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BYCATCH IN BIVALVE FISHERIES OF ALGARVE

UNIVERSIDADE DO ALGARVE
Faculdade de Ciências e Tecnologia
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Mestrado em Biologia Marinha

Trabalho efetuado sob a orientação de:
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DECLARAÇÃO DE AUTORIA DE TRABALHO

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

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ABSTRACT

The present study assessed bycatch in Algarve grid dredge fisheries and estimated fishing gear inflicted damage and mortality, with the purpose of formulating mitigation measures, specifically fishing gear modifications. Bycatch using this dredge has been shown to surpass target species catch and, although it would not be a major problem if the discarded individuals survive, it nonetheless creates an issue of concern for fishers. Fishing surveys were conducted bimonthly onboard commercial fishing vessels in the same coastal areas near Olhão, throughout six months, in order to ascertain seasonal variation. Fishing targeted commercially valuable clam species, either *Donax trunculus*, using the DDredge, or *Spisula solida* and *Chamelea gallina*, using the SDredge. All individuals captured were attributed scores from a damage table ranging from 1 to 4, where 1 or 2 equate organism survival and 3 or 4 mortality. Results showed significant differences between fisheries regarding total catch composition, confirming dredge capacity to maximize target catch, but none for bycatch, demonstrating similar benthic communities in all sampled sites. Bycatch reached a maximum of 57.5% in abundance, and was significantly higher using the DDredge. Damage and mortality, although overall low, varied as a result of the morphological characteristics of the taxa itself, as such Echinodermata was presented as most subject to damage. Higher percentages of bycatch in the DDredge indirectly led to higher mortality rates as well. Seasonality analysis indicated the influence of spring on an increase of bycatch abundance in the DDredge. The implementation of a BRD and net bag in the grid dredge are proposed to reduce bycatch, as well as its damage and mortality, while maintaining fishing yield. Comparative studies are advised as to evaluate BRD effects on catch composition, bycatch amount, mortality, and discard rates. Additionally, the re-evaluation of the damage table through survival experiments is recommended.

Keywords: bycatch, bivalve, metallic grid dredge, mortality, Algarve coast, BRD

RESUMO

A pesca acidental ou acessória é geralmente definida como a captura não intencional de organismos que não se enquadram na definição de captura alvo, por exemplo, indivíduos de espécies sem importância comercial ou juvenis das espécies alvo. A captura acessória inclui todos os indivíduos que são descartados para o mar, as rejeições e aqueles que, apesar de não serem considerados captura alvo, por qualquer outra razão sejam retidos e desembarcados. A pesca acessória é, assim, a diferença entre a captura total e a captura alvo.

Portugal é um pequeno país com a terceira maior Zona Económica Exclusiva (ZEE) da União Europeia. As comunidades costeiras portuguesas dependem da pesca e de atividades com ela relacionadas como meio de subsistência, sendo estas uma forte componente do património cultural português. Apesar de a atividade pesqueira ser regulada por legislação própria, continua a ser um elemento perturbador dos ecossistemas e das comunidades marinhas.

Este projecto focou-se na frota pesqueira que se dedica à captura de amêijoa branca (*Spisula solida*), pé-de-burrinho (*Chamelea gallina*) e conquilha (*Donax trunculus*) com ganchorra de grelha.

A ganchorra de grelha é utilizada na pesca de bivalves ao longo da costa algarvia e em especial na área do presente estudo. Esta ganchorra é composta por uma boca com um pente de dentes na barra inferior, acoplada a uma armação de grelha metálica onde a captura é retida. Os indivíduos de pequenas dimensões, incluindo juvenis da espécie alvo, isto é, abaixo dos 25 mm de tamanho mínimo legal, escapam por entre as barras da grelha, enquanto a captura alvo e indivíduos maiores da captura acessória são mantidos e trazidos a bordo. Encontra-se demonstrado para o uso desta ganchorra uma redução da captura de juvenis da espécie-alvo e uma rápida recuperação dos indivíduos que escapam através das barras da grelha. No entanto, a sua utilização acarreta consequências, já que esta arte de pesca não é tão seletiva como seria desejável, promovendo capturas acessórias e, consequentemente, rejeições.

O presente trabalho tem como objetivo avaliar a importância das capturas acessórias na pesca de bivalves com ganchorra de grelha no Algarve, determinar o dano e mortalidade causados por esta arte de pesca à captura total, aferir a existência de sazonalidade e propor medidas que minimizem a pesca acidental. Tais objetivos foram alcançados através da quantificação das capturas acessórias obtidas com ganchorras de grelha com diferentes

espaçamentos entre as barras paralelas, 8 mm para a captura de *D. trunculus* (DDredge) e 12 mm para *S. solida* e *C. gallina* (SDredge). A amostragem decorreu duas vezes por mês, entre Fevereiro e Julho, a bordo de embarcações de pesca comercial na costa algarvia perto de Olhão. A determinação da mortalidade de cada indivíduo foi calculada através da atribuição de uma escala de dano de 1 a 4, em que 1 ou 2 implicam a sobrevivência do organismo rejeitado e 3 e 4 a sua morte.

Foram encontradas diferenças significativas entre a composição das capturas totais das duas ganchorras, confirmando a capacidade de cada ganchorra maximizar a captura da sua respectiva espécie alvo. Porém, nenhuma diferença foi encontrada entre a composição da captura acessória, demonstrando a presença de comunidades bentónicas semelhantes em todos os locais de amostragem. A captura acidental atingiu um máximo de 57.5% em abundância e 35.1% em biomassa e foi significativamente maior usando a DDredge, devido à menor abundância da espécie alvo.

Dano e mortalidade, embora baixos, variaram em resultado das características morfológicas de cada taxa. As espécies alvo mostraram, em geral, baixas mortalidades devido à natureza resistente das conchas destas espécies de bivalves, com *S. solida* como mais resistente e *D. trunculus* mais susceptível a dano. Tanto na pescaria de *S. solida* e *C. gallina* como na de *D. trunculus*, Echinodermata foi o phylum com maior mortalidade e dano, em particular a classe Echinoidea, devido à sensibilidade a dano mecânico das placas fundidas que compõem estes organismos. Elevadas percentagens de capturas acessórias na DDredge causaram, assim, indiretamente taxas de mortalidade significativamente maiores, já que se verificou menor abundância de espécies resistentes a dano.

Análises de sazonalidade indicaram o aumento da abundância das capturas acessórias na DDredge desde o Inverno até à Primavera. Não foram observadas diferenças significativas entre o Verão e as restantes estações, presumivelmente devido ao baixo tamanho da amostra causado pelo fecho da pesca durante esses meses. Porém, visto que outros autores indicaram também a presença de sazonalidade na abundância das capturas da ganchorra de grelha, especificamente durante o Outono, torna-se evidente a necessidade de estudos adicionais que explorem estas variações.

Recomenda-se a implementação de um aparelho que reduza a proporção de rejeições (BRD) na ganchorra de grelha. Este BRD consiste numa grelha articulada diagonalmente posicionada na armação metálica da ganchorra e na criação de uma abertura no topo da mesma. O espaçamento entre as barras da grelha do BRD deverá ser largo o suficiente para a permitir a entrada e retenção da espécie alvo, mas estreito de modo a prevenir a entrada de

indivíduos da captura acessória de maiores dimensões, excluindo-os através da abertura mencionada. No entanto, é indispensável que esta alteração à ganchorra não cause redução no rendimento de pesca. Propõe-se, assim, que a grelha posterior da ganchorra seja eliminada e um saco de rede acoplado. Desta forma evita-se a perda de captura alvo pela abertura no topo da armação metálica durante a recolha da ganchorra, o único momento da operação de pesca em que esta se encontra numa posição vertical. Prevê-se que, com estas alterações, as rejeições sejam reduzidas, bem como o dano e mortalidade causados pela ganchorra de grelha, visto que a imediata exclusão de organismos lhes permitirá rápida recuperação de atividade e menor risco de predação.

Estudos comparativos que avaliem o efeito das modificações propostas são aconselhados. Deste modo, deverá proceder-se ao arrasto simultâneo de ganchorras com e sem BRD, de modo a avaliar os efeitos do mesmo no rendimento de pesca, composição das capturas, proporção de capturas acessórias, mortalidade e taxas de rejeição. Recomenda-se também a reavaliação da tabela de danos usada através de experiências de sobrevivência.

Palavras-chave: captura acessória; bivalve; ganchorra de grelha; mortalidade; Algarve; BRD

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1. INTRODUCTION

1.1. CONTEXT

Commercial fishing represents one of the greatest impacts on the marine benthic ecosystem (Chícharo, 2002a). Demersal fishing gears cause a loss of habitat through physical disturbance of the seabed, and also the capture and mortality of non-target organisms, which can lead to significant changes to the benthic community structure, both in short and long term (Jenkins *et al*., 2001).

The unintentional capture of non-target organisms is more than a scientific issue; it is also an economic, political and ethical matter (Hall *et al*., 2000). This problem impacts both marine ecosystems and fishing dependent societies, causing the need for a balance between these two factors.

In Portugal, dredge fishery has been exploiting clam beds since 1969 (Chícharo *et al*., 2002a) and currently targets *Spisula solida*, *Donax trunculus*, *Chamelea gallina* and *Ensis siliqua* in the South zone (Gaspar *et al*., 2015a). It has been suggested that seasonal variations of the benthic communities may be present in the Algarve (Alves *et al*., 2003), accordingly they should be taken into account when studying bivalve dredging impacts.

The optimal situation for the bivalve dredge fishery would be one where maximal efficiency, low bycatch of non-target species, retention of very few undersized individuals; and low proportion of damaged individuals would prevail. In order to achieve such goals, management measures should be implemented and fishing gear modified according to the local environment, status of target species populations and current discard rates.

Thus, the present work aims to assess and quantify the importance of discards in the Algarve bivalve dredge fisheries, evaluate its seasonal variation, estimate their mortality and propose measures to minimise both discards and mortality.

1.2. STUDY AREA

Located in the westernmost point of Europe, Portugal is a small country with an extensive coastline and an Exclusive Economic Zone (EEZ) of 1.7 million km^2 (European Commission, 2008), 18 times its terrestrial area of 92.212 km^2.

Portuguese coastal communities are, therefore, known for relying on fishing and fishing-related activities as means of subsistence, which translates into a great cultural heritage and dependence of the Portuguese society on these activities. Portugal is the greatest consumer of fishing products in the EU (56.7 kg per person) and the third most important employer in the EU fishery sector. In addition, Portugal is the 4th greatest exporter of bivalves to non-EU countries (European Commission, 2014). Among the artisanal fishing fleets, the bivalve dredge fleet is one of the most important, considering the number of fishers and other agents involved, the volume of the landings and the value of the target species.

According to the current legislation (Portaria 149/92), and regarding bivalve dredge fisheries, Portugal is divided in to three operation areas:

1) Northwest (NW) zone – from the limit of the territorial sea to the Pedrógão parallel (39º 55’ 04’’ N);
2) Southwest (SW) zone – from the Pedrógão parallel (39º 55’ 04’’ N) to the São Vicente cape parallel (37º 01’ 17’’ N);
3) South zone – from its coastline and São Vicente cape parallel (37º 01’ 17’’ N) to the limits of the territorial sea.

The present work will be carried out in the southeast zone of the Algarve coast, where the major part of the dredge fleet operates. In this area the dredging occurs during most part of the year due to the good weather conditions that characterize the region.

1.3. THE ALGARVE DREDGE FISHING FLEET

Artisanal fishing vessels compose 70% of the Portuguese fishing fleet (Oliveira *et al*., 2007b). The Portuguese dredge fishing vessels can be divided into two groups – local fleet and coastal fleet – each with certain specifications (Table 1.1) regulated by legislation and highly dependent on local weather conditions. These specifications include the overall length (OAL) in metres, the gross tonnage (GRT) in register tonnes, and the engine horsepower in kW.

The Algarve’s bivalve dredging fleet is the largest of the country accounting 53 fishing vessels licensed at the end of 2014, opposed to the 11 of the NW coast and the 21 of the SW coast. It is also the fleet that usually operates more days at sea per year, having reported an average of 177 days in 2014, whereas the NW and SW fleet operated only 88 and 98 days (DGRM Database, 2015), respectively, as expected considering that the weather and hydrodynamic conditions felt in the south are less severe than in the northwest and southwest coasts.

In the last fifteen years the number of fishing vessels, along with OAL, GRT and engine horsepower, has been decreasing (Figure 1.1), although annual catches of bivalve species have remained relatively stable, with the exception of 2002 through 2005 (Figure 1.6).

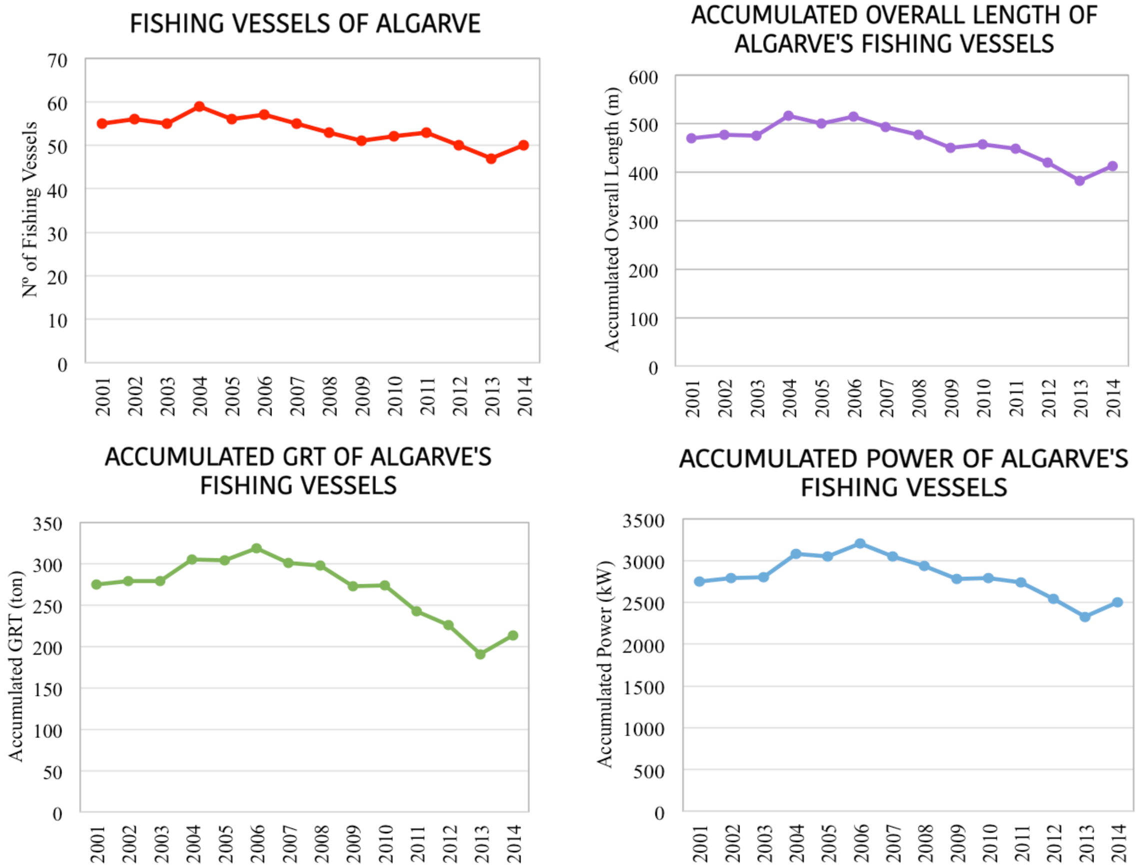

Figure 1.1. Number, accumulated length, accumulated GRT and accumulated engine power of Portuguese fishing vessels, licensed in operating bivalve dredges, from 2001 to 2014. Source: DGRM Database, 2015.

