UNIVERSIDADE DO ALGARVE

BYCATCH AND DISCARDS OF COMMERCIAL TRAWL FISHERIES IN THE SOUTH COAST OF PORTUGAL

Maria Esmeralda de Sá Leite Correia da Costa

Tese para obtenção do Grau de Doutor

Doutoramento em Ciências e Tecnologias das Pescas
(Especialidade em Biologia Pesqueira)

Trabalho efectuado sob a orientação de:
Professora Doutora Teresa Cerveira Borges

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Declaração de autoria de trabalho

Declaro ser 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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Maria Esmeralda de Sá Leite Correia da Costa

Cover image:
Bycatch @ Mercator Media
adapted by Maria Borges

À minha filha Rita, *ser de luz*, que veio dar à minha vida

uma nova força, energia e razão de viver.

E a meus Pais, razão da minha existência, a quem devo tudo o que sou.

In fact, the existence of bycatch and discards is not recent. It dates back biblical times, although according to social criteria different from the current epoch:

> 47 *The Kingdom of Heavens is still similar to a net that, thrown to the sea, catch all kind of fish species.* 48*As soon as it is full, the fishermen haul it to the beach, sits down and selects the good ones to the great basket and the bad ones throw them away*.

† • † • †

Na verdade, a existência do bycatch e das rejeições não é recente. Remonta deste os tempos bíblicos, embora segundo critérios sociais diferentes da época actual:

> 47*O Reino dos Céus é ainda semelhante a uma rede que, lançada ao mar, apanha toda a espécie de peixes.* 48*Logo que ela se enche, os pescadores puxam-na para a praia, sentam-se e escolhem os bons para as canastras e os ruins deitam-nos fora*.

(S. Mateus 13:47-48. 1976. *Bíblia Sagrada*. Editora Difusora Bíblica, 7ª Ed.)

Abstract

Bycatch and discards are a cause of great concern in commercial world fisheries, with important ecological, economic and conservation implications. With the recent inclusion of a discards ban ('landing obligation'), in the reform of the EU CFP, these issues have gained a tremendous attention from the economic, scientific, political and social point of view. Demersal trawl fisheries off the southern coast of Portugal capture an extraordinary diversity of species and generate considerable amounts of bycatch and discards. Bycatch includes commercially valuable target-species and bycatch species with low or no commercial value, but the great majority consists of unmarketable species, that are discarded. Bony fishes are dominant in bycatch and discards and the most discarded are of low or no commercial value. The reasons for discarding are fundamentally economic in nature (lack of commercial value) for bycatch species, and legal and administrative (legal minimum landing size) for commercially important species. The study of the reproductive biology of *Galeus melastomus*, discarded by crustacean trawls, suggests that a minimum landing size should be established for this species, and explains the importance of such a study in the assessment and management of fisheries. The discovery of a new species of the ray *Neoraja iberica* n. sp. contributes to the knowledge of the local marine biodiversity in Portuguese waters and of the global marine biodiversity. The three cases of abnormal hermaphroditism recorded in *Etmopterus spinax*, are the first cases known to date of hermaphroditism in this species. There is a need to find solutions to the problem of bycatch and discards of trawl fisheries in the Algarve coast. A combination of technical, regulatory and economic measures to minimize bycatch and reduce discards, before implementing a 'landing obligation', is thought to be the best approach to apply in the southern Portuguese multispecies trawl fisheries.

Key-words: Bycatch · discards · biodiversity · cartilaginous fishes · commercial trawl fisheries · South coast of Portugal (Algarve).

Resumo

Com a exploração crescente e contínua da maioria dos recursos marinhos ao longo do tempo, facilitada pela modernização da tecnologia nas artes de pesca, as capturas acessórias (bycatch), e a consequente rejeição de organismos marinhos ao mar passaram a ser rotina da maioria das pescarias comerciais a nível internacional. Somente no início do Século XX com a percepção dos elevados níveis de bycatch (38,5 milhões de toneladas, equivalente a 40,4% da captura total), e de rejeição (média de 7,3 milhões de toneladas de peixe por ano, correspondente a uma taxa global de captura de 8%), se tomou consciência de que, para além do desperdício de matéria-prima que representam, têm importantes implicações ecológicas, económicas e de conservação. Então, o bycatch e as rejeições tornaram-se objecto de preocupação cada vez mais crescente e do esforço mundial no sentido de gerir e conservar os recursos marinhos pesqueiros.

Actualmente, com a inclusão no recente regulamento da Política Comum das Pescas, da proibição das rejeições (‘obrigação de desembarque‘) e da necessidade de desenvolver medidas que permitam a redução dos actuais níveis elevados de bycatch e a eliminação das rejeições, torna-se não só imprescindível, mas também urgente, proceder a uma correcta identificação e quantificação dos níveis destas duas componentes da captura, à determinação da sua variabilidade no espaço e no tempo, e adquirir conhecimento profundo e claro sobre as razões que levam à prática das rejeições de organismos ao mar. Essa atitude tornará possível efectuar mudanças nas práticas de rejeição, auxiliar no processo de amostragem e permitir a criação de protocolos e medidas que visem tanto o cumprimento da ‘obrigação de desembarque’ como uma gestão mais eficiente do bycatch e das rejeições.

Neste estudo o bycatch total é considerado como sendo a porção da captura total que abrange todas as espécies capturadas acessoriamente (não-alvo), e que tem duas componentes muito importantes: o bycatch comercial, de espécies com valor comercial e que podem ser, subsequentemente, desembarcados e comercializados; e aquele rejeitado (designado por ‘rejeição’ ao longo do trabalho), composto quer por espécies comercializáveis quer, na sua grande maioria, por espécies que não têm qualquer valor comercial, e que são rejeitadas ao mar.

A presente tese tem por objecto principal o bycatch e as rejeições provenientes dos dois *métiers* da frota de arrasto demersal - o arrasto para crustáceos e o arrasto para peixes - das pescarias comerciais que se verificam nas águas da costa Sul de Portugal (Algarve), avaliando em termos de quantidade e composição de espécies, analisando a sua variabilidade e identificando as possíveis e principais causas que levam à prática das rejeições nestas pescarias, em particular. Neste estudo também se analisam as abundâncias e biomassas de espécies rejeitadas (entre métiers e dentro de cada métier), a dominância das espécies presentes na rejeição e as taxas (em número e peso) com que são rejeitadas.

Todas as análises foram baseadas em dados recolhidos durante 25 meses consecutivos (de Fevereiro 1999 a Março 2001) e resultaram da aplicação do método directo de amostragem, que consiste na actividade de um observador qualificado presente a bordo das respectivas embarcações. Durante este estudo surgiram algumas dificuldades que condicionaram o progresso contínuo e eficaz da amostragem inicialmente planeada, nomeadamente: a impossibilidade de não se poder ir a bordo das embarcações, quer por recusa inicial do consentimento, quer por quebra dos compromissos estabelecidos com os respectivos mestres ou armadores; as condições meteorológicas adversas que impossibilitaram, em muitas situações, as actividades e operações normais de pesca; e as situações políticas (greve) geradas pelos armadores da pesca de arrasto para peixes que se estenderam por um longo período de tempo.

Apesar das limitações sofridas neste estudo, os quais podem ocorrer em qualquer estudo de natureza científica, as conclusões a tirar dele são no sentido de que a pesca por arrasto na costa do Algarve, independentemente do métier que se considere, e em resultado da não selectividade inerente à rede de arrasto, captura uma extraordinária diversidade de espécies e gera quantidades consideráveis de bycatch que, por serem compostas na sua maioria por espécies sem valor comercial e por indivíduos de espécies-alvo abaixo o tamanho mínimo legal, dão lugar à sua rejeição em elevadas proporções.

