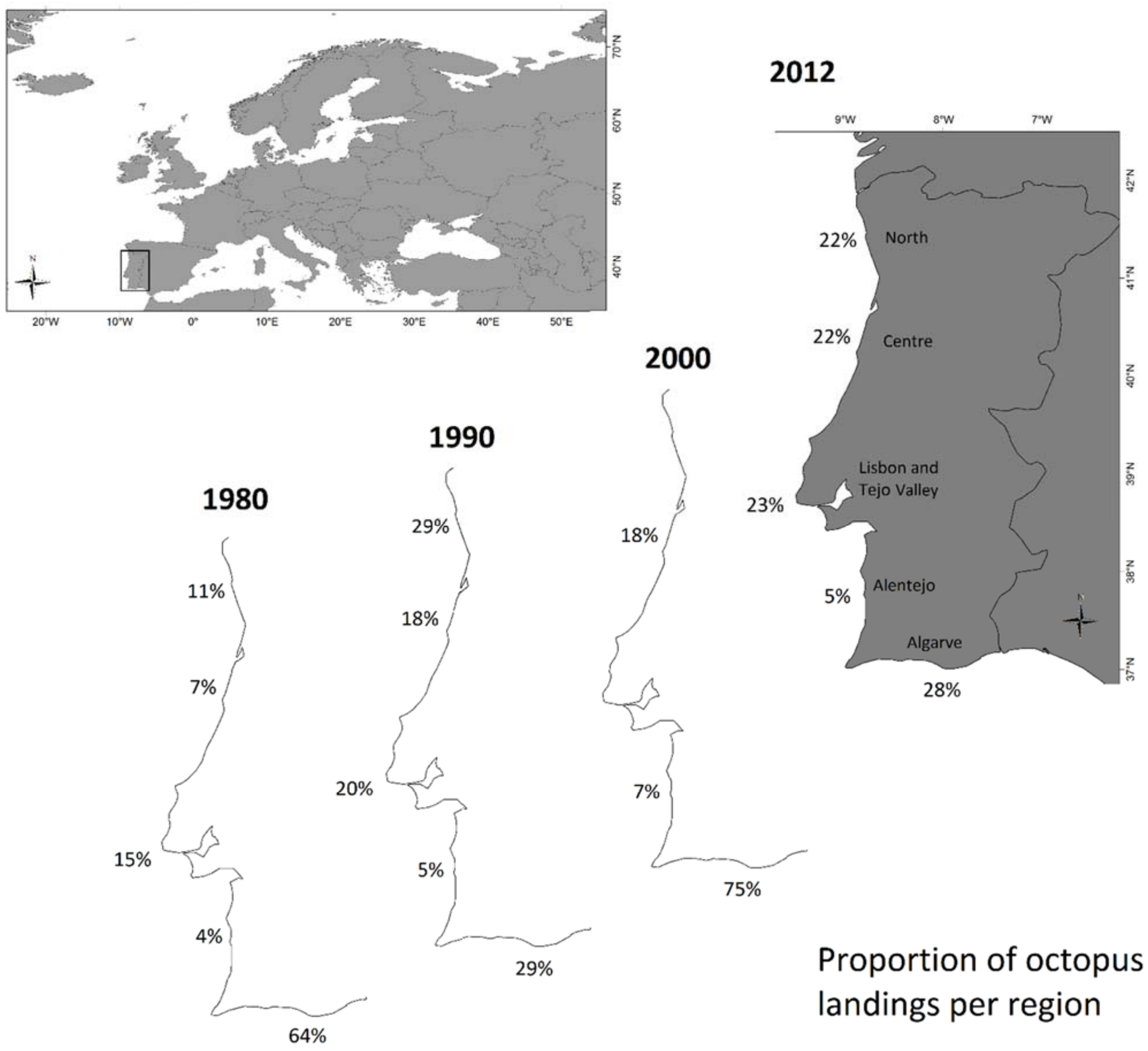

Figure 4.1. Map of mainland Portugal and proportion of landings (in quantity) of octopus per region over time (source: Instituto Nacional de Estatística (INE; Portuguese official statistics bureau), and predecessor official statistics bureaus).

4.3. The System-to-Be-Governed

4.3.1. The Natural System-to-Be-Governed

The Portuguese fishing takes place in a transition area between subtropical and temperate environments in the northern part of the Canary Current upwelling system, one of the four major eastern boundary upwelling systems in the Atlantic (Aristegui et al. 2009). This system is highly dynamic and productive with marked seasonality. Moreover, the system supports a complex food web (Bode et al. 2004) and a particularly rich marine biodiversity (Sousa et al. 2005).

The decrease in landings of finfish in Portugal, since the 1970s, has directed fishers to search for alternative resources (Pereira 1999; Erzini 2005). In the same period, therefore, landings of cephalopods, and mostly common octopus, increased (Figure. 4.2). Since the 1970s, the octopus fishery has been one of the most important fisheries in the country. The yield of common octopus more than doubled, from an average annual catch of 4,000 tonnes for the period 1970-1986 to 8,800 tonnes for the period from 1987-2013.

It appears that common octopus catches in Portugal remain at sustainable levels (Baeta et al. 2005) as landings have continued to rise in response to increasing effort. Whether this will continue to be the case in the long-term is unclear. The upward trend in landings is possibly a consequence of the fact that the octopus “benefits” from the current high level of fishing pressure and from discards of other species. As in the case of other cephalopods, there are huge annual fluctuations in octopus populations (fluctuations varying as much as 40 percent a year), implying that abundance varies from year to year. Figure 4.1 shows the landings per region over time, reflecting these fluctuations over time.

Octopuses are terminal breeders, with non-overlapping generations, a rapid non-asymptotic growth (i.e. high individual variability in increases in length or weight), a short lifespan, and a high sensitivity to environmental influences (Alford and Jackson 1993; Sobrino et al. 2002; Otero et al. 2008; Pierce et al. 2010; Sonderblohm et al. 2014). Age estimates for the eastern Atlantic demonstrate that octopuses live for one to two years (Domain et al. 2000; Perales-Raya et al. 2014) and annual abundance of the resource depends on the level of survival of the pelagic paralarvae, which in turn is strongly related to environmental conditions, such as upwelling intensity, temperature and the input of fresh water (Otero et al. 2008; Sonderblohm et al. 2014). Aside from the high fluctuations in abundance due to environmental factors, the fact that octopuses are terminal breeders and have non-overlapping generations also has implications for fisheries. Breeding females subsequently die and are thus no longer available to the fishery, just as every female removed by fisheries will not breed. Thus, if fisheries remove a whole generation of recruits there could be a shortage of adults to repopulate the stock. However, this is mitigated by a long breeding season, and variable growth which ensures that not all adults are present at the same time in the fishery, and by paralarval immigration and repopulation from other areas.

Octopuses are widespread and dwell upon a variety of bottom types (Pereira et al. 1995). Common octopuses are quite sedentary benthic organisms as adults, with their only well-known migration occurring when juveniles leave the pelagic realm and adopt the benthic near-bottom life style (Villanueva and Norman 2008). It is at this final stage of the life cycle that they become vulnerable to fishing. Considering this, disturbances on the sea bed and human activities (including trawling fisheries) can potentially affect the success of octopus recruitment. Moreno et al. (2014) identified eight distinct recruitment grounds for common octopus in Portugal. In some cases these grounds are under intense fishing pressure, both by small-scale fisheries using static gear and by bottom trawling (Pilar-Fonseca et al. 2014), potentially damaging the seabed habitat of the octopus, as well as directly removing the animals.

Current fishery management under the EU-CFP is very much focused on relatively long-lived fish and shellfish. Multispecies assessment and management is already difficult, and this is made worst by the lack of knowledge and experience of dealing with short-lived species with highly variable abundance or indeed with small-scale fishing that operates on a different spatial scale to trawling. The biological features of this species and its sensitivity to environmental influences present particular problems that make management a real challenge.

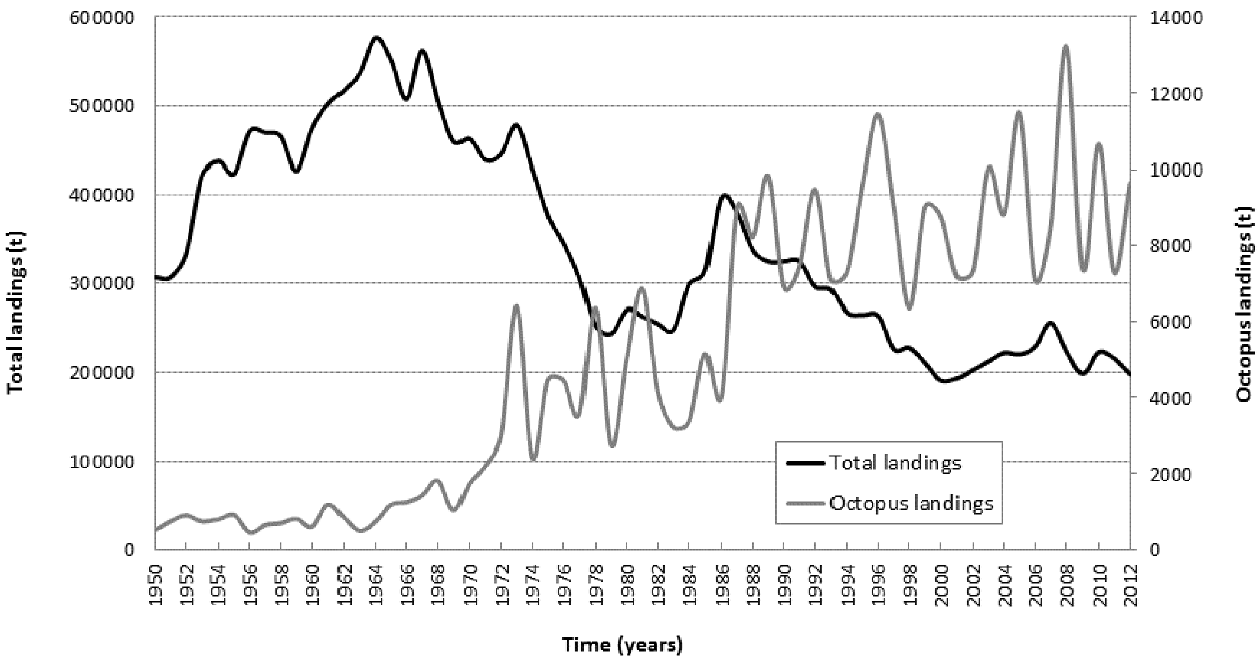

Figure 4.2. Time series of total landings and octopus landings in Portugal, in quantity. (Source: Instituto Nacional de Estatística (INE; Portuguese official statistics bureau), and predecessor official statistics bureaus).

4.3.2. The Socio-Economic System-to-Be-Governed

Portugal is a traditional fishing nation and fishing has long been an economically important activity for many coastal communities. Portuguese fisheries are generally characterized as multi-gear and multi-species small-scale fisheries. Sardine, horse mackerel, chub mackerel and common octopus usually form the largest volume of landings (INE 2014). The small-scale sector is a major component of Portuguese fisheries, accounting for 90 percent of all vessels registered (12 percent of GT, 40 percent of kW) and 68 percent of all fishers (INE 2014) (Table 4.1).

Table 4.1. Socio-economic indicators for the Portuguese fishery (data for 2013).

Socio-economic indicators	Total fisheries	Small-scale fisheries (percent of total)
Landings, quantity (thousand ton)	144.7	60.5 (42 percent)
Landings, value (million €)	253.2	167.1 (66 percent)
Fleet, number of boats	8,232	7,409 (90 percent [a]
Fleet, tonnage (GT)	99,917	12,241 (12 percent)[a]
Fleet, power (kW)	366,279	147,443 (40 percent)[a]
Number fishers	16,797	11,481 (68 percent)[b]
National per capita fish consumption (kg/person/year)[c]	61.6	–

Notes: a Refers to vessels employing static gear <12m in total length; b Fishers' employed in the local and coastal multi-gear (polyvalent) fleet; c Data for 2007 (Data source: EC 2012). Data Source: INE (2014).

Nowadays, the common octopus is one of the most important fishery resources in mainland Portugal in terms of value. In 2013, octopus landings generated 15 percent (€37.6 million) of the total official first sale revenue generated by fisheries, second only to sardines (16 percent; €39.7 million) (INE 2014). However, octopus catches are frequently unreported (anecdotal information suggests a minimum of 20 percent of unreported landings), easily making octopus the most valuable species caught in Portugal. Around 90 percent of officially landed common octopus is captured with pots and traps (Moreno et al. 2014) by the "local fleet" (comprised of small-size boats, less than 9m in length) and the "coastal fleet" (comprised of vessels generally ranging from 9-15m in length). These two fleets are of the utmost importance for a large proportion of fishing communities.

The fishing of octopus dates quite far back. It is a traditional fishery, primarily in the south (Algarve region), where octopus has been caught (and even exported) since, at least, the 15th century (Godinho 1963). It is still the main species landed in the region (INE 2014), and the local small-scale fishing industry is highly dependent on octopus. The commercial fishery of octopus was also originally mainly based in the Algarve region and used clay pots of various types and shapes, possibly derived from the ancient amphora. These were later replaced by dedicated pots which were hand-hauled, necessarily slow to handle and limited in capacity, and which resulted in a low catch rate and low annual landings. Official statistics show that average annual landings for the period 1927-1972 were approximately 1,025 tonnes (+/- 50 percent).

Between 1973 and 1986 the fishery was modified by the introduction of mechanical hauling devices (winches), which resulted in a sharp increase in effort and a fourfold increase in landings. The fishery also gradually expanded northwards and by 1992 octopus was being caught all over the Portuguese coast. To add to this, at the same time, the main gear in use shifted to baited wire mesh traps, resulting in the technological capacity multiplying. Effort is also believed to have increased substantially all along the coast while the proportion of unreported landings skyrocketed. Figure 4.3 shows a timeline analysis for the octopus fishery in Portugal.

Nowadays, the octopus fishery supports small-scale fishing communities all over the Portuguese coast as it is a source of guaranteed income for most small-scale fishers. This increased economic dependence of coastal communities on the octopus fishery is not exclusive to fishers operating creels and pots; the trawling fleet has also increased its economic dependence on octopus (Pilar-Fonseca et al. 2014).

Octopus catches, as most other catches, are required to be landed for first sale at DOCAPESCA S.A., a state-owned company (under the Ministry of Agriculture and the Sea) responsible for organizing the first sale of fish and managing fish ports. Fishery products are sold using a descending-bid type of auction, also known as the Dutch auction system. Octopus is sorted by size class – a system of four sizes, from T1 (for "Tamanho", i.e. size) to T4 – in order to set the initial price at auction. Weight and initial price decrease from T1 to T4 (bounded by the legal minimum landing weight of 750g). The weight range within each category has been loosely defined by DOCAPESCA according to local fishers' perceptions of "large" and "small" at different ports, thus eluding standardization for a number of years. Most interviewees were unsatisfied with the current auction model, accusing a few retailers of manipulating and significantly lowering auction prices. Fluvia et al. (2012) point to the fact that the Dutch auction system may not be the most appropriate mechanism for fishers to extract a high revenue from their catch. Only around half of the octopus caught in Portugal is ultimately sold in the Portuguese market. The largest buyer of octopus in Portugal estimates that it purchases around 80 percent of all octopus sold in auction, and exports half of its product wholesale to Spain and Italy, where octopus is then processed. Many other buyers at first auction also export their product, for example to Spain; several buyers in the Algarve region are Spanish.

The socio-economic systems in which the Portuguese common octopus small-scale fishery operates give rise to challenges for the governability of this fishery, in particular related to illegal effort deployment, landings of undersized octopus, and potential problems of economic viability of the fishery (at least temporarily).

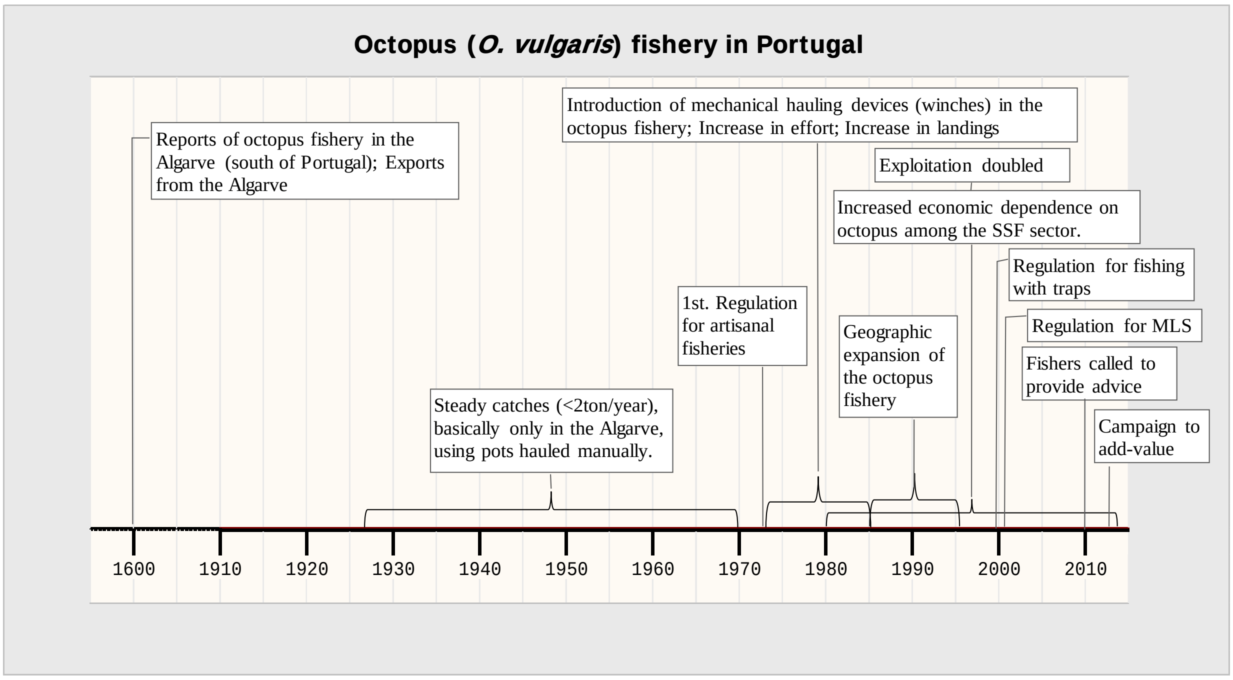

Figure 4.3. Timeline analysis of the common octopus fishery in Portugal.

4.3.3. The Governing System

Under the EU-CFP there is still no regulation for cephalopod fisheries, meaning that octopus fishery management in Portugal derives exclusively from government specific and general legislation, under the direct responsibility of the Directorate General for Marine Resources and Maritime Services and Safety, which, in turn, belongs to the Ministry of Agriculture and the Sea. The technical measures put in place to manage octopus generally derive from research advice provided by the national fisheries research institute, local governmental counterparts and higher education research institutions. Since 2010 fishers have also been called on, by the Secretary of State for Fisheries, to provide advice on octopus management (Table 4.2).

Management measures in place consist essentially of regulations defining a minimum landing weight and the gear used. The minimum landing weight for the common octopus is 750g. The legislation stipulates a maximum of 3000 non-baited pots per vessel (of any size). Baited trap limits vary according to the length of the boat: 750 traps per vessel under 9m in length, 1000 traps for vessels between 9 and 12m in length, and 1250 traps for vessels over 12m in length. The legislation also puts restrictions on the mesh size for traps, trap dimensions for different types of traps, and the mesh size for trawl fisheries. Finally, the legislation sets spatial-temporal constraints on the fishery, by setting a minimum distance from shore at which the gear can be deployed (e.g. 0.5 nm for vessels below 9m in length using pots and 1 nm for vessels over 9m in length using pots and/or traps, although this varies according to season). Regional rules have also been put in place, for example the prohibition of using live bait (Common green crab, *Carcinus maenas*) in the south coast fishing grounds (Algarve region).

Control and law enforcement are carried out by the maritime police and harbor authorities, while the armed forces (navy and air force) are also involved in monitoring and control at sea. The effectiveness of the monitoring and control system at sea is very limited, due mostly to lack of human resources to patrol large areas. This means that the number of traps deployed is in practice under no control. There is also limited enforcement on land, reducing the efficacy of the minimum landing weight legislation. According to fishers, compliance with rules and regulations is minimal, especially at times of economic difficulties.

The excessive amount of static gear in the water is a problem and leads to, or potentially increases, conflicts among fishers, raising questions of social justice. The accumulated investment in fishing gear is reportedly enormous and tends to be increasingly unbalanced, as some fishers continuously invest in gear (mostly plastic pots due to their low cost) and deploy all this gear in the water to secure fishing areas. Some static gear users accuse others of occupying all of the fishing grounds, and anecdotal reports have emerged of commercial exchange of gear in the water in order to secure access to certain fishing grounds. Simultaneously, encroaching on mobile gear areas results in accusations of foul play.

Monitoring of fisheries in Portugal is carried out through satellite tracking devices (vessel monitoring systems), fishing logbooks, dock-side monitoring and digital record keeping at auctions. There are also research programs (national fish-auction sampling programs and stock assessment research cruises) to provide further support for management advice and guide legislation. The current fisheries monitoring system and stock assessment practices in Portugal have long been identified as inadequate for the management of octopus as the data are collected so as to meet the requirements of finfish assessments and not those of short-lived resources mostly caught by static gear (see Pereira 1999). There is also the issue of lack of data, including socioeconomic data, on the small-scale octopus fishery, and indeed on small-scale fisheries in general.

In Portugal, small-scale fishers participate in management initiatives through a large number of small (and generally geographically arranged) fisher associations. Formal participation by small-scale fishers in the decision-making process is a recent innovation and is still rare. However, fisher participation in management appears to be developing rapidly.

The high dependence on octopus by the Portuguese small-scale fleet and the adverse socio-economic impacts in years when catches are low have been the main reasons that fishers have pressurized government bodies, leading to changes in legislation, and to increased interest by the industry to participate in the decision-making process. This was the case in 1996, when representatives of small-scale fishers approached the fishery management body and the national fisheries research institute with concerns about increasing effort and a potential future decrease in catches. They were of the opinion that the increase in effort over the previous years was putting the stock at risk of overexploitation and requested protective measures for the octopus (Pereira 1999). This resulted in the implementation of new legislation setting a minimum landing weight for octopus (Ordinance 27/2001). While fishers' concerns were taken into account, fishers were not formally involved in the decision-making process. A "bad" fishing year in 2010 was again the reason for fishers pressurizing the government. Low catches in 2009, after a particularly good fishing year (2008), resulted in some fishers in the Algarve region accusing others of employing methods (namely the use of live bait in traps) that they considered to be responsible for the decline in octopus abundance. The affected fishers demanded a change in legislation and one was introduced, forbidding the use of live bait in traps. The legislation was, however, subsequently retracted only to be reintroduced once again in the Algarve (Ordinance 230/2012). In this instance fisher associations were involved in an ad-hoc expert-group convened by the Secretary of State for Fisheries. Their advice was considered alongside the scientific advice. However, after two task forces and four pieces of legislation over a period of four years (2009-2012), the issue of employing live bait in traps remains controversial (Nov. 2014), and a source of much debate and disagreement between associations in the Algarve region.

Recently, several measures have been put in place that aim at improving the long-term sustainability and profitability of the octopus fishery. One such measure was a campaign by DOCAPESCA S.A. to promote the consumption of Portuguese fresh octopus, develop new recipes and uses for octopus (e.g. ready-to-eat meals) and, as such, increase the visibility and presence of Portuguese octopus in the Portuguese market so as to increase the economic value of the species. Another initiative of interest was DOCAPESCA's decision to hand over the running and management of several first sale auction sites ("lotas") to fisher associations. Octopus is the main species sold in these "lotas" in the Algarve region. The lotas now managed by fisher associations were previously amongst the least profitable, due mostly to illegal and unreported landings. It is believed that management by fisher associations will lead to increased compliance and added revenue for small-scale fishers.

Further measures are also being explored, such as an initiative to implement an adaptive management system, referred to as "responsive fisheries management system" (developed through the EU-funded EcoFishMan project; www.ecofishman.com), for the octopus fishery in the Algarve. This initiative, developed by the Centre of Marine Sciences (CCMAR) of the University of the Algarve, consists of a bottom-up co-management system based on the optimization of results. Over its first year monthly workshops, with representatives from fishing authorities, fishing associations and researchers, to propose and discuss management policies, were organized. The initiative, still in its early stages, has been well-received by management bodies and fishers alike. The fishery management authority is also exploring the possibility of establishing exclusive area-based concessions for the exploitation of octopus; in other words a form of Territorial Use Rights in Fisheries (TURF), a system already successfully implemented to achieve sustainable management of benthic resources, including for the management of octopus in Chile and Madagascar (see. Martín et al. 2010; Gelcich et al. 2012; Raberinary and Benbow 2012).

Although all the initiatives described above are still at early stages of development and hence not ready for performance evaluation, representatives from fisher associations tended to see these measures as a step in the right direction and as having the potential to increase the profitability and economic viability of small-scale fisheries. Still, major challenges remain for the governability of the octopus small-scale fishery, related to the governing system in place.

These include lack of a viable level of monitoring and assessment, poor control and enforcement, lack of respect for rules and regulations by fishers and lack of trust of fishers in management bodies. In addition, the low levels of organization, trust and cooperation between fishers themselves result in them having a limited influence on the decision-making process.

Table 4.2. Governance of the common octopus fishery in Portugal.

Octopus (*O. vulgaris*) fishery governance	
Governance mode	Hierarchical
Key management institutions and organizations	Ministry of Agriculture and the Sea; Directorate General for Marine Resources and Maritime Services and Safety.
Main stakeholders involved in the decision-making process	Management bodies (above), fisheries research institute (Portuguese Institute of the Sea and Atmosphere), higher education research institutions
Other stakeholders	Higher education research institutions, local governmental, fishermen associations
Main management measures	Minimum landing size of 750g for *O. vulgaris (*main measure); Gear restrictions.
Main legislation	Minimum landing size for octopus (Portaria nº 27/2001). Regulation for fisheries using traps (Decree Law 43/87 and Ordinance 1102-D/2000, emended by Ordinance 447/2009, altered by Ordinances 774/2009, 193/2010, 1054/2010, 132/2011, 97-A/2012 and 230/2012; Interdiction of using live bait in traps (Ordinance 230/2012).
Enforcement and control	Maritime police and harbour authorities, under the responsibility of the Directorate of Maritime Authority and the National Republican Guard; Armed forces (navy and air force).

4.3.4. Governing Interactions

The management of the Portuguese octopus small-scale fishery is undertaken through a top-down system and, in general, formal participation by small-scale fishers in the decision-making process is still scarce. Nevertheless, based on the interviews conducted, most new measures put in place so far have emerged from fishers' demands. Moreover, although formal fisher participation in the decision-making process only started in 2010, participation has increased significantly.

Governmental fisheries bodies, research institutions and small-scale fisher associations are attempting greater and more effective involvement and participation of fishers in the management of the octopus fishery. However, a general lack of internal consensus amongst fisher associations means that they lack a single voice and therefore still have little influence. Nevertheless, participation is increasing with more and more fishers attending meetings and workshops, and showing an interest and willingness to participate in management. Increased participation of fisher associations has, sometimes, resulted in increased expectations from fishers, some of which are not very realistic and are unlikely to be achievable (such as the establishment of subsidized closed seasons and areas).