Table 1.1. Local and coastal fleet fishing vessels specifications: 1) Overall length (m); 2) GRT (ton); 3) Engine horse power (kW) (Portaria N.º 1102 - E/2000; Oliveira *et al*., 2007a).

	Local Fleet	**Coastal Fleet**
Overall length (m)	≤ 9	9-33
GRT (ton)	1.18-6.31	3.19-23.64
Engine horse power (kW)	Closed deck: ≤75 kW Open deck: ≤ 45 kW	≥ 25 kW

1.4. FISHING GEAR - METTALIC GRID DREDGE

Three dredge types are used in Portuguese bivalve fishing: the north dredge (ND), which is usually used in the NW coast, the traditional dredge (TD) and the metallic grid dredge (Figure 1.2). Unlike the first two listed dredges, which rely on a diamond mesh net bag as retention system, the metallic grid dredge is differentiated by its rigid retention structure. According to Gaspar *et al*. (2001), the metallic grid dredge is also more selective and leads to less discard mortality than both the ND and TD.

In the south coast the metallic grid dredge is used to catch commercially valuable clam species. This gear was introduced in the Portuguese south coast in the year 2000 (Oliveira *et al*., 2007b), as a result of modifications to the traditional dredge through collaboration between the Portuguese Institute for the Ocean and Atmosphere (IPMA, ex-IPIMAR) and the fishers from the Setúbal region (Gaspar *et al*., 2001).

This dredge comprises a metallic frame (dredge mouth) with a toothed lower bar and a rectangular or semi cylindrical metallic grid box to retain the catch. The dredge mouth is welded to a triangular frame onto which the towing and hauling cables are attached. The metallic grid box, where the bivalves are retained, is kept 10 cm apart from the sediment by two "skates" placed at the rear of the grid to both improve the selectivity and efficiency of the gear and to reduce fishing gear impact (Gaspar *et al*., 2001; Gaspar & Chícharo, 2007; Martins *et al*., 2015). The dredge mouth is articulated to the metallic grid box by a net in order to improve the behaviour of the dredge during the tow. The space between teeth, number of teeth, tooth length and distance between the bars of the grid box depend on the target species. Usually, the length of the teeth used to catch bivalves does not exceed 20 cm, although in the case of the razor clam fishery the tooth length may reach 60 cm (Gaspar & Chícharo, 2007).

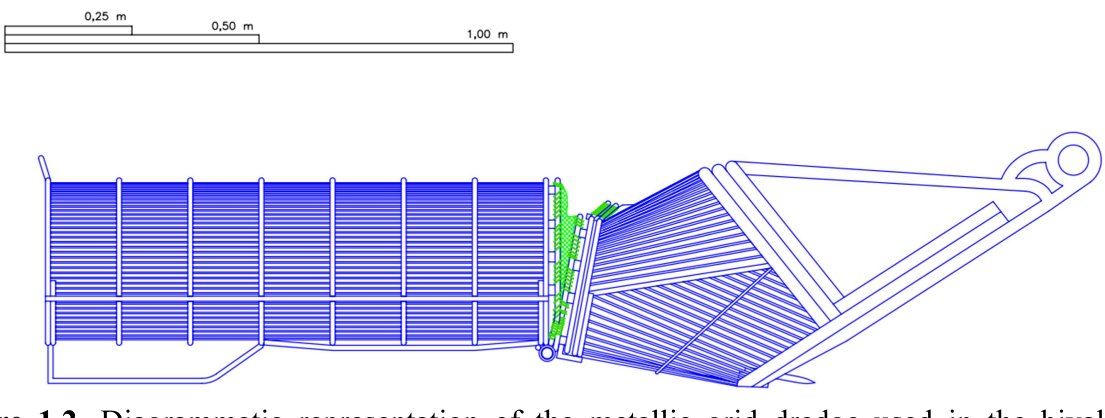

Figure 1.2. Diagrammatic representation of the metallic grid dredge used in the bivalve fishery. Schematic drawing made by Miguel Carneiro, IPMA.

1.5. FISHING OPERATION

The fishing gear must be previously prepared by tying two cables to it, one of them being the traction cable with a 3:1 warp to depth ratio, and the other a hauling cable with the purpose of emptying the gears into containers.

To successfully use the metallic grid dredge four phases of operation must be fulfilled:

1) Bivalve bed localization - Short one-minute tows are made in order to locate the bivalve bed. Then, once located, a five-minute tow is made to determine the fishing yield. If high, it leads to the marking of the area through a buoy.

2) Dredging - The boat is positioned and dredging begins with a tow of one to 30 minutes, depending on the target species, its density at the site and the type of substrate. In the case of larger vessels, the dredge is lowered over the stern with dredging parallel to the coast and, whenever possible, against the tide. In smaller ships, the dredge is set from starboard and hauled from the stern, performing circles at the bivalve bed.

3) Washing - When the tow is finished, the fishing gear is hauled to the surface, using a hydraulic or hand winch, and washed in order to remove the sediment and debris.

4) Catch sorting - The gear is then retrieved and the total catch is sorted in order to separate the retained catch from the discards. This sorting is made first through a rotary sieve that separates empty shells, rocks, sediment and small individuals, which pass through the grids and are returned to sea, and the remainder catch is, subsequently, collected in containers that are emptied on a sorting table and hand-sorted by the fishers, or crew, that select non-target species and individuals of the target species below the minimum landing size (Oliveira, 2014). After this selection the discards are returned to sea and the retained catch is stored for selling.

1.6. TARGET SPECIES

There are mainly four bivalve species of commercial interest in Algarve dredge fisheries: *Ensis siliqua*, *Spisula solida*, *Donax trunculus* and *Chamelea gallina*; of which the latter three will be addressed as the target species for the dredging fishing surveys performed in this project.

1.6.1. *SPISULA SOLIDA*

Figure 1.3. *Spisula solida*.

Spisula solida (Linnaeus, 1758), or white clam (Figure 1.3), is a suspension feeding bivalve species of the family Mactridae, with an Atlantic distribution ranging from the south of Iceland and Norwegian Sea to Morocco and, occasionally, Madeira Island (Pereira *et al*., 2007).

In Portugal this clam can be found on sandy bottoms at varying depths depending on the area of the coast. The density of *S. solida* is higher in the northwest coast between 16 and 30 metres depth, in the southwest coast at 3 metres and between 16 and 25 metres depth and, finally, in the south coast between 3 and 6.6 metres depth (Gaspar *et al.*, 2015a; 2015b; 2015c).

The white clam has separate sexes reaching maturity during its first year of life, in function of its age rather than its size. Synchronism in gonadal development and spawning usually occurs (Gaspar & Monteiro, 1999b; Joaquim *et al*., 2008). This synchronism plays a key role in the reproductive success of *S. solida,* since this species has external fertilization so the simultaneous presence of both male and female gametes in the water column will increase the probability of egg fertilization.

The reproductive cycle follows an annual schedule, in which the resting phase corresponds to summer, the ripe stage to winter and spawning to late winter, extending throughout spring (Joaquim *et al*., 2008). It has been suggested that spawning in *S. solida* is triggered by an increase in sea surface temperature (SST) and not by a definite temperature (Gaspar & Monteiro, 1999b; Joaquim *et al*., 2008).

During its first two years of life, *S. solida*, influenced by the food availability (Seed & Richardson, 1990), exhibits a rapid growth, reaching 25 mm, the minimum landing size, in approximately one year and a half (Gaspar *et al.*, 1995).

In the bivalve beds along the Algarve coast, the white clam is currently the most abundant species, both in biomass and number, although the population is mainly composed by juveniles below the minimum landing size, indicating that a good recruitment occurred in 2014 (Gaspar *et al.*, 2015a).

The annual catch of *S. solida* in south Portugal during the last 15 years was at its highest in 2003 and 2004, period when the catches reached about 1700 tonnes per year. Gaspar *et al*. (2003a) proposed a change in the legislation regarding daily quotas that may have also influenced the abrupt descent of the annual catch for *S. solida* in the next two years (132 tonnes in 2006). This negative trend remained until 2014 (Figure 1.6).

S. solida is one of the major target species of bivalve fisheries in this area, which increases the importance of regulating and implementing management measures for this activity, to allow population growth and recovery, consequently increasing fishing yield and annual catches.

1.6.2. *CHAMELEA GALLINA*

Figure 1.4. *Chamelea gallina*.

Chamelea gallina (Linnaeus, 1758), or striped venus clam (Figure 1.4), is a suspension feeding bivalve species of the family Veneridae with an equivalve and inequilateral shell that is marked by slightly irregular concentric grooves that are rounded and closely positioned (Pereira *et al*., 2007).

The striped venus clam can be found from the southwest and south of Portugal (Gaspar *et al.*, 2015a; 2015b) to the Mediterranean Sea, including the Black Sea (Poppe & Gotto, 1993). This species prefers sandy and muddy bottoms from 5 to 20 metres of depth

(Pereira *et al*., 2007) presenting higher densities at about 6 metres depth along the Algarve coast (Gaspar *et al.*, 2015a), similarly to *S. solida*.

This short life spanned species (Gaspar *et al.*, 2004) is gonochoristic and has a high growth rate, reaching a maximum length of 50 mm (Pereira *et al*., 2007). The gametogenesis in *C. gallina* starts in November, spawning between June and late September, and resting period from late September to December (Gaspar & Monteiro, 1999b).

In Portugal, the striped venus clam population of the south occupies a large area and is the second most present commercial species in both abundance and biomass, even though most individuals are below the minimum landing size (Gaspar *et al.*, 2015a).

The annual catch in tonnes for *C. gallina* in south Portugal displayed a somewhat erratic trend between 2001 and 2005, presenting both very low (2001 and 2004) and very high catches, reaching the maximum of the last 15 years in 2002 with an annual catch of 622 tonnes. This tendency stabilized in 2006, when the annual catch started to decrease, reaching its lowest value in 2010 (15 tonnes), after which it started to slowly increase, surpassing the catches of both *S. solida* and *D. trunculus* (Figure 1.6).

1.6.3. *DONAX TRUNCULUS*

Figure 1.5. *Donax trunculus*.

In Portugal, four species of the genus *Donax* are present, namely *D. trunculus*, *D. vittatus*, *D. semistriatus* and *D. variegatus*.

In terms of abundance and biomass the most frequent *Donax* species in the northwest coast is *D. vittatus* (Gaspar *et al*., 2015c); in the southwest coast is *D. trunculus* and *D. vittatus* (Gaspar *et al*., 2015b); and in the south coast, where the study area is located, *D. trunculus* (Gaspar *et al*., 2015a) (Figure 1.5) is the most abundant species. *D. variegatus* is morphologically the most distinct species of the above mentioned, occurring only sporadically and, therefore, with less commercial importance than the remaining species (Gaspar *et al.*, 2015a; 2015b).

The members of the family Donacidae, to which the genus *Donax* belongs, are suspension-feeders of phytoplankton (Mouëza & Chessel, 1976) and suspended particulate organic matter (Wade, 1964), a factor that influences the distribution of this taxon. Hence, these species can be typically found where the hydrodynamics favour the presence of suspended particles, namely in exposed sandy beaches (Ansell, 1983) from the British Isles to Morocco (Pereira *et al*., 2007). In the Mediterranean Sea, due to the low tidal amplitude, *D. trunculus* occurs between 0 and 2 metres depth (Salas, 1987). In the Atlantic Ocean it occurs between 0 and 6 metres (Gaspar *et al*., 2002b) and, specifically in Portugal, its higher densities are found from 0 to 3 metres (Gaspar *et al*., 1999b; 2015).

Some *D. trunculus* populations present depth segregation (Wade, 1967; Amouroux, 1972; Guillou & Le Moal, 1978; Ansell & Lagardère, 1980; Bayed & Guillou 1985; Guillou & Bayed, 1991; Le Moal, 1993) while others do not (Mouëza, 1975; Mazé & Laborda, 1988). Depth segregation is a phenomenon characterized by the occurrence of an age gradient as a function of depth distribution. Several studies have found that, in some cases, there is an increasing gradient, at the mid-tide level juveniles can be found at shallower depths and adults at greater depths, usually in the European coast (Wade, 1967; Guillou & Le Moal, 1978; Ansell & Lagardère, 1980; Guillou & Bayed, 1991; Le Moal, 1993), while in other cases there is a decreasing gradient, thus the inverse situation occurs, usually in the North African coast (Amoroux, 1972; Bayed & Guillou 1985).

The cause of depth segregation in *D. trunculus* has been correlated to both abiotic and biotic factors. The presence of juveniles at greater depths has been explained as result of a lower tolerance to the higher temperatures of shallower depths (Bayed & Guillou, 1985) and because dislodgement and predation would be less likely to occur at greater depths (Stenton-Dozey & Brown, 1994). However intraspecific competition between larvae and adults of *D. trunculus* has also been pointed as one of the causes for depth segregation. Considering that food and space availability are strongly related to this competition (Caddy, 1989) it is likely that larvae prefer to settle far away from larger individuals, at shallow depths where food availability is higher. As individuals grow, they move to greater depths, allowing space in the shallow depths for larval fixation (Scheltema, 1971).

In the Algarve coast depth segregation is present with an increasing gradient as younger and smaller individuals are distributed at lower depths, a factor to be considered while in this *D. trunculus* targeted fisheries. Due to the active hydrodynamics of the shallow areas, burrowing activity of juveniles is more important and efficient than in the adults that are subject to the lower hydrodynamics that prevail in deeper bathymetrics (Gaspar *et al*., 2002b).

Regarding the reproductive characteristics of *D. trunculus*, it can be stated that it is a gonochoristic species with a synchronic gonadal development. The gametogenesis occurs from November till the end of August and is characterized by a continuous spawning activity between March and August with two activity peaks, one in March and one in May-August (Gaspar *et al*., 1999b).

A few months after settlement, *D. trunculus* becomes sexually mature (Mouëza & Frenkiel-Renault, 1973; Gaspar *et al.*, 1999b) reaching a maximum shell length of 44 mm over 3 years lifespan (Mazé & Laborda, 1988; 1990).

In general, the annual catch of *D. trunculus* has been decreasing in the last 15 years: at its highest the annual catch was between 345 and 397 tonnes and in 2014 it was at 108 tonnes, the lowest catch in the period analysed (Figure 1.6).

Overall it can be stated that the annual catch from the southern Portugal populations of these three target species are low, particularly when compared with the early 2000's. Gaspar *et al*. (2015a) shows that the demographic structures are currently favouring juveniles, indicating a good recruitment in previous years and a possible recovery for these fishing activities in the future years. This recovery is a consequence of the application of adequate management measures regulated by legislation throughout the years.