Feita comparação das diversas componentes da captura, verificou-se que, apesar da proporção de bycatch a ser comercializado por ambos os métiers não ser muito distinta, o bycatch total capturado pelo arrasto de peixes excede largamente a captura de espécies-alvo, quando comparado com o arrasto para crustáceos, no qual a captura de espécies-alvo é consideravelmente superior. Crê-se que esta diferença se deva, essencialmente, à duração do tempo de arrasto, que é cerca de quatro vezes inferior no arrasto para peixes. Verificou-se também que o arrasto para peixe rejeita maiores proporções de organismos, e a taxas (em kg/h) consideravelmente superiores, presumindo-se que este facto esteja relacionado com a captura de pequenos organismos pelágicos (e.g. trombeteiro, *Macroramphosus* spp.) cuja distribuição em profundidade se sobrepõe ao intervalo de profundidade explorado pelos arrastões.

A aplicação de testes e análises estatísticas aos dados das capturas, bem como de análises multivariadas aos dados de abundância e biomassa de cada espécie presente nas rejeições, veio revelar não haver padrões sazonais significativos quer nas diversas componentes da captura, quer na taxa de rejeição dessas espécies, sugerindo que a variação das capturas seja, provavelmente, reflexo da persistência na composição das comunidades de peixes demersais ao longo do tempo, e que não existem quaisquer alterações no comportamento de pesca, sempre sujeita a operações determinadas em ordem a tirar a maior vantagem da disponibilidade das espécies comercialmente mais importantes. A maior quantidade de rejeições registadas pontualmente nas estações do outono e inverno é relacionada com a diminuição de preços do mercado local para algumas espécies comerciais de bycatch que de outra forma seriam retidas.

Nas águas continentais portuguesas o arrasto demersal corresponde a uma pescaria multiespecífica, o que é claramente confirmado pela diversidade de espécies, pertencentes a um grande leque de famílias, encontrada durante este estudo. Contudo, a diversidade de espécies capturada pelo arrasto para peixes é inferior à capturada pelo arrasto para crustáceos, em virtude de no primeiro a pesca ser levada a cabo durante menos tempo, em áreas mais restritas e numa gama de profundidades mais baixas.

Em ambos os métiers os peixes ósseos dominam as capturas de bycatch e rejeições, representando uma percentagem extremamente elevada de rejeição em termos de abundância e biomassa. As espécies que mais contribuíram para o bycatch comercial foram as dos peixes cartilagíneos (e.g. pata-roxa, *Scyliorhinus canicula*) no arrasto para crustáceos, e a cavala (*Scomber colias*) e a sardinha (*Sardina pilchardus*) no arrasto para peixes, cuja comercialização depende da quantidade total capturada e dos preços de mercado praticados consoante a época do ano. De entre um número limitado de espécies de peixes ósseos dominantes nas rejeições de baixo valor comercial e, na sua maioria, sem valor comercial, mas particularmente relevantes na cadeia alimentar, salientam-se no arrasto para crustáceos, por ordem decrescente de importância: (1) o verdinho (*Micromesistius poutassou*), o trombeteiro e a mini-saia (*Capros aper*) em abundância, e em biomassa (2) o verdinho, o leitão (*Galeus melastomus*), a mini-saia e o congro (*Conger conger*); e no arrasto para peixes, (3) o trombeteiro e a mini-saia em abundância, e em biomassa (4) a cavala, a pata-roxa, o trombeteiro e a boga (*Boops boops*).

Este estudo permite concluir que as razões que levam à prática das rejeições, em particular nas pescarias de arrasto na costa Sul de Portugal, são fundamentalmente de natureza económica para as espécies de bycatch, pois que a maioria não tem valor comercial (e.g. trombeteiro, mini-saia, maioria de peixes cartilagíneos e invertebrados marinhos), e de natureza jurídico-administrativa para as espécies-alvo de importância comercial, em virtude de a maioria dos indivíduos ser inferior ao tamanho mínimo legal de desembarque (e.g. pescada, esparídeos do género *Pagellus*, gamba-branca *Parapenaeus longirostris*). As espécies-alvo, como as espécies bycatch, são igualmente rejeitadas por causa do estado de degradação ou da má qualidade dos indivíduos, em resultado de lances de longa duração, o que sucede em particular nas espécies menos resistentes à deterioração (e.g. pescada, verdinho, abróteas *Phycis* spp.). Razões económicas importantes que levam à rejeição de espécies bycatch são também a inexistência de mercados disponíveis para muitas espécies comerciais de bycatch (e.g. cabras *Trigla* spp., maioria de peixes cartilagíneos) e o baixo valor comercial de algumas espécies (e.g. verdinho, leitão, pata-roxa).

A constatação de que os peixes cartilagíneos são uma componente bastante importante tanto no bycatch como nas rejeições resultantes da pesca por arrasto na costa Algarvia, aliado ao seu baixo potencial reprodutivo (e.g. longos períodos de gestação, baixa fecundidade, idade tardia a que atingem a maturidade), em particular nas espécies demersais, que os torna muito mais vulneráveis à pressão exercida pela pesca do que a maioria dos peixes ósseos, e com pouca capacidade de recuperarem após grandes declínios nas suas populações, motivaram nesta tese o estudo específico da biologia reprodutiva de uma das espécies de tubarões de profundidade rejeitadas. A escolha recaiu sobre o leitão, *Galeus melastomus* Rafinesque, 1810 (Chondrichthyes: Scyliorhinidae), em virtude de ser uma das espécies de elasmobrânquios mais capturadas como bycatch e a segunda espécie de peixe mais rejeitado em biomassa pelo arrasto para crustáceos. Além disso, toda a informação biológica de base, em particular sobre a biologia reprodutiva em relação a esta espécie, era inexistente anteriormente a este trabalho. Em face das análises dos estados de maturação, períodos de postura, idade de primeira maturação e actividade reprodutiva de machos e fêmeas, sugere-se que sejam aplicados tamanhos mínimos de desembarque a esta espécie de elasmobrânquio, e põe-se em evidência a utilidade de um estudo desta natureza na avaliação e gestão das pescarias.

Esta tese inclui mais dois estudos posteriores à sua planificação, que surgiram no decorrer da amostragem. Um desses estudos refere-se à descoberta de uma nova espécie de raia à qual

foi atribuído o nome científico de *Neoraja iberica* n. sp. e o nome comum de raia pigmeia ibérica. Este estudo, no qual se pode encontrar uma pormenorizada e completa descrição taxonómica desta espécie, contribui quer para o conhecimento da biodiversidade marinha nas águas portuguesas, quer para o da biodiversidade marinha global. O outro estudo refere-se à descoberta de três casos de hermafroditismo anormal encontrado na lixinha-da-fundura, *Etmopterus spinax* (Linnaeus, 1758) (Chondrichthyes: Etmopteridae), considerados como os primeiros conhecidos, até à data, de hermafroditismo registado nesta espécie, e o segundo em elasmobrânquios registado nas águas portuguesas. Este estudo, para além de descrever os espécimes hermafroditas, faz referência ao facto de o hermafroditismo ser uma condição de reprodução extremamente rara dentro do grupo dos elasmobrânquios e discute este fenómeno em outras espécies de tubarão.

Os resultados deste estudo são no sentido de demonstrar que o bycatch e as rejeições provenientes da pesca comercial por arrasto demersal na costa do Algarve constituem, efectivamente, um problema nas pescarias portuguesas, para o qual é necessidade urgente procurar soluções que permitam inverter esta situação. Nesta linha, e neste estudo, se referem as medidas técnicas, regulamentares e socioeconómicas actualmente disponíveis que possibilitam a minimização do bycatch e a redução das rejeições. E, no final do trabalho, se deixa opinião sobre aquelas que melhor se adequarão às pescarias de arrasto na costa Sul de Portugal, tendo em conta os resultados obtidos.

Palavras-chave: Bycatch · rejeição · biodiversidade · peixes cartilagíneos · pesca comercial de arrasto · costa Sul de Portugal (Algarve).