In short, governing interactions are changing in Portugal, with increasing attempts by the small-scale octopus fishing sector to participate in management, as a result of the socio-economic turmoil the sector has been facing and due to a growing socio-economic dependence on the octopus fishery. Authorities are increasingly discussing concerns with fishing communities and appear to be open to fishers' opinions and proposals. There is no doubt that this openness to increased participation presents an opportunity to improve the governability of the fishery, since both monitoring and control are more effective with the active support and participation of fishers. However, the structure and procedures needed to achieve a fully participatory approach remain to be determined. In addition, there remains a concern that a lack of a broad-scale vision, one which considers the octopus fishery in the context of existing socioeconomic conditions, biological sustainability considerations and the evolution of the marine and maritime sectors in Portugal and the EU, may threaten the sustainability of the resource.

4.4. Discussion and Conclusions

Any attempt to improve governance inevitably requires an assessment of the system's governability and this, in turn, requires the understanding of the system's basic qualities (Bavinck et al. 2013). The governability assessment framework provided a good basis for defining and assessing a data poor fishery such as the small-scale octopus fishery in Portugal.

The Portuguese small-scale octopus fishery is faced with many challenges which need to be taken into account for successful management and governance. Particularly important challenges for management relate to the biology of the species itself, the lack of a viable level of monitoring and assessment, and a general lack of understanding about the resource (i.e. about octopus as a species) and knowledge about the fishery by managers. These current limitations have resulted in the inappropriate management of the resource.

Under the EU-CFP there is still no assessment program for cephalopod fisheries (ICES 2013) and no routine assessment of *O. vulgaris* stocks in EU waters. In addition, there is a general lack of detailed data collection on cephalopod fisheries, something that Pierce et al. (2010) identified as a major impediment to the routine assessment of southern European cephalopod stocks. Biological data collection for the common octopus in Portugal is done in a way that meets the requirements of finfish assessments but is not suitable for assessing octopus and, as such, existing datasets are inadequate to support the assessment and management of octopus (Pereira 1999). The biological features of the species (e.g. short lifespan, terminal breeders) make it simultaneously difficult to assess abundance and regulate catch levels. To add to this, the sensitivity of octopuses to environmental influences (such as variations in temperature and salinity/rainfall), and the resulting natural inter-annual variability of abundance, presents further problems for management.

Nonetheless, new assessment approaches are currently being refined and trialed for EU cephalopod stocks (see ICES 2014), including the use of production models which incorporate environmental effects, and population biomass models (Gras et al. 2014). Although wide fluctuations in abundance occur (typically averaging around 40 percent a year), studies in Galicia (Spain) suggest that abundance of the upcoming cohort is potentially highly predictable based on knowledge of environmental conditions (Otero et al. 2008). These are promising new developments for a better assessment and management of octopus stocks. However, even if future abundance can be to some extent predictable, natural abundance variations require fishers to be adaptable, for example to switch to other target species in years of low abundance. However, the dominant rhetoric within the fishing sector is that octopus will continue to provide increasing volumes of landings at a high price. Not surprisingly, therefore, coastal communities are content to specialize in octopus fisheries.

The nature of the small-scale octopus fishery, including the high social and economic dependence of fishers on octopus, and the aforementioned lack of routine monitoring and assessment, make it imperative to involve fishers in the implementation of effective monitoring solutions on board vessels and in monitoring landings. In addition, the involvement of fishers in decision-making and management is probably the only way to increase compliance with rules and regulations. A vast body of literature exists on the advantages of involving stakeholders, mainly fishers, in the decision-making process (Pita et al. 2012). All this literature suggests that stakeholder involvement facilitates common understanding, contributes to establishing trust, increases stakeholders' responsibility and accountability, enhances the legitimacy and acceptance of management policies and decisions, and increases the likelihood of compliance (e.g. Jentoft and McCay 1995; Coffey 2005; Marshall 2007; Berghofer et al. 2008; Pita et al. 2010) thus improving governance.

The octopus fishery was systematically ignored by management bodies in Portugal for a long time. However, this trend seems to be changing and there appears to be openness on the part of management bodies to support new management initiatives for small-scale octopus fishing. This provides an excellent opportunity for the development of new management frameworks. Several initiatives to implement new marketing strategies to increase the added-value of catches and facilitate co-management are already being explored. These initiatives can be particularly promising for the management of octopus fisheries by small-scale fishing communities. Moreover, the new opportunities created with recent marketing strategies, and the development of mechanisms which put fishers in direct contact with the market, can result in younger generations once again being attracted to fishing. All these new developments have the potential to increase empowerment of the fishing community and their sense of ownership of resources, as well as to enhance stewardship.

The future of the octopus fishery in Portugal depends on more appropriate stock assessment and monitoring as well as on the successful implementation of management measures in cooperation with the fishing industry. Such measures would help reduce fishing effort (in particular the deployment of excessive numbers of pots), improve compliance with rules and regulations and increase the added-value of the catch. It is important to note that all the changes to octopus fishery legislation so far have resulted from pressure from the small-scale fishing sector. Small-scale fishers are increasingly more organized and interested in taking part in the decision-making process. This willingness to participate, together with the increasing openness from management bodies to fishers' participation, constitutes the minimal conditions for governance interactions (Bavinck et al. 2013). The empowerment of small-scale fishers and active participation of the fishing community in the management of the fishery is essential as it leads to an increased sense of ownership and thus compliance with rules and regulations. A shift to co-management, a requirement of the newly reformed CFP, could be the best, and indeed the only effective, way to achieve long-term sustainability for the octopus fishing fleet. However, there is still a way to go to move forward co-governance arrangements in the small-scale Portuguese fisheries. Improving communication channels between authorities, industry and fishers (and indeed within the small-scale fishing sector) is extremely important. A simpler and clearer framework for participation at local/regional levels and technical assistance programs to aid fishing associations could be key for empowering coastal communities to face the upcoming challenges that the recently reformed CFP will bring, such as the landing obligation, the decentralization of governance, the empowerment of the fishing sector, and the implementation of differentiated management arrangements for small-scale fisheries.

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Chapter 5.

Participatory assessment of management measures for *Octopus vulgaris* pot and trap fishery from Southern Portugal

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Abstract

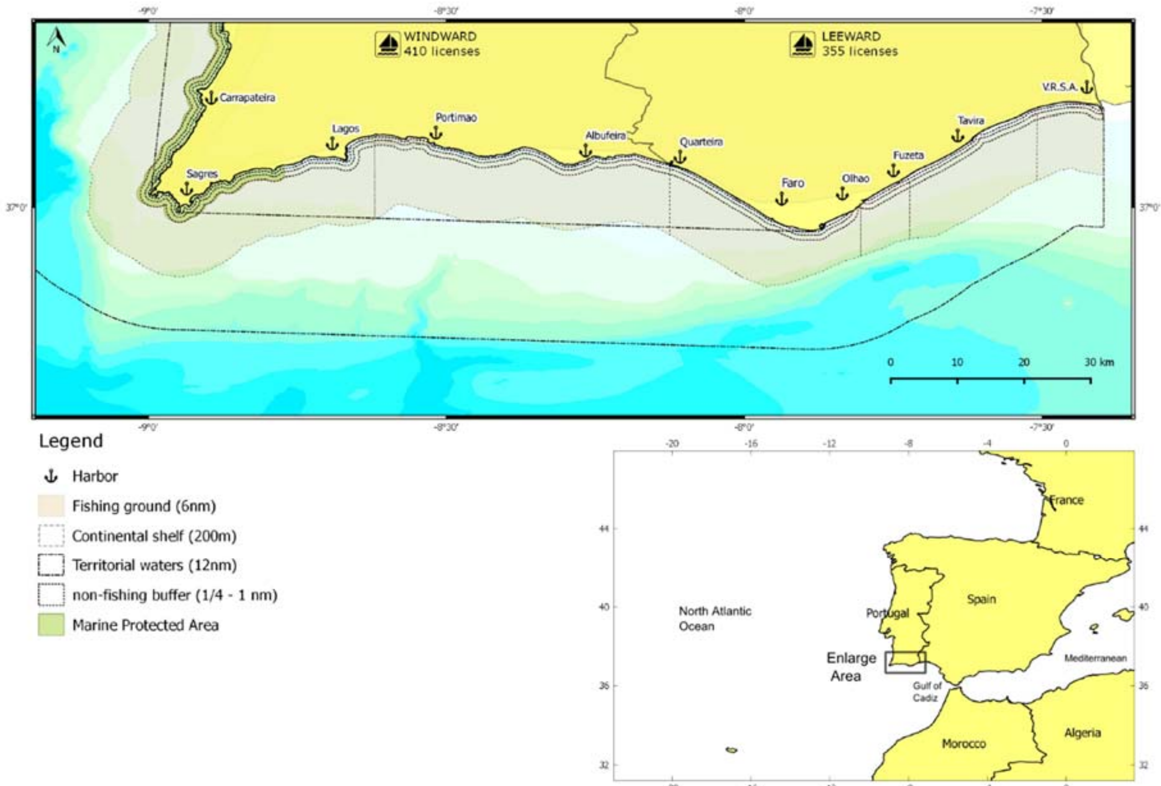
The last European Union reform of the Common Fishery Policy (CFP) is moving towards an ecosystem approach to fishery management and requires stakeholders' involvement as a key component for achieving sustainability. In southern Portugal, the *Octopus vulgaris* pot and trap fishery provided an ideal testing environment for the implementation of a fisher participation process to move towards co-management. The strong fluctuations in *O. vulgaris* landings due its short life cycle and environmentally controlled recruitment have played a major role in the recent policy making process, where fisher associations constantly demanded regulation changes, resulting in short term ordinances. In the work herein, representatives of fisher's associations from the region and other stakeholders were asked to propose management measures, and a total of 52 measures were compiled. During a one year period 7 participatory workshops were held, were attended by 60 participants from 10 fishing associations and 16 institutions (research and authorities) who discussed these measures. Outputs were structured within the framework of a SWOT (strengths, weaknesses, opportunities, threats) analysis, based on four fundamental pillars: ecological, economic, social and governance. The excess of fishing effort is the major concern among fishers, and the implementation of a biological fishing closure has been the most popular measure proposed. This analysis provides relevant information to both fishery managers and fisher's representatives, contributing towards environmental, economic, and social stability, and for the sustainability of the octopus pot and trap fishery in the region.

Keywords: co-management, *Octopus vulgaris*, pots and traps, Portugal, participatory meeting

5.1. Introduction

In 2014, the common octopus (*Octopus vulgaris*) landings in Portugal accounted for 44.1 million euros in value, representing 15% of the total revenue from the first sale generated by all fisheries, and positioning octopus as the second most valuable species after sardine (DGRM, 2014) . The Algarve region (southern Portugal) represents one of the most important regions for octopus fishing in the country, not only in terms of fleet size and volume of landings, but also because the octopus fishery is an important source of employment in coastal areas and a traditional component of the local and national diet (Pita et al., 2015).The Algarve is where the octopus fishery began and the region has the largest fleet dedicated to fishing this mollusk nationwide, with 765 fishing licenses in 2014 (Data source: Directorate General for Marine Resources and Maritime Services and Safety – DGRM 2015), distributed among 10 harbors covering a total fishing ground area of about 2569 km2 (Figure 5.1).

Figure 5.1. Distribution of octopus fishing ports and fishing grounds for the Algarve region



(South Portugal) (Source: National Directorate of Marine Resources, Safety and Marine Services-DGRM).

Between 1990 and 2014, octopus landings in the Algarve region have presented a large variability, ranging from a minimum of 1193 tons to a maximum of nearly 5500 tons per year. Monthly landings average 211.5 kg, with summer months recording the lowest average (180.1 kg), while winter and spring were significantly larger (249.4 kg and 219.9 kg respectively). The number of vessels recording landings also exhibit a seasonal pattern, with a maximum in winter (705) and a minimum in summer (605), around 12% less than the rest of the year. Prices show an average of 4.1 € / kg year around, registering the lowest price during the autumn (3.7 € / kg) (Figure 5.2).

As reported by Pita et al., (2015), who described the management of the small scale *O. vulgaris* fishery in Portugal, this resource is excluded from quota or other regulations at the European level, and each member-state assumes the management of its own fishery. The first management measures were published in 1987, as part of the national decree nº47/1987. The document represents the main set of laws for the conservation of aquatic biological resources and their fisheries in the whole country. Later, ordinance nº1102D/2000 constituted the first specific *O. vulgaris* trap fishing regulation. Since 2000, 13 other ordinances regarding the octopus fishery have been released, covering a broad variety of issues, from gear and boat limitations to bait restrictions, and including regional constraints and short-term experimental policies. The policy making process during the last 15 years has stemmed from several action-groups with representatives from the fishing community, authorities and researchers, through a process driven by requests by fisher associations as a consequence of the strong fluctuations in *O. vulgaris* abundance in the region (Pita et al., 2015). This *ad-hoc* legislation has therefore not followed any long-term management strategy.

Pierce et al., (2010) provided an in-depth review of cephalopod fishery management strategies around the world, concluding that worldwide efforts show no consensus in either management objectives or assessment methods. The authors presented an overview of cephalopods fishery management for four European countries, showing part of the complex interactions among public bodies in the policy-making process. More recently, Pita et al. (Pita et al., 2015) described the current situation of the small-scale fishery in Portugal and its legal status, presenting the latest challenges in governance. Importantly, the interaction between the short life cycles of cephalopods and environmental variability have been identified by experts as a major concern in the achievement of sustainable management (Pierce et al., 2008; Rodhouse, 2010)

Assessment of detailed management strategies for cephalopods is, nevertheless scarce in the scientific literature. Jouffre (2005) analyzed minimum landing size and closing seasons for *Octopus cyanea* in Senegalese waters, while Narvarte et al. (2006) compared *Octopus tehuelchus* abundance in open areas and marine protected areas in northern Patagonia (Argentina). Fernández-Rueda and García-Flórez (2007) presented an assessment of management strategies for *O. vulgaris* in north-west Spain. Leite et al. (2009) described the ecology of *Octopus insularis* and its implications for management in north-east Brazil, and proposed a management plan for the species in the area. Benbow et al. (2014) and Oliver et al. (2015) described the effects of a temporary octopus closing season in south-west Madagascar. In most circumstances, the objectives of managing a resource such as *O. vulgaris* implies fast response since the species exhibits a high flexible life cycle capable of responding quickly to different levels of fishing pressure (Boyle and Rodhouse, 2005)

Regardless of the management strategy used the agreement with and compliance by all involved is a key factor in the implementation process (Janssen, 2015). Co-management, as a system in which responsibility for management is shared between the state and user groups has been reported as a possible strategy towards sustainability of fishery resources (Linke and Bruckmeier, 2015). Co-management requires the participation and empowerment of stakeholders and shared responsibility between resource users and managers, where a process-based instead of result-based management approach is essential. It also requires institutional embedding and the decentralization of decision-making, as well as equity and justice regarding access to and use of resources (Linke and Bruckmeier, 2015). In order to move towards co-management, a dialogue process needs to be established between the administration and fishers where communication is the key element, and compromise and knowledge co-creation is fundamental (Berkes, 2009; Janssen, 2015). A transdisciplinary

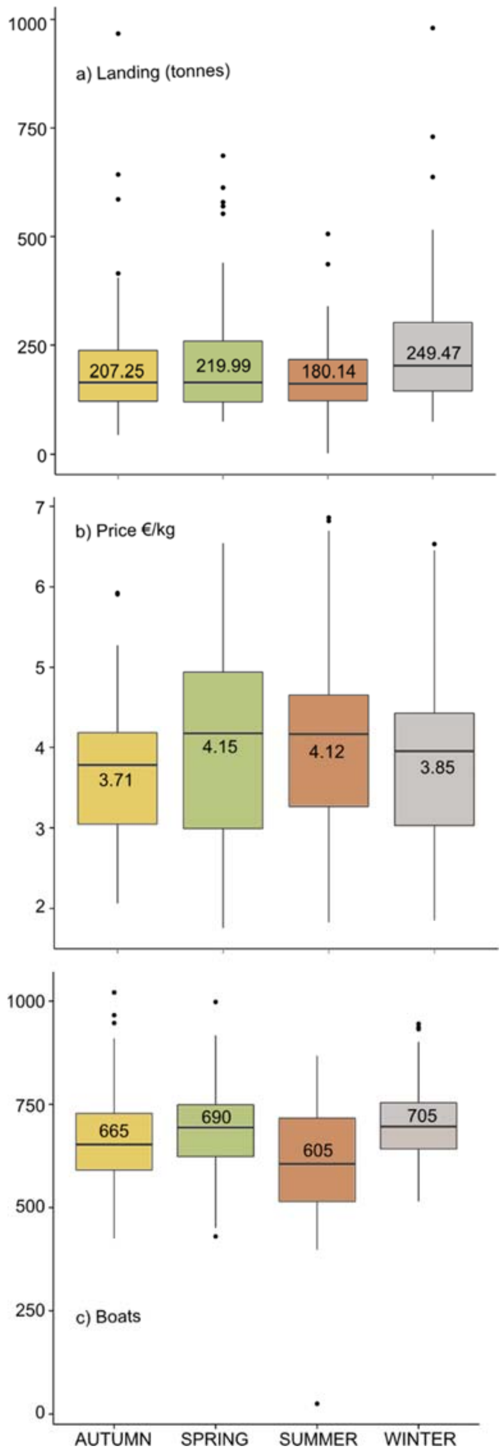


Figure 5.2. Box-plot of the landings in tons (a), first sale price (b) and number of boats (c) from data recorded at fishing auctions in the Algarve region (1990-2014). Data were grouped by season: (spring = April to June; summer = July to September; autumn = October to December; winter = January to March). Values in the boxes are mean values. Source: DGRM 2015.

approach, with strong cooperation between scientists from different disciplines, resource users and managers may create good conditions for such compromise (Çelik et al., 2012; Freire-Gibb et al., 2014; Glass et al., 2015; Siaosi et al., 2012; Viegas et al., 2014).

Considering the above mentioned we set out the first steps towards the development of a co-management strategy for the *O. vulgaris* fishery in the Algarve region, Portugal. The present work provides an overview of the participatory process developed including the main management measures discussed between experts on octopus fishery research, the research team, fishers and management authorities. By presenting this analysis we aim to contribute for the establishment of groundwork that may provide advice for the future development of a co-management plan for this fishery in the Algarve region. Further, the results reported herein can be a useful reference to be shared among other small-scale cephalopods fisheries facing similar challenges, where moving towards a co-management process represents an alternative for achieving the sustainable use of marine resources.

5.2. Methodology

Figure 5.3 provides an overview of the methodological approach in which the process was divided in four main phases. In the first phase, fifty-two management actions were proposed by the stakeholders: experts on the octopus fishery, fishers and management authorities. This was done by a consultation process via email and telephone in January 2014, where participants were asked in an open-ended format, to list the main management actions they considered relevant for the sustainable management of the octopus fishery in the Algarve.

In phase two the research team structured the information by clustering different management actions according to common broader category designated management measures. Hence, phase two and three served for participants to validate the systematization process. Consequently, participants had access to the list of management measures including the management actions for each. Next, phase three was structured as a participatory process with skilled facilitation. For this purpose, a co-construction process was developed between all participants for assessing the management measures. This phase lasted from June 2014 until April 2015. During this period seven monthly workshops of three hours each were organized. All participants of phase one where invited and each event was publically publicized. Each workshop started with the voting of the most relevant management measures to be discussed. After this identification, participants worked in groups of three up to eight elements to identify the goals of the measure, how to implement it, what would be needed and what are the current threats or opportunities to its implementation. Each workshop finished with the presentation of the conclusion achieved by each groups, identification of common points and divergences. During the seven workshops, eighteen measures were discussed, yet for the purpose of the present work we focus on seven that promoted an in-depth analysis. All workshops were tape recorded and transcribed; this information was used to develop a report of each workshop delivered to participants after every meeting.

Finally, phase four provided a critical overview of the outcomes of phase three. The first step of this phase was to understand the impact that each regulation could have on the different stages of the octopus life cycle. Secondly, the assessment of the management measures made in phase three was complemented by a literature review. Finally, and taking into account the results of the previous steps, the research team and experts developed a SWOT analysis that provided a critical view of phase three.

5.3. Results and Discussions

In phase two 60 participants belonging to 10 fisher associations and 16 institutions took part in the identification of management actions and assessment of the seven main measures (Table 5.1). The essential life cycle stages of *O. vulgaris* driving its fishery can be divided in five: paralarvae, recruitment, growth, mating and spawning (Boyle and Rodhouse, 2005; Robin et al., 2014). Considering these stages, an assessment of the direct impact of each management measures in the octopus life cycle was undertaken (Table 5.2). Four out of the seven management measures analyzed have direct impact on at least three stages of the life cycle of the octopus: Closed Season (CS), Minimum Allowable Distance from the Coastline (MADC), Maximum Allowable Number of Traps/Gears (MAN) and Minimum Landing Weight (MLW). Bait Selection (BS) and Maximum Allowable Catch (MAC) might only impact on the grow of this species. Fishing schedule was the only measure considered not to impact directly on any of the octopus life stages identified previously. The following sections describe the main outputs of the SWOT analyses applied to each of management measures previously identified (Table 5.3).

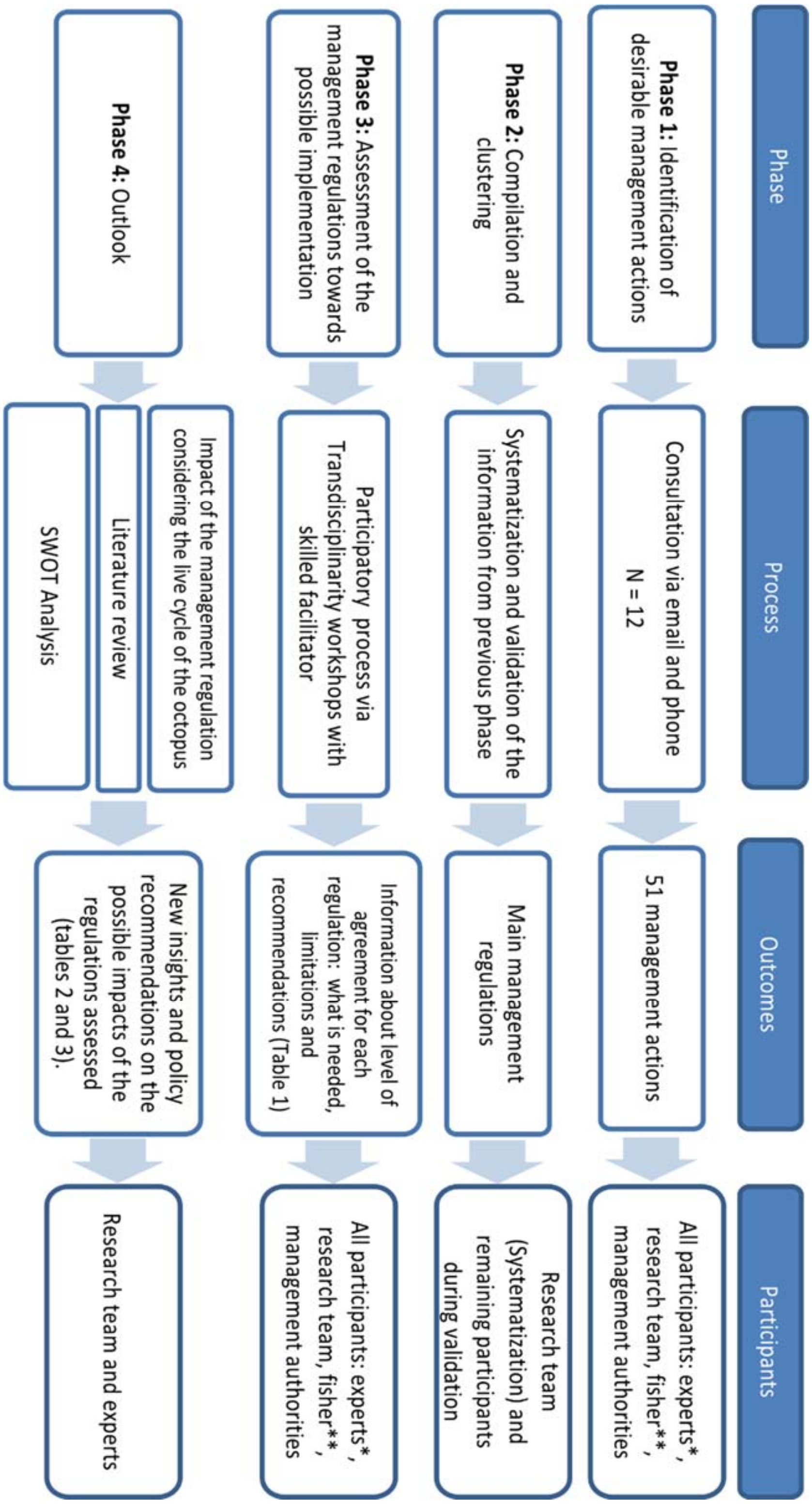


Figure 5.3. Methodological approach. Note: *Experts included researchers focused on the octopus fishery that are not part of the research team. ** Octopus fishers that play a key role

in the existing organizations dedicated to this fishery, as well as, some technicians responsible for the management of the organizations.

5.3.1. Closed season (CS)

Temporal closures have been widely used as a management option with different degrees of success (Arendse et al., 2007; Augustyn et al., 1992; Leite et al., 2008; Myers et al., 2000; Pipitone et al., 2000; Sluczanowski, 1984; Ye, 1998). As mentioned by Gulland [30] these strategies are usually implemented to reduce fishing effort, improve the species' spawning potential by protect adults during the spawning season, and protecting juveniles from depletion during times of recruitment. In the current case, the CS was evoked as a way to protect young recruits from fishing, as well as, to optimize the economic value of the catch (Table 5.1). It should be noted however that this measure was in force as a regional ordinance during August 2005 (Ordinance nº635/2005), but was removed soon after due to inconsistent results and lack of assessment (Ordinance nº840/2005).

Fishers may respond to a closure by intensifying fishing effort during the open season, as it has been reported for the octopus fishery in Madagascar, where fishers increased their effort considerably when the fishery re-opened (Benbow et al., 2014; Oliver et al., 2015). Consequently, this intensive effort after a closure will lead to a large increase of octopus supply (landings) at first sale, with a drop in price as a result (Table 5.3). This situation is well-known for this region, where during the autumn and winter months (October to March) first sale prices present lower averages as a result of large market supply due to fishing abundance peaks. Thus, before implementing a fishery closure, social and economic impacts must be carefully considered. As mentioned in Table 5.3, temporary unemployment and significant economic losses for fishers, local markets and industries may occur. Provision of temporary licenses and subsidies were proposed as a solution to this drawback, even though recent research showed that moving effort to other species may result in the over-fishing of those species (Erzini, 2005).

The duration of the CS was also discussed (Table 5.1), yet no conclusion was achieved and participants considered that the time and period should be on based in scientific knowledge. However, current knowledge shows that the reproduction stage of this short-lived mollusk

Table 5.1. Proposed management measures, their goals, strategy for implementation proposed for the octopus trap fishery in the Algarve region, south Portugal. (Note: LPUE: landings per unit effort; N.A.: not applicable.)