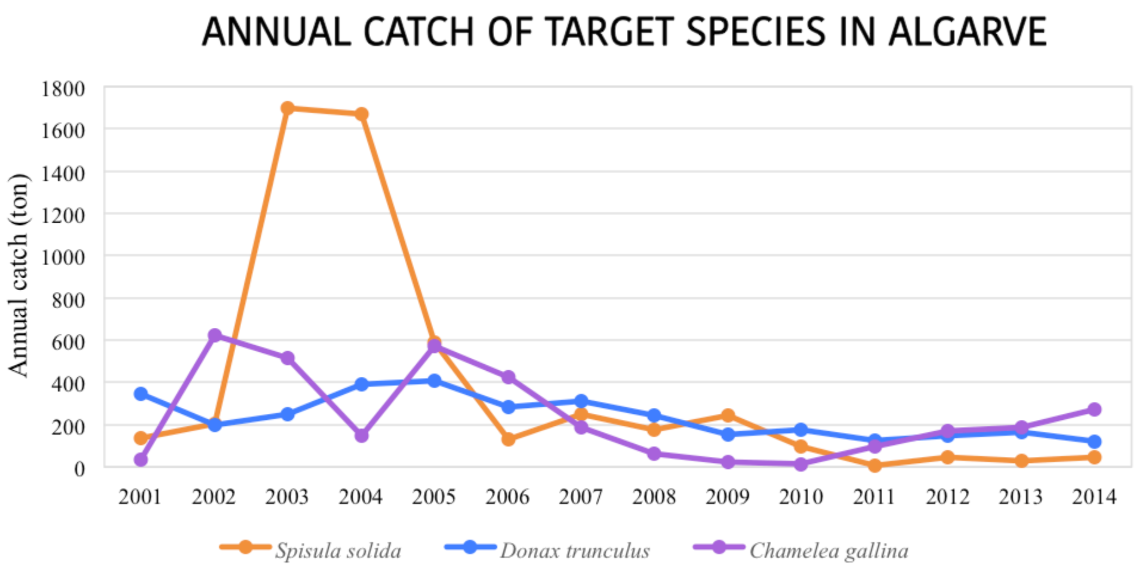

Figure 1.6. Annual catches (2001 to 2014) for *Spisula solida*, *Donax trunculus* and *Chamelea gallina* populations of the Algarve. (Source: DGRM, 2015).

1.7. LEGISLATION

The EU formally created the Common Fisheries Policy (CFP) in 1983 with the goal of regulating and bringing to an end disputes among member states over fishing issues (Miles, 1989). Currently, the CFP encourages a more sustainable fishing policy, promotes the quality of farmed fish and eradication of discards, while maintaining an eco-friendly approach (European Commission, 2014). These goals are attained by enforcing a multitude of measures such as the Total Allowable Catch, fishing quotas and landing obligations for several fisheries. As of January 1st 2015, a landing obligation was implemented to pelagic and industrial fisheries, and in salmon and cod fisheries of the Baltic, in order to end discards. Although imposed with some exemptions, such as high survivability and *de minimis*, the EU aims to enforce the landing obligation to all fishers by 2019.

Meanwhile, measures regarding most small-scale fisheries, such as the bivalve dredge fishery, are regulated through legislation defined by national governments.

Management measures in place intend to reduce or limit effective fishing effort (input controls) as well as to restrict the total catch to predefined limits (output controls). Management input controls include restrictions on fishing capacity (number and size of fishing vessels), vessel usage (fishing time) and fishing effort controls (product of capacity and usage), whilst output controls comprise daily catch quota per vessel and species, and limiting bycatch (Pope, 2002). In addition to the control measures described above, other technical measures are also in place, namely limits on gear specifications, minimum landing sizes and seasonal closures.

Changes in legislation are propelled by changes in the acquired knowledge regarding the subject matter. Scientific projects provide the necessary information on the target species biology and population and on the current situation of the exploited ecosystem. Through this information, which in Portugal is gathered by IPMA, legislation is built taking into account the necessary equilibrium between the conservation status of the exploited target species and the socio-economic aspect of fisheries.

Figure 1.7 illustrates this idea by presenting a timeline of the evolution of Portuguese legislation regarding bivalve dredge fishing. As is shown, legislation is fluid, evolves and increases complexity as time passes, endeavouring to find stability between the target populations, environmental conditions and market demand.

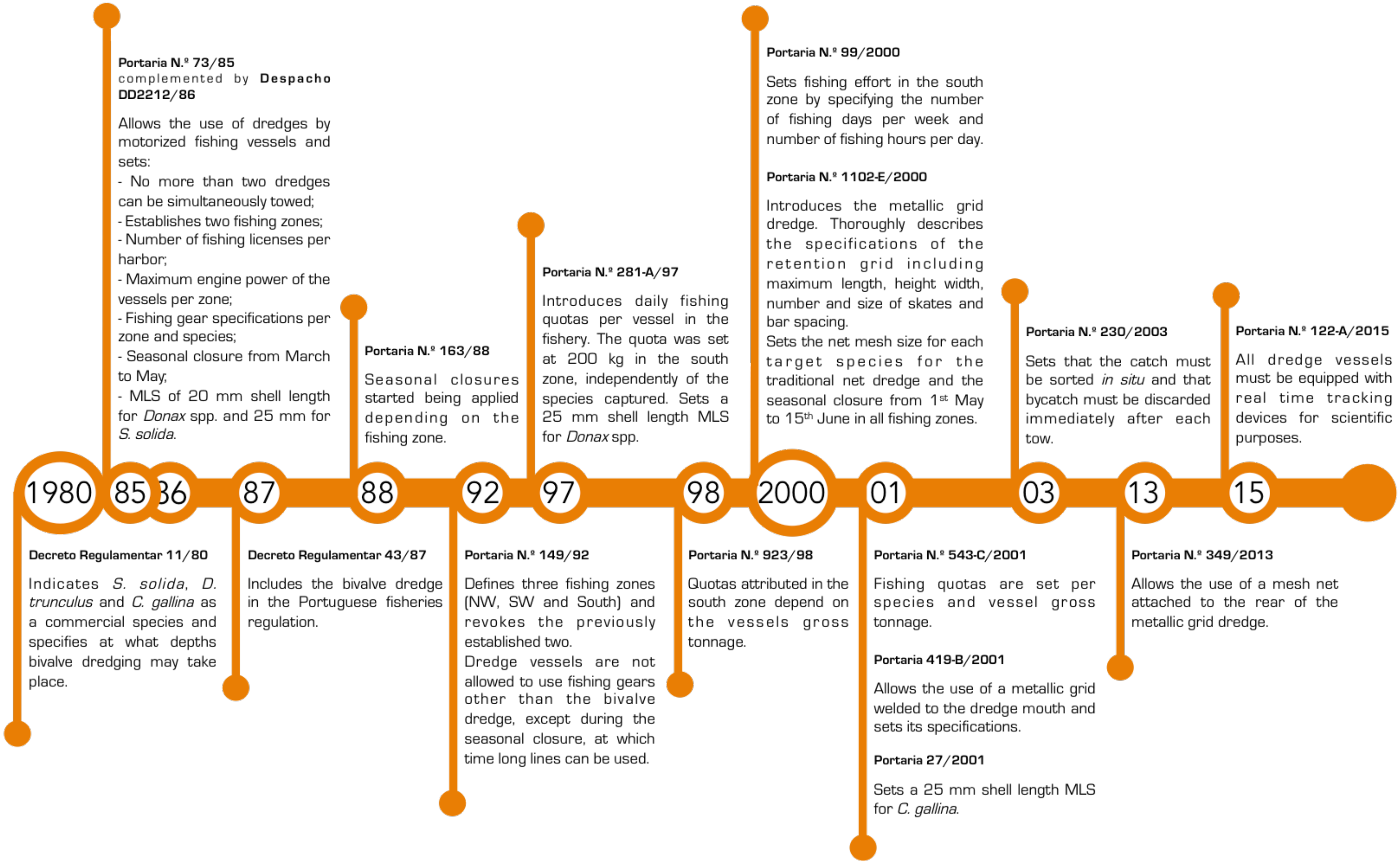

Figure 1.7. Portuguese legislation timeline focusing on major innovations and changes regarding the use of bivalve dredges targeting *Spisula solida*, *Chamelea gallina and Donax trunculus*.

Currently, legislation for the Portuguese south coast comprises Portaria N.º 1102-E/2000; Portaria N.º 27/2001, Portaria N.º 230/2003, Portaria N.º 171/2011, Portaria N.º 349/2013 and Portaria 122-A/2015.

Portaria N.º 349/2013 alters and republishes Portaria N.º 1102-E/2000 which approves the Fisheries Regulation for Towed Gears, that regulates Portuguese bottom trawling, pelagic trawling and dredge fisheries. The next paragraphs describe the most important measures presented in this Portaria, regarding the bivalve fishery of Algarve and the three target species of this project.

The aforementioned legislation establishes and delimits three operation areas (NW; SW and south zones) and refers to the minimum depth of 2.5 metres for towed dredging and 300 metres as the minimum distance to the coastline during the summer season. Moreover, currently, it is not allowed to tow more than two dredges simultaneously.

Fishing vessels must not have an engine power higher than 73.5 kW, with the exception of fishing vessels licensed before December 31st of 1999.

Both manual and towed dredges characteristics are described and regulated but, given the scope of this project, only the towed dredge characteristics will be specified. The maximum mouth width of dredges must not exceed 1 metre and tooth length depends on the target species, although a limit of maximum length of 200 mm for *S. solida*, *D. trunculus* and *C. gallina* is in place. Interval between teeth must not be inferior to 15 mm. Minimum mesh size for targeting *S. solida*, *C. gallina* and *Donax* spp. is 30 mm. Instead of a net bag a retention grid may be used. The maximum length, height and width of the retention grid are 125 cm, 50 cm and 80 cm, respectively. This grid may be equipped with three skates welded at the bottom, two of them placed in the rear and the other in the front. Minimum distance between bars of the grid depends on the target species, being 12 mm for *S. solida* and *C. gallina* and 8 mm for *D. trunculus*. It is forbidden to use a blade or blade like devices instead of a tooth bar.

A seasonal closure from May 1st to June 15th is set for all fishing zones.

Minimum landing sizes for commercial target species of Portugal are established by Portaria N.º 27/2001. The Minimum Landing Size (MLS) is a fishing size limit enforced with the goal of protecting the spawning biomass, thus maintaining a healthy and structured population. This measure, among others, ensures sustainability along with a more productive fishery. The MLS is set considering the size/age of first maturity, life span and growth of the species (Gaspar *et al*., 1995; Gaspar, 1996). The MLS established for the three target species under study, *S. solida*, *D. trunculus* and *C. gallina*, is 25 mm shell length.

Portaria N.º 230/2003 imposes that the catch must be sorted *in situ* and bycatch discarded immediately after each tow,

Portaria N.º 171/2011 modifies Portaria N.º 99/2000 (Figure 1.7) regarding working hours. It limits the local fleet to six days per week (Monday to Saturday) and the coastal fleet to five days per week (Monday to Friday), both from 5h00 to 14h00, from 1st June to 30th September, and from 6h00 to 15h00 during the rest of the year.

Recently, Portaria N.º 122-A/2015 mandates that, from 1st January onwards, all dredge vessels should be equipped with real time tracking devices.

2. STATE-OF-THE-ART

Bycatch is generally defined as catch that is not specifically targeted, however this notion is largely dependent on individual differing perceptions on what non-target catch constitutes. Furthermore, terminology ambiguities, historical differences between world fisheries, and the choices of individual fishers add complexity to this matter. Consequently, a standard international bycatch definition is currently nonexistent.

Literature demonstrates that bycatch is a relatively imprecise term used with different meanings by different authors (McCaughran, 1992; Hall, 1996; NMFS, 1998). All the more when used regarding a specific element of the catch over an extended period of time, as economic interests change overtime, that is “yesterday’s bycatch may be today’s target species” (Murawski, 1992).

The Food and Agriculture Organization of the United Nations (FAO) adopted the definition of McCaughran (1992) (Alverson *et al.*, 1996). Hence, the total catch includes all that is harvested by the fishing gear and reaches the deck of the fishing vessel. The discard catch is a portion of the total catch that, for one reason or another, is thrown into the sea. Thus, the landed or retained catch is whichever is brought ashore and that can be divided into target catch and incidental catch. Bycatch is considered to be a sum of the discards and the incidental catch. Simply put, bycatch is the difference between the total catch and the target catch.

Additionally, the 1998 report of the National Marine Fisheries Service (NMFS, 1998) went further and included in its bycatch definition the unobserved mortality caused by a direct encounter between any organism and the fishing gear. Including so incidental mortality and ghost fishing.

Still, some authors have a more restrictive view on the subject. For instance, Hall (1996) considered bycatch only the portion of the capture that is discarded at sea dead, or injured to an extent that death is the most likely outcome. This definition disregards the incidental catch brought on land and excludes the release, the portion of the capture that is returned to sea with the outlook of survival. However, this dismisses the fact that predator and scavenger abundance increases on the path of some fishing gears, such as the bivalve dredge (Chícharo *et al*., 2002b; Alves *et al*., 2003), which may decrease the survival odds of released catch and thus underestimate the discarded catch.

Overall, bycatch is an ambiguous term with multiple meanings that must be properly described and defined by each author. Nonetheless, all can agree that bycatch is a wasteful occurrence in which resources are not being directed to their highest and best use.

During this project the same set of operational definitions adopted by FAO (McCaughran, 1992; Alverson *et al*., 1996) will be used.

Estimating global discards poses a significant challenge considering the multitude of factors that play a part in this problem, such as: 1. Chosen bycatch definition; 2. Locating reliable data; 3. Discard rate calculation methodology. This may result in a struggle in comparing discard rates from different authors and, in either an overestimation, or underestimation of such.

In fact, in 1983, Saila estimated that 6.72 million tonnes of fish were discarded each year in global commercial fisheries, while a decade later Alverson *et al*. (1996) estimated a much greater average of 27 million tons, from 1980 to 1992. Although this estimate was made excluding freshwater and marine mollusc fisheries, the authors suggest that such an increase in discard rates must be due to not only a worsening discard problem, but also a growth in available data.

Most recently, Kelleher (2005) estimated that 8% of the weight of the global catch is discarded, which totals 7.3 million tonnes of annual discards from 1992 to 2003, of which 65373 tonnes correspond to the dredge fishery. Albeit having used different methodology from Alverson *et al*. (1996), Kelleher's (2005) results strongly suggest that, overall, a significant discard reduction took place, most likely by virtue of an increase in efficient management measures, public awareness, selective fishing gears and a broader range of target species.

Although existing ever since fishing first began (Alverson *et al*., 1996), bycatch has been ignored for decades and only became a publically visible issue recently when the general public discovered cases involving charismatic species such as dolphins (Perrin, 1968) and turtles (Magnuson *et al*., 1990).

With the growth of world fisheries, the consequent increased competition and added rise of environmental groups, the issue of bycatch, which in the past occurred at a lower magnitude and with a less intense impact, became an emerging concern (Alverson & Hughes, 1996).

According to Hall *et al*. (2000) there are only two variables that can be changed in order to achieve the reduction of bycatch: effort and bycatch-per-unit effort. By implementing regulatory bans, limits, trade sanctions; and through consumer boycotts and gear changes, the level of effort can be reduced. Taking management actions, implementing technological and operational changes and training fishers, is the way to reduce the average bycatch caused by each unit of effort. Bycatch reduction can only be achieved through these alterations, because bycatch is no more than the result of our own deficient ability in selecting what we harvest from the ocean (Hall *et al.*, 2000).