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Costa ME, Erzini K and Borges TC. 2008. Bycatch of crustacean and fish bottom trawl fisheries from southern Portugal (Algarve). Scientia Marina 72(4): 801-814 (Part of Chapter 2).

Costa ME, Borges TC and Erzini K. Discards composition and rates from the coastal bottom trawl fisheries off the southern (Algarve) Portuguese waters. In preparation (Part of Chapter 3).

Costa ME, Erzini K and Borges TC. 2005. Reproductive biology of the blackmouth catshark, *Galeus melastomus* (Chondrichthyes: Scyliorhinidae) off the south coast of Portugal. Journal of the Marine Biological Association of the United Kingdom 85: 1173-1183 (Part of Chapter 4).

Stehmann MFW, Séret B, Costa ME and Baro J. 2008. *Neoraja iberica* n.sp., a new species of pygmy skate (Elasmobranchii, Rajidae) from the southern upper slope of the Iberian Peninsula (Eastern North Atlantic). Cybium 32(1): 51-71 (Chapter 5).

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Contents

Prologue

Uncontrolled fishing effort has led the international community to seek rules to protect marine resources. Although various technical measures aimed at reducing bycatch have been implemented, these are largely ignored in several European fisheries. Consequently, unacceptable levels of bycatches are discarded in these fisheries, which is the cause of great concern due to the negative impacts on the fishery stocks and on the marine ecosystem. For this reason, the European Union (EU) has made regulations with directives (EC No. 1639/2001, renovated by Decision 2010/93/EC) requiring its members to gather information on the levels of discards of species which are commercially exploited, and to report this to the European Community. From their reports it appears that Portugal has complied fully and that complete and detailed data are still scarce.

Recent proposals from the European Commission (EC) faced the problem of discards as a priority and establish procedures in order to reduce unwanted bycatches. The inclusion of a ‘landing obligation´ (discard ban) of all commercial stocks in the recent (11st December, 2013) Regulation of the EU Common Fisheries Policy (CFP) is one of the most emblematic and demanding proposals in terms of implementation in the area of CFP reform.

This work incorporates the data collected during the survey conducted during the years 1999-2001 and relates them with the more recent scientific publications. Beyond the intention of completing this phase of my scientific training, in this work I tried to contribute to the information on bycatches and discards of trawl fisheries in the south coast (Algarve), by providing better knowledge on the scale of the problem, the species involved and the reasons that contributed to the level of bycatches and discards found, as well as identifying the various measures available that can be used to minimise them, leading to fishing practices with less waste and a more rational use of marine resources. By providing this information, it is hoped that this work will be useful both in the assessment of fishery resources in our country and for the evaluation of Portuguese fisheries in national and/or regional programs, which certainly will emerge as a result of the recent 'landing obligation' imposed on the new CFP reform.

Chapter 1

General Introduction

Hauling of a demersal trawl net @ MECosta photo adapted by Pedro Correia

Review of the current state of knowledge on bycatch and discards

Since the increasing and continuous exploitation of most marine resources over time, as a result of improvements in fishing technologies, bycatches and discards have been a matter of great concern in the global context of commercial fisheries (Alverson and Hughes, 1996; Hall, 1996; Hall and Mainprize, 2005; Hall *et al.*, 2000; Northridge, 2009). The confirmation that the discarded bycatch constitutes an important source of wasted marine resources unfavorable to its rational use (to the extent that it is harvested but not consumed), occurred in the 1970s (Allsopp, 1982; Matsuoka, 2008; Slavin, 1982) and, thereafter, there was a growing interest and increasing dissemination of this subject. In the 90s, estimates of discards made by The Food and Agricultural Organization of the United Nations (FAO) (Alverson *et al.*, 1994) and the creation of the FAO Code of Conduct for Responsible Fisheries (FAO, 1995) led to the globalization of this phenomenon, causing concern to the scientific community about the problems originated by the bycatch and the discards associated with it (Alverson & Hughes, 1995; Crean & Symes, 1994; FAO, 1996; Hall and Mainprize, 2005; Hall *et al.*, 2000; Kelleher, 2005; Klima, 1993; Kumar and Deepthi, 2006; Matsuoka, 2008; Murawski, 1995; Tillman, 1993).

The knowledge about the alarming levels of bycatch and discards and the resulting ecological, economic and conservation consequences, attracted the attention of the international scientific community, and determined their research and management actions, in seeking solutions to the reduction of bycatch and discard levels as well as of the inherent economic, political and ecological implications, leading to an evolution of fisheries management strategies (Dunn *et al.*, 2011; Hall, 1996; Hall and Mainprize, 2005; Hall *et al.*, 2000, ICES, 2008a; Lewison *et al.*, 2004a; Olsen, 1995). The demand for such solutions has intensified greatly over the last two decades (ICES, 2008a), with a growing number of studies, aiming to obtain a deeper knowledge of the bycatch (e.g. Andrew *et al.*, 1995; Castriota *et al.*, 2001; Damalas and Vassilopoulou, 2011; Queirolo *et al.*, 2011; Pálsson, 2005) and discard levels (e.g. Allain *et al.*, 2003; Catchpole *et al.*, 2005a; Cetinić *et al.*, 2011; Cotter *et al.*, 1995; Damalas and Vassilopoulou, 2011; Fernandes *et al.*, 2011), the discarding practices (e.g. Tingley *et al.*, 2000; Tzanatos *et al.*, 2007; Ulleweit *et al.*, 2010), the destination of discards as an energy flow to subsequent consumption by organisms (e.g. Castro *et al.*, 2005; Catchpole *et al.*, 2006; Erzini *et al.*, 2003; Hill and Wassenberg, 1990, 2000; Svane *et al.*, 2008) and their effects on the ecosystem (e.g. Cabral *et al.*, 2002;

Tsagarakis *et al.*, 2008), the mortality or survival of bycatch and/or discarded species (e.g. Carruthers *et al.*, 2009; Chopin *et al.*, 1995; Davis, 2002; Düzbastilar *et al.*, 2010; Kaiser and Spencer, 1995) and the development of technology that would allow the reduction of bycatch and discards levels (Broadhurst, 2000; Enever *et al.*, 2010; He and Balzano, 2013; Lucchetti, 2008; Revill *et al.*, 2006; Sardà *et al.*, 2006; Stone and Bublitz, 1995).

Both bycatch and discards still represent concepts difficult to define in a satisfactory way (Alverson and Hughes, 1996; Alverson *et al.*, 1994; Crowder and Murawski, 1998; Davies *et al.*, 2009; FAO, 2010a,b, 2011a; Hall, 1996; ICES, 2008; Kelleher, 2005). The definition of bycatch varies among countries and researchers (Alverson *et al.*, 1994; Crean and Symes, 1994; Crowder and Murawski, 1998; Davies *et al.*, 2009; Hall, 1995; 1996; Hall and Mainprize, 2005; Kelleher, 2005; Morizur *et al.*, 2004) but, generally, the term `Bycatch` has commonly been used to define the catch of species for which there is no direct effort, i.e., to which fishing is not directed (Andrew and Pepperell, 1992; Anon., 2003; CEC, 1992b; Clucas, 1997; Kennelly, 1995; Saila, 1983; Perret *et al.*, 1995; Romine, 1995; Smith, 1995). Part of this bycatch could be retained, landed and marketed if the species have some commercial value. Depending on the nature of the fisheries, local custom, or any other reasons that do not comply with existing legal norms, part of this bycatch is returned to the sea (Alverson *et al.*, 1994; Bache, 2003; Saila, 1983), forming the so-called 'Discards' which is commonly defined as the part of the bycatch that is not used and is, therefore, thrown overboard (Anon., 2008; Bache, 2003; Catchpole *et al.*, 2005b; Clucas, 1997; Elliston *et al.*, 2005; CEC, 1992b, 2002; Kelleher, 2005; Saila, 1983).