Measure	Primary goal	Other goals	Strategy for implementation	Enforcement
Closed Season (CS)	Boost octopus LPUE in the following months by protecting young recruits from fishing (growing)	Optimize the value of the catch by increase mean landing weight	Stop fishing during 1 or 2 months based on the annual cycle of the resource	Ban any type of octopus fishing (commercial or recreational)
Fishing Schedule or Weekends stops (TS)	Indirect mechanism of e ort control by limiting working time	To prevent thief of fishing gear	Stop fishing during certain hours or days and or weekends	Prohibit the departure of any trap fishing boat from the harbor during stops
Maximum Allowable Number of Traps or Gears (MAN)	Control fishing e ort	Equal competition	Setting a maximum number of fishing traps according to boat size and type and number of crew	Tagging system to identify every trap and buoy
Bait Selection (BS)	Non-direct measure for control fishing e ort (number of traps)	N.A.	Dead bait requires lifting up trap sets daily for re-baiting while live bait (crab) allows deployment of traps for longer periods of time	Ban the use of certain kinds of bait for octopus
trap fishing Minimum allowable distance from the coastline (MADC)	Enhance spawning biomass by protection of brooding females and spawning grounds	Increase octopus recruitment by protection of juveniles or protect essential habitats	Define boundaries of nursery grounds by mapping the seafloor and reproduction season to establish MADC	Banning fishing in coastal waters,depending on boat size gear type and time of the year
Maximum Allowable Catch (MAC)	Regulate the distribution of the resource biomass among fishers	Bu er the impact of over-supply on prices at times of abundance booms	Establish a maximum weight for landings according to boat size and crew members	Monitoring landing by boat at fishing harbors establish fine scale according to degree of the transgression
Minimum Landing Weight (MLW)	Ensure that a part of the octopus stock is able to reproduce	Increase harvest yield by increasing the average individual body weight at landing	Increase the minimum landing weight to near the W50 estimation	Ban the commercialization of octopus under certain minimum body weight

Table 5.2. Impact of the proposed management measures in the main stages of the octopus life cycle. (Note: N.A. - Not Applicable

Measure	Paralarvae survival	Recruitment	Growth	Mating	Spawning
Closed Season (CS)	N.A.	increase recruitment biomass due to fast growing of juvenile octopus	increase general growth	enhance mating by protection adults during reproduction	Improve spawning by protecting brooding females and grounds
Fishing Schedule or Weekends stops (TS)	N.A.	N.A.	N.A.	N.A.	
Maximum Allowable Number of Traps or Gears (MAN)	N.A.	N.A.	Support growth by limitation of the catch (those individuals not fished today will grow for tomorrow)	Support mating by limitation of the catch (those individuals not fished will be able to breed)	Support spawning by limitation of the catch (those individuals not fished will be able spawn)
Bait Selection (BS)	N.A.	N.A.	Bait and its residuals might work as artificial food supply a ecting growth rate and species trophic interactions	N.A.	N.A.
Minimum allowable distance from the coastline (MADC)	N.A.	Increase fishing recruitment by importation of new individuals from coastal areas	Support growth of young individuals in these areas	Increase mating success by protection of mating grounds and seasons	Increase spawning success by protection of mating grounds and seasons
Maximum Allowable Catch (MAC)	N.A.	N.A.	Support growth by limitation of the catch (those individuals not fished today will grow for tomorrow	N.A.	N.A.
Minimum Landing Weight (MLW)	N.A.	N.A.	Increase juvenile growth	May protect young adults allowing them to mate before they are fished	May protect young adults allowing them to spawn before they are fished

occurs all year around (Lourenço et al., 2012) and that there is a strong environmental influence on the paralarvae phase, where rainfall has been identified as one of the main drivers affecting recruitment strength (Sonderblohm et al., 2014). Therefore, the species stock-recruitment relationship is not clear, with the number of recruits to the fishery depending mostly on paralarvae survival rather than number of spawning females. A temporal closure might increase spawning biomass, but the conversion to benthic recruitment might not be proportional as this is strongly influenced by environmental factors (Table 5.2 and 5.3). Temporal rotative closures could be efficient in increasing reproductive output and recruitment if target areas were well defined and rotate among different habitats and periods, where different spaces are closed and re-opened on a systematic basis, as has been proposed by Sluczanowski (1984) for the abalone fishery of the coast of Western Australia. This strategy would allow keep the market supply of octopus year around. However, as recognized by the management authorities and fishers during phase three, this regulation is a major challenge due to law enforcement and may result in implementation failure because of the national dimension of this fishery.

Finally, the CS was also referred as a way of protecting juveniles from depletion during times of recruitment (Table 5.1). Therefore, the CS would improve fishing yield by allowing small individuals to grow to a more marketable size, re-opening the fishery when the octopus cohort has reached an optimal average size. This strategy is well supported by Lande et al. (1994), who developed optimal harvesting models for certain fishing resources and obtained promising results. Yet, as previously mention, this strategy depends on the flexibility of the management system which has been characterized by participants as slow and inflexible. Moreover the major challenge identified for the implementation of a closure was law enforcement constrains (Table 5.1) due to the limited resources of the authorities and the large area of the fishing grounds. Among the threats identified, the lack of compliance with regulation was recognized as a strong possibility in case this measure was put forward; with the high value in parallel markets during a CS promoting further illegal fishing.

5.3.2. Fishing schedule (FS)

Octopus trap fishing in the region occurs mostly during night-time. Fishers leave the harbor to the fishing grounds around sunset and catches are landed for the first sale in the early morning of the next day (Borges, T., 2001). Fishers synchronize their landing times with the fish auction schedule, which depends on the time of the year and harbor. For example, in hot summer days the first sale is moved to early morning to avoid freshness problems due to high temperatures. In Galicia, northwest Spain, the octopus fishery, as many others in that region, has a fishing schedule as part of their management plans (*Resolución do 30 de maio*, 2014). This schedule has been synchronized with market dynamics rather than resource ecology. The proposal of fishing schedules as a management measure in the Algarve is not based on the ecology or behavior of the octopus either (Table 5.1). Nevertheless, it is well known that *O. vulgaris* is a night hunter, performing short night time movements (Boyle and Rodhouse, 2005). Also, many marine benthic species along the continental shelf perform diel cycles (Aguzzi et al., 2009); thus some species are more available for fishing than others in certain times of the day. Daylight versus night-time trap fishing has not been compared yet for this species, and might be an important factor to assess regarding the implementation of a fishing schedule.

During the workshops two types of fishing schedules were considered: daily and weekend stops (Table 5.1). A daily fishing schedule was favored as an effort control mechanism; fishing boats, depending on the number of crew members, should only be allowed to handle a certain number of traps during the allowed fishing time (Table 5.3). Furthermore, a daily schedule was identified as an alternative for controlling trap robbery and poaching, as all boats must stay in the harbor during the non-fishing time. The second type of schedule implied solely a weekend stop. This schedule received higher support by participants, mostly because landing sites are closed during the weekends, and octopus landed during this period is stored in refrigeration rooms to be sold on Mondays, achieving lower average prices (Table 5.3). The major constraint to the implementation of any fishing schedule is the need to adapt it to the harbor-specific hydrology conditions (i.e. tides, navigation channels, sandbars, inlets, among others.). However schedules may provoke economic losses by losing “time windows” of good weather condition for fishing, resulting in the reduction of potential fishing days, especially during the winter (Table 5.3). Participants, during phase three, concluded that this strategy should be applied as a gentleman’s agreement among fishers rather than as a policy for the whole region due to harbor-specificities.

5.3.3. Maximum allowable number of traps/gears (MAN)

Limitation in the number of gears in a license-managed fishery is often used when there is excessive fishing effort (King, 2013). The management of the octopus fishery in Portugal is mainly controlled by the limitation in the number of traps or pots (together with a minimum landing size), yet during phase three participants recognized that the limitations defined by law have been largely bypassed, with many fishermen freely admitting the use of far more traps than allowed by law. Further, it has been concluded that this measure is provoking one of the major conflicts among fishers. Fonseca (2003) based on a time series analyses of octopus landings for this region, found that the number of operative boats has been decreasing during the last 20 years due to an apparent economic over-fishing, which has been balanced by a permanent increase of the number of traps by boat to compensate for economic losses.

One of the major concerns identified for MAN was the current inequality in the number of traps per boat, since the amount of gear seems to be solely limited by the capacity for investment rather than the current regulation. Moreover, the maximum number of traps/pots per boat has been recognized in the national legislation as one of the most unsuccessful policies implemented in the fishery (ordinance nº230/2012). The inefficiency of this policy is caused mostly by the combination of large quantities of fishing gears and the dimension of the fishery, with around 500 boats operating in more than 2000 square kilometers across the Algarve coastline demands for high on sea monitoring costs (Table 5.3). The development of an identification plate system was proposed during phase three and was considered an effective method for controlling the number of traps (Table 5.1 and 5.3), although it was recognized as a costly alternative. In any case, the management authorities have shown openness to alter the current legislation to update the number of trap/pots allowed.

5.3.4. Bait selection (BS)

During the last 50 years many important alterations in the Algarve octopus fishery dynamics have occurred, including: the switch from clay pots to baited plastic based traps, the introduction of the mechanical winch and the expansion of fishing grounds to the northwest coast. Baited traps, which were introduced in the early 1990's (Pita et al., 2015) have become a very popular choice amongst octopus fishers. Since then, fishers have been using small pelagic fish as bait in the octopus traps, mainly Atlantic chub mackerel *Scomber colias* due to its low cost and high abundance in the region. More recently, at the end of the last decade

(2000-2010), the use of live green crab *Carcinus maenas* was introduced by some fishers as alternative bait.

In the octopus national management ordinances bait specifications for octopus traps was not a concern until recently, when in 2010 a group of fishers from the Algarve called for a prohibition of the use of green crab as bait. This prohibition was accepted by the management authorities and put in action by in 2012. Yet, as mentioned in the regulatory document (ordinance 230/2012) this regulation was established as an indirect way of controlling the excessive number of traps. Some fishers support the ban and argue that live bait allows for the handling of more traps without the need for daily re-baiting, thereby increasing fishing effort (Table 5.1 and 5.3). Compared to live green crabs, small pelagic fish require a daily deployment and re-baiting of traps, due to amphipod scavenging of the bait (Castro et al., 2005). Although the impacts of bait choice selection and trophic interactions on the marine ecosystem has not been assessed, it is believed to be an important factor affecting the *O. vulgaris* population dynamics. In terms of co-management the bait selection regulation represents a conflicting issue promoting fragmentation and diminishing the capacity for collective-action.

From an ecological perspective, the use of a high number of baited traps in the region, while representing a threat to the octopus population, might work as a 'food subsidizer' supporting bigger population biomass, and increasing yields over time. For example, in the American lobster fishery of the Gulf of Maine (northeast United States) large quantities of *Clupea harengus* used as bait have been related to increases in landings (Saila et al., 2002). Much closer, in the Sahara bank fishing grounds (north-west Africa) increasing octopus catches have been related to the discards of bottom trawlers, which may contribute as an artificial food source for the octopus population (Balguerías et al., 2000). Nevertheless, the impact of the large number of traps on the octopus population, as well as their interaction with the ecosystem has not yet been assessed. For the Algarve region, the number of octopus trap losses by year has been estimated in approximately 50 thousands of units (Erzini, 2007).

5.3.5. Minimum allowable distance from coastline (MADC)

Although the protection of inshore nursery grounds has been a common practice worldwide since the beginning of human settlements, the dimensions and timing of the areas closed to fishing has always been a point of confrontation (Gelcich et al., 2008). The identification of these areas has been the focus of recent European research programs to support fish management. Regarding sedentary species, closing of coastal areas to fishing may allow for the aggregation of parental stock and increase fertilization and spawning success (Valavanis et al., 2004). The overall strength of this strategy is that it is expected to increase octopus benthic recruitment and juvenile growth to supply new individuals for the fishery.

The Portuguese current legislation regarding the MADC for baited traps stipulates a distance of ½ nm off the coast for coastal boats (>9m length) and ¼ nm for local boats (<9m length) between the 1st of March and the 30th of September, while in the rest of the year the distance is of 1nm and ½ nm respectively (ordinance nº132/2011). This distance is defined through the projection of an imaginary line off the coastline rather than depth. Nevertheless, in other latitudes the minimum distance off the coast is set according to depth bathymetry (*Resolución do 30 de maio*, 2014). This depth limitation, rather than imaginary projected distances off the coast, was referred in Phase three as a more adequate and accurate policy for designing habitat boundaries (Table 5.1 and 5.3).

There is strong evidence that *O. vulgaris* performs onshore shallow-water migrations in spring during the breeding season (Caddy, 1983; Robin et al., 2014). Adult females move to coastal areas searching for shelter to lay their eggs. During Phase three, fishers identified the use of non-baited pots (clay pots) in these areas as detrimental for the brooding stock, by catching the females during egg-caring time. However, the use of baited traps in the breeding sites should not be considered as a threat for females, mainly because they neglect to eat while protecting the eggs, dying of starvation afterwards (Boyle and Rodhouse, 2005). Despite this evidence, interaction of males and females with the fishing gear in coastal waters during key phases such as mating and spawning has not been studied.

5.3.6. Maximum Allowable Catch (MAC)

During Phase three, an individual catch quota was proposed to fix a daily maximum allowable catch in weight according to boat size and number of crew. In theory, this regulation could work as a self-regulating method for traps, where fishers, independently from the gear they use, had to adjust their effort to a fixed daily quota. Basically, bigger boats with more crew members would be allowed to catch more than smaller boats, where the maximum allocated to a fisher should be decided on the basis of equal allocations to all fishers (King, 2013).

Historically, this fishery in the Algarve region displays a annual cycle due the presence of two spawning events: late summer and early spring (Lourenço et al., 2012). During November and February-March, there is high abundances of octopus due to an input of new recruits from both spawning events which produce a boost in landings and subsequent drop in price (Caddy, 1983). In this scenario, fishers double their efforts to compensate for the lower price in order to be economically sustainable, making prices drop even further, and catching the yearly surplus very fast. A catch quota was identified as an opportunity to avoid this situation, where excess in daily landings could be easily avoided by fixing a maximum allowable quota (Table 5.1 and 5.3). Moreover, the octopus trap and pot fishery is considered a single species fishery using a high selective gear, where discarding is not considered a problem (Baeta, 2009). Therefore, a guaranteed share of the resource allows fishers to go fishing when the market price is more attractive, and catches are expected to last over a longer period of time (King, 2013).

Despite the potential strengths of this measure as a non-direct control of effort and a price stabilizer, its major weakness is the fact that it might require the implementation of a costly daily monitoring system (Table 5.3). In a daily quota scenario, limited supply of octopus at first sale can also lead to an increase in price and, thus, increase attractiveness for parallel markets, working as a stimulus for poaching. Further, it has been reported that after fishing, cannibalism is probably the second most important cause of mortality of *O. vulgaris* (Boyle and Rodhouse, 2005). Therefore, in periods of booming abundance, limiting fishing landings by quotas may lead to increased cannibalism among the adult octopus population. Besides these disadvantages, wrong quota estimates due to weak yearly recruitments could lead to serious overfishing problems.

Overall, an implementation of quotas by boat and crew size corresponds to basic concepts of equality and fair distribution of the harvest among fishers. However, catch limits by boat may lead fishers to purchase new licenses from other boats, in order to fulfill the market demand and increase profits. This situation was identified during phase three, where new licenses are not available anymore, and purchasing old boats from other harbors and transferring licenses between captaincies has become a common practice in recent years.

5.3.7. Minimum landing weight (MLW)

The establishment of a minimum landing size or weight (MLW) has been recognized by some authors (Didier Jouffre, 2005; García Allut, 2003; King, 2013) as the oldest of all regulations applied to fisheries, where traditionally the implementation of a size limit prevents the marketing of small fish, allowing the species to spawn at least once before capture (King, 2013). In the case of *O. vulgaris* this might not be appropriate due its high fecundity and semelparity strategy. Nonetheless, during phase three (Table 5.1, 5.2 and 5.3) it was recognized that this regulation ensures that a certain part of the population is able to reproduce, and also improves fishing yield by increasing average individual body weight of the catches (bigger, more valuable octopus).

Regarding the aim of allowing octopus to reproduce, the current MLW (750g) does not correspond to the size commonly referred to L_{50} by fish biologists. Recent data for *O. vulgaris* in the gulf of Cadiz showed that 750g is far from its L_{50}, which was estimated to be 1920g for females and 1300g for males (Pereira, *unpublished data*). Nevertheless, Robin et al. (Robin et al., 2014) reported that immature octopus females are receptive to mating even when not fully developed, as they can store spermatophores until eggs are ready to be fertilized.

Therefore, if the goal of management is to protect young octopus from fishing, this can be easily achieved using other control measures based on the species ecology rather than by setting a MLW. For example, a banning of fishing in shallow waters may protect juveniles due to a size segregation pattern by depth, since bigger octopus are usually located in deeper waters (Katsanevakis and Verriopoulos, 2006). However, from a social point of view, well publicized and enforced size limits are a constant public reminder of the need for conservation, and there is a general public sympathy for such regulations (King, 2013).

In relation to improving fishing yield with a MLW, this concept is based on the high growth rates of the species, where an increase in individual landing weight may improve Landings Per Unit Effort (LPUE) due to catches of larger octopus. Accordingly, price by kilogram at the first sale is size dependent, and larger individuals result in higher average prices. In the workshops an increase of the current MLW was proposed, as a result of a comparison with neighborhood fisheries from the Gulf of Cadiz and Galicia, where the MLW is 1000g. Thus, this proposal was considered to be a reasonable strategy to increase fishing yield as a short term outcome.

5.4. Final considerations

Most of the management measures proposed and discussed during this study target a main common goal: regulation of fishing effort. Paradoxically, measures based on fishing effort, rather than catches or fishing mortality, present the main weakness for sustainable management due to the fact that any improvement in gear efficiency will cause increase in effective effort even though apparently effort remains the same (King, 2013). For example, regulation of trap numbers where the use of two different baits is allowed, and one bait is more attractive resulting in a larger LPUE, will lead to improved gear efficiency even when the number of traps is the same for all fishers. These changes in fishing effort due to bait impacts, among others, have not been assessed for this fishery, and represent an opportunity to underpin management for this activity. Moreover, economic forces moving fishers to increase gear numbers in response to the current market dynamic are poorly understood, representing a threat to economical sustainability.

The dynamic of the current fishery management of *O. vulgaris* for the Algarve area is mostly driven by the species life cycle and its environmental-recruitment interactions. Bad fishing years as a result of weak year-classes recruitment has lead fishers' representatives to demand short-term policies. In fact, there is no management plan for this resource in the region, where measures have been executed as a result of a cause-effect dynamic. The absence of a consensual fishing strategy for the octopus fishery in the region represents the main weakness in management, where implemented policies are not integrated in a specific management plan, and the assessment of the performance of the current outputs has not been considered. Therefore, any attempt to move towards sustainable management of this fishery should firstly include the development of a specific management plan, where periodic evaluation of the results of each measure would provide information for needed adjustments to the initial plan.

In the current license-management system, large differences exist in the number of traps between boats, leading to undue levels of fishing effort. In this scenario, where each fisher is motivated to compete for a maximum share of the resource, it is almost inevitable that fishing effort will continue to increase, provoking a typical 'tragedy of the commons' situation (Hardin, 1968). For this reason, the shift towards the implementation of new governance models such as co-management seems to be an opportunity in the region, where increased interest in stakeholders' involvement is recognized as a positive development. Moreover, the socio-economic impacts of every strategy implemented in recent years has been putting an enormous pressure on the final decisions of the fisheries authorities. Hence, a shared-responsibility management system, instead of the top-down approach in place, may improve the capacity of the system to face upcoming challenges and provide a broader scope of plausible solutions. During the workshops participants shared knowledge and developed a co-assessment of important management actions. The outcome of such process might be classified into two main parts: first management actions have been identified by fishers and second a dialogue process among stakeholders was established. An outlook on the overall process by using the SWOT allowed for a critical reflection of the proposed measures, which brought new insights and policy recommendations. The participatory workshops outputs highlight the importance of this dialogue process towards the establishment of trust between stakeholders. Law enforcement by the management authorities is considered a key element for most of the management options which underlines the degree of mistrust between fishers and authorities. The specificities of the octopus life cycle and dependency on environmentally driven recruitment demands a close coordination between the management authority, resource users, monitoring service (research institution) and the enforcement branch (maritime police). The basic premise of management as stated above, is to ensure that administrative and organizational capabilities among the stakeholders may are efficient enough to follow up the resource dynamic, where fisher's representatives may play a fundamental role.

Table 5.3. Strengths, weaknesses, opportunities and threats of the 7 management measures proposed for the octopus trap fishery in the Algarve region, south Portugal. (part 1)

Measure	Strengths	Weakness	Opportunities	Threats
Closed Season (CS)	• Protection of key life-cycle stages: mating, spawning, recruitment. • Increased average body weight due to fast growth of octopus. • Non-baited pots left during the closure work as shelters for brooding females.	• Strong impact of environmental variability on the octopus life cycle timing that a ect the e ectiveness of a fixed CS. • May lead to higher seasonal unemployment rates.	• Storage of frozen octopus during the beginning of the opening season (catch boost). • Temporal licenses could be issued for other species to provide alternatives to octopus fishers. • Bringing fishing gears inshore during closures may help enforcement of fishing gear restrictions (e.g. maximum number of traps).	• Limitation of artificial food supply (bait) to the ecosystem during the closure • Leads to maximizing of fishing e ort right after the closure, provoking price crash. • illegal fishing during closure.
Fishing Schedule or Weekends stops (TS)	• Allow better control of the fishing fleet (safety, security, law enforcement). • Reduce catch theft among fishers.	• Due to high number of fishing gears, it may not be feasible to put all the traps on land during the weekend stops (not real stop, gears continue fishing). • Schedules at regional / national level may not be suitable due to harbor-specific features (e.g. sandbars/ coastal lagoons channels depending on tidal regime). • Small harbors in the region already have schedule according to local constraint. • Fishing dynamics of every fishing ground and weather conditions dictate schedules	• Increase average first sale value: octopus catches during weekends are classified in the low freshness category (lower prices) since they are stored until Monday. • Allow fisherman to have free time during the weekend. • Weather conditions and local dynamics of many local harbors (like sandbars inlets, coastal lagoons, tides regimes, etc) are driving the fishing time schedule by themselves	• Illegal fishing can occur during 'non fishing time' when the boats are in the harbour. • Economic losses due to loss of 'windows of opportunity' of good weather conditions for fishing. • Reduction of potential fishing days.

Table 5.3. Continuation (part 2)

Measure	Strengths	Weakness	Opportunities	Threats
Maximum Allowable Number of Traps or Gears (MAN)	• Fishers recognize the excess of e ort as one of the main problems a ecting this activity. • Large numbers of traps = large numbers of lost traps that may represent a direct source of pollution and result in ghost fishing.	• Control of number of traps has been considered ine cient by the current legislation due to constraints on enforcement (e.g. enforcement costs).	• Development of an identification plate system that may be an e ective method of controlling the number of traps 'on land'. • The high number of baited traps with small pelagic fishes is believed to work as a food subsidy for the octopus population, where landings have shown an increasing trend during the last 20 years	• High numbers of traps represent longer fishing time on-board, with health problems associated with long working hours in hard conditions.
Bait Selection -live (BS)	• Live bait may reduce fishing trips as there is no need for daily re-baiting, reducing fishing costs. • Live bait is considered more hygienic for handling on-board.	• Lack of agreement among fishers. • Conflicting subject. • Lack of compliance regarding the live bait prohibition.	• The dialogue established in Phase three might promote cooperation. • Assessment of the ecological impact of live bait can shed some light to support management.	• Demand for large amounts of non-native live bait may impact the ecosystem. • Demand for large amounts of live bait may induce over-exploitation of native species. • Live bait may allow deployment of traps for longer periods of time inducing to overpass the limit.

Table 5.3. Continuation (part 3)

Measure	Strengths	Weakness	Opportunities	Threats
Bait Selection -dead (BS)	• Dead brined bait is cheap and highly abundant in the region. • Is believed to be more attractive than live bait.	• Dead brined bait requires lifting of trap daily for re-baiting. • Lack of agreement among fishers.	• Alternative way to control fishing e ort (trap numbers). • Assessment of the impact of dead bait in the marine ecosystem can shed some light to support management. • The dialogue established in Phase three might promote cooperation.	• Cost-e ciency relationship of the fishing operation due large bait investment is provoking the decline of small boats (< 9m).
Minimum allowable distance from the coastline (MADC)	• Enhance mating success by protection of essential habitats such as spawning grounds and nurseries, among others (e.g. reefs, jetties, coastal lagoons, etc).	• Scarce knowledge of the sea floor and habitats (mostly for leeward Algarve)	• There is strong local knowledge based on fishing experience and years of navigation from local fishers that can be systematically included in detailed mapping of the fishing grounds. • Together with essential habitats, biological information can become a powerful tool for management.	• Scarcity of protected sites for octopus spawning. • Banning certain types of fishing gear from areas, where other fishing gear or practices operate may induce over-deployment of more threatening gear: e.g. using shelter traps (pots) in shallow-waters during the brooding season may increase brooding females mortality.

Table 5.3. Continuation (part 4)

Measure	Strengths	Weakness	Opportunities	Threats
Maximum Allowable Catch (MAC)	• Monitoring and controlling landings in the harbor migh be more cost/ e ective then patrol in the sea. • Fair distribution of the harvest among fishers according to boat size and crew number. • Bio-economic models among others can support the MAC estimation based on optimal harvesting theories and octopus population dynamics.	• Geographically isolated harbors may result in weak compliance levels. • Unpopular measure due to direct limitation of the catch, provoking considerable resistance among fishers. • Loss of profit at times of high abundance due to small window of opportunity in octopus life-cycle. • Problems associated with accurate estimations of the quota (uncertainty).	• Excess in MAC landing could be easily avoided by stopping fishing during the operation at the sea. • Daily quota are supposed to works as a price stabilizer by limiting supply. • Alternative strategy to control number of traps. • To supply markets with high demands, fishers may need to associate/ cooperate to achieve larger volumes.	• High demand for the resource within a limited supply could drive fishers to commit illegal practices due to attractive prices. • Wrong estimations may lead to overfishing.
Minimum Landing Weight (MLW)	• An increase in the average size/ body weight of the fished population is expected to increase fishing yields assuming low natural mortality rates. • May ensure an increase of the spawning biomass.	• Current MLW does not correspond to the size commonly referred to by fisheries biologists as L50. • Requires strict control at harbors due fresh water enrichment (octopus gain weight).	• Improve revenues at first sale by increasing average weight of the landed individuals (larger octopus command higher prices). • Current MLW does not correspond to the size commonly referred to by fisheries biologists as L50: if increased might improve reproduction rates.	• Increasing MLW may lead to increase illegal operations.

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Chapter 6.
General discussion

6.1. Fishery dynamics, life cycle and environment

The increasing importance of the octopus fishery in Portugal, especially in the Algarve with the country's largest fleet using pots and traps, demands a deep understanding of the resource ecology in a high fishing pressure environment. Many cephalopod species, including octopuses, may be better suited as targets for fisheries exploitation than finfishes and other harvested marine groups (Jereb et al., 2014). The short life cycle, rapid growth and high fecundity of *Octopus vulgaris* lead to a rapid turnover of the population (1-2 years), speeding the recovery from high fishing pressures (Guerra et al., 2010). Thus, sustainable management of octopus fisheries may benefit strongly from this ecological perspective, where the interaction of life cycle seasonality and fishing is the cornerstone in population assessment attempts.