It is important to state that attention to bycatch in all fisheries must be given and not only to those that involve emblematic species. Not only because an effort should be made to maintain the equilibrium and sustainability in the marine ecosystem, but also because, for example, the bycatch of fish, crustaceans and other invertebrates in one fishery may severely affect another. In addition, bycatch impacts the ecosystem by altering the population structure of predator or prey. Clark & Hare (1998) described that the bycatch of juvenile Pacific halibuts that occurs during fisheries for other groundfish in Alaska, has an effect, not only in the yield of Pacific halibut fisheries in Alaska, but also in British Columbia, which implies that a bycatch reduction could improve population growth and production. Moreover, bycatch impacts on the ecosystem can alter trophic interactions by altering the relative abundance of species (Crowder & Murawski, 1998).

For all these reasons, bycatch is more than a scientific issue; it is also an economic, political and ethical matter (Hall *et al*., 2000). It should be noted that, although there are vast and extensive studies on bycatch from trawl fisheries, research on bycatch in bivalve dredge fisheries is still relatively scarce.

Additionally, Broadhurst *et al*. (2007) describes a five-step procedure to solve bycatch issues. Firstly bycatch must be quantified, its main species identified and measured, in order to determine and develop modifications to the current practices and fishing gear, then these alternatives must be tested through field experiments, and, lastly, acceptance of the interested stakeholders must be secured.

Bycatch reduction devices, BRDs, can be introduced as a fishing gear modification in order to solve bycatch problems. These devices aim to reduce bycatch rates by either separating species according to their behaviour or mechanically excluding them according to their size (Broadhurst, 2000); as such they often require further assessment and adjustment (Broadhurst *et al*., 2007).

For instance, "escape windows", horizontal and/or vertical panels, strategically placed funnels and panels of square meshes in cod ends (Watson *et al*., 1986; Matsuoka & Kan, 1991; Broadhurst & Kennelly, 1994, 1996; Brewer *et al*., 1998) are commonly used in prawn fisheries, in order to separate the target species from fish. Meanwhile, simple panels or grids placed in the fishing gear can be used to mechanically preclude the catch according to its size (Kendall, 1990; Isaksen *et al*., 1992; Andrew *et al*., 1993; Robins-Troeger, 1994).

BRDs use has been described in Portuguese fisheries for the crustacean-trawl fishery off the coast of Algarve, a multi-species fishery that currently uses a modified Nordmøre grid to reduce bycatch (Fonseca *et al*., 2005), as well as for a demersal purse seine fishery (Gonçalves *et al*., 2008).

Fishers benefit from the use of BRDs since, as Brewer *et al.* (1998) stated for the case of prawn fisheries, a reduction in bycatch would be economically beneficial by 1. Reducing damage to prawns and, subsequently, creating higher catch values; 2. Reducing net drag, thus lowering the fuel costs; and 3. Generating longer tow times, since the cod end would fill slower; and 4. Creating shorter sorting times.

Therefore, considering the key role that gear modifications play on bycatch reduction, it is crucial to develop further studies on the bycatch of the metallic grid dredge, in order to ascertain if further modifications and improvements can be implemented. In addition, studying the eventual occurrence of seasonal variation in the amount and type of bycatch is also important to determine the need for operational changes in bivalve dredging throughout the year.

Yet, it should be noted that, while discard rates may improve with particular gear designs and BRDs implementation, these solutions operate on the assumption that the escaping organisms suffer negligible mortality (Crowder & Murawski, 1998). Thus, it becomes evident the importance of survival experiments that attest to the efficiency of fishing gear modifications.

Broadhurst *et al*. (2006) gathered and reviewed 88 studies published on the topic of bycatch and collateral mortality in trawl fisheries. They concluded that scientists have been estimating collateral mortality caused by towed fishing gear since Fulton (1890) examined the presence of immature fishes in fish beam trawls of Scotland. But, even though the reviewed research was extensive, only 11 studies regarded discard mortality in bivalve dredge fishing (e.g. Gruffydd, 1972; Gaspar & Monteiro, 1999a; Gaspar *et al*., 2001; Palma *et al.,* 2003) while the vast majority of them analysed only the bycatch and mortality of fish and shrimp trawls (Lancaster & Frid, 2002; Davis & Parker, 2004). To overcome this lack of knowledge, it is necessary to increase the research regarding bivalve dredge fishing, namely by quantifying its bycatch and discard mortality.

In Portugal, IPMA has been conducting several studies on dredge selectivity with the goal of finding which gear design was the most appropriate for bivalve dredge fishing. Gaspar (1996) and Gaspar *et al.* (1999a; 2002a) tested a combination of three different tooth spacing and four different mesh sizes, and found that space between the dredges teeth has no effect on selectivity, but that mesh size does. Throughout the experimental phase of the Gaspar *et al*. (2002a) study, scuba divers conducted underwater observation during the bivalve traditional dredge tow, and detected that, immediately after the beginning of the tow, the dredge mouth became blocked by sand. This "sand wave" restricted the passage of the fauna by the interval between teeth, thus reducing selectivity and efficiency of the traditional dredge (Gaspar & Chícharo, 2007).

This line of investigation, carried out by IPMA, led to the conclusion that the bivalve fishery would benefit from a more suitable newly designed dredge. Hence, the metallic grid dredge arose as a result of several dredge modifications in an attempt to do so. Gaspar *et al*. (2001) compared this newly designed dredge with the traditional dredge in the *Callista chione* fishery. The results showed that the traditional dredge had low efficiency and selectivity when compared to the new dredge. In fact, in the new dredge, bycatch and amount of juveniles of the target species was reduced significantly. Thus, this study proved that the metallic grid dredge was more appropriate for bivalve dredge fishing than the traditional one. Nevertheless, it was pointed out that the proportion of bycatch species in the catch was still high.

Palma *et al*. (2003) evaluated bycatch in bivalve dredge fishing of the Algarve using the metallic grid dredge, but focused only on fish species and did not quantify invertebrate species. They found that the bivalve dredge fishery has a moderate impact on flatfish species.

Gaspar *et al.* (2003b) compared three different designs of bivalve dredges (north dredge, traditional grid dredge and metallic grid dredge) in the fishery targeting *S. solida* and found that the achieved results corroborated Gaspar *et al.* (2001) by concluding that a lower bycatch proportion occurred when using the metallic grid dredge. This is due to the rigid nature of the retention grid that allows the escape of undersized individuals and non-target species, unlike the north and traditional dredges that rely on a flexible retention net that, when stretched, causes the mesh to close, and consequently decrease selectivity (Gaspar & Chícharo, 2007).

Further confirming these conclusions, Leitão *et al.* (2009) also compared the ND, TD and metallic grid dredge, adding that, although the metallic grid dredge presents lower bycatch rates than any other dredge, it presents the highest estimated mortality of bycatch. Stating that, apparently, the use of a net bag reduces bycatch mortality, despite also significantly decreasing fishing yields of the target species.

The above studies clearly shows that the low selectivity of the dredge gear inevitably results in some level of unintended catch and, ergo, not all individuals captured will be landed.

Although IPMA succeeded in developing a more efficient and selective dredge in this fishery, the amount of bycatch is still high (Gaspar *et al.*, 2001; 2003b). In some periods (late spring, early summer), it was observed that the quantity of bycatch could surpass the catch of the target species. Furthermore, discarding of bycatch by commercial dredge fishing vessels is a common practice, but should not be a major problem if the discarded individuals survive (Gaspar & Chícharo, 2007). However, survival probability decreases if sorting times are long and/or conditions on deck are unfavourable, in fact, Gaspar & Monteiro (1999a) verified that there is a direct relation between the length of exposure and *S. solida* juvenile mortality. Hence, the damage suffered during the tow is dependent on the size of the specimens discarded and susceptibility to predation after discarding (e.g. Medcof & Bourne, 1964; Fonds, 1994; Kaiser & Spencer, 1995; Broadhurst *et al*., 2006). Although in the Portuguese dredge fishery most discarded species are invertebrates (bivalves, gastropods and echinoderms), most catches are only sorted at the end of the fishing day, which may decrease the survival of discarded individuals (Gaspar & Monteiro, 1999a). Therefore, efforts to reduce the bycatch in Portuguese dredge fisheries must be carried out, which will involve the development of modifications to the grid dredge to further improve selectivity and minimise bycatch (Gaspar & Chícharo, 2007).

As a conclusion, the subject of bycatch in bivalve dredge fisheries still presents information gaps. For this reason, further research is needed for these fisheries, in order to improve their performance and sustainability, as well as lead to the the proposal of specific regulations aiming to minimise the inevitable impacts on the resources and marine environment.

3. OBJECTIVES

The present work aims to assess the importance of discards in the bivalve dredging fishery and to propose modifications to the fishing gear in order to minimise these undesired catches. To attain these major goals it is important to achieve the following specific objectives:

1. Quantify bycatch in *Spisula solida*, *Chamelea gallina* and *Donax trunculus* fisheries of Algarve when using a metallic grid dredge;
2. Ascertain seasonal variation in this bycatch between February and July;
3. Estimate bycatch mortality;
4. Formulate mitigation measures so as to minimise bycatch, specifically by proposing modifications in the fishing gear.

4. MATERIALS AND METHODS

4.1. SAMPLING DESIGN

Sampling surveys took place onboard two commercial fishing vessels (Cláudia Marina and Renovadora) on a bimonthly basis from February to July (Table 4.1) in the same coastal areas of Algarve, near Olhão (Figure 4.1). However, in order to protect the species during spawning and larval settlement, a mandatory seasonal closure, between May 1st and June 15th, was accomplished and sampling was not conducted during this period.

Due to the bathymetric distribution of bivalve populations, two different depths were sampled taking into consideration the distribution depth of the target species, one for the coexisting species *S. solida* and *C. gallina* (5-10 m depth) using the **SDredge** on board Renovadora and another for *D. trunculus* (2-4 m depth) using the **DDredge** on board either Cláudia Marina or Renovadora. SDredge and DDredge gear specifications were identical with the exception of space between bars, being 12 mm for the SDredge and 8 mm for the DDredge. Tow speed ranged between two and four knots.

On each sampling day and per location, two 5-minute tows, using simultaneously two dredges, were performed.

All the catch from each tow and dredge was analysed separately in the laboratory in order to characterize the catch composition and determine the discards rate. With this purpose all individuals presented in the catch were identified, measured and weighted. The species identification was made according to Bucquoy *et al*. (1882–98), Tebble (1966), FAO (1987), Poppe & Goto (1993), Huber *et al.* (2015) and Galindo *et al*. (2016).

Discard mortality was estimated using a damage scale (Table 4.2) and applying it to all individuals following the method adopted by Gaspar *et al.* (2001).

Table 4.1. Days and area sampled throughout winter, spring and summer.

Sampling Day	Latitude	Longitude	Dredge	Fishing Vessel
08.02.2016	N 36°59.789'	W 7°48.471'	DDredge	Cláudia Marina
17.02.2016	N 36°59.377’	W 7°48.359’	DDredge	Renovadora
23.02.2016	N 36°59.513'	W 7°48.709'	DDredge	Cláudia Marina
03.03.2016	N 36°59.693'	W 7°48.472'	DDredge	Renovadora
11.03.2016	N 36°59.307’	W 7º49.549’	DDredge	Cláudia Marina
14.03.2016	N 36°59.05'	W 7°49.967'	DDredge	Renovadora
21.03.2016	N 36°59.321'	W 7°49.409'	DDredge	Cláudia Marina
22.04.2016	N 37°01.917'	W 7°45.700'	DDredge	Renovadora
22.04.2016	N 36°59.285’	W 7º49.254’	DDredge	Cláudia Marina
26.04.2016	N 36°59.574'	W7º48.134'	DDredge	Cláudia Marina
26.04.2016	N 37°00.117'	W 7°47.550'	SDredge	Renovadora
30.06.2016	N 36º59.184’	W 7º50.016’	DDredge	Cláudia Marina
30.06.2016	N 36º59.539’	W 7º49.138’	SDredge	Renovadora
06.07.2016	N 37º00.978’	W 7º46.752’	SDredge	Renovadora
22.07.2016	N 36º59.183’	W 7º49.872’	SDredge	Renovadora

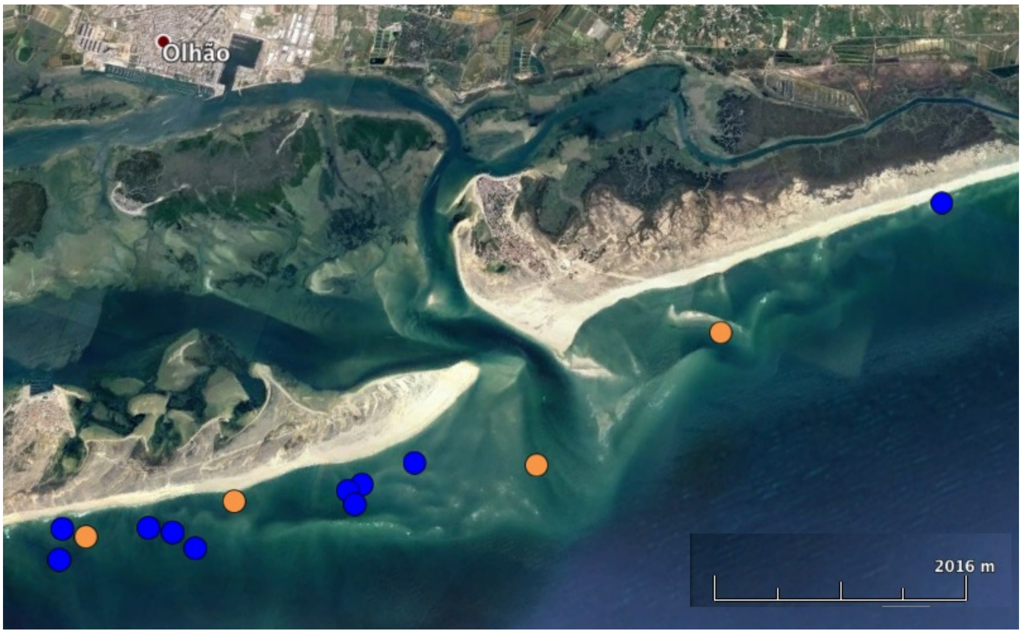

Figure 4.1. Location of sampling sites (DDredge; SDredge).

Table 4.2. Damage scale and criteria for each taxon (adapted from: Gaspar *et al.*, 2001).