According to Hall (1995), bycatch can be classified according to the type and level of impact it exerts (critical, sustainable/non-sustainable, non-biological, unknown-level, ecosystem-level and charismatic). Discards can also be grouped into several categories according to the frequency with which they are discarded (occasional, frequent, regular), to the public sensitivity (sensitive or protected species) and to their economic importance (species with or without commercial value) (CEC, 1992b).

In any fishing activity, the bycatch is usually considered unavoidable and happens with any type of fishing gear and in any region of the world (Kennelly and Broadhurst, 1995; Larsen, 2000; Murawski, 1995; Perret *et al.*, 1995; Poulsen, 1995; Romine, 1995; Saila, 1993; Zann, 2000), and the discarding of fish and other organisms is a common practice in most international fisheries (Alverson *et al.*, 1994; Elliston *et al.*, 2005; Rochet *et al.*, 2002). Many fisheries around the world exhibit high spatial and temporal variability in the bycatch and discarding (Alverson *et al.*, 1994; Andrew and Pepperell, 1992; Cotter *et al.*, 1995; Crean and Symes, 1994; Howell and Langan, 1987; Kelleher, 2005; Kennelly, 1995; Liggins and Kennelly, 1996; Margeirsson *et al.*, 2012; Morizur *et al.*, 2004; Stobutzki *et al.*, 2001), which can be related to the technical characteristics of the vessels and gears, fishing strategies, environmental factors, composition and biology of exploited species and legal market constraints (Kelleher, 2005; Rochet and Trenkel, 2005). The amounts and composition of bycatch and corresponding discards, vary considerably depending on a variety of factors, including the nature of fish stocks, the methods and fishing gear used, the selectivity of the fishing gear, the fishing areas (habitat), the target species and their availability and market value, the duration of trip and fishing hauls, the fishing depth and seasons (CEC, 1992b; Cotter, 1995; Hall, 1996; Kelleher, 2005; Larson *et al.*, 1996; Maguire *et al.*, 2006; Saila, 1983).

Nevertheless, the importance of discards, compared to the landings, depends largely on the fishing gear used (Alverson *et al.*, 1994; Rochet *et al.*, 2002), with the selectivity of the gears being one very important factor on which the amount of bycatch depends (Anon., 1999, 2000, 2004; Bache, 2003; Kennelly, 1995). Although many gears are selective in terms of size, certain gears are not selective in terms of species. In demersal fisheries, the fishing fleets that use non-selective fishing gear, as is the case of demersal trawls which capture almost everything in their path (and therefore have low species selectivity), the bycatch and discard rates are potentially higher than those produced by fishing fleets using more selective fishing gear, such as purse seiners and longlines (Alverson *et al.*, 1994; Broadhurst *et al.*, 2007; Klima, 1993; Kelleher, 2005; Kennelly, 1994, 1995; Kennelly and Broadhurst, 1995; Saila, 1983). Nevertheless, this situation should not be generalized since, in some crustacean trawl fisheries, the ratio of bycatch:catch shows low values (Hall *et al.*, 2000).

The demersal trawl fisheries, especially trawling for crustaceans, have been the focus of particular attention due to the non-selectivity of the fishing gear. This results in high levels of bycatch and discards of individuals of target species below minimum legal size, of juveniles of certain species, which upon reaching larger size are caught intentionally by other commercial and/or recreational fisheries (Alverson *et al.*, 1994; Andrew and Pepperell, 1992; FAO, 1996; Fennessy, 1994; Howell and Langan, 1987; Kennelly, 1995, 1998; Saila, 1983), as well as of endangered or threatened protected species (Lewison *et al.*, 2004a,b; Matsuoka, 2008).

In many commercial fisheries worldwide, bycatch species are caught in large quantities by demersal crustacean trawls, greatly exceeding the catch of target species (Campos *et al.*, 2002, 2003a, 2004). According to Morizur *et al.* (1992), the coastal trawls reveal a great spatial heterogeneity in the captures and fishing practices, generating discards that for some species can be higher (> 50%) than landings, being of great importance particularly in regard to discards of immature individuals, as a result of commercial and regulatory constraints.

Several reasons may lead to the discarding of the entire or part of catch at sea, including the most economically important species (Anon., 2003; Clucas, 1997; Howell and Langan, 1987; Kelleher, 2005; Rochet and Borges, 2006). Discarding may be due to: i) *technical* reasons for marketable species (e.g. the fishing gear itself and limitations/problems associated with its use, onboard storage capacity, bad weather), ii) *economic* reasons (e.g. species with no or low commercial value, inexistence of a ready market for certain species, damage or poor quality of species), iii) *legal and administrative* reasons (e.g. minimum legal sizes of marketable species, excess of commercial fishing quotas, unauthorized fishing licenses, prohibited fishing zones and seasons, prohibited capture of threatened and protected species, forbidden fishing with illegal gears) and iv) *biological/ecological* reasons (e.g. species composition, year class, patterns of distribution of species which in turn conditions the directed fishery for one or multiple species) (e.g. Alverson, 1998; Anon., 2003; Bök *et al.*, 2011; Catchpole *et al.*, 2002, 2005b; CEC, 1992b; Cotter *et al.*, 1995; D´Onghia *et al.*, 2003; Dunn *et al.*, 2011; Edelist *et al.*, 2011; Kelleher, 2005; Machias *et al.*, 2001, 2004; Moranta *et al.*, 2000; Morizur *et al.*, 2004; Sánchez *et al.*, 2004, 2007; Sartor *et al.*, 2003; Ulleweit *et al.*, 2010).

Higher variability in the discards is expected to be greater within (Rochet *et al.*, 2002, Ulleweit et al., 2010) rather than between métiers, and also when sampling is considered at haul level (Borges *et al.*, 2005b; Cotter *et al.*, 1995; Pravoni *et al.*, 2001; Tamsett *et al.*, 1999) instead of trip level. Moreover, Kelleher (2005) foresees that the reasons for discarding are expected to be different from species to species, so any efforts intending to reduce discards will be more effective if focused on species that are partially discarded. A deep and clear knowledge about all the reasons leading the current practice of discards of organisms at sea is a mandatory requirement in order to make changes in the practice of discarding, to help in the improvement of sampling and allow the creation of protocols and policy measures aiming at a more efficient management of discards and therefore the bycatch (Anon., 2000; Kelleher, 2005; Walmsley, 2004).

However, for most NE Atlantic and Mediterranean trawl fisheries, discarding also occurs mainly because the catch is of no commercial value (e.g. Borges *et al.*, 2000-2002; Castriota *et al.*, 2001; D´Onghia *et al.*, 2003; Edelist *et al.*, 2011; Machias *et al.*, 2001; Monteiro *et al.*, 2001; Moranta *et al.*, 2000; Sánchez *et al.*, 2004, 2007; Sartor *et al.*, 2003), and because the potentially commercial species are either below minimum landing sizes (e.g. Bök *et al.*, 2011; Catchpole *et al.*, 2002; Edelist *et al.*, 2011; Machias *et al.*, 2001, 2004; Moranta *et al.*, 2000; Sartor *et al.*, 2003) and/or are of low commercial value (e.g. Borges *et al.*, 2001; Machias *et al.*, 2001, 2004; Sánchez *et al.*, 2007; Ulleweit *et al.*, 2010).

Evaluation of bycatch and discards in coastal commercial fisheries allows reaching important ecologic and economic considerations which are essential to good fisheries management (Allain *et al.*, 2003; Alverson and Hughes, 1996; Alverson *et al.*, 1994; Crean and Symes, 1994; Rochet and Borges, 2006; Saila, 1983). By contributing to overfishing and resulting in modifications in the structure of benthic communities (Alverson *et al.*, 1994; Castriota *et al.*, 2001; Dayton *et al.*, 1995; De Groot, 1984; Jones, 1992; Maguire *et al.*, 2006; Rebecca *et al.*, 2004), high levels of bycatch and discards can threaten, in a long term, the sustainability of the fisheries and the marine biodiversity important for maintaining the ecosystems balance (Bache, 2003; Catchpole *et al.*, 2006; Crean and Symes, 1994; Everett, 1995; Watson, 2007; Wilson, 1990).