The octopus life cycle characteristics that are considered critical to support fisheries can be divided in two main groups according to their impacts on the population dynamic: (1) those mainly driven by environmental factors affecting the reproductive output (recruitment); and (2) growth and development of the juveniles, where food availability and natural predation are considered significant factors (Jereb et al., 2014). The latter have been indicated in overexploited finfish stocks as an advantage for *O.vulgaris*, as they can occupy vacated niches and flourish under 'predation release' where natural predators have been removed by fisheries (Caddy and Rodhouse, 1998). The ecosystem perturbations caused by intensive fishing generally are leading to changes in the trophic structure in favour of the short-living opportunistic species (Boyle and Rodhouse, 2005). Thus, the key challenge to successful management is the understanding of the role of octopuses in exploited communities and ecosystems, particularly with respect to the trophic interactions, and the fact that many species increase due to a decline of key predators, hence thriving in the disturbed environments (Pierce and Guerra, 1994).

6.1.1. Effects of pot and trap fishing

Understanding the effects of trap and pot fishing on the octopus populations should include a deep review of fishing operations and its interactions with the ecosystem. The Algarve region maintains the largest fishing fleet for *O. vulgaris* in the country, accounting for 634 boats in 2014 (DGRM, 2014). Under the assumption that each boat uses the maximum number of traps allowed by the national legislation, around 431,750 traps are placed daily in the fishing ground area (not including non-baited pots). Moreover, if each trap unit is baited with a single fish (mean weight = 95 g) (Pereira, J., personal communication, 2015), mostly Atlantic chub mackerel (*Scomber colias*), around 39 tons of fish are used in a single day of fishing in the Algarve region. However this value is believed to be an underestimate, as many fishermen from the area admitted at least to double this maximum number of traps by boat. In spite of the lack of precision of the estimates, it is certain that large quantities of Atlantic chub mackerel are used as bait in the octopus fishery in the region. Thus, the effects of large quantities of baited traps and daily re-baiting discards (bait residuals thrown into the sea) on the ecosystem remain unknown.

Some studies have been suggesting that discards of dead material have been subsidizing benthic cephalopod populations, favoring its fisheries (Balguerías et al., 2000). Torres et al. (2013) in a study of the fishing impacts on the Gulf of Cadiz ecosystem, analyzed the food web structure, showing the important role of detritus on demersal resources, where strong bentho-pelagic relationships were described. Moreover, an important fraction of this detritus was composed of discards, mostly Atlantic mackerel, suggesting there is a high impact of trawling and purse seine fisheries on the Gulf of Cadiz food web. Due to its proximity to the previously studied area (Torres et al., 2013) Algarve fishing grounds are expected to exhibit similar trophic dynamics, where fisheries may have significant impacts on the marine life, highlighting the importance of the ecosystem approach for fisheries management.

From an ecological perspective, the existence of high number of baited traps in the region, instead of representing a threat to the octopus population through fisheries caused biomass removal, might work as a 'food subsidizer' supporting bigger population biomass, and increasing yields over time. For example, in the American lobster fishery of the Gulf of Maine (northeast United States) large quantities of *Clupea harengus* used as bait have been related to Landing per Unit Effort (LPUE) increases (Saila et al., 2002). Much closer, in the Sahara bank fishing grounds (north-west Africa), increasing octopus catches have been related to bottom trawling discards, which may contribute as an artificial food source for the octopus population (Balguerías et al., 2002).

Another octopus fishery to consider in the analysis of the impact of bait choice on the ecosystem is in the northwest Iberian Peninsula the Galician fleet using traps. This fishery has been described as very similar to the Portuguese one (Freire and García-Allut, 2000). It was composed of 710 active boats during the fishing season 2013-2014 (Guerra et al., 2015) compared with 634 for the Algarve counterpart (DGRM, 2014). In spite of their similarities in boat numbers and fishing gear characteristics, landings in both areas have been displaying different trends. Galician fishery shows an average in landings around 5,000 tones/year during the last 20 years (Guerra et al., 2015, FAO, 2014, Otero et al., 2005;) with a decline of approximately 50% in recent years from 4,205 tons in 2010 to 2,586 tons in 2014(Guerra et al., 2015). The Algarve fishery exhibits an average of 2,539 tons/year since 1990 to 2014, where the first half of the series recorded an average landings around 2,145 tons/year (1990-2002) and the second half (2003-2014) 2,965 tons/year respectively, showing slight increase (Sonderblohm et al., 2014). Although the differences are likely related to the fact that those are different stocks under the natural fluctuations driven by oceanographic conditions, the number of traps by boat and type of bait might play a significant factor affecting both trends.

In order to understand the difference between the two fisheries it is necessary to define details of the fishing gear in both areas. The fishery in Galicia is regulated by a detailed management plan (Resolución do 30 de maio, 2014) controlling the number of traps per vessel to between 200 to 800 units according to boat size and crew members (2014). At the same time, the maximum number of traps allowed in Algarve has been set between 750 to 1,250 units (Portaria 230, 2012), but the fishermen admitted real numbers to be at least twice the allowed. Considering this, a much higher density of traps is expected in the Portuguese fishing grounds of the Algarve. Curiously, since 2009 Galician fishermen have switched from the traditional bait (Sardine or Atlantic mackerel) to an artificial bait called 'membrillo' which is a jelly-like compound made out of a by-catch mix (Peiro, 2014). This new bait lasts longer in water without the need of daily re-baiting. Thus, a reduction on bait discards is expected and might therefore be reasonable to consider that bait leftover from pelagic fishes discarded into the ecosystem may work as a food subsidizer, where the trophic ecology of the benthic communities may largely depend upon this food supply.

Besides the impact of the bait discarded into the ecosystem, other aspects of the fishing gear can be identified. For example, for the Algarve region more than 50 thousand octopus traps are estimated to be lost every year (Erzini, 2007). In the nearby octopus fisheries of the Gulf of

Cadiz, Sobrino et al. (2011) have estimated pots losses around 9,000 units per month, resulting in 108,000 traps lost per year. Despite the marine pollution and the effects of ghost fishing, the reported large quantities of trap lost in Algarve and Cadiz might also work as a refuge for benthic organisms to avoid predation, where the brooding octopus females could find a place to lay their eggs. The seabed of the continental shelf of leeward Algarve and the western area of the Gulf of Cadiz (Huelva coast) presents large areas of sand, mud and gravel bottoms (Gonçalves et al., 2008; Torres et al., 2013) where the lost traps might be working as the artificial structures used by octopus, probably increasing shelter availability in an ecosystem otherwise dominated by soft bottoms.

Pots and traps for octopus have been considered very low impact fishing gears due to a very low by-catch rates and negligible environmental disturbance (Baeta et al., 2009). In spite of low concern about the fishing gear due to the low by-catch and passive fishing method, marine and coastal pollution should be considered in assessment of the impact on the ecosystem. The large amounts of lost pots and traps are believed to have profound pollution effects even in places very distant from the fishing grounds. Surprisingly, a newspaper article published in 2013 reported the finding of non-native octopus pots on the shores of the Cayman Islands (Connolly, 2013). The markings on the pots are often lettering or words in different languages, including French, Arabic, English and Portuguese, suggesting that these gears found on the Caribbean Sea came from the east coast of the Atlantic Ocean, possibly from fisheries in Morocco, Mauritania, Senegal and Portugal, among others. This example is shedding light on how the ocean currents are distributing a wide variety of marine debris worldwide. Similarly, along the coast of Portugal it is very common after winter storms to find among other fishing gears also large amount of pots and traps stranded on the beaches. The construction material of these fishing gears is commonly PVC plastics and the impact of their long degradation processes on the marine environment is still largely unknown (Andrady, 2011; Romeo et al., 2015)

6.1.2. Environmental factors and recruitment

Besides the anthropogenic factors discussed above and their effects on the octopus populations and the ecosystem, this thesis has explored the environmental factors affecting the reproductive output (recruitment) of *O. vulgaris* in the Algarve, focusing on the leeward area.

The recent free access to large environmental datasets for the region has allowed exploration of the effects of environmental variables on the octopus landings and build the hypotheses. Summarizing, two main octopus life cycles have been suggested: one dominated by the regional hydrology, namely river runoff and rainfall, and a second one related within oceanographic processes (upwelling-relaxation). Moreover, each of these processes is more dominant according to the fishing ground division: leeward is likely to be dominated by regional hydrology while windward seems more driven by the upwelling-relaxation process, where the landings statistics has exhibited different patterns. Likewise, the intensity of these processes may vary between years for the two subregions, resulting in differences in the lifecycles described. These spatial considerations, even at local scale, highlight the importance of the ecosystem approach for management of this fishery.

Models for forecasting recruitment in cephalopod fisheries around Falkland Island have been developed in recent years showing high robustness (Agnew et al., 1998, 2000; Roa-Ureta, 2012). In Europe, the English Channel squid fishery has been accurately predicted using Generalized Linear Models (GLM) including environmental variables (Duhem and Robin, 2014). The use of similar modelling techniques to forecast recruitment of *O. vulgaris* in Algarve can be very useful for support management. Moreover the inclusion of field research to calibrate modelling estimations by measuring benthic recruitment in shallow waters few months before the population reaches its minimum fishing size (>750 g), may result in highly accurate predictions.

In addition, recent studies have indicated high site fidelity of adult octopus to specific substrates, where movements along the seafloor have been limited to less than 1 km (Mereu et al., 2015). These results may support the implementation of Territorial Use Rights for Fishing (TURF) where allocating secure and exclusive privileges for fishing in a specified area to fishermen groups guarantees that the available biomass is not been fished out by competitors outside the area. Simultaneously, higher density of spawning dens has been associated to specific substrates, indicating restricted spawning areas (Guerra et al., 2015). According to these studies, identification of the spawning areas and their protection may ensure a source of para-larvae and juveniles to sustain commercial fisheries.

6.2. Fishery Management and stakeholder involvement

The studies of different management schemes implemented in several pot and trap fisheries of *O. vulgaris* in Europe match a main common goal: regulation of fishing effort (references). Paradoxically, measures based on fishing effort, rather than catch or fishing mortality, present the main weakness as any improvement in gear efficiency will cause increase in effective effort even though apparent effort remains the same. For the Algarve region, recent struggles due to the prohibition of a certain type of bait has brought to attention the main problem identified during the work of this thesis: excess of fishing gear. The estimation of number of traps in the region together with recent reports of gear losses and the consequences of it show the importance of analyzing the impact of this fishing gear on the octopus population and the ecosystem. More field research with novel techniques, e.g. video recording, is needed, including tagging and in situ observations, which could provide insight necessary for better assessment of the fishing gear impacts.

6.2.1. Fishing closure

During the last phase of this thesis work (2014-2015), fishermen from the Algarve region have proposed a closure for *O. vulgaris* trap's fishing to protect reproduction and recruitment, where a document has been submitted to national authorities. Several concerns arose from this proposal regarding the multiple dimensions of fishery management. Among them, the time definition of the closure according to species life cycle has been discussed where fishermen have asked the scientific community to provide science-based information to choose the season of closure. However, despite the life cycle analyses and species reproductive biology described in the previous chapters, it is very necessary to set measurable goals of this management regulation in order to assess the results, where stakeholders must have a clear idea about the objectives, implementation and evaluation of detailed outputs in order to adjust or change this management measure along the management route. The lack of common reference points across the different octopus fisheries in Europe and in the world has been identified as a common failure (Peiro, 2014).

Previously, a closure was already implemented in the Algarve region during summer 2005 by the publication of an ordinance (Portaria 635, 2005). This regulation was implemented after several fishermen called for protection during the reproduction season, because of the marked drop in landings during summer months has provoked confrontations among stakeholders. However, this closure was considered ineffective and withdrawn from the Portuguese legislation after few months (Portaria 840, 2005). Lessons learnt from this experience highlight the importance of the definition of detailed reference points to measure the expected results in order to develop a results based management.

In the broader picture of this bottom-up management process, it is important to highlight that unsuccessful attempts to improve management and promote fishermen participation may lead to big disappointments and lack of trust. This is the case of the Iberian sardine management plan adopted for this region since 2012 – 2015 (DGRM, 2012), where problems related with bad recruitment in recent years has lead scientific advice to reduce catch quotas, resulting in strong disagreement within the fisheries sector (Costa, 2015). In this human dimension of the fishery management, it is necessary to develop a common plan, where goals, implementation, enforcement and evaluation of each management regulation is clearly explained, in order to assess their performance. This assessment may become a periodic exercise, where stakeholders must be involved through the identification of reference points in order to measure and adjust the plan according to the current scenario. This is highly important in the case of a natural resource such as *O. vulgaris*, where its short life cycle and large landings fluctuations result in rapidly changing dynamics, and management decisions must follow up this species cycle and ecosystem interactions.

Recent assessments on spatial closures for octopus have been made for some small scale fisheries in Madagascar (Benbow et al., 2014; Oliver et al., 2015). These authors suggest that periodic harvest or pulse fishing schemes in small specific areas instead of large seasonal closures may have positive results. However, these analyses have identified the most important factors for the success of this management measure as strong leadership that people trusted, and high levels of social capital to guarantee compliance. Regardless the scientific knowledge about the resource, levels of trust between users and public institutions are key elements for the implementation of any management measure in fisheries, where common property institutions play a major role.

6.2.2. Common challenges in co-management

Public perceptions of the concepts of co-management and sustainability among the octopus fishermen, researchers and authorities are very different. For instance, a marine researcher may identify a fishing closure to be a management goal, to protect the spawning stock, guarantee presence of para-larvae that may have better chances to survive and recruit after a while, keeping the population numbers above a certain level. In this approach, variables which control the number of spawning females are selected, such as fishing effort controls across an area or season, with the aim to protect spawning ground and season (temporal closure). But even though the idea of protecting the spawning is shared between fishermen, authorities and researchers, all of them may have different motivation. A fishermen will seek to maximize his catch in relation to competition and recover his daily investment in bait and fuel, where the sustainability of the operations depends on the quantity and price of the resource. In this scenario, where the access to the fishing ground among fishermen is open, there is no guarantee that the octopus not fished today will be available for fishing tomorrow, resembling a typical tragedy of the commons scenario (Hardin, 1968). Under this competition pressure, fishermen may improve their capacity and efficiency, using longer longlines with more traps, where protection of the spawning females is no longer a priority.

On the other hand, management authorities are in charge of a wide list of administrative duties, where the management of the octopus fishery in the Algarve is just one of the fisheries in the Portuguese coast. In addition, the management structure is based far away from the activity, where the protection of the spawning ground and season is understood to be a common tool in the management area and well received to meet precautionary approaches, but managers are not familiar with the daily fishing activities and the ecosystem where the fishery takes place. Hence, though the goal of the closure is well understood, its implementation is a major challenge, where lack of compliance and trust within the fishermen and poor enforcement capacity are authorities' concern for achieving sustainability. In this way, the current management structure must be reviewed, where management goals, basic concepts and models need to be rethought among stakeholders.

Lately, examples of co-management of demersal resources have been increasing in the scientific literature (Jentoft, 1989; Berkes, 2009; Linke and Bruckmeier, 2015). Moreover, octopus trap fisheries across Europe are largely similar (Pierce et al., 2010). The common challenges shared between the European fisheries and their counterparts in other seas around the world may help to re-build concepts of sustainability and co-management for this activity, where stakeholder's involvement is a key factor for the development of new approaches. This structural changes in management process for small scale fisheries have arisen in significant number from sites in Africa (Watanuki, 2008), America (Begossi and Brown, 2003) and the Pacific region (King and Lambeth, 2000), among others.

The region of Algarve has a very dynamic interaction between management authorities and fishermen representatives during the last 20 years (Pereira, 1999). Several demands from the fishermen have been submitted, normally after marked drops in the resource abundance. These demands have resulted in several consultation processes regarding specific situations, where authorities have called in the expert advisors resulting either in modification of existing policies or the publication of new ordinances, most of them focusing on fishing effort controls on short term. These governance processes have been recently review by (Pita et al., 2015), where lack of trust and little cooperation among fishermen has been identified as the major weak point of the sector.

6.3. Future remarks

The current scenario of the octopus fisheries in the Algarve region demands new approaches, where multiple dimensions of fishery management must be integrated. The cooperation of scientists from different disciplines, resource users and managers may create good conditions for the development of novel approaches, where responsibility for management is shared between the state and user groups, an approach which has been suggested as a feasible strategy towards sustainability in fishery resources. A good starting point for the development of a framework to support the management of the octopus fisheries in the Algarve may include at first hand a close cooperation between the fishing sector and applied scientific research to promote fishing sustainability. During the participatory meetings held in the last phase of this thesis, fishermen have expressed their willingness to collaborate with scientists to better understand octopus life cycle in the Algarve. This cooperation between researchers and fishermen can be considered a kick-off of novel approaches to develop fishing plans in order to improve both fishing yields and profits, as well as ecological sustainability of this important fishery.

Considering the above mentioned idea, we set out the first steps towards the development of a co-management strategy for the *O. vulgaris* fishery in the Algarve region, Portugal. The last part of the present work provides an overview of the main management regulations discussed between experts on octopus fishery research, the research team, fishermen and management authorities. By presenting these analyses we aim to contribute to the establishment of the groundwork for the future development of a co-management plan. Further, the results reported herein can be a useful reference shared and compared among other small-scale cephalopod fisheries facing similar challenges, where moving towards a co-management process seems a valid alternative for achieving the sustainable use of marine resources.

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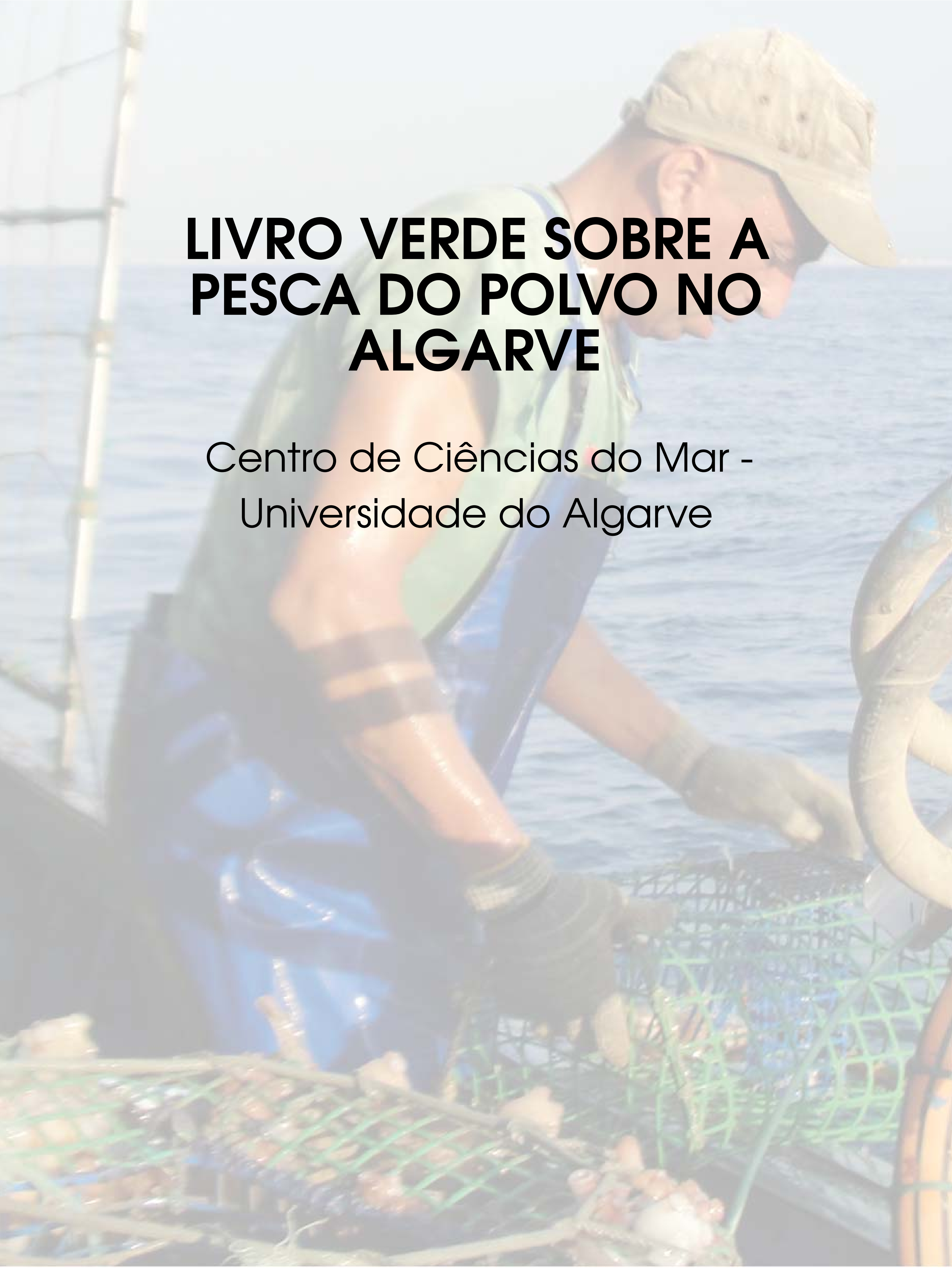
Annex I

Green Paper of The Octopus Fishing in Algarve



LIVRO VERDE SOBRE A PESCA DO POLVO NO ALGARVE

Centro de Ciências do Mar - Universidade do Algarve

Projecto Tertúlias do Polvo 2015, Universidade do Algarve

Campus Gambelas
24 Abril 2015

CONTEÚDO

GLOSSÁRIO

Alcatruz: pote de barro ou plástico de várias formas utilizado como armadilha para captura de polvos. Na legislação portuguesa o nome atribuído é armadilha de abrigo.

Cadeia trófica: (ou cadeia alimentar), é uma sequência de organismos interligados por relações de alimentação.

Captura acessória: captura acidental de espécies que não são alvo da pescaria ou que não satisfazem certos critérios.

Cefalópode: é uma palavra de origem grega composta por *kephale*, que significa "cabeça" e *pode*, que significa "pé". Designa uma classe de moluscos da qual fazem parte o polvo, o choco e a lula.

Covos: nome dado às armadilhas de malha de plástico para capturar polvo, entre outras espécies (e.g. crustáceos) mediante o uso de isco. Na legislação portuguesa são denominados como armadilhas de gaiola. Um conjunto de covos é denominado *teia*.

Eclosão: corresponde à saída de um organismo de dentro do ovo uma vez completado o seu desenvolvimento.

Esforço de pesca: quantidade de pesca exercida sobre um recurso. O *esforço de pesca* é diferente para cada pescaria e depende do tipo de artes de pesca utilizadas e do nível tecnológico das operações. Na pesca do polvo, o *esforço de pesca* pode ser medido em número de barcos a pescar por dia, número de horas a pescar por maré, número de armadilhas a utilizar durante cada saída ao mar, entre outros.

Espécie oportunista: refere-se aos primeiros indivíduos capazes de colonizar ambientes perturbados, normalmente com elevada capacidade reprodutiva, crescimento rápido, e altas taxas de substituição (*recrutamento* e mortalidade). O polvo comum, *Octopus vulgaris,* é considerado pelos especialistas como uma espécie oportunista.

Espécie-alvo: espécie que se pretende capturar com determinada arte de pesca. No caso das pescas com armadilhas no Algarve, o polvo representa a espécie-alvo mais comum.

Frescura tipo II*:* é uma escala de classificação utilizada pela Docapesca para identificar o polvo transaccionado em lota após 24 horas de captura. Este tipo é comum ser pescado durante o fim-de-semana para venda no leilão na segunda-feira seguinte.

W_{50}: corresponde a um índice utilizado em biologia pesqueira que indica o peso médio ao qual 50% da população já atingiu a maturação sexual. Na gestão pesqueira este parâmetro é utilizado para definir o tamanho mínimo de captura (ou peso no caso do polvo) para assegurar que pelo menos 50% da população está em condições de se reproduzir.

Licenças territoriais de pesca: são autorizações para pescar numa área específica, fornecida de forma exclusiva a grupos organizados de pescadores, como associações ou cooperativas.

Medidas de gestão: corresponde a um sistema de regras com base em objectivos definidos num plano de gestão. No caso das pescas, tem como objectivo principal a conservação dos recursos pesqueiros. As medidas de gestão são postas em prática através dum sistema de controlo e vigilância (*sistema de fiscalização*).

Mn (milha náutica): é a unidade de medição marítima, equivalente a 1852 metros.

Mortalidade natural: frequentemente representada por M, num *stock* explorado pelas pescas, é aquela causada por qualquer outro factor que não seja a pesca, como por exemplo: predação, canibalismo, doença, etc.

Octopus vulgaris: é a espécie de polvo mais comum na costa portuguesa e existe praticamente ao longo de toda a sua extensão, desde a zona intertidal (zonas rochosas entre-marés) até profundidades superiores a 150m.

Paralarvas plantónicas: são jovens *cefalópodes* imediatamente após a desova e antes do seu assentamento no fundo marinho. O choco e algumas outras espécies de polvo eclodem já como juvenil – não têm paralarva. Durante esta etapa, que no caso do polvo dura cerca de 2 meses, as paralarvas habitam a coluna de água. O termo paralarva reflecte o facto de se tratar de uma larva que se parece à forma adulta da espécie. São transportadas pelas correntes marinhas mas também nadam activamente.

Plano de gestão: é um acordo formal ou informal entre uma entidade de gestão das pescas, os pescadores e outras partes interessadas, onde se especificam as regras que se aplicam ao recurso a gerir, conforme os objectivos de gestão. No plano de gestão definem-se também os prazos e responsabilidades de cada parceiro e os métodos de avaliação destes objectivos.

Pontos de referência biológica: são indicadores que visam a conservação dos recursos. O objectivo é definir limites para as pescas para garantir a auto-manutenção do stock.

Pontos óptimos de captura: correspondem a pontos óptimos teóricos, onde a maioria da população a pescar já atingiu o seu máximo peso, maximizando assim o rendimento das pescas.

Recrutamento: refere-se à entrada de novos indivíduos numa população ou na pesca (recrutamento à população ou à pesca). No caso do polvo, o termo refere-se mais vulgarmente ao assentamento da *paralarvas* no fundo marinho (recrutamento à população), onde cresce até ao peso mínimo de captura (750gr – altura em que recruta à pesca).

Rejeições: são os organismos marinhos pescados que se devolvem ao mar durante a actividade de pesca, devido ao seu baixo valor comercial, peso abaixo do mínimo permitido, regulamentações de excesso de quotas, entre outros factores.

Rendimento máximo sustentável (RMS –* ou *MSY): corresponde a uma abordagem de gestão das populações a longo prazo que consiste em fixar taxas de captura. O respeito destas taxas permite manter uma determinada população com uma taxa de crescimento máximo e assim possibilitar que a produtividade seja o máximo possível. Este conceito é utilizado frequentemente para estabelecer quotas de pesca na Europa, como no caso do bacalhau, atum, verdinho, entre outros. Os especialistas referem que este cálculo não é apropriado para espécies como o polvo, sendo utilizado com mais frequência para espécies de peixes.

Sistema de fiscalização: é o sistema de verificação da aplicação das normas jurídicas que regulamentam as pescarias num país ou região. O controlo pode ser exercido directamente pela autoridade, através de fiscais.

Stock: (ou manancial), é um subconjunto duma espécie com parâmetros de crescimento e mortalidade semelhantes, e que habita uma área geográfica particular. No caso do polvo na região de Algarve, considera-se a existência de dois stocks: costa oeste e costa sul. É a unidade base de gestão de recursos vivos.

Teia: Conjunto de c*ovos* ou *alcatruz*es.