Taxon/Score	1	2	3	4
Bivalvia	In good condition	Edge of shell chipped	Hinge broken	Crushed/dead
Gastropoda	In good condition	Edge of shell chipped	Shell cracked or punctured	Crushed/dead
Asteroidea	In good condition	Arms missing	Worn and arms missing	Dead
Ophiuroidea	In good condition	Arms missing	Worn and arms missing/minor disc damage	Major disc damage/dead
Echinoidea	In good condition	< 50% spine loss	> 50% spine loss/minor cracks	Crushed/dead
Anomura	In good condition	Out of shell and intact	Out of shell and damaged	Crushed/dead
Brachyura	In good condition	Legs missing/small carapace cracks	Major carapace cracks	Crushed/dead
Actinopteri	In good condition	Small amount of scales missing/small cuts or wound	Large amount of scales missing/severe wounds	Dead
Polychaeta	In good condition			Sectioned
Other Decapoda	In good condition			Dead

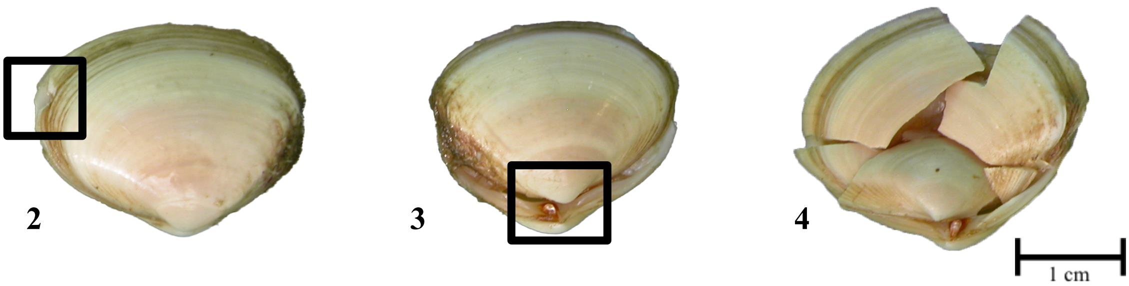

Figure 4.2. Damage scale (score 2, 3 and 4) presented in *Spisula solida* individuals as an example for the Bivalvia taxon.

4.2. DATA ANALYSIS

Data analysis was made for both abundance and biomass considering the two used dredges, SDredge and DDredge, and sampled months (February to July) aiming to find out if there is any significant difference in the catch and bycatch composition and mortality between gears and among months. In the latter case tests were only applied to DDredge since the surveys using the SDredge were only performed in 4 months.

The relationships between samples were examined by non-metric multidimensional ordination plots (MDS) and cluster analysis (Clark and Warwick, 1994). SIMPER analysis (similarity percentage – species contribution) was undertaken in order to highlight the taxa that most contributed to the dissimilarity between dredges. Abundance data was square-root-transformed prior to cluster analysis using the Bray–Curtis method to produce a similarity matrix. The analysis of similarities (ANOSIM) routine (Clark and Warwick, 1994) was used to detect any strong difference on bycatch and mortality composition. These analysis were performed using the PRIMER 6.0 ©software package (Clark and Warwick, 1994).

Analyses of variance (ANOVA) or Kruskal–Wallis ANOVA were used to investigate differences on the proportion the bycatch and mortality obtained from each dredge. Multiple comparisons were performed using the Dunn's test. Prior to the application of ANOVA or Kruskal–Wallis ANOVA, data were transformed to arcsine square root values when expressed as a percentage. ANOVA tests were undertaken using SIGMASTAT 12.3 © statistical software.

To determine the existence of correlation between debris weight and organism damage a Spearman's rank correlation was employed using GraphPad Prism 7 ©.

5. RESULTS

5.1. CATCH COMPOSITION

A total of 60 tows carried out during 15 fishing surveys caught 85257 individuals belonging to 52 species distributed by six different phyla. Molluscs (96.1% of the total abundance and 50.0% of the total number of species) and arthropods (3.4% of the abundance and 21.2% of the species) were the most represented taxa. On the other hand echinoderms, annelids, chordates and nemerteans presented a residual abundance (less than 1% of the abundance and 28.8% of the species). Bivalvia was the most represented class with 20 species, followed by Malacostraca and Gastropoda with 11 and 6 species, respectively.

The 16 tows performed between April and July using the SDredge collected 43 different taxa (Table 5.1) and 59.6% of the total number of individuals caught by both dredges. Bivalvia, Malacostraca (especially Anomura infraorder) and Echinoidea were the most abundant taxa. On average, debris represented 26.7% of the total weight of the hauls. Overall, the three target species and a small hermit crab (*Diogenes pugilator*), were the most frequent species in terms of both abundance and biomass. In addition, *S. solida* and *C. gallina* were the most common target species, whereas the relative importance of *D. pugilator* was more evident in abundance than in biomass (Tables 5.1 and 5.2). Average SDredge bycatch rate was 13.6% and 6.3% for abundance and biomass, respectively.

The catches of the DDredge, collected from 44 tows performed between February and June, comprised 40.4% of the total number of individuals caught by both dredges. Total species richness reached 37 taxa, with Bivalvia and Malacostraca being the most abundant classes (Table 5.1). On average, debris represented 51.6% of the total weight of the hauls. *S. solida*, followed by *D. trunculus*, *D. pugilator* and *C. gallina,* were the most frequent species in both abundance and biomass (Tables 5.1 and 5.2). Average DDredge bycatch rate was 46.0% and 32.9% for abundance and biomass, respectively.

Disregarding undersized individuals of the target species, the bycatch species with greater abundances in the SDredge were *D. pugilator*, *Echinocardium* sp. and *Echinocardium mediterraneum*, while *D. pugilator*, *Echinocardium mediterraneum* and *Atelecyclus undecimdentatus* were those with the higher biomasses. In the DDredge *D. pugilator*, *Ensis siliqua* and *Ophiura ophiura* were the most abundant species, whereas *D. pugilator*, *E. cordatum* and *Mactra glauca* had higher biomasses (Tables 5.1 and 5.2).

MDS and cluster analysis (Figures 5.1 and 5.2) of the total catch composition showed two different groups corresponding to each dredge type. The ANOSIM analysis corroborated this trend by showing significant differences for both abundance ($R = 0.647$, $p < 0.01$) and biomass ($R = 0.734$, $p < 0.01$). SIMPER analysis highlighted that the main contributors to these differences were *S. solida*, *D. trunculus* and *D. pugilator* and estimated an average dissimilarity between dredges of 51.9% and 56.2% for abundance and biomass, respectively.

The monthly bycatch abundance per tow was somewhat higher for the DDredge – 32.3% to 57.5% (average: 45.7%) – than for the SDredge – 3.5% to 30.4% (average: 13.6%) (Tables 5.1 and 5.2). A similar trend was observed for monthly bycatch biomass per tow, ranging between 23.4% to 42.1% (average: 32.9%) for the DDredge and between 1.0% to 6.5% (average: 6.3%) for the SDredge (Tables 5.1 and 5.2). On opposite to the observed for catch composition, the MDS and cluster analysis applied to bycatch failed to group samples from the DDredge and SDredge (Figures 5.3 and 5.4) indicating that the composition of bycatch both in abundance and biomass is somehow identical. The ANOSIM test applied showed no significant differences between SDredge and DDredge for bycatch composition, neither in abundance ($R = 0.284$, $p = 0.025$) nor in biomass ($R = 0.25$, $p = 0.045$) (Figures 5.3 and 5.4). However, the Kruskal-Wallis One Way ANOVA test performed indicated a statistically significant difference on the bycatch proportion between the dredges (K–W, $H = 19.181$, $df = 1$, $P < 0.001$).

5.2. SEASONALITY

Concerning an eventual seasonal trend in the catches of the DDredge, through ANOSIM analysis, significant differences were not detected between monthly samples, neither for the total catch composition, both in abundance ($R = 0.261$, $p < 0.01$) and biomass ($R = 0.267$, $p < 0.01$), nor for bycatch composition, also in both abundance ($R = 0.233$, $p < 0.01$) and biomass ($R = 0.262$, $p < 0.01$). Notwithstanding, significant differences between DDredge monthly bycatch percentages were found (K–W, $H = 15.307$, $df = 3$, $P = 0.002$), namely between February and April (Dunn's Method, $Q = 3.798$, $P < 0.05$) and February and March (Dunn's Method, $Q = 2.761$, $P < 0.05$). Seasonality in the SDredge was not evaluated due to lack of data.

Table 5.1. Mean number of bycatch individuals per taxon and month.

	SDREDGE				**DDREDGE**				
Bycatch	**April**	**June**	**July**	**TOTAL**	**February**	**March**	**April**	**June**	**TOTAL**
ANNELIDA	**0.50**	**4.50**	**0.88**	**1.69**	**0.49**	**0.00**	**0.17**	**0.00**	**0.18**
Polychaeta									
Glycera sp.	0.25	2.25	0.25	0.75					
Nephtys sp.	0.00	1.50	0.50	0.63					
Ophelia sp.	0.25	0.75	0.00	0.25	0.49	0.00	0.08	0.00	0.16
Phyllodocidae	0.00	0.00	0.13	0.06					
Sigalionidae					0.00	0.00	0.08	0.00	0.02
ARTHROPODA	**17.75**	**47.25**	**32.63**	**32.56**	**10.83**	**72.69**	**70.83**	**49.75**	**53.23**
Malacostraca									
Decapoda									
Penaeus kerathurus					0.00	0.00	0.08	0.00	0.02
Anomura	**16.25**	**41.25**	**27.75**	**28.25**	**8.67**	**69.88**	**65.83**	**34.75**	**48.89**
Diogenes pugilator	15.50	41.25	27.25	27.81	8.67	69.63	65.58	34.50	48.70
Spiropagurus elegans	0.75	0.00	0.50	0.44	0.00	0.25	0.25	0.25	0.18
Brachyura	**1.50**	**6.00**	**4.88**	**4.31**	**2.17**	**2.81**	**4.92**	**15.00**	**4.32**
Atelecyclus undecimdentatus	0.25	0.75	2.38	1.44	0.00	0.69	0.50	0.00	0.39
Liocarcinus navigator					0.00	0.00	0.08	0.00	0.02
Liocarcinus sp.	1.00	4.50	1.25	2.00	1.92	1.81	3.08	12.50	3.16
Pinnotheres pisum	0.25	0.00	0.00	0.06					
Pinnotheres sp.	0.00	0.00	0.38	0.19	0.08	0.13	0.00	0.00	0.07
Polybius henslowii	0.00	0.75	0.75	0.56	0.00	0.06	0.00	2.50	0.25
Portumnus latipes					0.17	0.13	1.25	0.00	0.43
Thia scutellata	0.00	0.00	0.13	0.06					
CHORDATA	**0.00**	**0.00**	**0.13**	**0.06**	**0.00**	**0.13**	**0.25**	**0.25**	**0.14**
Actinopteri									
Trachinus draco					0.00	0.13	0.25	0.25	0.14
Leptocardii									
Branchiostoma lanceolatum	0.00	0.00	0.13	0.06					
ECHINODERMATA	**0.25**	**7.25**	**11.50**	**7.63**	**1.58**	**7.19**	**6.33**	**13.50**	**6.00**
Asteroidea									
Astropecten sp.	0.00	0.00	0.13	0.06					
Echinoidea	**0.00**	**7.25**	**7.88**	**5.75**	**0.42**	**3.00**	**2.83**	**4.50**	**2.39**
Echinocardium cordatum	0.00	0.00	0.75	0.38	0.08	2.50	2.75	3.25	1.98
Echinocardium fenauxi	0.00	0.00	0.13	0.06	0.17	0.19	0.00	0.00	0.11
Echinocardium mediterraneum	0.00	0.00	4.88	2.44	0.00	0.00	0.00	0.25	0.02
Echinocardium sp.	0.00	7.25	2.13	2.88	0.17	0.31	0.08	1.00	0.27
Ophiuroidea	**0.25**	**0.00**	**3.50**	**1.81**	**1.17**	**4.19**	**3.50**	**9.00**	**3.61**
Amphiura sp.	0.00	0.00	0.13	0.06	0.25	0.00	0.00	0.00	0.07
Ophiura ophiura	0.25	0.00	3.38	1.75	0.92	4.19	3.50	9.00	3.55
MOLLUSCA	**2796.44**	**5815.89**	**1961.57**	**3133.87**	**752.53**	**711.24**	**555.97**	**1185.40**	**723.26**
Bivalvia	**2794.69**	**5812.14**	**1956.45**	**3129.93**	**748.69**	**710.05**	**555.31**	**1181.15**	**721.22**
Acanthocardia tuberculata	0.00	0.00	0.25	0.13	0.00	0.06	0.00	0.00	0.02
Callista chione	0.00	0.00	0.13	0.06					
Chamelea gallina **undersized**	2.50	0.50	6.63	4.06	1.42	7.81	5.08	7.25	5.27
Corbula gibba	0.00	0.00	0.13	0.06					
Donax semistriatus					0.25	0.25	0.08	0.00	0.18
Donax trunculus **undersized**	0.50	0.00	0.50	0.69	4.92	2.31	16.42	39.00	10.20
Donax variegatus	0.00	0.00	0.50	0.25	0.00	0.00	0.00	0.25	0.02
Dosinia exoleta					0.00	0.00	0.25	0.00	0.07
Ensis siliqua	0.75	0.00	1.00	0.69	1.33	2.13	8.92	4.50	3.98
Laevicardium crassum	0.25	0.00	0.38	0.25	0.17	0.19	0.25	0.25	0.20
Macomangulus tenuis	0.00	0.75	0.00	0.19	0.00	0.00	0.17	0.50	0.09
Mactra corallina var. *atlantica*	0.00	0.00	0.88	0.44	0.00	0.19	0.00	0.00	0.07
Mactra corallina corallina	0.00	0.00	1.50	0.75					
Mactra glauca	1.50	0.00	1.75	1.25	3.33	0.19	0.00	0.00	0.98
Mactra corallina stultorum	0.00	0.00	3.13	1.56	0.17	2.44	0.33	0.00	1.02
Modiolus modiolus	0.00	0.00	0.25	0.13					
Ostrea edulis					0.00	0.00	0.00	0.25	0.02
Ostrea sp.	0.75	0.00	0.00	0.19					
Spisula solida **undersized**	70.75	341.25	541.75	373.88	219.25	299.70	254.08	417.25	276.01
Spisula subtruncata	0.00	0.00	0.13	0.06	0.00	0.13	0.33	0.25	0.16
Gastropoda	**1.75**	**3.75**	**5.13**	**3.94**	**3.83**	**1.19**	**0.67**	**4.25**	**2.05**
Calyptraea chinensis	0.00	0.00	0.13	0.06					
Columbella rustica					0.08	0.00	0.00	0.00	0.02
Euspira catena	0.25	0.75	0.13	0.31	0.75	0.25	0.50	0.00	0.43
Euspira guilleminii	0.00	3.00	0.75	1.13	2.50	0.56	0.08	0.25	0.93
Euspira nitida	0.00	0.00	0.13	0.06					
Tritia reticulata	1.50	0.00	4.00	2.38	0.50	0.38	0.08	4.00	0.66
NEMERTEA	0.00	0.00	0.13	0.06					
TOTAL CATCH	2814.94	5874.89	2006.82	3175.87	765.43	791.24	633.56	1248.90	782.80
TOTAL BYCATCH	97.25	405.25	609.25	430.25	247.57	396.58	364.17	537.25	359.89
BYCATCH %	**3.45**	**6.90**	**30.36**	**13.55**	**32.34**	**50.12**	**57.48**	**43.02**	**45.97**
SPECIES RICHNESS	17	13	39	43	22	26	26	20	37

Table 5.2. Mean weight (g) of bycatch individuals caught per taxon and month.