Both in economic and ecological terms, the discarding of bycatch represents an unnecessary loss (Allain *et al.*, 2003; CEC, 1992b). In ecological terms, the major impact of this practice is reflected in the ecosystem structure and in the marine diversity (Borges *et al.*, 2001; Castriota *et al.*, 2001; Matsuoka, 2008). The change in the ecosystem balance caused by the bycatch and the waste of raw material caused by its discards, which is lost in food chains and does not reach the consumers, creates changes in the food chains and does not provide any advantage except to serve as additional food for scavengers (Alverson *et al.*, 1994; Castriota *et al.*, 2001; CEC, 1992b; FAO, 2010a; Van Beek, 1998) and to promote decomposition processes (Cabral *et al.*, 2002; Goñi, 1998). Through discarding, scavengers learn how to take advantage of discards and their foraging habits are thus altered (Castriota *et al.*, 2001; Hill and Wassenberg, 1990, 2000; Kaiser and Hiddink, 2007; Van Beek, 1998; Wassenberg and Hill, 1989). For most fisheries and species, it is often assumed that the organisms are dead or dying when they are discarded (Cotter *et al.*, 1995; Hill and Wassenberg, 1999; Kelleher, 2005; MacDonald *et al.*, 1994; Saila, 1983; Van Beek *et al.*, 1990; Wassenberg and Hill, 1989), and while their biomass returns to the ecosystem, the effects are not well understood (Andrew and Pepperell, 1992; CEC, 1992a, 2002; EC, 2007; Kennelly, 1995). Nevertheless, there are studies that claim that in some situations and depending on variability variety of factors (Broadhurst *et al.*, 2006; Davies, 2002; Davies and Ryer, 2003; Suuronen, 2005), a percentage of the catch eventually survives (e.g Davies and Olla, 2001, 2002; Mesnil, 1996; Van Beek *et al.*, 1990; Wassenberg and Hill, 1989, 1993). Known ecological impacts also include the decrease in local biodiversity (Kelleher, 2005) by reducing prey and top predators in the trophic chain to unsustainable levels (Hall *et al.*, 2000).

In economic terms, the discarding practice, by reducing the availability of accessory species that are targeted by other fisheries, represents a significant loss in stock productivity and may adversely affect the size and the structure of the populations (Crean and Symes, 1994; Catchpole *et al.,* 2006; Watson, 2007). This is particularly important when large quantities of juveniles of high commercial value are discarded because it results in a significant effect on the recruitment of relevant species to commercial fisheries (CEC, 2002; EC, 2007). Regarding non-commercial species, discarding represent economic losses as these could be used in the production of derivatives such as fishmeal, oils and fish pastes, and other products with application in cosmetic, pharmaceutical and biomedical industries, as happens in some world fisheries (e.g. Alonso *et al.*, 2010; Kumar and Deepthi, 2006; Lobo *et al.*, 2010; Raffi, 2011).

In multispecies fisheries, the impacts of discarding large amounts of organisms are known to be highly significant (Alverson *et al.,* 1994; Saila, 1983), and depending on the life strategies of each species, the effects on populations of target species of commercial fisheries can be completely different from those exerted on populations of species with no commercial value (Alverson *et al.*, 1994; Goñi, 1998). Species which tend to have a K-selected life history strategy (i.e., slow growth, long lifespan, low fecundity, long gestion and late maturing), as is the case of the most vulnerable species, are particularly subject to overexploitation, and may go into decline in decades or less (Hoening and Gruber, 1990; Stevens *et al.*, 2000).

The recovery of these K-selected species from depletion is extremely slow when compared with those which have a r-selected life history strategy (Musick, 1999; Stevens *et al.,* 2000), suffering a much greater impact, particularly if quotas and fishing strategies are directed to r-selected target species (Alverson *et al*., 1994; Musick, 1999). Therefore, high discards of marketable species can have smaller impacts than low discards of sensitive species (Alverson *et al.,* 1994). However, some authors advocate that although the removal of a large number of individuals from an ecosystem may have unpredictable effects, it cannot be stated that large amounts of bycatch always result in unfavorable biological and ecological impacts (Alverson and Hughes, 1996; Perret *et al.*, 1995; Zhou, 2008).

There is a general concern about the consequences of the discarding of bycatch, both by those responsible for the assessment and management of fisheries and by the global environmental and activist groups related to the conservation of marine resources, alarmed by the consequences that fishing activity has on the vulnerable, sensitive and/or protected marine species (e.g. birds, turtles, mammals, sharks and rays) (Alverson *et al.*, 1994; Dayton *et al.*, 1995; De Groot, 1984; Jones, 1992; Kelleher, 2005; Maguire *et al.*, 2006; Read *et al.*, 2006; Rebecca *et al.*, 2004). Bycatch of these unmarketable species has become an increasingly important factor in the management of certain fisheries (CEC, 1992b; ICES, 2009a), being of particular concern when the so-called "charismatic" species are on the list of vulnerable or endangered species (Bache, 2003). Despite global efforts that have been made to conserve and manage marine fisheries resources, when it comes to unwanted or regulated bycatch, the accidental capture and mortality of protected species caused by commercial or recreational fisheries, is still a significant and growing problem (Watson, 2007).

The bycatch of elasmobranchs, one of the vulnerable groups of organisms, is of significant and increasing concern in fisheries worldwide, causing substantial ecological, economic and conservation problems (Camhi *et al.*, 1998; Stevens *et al.*, 2000; Stobutzki *et al.*, 2002; Walker, 2005). As K-life history strategists, the elasmobranchs have special reproductive characteristics (long gestation periods, usually exceeding two years, low fecundity and late maturity), which makes them particularly vulnerable to fishing pressure when compared to the majority of finfish (Anderson, 1990; Cailliet *et al.*, 2005; Cavanagh and Claudine, 2007; Ellis *et al.*, 2008; Fowler *et al.* 2005; Gallucci *et al.*, 2006; Hoff and Musick, 1990; Holden, 1974, 1978; Walker, 2005). These biological characteristics have serious implications for populations of elasmobranchs to the extent that there is limited ability of many species to recover after major declines in their populations (Stevens *et al.*, 2000, 2005; Musick, 2005), caused either from overfishing (direct or indirect) or other threats from human activity (e.g. pollution and habitat destruction) (Cailliet *et al.*, 2005; Camhi *et al.* 1998; Cavanagh and Claudine, 2007; Fowler *et al.*, 2002, 2005; Gallucci *et al.*, 2006; Walker, 2005). Moreover, the elasmobranchs are known to have an important ecological role as predators near or at the top of the marine trophic chains and are considered as indicators of the state of the fishery (Stevens *et al.*, 2000). However, Serena *et al.* (2009) believe that the recent declines in traditional target species may lead to a decrease in discards of these fishes as, to compensate for this decline, higher amounts of "alternative" bycatch species are being retained.

Some authors consider it essential to improve research and monitoring of the elasmobranch bycatch (Cavanagh and Claudine, 2007), and call upon the need to carry out studies on the biology of these species (size composition and sex ratio, distribution and habitat, age and growth, length by maturity stage and other aspects of the reproductive biology) in order to provide data to fisheries managers for the purpose of assessing the status of stock condition and to ensure the sustainability of elasmobranchs populations (Ellis *et al.*, 2008; Jones *et al.*, 2008). All this biological information is still considered insufficient for most elasmobranchs, particularly in the case of deep sea sharks (Ellis *et al.*, 2008; Martin and Treberg, 2002).