Total admissível de captura (TAC): corresponde ao limite em peso ou número de uma determinada espécie que pode ser capturada num período de tempo (habitualmente um ano civil) consoante uma estratégia de gestão estabelecida. Divide-se em quotas que são atribuídas a uma área definida ou a um grupo de pescadores. O seu cálculo baseia-se normalmente no conceito de RMS (MSY).

1. OBJECTIVO

Ao longo de um ano (2014-2015) o CCMAR promoveu reuniões mensais que juntaram na mesma mesa os diversos intervenientes da pesca do polvo no Algarve, pescadores e respectivas associações, instituições governamentais, investigadores, entre outros. Nestas reuniões designadas "Tertúlias do Polvo" foram discutidas conjuntamente uma série de *medidas de gestão* para a pesca deste *cefalópode*, incluindo estratégias de implementação.

Com base nos resultados obtidos ao longo das Tertúlia do Polvo, o CCMAR propõe o presente documento com o intuito de contribuir para a gestão do polvo no Algarve. O documento foi designado de Livro Verde e apresenta informação científica relevante para a tomada de decisão relativamente às medidas de gestão, tal como expõe a opinião dos investigadores envolvidos nestas reuniões. Esta análise baseia-se no conhecimento científico disponível e identifica os pontos em que a informação existente não é suficiente para se alcançar uma conclusão. Desta forma, este documento visa ser um instrumento de apoio aos pescadores e autoridades para um futuro *plano de gestão*. O conceito do Livro Verde é a criação de um documento, sem nenhum compromisso de acção, que apresenta a perspectiva de um conjunto de indivíduos em instituições interessados em contribuir com informação e opiniões sobre um determinado assunto. Para além de identificar uma determinada posição sobre o assunto, o Livro Verde pretende suscitar a discussão de todas as partes interessadas. Não é um documento fechado e pode em qualquer altura incluir novos contributos.

Na gestão das pescas, a definição das metas e o planeamento são passos fundamentais para avaliar a precisão dos resultados de qualquer medida sobre o recurso e o seu ecossistema. Este processo deve ser entendido como uma aprendizagem permanente das estratégias implementadas, principalmente quando consideramos um recurso como polvo comum (*Octopus vulgaris*), com um ciclo de vida curto, crescimento rápido e uma elevadíssima variabilidade natural como resultado das variações ambientais e da forte pressão pesqueira. Estas características obrigam-nos a analisar cuidadosamente as estratégias existentes e as alternativas para a gestão deste recurso pesqueiro de grande importância para a região.

2. CARACTERIZAÇÃO DO RECURSO E SUAS IMPLICAÇÕES NA GESTÃO

2.1 Características biológicas do polvo

O polvo comum (*Octopus vulgaris*) apresenta posturas muito numerosas (na ordem dos 500 mil ovos por fêmea), sendo um reprodutor terminal, já que as fêmeas e os machos morrem após a reprodução.

Mediante o ciclo de vida do polvo verifica-se que, após o nascimento dos ovos (*eclosão*) se dá uma fase de *paralarva planctónica*, que dura aproximadamente 2 meses (1). Durante este período os indivíduos são transportados pelas massas de água sofrendo elevadas taxas de mortalidade até ao assentamento no fundo (2). Após este assentamento (*recrutamento à população*) o crescimento é extremamente rápido, estimando-se que o peso aumente cerca de 5% por dia (3). A longevidade desta espécie é curta, entre os 9 e os 18 meses de vida, dependendo da temperatura da água. Temperaturas mais altas aceleram o metabolismo e encurtam o tempo de desenvolvimento (4). A distribuição do polvo no fundo apresenta um padrão de segregação por classes de tamanho e profundidade. Os indivíduos maiores localizam-se em águas mais profundas até os 200m (limite da plataforma continental) a partir deste ponto a abundância reduz-se drasticamente (5). Embora o polvo seja descrito como um organismo territorial e sedentário, têm sido registados padrões migratórios para águas pouco profundas durante o acasalamento e posturas, ainda que não exista, até agora, qualquer referência científica relativa a estes movimentos no Algarve.

A abundância de juvenis e adultos submetidos às pescas é regulada pelo *esforço de pesca* considerada como a maior fonte de mortalidade da espécie. (i.e. mortalidade por pesca).

Vários estudos realizados no Algarve indicaram que a época de reprodução se estende desde Maio até Setembro, com um pico máximo entre Agosto e Setembro, altura em que foi identificado um elevado número de fêmeas reprodutoras (6) (Figura 1). Apesar da evidência de sazonalidade no ciclo de reprodução, existem indivíduos maturos durante todo o ano (7). As variações anuais das condições meteorológicas e hidrográficas podem provocar alterações nos tempos de reprodução, desova, *recrutamento*, etc. Entre estas variáveis ambientais, as variações de salinidade, como consequência das chuvas, foram identificadas como o factor mais importante para o sucesso do *recrutamento* da espécie na região, possivelmente afectando a sobrevivência das *paralarvas* (8).

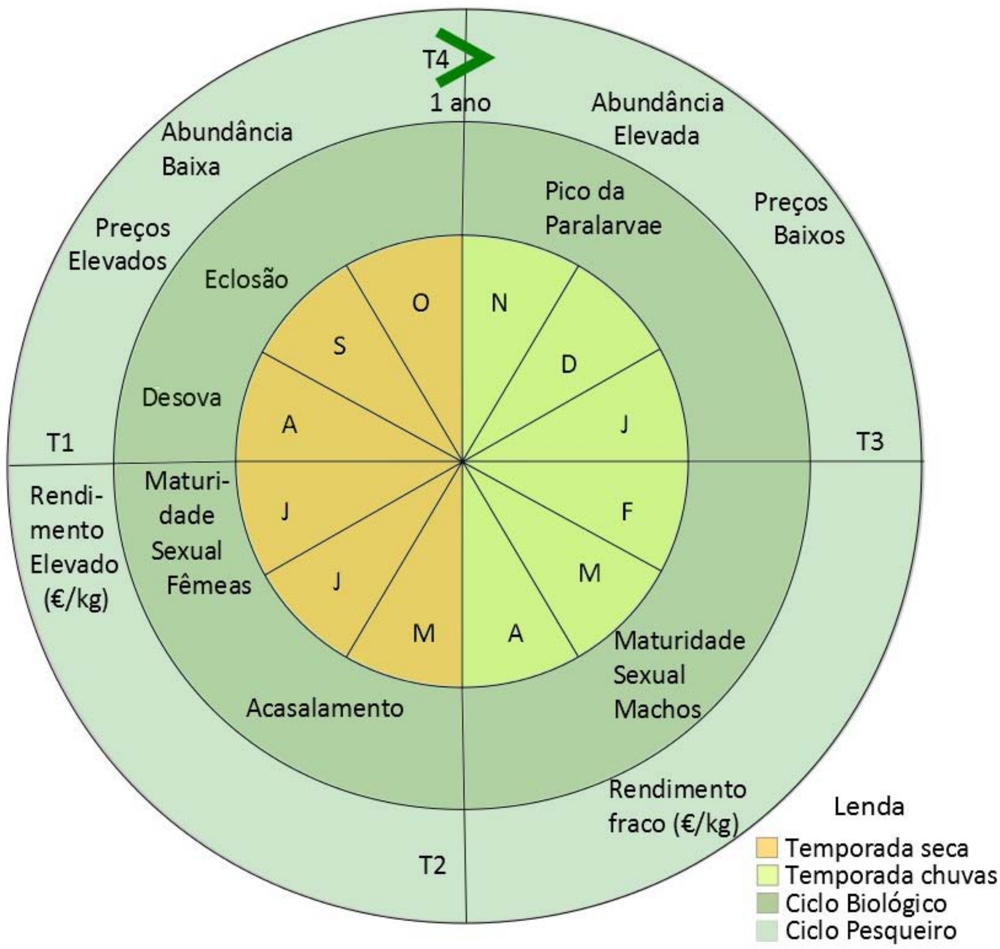


Figura 1. Ciclo de vida do polvo no Algarve baseado em compilação bibliográfica (fonte: 7, 8 e 9). As letras no círculo interior indicam os meses do ano, os códigos T são as classes de tamanho do polvo na escala comercial da Docapesca (T4= 0.75 – 1 Kg; T3 = 1 – 2 Kg; T2 =2 -3 Kg; T1 > 3 Kg). A seta indica a direção do inicio dum ciclo, o círculo mais exterior mostra ao longo do ano a variação da abundância, preço e rendimento. Esta distribuição é uma aproximação à realidade.

2.2 Características dos desembarques no Algarve

Como recurso pesqueiro, o polvo apresenta flutuações naturais de abundância significativas que dependem do *recrutamento* em cada ano. Durante os últimos 20 anos, entre 1990 e 2014, os desembarques de polvo na região têm registado grande variabilidade, com um mínimo mensal de 2 toneladas e um máximo de quase 1000 toneladas (figura 2). Estes dados apresentam alguma sazonalidade, sendo os meses de Verão os que registam médias mais baixas (figura 3).

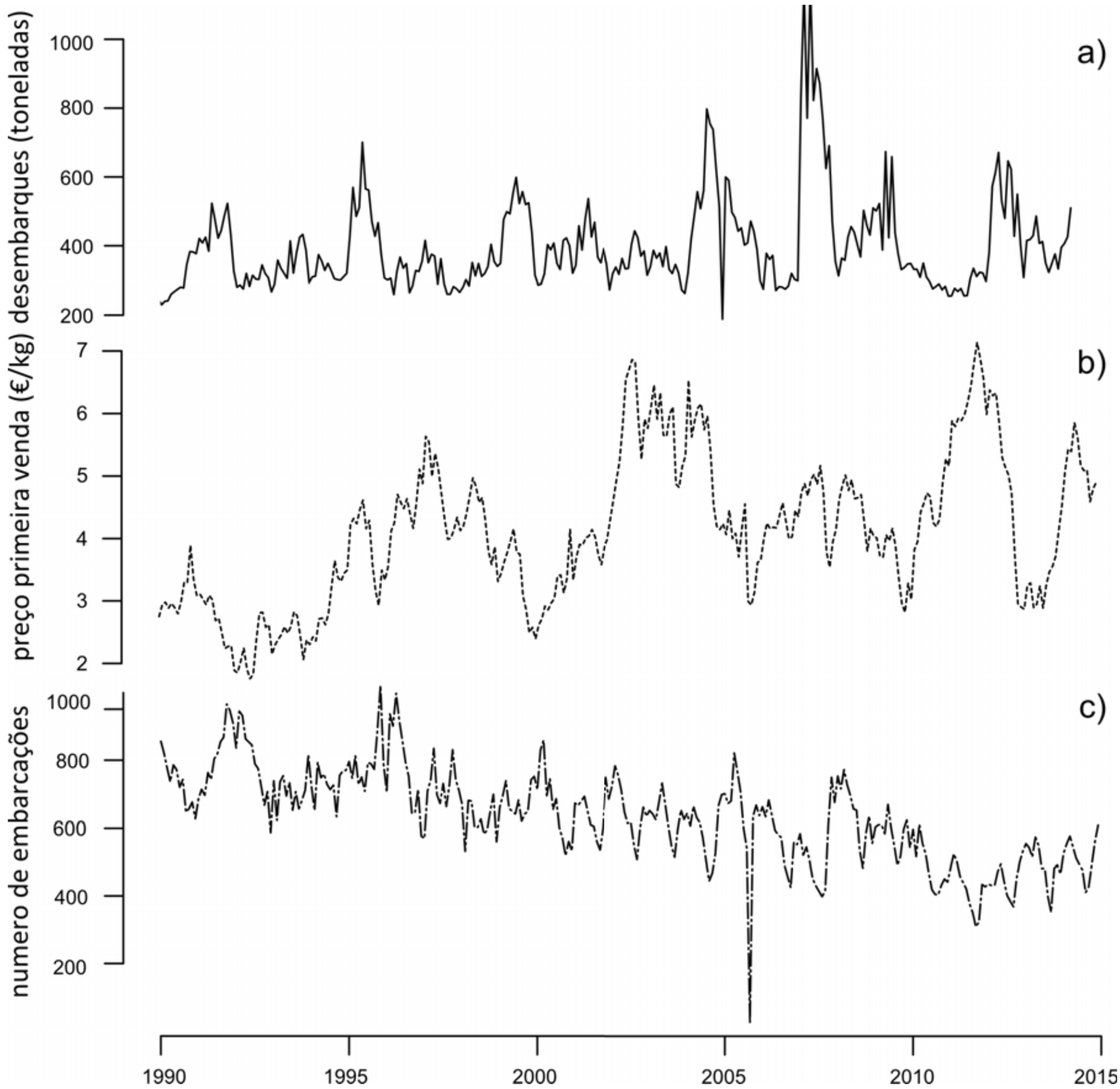


Figura 2. Desembarques em toneladas (a), preço de primeira venda em euros por quilograma (b) e quantidade de embarcações por mês (c) da frota de armadilhas do polvo na região de Algarve durante 1990-2014 (fonte: DGRM).

O número de embarcações a efectuar desembarques em lota também apresenta os valores mais baixos nos meses de Verão, quando o valor da primeira venda atinge a média mais alta (4.12€/kg). Os valores mais baixos de venda em lota são o resultado de maiores desembarques (maior oferta), especialmente nos meses de Inverno e Primavera em que o preço médio é 3.71€/kg.

A biologia pesqueira e a avaliação de recursos pesqueiros são as áreas científicas que se ocupam do estudo dos recursos, da pesca e dos seus efeitos sobre os recursos, com vista a fornecer as bases científicas para a sua gestão. Os métodos de avaliação de populações de recursos pesqueiros existentes trabalham com informação proveniente da captura, esforço de pesca e ou, crescimento e reprodução do recurso. Desta forma, a variabilidade ambiental não é considerada nos actuais métodos de avaliação. No caso do polvo, os factores ambientais apresentam uma elevada influência no seu ciclo de vida e *stock*, como se pode observar pelos dados apresentados na figura 2 e 3. Como tal, os métodos de avaliação de populações mais frequentes não serão adequados para analisar a pesca do polvo.

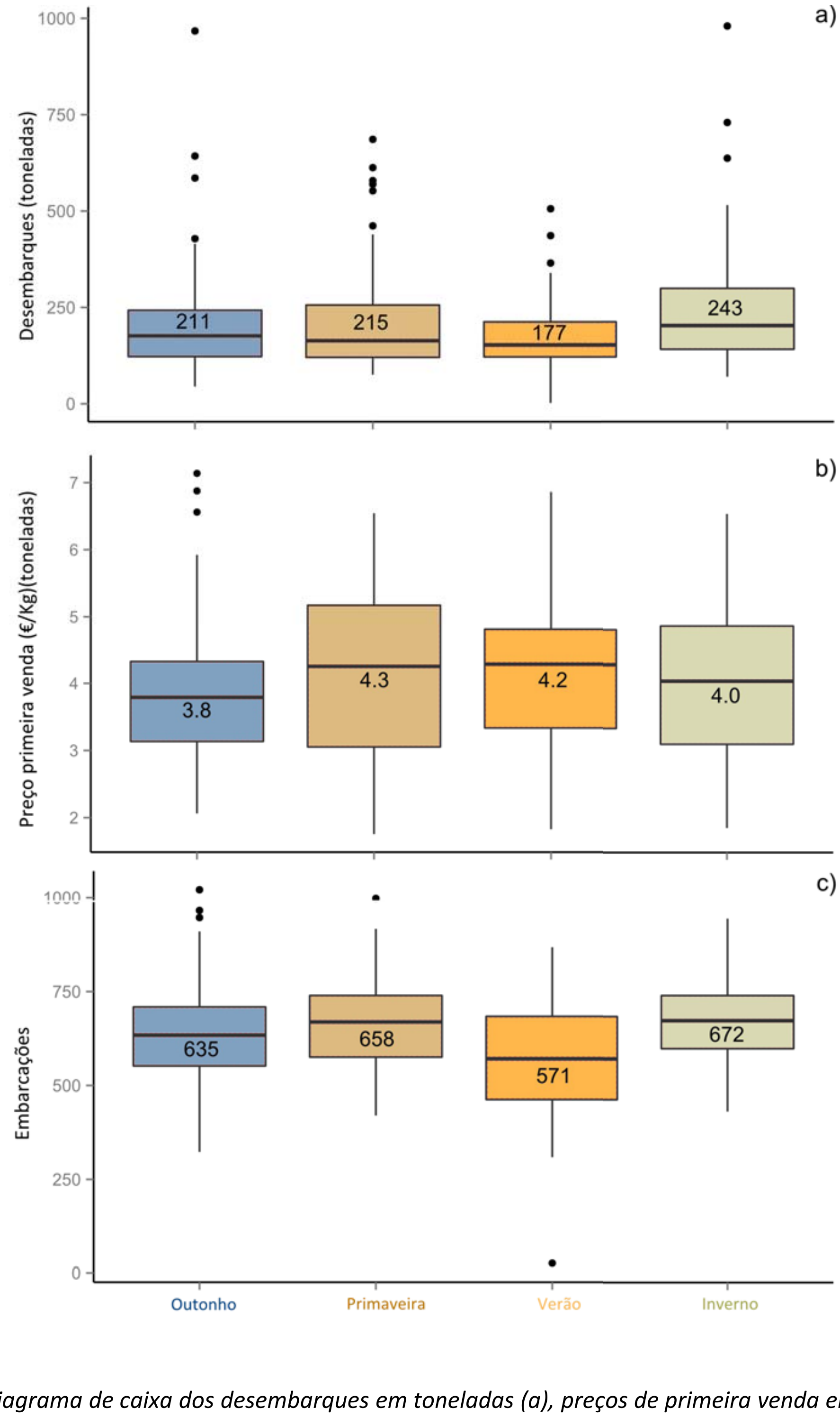


Figura 3. Diagrama de caixa dos desembarques em toneladas (a), preços de primeira venda em euros (b) e número de barcos da pesca do polvo no Algarve (c) durante 1990-2014 agrupados nas quatro estações do ano (Primavera = Abril a Junho; Verão = Julho a Setembro; Outono = Outubro a Dezembro; Inverno = Janeiro a Março). Os valores nas caixas correspondem aos valores médios (fonte: DGRM).

2.3 Enquadramento regulamentar das pescas do polvo

Em Portugal a gestão da pesca do polvo é efectuada com base no controlo do esforço por número de licenças, quantidade e tipologia das artes. Para além disso, a produtividade da população é gerida através do peso mínimo de desembarque. Todas estas medidas têm como objectivo a manutenção da abundância média do recurso. O recurso não é abrangido por *sistema de quotas* ou por regulamentações europeias, sendo que cada estado-membro assume a gestão da sua própria pescaria.

As primeiras *medidas de gestão* nacionais com implicações nesta pescaria surgem em 1973 no âmbito do Regulamento da Pesca Artesanal (Portaria 9/73 de 6 de Janeiro do Ministério da Marinha). Em 1987 foram publicadas mais medidas de gestão através do Decreto-Lei nº47/1987. Este documento apresenta o principal conjunto de leis para a conservação dos recursos biológicos aquáticos em todo o país, assim como o enquadramento das pescas. Posteriormente, a portaria Nº1102D/2000 constitui a primeira regulamentação dirigida à pesca de armadilhas, incluindo explicitamente a pesca do polvo. Desde este regulamento, foram definidas 10 portarias dirigidas à pescaria do polvo (Tabela 1). Estas abrangem diferentes aspectos da actividade, que vão desde condicionalismos ao tipo de artes e embarcações até à proibição do isco vivo, incluindo restrições regionais e medidas experimentais.

O processo de legislação do polvo tem vindo a ser efectuado ao longo dos últimos 15 anos como resultado de diversos encontros entre pescadores, autoridades e investigadores, verificando-se a participação activa da região Algarvia o que evidência o seu papel fundamental na exploração do recurso. Este processo foi sobretudo impulsionado pelas fortes oscilações nos desembarques de polvo com implicações no investimento e rendimentos. Das 15 leis publicadas no diário da república que afectam a pesca do polvo, mais de metade (8 portarias) foram implementadas unicamente para a região do Algarve, especificamente à costa sul do distrito de Faro, desde o Cabo São Vicente até à Foz do Rio Guadiana, sem inclusão da costa Oeste.

Tabela 1. Cronologia das leis publicadas em Diário da República referentes a pesca com armadilhas de abrigo e gaiola para a captura do Polvo comum Octopus vulgaris (fonte: Diário da República).

Ano	Ref.	Assunto principal	cobertura
1973	9	Regulamento da pesca artesanal	nacional
1987	43	Quadro legal regulamentador do exercício da actividade da pesca em Portugal	nacional
1987	281-D	Implementação de paragem durante o fim-de-semana para todos os barcos de pesca	nacional
1997	281-C	Implementação do peso mínimo de captura para o Polvo(>750grs)	nacional
1997	375-A	Alteração gradual do peso mínimo de captura para o Polvo (>500grs)	nacional
2000	1102 -D	Regulamento para a pesca com armadilhas	nacional
2005	635	Defeso experimental a aplicar durante 1 ano	regional
2005	840	Correções nos limites regionais do defeso (costa Sul do Algarve)	regional
2001	27	Confirmação do peso mínimo de captura para o polvo (750g)	nacional
2008	249	Alteração da distância mínima à linha de costa (costa sul do Algarve)	regional
2009	447	Alteração do decreto de lei 1102-D (2000)	nacional
2010	193	Alteração da distância mínima à linha de costa (costa sul do Algarve)	regional
2010	1055	Proibição da utilização de isco vivo (*Carcinus maenas*) (costa sul do Algarve)	regional
2011	132	Permissão da utilização de isco vivo (*Carcinus maenas*) pelo período de 1 ano (costa sul do Algarve)	regional
2012	97-A	Extensão da permissão de isco vivo (*Carcinus maenas*) pelo período de 120 dias (costa sul do Algarve)	regional
2012	230	Proibição da utilização de isco vivo (*Carcinus maenas*) (costa sul do Algarve)	regional

2.4 Importância económica da pesca do polvo no Algarve

Em 2013, os desembarques do polvo em Portugal produziram 37.6 milhões de euros, que representam 15% da receita total de primeira venda gerada por todas as pescarias. Desta forma o polvo aparece em segundo lugar, depois da sardinha no que respeita ao valor da primeira venda (10). O Algarve apresenta-se como uma das regiões mais importantes de Portugal para a pesca ao polvo, totalizando 16.2 milhões de euros, e representando 43% dos desembarques para todo o pais (Figura 4). Além disso, a região possui a maior frota nacional dedicada à pesca deste molusco, representada por 765 licenças de pesca para 2014, distribuídas ao longo de 14 portos de registo (410 no barlavento e 355 no sotavento) (Figura 5). Deve salientar-se, no entanto, que o número destas licenças tem estado a diminuir (Figura 6).

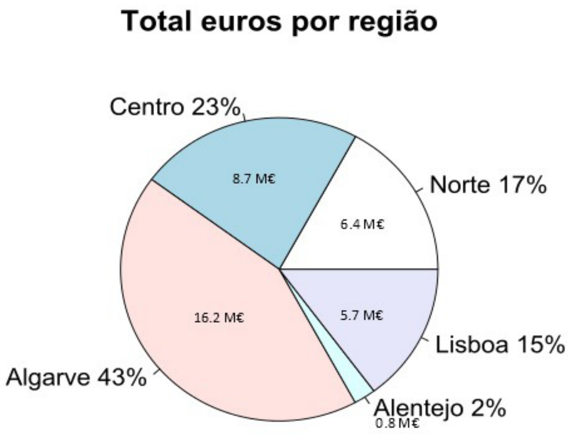


Figura 4. Proporção do valor da primeira venda (€) de polvo entre as diferentes regiões de Portugal continental (Unidades Territoriais para Fins Estatísticos - NUTSII) para o ano de 2013 (fonte: DGRM).

3. MEDIDAS DE GESTÃO PARA A PESCA DO POLVO

No início das tertúlias do Polvo (Maio de 2014), foi pedido aos participantes a identificação das medidas de gestão que gostariam de ver implementadas na pesca do polvo com armadilhas na região do Algarve. Foram recebidas 51 medidas de gestão de 8 associações de pescadores, 3 instituições públicas e 1 centro de investigação. Estas propostas foram classificadas em 18 medidas específicas para serem discutidas durante as tertúlias (Anexo 1). Para o presente documento, estas medidas foram tipificadas em 7 medidas principais, de acordo com os seus objectivos, de forma a facilitar a análise que se propõe neste documento. Em seguida apresenta-se uma análise crítica baseada na informação registada durante as discussões dos participantes nas tertúlias, e comparada com os estudos científicos relevantes para cada aspecto. No entanto, é importante destacar que parte desta informação é extraída de investigação desenvolvida noutras áreas geográficas, sob o pressuposto de que a ecologia da espécie seja semelhante para diferentes zonas e pescarias. Posto isto, há necessidade de investigação direccionada aos diferentes temas de gestão ao nível regional.

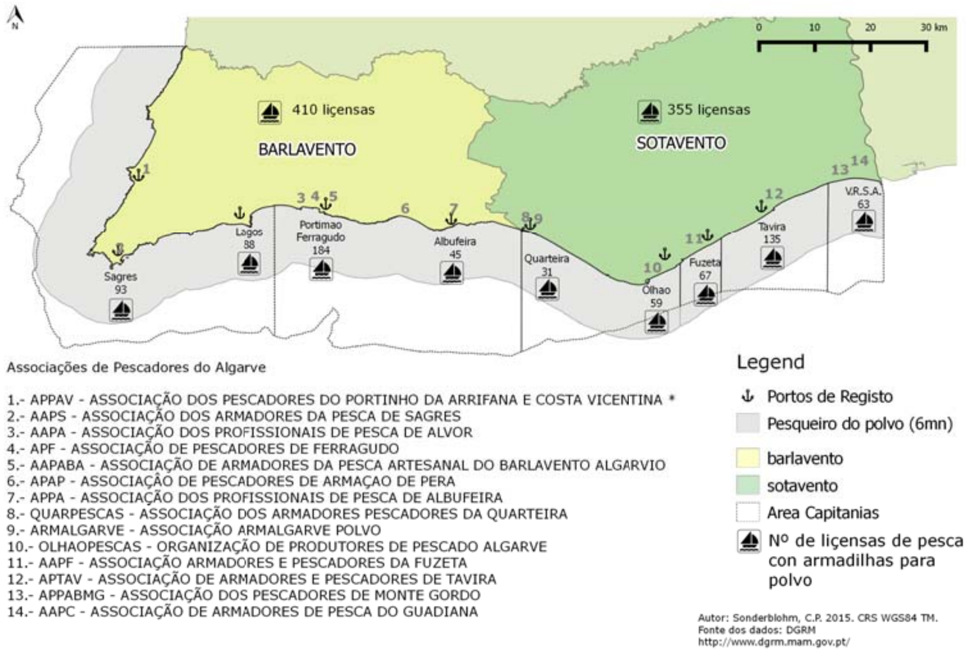


Figura 5. Mapa das associações de pescadores do Algarve e número de licenças por porto de registo (fonte: DGRM).