	SDREDGE				DDREDGE				
Bycatch	**April**	**June**	**July**	**TOTAL**	**February**	**March**	**April**	**June**	**TOTAL**
ANNELIDA	**0.13**	**0.35**	**0.43**	**0.33**	**0.16**	**0.00**	**0.06**	**0.00**	**0.06**
Polychaeta									
Glycera sp.	0.10	0.18	0.11	0.13					
Nephtys sp.	0.00	0.13	0.30	0.18					
Ophelia sp.	0.03	0.05	0.00	0.02	0.16	0.00	0.03	0.00	0.05
Phyllodocidae	0.00	0.00	0.01	0.01					
Sigalionidae					0.00	0.00	0.03	0.00	0.01
ARTHROPODA	**56.33**	**137.63**	**128.21**	**112.59**	**15.94**	**136.43**	**118.54**	**106.7**	**95.99**
Malacostraca									
Decapoda									
Penaeus kerathurus					0.00	0.00	1.10	0.00	0.30
Anomura	**47.05**	**106.33**	**66.54**	**71.61**	**12.19**	**118.91**	**105.03**	**54.18**	**80.13**
Diogenes pugilator	43.43	106.33	65.34	70.11	12.19	118.08	103.65	50.78	79.15
Spiropagurus elegans	3.63	0.00	1.20	1.51	0.00	0.83	1.38	3.40	0.99
Brachyura	**9.28**	**31.30**	**61.68**	**40.98**	**3.75**	**17.52**	**12.42**	**52.60**	**15.56**
Atelecyclus undecimdentatus	8.13	22.20	48.24	31.70	0.00	11.73	3.72	0.00	5.28
Liocarcinus navigator	0.00	0.00	0.00		0.00	0.00	0.23	0.00	0.06
Liocarcinus sp.	1.13	7.30	2.89	3.55	3.34	4.66	5.78	26.45	6.59
Pinnotheres pisum	0.03	0.00	0.00	0.01					
Pinnotheres sp.	0.00	0.00	0.04	0.02	0.01	0.01	0.00	0.00	0.00
Polybius henslowii	0.00	1.80	10.24	5.57	0.00	0.89	0.00	26.15	2.70
Portumnus latipes					0.40	0.23	2.69	0.00	0.93
Thia scutellata	0.00	0.00	0.28	0.14					
CHORDATA	**0.00**	**0.00**	**0.04**	**0.02**	**0.00**	**4.14**	**14.60**	**3.63**	**5.82**
Actinopteri									
Trachinus draco					0.00	4.14	14.60	3.63	5.82
Leptocardii									
Branchiostoma lanceolatum	0.00	0.00	0.04	0.02					
ECHINODERMATA	**0.88**	**68.55**	**100.45**	**67.58**	**2.72**	**24.99**	**39.08**	**67.78**	**26.65**
Asteroidea									
Astropecten sp.	0.00	0.00	4.58	2.29					
Echinoidea	**0.00**	**68.55**	**94.11**	**64.19**	**1.97**	**22.90**	**37.42**	**62.68**	**24.77**
Echinocardium cordatum	0.00	0.00	8.89	4.44	1.43	20.23	37.10	44.08	21.87
Echinocardium fenauxi	0.00	0.00	2.69	1.34	0.38	0.37	0.00	0.00	0.24
Echinocardium mediterraneum	0.00	0.00	64.58	32.29	0.00	0.00	0.00	1.70	0.15
Echinocardium sp.	0.00	68.55	17.96	26.12	0.16	2.30	0.32	16.90	2.50
Ophiuroidea	**0.88**	**0.00**	**1.76**	**1.10**	**0.75**	**2.09**	**1.66**	**5.10**	**1.88**
Amphiura sp.	0.00	0.00	0.03	0.01	0.04	0.00	0.00	0.00	0.01
Ophiura ophiura	0.88	0.00	1.74	1.09	0.71	2.09	1.66	5.10	1.87
MOLLUSCA	**18934.45**	**26426.15**	**9566.40**	**16123.35**	**3056.61**	**2910.04**	**2116.70**	**4310.**	**2860.92**
Bivalvia	**18928.85**	**26417.80**	**9551.60**	**16112.46**	**3048.70**	**2906.82**	**2114.73**	**4300.**	**2856.17**
Acanthocardia tuberculata	0.00	0.00	4.53	2.26	0.00	0.46	0.00	0.00	0.17
Callista chione	0.00	0.00	3.71	1.86					
Chamelea gallina **undersized**	44.54	7.24	209.98	16.36	5.76	23.85	17.03	18.52	16.57
Corbula gibba	0.00	0.00	0.01	0.01					
Donax semistriatus					0.64	0.64	0.21	0.00	0.47
Donax trunculus **undersized**	166.28	61.60	92.93	0.34	8.95	2.73	31.35	72.90	18.61
Donax variegatus	0.00	0.00	2.64	1.32	0.00	0.00	0.00	0.68	0.06
Dosinia exoleta					0.00	0.00	3.88	0.00	1.06
Ensis siliqua	5.08	0.00	4.35	3.44	6.04	7.06	38.64	16.90	16.29
Laevicardium crassum	11.60	0.00	19.55	12.68	4.77	4.91	6.83	11.15	5.96
Macomangulus tenuis	0.00	0.05	0.00	0.01	0.00	0.00	0.18	0.23	0.07
Mactra corallina var. *atlantica*	0.00	0.00	2.09	1.04	0.00	1.12	0.00	0.00	0.41
Mactra corallina corallina	0.00	0.00	10.95	5.48					
Mactra glauca	39.98	0.00	18.90	19.44	67.12	1.63	0.00	0.00	18.90
Mactra corallina stultorum	0.00	0.00	24.45	12.23	1.61	15.62	2.69	0.00	6.85
Modiolus modiolus	0.00	0.00	0.14	0.07					
Ostrea edulis	0.00	0.00	0.00		0.00	0.00	0.00	0.95	0.09
Ostrea sp.	8.55	0.00	0.00	2.14					
Spisula solida **undersized**	2.13	0.00	3.25	755.25	596.65	853.77	688.74	1139.	764.62
Spisula subtruncata	0.00	0.00	0.31	0.16	0.00	0.35	0.86	0.70	0.43
Gastropoda	**5.60**	**8.35**	**14.80**	**10.89**	**7.91**	**3.23**	**1.97**	**9.70**	**4.75**
Calyptraea chinensis	0.00	0.00	0.01	0.01					
Columbella rustica					0.10	0.00	0.00	0.00	0.03
Euspira catena	1.23	1.25	0.36	0.80	1.68	0.99	1.65	0.00	1.27
Euspira guilleminii	0.00	7.10	2.49	3.02	5.17	1.58	0.18	0.58	2.08
Euspira nitida	0.00	0.00	1.45	0.73					
Tritia reticulata	4.38	0.00	10.49	6.34	0.96	0.66	0.14	9.13	1.37
NEMERTEA	0.00	0.00	0.19	0.09					
TOTAL CATCH	18991.78	26632.68	9795.71	16303.97	3075.43	3075.60	2288.98	4488.	2989.44
TOTAL BYCATCH	383.23	1347.88	1185.59	1025.57	718.27	1080.91	964.66	1449.	983.81
BYCATCH %	**2.02**	**5.06**	**12.10**	**6.29**	**23.36**	**35.14**	**42.14**	**32.30**	**32.91**

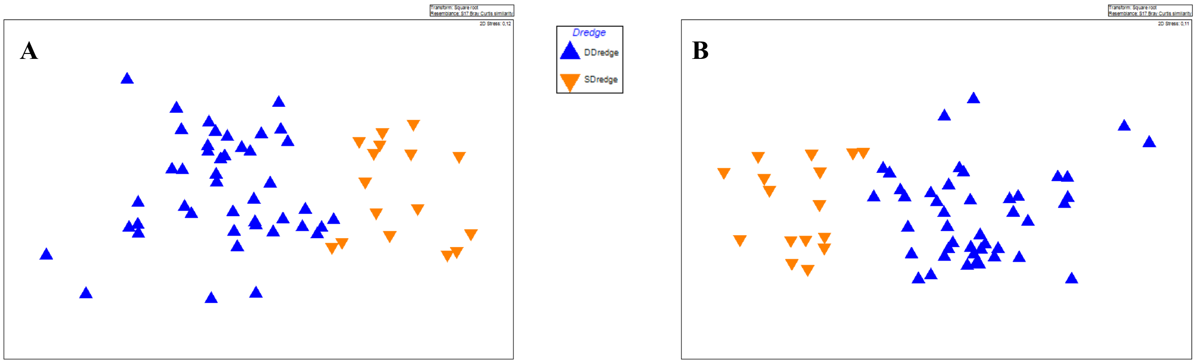

Figure 5.3. Bray-Curtis Multidimensional Scaling Ordination (MDS) analysis for total catch composition (A) abundance (stress value = 0.11) and (B) biomass (stress value = 0.12).

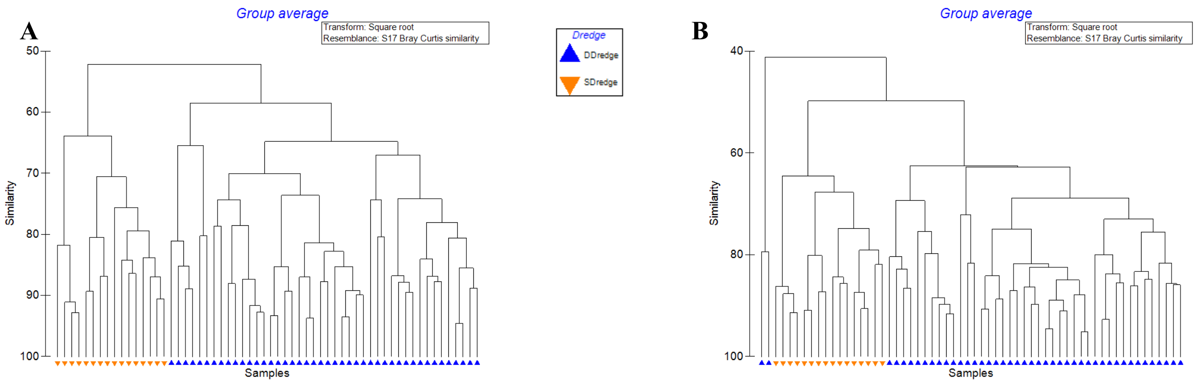

Figure 5.2. Bray-Curtis cluster analysis for total catch composition (A) abundance and (B) biomass.

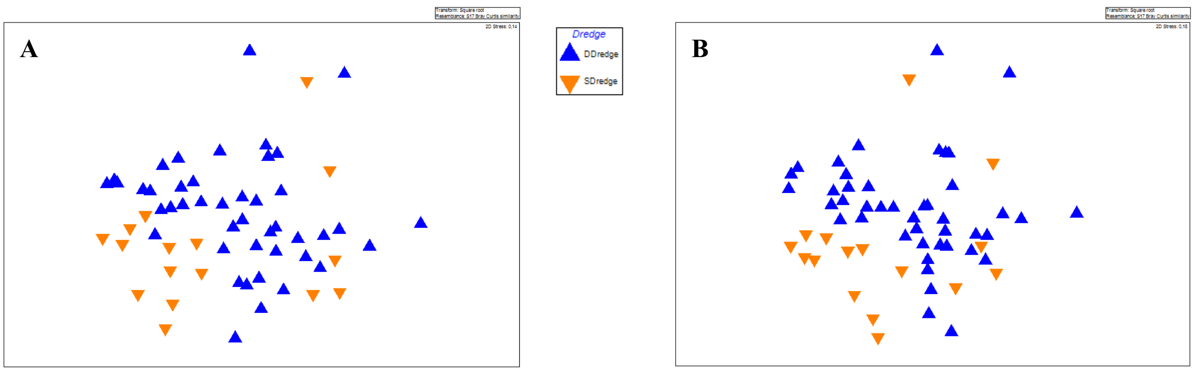

Figure 5.4. Bray-Curtis Multidimensional Scaling Ordination (MDS) analysis for bycatch composition (A) abundance (stress value = 0.14) and (B) biomass (stress value = 0.18).

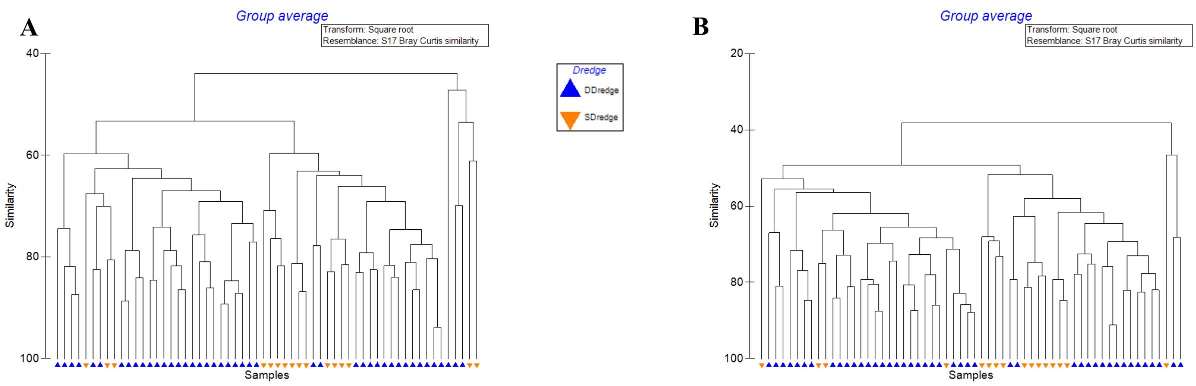

Figure 5.5. Bray-Curtis cluster analysis for bycatch composition (A) abundance and (B) biomass.

5.3. DAMAGE AND MORTALITY

Damage corresponds to the proportion of damaged individuals, i.e. assigned with a damage score of 2 or higher, while mortality is estimated through the number of individuals with high likelihood of death, i.e. with a damage score of 3 and dead individuals (score 4). Overall, damage and mortality comprised respectively 1.1% and 0.9% of the total catch for the SDredge and 3.6% and 2.4% for the DDredge (Table 5.3).

Among the target species, *S. solida*, the most abundant species in both dredges, showed particularly low percentages of damage and mortality, with 0.7% and 0.6% in the SDredge and 1.2% and 1.0% in the DDredge, respectively. This evident similarity between damage and mortality levels reveals that most individuals scored either 3 or 4 in the damage scale. Mortality of undersized *S. solida* was also particularly low, 0.6% in the SDredge and 0.8% in the DDredge (Table 5.4).

D. trunculus displayed a particularly high sensitivity to the damages inflicted by the bivalve dredges. Highest damage and mortality occurred in the SDredge, 11.2% and 9.5% respectively (Table 5.3), and in the DDredge with 36.0% mortality of commercially undersized individuals (Table 5.4).

C. gallina, the least abundant target species, presented quite similar percentages of damage and mortality, both with 1.6% in the SDredge and 2.7% and 2.5% in the DDredge, respectively (Table 5.3). Mortalities of undersized individuals were 1.5% and 3.5%, respectively (Table 5.4).

Overall, each type of dredge presented lower damage and mortality for its respective target species than for the remaining target species. Consequently, the SDredge caused higher damage and mortality for *D. trunculus*, while the DDredge induced the same effects for *S. solida* and *C. gallina* (Table 5.3).

Among all bivalves caught, *Mactra* was the most abundant genus, showing exceptionally high damage and mortality levels on both dredges, with *Mactra glauca* being the most sensitive species with a maximum mortality of 93.0% in the DDredge. In both dredges, all *Mactra* species collected showed more than 75% of damage and mortalities over 60% (Table 5.3).