The reduction of bycatch and discards is one of the important aspects taken into account in fisheries and the appropriate measures for the reduction, to be taken in order to protect juveniles and spawners, are listed in the FAO Code of Conduct for Responsible Fisheries since 1995 (FAO, 1995). It is necessary to estimate bycatch and discards in order not only to assess the impact that fishing has on non-commercial species and on the entire ecosystem (Alverson *et al.,* 1994; Hall, 1999), but also to obtain empirical data so that the process that leads to the discarding practice can be studied (Rochet *et al.,* 2002). The search for solutions towards addressing the problem of bycatch and discards has intensified greatly over the last two decades (ICES, 2008a).

Accurate studies on the impacts that bycatch and discards exert at the population level should take into account not only the discards in terms of number and weight and the discard mortality but also the survival of discards (Alverson and Hughes, 1996). The search for solutions to reduce the problem of discards requires making local studies in order to determine the range and variability of discards in space and time (Allain *et al.,* 2003; Saila, 1983). It is also necessary to identify, quantify and compare the levels of discards in fisheries using different type of fishing gears (Borges *et al.*, 2002; Erzini *et al.*, 2002). Given the high rates and large variability in the discards observed in many commercial fisheries, routine monitoring of the discards is essential not only for stock assessment and management, but also to help in the evaluation of mitigation techniques or the ecological effects caused by the discard measures (Borges *et al.,* 2002).

The presence of observers onboard fishing vessels is considered essential by many authors in order to observe the discarding practices as well as to record the causes and/or reasons that lead to discards (e.g. ; FAO, 1996; Kelleher, 2005; Kennelly, 1995; Liggins *et al.*, 1996; Morizur *et al.*, 1996, 2004; Nolan and Yau, 1997; Weber, 1995). The European Union considers that onboard observer programs are useful to estimate the total catch, including landings and discards, and that the data collected by this method are more comprehensive since they include the area and the fishing method and allow a better quality control (Rochet and Borges, 2006). The introduction of these programs in fisheries will improve the accuracy of the bycatch and discard estimates in world fisheries (CEC, 2008a; Elliston *et al.*, 2005; Watson, 2007). However, the significance of the sampling onboard is still limited, due to the voluntary and costly nature of the sampling programs (Rochet and Borges, 2006).

The European Commission also considers that to assess the impact of the reduction of the discarding practices, it is necessary to collect discard data at the métier level (CEC, 2008a,b; EU, 2008a). The term "métier" was adopted by the European Data Collection Framework (DCF) (CEC, 2008b) and is defined by the European Community as "a group of fishing operations targeting similar (assemblage of) species, using similar gear, during the same period of the year and/or within the same area, and which are characterised by a similar exploitation pattern" (EU, 2008a)".

Bycatch and discard amounts in the global context of fisheries

The first estimates of the total bycatch from all of the world´s oceans pertain to the 1970s and to the shrimp trawl fishery. The US National Academy of Science estimated an annual shrimp bycatch from 5 to 21 million tonnes (t) and, in 1975, an annual discarded fish bycatch from shrimp fisheries of 3 to 4 million t was estimated by an FAO roundtable (Slavin, 1982). In 1980, a global bycatch range of 5 to 16 million t was estimated, based on a ratio of by-catch fish to shrimp according to geographical areas (5:1 for temperate waters and 10:1 for tropical waters) (Allsopp, 1982). The FAO presented a revised annual discard estimation of 5 million t (Slavin, 1982) but Slavin suggests a conservative estimate of 3 to 5 million t per year of the discarded bycatch (Slavin, 1982).

In the late 1980s and early 1990s, Saila (1983) estimated for the first time the average world fisheries discard rate at 10%, or about 6.72 million t. FAO estimated an average global discard of 27.0 million t (reported range 17.9-39.5 million t) (Alverson *et al.*, 1994), corresponding to about 35% of the production of the world's marine fisheries (Alverson and Hughes, 1996); while Andrew and Pepperell (1992) estimated a global by-catch in world shrimp fisheries as high as 16.7 million t.

In the study by Alverson *et al.* (1994), bottom trawl fisheries were found to generate more discards than any other type of fishery and a mean total shrimp bycatch of 11.2 million t (range 16-17 million t) was estimated. However, Everett (1995) considers that these figures may be underestimated because these estimates do not include: 1) the mortality rates of the species that escape from fishing gear during fishing operations; 2) the discard rates of mammals, turtles and marine invertebrates; and the 3) the recreational and subsistence fisheries. Also, the databases used in the estimation were incomplete. Moreover, issues related to methodological weakness, which did not take into account the landings of non-target catches leading to over-estimations of discards (Matsuoka, 2008), and issues related to lack of information on discards from artisanal, recreational and subsistence fisheries, illegal fishing and under-reporting in log books leading to under-estimation of discards, were later recognized by FAO (FAO, 1996).

In the mid-1990s, FAO global discards estimation was adjusted to 20 million t, equivalent to 25 percent of the reported annual production from marine capture fisheries (FAO, 1999).

In the XXI century, the most recent estimate of the total amount of fish discarded annually by commercial fisheries worldwide was published by FAO in 2005, based on data covering the period 1992-2001 (Kelleher, 2005). According to this study, the global discard rate (proportion of the catch discarded in relation to total captured) by weight is estimated at 8%, which is equivalent to an average of 7.3 million metric tons of fish per year, varying widely depending on the type of fishery (from 3.7% in small-scale artisanal fisheries, up to 52% in demersal fishing trawls directed at fish and crustaceans). This estimate is considerably lower than the estimated 27 million tons in 1988-1990 (Alverson *et al.*, 1994) and Zeller and Pauly (2005) believe that this discard reduction over the years may be a result of improvement in fishing practices, the reduction of wasteful fisheries or of the increase in the retained capture (e.g. for reduction into fishmeal).

Davies *et al.* (2009) analyzed data from major fisheries in 23 countries from 2000 to2003 (including the Northeast Atlantic) and reached bycatch estimates of 38.5 million tons, corresponding to 40.4% of the total marine catch, believing that the amount of the bycatch is probably higher. To these authors, bycatch is resulting either from lack of management in fisheries or from continuous gaps in fisheries policy and management.

Bycatch and discards in the European Union context

The discarding of organisms to the sea has been a significant problem in the European Union fisheries (EU) and has concerned the European Commission since 1992 (Anon., 1999, 2000). The most recent global discard estimates indicate that for the period 1992-2001, the Northeast Atlantic (FAO area 27) fisheries, where the majority of European Union fisheries are included, are responsible for generating around one-fifth (1.332 million tonnes, 13% average discard), accounting for 19.5% of the annual global discards (Kelleher, 2005).

Within the EU fisheries, there is a large variability in the discards. According to the ‘Scientific, Technical and Economic Committee for Fisheries’ (STECF), the level of the bycatch discarded in the European demersal trawl fisheries for the period 2003-2005, represents between 20% and 60% of the total catch by weight (CEC, 2007a). In the North Sea, the discard estimates vary between 500,000 and 880,000 tons (40% of the total catch by weight) (CEC, 2007a,b; EC, 2007). The West of Ireland and Scotland show discard estimates varying between 20% and 40% of the total catch by weight (EC, 2007), depending on the fleets, target species and depth (CEC, 2007a,b). In the Mediterranean Sea and the Black Sea discards amount to 18,000 tons, corresponding to an average discard rate of 4.9% (CEC, 2007b; EC, 2007). In the Baltic Sea, some fisheries contributed with quite insignificant discard values (average of 1.4%) when compared to the main demersal trawl fisheries (70-90%) (CEC, 2007b; EC, 2007).