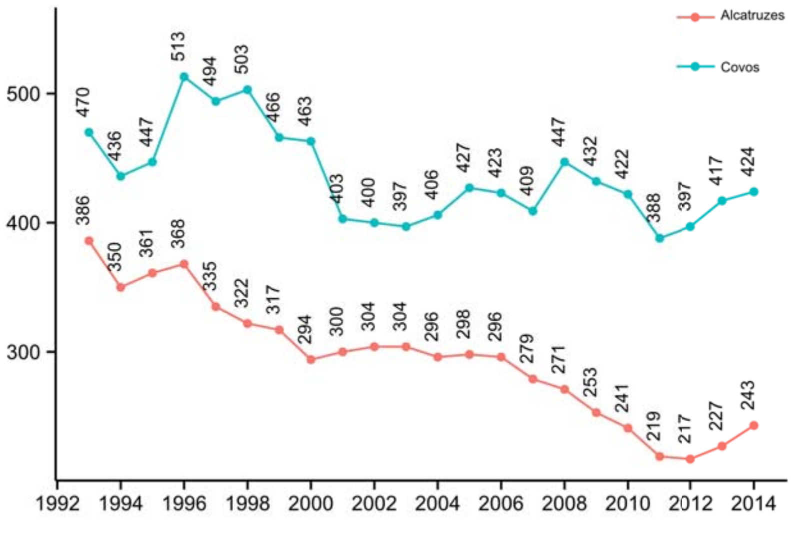


Figura 6. Evolução anual do número de licenças para pesca com armadilhas (covos e alcatruzes) no Algarve durante 1990-2010 (fonte: DGRM).

4. ANÁLISE DAS MEDIDAS DE GESTÃO

4.1 Época de defeso

Os defesos são reconhecidos como medidas eficazes para proteger os juvenis ou a desova em diversas espécies marinhas, mas os seus efeitos vão para além destes objectivos, já que se traduzem numa tentativa de redução efectiva do esforço global de pesca (11). No caso do polvo, os argumentos mais citados para a definição de uma época de defeso baseiam-se na protecção de juvenis e desova para induzir um aumento dos desembarques nas semanas e meses após o encerramento à pesca. Para cumprir estes objectivos a pesca deve ser proibida para todas as artes a operar durante determinados meses ou estações (e.g. defesos temporais durante o Verão), numa determinada área (e.g. defeso espacial - junto à costa), ou por uma combinação de ambos. A implementação de uma época de defeso foi proposta durante as tertúlias, no entanto deve salientar-se que o defeso já tinha sido implementado de forma oficial no Verão de 2005, através da publicação da Portaria Nº635/2005 (Tabela 1). É importante destacar que esta lei apenas incidiu na costa sul do Algarve, por um período de um ano, sendo referida como uma medida experimental que, actualmente não está em vigor.

Em outras regiões do mundo, como por exemplo na Galiza, existe uma época de defeso que dura um mês e se estende de 31 de Maio a 1 de Julho. Mais perto, no golfo de Cádiz o defeso é feito em duas épocas, a primeira entre 1 de Junho e 15 de Julho, e a segunda entre 15 de Setembro e 31 de Outubro (13). Outros países que usam o defeso como estratégia de gestão nas pescas do polvo são: Grécia, México, Chile, Madagáscar, Japão, e Venezuela (1).

Avaliação da estratégia

A definição de uma época de defeso biológico para o polvo deve funcionar como uma época de paragem de pesca de forma a proteger fases consideradas chave do ciclo de vida, como por exemplo a época de reprodução, a época de desova, ou a época de *recrutamento* à pesca. Assim, seria expectável que através da protecção da época de reprodução e postura se aumentasse o sucesso reprodutivo e, em consequência, o número de *paralarvas*. Porem, a relação do número de *paralarvas* com o tamanho da população tem mostrado uma enorme variabilidade, indicando não ser proporcional, e depender do sucesso das *paralarvas,* principalmente em relação aos factores ambientais.

Por outro lado, existem evidências científicas que apontam resultados colaterais na implementação do defeso como o aumento do *esforço de pesca* nos primeiros dias após abertura, que devem ser cuidadosamente avaliados (14). Assim, é esperado um aumento substancial no *esforço de pesca* imediatamente após a abertura, provocando a rápida redução na abundância do polvo até o recrutamento de novos indivíduos. Este fenómeno alerta para um possível cenário de exploração excessiva logo a seguir ao levantamento do defeso. Por outro lado, a maior abundância do recurso durante um curto período de tempo poderá levar ao aumento da oferta de polvo na primeira venda, o que pode provocar uma queda de preços.

Paralelamente é expectável que durante o defeso do polvo se verifiquem alterações na abundância de alimento no ecossistema marinho como peixes pelágicos que são utilizados como isco nesta pescaria (principalmente cavala). Os resíduos destes peixes, rejeitados durante a operação diária de pesca, podem estar a funcionar como uma importante fonte de alimento no ecossistema. Assim, fechar a pescaria por longos períodos de tempo (mais de 1 mês) pode implicar alterações na cadeia alimentar do ecossistema. Estas implicações devem ser cuidadosamente avaliadas.

A definição de um defeso deve ainda considerar cuidadosamente os impactos sociais e económicos, que ultrapassam os objectivos desta análise. Na realidade, a dinâmica natural do recurso demonstra elevadas flutuações nos desembarques ano após ano, o que resulta numa preocupação acrescida para as autoridades. Assim, o encerramento de áreas de pesca pode provocar elevadas taxas de desemprego para as tripulações da região. Este impacto deve ser sujeito a avaliação.

O encerramento da pesca na tentativa de controlar o preço do polvo foi ainda considerado pelos pescadores durante as tertúlias como um "defeso económico". Neste caso, estudos de economia recentemente publicados abordam o assunto com modelos matemáticos, denominados *pontos óptimos de captura* (15), utilizando-se metodologias para determinar a altura certa para obter o maior rendimento económico de determinado recurso. Desta forma, recomenda-se a exploração desta estratégia com o apoio de especialistas da área de economia. Deve salientar-se que durante as tertúlias foi discutida a hipótese de utilizar câmaras de congelação para armazenamento de polvo durante períodos de maior abundância, para sua venda durante o período de defeso. Esta alternativa pode vir a garantir a oferta do produto durante o ano inteiro, contribuindo para uma estabilização dos preços.

Finalmente, durante as tertúlias as associações de pescadores indagaram a comunidade científica sobre qual o período de tempo mais apropriado para a definição do defeso biológico. Importa primeiramente definir o objectivo do defeso. Importa depois considerar que as constantes mudanças temporais do ciclo de vida deste molusco nas águas algarvias (devido à dinâmica dos factores hidrográficos e meteorológicos) não permitem fixar datas com precisão por períodos prolongados (por exemplo, por mais de um ano). Uma solução possível para a determinação de um período de defeso seria a colaboração de investigadores e pescadores para o desenvolvimento de metodologias para acompanhar as flutuações observadas a bordo, acompanhando o ciclo de vida do polvo mensalmente. Na realidade, a definição de uma época de defeso de forma 'teórica' como medida de precaução para evitar a sobre-exploração da espécie não parece apresentar boas probabilidades de sucesso.

4.2 Horário de pesca

A implementação de horários de pesca tem como objectivo principal regular o *esforço de pesca* através da limitação de horas efectivas de trabalho no mar. Como resultado as embarcações conseguem apenas utilizar um determinado número de armadilhas, de acordo com o tempo que têm disponível para a operação de pesca e com a eficiência da tripulação. Durante as tertúlias foi sugerida a criação de horários na pesca do polvo também para combater roubos de artes de pesca (a pesca furtiva é facilitada pelo desencontro de horários dos vários intervenientes). Outra medida proposta dentro da mesma estratégia foi a proibição de saída de qualquer embarcação de pesca de armadilha durante 48h no período do fim-de-semana, de sexta-feira à tarde até domingo à tarde.

Na legislação portuguesa, esta medida já esteve implementada a nível nacional pela aplicação da Portaria Nº281D/1987 para toda a frota local e costeira no continente (exceptuando a frota de arrasto), contudo já não se encontra em vigor. Na Galiza, no mais recente plano de gestão de pesca experimental foi implementado um horário diário (para todos os dias da semana) na pesca do polvo com armadilhas: das 06:00 às 16:00, com excepções justificadas por condições meteorológicas comunicadas previamente às autoridades do porto (12). Outras localidades espanholas que praticam horários de pesca para o polvo são: Golfo de Cádiz (paragem ao fim-de-semana), Almeria, Granada, Valencia, entre outros. Desconhece-se se esta medida é aplicada em outros países.

Avaliação da estratégia

A implementação de horários de pesca não parece ser fundamentada por qualquer questão da biologia do recurso. No entanto, é sabido que o polvo caça durante a noite desenvolvendo, para isso, pequenas movimentações nocturnas (1). No Algarve, alguns portos de desembarque seguem horários de pesca não obrigatórios regidos por tradição (paragens ao fim-de-semana) e/ou por restrições devidas a condições ambientais adversas (entrada/saída das barras, marés, ventos, etc). Considerando que são condições específicas, como a dinâmica de pesca de cada local e as condições atmosféricas, que ditam os horários a que se devem submeter os pescadores de determinado porto, recomenda-se que esta estratégia seja estabelecida pelos próprios pescadores dentro de cada porto, em vez de se tornar uma decisão legal dentro duma área geográfica maior. Seria assim importante que barcos a operar em pesqueiros (capitanias) que não a de matrícula respeitassem os horários da capitania em que trabalham. Assim, sugere-se que sejam os pescadores a definir estes horários, em colaboração com as lotas e as autoridades locais, contrariamente à implementação de uma medida de âmbito regional ou nacional. Neste âmbito convém relembrar que durante o fim-de-semana não operam leilões de primeira venda na maioria dos portos, pelo que o polvo que é pescado durante estes dias tem que ser guardado em câmaras de refrigeração para venda na segunda-feira seguinte, sendo classificado como *frescura tipo II*, o que resulta em preços de primeira venda mas baixos.

4.3 Máximo admissível de captura

Totais admissíveis de capturas (TAC), localmente representados por quotas, são limites de captura expressados em peso (toneladas ou kg) para restringir as capturas duma determinada espécie a um nível determinado através do cálculo de um *ponto de referência biológica,* por exemplo o *Rendimento Máximo Sustentável (RMS)*. A implementação de um máximo admissível de captura diária (o qual se denomina por vezes quota diária) foi sugerida durante as tertúlias como uma medida alternativa para controlar o *esforço de pesca.* Esta estratégia não é um verdadeiro TAC já que não pressupõe a existência de um limite máximo de extracção do recurso numa época de pesca, baseando-se simplesmente no pressuposto de que ao impor-se um limite diário se está a condicionar a rentabilidade das artes caladas, pois indiferentemente do número de armadilhas ou isco a usar, um pescador só pode trazer a terra uma quantidade máxima de polvo que ficar estabelecida em relação ao tamanho da embarcação ou número de tripulantes.

Na Galiza esta medida de gestão foi implementada por época, barco e tripulação a bordo (ex: no Verão os barcos têm permissão para desembarcar um máximo de 30kg/dia, mais 30kg/dia por cada tripulante embarcado, até um máximo de 210kg/dia/barco (12). No decorrer das tertúlias referiu-se um valor de 250-300kg por barco, mas a estimativa não foi definida com base em qualquer análise.

Não existem referências de implementação desta medida para a espécie a nível nacional. Também não se conhecem exemplos para outras regiões relativamente à implementação desta estratégia.

Avaliação da estratégia

Do ponto de vista da gestão, a definição de quotas para garantir a conservação deste recurso, carece de robustez científica devido aos métodos de avaliação de *stock*s para este grupo de invertebrados se apresentarem inadequados. A implementação de quotas por embarcação e por tripulação na pesca do polvo do Algarve responde a limitações no *esforço de pesca*, e questões éticas de equidade e distribuição de capturas entre pescadores e embarcações, e não a *pontos de referência* biológica estimados para a espécie.

Esta estratégia, enquanto alternativa para o controlo de *esforço de pesca*, pode ser entendida como uma oportunidade de criar um ambiente de confiança, onde as preocupações relativas ao número de armadilhas e às opções de isco passem para segundo plano. Entretanto, supõe-se que esta estratégia funcione também como um estabilizador de preço por limitação da oferta na primeira venda, onde nas temporadas de extrema abundância a existência de quotas pode ter um efeito estabilizador. No entanto, a imposição de um tecto de produção em anos de grande abundância pode ser perverso em termos de oferta alimentar, mesmo que o retorno económico para a pesca seja pouco afectado pelo equilíbrio entre procura e oferta. Deve ainda salientar-se que a elevada procura aliada a uma oferta limitada por quotas pode dirigir pescadores à pesca ilegal, devido a atractivos mercados paralelos. Finalmente é recomendável avaliar esta estratégia utilizando modelos matemáticos, com inclusão de informação económica, para simular as pescas e determinar quotas diárias.

4.4 Peso mínimo de captura

Limitar o comprimento ou peso das *espécies alvo* numa pescaria é um dos métodos mais antigos utilizados na gestão das pescas. Estas regulações frequentemente envolvem a devolução ao mar de indivíduos com tamanho inferior a um mínimo legal, para evitar a comercialização de exemplares muito pequenos e, assim, garantir que os indivíduos capturados se tenham reproduzido pelo menos uma vez antes de serem capturados. Esta regulamentação está portanto frequentemente associada ao conceito biológico designado como W_{50} (11). Porém para o polvo o peso mínimo não está associado ao mesmo conceito, já que os exemplares capturados nunca se reproduziram antes da captura (a reprodução antecede a morte e as fêmeas só muito raramente são capturadas após a desova). Por outro lado, estatisticamente, menos de 10% dos indivíduos amadurecem a um peso inferior a 750g. A estratégia legislativa para o polvo resume-se a proporcionar um retorno de biomassa na população que se aproxime do máximo possível. Na legislação portuguesa, a publicação da Portaria Nº281-C/1997 regulamentou pela primeira vez o peso mínimo de captura para o polvo em 750g. Devido ao seu impacto no sector, este valor foi reduzido para 500g pela Portaria Nº375-A no mesmo ano. Depois de 4 anos, o valor voltou para os 750g pela Portaria Nº27/2001, que se mantém em vigor actualmente. Como estratégia de gestão, esta medida tem sido implementada em vários países: Espanha (1kg); Grécia (0.5kg); sul do Brasil (1kg), nordeste do Brasil (0.6kg); norte do Chile (1kg), México (110mm comprimento do manto), Madagáscar (0.35kg); Havai (0.45kg); Venezuela (0.4kg) entre outros.

Avaliação da estratégia

O peso mínimo de captura de 750g situa-se abaixo do valor de W_{50} que foi definido para esta espécie. No Golfo de Cádiz o W_{50} foi calculado em 1920g (fêmeas) e 1300g (machos) (7). Considerando a rápida taxa de crescimento da espécie, assim como a escassez de predadores naturais nos pesqueiros, um aumento no peso mínimo de desembarque parece uma estratégia razoável para aumentar o rendimento de pesca. A optimização da produtividade em termos de biomassa da população ocorre a cerca de 1100g de peso individual (*J. Pereira comunicação pessoal*). Entretanto, é expectável que através do incremento do peso mínimo se verifique um aumento da classe de tamanho médio dos desembarques, o que se deverá traduzir, em termos de mercado e devido ao peso, num aumento do preço da primeira venda. Embora parâmetros como o W_{50} sejam indicadores biológicos importantes, uma avaliação económica revela-se necessária por forma a determinar o peso individual que proporcione um rendimento óptimo.

4.5 Número máximo permitido de armadilhas

As artes de pesca podem ser controladas em número, tipo ou tamanho. Habitualmente estas regulações são implementadas para permitir que os recursos sejam distribuídos entre um grande grupo de pescadores (11). No caso do polvo, onde grande parte do emprego nas comunidades piscatórias do sul depende desta actividade, a estratégia visa regular o *esforço de pesca* garantindo assim a competição equilibrada pelo recurso. Em Portugal estão legislados o número dos covos e a malhagem permitida, mas a dimensão dos mesmos pode variar consideravelmente.

Na portaria Nº1102-D/2000 de 22 de Novembro o número de armadilhas foi definido pela primeira vez de acordo com o tamanho da embarcação. Entre 2009 e 2012 estes valores foram alvo de 3 modificações (Tabela 2), sendo os limites atuais de 750 em embarcações até 9 metros de comprimento, 1000 para embarcações entre 9 e 12 metros, e 1250 para embarcações com mais de 12m. O número máximo de *alcatruz*es mantém-se em 3000 unidades.

O sector reconhece a fragilidade da fiscalização no que diz respeito ao cumprimento do número máximo permitido. É referido por um lado que a legislação não contempla as necessidades reais em número de covos que permitam viabilizar economicamente a actividade, mas por outro também que existe uma apetência do sector em ultrapassar esse mínimo sustentável.

Tabela 2. Histórico da legislação sobre o número de armadilhas de abrigo e gaiola para a pesca do polvo em Portugal (fonte: Diário da República).

		Covos				Alcatruzes
		convês aberto	convês fechado	convês fechado	convês fechado	
Ano	**Ref**	**até 9 m**	**até 9 m**	**9 m - até 12 m**	**mais de 12 m**	**todas***
2000	1102/D	N.A.	500	750	1000	3000
2009	447	N.A.	500	750	1000	3000
2011	132	500	750	1000	1250	N.A.
2012	230	N.A.	750	1000	1250	N.A.

Durante as tertúlias foi proposto um sistema de marcação individual de armadilhas com placas numeradas (em que parte da informação só é decifrável pelas entidades oficiais), muito similar ao utilizado na Galiza (12), onde as autoridades dão a cada pescador um número de placas individuais de marcação de artes e as instruções para a sua utilização. Todas as artes encontradas sem a marca são consideradas ilegais. Outras regiões que condicionam o número de armadilhas são: Golfo de Cádiz (Espanha), Grécia, Sul do Brasil, entre outros.

Avaliação da estratégia

O elevado número de armadilhas existente na região, contrariamente à opinião geral do sector, não parece funcionar como uma ameaça em termos biológicos para os polvos, mas sim como uma fonte de alimento e abrigo, que pode estar a suportar elevada biomassa populacional, aumentando assim o rendimento nos últimos anos. Na realidade, esta hipótese parece suportada por evidências de outras pescarias similares, como no Golfo de Maine na costa nordeste dos Estados Unidos, onde o uso de grandes quantidades do arenque do Atlântico (*Clupea harengus*) como isco na pesca de lavagante (*Homarus americanus*) com armadilhas parece contribuir para o aumento das capturas nos últimos anos (16). Mais perto, nos pesqueiros do banco do Sahara, na costa oeste de África explica-se o aumento das capturas de polvo com as rejeições da pesca de arrastro, que parecem contribuir para a alimentação das populações deste molusco (17). No entanto, o impacto do elevado número de armadilhas no ecossistema algarvio e as suas interacções na *cadeia trófica* devem ser avaliados.

Um dos maiores problemas identificados pelos pescadores nas tertúlias foi a elevada quantidade de armadilhas por barco, reconhecida pelo sector como excesso de artes, que leva a elevados investimentos, e que resultam em elevados níveis de competição. Até ao momento a fiscalização no terreno revelou-se inadequada para controlar o número de armadilhas. Na realidade, as teias são praticamente impossíveis de localizar no mar por causa da inexistência de bóias de sinalização (obrigatórias). Assim, apenas os proprietários sabem, com exactidão, onde se encontram as suas artes, tornando impossível uma fiscalização eficiente em relação ao número permitido de armadilhas.

Assim, o número permitido de artes caladas na região algarvia, estimada com base no número de licenças aprovadas para o ano 2014 (embarcações locais e costeiras), é de 431750 *Covos* e 834000 *alcatruzes*, totalizando 0.2 e 0.4 armadilhas por m^2 respectivamente (*fonte DGRM*; Figura 7). Através de uma análise temporal de desembarques de polvo na região concluiu-se que o número de embarcações a operar tem diminuído nos últimos 20 anos devido a uma aparente sobre-exploração económica (18). Esta diminuição em número de unidades de pesca tem sido acompanhada, presumivelmente, por um aumento no número de armadilhas por embarcação, de forma a compensar as perdas económicas e a aumentar a competitividade. Do ponto de vista económico, condicionalismos ao número de artes podem levar a um aumento nos custos de captura, o que se pode traduzir na possível ineficiência da operação de pesca (11).

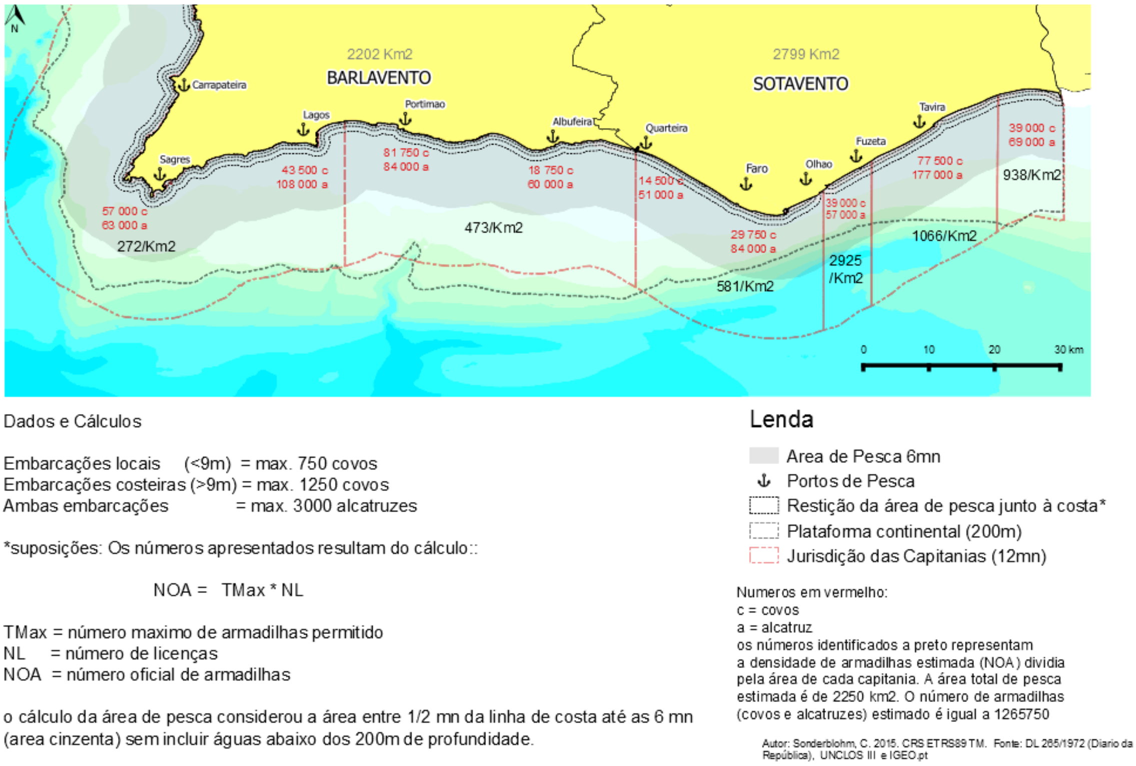


Figura 7. Numero permitido de artes caladas por capitania conforme a legislação em vigor (fonte: DGRM).

4.6. Selecção de isco

As especificações legais relativas ao isco permitido para a pesca do polvo com armadilhas no Algarve não foram consideradas como uma preocupação até ao ano de 2010, em que a portaria Nº1055 introduziu pela primeira vez a interdição do uso do caranguejo vivo (*Carcinus maenas*) nesta pescaria. Mais tarde, a Portaria Nº132/2011 revogou esta medida alegando falta de adequação para a pescaria da costa oeste (considerando características diferentes em termos hidrográficos para os pesqueiros) e estabelecendo, por isso, a divisão da costa sul a partir do cabo São Vicente. A Portaria Nº97-A/2012 manteve a revogação por um período de 120 dias até que, finalmente, a Portaria Nº230/2012 proibiu definitivamente a utilização do caranguejo como isco na costa sul até que a situação de "excesso de artes seja controlada". Esta medida foi implementada como resultado de um conjunto de reuniões entre autoridades, associações e investigadores. Não se conhecem exemplos de regiões em que a selecção de isco seja alvo de regulamentação, o que indica que a estratégia de gestão aplicada ao Algarve não parece associada ao isco mas, como evidenciado na última portaria, a uma estratégia para controlar o número excessivo de armadilhas em uso.

Avaliação da estratégia

Durante os últimos 50 anos ocorreram diversas alterações na dinâmica da pesca do polvo no Algarve, tais como: utilização de armadilhas iscadas em vez de *alcatruzes*, introdução de guincho mecânico, entre outras. Estas alterações podem ter provocado mudanças significativas no ecossistema marinho, sendo que o seu impacto biológico nunca foi estudado. A introdução de armadilhas iscadas como novas artes de pesca nos anos 90 tornou-se uma opção popular para os pescadores de polvo (10). Desde esta altura, começou a utilização de pequenos pelágicos como isco (privilegiando-se a cavala devido ao seu reduzido custo e à abundância na região). Não se sabe com exactidão quando começou a ser usado o caranguejo mouro como 'isco vivo' na pesca do polvo na região, mas presume-se que deve ser uma prática recente de finais da década 2000-2010. Um dos argumentos que contrariam o seu uso baseia-se no facto da utilização de caranguejo permitir iscar os *covos* por longos períodos de tempo, já que os caranguejos resistem vivos dentro das armadilhas, permitindo lidar com mais teias sem a necessidade de iscar diariamente. Assim, esta proibição aparece como uma forma de forçar os pescadores a usar pequenos pelágicos (isco morto), o que exige que as *teias* sejam levantadas diariamente, limitando assim a capacidade logística de usar mais armadilhas.

Na realidade, a utilização de grandes quantidades de isco é um factor importante que pode condicionar a cadeia alimentar nos pesqueiros, e o seu impacto deve ser avaliado, como foi indicado da estratégia anterior. Reforça-se aqui a oportunidade de implementar um programa de observação em conjunto com os pescadores de polvo que pode providenciar informações importantes relativamente ao recurso, assim como fortalecer a cooperação entre pescadores, autoridades e instituições de investigação. Paralelamente é importante salientar que, no decorrer das tertúlias, os operadores evidenciaram que é usual o não cumprimento da regulamentação que proíbe a utilização de isco vivo.

4.7 Distância mínima à linha de costa

Áreas fechadas à pesca junto à costa durante períodos de acasalamento e desova podem permitir aos indivíduos adultos a reprodução sem maiores interferências (11). No caso da legislação do polvo no Algarve, 9 das 12 portarias publicadas focaram-se na protecção das fêmeas reprodutoras em áreas costeiras através do estabelecimento de uma distância mínima à costa para a pesca. A portaria Nº1102D/2000 definiu, pela primeira vez, uma distância mínima à linha de costa de acordo com o tamanho das embarcações e as artes utilizadas. Nesta regulamentação, *alcatruz*es de barro ou plástico (não iscados) foram condicionados a operar a mais de ½mn da linha de costa (embarcações locais) e a mais de 1mn (embarcações costeiras). A legislação em vigor encontra-se na Tabela 3.

Tabela 3. Distância à linha de costa em vigor para as embarcações da pesca de polvo com armadilhas para Portugal continental (fonte: Diário da República).

Embarcação	Comprimento	Tipo	distância à linha de costa	distância à linha de costa
			1 de outubro até 28 fevereiro (inverno)	*1 de março até 30 de setembro* (verão)*
local	até 9m	covos	1/2 milha	1/4 milha
costeira	maiores de 9m	covos	1 milha	1/2 milha
local	até 9m	alcatruzes	1/2 milha	1/2 milha
costeira	maiores de 9m	alcatruzes	1 milha	1 milha

Em outras regiões a protecção de áreas de criação ou mananciais de interesse pesqueiro têm sido amplamente implementadas com diferentes graus de sucesso (11), sendo um dos principais objectivos a maximização da produtividade do *stock* comercial. No caso do polvo, existem restrições deste tipo no norte da Espanha, nas Astúrias e na Galiza, mas, contrariamente a Portugal, estas são delimitadas relativamente a zonas específicas e profundidades definidas. Esta estratégia também se encontra implementada na Grécia, no Golfo de Cádiz e no Japão, entre outros.