Ensis siliqua displayed mortalities of 100% in both dredges, although its abundance per tow was not particularly high in the SDredge (maximum N = 3; minimum N = 1; average N = 0.7), contrarily to the DDredge (maximum N = 42; minimum N = 1; average N = 4.0) (Table 5.3).

The five species of the class Gastropoda caught by the SDredge showed no mortality and only low damage – 10.5% – in *Tritia reticulata*, the most abundant gastropod species caught using this type of dredge. Meanwhile, despite low, the DDredge caused mortality and damage to all four gastropod species, except to the least represented species, *Columbella rustica* (maximum N = 1; average N = 0.02), which suffered 100% damage and mortality (Table 5.3).

D. pugilator, the most abundant bycatch species caught by both dredges, showed low damage – 6.7% and 4.8% – and even lower mortality level – 0% and 0.1%, for SDredge and DDredge, respectively. The same trend was registered for the serpent star, *Ophiura ophiura*, that presented very high damage – 82.1% and 93.0% – but remarkably low mortality – 0% and 11.5% (Table 5.3).

Liocarcinus sp. displayed slightly low damage – 25% and 38.9% - and even lower mortality – 0% and 5.8%, for the SDredge and DDredge, respectively. The presence of ovigerous females was also accounted, representing 10.5% and 22.6% of the total number of individuals caught by the SDredge and DDredge, respectively. *Polybius henslowii* was the most delicate arthropod species in the SDredge – 66.7% damage; 55.6% mortality – with 85.7% of the sampled individuals being immature (CW < 37.8 mm; Magalhães *et al*., 2014). Meanwhile *Atelecyclus undecimdentatus* was the most sensitive species in the DDredge – 82.4% damage; 70.6% mortality (Table 5.3).

All echinoids caught belonged to the genus *Echinocardium*, also known as heart urchins. This taxon was among the most sensitive, particularly in the DDredge, where all the accounted species presented damage and mortality higher than 50%. The most abundant taxa in the SDredge, *Echinocardium* sp. (maximum N = 20; minimum N = 3; average N = 2.9) showed a damage and mortality of 56.5%, while in the DDredge, *Echinocardium cordatum* – (maximum N = 9; minimum N = 1; average N = 2.0) – displayed 59.8% damage and 51.7% mortality (Table 5.3).

Class Polychaeta was represented by four taxa in the SDredge and two taxa in the DDredge, all with low abundance (maximum N = 4; minimum N = 1; average N = 0.18) and damage and mortality lower than 50%, excepting the very underrepresented Sigalionidae (maximum N = 1; average N = 0.02) (Table 5.3).

The least represented taxa in both dredges, Actinopteri, Asteroidea, Leptocardii, Nemertea, and Decapoda that did not belong to Anomura or Brachyura, occurred with a single species and always with low abundance (Table 5.1). Actinopteri, represented by *Trachinus draco*, was the most abundant (maximum N = 1; average N = 0.1) with damage and mortality of 16.7%. Asteroidea presented 100% damage but 0% mortality. Nemertea had the highest damage and mortality – 100% – while the remaining taxa, other Decapoda and Leptocardii, both had 0% damage and mortality (Table 5.3).

Significant differences between SDredge and DDredge mortality percentages were obtained (K–W, $H = 10.845$, $df = 1$, $P < 0.001$). No monthly damage differences were found for the DDredge (K–W, $H = 5.758$, $df = 3$, $P = 0.124$).

No significant correlation was found between damage percentages and debris weight (Spearman $r = -0.078$).

Table 5.3. Mean number and proportion of damaged and dead individuals per taxon and dredge type.

	SDREDGE					DDREDGE				
		Damage		Mortality			Damage		Mortality	
Species	Total	N	%	N	%	Total	N	%	N	%
ANNELIDA	**1.69**	**0.63**	**37.04**	**0.63**	**37.04**	**0.18**	**0.09**	**50.83**	**0.05**	**25.41**
Polychaeta										
Glycera sp.	0.75	0.31	41.67	0.31	41.67					
Nephtys sp.	0.63	0.31	50.00	0.31	50.00					
Ophelia sp.	0.25	0.00	0.00	0.00	0.00	0.16	0.07	43.67	0.05	29.11
Phyllodocidae	0.06	0.00	0.00	0.00	0.00					
Sigalionidae						0.02	0.02	100.00	0.00	0.00
ARTHROPODA	**32.56**	**3.75**	**11.52**	**0.63**	**1.92**	**53.23**	**4.18**	**7.86**	**0.68**	**1.28**
Malacostraca										
Decapoda										
Penaeus kerathurus						0.02	0.00	0.00	0.00	0.00
Anomura	**28.25**	**2.19**	**7.74**	**0.06**	**0.22**	**48.89**	**2.36**	**4.83**	**0.07**	**0.14**
Diogenes pugilator	27.81	1.88	6.74	0.00	0.00	48.70	2.32	4.76	0.07	0.14
Spiropagurus elegans	0.44	0.31	71.43	0.06	14.29	0.18	0.05	25.00	0.00	0.00
Brachyura	**4.31**	**1.56**	**36.23**	**0.56**	**13.04**	**4.32**	**1.82**	**42.11**	**0.61**	**14.21**
Atelecyclus undecimdentatus	1.44	0.69	47.83	0.25	17.39	0.39	0.32	82.35	0.27	70.59
Liocarcinus navigator						0.02	0.00	0.00	0.00	0.00
Liocarcinus sp.	2.00	0.50	25.00	0.00	0.00	3.16	1.23	38.85	0.18	5.76
Pinnotheres pisum	0.06	0.00	0.00	0.00	0.00					
Pinnotheres sp.	0.19	0.00	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.00
Polybius henslowii	0.56	0.38	66.67	0.31	55.56	0.25	0.16	63.64	0.09	36.36
Portumnus latipes						0.43	0.11	26.32	0.07	15.79
Thia scutellata	0.06	0.00	0.00	0.00	0.00					
CHORDATA	**0.06**	**0.00**	**0.00**	**0.00**	**0.00**	**0.14**	**0.02**	**16.67**	**0.02**	**16.67**
Actinopteri										
Trachinus draco						0.14	0.02	16.67	0.02	16.67
Leptocardii										
Branchiostoma lanceolatum	0.06	0.00	0.00	0.00	0.00					
ECHINODERMATA	**7.63**	**4.63**	**60.66**	**2.81**	**36.89**	**6.00**	**4.89**	**81.44**	**1.80**	**29.92**
Asteroidea										
Astropecten sp.	0.06	0.06	100.00	0.00	0.00					
Echinoidea	**5.75**	**3.06**	**53.26**	**2.81**	**48.91**	**2.39**	**1.57**	**65.71**	**1.39**	**58.10**
Echinocardium cordatum	0.38	0.31	83.33	0.31	83.33	1.98	1.18	59.77	1.02	51.72
Echinocardium fenauxi	0.06	0.00	0.00	0.00	0.00	0.11	0.09	80.00	0.09	80.00
Echinocardium mediterraneum	2.44	1.13	46.15	0.88	35.90	0.02	0.02	100.00	0.02	100.00
Echinocardium sp.	2.88	1.63	56.52	1.63	56.52	0.27	0.27	100.00	0.25	91.67
Ophiuroidea	**1.81**	**1.50**	**82.76**	**0.00**	**0.00**	**3.61**	**3.32**	**91.82**	**0.41**	**11.32**
Amphiura sp.	0.06	0.06	100.00	0.00	0.00	0.07	0.02	33.33	0.00	0.00
Ophiura ophiura	1.75	1.44	82.14	0.00	0.00	3.55	3.30	92.95	0.41	11.54
MOLLUSCA	**3133.87**	**28.19**	**0.90**	**25.88**	**0.83**	**723.26**	**19.42**	**2.68**	**16.64**	**2.30**
Bivalvia	**3129.93**	**27.94**	**0.89**	**25.88**	**0.83**	**721.22**	**19.14**	**2.65**	**16.53**	**2.29**
Acanthocardia tuberculata	0.13	0.06	50.00	0.06	50.00	0.02	0.00	0.00	0.00	0.00
Callista chione	0.06	0.06	100.00	0.06	100.00					
Chamelea gallina	24.25	0.38	1.55	0.38	1.55	10.82	0.30	2.73	0.27	2.52
Corbula gibba	0.06	0.00	0.00	0.00	0.00					
Donax semistriatus						0.18	0.02	12.50	0.00	0.00
Donax trunculus	19.00	2.13	11.18	1.81	9.54	142.32	6.23	4.38	4.85	3.41
Donax variegatus	0.25	0.00	0.00	0.00	0.00	0.02	0.02	100.00	0.02	100.00
Dosinia exoleta						0.07	0.02	33.33	0.02	33.33
Ensis siliqua	0.69	0.69	100.00	0.69	100.00	3.98	3.98	100.00	3.98	100.00
Laevicardium crassum	0.25	0.00	0.00	0.00	0.00	0.20	0.02	11.11	0.02	11.11
Macomangulus tenuis	0.19	0.19	100.00	0.19	100.00	0.09	0.02	25.00	0.02	25.00
Mactra corallina var. *atlantica*	0.44	0.38	85.71	0.31	71.43	0.07	0.07	100.00	0.05	66.67
Mactra corallina corallina	0.75	0.56	75.00	0.56	75.00					
Mactra glauca	1.25	1.13	90.00	1.00	80.00	0.98	0.95	97.67	0.91	93.02
Mactra corallina stultorum	1.56	1.19	76.00	1.13	72.00	1.02	0.77	75.56	0.64	62.22
Modiolus modiolus	0.13	0.00	0.00	0.00	0.00					
Ostrea edulis						0.02	0.00	0.00	0.00	0.00
Ostrea sp.	0.19	0.19	100.00	0.00	0.00					
Spisula solida	3080.68	21.00	0.68	19.69	0.64	561.26	6.73	1.20	5.75	1.02
Spisula subtruncata	0.06	0.00	0.00	0.00	0.00	0.16	0.00	0.00	0.00	0.00
Gastropoda	**3.94**	**0.25**	**6.35**	**0.00**	**0.00**	**2.05**	**0.27**	**13.33**	**0.11**	**5.56**
Calyptraea chinensis	0.06	0.00	0.00	0.00	0.00					
Columbella rustica						0.02	0.02	100.00	0.02	100.00
Euspira catena	0.31	0.00	0.00	0.00	0.00	0.43	0.09	21.05	0.05	10.53
Euspira guilleminii	1.13	0.00	0.00	0.00	0.00	0.93	0.05	4.88	0.05	4.88
Euspira nitida	0.06	0.00	0.00	0.00	0.00					
Tritia reticulata	2.38	0.25	10.53	0.00	0.00	0.66	0.11	17.24	0.00	0.00
NEMERTEA	0.06	0.06	100.00	0.06	100.00					
TOTAL	3175.87	37.25	**1.17**	30.00	**0.94**	782.80	28.60	**3.65**	19.19	**2.45**

Table 5.4. Mean number and proportion of dead undersized individuals of the target species for each dredge type.

	SDREDGE			DDredge		
		Mortality			Mortality	
Species	Total	N	%	Total	N	%
Chamelea gallina **undersized**	4.06	0.06	1.54	5.27	0.18	3.45
Donax trunculus **undersized**	0.69	0.00	0.00	10.20	3.68	36.08
Spisula solida **undersized**	373.88	2.19	0.59	276.01	2.27	0.82

6. DISCUSSION

As stated by Broadhurst *et al*. (2007), quantification is the first step in order to solve bycatch issues. Thus, this study assessed the importance of discards in bivalve dredging fisheries in the Algarve coast through the quantification of the bycatch using two different types of dredges. This assessment was performed during six months in order to ascertain if an eventual seasonal trend in the bycatch would justify the implementation of operational changes in this fishery throughout the year.

The present results show that the SDredge and DDredge displayed significant differences for total catch composition, due to target species and *D. pugilator* abundance and biomass. This confirms that each type of dredge is well adapted to maximise the catch of its target species. Nevertheless, no differences between the two dredges bycatch composition were verified, hence demonstrating the similarity of the benthic communities in the closely located sampled sites. Yet, significantly lower bycatch percentages were found in the SDredge, which is probably related to the high density of *S. solida* in Algarve bivalve beds when compared to the density of *D. trunculus*. Indeed, Gaspar *et al.* (2015) reported for the area where the surveys were conducted higher fishing yields for *S. solida* than for *D. trunculus* (957 g/5 minutes tow and 248 g/5 minutes tow, respectively), which reflects differences on the abundance and density of these species. Therefore, to attain the daily quota (200 kg for both species) fishers spend less time towing and dredge a lower area when the SDredge is used. All these justify the lower proportion of bycatch obtained from the SDredge when compared to the DDredge.

Bycatch in bivalve dredging of Algarve has been reported to exceed target catch in quantity during late spring and early summer (Gaspar & Chícharo, 2007). Similarly, the present results indicated that bycatch represented up to 42.1% of the total catch in weight and 57.5% in number, both maximum percentages occurring in the DDredge. Gaspar *et al.* (2001) observed a mean bycatch percentage of 31% in the *Callista chione* dredge fishery that occurs in the west coast of the Portuguese mainland, whereas Leitão *et al*. (2009) in a comparative study conducted in the same area and using a grid dredge obtained a mean percentage of bycatch of 9% for the *S. solida* fishery. Similarly, Pranovi *et al*. (2001) reported very high discard rates (90%) for the "rapido" trawl *Pecten jacobaeus* (scallop) fisheries of the Adriatic Sea, due to the low density of the target species. All these results indicate that bycatch in the dredge fishery is related to both dredge design and local macrobenthic communities.

No seasonality was found for the DDredge on abundance and biomass on both total catch composition and bycatch. Accordingly, several authors (Dolbeth *et al*., 2007; Freitas *et al*., 2011; Carvalho *et al*., 2015) concluded that hydrodynamic events, such as storms, have greater influence in changing the macrobenthic community patterns off the Algarve coast than seasonality.

Nevertheless, Sardá *et al*. (2000b), supported by several other authors (Gracia *et al.*, 1996; Pinedo *et al.*, 1996; 1997; Sardá *et al*., 2000a), emphasised the existence of a well-known annual variation in abundance and biomass of soft bottom macroinfaunal assemblages in the Catalan coast. Additionally, Jenkins *et al.* (2003) detected seasonal variation in the catch abundance of the queen scallop (*Aequipecten opercularis*) in the bivalve dredge fishery of the north Irish Sea. These authors attributed seasonality to changes in swimming behaviour and correlated it to variations in seawater temperature; therefore evidencing that seasonality in the catch abundance can also be influenced by species behaviour. Furthermore, Alves *et al.* (2003) and Palma *et al*. (2003) reported higher abundances in benthic communities and flatfish discards in bivalve dredge fisheries of Algarve during autumn, respectively. Correspondingly, our results showed significant seasonal variation in bycatch abundance of the DDredge, evidencing an increasing trend from winter (February) to spring (March and April). However, no significant differences were observed between June and the remaining sampling period presumably as a result of the low number of samples collected during this month which was related to the closure of the fishery, due to the presence of phycotoxins. These findings support the need of further research to include surveys throughout the year, in order to find out if significant differences occur on the proportion of bycatch among seasons.