To comply with the United Nations Food and Agriculture Organization Code of Conduct for Responsible Fisheries (CCRF), ensuring that long-term fishery resources exploitation is carried out in a sustainable manner, consistent with an ecosystem approach to fisheries (FAO, 1995), all significant sources of mortality induced by fishing, in which discards are included, should be quantified and accounted for (FAO, 2010a). For that purpose, the European Union (EU) has been implementing the estimation of discards within the scope of the Data Collection Framework (EC Regulations Nos. 1543/2000, 1639/2001 and 1581/2004) (EC, 2000, 2001, 2004). The information is then included in stock assessment models to improve assessments and also used to provide a better insight into the effects of fisheries on the marine ecosystem (EU, 2008b). Based on the EC Regulation No. 1639/2001 ('Data Collection Regulation') (EC, 2001), discard data have been collected by the EU member states since 2002 in order to gather and improve the availability of data in certain EU fisheries (Anon., 1999, 2000; CEC, 2007a,b; EC, 2001, 2007a; ICES, 2007; Rochet and Borges, 2006).

The need for establishing survey methodologies for discards and for accurate discard estimations common to the member states, led the International Council for the Exploration of the Seas (hereafter ICES) to establish, at the Workshop on 'Discard Sampling Methodology Raising and Procedures' in 2003, different statistical formulae, based on the use of two statistical estimators, in order to calculate discards and accuracy for a given population (ICES, 2004). Considering that these statistical formulae were based on assumptions that in practice were not used for the purpose of sampling programs and of fisheries, ICES proposed in 2006, a workshop on the most appropriate procedures to take into account in the data collection of discards, to be applied to the different member states, through the 'Planning Group on Commercial Catch, Discards and Biological Sampling' (PGCCDBS) (ICES, 2006a). Currently, and in light of the data collection system ('Data Collection Framework', DCF), there is still an obligation, imposed by European regulations (EC Decision 2010/93/EC) (ICES, 2010a; EU, 2011), for each member state to collect information on the discard rates of commercially exploited species. However, the discard data remains incomplete for some member states and for some fishing areas (EC, 2010).

Although several technical measures to protect juvenile fish and reduce the capture of undesired (bycatch) species and their discarding are in place under Community legislation (e.g. changes in mesh sizes, minimum landing sizes, catch composition rules according to defined mesh size ranges, area and real-time closures) (CEC, 2002), unacceptably high levels of discards are still found in numerous European fisheries managed under the EU Common Fisheries Policy (CFP) (CEC, 2008b; STECF, 2008).

The negative impact that the discards exert on fish stocks and on marine ecosystem has been also a serious concern of the European Commission (EC) (Anon., 1999, 2007; CEC, 2007a,b). To this end, the European Commission prepared, in March 2007, a policy proposal which addresses the problem of discards as a priority, and outlines the procedures to be taken in order to reduce bycatch and eliminate unwanted discards in European fisheries (CEC, 2007a,b). In the international framework, the reduction and prohibition of discards imposed by law are not new measures, which had already been implemented in some fisheries in Norway, Iceland, Canada and New Zealand (Anon., 1999; CEC, 2007a,b; EC, 2007, 2008). However, due to the diverse implications regarding European multispecies fisheries (particularly regarding social aspects, environmental factors, species and fishing gears), the EU has suspended the implementation of the legislation to ban discards in all EU countries (Borges, 2010). Nevertheless, the European Commission remained committed to reducing discards, and to establishing a suitable plan to reduce bycatch and discards in EU fisheries (Anon., 2009a-2011a).

Maria Damanaki, European Commissioner for Maritime Affairs and Fisheries, considers that, in light of the new Common Fisheries Policy, it is essential to have "an obligation for landing discards, albeit gradually implemented" (Anon., 2011b). In this regard, the EC proposed the reduction and elimination of the practice of discards (EC, 2011a) in the recent revision of the EU Common Fisheries Policy. The inclusion of such a mandatory discard ban, where all individuals of commercial stocks that are caught will have to be landed (*Article 15* of the Proposal for a Regulation of the European Parliament and of the Council on the Common Fisheries Policy; EC, 2011a), was considered an incentive to avoid catching unwanted species and its implementation is intended to be phased-in, fishery by fishery, initially from 2014 to 2016 (EC, 2011a), but more recently from 2015 to 2019 (EC, 2013a,b).

Bycatch and discards in the Portuguese fisheries context

Portugal, part of FAO area 27 and integrated in the EU, ranks among the top 10 countries presenting the highest discards (total and rate) generated by shrimp trawl fisheries, amounting to over 35,000 tonnes (70% discard rate) in 1996 (Kelleher, 2005).

There are some studies in Portugal that address different aspects of the issue of bycatch and/or discards of fish. In the late 1990s, and during the peak awareness of the international problem of bycatch and discards, Borges *et al.* (1997) conducted the first Portuguese study of commercial fishing discards on the south coast of Portugal. The proposed goals consisted in evaluation of the discards from the commercial purse seines (pelagic and demersal), trammel nets and demersal trawls (for crustaceans and fish), both quantitatively and qualitatively; relating the discarded species to those of commercial interest, and distinction of the practices of discarding in each métier.

The results of the Borges *et al.* (1997) preliminary study, conducted over 18 months (1996-1997), provided the information that there is a high species biodiversity, considering the number of species caught unintentionally, and therefore discarded. The results also showed that, compared to the total catch, about 66% of species were discarded, and the reasons for discarding varied according to the species or métier. It was shown that trawling is the métier which contributes most to high rates of discards, crustacean trawlers being responsible for higher discard rates (83% average), followed by fish trawlers (79% average). Discards resulting from the Algarve (southern Portugal) trawl fishery were estimated at between 9,000 and 13,000 tonnes (average discard ratio of 70%) (Borges *et al.*, 2001). These authors conclude that discards in terms of composition and quantity, are a significant problem for the fisheries in Portugal and suggest that further studies should be done, increasing the sampling effort, assessing the variability of the discard rates and amounts, the destination of discards, and the relevance that the practice of discarding may have in the marine ecosystem, suggesting measures to reduce bycatch and discards in these types of fisheries.

Following this, Borges *et al.* (2000) carried out, for two consecutive years (1998-2000), more detailed studies on discards of commercial fishing in the same area, increasing the sampling effort by 23% to 27%. The quantification of discards, the identification of the reasons for discarding and the classification and biological characterization of the discarded species were the main intentions of the continuing study. This study continued to show a high biodiversity of species discarded in high percentages (67%) as well as the greatest contribution of both crustacean and fish trawls to the highest discard ratios (59% and 43%, respectively).

Between 1999 and 2001, Borges *et al.* (2002) developed the first multidisciplinary study on the specificity of bycatch and discards issues on the south coast of Portugal, reporting a discard ratio of about 67%, higher in crustacean (33%-89%) than in fish (27%-75%) trawls. These authors also pointed out the fact that only 33% of species caught by trawlers were marketed, the rest being discarded. The observations of selectivity of trawl nets, performed in this study, showed the efficacy of selective net devices (rigid system of selective grids) in the catches of target species, and consequent reduction in the amount of bycatch.

The three studies carried out by Borges *et al.* (1997, 2000, 2002) show that discards are indeed a significant problem for demersal trawl fisheries off the southern coast of Portugal (Algarve), and lead to the conclusion that, although there are several reasons for discarding about 80% of fish caught by trawls, the prime reason is economic, since a considerable number of species for which there is no readily market available were discarded. Regarding the commercially valuable species, the main reason for discard is legal and administrative (sizes below de legal minimum landing size). These studies underline the existence of a significant richness of marine species in the waters of southern Portugal, as well as substantial loss of raw materials and potential new markets with consequent economic losses.

Castro *et al.* (1999) carried out a preliminary study on the impact of discards in trawl fisheries in the Algarve during 1997 and 1999, investigating the factors that influence the composition, quantity and variability of bycatch and discards, and evaluating the fate of discards. As a result of this study, the authors argue that 56% of the discards, mostly comprised of fish, are consumed by seabirds at the surface, and that the remaining fraction (44%) falls in the water column, with around 3% (equivalent to 12% of fish biomass) being consumed by pelagic fish. These authors also found that after consumption in the water column, an average of 41% of the initial discards reach the seabed, being readily consumed by scavenger species, therefore assuming that discards are completely recycled by the marine system in less than 48 hours.