Avaliação da estratégia

A definição de áreas de protecção para desova é prática comum em diversos países desde há muitos anos, no entanto não há concordância em relação às suas dimensões e à altura em que devem ser implementadas (19). A identificação destas áreas tem sido o foco de diversos programas europeus de investigação como forma de apoio à gestão (20), com as novas tecnologias de informação (como os sistemas de informação geográfica) a desempenhar um papel fundamental.

Em termos da ecologia da espécie, existem fortes indicações de que o polvo realiza migrações para águas pouco profundas na Primavera, por causa da época de reprodução (21), sendo que no sotavento algarvio a época se estende de Maio a Setembro, com um pico de desova em Agosto e Setembro (6). Por outro lado, o uso de armadilhas iscadas neste período e nos locais de desova não deveria ser considerado uma ameaça para as fêmeas, uma vez que estas não se alimentam enquanto protegem os seus ovos, morrendo após esta fase. Apesar desta evidência, as interacções entre as artes de pesca e as relações macho-fêmea em águas costeiras, durante fases chave como o acasalamento e desova, não foram alvo de avaliação. Desta forma verifica-se que é necessário identificar os locais de reprodução e desova para a região de acordo com a informação disponível relativamente aos habitats. Recomenda-se o uso de Sistemas de Informação Geográfica (SIG) para dar suporte ao armazenamento e análise deste tipo de informação. A integração e incorporação do conhecimento tradicional local combinado com informação científica disponível é também recomendada.

5. CONSIDERAÇÔES FINAIS

A falta de resultados consistentes na gestão da pesca do polvo no Algarve, tal como em outras regiões, deve-se maioritariamente às particularidades do ciclo de vida da espécie e às interacções pesqueiras/ambientais. Assim, a título de exemplo, anos maus de pesca, que resultaram de *recrutamento*s fracos, levaram os representantes de pescadores a solicitar políticas de gestão de recursos de curto prazo, sem existir sequer um *plano de gestão*. Muitas estratégias implementadas actualmente parecem basear-se em princípios fundamentais das relações entre o tamanho do *stock* e o *recrutamento*, com protecção de estados-chave do ciclo de vida do polvo, nomeadamente o acasalamento e desova. O objectivo é garantir uma reprodução bem-sucedida e, deste modo, garantir uma nova postura de indivíduos disponíveis para a pesca na próxima temporada. No entanto, a variabilidade do recurso face aos factores ambientais tem contrariado estes pressupostos, provocando um clima de desconforto entre utilizadores e autoridades. Deste modo, aconselha-se uma abordagem adaptativa para a gestão desta pescaria, com promoção da colaboração entre os pescadores e autoridades de forma a permitir a implementação rápida de medidas de gestão que consigam acompanhar o curto ciclo de vida da espécie e acomodar as suas interacções com o ecossistema.

Apresentam-se em seguida algumas considerações para cuidada análise dos diversos interessados:

- Como o polvo apresenta um ciclo de vida curto, que resulta em alta sazonalidade anual da pesca dirigida, recomenda-se o estabelecimento de um sistema de monitorização e avaliação permanente baseado em dois pontos principais: amostragens independentes e análises de desembarques. Paralelamente devem procurar-se metodologias inovadoras para a colecção de dados relativos aos juvenis, assim como realizar estudos de idade e crescimento para confirmar a idade das capturas comerciais. Os resultados devem ser divulgados e discutidos com representantes do sector e investigadores. Existem diversos exemplos de sistemas de gestão suportados pelo acompanhamento permanente do ciclo de vida da população de polvo, onde a avaliação é efectuada em diferentes fases: pré-temporada, temporada e pós-temporada.
- Devido ao elevado impacto que as variáveis ambientais têm na sobrevivência das *paralarvas*, e sendo que, em estudos recentes, a intensidade e sazonalidade das chuvas foi identificada como um factor limitante para a sobrevivência destas no Algarve, recomenda-se o estudo e a monitorização das variáveis climáticas e da sua relação com os desembarques.
- Também se recomenda a identificação das áreas de reprodução com recurso a Sistemas de Informação Geográfica. A identificação dos limites destas áreas deve

ser efectuada de acordo com o tipo de habitat. Informações relativas ao tipo de substrato, espécies inventariadas e batimetria podem ajudar na definição destas áreas.

- Para além da promoção da conservação dos recursos pesqueiros, o histórico da legislação do polvo nos últimos anos indica a necessidade de analisar as estratégias implementadas de acordo com estudos económicos, sobretudo em medidas cujo objectivo é controlar o *esforço de pesca* (tais como a implementação de quotas individuais, defesos, número de licenças e artes, entre outros). Algumas referências bibliográficas utilizadas neste documento indicam que estas estratégias de gestão têm sido alvo de numerosos estudos, como por exemplo aqueles referentes aos *pontos óptimos de captura* de recursos naturais, apresentando soluções práticas para o problema. A inclusão destas análises económicas combinadas com análises biológicas podem produzir resultados mais consistentes para serem considerados na gestão do recurso.

- É fundamental considerar os impactos das decisões de gestão na dinâmica das pescas e nas suas interacções com o ecossistema. Nos últimos 20 anos, devido à grande pressão pesqueira, tem sido documentada uma diminuição substancial da abundância das espécies de peixes comerciais. No entanto o polvo, *Octopus vulgaris,* apresenta tendência crescente entre 1990 e 2010. Assim, a título de exemplo, é importante considerar o potencial do isco como subsídio alimentar no ecossistema, onde o impacto do uso dos diferentes tipos de isco se encontra ainda por avaliar.

- Os impactos *socioeconómicos* de cada estratégia implementada nos últimos anos têm vindo a imputar uma enorme pressão nas decisões finais das autoridades. Assim, a história da legislação das pescas do polvo tem evidenciado um comportamento acção-reacção, sem a definição de um *plano de gestão* formal. Todos estes aspectos parecem indicar a necessidade de promover um sistema de gestão com responsabilidades partilhadas, em que os diferentes interessados intervêm de forma transparente, analisando conjuntamente as diferentes estratégias de gestão. Esta solução pode melhorar a capacidade de resposta face aos novos desafios, promovendo assim soluções novas e mais eficazes.

- O exercício de partilha de ideias e conhecimentos que foi desenvolvido ao longo das tertúlias foi gratificante. É de realçar a disponibilidade dos diversos participantes, que despenderam o seu valioso tempo para dar o seu contributo, fazendo assim destacar a importância da participação pública para a promoção de diferentes perspectivas de gestão. Neste espaço, a partilha de responsabilidades foi entendida como um ambiente favorável para melhorar o sistema actual de gestão. Neste âmbito, espera-se que o presente manual seja útil na procura de novas abordagens para a pesca e gestão do polvo na região e que o diálogo se mantenha de forma a potenciar novas formas de gestão.

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ANEXO 1

MEDIDAS DE GESTÃO PROPOSTAS PELOS PARTICIPANTES NO PROJECTO "TERTÚLIA DO POLVO"

MEDIDA DE GESTÃO	MEDIDAS ESPECÍFICAS
Definição de época de defeso	- Duração mínima de 3 meses (a definir com a comunidade científica) - Duração de 1 mês (a definir em conjunto com a direcção de todas as associações algarvias) - Defeso definido para 2 meses: Agosto e Setembro - Defeso de 1 a 31 de Maio e de 15 a 31 de Agosto (sugestão de datas que devem ser comprovadas pela comunidade científica) - Vários meses de defeso (mínimo 2) coincidindo com a época reprodutiva e de recrutamento da pesca - A definir pela comunidade científica - Defeso a iniciar quando se verifica a ocorrência de um aumento considerável de juvenis na captura - Definição de paragem em épocas de preços fracos (em épocas excepcionais de preço com valores mínimos record) - Definição de época de defeso a nível nacional Fiscalização da época de defeso: - Manutenção de todas as armadilhas em terra durante o defeso - Proibição de venda de polvo no período de defeso - Interdição da pesca desportiva de polvo no período de defeso
Definição de horários e dias de pesca	- Paragem da actividade durante o período de fim-de-semana (48 h) para não saturar o mercado na segunda-feira e manter a qualidade e higiene do pescado - Definido de acordo com a obtenção de maior qualidade da produção, logo maior rentabilidade para a embarcação Definido considerando as limitações das barras
Definição de quotas de pesca por embarcação	- Considerar diferencialmente embarcações locais e costeiras - Considerar o número de tripulantes por embarcação - Implementar um limite máximo de captura diária de polvo em 250 kg/ 300 kg

ANEXO 1 (cont.)

MEDIDA DE GESTÃO	MEDIDAS ESPECÍFICAS
Diminuição da fiscalização na pequena pesca	
Intensificação da fiscalização nesta pescaria	- Relativamente ao número de artes utilizadas por embarcação - Relativamente à não utilização de isco vivo - Relativamente ao controle da captura de juvenis (Peso Mínimo de Captura)
Promoção da fiscalização coordenada entre as associações de pesca e autoridade marítima	
Aumento do peso mínimo de captura	- Sem peso definido - Para 900 gr - Para 900gr/1000 gr - Para 1000 gr
Manutenção do peso mínimo de captura (750g)	
Diminuição do esforço de pesca	- Diminuição do número de armadilhas / covos - Diminuição do número de licenças - Para cumprir a legislação definida
Revogação da portaria Nº230/2012 referente, entre outros, à proibição da utilização de caranguejo mouro na pesca por arte de armadilha	
Manutenção da Portaria Nº 230/2012 referente, entre outros, à proibição da utilização de caranguejo mouro na pesca por arte de armadilha	

ANEXO 1 (cont.)

MEDIDA DE GESTÃO	MEDIDAS ESPECÍFICAS
Alteração da Portaria Nº 230/2012 referente, entre outros, à proibição da utilização de caranguejo mouro na pesca por arte de armadilha	- Permitir o uso do isco vivo - Proibir a pesca por covos a menos de 1 mn da costa entre o 30/09 a 30/04 (neste período a pesca só deve se feita por alcatruzes / armadilhas de abrigo). Esta proibição deve aplicar-se a todas as embarcações, locais e costeiras - Proibição permanente da pesca com armadilhas de abrigo e de gaiolas, dentro de 1 mn de distância à linha de costa, na costa algarvia - Definir limite de distância mínima à linha de costa para as armadilhas de abrigo idêntico ao das armadilhas de gaiola. Ou seja, ½ milha de distância da linha da costa para embarcações até 9 m de cff (inclusive) e 1 milha de distância da linha da costa para embarcações com cff >9 m, durante todo o ano.
Redução da captura de espécies acessórias (by-catch) para um máximo definido (<10-15% do total das capturas)	
Definição de um período máximo de calagem de covos em determinadas áreas ou profundidade costeiras (<20-30m) inferior a24h (todos os dias para o porto) - áreas de reprodução, viveiro, etc.	
Definição da legislação para esta pescaria com âmbito local	
Implementação do processo de certificação do polvo algarvio	
Definição de um procedimento de comunicação entre as várias associações de pescadores de polvo para a concretização do plano de gestão	- Criação de um grupo de trabalho dedicado exclusivamente ao polvo entre as 10 associações, com representantes de cada uma - Criação de uma comissão de acompanhamento multissectorial (ex: DGRM, Docapesca, Armadores, etc)
Definição de um programa de observadores a bordo conjuntamente com a universidade para avaliar o futuro plano de gestão e para efectuar a recolha de dados	

Annex II

EcoFishMan MP0.- The Portuguese octopus artisanal fishery of Santa Luzia, in leewardAlgarve (south Portugal)

EcoFishMan MP0.- The Portuguese octopus artisanal fishery of Santa Luzia, in leeward Algarve (south Portugal)

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Contents

Glossary

contramestre foreman, in charge of coordinating any fishing operation onboard. 10

covo It is a semi-cylindrical shaped trap built with a structure of iron bars covered with plastic netting normally baited with small pelagic such as sardine or mackerel. 4

mestre de terra retirement boat captain who works inland doing fishing gears. 9, 10

mestre boat captain in local fisheries. 9, 10

métier The word métier is a combination of fishing gear, target species, fishing geographical area. 2

teia Deployed fishing traps (*covos* or *alcatruzes*) in lines of several hundred units connected to a main line. A standard *teia* comprises around 800 to 1200 *covos* at the moment of writing (2013), having increased remarkably in the last few years. 4

Acronyms

APTAV Tavira Fishermen Association. 10–12

DGAM Directorate of Maritime Authority. 10

DGPM Directorate General for Maritime Policy. 10

DGRM Directorate-General of Aquaculture and Fisheries. 1, 10, 12, 14

DOCAPESCA Ports and Fishing Auctions Co.. 3, 8, 12

FORMAR Vocational Training Center for Fisheries and Sea. 9

GNR National Republican Guard. 10

IPMA Portuguese Institute for the Ocean and Atmosphere. 1, 7, 8, 10, 12, 14, 16

MAMAOT Ministery of Agriculture, Sea, Environment and Land Ordination. 10

MLS Minimum Landing Size. 2, 13, 14, 16

MP Management Plan. 10, 16

MSY Maximum Sustainable Yield. 13

RFMS Responsive Fishery Management System. 1, 12, 13

SSB Spawning Stock Biomass. 13, 16

List of Symbols

LPUE Landing per Unit of Effort ($\frac{Kg}{Day}$). 6–8

nm nautical miles. 1

Overview

Santa Luzia is a small coastal village located at southeast Portugal which depends exclusively on *Octopus vulgaris* fisheries as the main livelihood. During the last 20 years (1990-2010) Santa Luzia harbour has recorded an average of 53 tonnes/month (*s.d.* 43) within high variability, with a year maximum of 970 *t* in 2005 and a minimum of 260 *t* in 1990, representing around 4 M €/year at the first sale. This fishing is carried out by a small fleet of around 38 boats (<12 m of length) with small traps known as *covos* or *alcatruzes*. The fishing grounds cover an area of about 750 Km^2 mostly composed of soft bottoms off the Algarve leeward coast, between 1 and 6 *nautical miles* (nm) off the shore. Currently, top down management is carried out by the Directorate-General of Aquaculture and Fisheries (DGRM)[i] which set the policies and regulations based on scientific advice provided by the Portuguese Institute for the Ocean and Atmosphere (IPMA)[ii] and enforced by the local marine authorities through the captaincy of Tavira.[iii] Recently, during the year 2012, octopus fishermen from Algarve region, including Santa Luzia, were confronted by policy changes taken by DGRM at national level, affecting the operation of the fleet. National fishing authorities have been looking toward stakeholders involvement in order to improve the current fishing practices, highlighting the importance of local and regional constraints in the current management system.

[i] DGRM Directorate-General of Aquaculture and Fisheries

[ii] IPMA Portuguese Institute for Fisheries and Sea Research

[iii] Tavira is one of the 9 captaincy's in which is divided the marine territory at south Portugal (Algarve region)

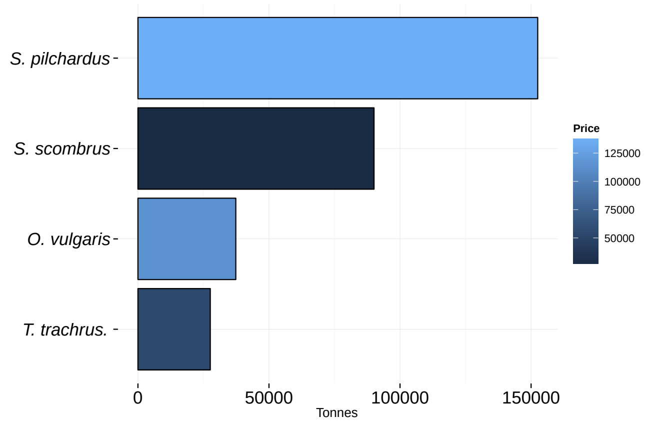


Figure 1. Main species landings for Portugal continental waters during 2010-2012 (source: DGPA). Prices are in color scale and represent total millions of €

1 Fishery identification

1.1 Description of the fisheries

1.1.1 Harvest, by volume and value

During the last three years (2010-2012) *Octopus vulgaris* has been ranked 3^{th} in landing statistics for the whole country after *Sardina pilchardus* (European pilchard) and *Scomber scombrus* (Atlantic mackarel) (Fig. 1). However, is the second revenue earner within the domestic fisheries sector after sardine due its higher market value when compared to the other specie (Pereira *in* ICES (2012)). Historically, the Santa Luzia octopus fishery has been one of the most important in the country yielding an average annual catch of 550 t during the past decade (1990-2010), which represent a market value by year of around 4 millions €, corresponding to 30 % of the Algarve fishing sector production.

1.1.2 Fishing fleet

Boats are usually split in two categories, *local* and *coastal*.[i] Also, they can be classified into open and close deck, the latter with the bridge usually located toward the bow. The size of the boat, type of deck (open or closed) and engine power determine how each is classified and the respective licenses. The current fleet is comprised of 38 boats (October 2012): 17 *local* and 21 *coastal*. The number of

[i] *local* boats are those $\leqslant 9$ m in total length; *coastal* > 9 m; according to ordinance $N^{\circ}43/1987$, in the National Gazette *Diario da Republica*

boats is controlled yearly by licensing at the corresponding captaincy. Data on licenses for this area during 1993-2008 showed two different trends (Table 1). A evident sharp decreased during the 90´s possibly due the implementation of European policies for fishing effort reduction.[i] The second half, from 2000 onwards has recorded a slowly increase, mostly on small boats. Currently, is not possible to get new boats or licenses for octopus fishing (or any other professional fishing *métier* or open new licenses, fisherman can only purchase access by transferring old boats permission into new ones.

Table 1. Number of licenses approved by type of fishing gear for Tavira Harbor (source: DGPA Olhão)

	Clay pot (*alcatruz*)		Baited pot (*covo*)	
Year	Local	Coastal	Local	Coastal
1993	50	19	36	26
1998	22	31	23	40
2003	23	27	17	33
2008	31	28	32	25

1.1.3 Target species

The highly selective fishing gear results in very efficient catches of *O. vulgaris* (common octopus), recording a high species diversity by-catch in numbers but not in weight. Discards represent less than 16 % of the catches in weight for this fishery, consisting mainly of small indiviudals (Baeta, 2009). Another octopus species, *Eledone cirrosa* (curled octopus), is hardly ever caught by this fleet. Among the fish species, *Conger conger* (European conger), *Helicolenus dactylopterus* (black belly rosefish), and *Diplodus vulgaris* (common seabream), are some of the by-catch species most commonly obtained. A few crustacean decapods such as *Carcinus maenas* (green crab), *Homarus gammarus* (European lobster) and some equinoderms are also caught in small amounts (less than 5 % of the total catch). Octopus under 750 *gr* Minimum Landing Size (MLS)[ii] are discarded alive to the sea.

[i] Portugal's accession to the European Economic Community (EEC) in 1986 was characterized by a strong incentive for scrapping of fishing vessels according to *Council Directive* $83/515/EEC$ of October 4^{th} 1983 implemented by the national Decree-Law $n\circ\ 341-B/86$

[ii] MLS for *O. vulgaris* is 750gr; according to ordinance $N^{\circ}447/2009$, in the National Gazette *Diario da Republica*

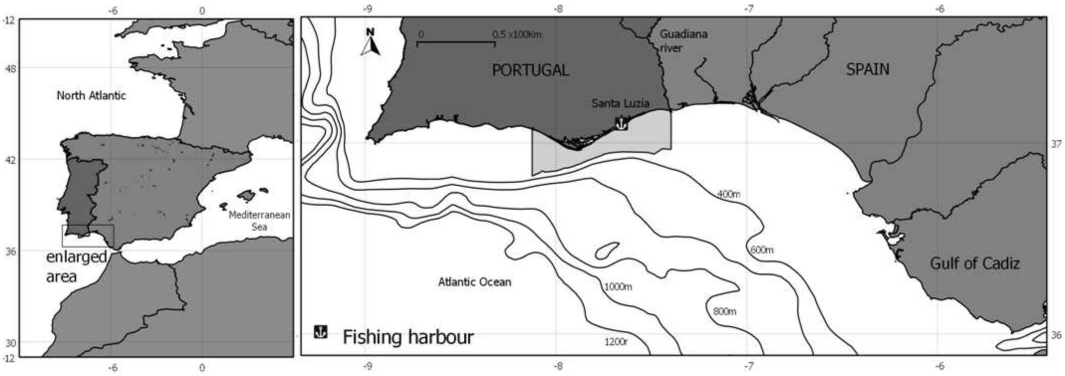


Figure 2. Location of the fishing grounds (gray filled polygon) (*GRS WGS84*, proj. *transv. mercator*).

1.1.4 Fishing grounds

This area covers the western border of the Gulf of Cadiz, at the southern edge of the Iberian Peninsula, protected from the west swells coming from the Atlantic, mixing with local waters coming from the Ria Formosa saltmarsh (Fig. 2). This transition zone, between the Atlantic and Mediterranean, receives the outflow of the 4^{th} longest river of the Iberian peninsula, the Guadiana river, and some other small rivers flowing from Portugal and Spain. The fishing grounds cover an area of about 750 Km^2 mostly composed of soft bottoms (sandy and sandy gravel) off the Algarve leeward coast.[i]Depending on the time of the year and resource dynamics, the fleet can extend east towards Spanish territorial waters, close to Isla Cristina (for some licensed boats) and west, to the rocky bottoms off Portimão and Armação de Pera harbours, in the windward Algarve coast. The fleet operates between 1 and 6 *nm* of the coastline most of the year; only during the summer, move inshore to a mere $1/2$ *nm* of the beach[ii]. The vessels do not go farther than 6 nm from the coast, beyond which the trawlers are licensed to operate. Most of the landings still take place in Santa Luzia fish auction site[iii]inside the Ria Formosa lagoon, where the local harbour is located.

[i]Algarve coast is locally split into two main areas according to the wind direction; *Windward*, facing west and southwest more exposed to north Atlantic swells; *Leeward*, facing southeast, more affected by Gulf of Cadiz system

[ii]see legal framework in section 3

[iii]Ports and Fishing Auctions Co. (DOCAPESCA) is the national state owned company officially in charge of the first sale of fish landings across the country

1.1.5 Fishing Gear

There are mainly two types of gears, named *covos* (Fig. 3a) and *alcatruzes* (Fig. 3b). The *covos* are the more popular fishing gear in the community, since approximately 1986. They are a semi-cylindrical shaped trap around 71 *cm x* 42 *cm x* 22 *cm* (length, breadth, height) built with a structure of iron bars (0.8 *mm* ∅) covered with plastic netting of 4 *cm* mesh size. The dimension and shape of the *covo* varies from boat to boat, making it easy to recognize each trap's owner by the local fisherman without any other ownership mark. Trap numbers are regulated according to boat and trap size (Table 2).

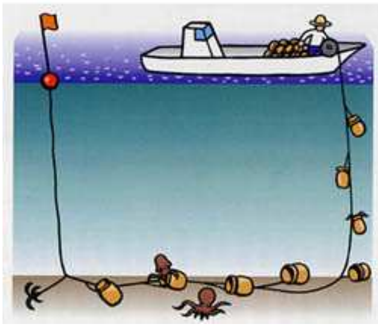
Table 2. Number of baited pots allowed according to ordinance in force (n○ 230/2012 in the National Gazette *Diario da Republica*). Non-baited pots (*alcatruz*) maximum is 3000 units for any size of boat.

length	**classification**	$N^{\circ} Pots \leqslant 0.25m^2$	$N^{\circ} Pots > 0.25m^2$
$\leqslant 9m$	local	750	500
$> 9- \leqslant 12m$	coastal	1000	750
$> 12m$	coastal	1250	1000

The other gear, the *alcatruz* pot is one of the oldest fishing gears in the Mediterranean, in recorded use since ancient Egypt. There are presently two types depending on the material used in the manufacture: clay and plastic. The first, consist of the original pot descended from the amphora shape, about 30 *cm* height with an entrance of 10*cm* ∅ and a small hole at the opposite end to allow the water to go out when is the trap is pulled aboard. Presently these have been mostly replaced by the plastic alcatruz, cheaper and more resistant to wear, with more or less the same measurements but a different shape. Both traps and pots are deployed in lines of several hundred units knows as a "teia" (fig. 3c). Each covo or alcatruz is connected to the main line by a line of smaller diameter known as the "alfoque", at regular intervals of around 18 meters. Each *teia* has a rope called the "arinque" at both ends which connects to an anchor weight called the "poita" and to the pulling line ending in a buoy. A standard teia comprises around 800 to 1200 *covos* at the moment of writing (2013), having increased remarkably in the last few years. Fonseca (2003) in a description of the same fishery, recorded that each teia comprised 600 *covos*, and each boat normally carried 1 to 3 teias. The *covos* are usually baited with small salted pelagic fish such as *Scomber scombrus* (mackerel) or *Sardina pilchardus* (sardine), and more recently with *Carcinus maenas*, but this is currently banned.

(a) *covo*: baited plastic trap

(b) *alcatruz*: clay pot non-baited



(c) *teia*: display on the bottom of the fishing gear (Illustration source: http://www.kup.at/journals/)

Figure 3. Main fishing gear used in Santa Luzia

1.2 Key biological aspects of the resource

1.2.1 Life cycle

Octopus vulgaris has a very short life span, from 12 to 14 months (fig. 4), and is semelparous, with egg care by the female. The female fecundity is very high, ranging from 100.000 to 500.000 eggs. The spawning peak in the fishing grounds extends throughout the year, with a marked peak during summer, similar to Mediterranean populations (Moreno *et al.*, 2008). Females move to shallower waters close to the coast during the spawning, starving until death after the hatching occurs (Mangold and Von Boletzky, 1973). Paralarvae are planktonic for 40 days, after which they will settle to the bottom and grow to 750g in 4 months more (Cabranes *et al.*, 2008), depending on environmental conditions. Growth is very quick, juveniles can reach 0.5 – 0.6 kg within six months of hatching, at a mean temperature of 18 °C (Guerra *et al.*, 2010).

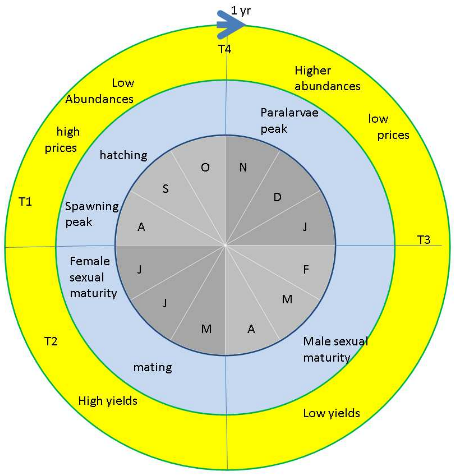


Figure 4. Theoretical 1^{yr} life cycle of *Octopus vulgaris* for the Algarve region based on scientific references and local ecological knowledge (LEK), Letter T in the outside yellow circle refers to size classes: $T1 \geqslant 3kg$, $T2 \geqslant 2kg$, $T3 \geqslant 1kg$, $T4 \geqslant 0.75kg$. Letters in the inner circle correspond to month of the year.