Bivalve target species presented low damage and mortality. *S. solida* was the least sensitive to dredging whereas *D. trunculus* was the species most affected. Likewise, undersized individuals of the target species displayed low mortality, with the exception of *D. trunculus* that registered slightly higher mortality. Several authors have also demonstrated a higher susceptibility of juvenile bivalves to damage. Birkett (1959) and Trewin & Welsh (1972) reported selective breakage of small *Mactra corallina stultorum*, thus proving size-dependent fragility in this species. Additionally, Medcof & McPhail (1964) reported an indirect mortality of approximately 50% for undersized *Mya arenaria* due to breakage or smothering.

Ensis siliqua, or pod razor shell, is a thin-shelled commercially targeted bivalve that was banned from being fished and landed in the south coast of Portugal until December 2015 (Portaria 170-A/2014) and has been recommended by IPMA to remain closed until the end of 2016 (Gaspar *et al*., 2015a). In this region this species is more abundant between 3 and 5 metres (Gaspar *et al*., 2015a) and usually burrows close to the sediment surface, although it can burrow down to 60 cm when disturbed (Gaspar *et al*., 1998). *E. siliqua* suffered very high mortality independently of the dredge used, which is justified by the tooth length of the dredge bar (200 mm) and the maximum burrowing depth of *Ensis* (60 cm) (Gaspar *et al*., 1998). Indeed, in a resting situation, without perturbation, this species burrows close to the surface, with its siphon sticking out of the sediment. When it feels any perturbation, such as dredging, it burrows deeper in the sediment in a defensive response. Therefore, when DDredge and SDredge are used most of *Ensis* individuals are hit by the teeth in the upper and middle portions of the shell, leading to its breakage (Gaspar *et al*., 1998). Robinson & Richardson (1998) detected higher vulnerability to predation in discarded individuals of *Ensis arcuatus* due to slow reburial. So, although undetected during this study, even if pod razor shells are discarded alive, their survival is probably very low.

Species belonging to the *Mactra* genus are thin-shelled bivalves with fast burrowing rates (Trueman, 1968; Michael *et al*., 1990). Gaspar *et al*. (2001) assessed the relative vulnerability of the species caught by the metallic grid dredge targeting *Callista chione*, reporting an expected mortality of 84.9% for *Mactra glauca* and 50% for *Mactra corallina* (currently denominated *M. stultorum*), similar to those obtained in the present study. However, Gaspar *et al*. (2002a) reported high resilience of *Mactra corallina* to dredging for the north dredge, which may relate to the retention system used, a net bag.

The small hermit crab (*Diogenes pugilator*) is a species of the Malacostraca class and Anomura infraorder that does not exhibit strong selection for the type of gastropod shells that inhabits (Manjón-Cabeza & García Raso, 1999), thus occurring in a large variety of shell sizes and shapes. This crustacean shows preferential distribution in shallow bathymetrics, between 1.3 and 8 m depth (Dolbeth *et al*., 2006) and therefore was found in higher abundance in the catch of the DDredge when compared to its abundance in the SDredge, since *D. trunculus* beds occur between 0-and 6m depth whereas *S. solida* beds occur between 3 and 11 m depth with higher abundance between 5 and 10m. Despite being the third most abundant species, this species showed high resilience to dredging, with damage lower than

10% and mortality below 1%, mainly of individuals that abandoned the protective shells. This low sensitivity, together with a frequent recruitment every four months in the Portuguese coast (Dolbeth *et al*., 2006), leads to the conclusion that *D. pugilator* is not a species at risk due to bivalve dredging in the Algarve coast.

Liocarcinus sp., or swimming crab, is a sublittoral species that occurred with higher abundance among Brachyura species, although with low damage and mortality, thus corroborating data reported by Gaspar *et al*. (2003b) regarding the metallic grid dredge. Nonetheless, Bergmann *et al*. (2001) examined *Liocarcinus depurator* physiological responses to aerial exposure and found that, although not directly lethal, emersion stress may have metabolic consequences and increase susceptibility to predation. Additionally, there is scarce knowledge on the mechanical damage consequences on ovigerous females, which recommends that the currently used damage score should be tested in order to account for this variable.

Polybius henslowii is a benthopelagic species described by González-Gurriarán (1987) and Fariña *et al*. (1997) as "frequent and notably abundant" along the Portuguese and Spanish continental shelf. Although unregulated regarding the MLS, this species is marketed in Portugal during summer, when gonads are mature and voluminous (Costa *et al.*, 2003). However, in the event that this species becomes a commercially exploited fishing resource, Magalhães *et al*. (2014) proposed a MLS of 37.8 mm in carapace width, based on the species size at first sexual maturity, i.e. the size at which 50% of the females are sexually mature. During the present fishing surveys, a remarkably high proportion of *P. henslowii* individuals caught were immature and undersized specimens. Regarding damage and mortality rate inflicted by dredging to this species, in the present study it was observed that *P. henslowii* is highly sensitive since damage and mortality always surpass 36%. Leitão *et al.* (2014) registered much lower damage (16%) and mortality (10.4%) for this species during 15 minute tows targeting *S. solida* using the north dredge.

Lastly, *Atelecyclus undecimdentatus*, or broad circular crab, suffered high damage and mortality using the DDredge. Accordingly, Leitão *et al*. (2009) considered this crab to be unable of passing through the grid dredge, thus being particularly susceptible to damage.

Echinoidea, the class with relevant abundance most subject to lethal injury by both dredges, was composed by four species of the *Echinocardium* genus, i.e. heart urchins. Such high susceptibility to damage has been previously evaluated (Wassenberg & Hill, 1993; Kaiser & Spencer, 1995; Gaspar *et al*., 2001, 2003b; Leitão *et al*., 2009) and attributed to the fact that the fused plates of sea urchins imply low flexibility and high sensitivity to mechanical damage (Kaiser & Spencer, 1995).

Leitão *et al.* (2009), as well as Gaspar *et al*. (2003b) reported that the three previous taxa, *P. henslowii*, *A. undecimdentatus* and Echinoidea, were more resistant to damage when either the north dredge or traditional dredge were in used, indicating a lower mortality of these taxa when a net bag is used.

Several studies have attested high resilience of the serpent star (*O. ophiura*) to bottom fishing (Kaiser & Spencer, 1995; Hill *et al*., 1996; Ramsay *et al*., 1998; Bergman & van Santbrink, 2000) by depicting damage as a consequence of arm breakage and attributing low mortality to the high regeneration capacity of this species, or by relying on its high reproductive resilience to detract from high damage and mortality (Pranovi *et al*., 2001). However, in the *Nephrops* trawling, with much longer towing duration and occurring in much deeper waters than in the present bivalve dredge fisheries, Bergmann & Moore (2001) reported that 91% mortality occurred 14 days after fishing and immediate re-immersion. These authors highlighted that previous research contemplated only short-term survival, not considering that fishing-related stress and damage could cause higher susceptibility to bacterial infection and subsequent death.

Ultimately it can be concluded that, although overall low, damage and mortality varies between species due to the morphological characteristics of the taxa itself, as is the case of fragile echinoderm species, or due to characteristics of the fishing gear used that are not fitted to the ecology of certain species, as it is the case of *E. siliqua*.

Finally, our results showed significant differences on the mortality rate between the SDredge and DDredge which is related to the lower proportions of thick shelled and damage resistant bivalves, as *S. solida* and *C. gallina*, in the catch of the DDredge.

Nonetheless, there is no information on indirect mortality for all bycatch species caught in these fisheries, so, despite the low mortality estimated in this study, discarded individuals may be slow to recover their activity, due to dredging induced stress, becoming more vulnerable and subject to predation (Robinson & Richardson, 1998; Chícharo *et al*., 2002b). However, several authors (Gruffydd, 1972; Caddy, 1973; Kaiser and Spencer, 1995; Broadhurst *et al.* 2002) have indicated low rates of indirect mortality in molluscs and crustaceans, the two most abundant taxa obtained in the present study, and that larger individuals are typically more resistant to damage (Birkett, 1959; Trewin & Welsh, 1972; Medcof & McPhail, 1964). Consequently, reduction of bycatch is desirable for the bivalve grid dredge fisheries, particularly when considering its high percentages.

7. TECHNICAL RECOMMENDATIONS AND FUTURE RESEARCH

The design of the currently used grid dredge allows the escape through the space between bars of the grid of smaller individuals of both target and accessory species. Notwithstanding, since the dredge characteristics are adapted to the target species, it retains all individuals of larger dimensions that are later hauled, sorted onboard and discarded. Regarding bycatch, this gear proved to be much better than the traditional and north dredges, since the amount of bycatch is significantly lower (Gaspar *et al*., 2001; 2003b; Leitão *et al*., 2009). Nevertheless, significant proportions of bycatch have been observed in grid dredge fisheries of Algarve in late spring and early summer (Gaspar & Chícharo, 2007) and were corroborated during this project, particularly in samples from DDredge. A strictly scientific approach to this situation would state that high percentages of bycatch should not be a major problem if the discarded individuals survive (Gaspar & Chícharo, 2007), however bycatch, other than a scientific issue, is also an economic, political and ethical matter (Hall *et al*., 2000).

The morphological diversity of the bycatch species caught by bivalve dredging prompts the need for a dredge design that is simultaneously efficient, selective, and causes lowest possible damages to all organisms. Taking that into consideration, the current overall design of the metallic grid dredge should be maintained and only some slight modifications should be introduced (Figure 6.1). In order to allow the escapement of most bycatch individuals, a bycatch reduction device (BRD) should be introduced in the grid dredge. Thus it is suggested the introduction of a BRD in the metallic cage by incorporating, in the middle of the collecting system, an oblique metallic grid ending at an escape exit at the top of the cage. Thus, it is expected that individuals larger than the openings be guided upwards to the escape exit, while smaller individuals pass through the openings of the BRD. The space between the bars of the BRD must be larger enough to enable target individuals to pass through it in order to not affect fishing yields. The selection of the individuals that pass through the BRD will occur in the grid cage. This type of BRD's, i.e. a simple grid that mechanically precludes catch according to its size, have been extensively reported as efficient in allowing bycatch to escape while maintaining the target catch. Hannah & Jones (2007) have verified a significantly high decrease in fish percentages of bycatch in the ocean shrimp (*Pandalus jordani*) trawl fisheries through the implementation of a rigid-grate BRD. Likewise, Silva *et al*. (2012) reported significant bycatch reductions owing to Nordmøre grid use in the Brazilian artisanal shrimp fishery. These authors highlighted an extremely high (97%) reduction in brachyurids weight, a relatively abundant taxa in the present surveys. Despite extensive research that confirms high bycatch reductions due to the introduction of BRDs (e.g. Brewer *et al*., 1998, Fonseca *et al*., 2005), information on BRDs in bivalve fisheries are scarce, since most authors focus their investigation on prawn and shrimp trawl fisheries.

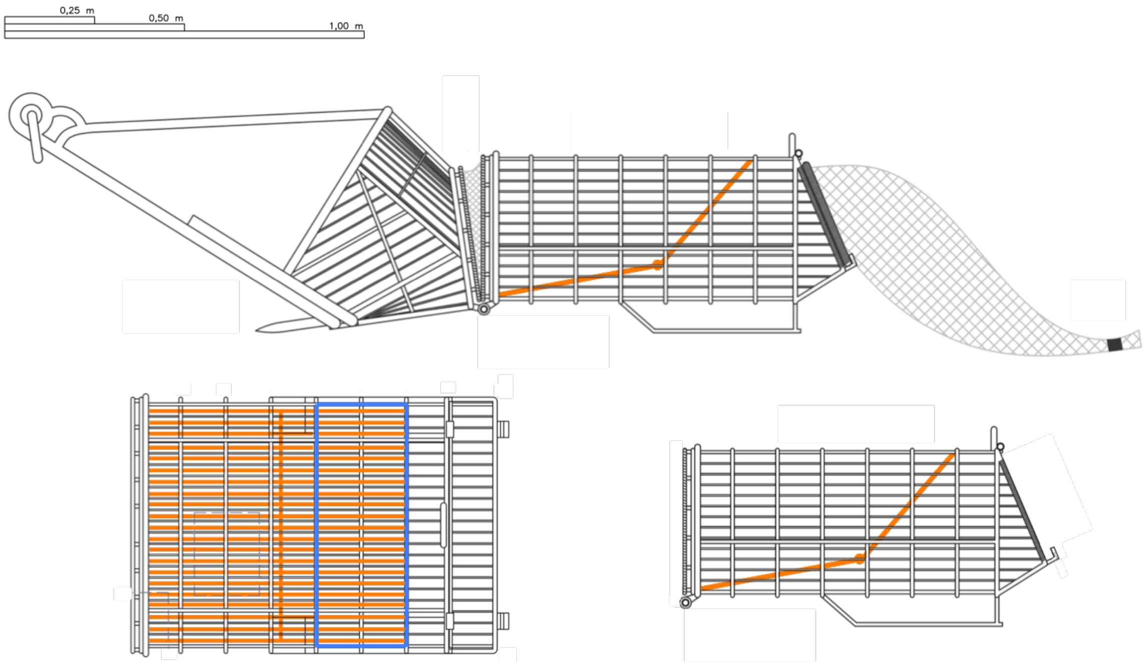

Figure 6.1. Schematic illustration of the proposed technical modifications to the metallic grid dredge, featuring a BRD and a net bag. (A) Full side view; (B) Top view of the retention grid; (C) Side view of the retention grid. Based on schematic drawings by Miguel Carneiro, IPMA.

Survival of escaped organisms should be considered since the use of BRDs assumes that excluded individuals suffer negligible mortality (Crowder & Murawski, 1998). Considering that underwater observations by Gaspar *et al*. (2001) already detected that undamaged individuals that pass through the parallel rods of the metallic grid dredge rebury immediately or recover activity, the likelihood of survival of the escaped individuals is high. The introduction of this BRD is expected to reduce both direct and indirect mortality since it will allow the immediate escape of larger individuals from the fishing gear during the tow. Indeed, mortality due to desiccation on deck and damaging during the loading of the catch on the deck will, thus, decrease. Moreover, the individuals that immediately escape from the dredge are subject to less stress and, subsequently will recover their activity faster, thus decreasing the risk of predation.

Nonetheless, the modification proposed will also negatively influence the fishing yield, as, during hauling, the probability of loss of target catch through the opening at the top of the dredge is high. To overcome this, another gear modification is needed. We propose to remove the posterior part of the grid cage and to attach a net bag to the rear of the gear, as to retain the catch during hauling (Figure 6.1).

Gear-based solutions for bycatch involve the determination of an optimal combination of characteristics that decreases the amount of bycatch, while maintaining or increasing the catch of target species. The likelihood of fishers' acceptance of a new fishing gear is low if the fishing yield decreases comparatively to the previous gear design. In fact, Fonseca *et al*. (2005) have expressed concerns regarding the fishers' acceptance of the implementation of the Nordmøre grid in Portuguese crustacean-trawl fishery, since its use lead to a decrease in the fishing yield.

In conclusion, results gathered in the present study recommend technical modifications in the current design of bivalve dredges, in order to include a BRD and net bag. Comparative studies aiming the evaluation of the effects of the BRD on catch composition should be conducted. With this purpose, dredges with and without BRD should be towed simultaneously in order to allow the comparing of fishing yield, bycatch amount, mortality, and discard rates. Additionally, the currently used damage scores should be re-evaluated and calibrated through survival experiments to better estimate mortality rates associated to dredging.

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