1.2.2 Ecology

This species is very territorial, with competition for space playing a key role in recruitment dynamics. Our analyses suggest that high variations in abundance of the fishing population are driven by environmental variables, affecting the paralarval stage, as has been demonstrated by several scientific studies (Pierce, 2010). In our case, rainfall between October and December has been found to have a negative correlation with landings of the following year for the same months (paper in elaboration). On the other hand, we suggest that the lack of large predators in the fishing grounds due to high fishing pressure from other fleets (trammel-nets, long-line, bottom trawling, etc) the discards from bottom trawling and bait used (food supply) allow *O. vulgaris*, as an opportunistic species, to succeed in the fishing grounds, conquering the predator niche of the ecosystem, where cannibalism becomes the second major cause of mortality for the adult population, after fishing.

1.2.3 Status

Octopus presented a marked seasonality in this area: during rainy seasons (October to March) higher LPUE are recorded (>75kg/day/vessel), whereas in summer months they usually fall to around 50 kg/day/vessel (Fig. 5). Resource abundance is however unpredictable, due to ecological features of the species, where recruitment is regulated by environmental conditions. In this sense, traditional stock assessment analyses for this resource have not been used. Studies regarding gear selectivity, time series analyses, recruitment patterns, age and growth have been used to evaluate the status of the fishery. Octopus fisheries scientists from IPMA consider this fishery to be non-threatened, with no worrying signs of a serious depletion of the resource abundance reported. After the recruitment-environment interactions in the early stages of octopus, the adult population is controlled by fishing effort.

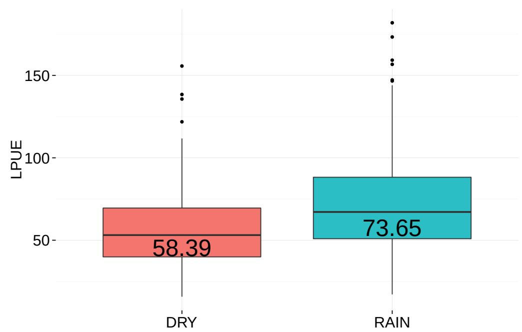


Figure 5. Boxplot of LPUE by season of the year of *O. vulgaris* for Santa Luzia harbor between 1990-2010 ($p < 0.05$; ANOVA test). Numbers inside the box are the mean

1.3 Economy

1.3.1 Economic performance

Demand and supply dictate the daily profit of each boat. Over the last 8 years (2003-2010), prices at auction oscillated between 1.75€/kg and 6.89 €/kg, with winter months recording the lowest values (especially November)(Fig.6) concurring with the landing peak. Therefore, the mean monthly income per boat is highly variable, a good fishing day for one boat during ‘high abundance season is around 400 to 600 kg, representing 1000 to 1500 € first sale price (estimating prices between 2 and 3 € per kg), without accounting for taxes, social security discounts and gas/bait expenses. The yearly number of fishing days is also very variable (5 to 20 days per month). Boats do not fish every day, because of weather and sea conditions, and normally stop during the weekend. Summer months are, as a general rule, the most profitable, due to higher octopus prices, but commonly present a very low landing volume (around 50 kg/day/vessel), while winter months have recorded the lowest prices but in contrast much higher abundance.

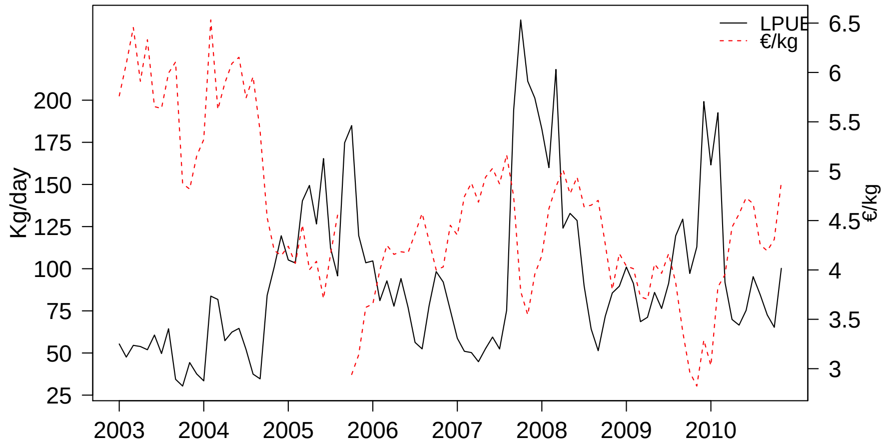


Figure 6. Monthly time series of *O. vulgaris* LPUE and prices between 2003-2010 recorded at Santa Luzia fishing auction (source: IPMA).

1.3.2 Markets

The octopus landed in Santa Luzia have the first sale locally at DOCAPESCA, in a decreasing price auction, where buyers purchase daily landings. The octopus is sorted by size class and freshness stage, in order to set the initial price. Most middlemen are from Spain, transporting the product to their own factories, where most of the octopus is frozen and packed for export to other markets (Spain, Italy, Greece, USA, among others). Only a small amount is commercialized locally[i] at the neighbor fish markets of Olhão and Tavira.

1.3.3 Processing facilities

There is no freezing and storage facility in the fishing community.

[i]Octopus landings are illegally commercialized locally due lack of processing facilities, even local restaurants are commonly buying octopus to commercial retailers

1.4 Social

1.4.1 Fishermen

Each boat has a crew of 5 people. The captain of the boat or *mestre*, usually the owner, and 4 fisherman working on the deck, rotate tasks during the fishing trip. A total of 200-250 active octopus fishermen are currently expected to work in Santa Luzia, excluding the old retired fishermen, who still work on land building and fixing traps. No female fishers have been observed.

1.4.2 Traditional Status

It is important to highlight that Santa Luzia has a long fishing tradition since the tuna trap fishing, where current old generations of fishermen *mestre de terra* and their families were working until early 1970´s (Mr. Antonio Serrador, personal communication, April 2013). Another relevant contemporary activity, has been the EU-Morocco fishing treaty, where some local fishermen has been fishing in Moroccan waters during last two decades, but this treaty has presented several interruptions, forcing many fishermen to switch to local resources, as octopus. Octopus fishing not only represents the first economic activity in the area, but is also a part of the local culture. Santa Luzia has been nick-named the Octopus capital (*Capital do Polvo*) of the Algarve coast.

1.4.3 Educational level

To the best of our knowledge and based on interviews with crew members from different fishing boats, most of the fishermen have not finished secondary school. Strong fisherman tradition has played a major role in the transmission of knowledge from old to younger generations. Some captains were trained in the Lisbon technical school of navigation (20-30 years ago), where they got the certification and licenses. Nowadays, the Vocational Training Center for Fisheries and Sea (FORMAR) located in the neighbourhood community of Olhão, is the local education center for fishermen, where courses on marine safety and hygiene, as part of the implementation of mandatory marine policies for fisherman, take place.

1.4.4 Demography

The population of Santa Luzia numbered 1455 inhabitants in 2011 (Parish of Santa Luzia, 2013)

2 Existing management structures & processes

2.1 Authorities and Institutes

Currently, the elaboration of policies is carried out by the DGRM as part of the Directorate General for Maritime Policy (DGPM) which belong to the Ministery of Agriculture, Sea, Environment and Land Ordination (MAMAOT). The IPMA provides the scientific support, based on research and official landing statistics, playing a major role in policy formulation (fig. 7). At the local level, the law enforcement and management for Santa Luzia octopus fisheries is carried out by Tavira captaincy, which belongs to the Portuguese Naval force, named the south department of the Directorate of Maritime Authority (DGAM). Maritime police and the National Republican Guard (GNR)are the local authorities responsible for the fishing ground waters as well as Santa Luzia harbor.

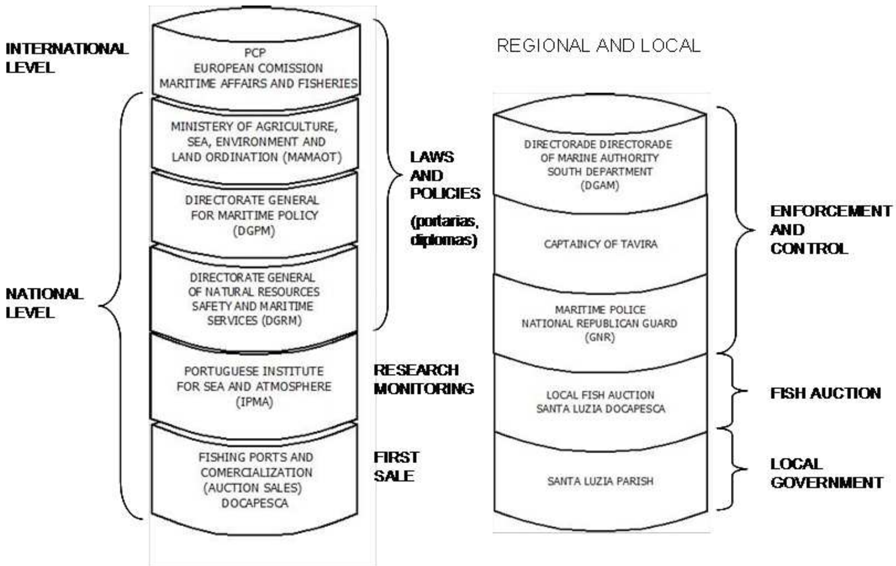


Figure 7. Scheme of Portugal administrative institutions involve in fish management.

2.2 Identification of potential operators

The main group to consider in the Management Plan (MP) are the local Fishermen of Santa Luzia represented by Tavira Fishermen Association (APTAV). They can be grouped by their role and status in the fishery, classified into 5 main categories: boat captain *mestre* , foreman *contramestre* , sailor *camarada*, retired captain *mestre de terra* and boat owner *armador*; where the latter is commonly

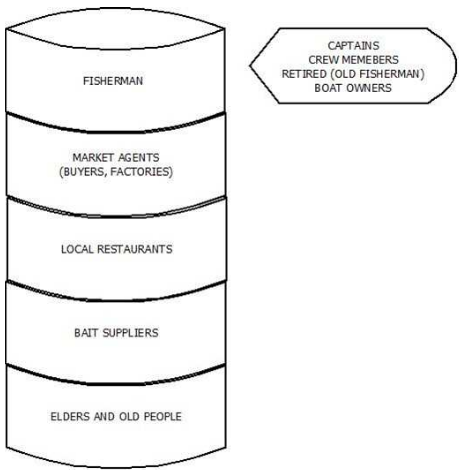


Figure 8. Potential stakeholders to be involved in the RFMS design

the boat captain. The Santa Luzia fishing community is typically composed of a few families, where some boats belong to the same family group. There is another important stakeholder, the buyers or business agents, who buy octopus at the fishing auction, then transport, process (mostly freezing), and finally commercialize the product into the markets. This group is mainly composed of Spanish private investors, who have many years in the business. Bait suppliers, local restaurants, the local fish auction employees, elders and old people of this community, can be considered strategic actors to be included in any fishing management plan design (Fig. 8).

2.3 Potential constraints

- Lack of a specific local organization: octopus Fishermen from Santa Luzia belong to APTAV (main fishing village neighbor) which represent not only Santa Luzia.

- Fisheries administration is centralized in Lisbon public institutions, where the decision making process takes place. Regional and local authorities have no administrative power to create local fishing policies.

- Strong political proselytizing from Fishermen's associations from the region (Algarve). Local leaders represent them in front of the national government.

- The decision making process is not well implemented in order to promote consultation of the parts involved. Policies are mainly designed at the national level, missing local and regional scales.

- Consultation meetings with the administration do take place in Lisbon. Association representatives are involved in the discussion of policies. However, agreements between representatives are uncommon and often preclude them from obtaining adequate deals for their interests.

2.4 Prospect of implementing cost recovery

The lack of a local octopus fishermen's organization, where APTAV represent all the Fishermen from Tavira and surrounding areas, currently makes it impossible for the Santa Luzia octopus fishermen to implement management and assume research costs by themselves. Moreover, this aspect of the fishery is considered by the fishermen as "someone else's" problem, where octopus management policies are the responsibility of the government. However, financial support from the market partners (commercial agencies, buyers, fish product companies) can be considered as potential candidates in the implementation of a RFSM due to common interest.

2.5 Data collecting and processing

Daily official landing data is recorded and systematically saved from the first sale in the local auction by DOCAPESCA, where landing by size classes is taken everyday, as well as price. Then, data are processed and managed by DGRM and IPMA, where they are saved in a relational database. The Cephalopod working group of IPMA have access to this database, and with official authorization it can be used for scientific purposes, as students thesis and research projects. Data on fishing effort is scarce, no local monitoring program exists, except for some field work carried out by MSc and PhD students. A possible solution could be the use of logbooks by the boat captains and the implementation of agreements between universities and local institutes with APTAV or individual fishermen to promote scientific observer programs on-board local vessels.

2.6 Potential advantages and disadvantages of a RFMS

The current fishing policies governing octopus fishing in the leeward coast of Algarve has been traditionally nationwide coverage, resulting in a lack of local features, like type of habitat, depth and weather conditions, among others, which differs from windward Algarve, southwest and the rest of the country. During the past year, a debate in relation to the type of bait used in octopus fishing between

Algarve communities and its fishermen associations was carried out, resulting in the first local-specific regulation for the management of this resource in the country[i], showing the importance of including local constraints in the policy-making process. Here, table 3 is presenting potential advantages/disadvantages if a RFMS is implemented, as result of field work experience during the last two years in the community.

Table 3. Potential advantages and disadvantages of an RFMS

Advantages	Disadvantages
• Include local knowledge and common sense solutions proposed by themselves (Fishermen)	• Local community divisions, disagrement between fishermen family groups due different approach and interests
• Control and enforcement is more efficient if local fishermen are include in the decision making process, more commitment	• Possible failures in the implementation of a RFMS could create conflicts between themselves
• Fishing practices can be more efficient and profitable with a good managment and harvesting plan	• Lack of time available to discuss RFSM, the working schedule is heavy
• Possibility to consider local constraints in the regulations, like type of habitat, depth, weather conditions, etc	• Lack of interest, they feel not responsible for management and control
• Possibility of improvement in response time. Policy modification proposals as a result of local evaluation and analysis could be implemented faster	• Lack of local organization to participate in a RFMS, the community belong to a broader fishing association in the neighbourhood community of Tavira

3 Management objectives and instruments

3.1 Existing management instruments

3.1.1 Management objectives

Currently no quota-managed cephalopod fishery in Europe exist (Pierce, 2010). Maximum Sustainable Yield (MSY) or Spawning Stock Biomass (SSB), or any similar references points are not available, due lack of stock assessment for this resource, which requires detailed data on fishing effort, catches and biological parameters, not available for the majority of the artisanal fisheries of South Europe. In Portugal, fishing effort as an input control has been the main target of current policies, where the maximum number of traps is regulated, but very difficult to control. MLS of 750 grams is the only output regulation. Local fisherman have

[i]ordinance $N^{\circ}97-A/2012$, in the National Gazette *Diario da Republica*

proposed temporary closures, mainly in summer months, during the peak of the spawning season, asking for subsidies from the central government without success. Other measures proposed by the community are non-fishing protected areas (close to the coast, shallow reefs, etc), working schedule (to control fishing effort -no weekend fishing-), etc. Some spatial restrictions exist without explicit resolutions in the written policies, for example, boats do not fish over 6 *nm* off the coastline because demersal bottom trawling. A minimum distance off the coastline is clearly expressed.[i] Small boats < 9 *m* in length are allowed to fishing $1/2$ *nm* off the coastline; while boats $\geqslant 9$ *m* is 1 *nm*. During summer, between the 1^{st} of May and October 30^{th} boats can get closer, a mere $1/4$ *nm* and $1/2$ *nm* corresponding to boat size.

3.1.2 Legal framework

The octopus fishing legal framework is defined by regulatory decree n° 1102 - D/2000 (November 22nd) in the National Gazette *Diario da Republica* (Table 4). This fishery is managed mainly by two input effort control policies: number of fishing traps depending on the boat size and minimum distance from the coastline (Table 1). Output control for this species is based on MLS of 750 grams.[ii] Mesh size is also regulated, mainly to separate it from other traps targeting crustaceans (crabs) fish and cuttlefish, but size selectivity of *O. vulgaris* in traps and pots is not significantly dependent on mesh size or on pot size. Recently, regulations on bait use, have centered the major debate among octopus fisherman. The recent banning of live bait *C. maenas* has provoked confrontation between fisherman associations and individual stakeholders in the Algarve community. Discussion were focused on fishing effort issues, as it was alleged that this specific type of bait facilitated the use of an excessive number of traps, with implications for space utilization.

Recently, central administration office (DGRM) has explicit promoted the co-participation of the local fishing organizations in the management of *O. vulgaris* in the latter ordinance[iii] where referred the creation of an octopus working group, formed by IPMA, DGRM and fishing association members.

3.1.3 Fishing licenses

Santa Luzia fishing boats are licensed by DGRM and its regional department for the Algarve. New licenses for octopus traps are no longer available and access to

[i] ordinance n○230/2012 in the National Gazette *Diario da Republica*

[ii] regulatory decree 43/87 on July 17th in the National Gazette *Diario da Republica*

[iii] ordinance N° 230/2012, in the National Gazette *Diario da Republica*

Table 4. Legal framework for *O. vulgaris* trap fishing activities in Portugal.

Ordinance	Date	Subject
nº 43/87	July, 17th	Main Portuguese fishing management code, including CEE constraints. Octopus vulgaris minimum landing weight (MLW) of 750 g
nº 1102 -D/2000	Nov. 22nd	General provisions, regulations and definition of the fishing gear 'armadilhas' pots. Main ordinance.
nº 447/2009	April, 28th	Allow a minimum distance from the coastline (coastal boat = 1/2 nm; local boat= 1/4 nm) during summer months (1st march- 30 september)
nº 193/2010	April, 8th	Extend the established minimum distance from the coastline (coastal boat = 1/2 nm; local boat= 1/4 nm) during summer months (1st march- 30 september)
nº 1055/2010	Oct. 14th	Banning the use of live bait *C. maenas*
nº 132/2011	April, 4th	Allow the use of *C. maenas* as live bait. Modify number of pots per boat. Establish a minimum distance from the coastline (coastal boat = 1/2nm; local boat= 1/4 nm) during summer months (1st march- 30 september)
nº 97 -A/2012	April, 5th	Extend for 120 days the use of *C. maenas* as live bait in the octopus fishing. Allow coastal boats to fish 1/2 nm from the coastline
nº 230/2012	Aug. 3th	Banning the use of live bait *C. maenas*. Modify number of pots per boat. Establish a minimum distance from the coastline (coastal boat = 1/2nm; local boat= 1/4 nm) during summer months (1st march- 30 september)

this type of fishing is only possible through the purchase of an old licensed boat, from which the licenses can be transferred[i] .

3.2 Potential Outcome Targets

3.2.1 Biological outcome targets (BOTs)

Increase the minimum landing weight to 1100 gr. Experts from IPMA suggest the MLS should increase due to three main reasons:

- An exploitation optimization strategy, maximizing total output weight by balancing individual weight with population numbers at weight class;
- An economic strategy, maximizing economic return per kilogram (due to differences in market price per kg);
- A biological strategy, allowing a greater number of individuals to escape fishing before they reach the minimum landing weight (only a small proportion of the population, 8-10%, have reached maturity at the current MLS of 750g). Due to the extreme natural mortality rates of larvae prior to settlement, the SSB is only very slightly relevant as a factor to consider to include in BOTs as is banning reproduction season and areas (shallower waters during summer months), since either will only might have marginal and local effects on population numbers.

3.2.2 Social outcome targets (SOTs)

Fishing effort has been increasing year by year, mainly due to competition between fisherman in the same fishing grounds (*tragedy of the commons*)[ii], where several fishing fleets share the same fishing grounds. Moreover, fishing costs and materials, and market regulating prices have been driving this fishery to increase production. This extra-effort has reflected in the daily life style of the community, where fisherman have to work more hours to support their livelihood. In this sense, octopus fishing has became more demanding, forcing them to work around 12 hours a day during the night-time. We suggest to include social and health targets in any MP to promote healthy working schedules, reducing fishing effort and improving market prices.

[i] Regulatory decree N° 43/87 of July 17^{th} in the National Gazette *Diario da Republica*

[ii] was a concept introduce by the ecologist Garrett Hardin in a essay published in 1968 entitled *The Tragedy of the Commons*, published in the journal Science dealing with the social dilemma of exploitation of natural resources

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Annex III

The Octopus Route, Centre of Science from Tavira (summer activities)

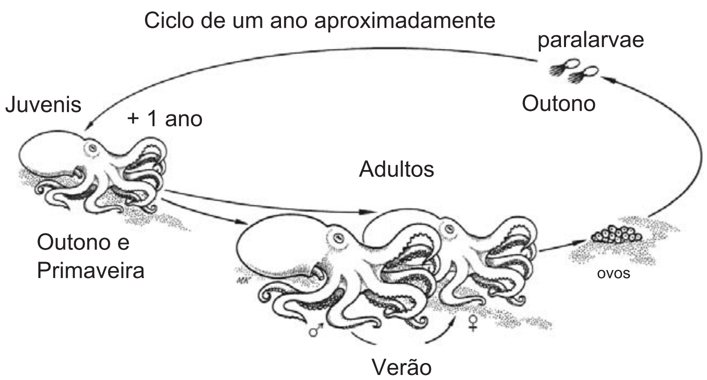
Reprodução e ciclo de vida

Durante a criação, o macho usa um dos seus braços especializados chamados de *hectocotylus* para fertilizar os ovos dentro do manto da fêmea. Esta deposita os ovos fecundados num "ninho" em fileiras que podem atingir até 500.000 ovos.

Durante a maturação dos ovos, a fêmea não se alimenta e normalmente morre pouco depois dos ovos eclodirem.

Os filhotes são conhecidos como *paralarvae* e apresentam um tamanho menor que um grão de arroz (1-2mm). Após esta fase, deixam a superfície dos mares para ir ate o fundo marinho, para viver a grande profundidade até aproximadamente um ano, quando são normalmente pescados.

Curiosidade: as artes de pesca como o alcatruz de barro, antigamente muito utilizado em Santa Luzia, servem como uma espécie de "ninho" para as fêmeas ovadas, usando seu interior como refúgio durante o período de incubação dos ovos.



Gestão das pescas

A legislação portuguesa foca dois aspetos fundamentais: peso mínimo de captura do polvo e o número máximo de armadilhas por embarcação.

O peso mínimo é de 750 gramas, para garantir que parte da população consiga atingir a fase adulta e assim reproduzir-se. Em relação às armadilhas, o número máximo de covos é de 750 para embarcações locais até 9 metros de comprimento, 1000 para barcos entre 9 e os 12 metros e de 1250 para embarcações costeiras maiores que 12 metros. O número máximo de alcatruzes por embarcação, de qualquer tipo, está fixado em 3000 unidades.

Curiosidade: Antigamente a frota pesqueira do polvo parava durante o verão - altura da reprodução da espécie - quando as fêmeas procuram as águas quentes junto à costa para desovar.

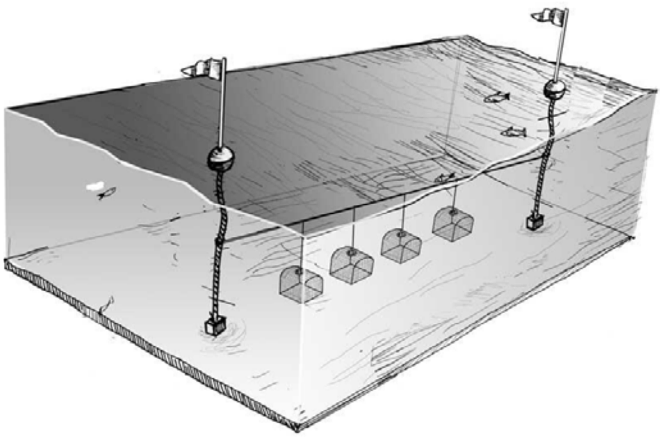
Métodos e artes de pesca

Existem duas artes de pesca para apanhar polvo: os covos e os alcatruzes. Os covos são gaiolas de plástico, que utilizam o isco para atrair os polvos, e os alcatruzes são recipientes, de barro ou plástico, em forma de pote que não precisam de isco. Os alcatruzes originalmente eram feitos de barro, partiam-se facilmente, porém não provocavam tanto lixo no mar como os atuais, feitos em plástico PVC.

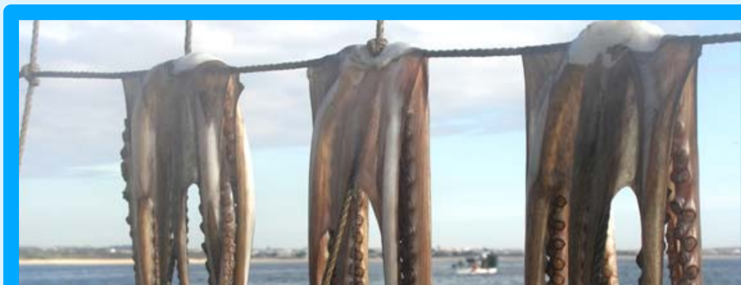
Para pescar o polvo, ambas artes são colocadas em séries de centenas de armadilhas, numa estrutura denominada como teia. A pesca é habitualmente feita durante a noite, dependendo das condições do mar e altura do ano, os barcos saem do cais ao fim do dia para voltar durante a manhã seguinte a descarregar na lota a captura.

Para além do polvo, os covos de outras dimensões tambem apanham diversos peixes e crustáceos com grande valor comercial, nomeadamente navalheiras, lagostins, lagostas, santolas e lavagantes.

Curiosidade: Cada embarcação possui um guincho hidráulico, conhecido como o alador, peça fundamental, introduzida ao início da década de 70 que mudou definitivamente a capacidade de pesca da frota nacional, aumentando o número de capturas.



Os covos são colocados na água presos a um cabo com algumas centenas de metros de comprimento, e estão separados entre si cerca de dez metros, formando uma caçada ou "teia" (imagem: http://sesimbraepeixe.pt/).



Textos: Brígida Baptista e Carlos Sonderblohm, 2015
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ROTA DO POLVO

História

A história da vila de Santa Luzia esteve, desde a sua fundação, ligada à Ria Formosa e ao Oceano Atlântico. Os primeiros registos da existência de cabanas de junco de apoio à pesca nesta área sobranceira à ria são do século XVI.

Mais tarde, em 1837, já existiam na aldeia 53 fogos de habitação, para além das muitas cabanas de junco. A partir da década de 20 do século XX, Santa Luzia inicia a pesca do polvo com alcatruzes e covos, com grande desenvolvimento até aos dias de hoje.

É a freguesia mais pequena do concelho de Tavira com 1.455 habitantes, mantendo na sua essência os costumes e saberes das gentes do mar.

Curiosidade: De acordo com os registos, Santa Luzia nasceu por volta de 1577, quando, por iniciativa dos pescadores se edificou uma ermida dedicada à santa com o mesmo nome, mártir siciliana e protetora dos que sofrem dos olhos.

Desembarques

A vila de Santa Luzia reconhecida na atualidade como a "Capital do polvo" é um importante porto pesqueiro do Sotavento Algarvio onde desembarcaram nos últimos 25 anos entre 7 a 250 toneladas por mês.

Desempenha um papel fundamental nas pescas da região, representando cerca de 30% da produção pesqueira do Algarve. A frota pesqueira de Santa Luzia é constituída por 38 barcos, divididos conforme o seu tamanho: 17 de pesca local (<9 m de comprimento) e 21 de pesca costeira (>9m).

Curiosidade: Santa Luzia é o único porto de pesca a nível nacional que se dedica exclusivamente ao polvo, sendo um dos portos pesqueiros mais importantes da comunidade europeia para esta espécie.

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