Experimental studies on the selectivity of gillnets and longlines, carried out by Erzini *et al.* (1999) on the south coast of Portugal, provided information that proves the existence of large differences in the species composition of the catches between both gears and that significant discard amounts of pelagic species with low (or zero) market value and small size are generated by these fishing gear, particularly gillnets (26.4- 49.5% by weight).

During 1998 and 1999, Monteiro *et al.* (2001) studied the discards resulting from bottom crustacean trawl fisheries in the Algarve in terms of species composition and amounts discarded, reporting discard values from 5% (6.2 kg) to 76% (169.1 kg), lower than those reported by Borges *et al.* (1997). Of the 91 species identified in this study, fishes (bony and cartilaginous) represent a fairly significant portion of discards, both in weight (82%) and in number (85%).

A study on the selectivity of trammel nets carried out by Erzini *et al.* (2001) on the coastal waters of the Algarve, allowed Gonçalves *et al.* (2007) to study the discards generated by this type of fishing gear. These authors concluded that, during 1999-2000, high proportions of catches (49% by number) and a significant number of species (n=105) were discarded by trammel nets, and that the main reasons of this practice are economic issues (low or no commercial value of species, poor quality of commercial species and catches of insufficient amounts of marketable species) and legal and administrative issues (species smaller than the minimum legal size established).

Erzini *et al.* (2002), in a study on the composition of the species discarded by five fisheries (crustacean trawlers, fish trawlers, demersal purse-seiners, pelagic purse-seiners and trammel nets) on the south coast of the Algarve, support the high diversity of species (n=236) and consider it one of the characteristics of discards from the commercial fishing activity. These authors associate the differences in each type of fishery, in terms of species composition and discarded biomass, to the selectivity of the fishing gears and to the depth at which the fishery takes place, suggesting that the practice of discarding can have distinct but significant impacts on the marine ecosystem.

Through experiences with longlines on the Algarve coast in 1998, Erzini *et al.* (2003) studied the consumption of discards in the water column on trawl fishing grounds. Results of this study showed that consumption of discards by predators is substantially higher on the continental shelf below 100 meters depth and are rather insignificant in deep (>200 m) waters.

During 1994 and 1996, Cabral *et al.* (2002) conducted a study within the Tagus estuary with the main purpose to evaluate the importance of discards of the brown-shrimp beam trawl fishery in the estuary´s nursery areas and found that an extremely high percentage (90%) of the catches, equivalent to 1527 tonnes/year, were discarded by this type of gear. Four years latter, through experiments designed to study the survival of the beam trawl´s discarded fish and crustacean species, these authors noticed that the mortality rates were quite different from species to species and vary according to season and time of day. From the study of the chemical decomposition of the main discarded organisms these authors also found that these discards represent an extraordinary input of organic matter (35 and 140 tonnes/year of nitrogen and carbon, respectively) into the Tagus estuary´s nursery areas.

After carrying out a study on discards resulting from the use of beach seine nets conducted, in 1999, on the central coast of Portugal (south of Lisbon), Cabral *et al.* (2003) found that this type of fishing gear generates large quantities of bycatch, being the majority of the species discarded in very high percentages (approx. 100%) mainly due to legal and administrative (marketable species with sizes lower than the minimum legal) reasons.

The fate of discards from demersal trawling for crustaceans on the southern coast of Portugal was addressed again by Castro *et al.* (2005) who suggests that the discarding of organisms to the sea has an important impact on the structure of the deep sea marine ecosystem, to the extent that the large amounts of material that are returned to the sea in the form of dead organisms serve as additional food for scavenger species, fostering their growth in terms of abundances and biomasses. The main beneficiaries were found to be the small bottom scavengers with a preponderant role in the recycling of the organic matter.

During 2003 and 2004, Gonçalves *et al.* (2004) evaluated experimentally the effectiveness of a diamond-shaped mesh net as a selectivity device (or ´Bycatch Reducing Device´, BRD) in fisheries for demersal purse seines in the Algarve, in order to reduce bycatch and discards, examining the survival and physical condition of the fish that escape from these same devices. Results of this study led Gonçalves *et al.* (2008a) to show that, of the 46 species of fish, molluscs and crustaceans caught by demersal purse seines, almost 70% were discarded, representing 50.5% (8266 kg) of the total catch. The discards consisted mainly of pelagic fish with low commercial value and juveniles of demersal species with high commercial value, being the main reasons for discarding of economic (species with low commercial value, in 56.6% of the cases), and legal and administrative (species below the minimum legal size, in 40% of the cases) origin. The BRD employed proved to be an effective device in reducing bycatch, and it was found that a very significant fraction of species (61.8% of the total weight and an average of 49% of individuals) that would normally be discarded could escape through the device, causing no significant impact on the survival rate and physical condition of the fish crossing the device.

An experimental fishery using trammel nets in the Algarve was carried out, during 2000, by Gonçalves *et al.* (2008b) with the purpose to quantify the discards of marine invertebrates with no commercial value, relating them to gear selectivity, soaking time of the fishing gear in the water, depth and season. Results of this study show that trammel nets are the fishing gear most responsible for the bycatch and discards of these invertebrates between 15 and 60 meters depth. Of the 156 (87.6%) species discarded by this type of gear, this taxonomic group represents 48% of the total catch and 65% of discards in number. Invertebrates with higher commercial value, particularly cephalopods, are mostly discarded for economic reasons (poor quality of species and/or captured in insufficient amounts to justify its sale), but also for legal and administrative issues (smaller than minimum legal size). In general, it was found that discards of invertebrates without commercial value vary considerably with soak time, decreasing with increasing depth and exhibiting high but not statistically significant seasonal variability in the amounts discarded.

In order to contribute to improved artisanal fisheries management and bycatch reduction, Batista *et al.* (2009) conducted a study between 2004 and 2005, which characterized the trammel net fishery targeting soles and cuttlefish on the central West coast of Portugal, and evaluated the factors affecting the variability in the captures as well as in bycatch and discards. Results of this study show that this type of fishing gear captures a wide variety of species (n=112), of which 87.5% (n=98) are discarded, corresponding to a discard rate of 21.9% in weight and 52.8% in number. Regarding bycatch, this represents 59.6% of the total catch, 41% of which is discarded (ca. 22% in weight and 53.8% in number. The commercially valuable species were discarded mostly because of their damaged condition (90% of species) and to a lesser extent because of their size below below de legal minimum landing size. The lack of commercial value was responsible for the discarding of 35% of species.

Aware of the weak representativeness of discards data in fisheries assessment, which only began to be collected for this purpose very recently by some countries of the European Community through discards sampling programs, Fernández *et al.* (2010) presented a model for fisheries assessment where some discards estimates available for the stock of hake in VIIIc (Spain) (1994-2007) and IXa (Portugal) (2004-2007) of ICES areas were incorporated. Results of this study led to draw the conclusion that the practice of discards varied considerably over the years modeled and that about 60% of the individuals captured, mainly juveniles, were discarded. The incorporation of the discard data in the assessment model lead to higher estimates of recruitment and fishing mortality (F) of younger individuals, and lower estimates of spawning stock biomass (SSB) and F in older individuals (2-5 years).

As the demersal trawl fishery is characterized by high percentages of bycatch and discards at sea, particularly the crustacean trawl métier, the Portuguese Sea and Atmosphere Institute (Instituto Português do Mar e da Atmosfera, IPMA), has been dedicated since the last decade to the improvement of size and species selection of bottom trawls carried out in Portuguese continental waters, aiming to reduce the unwanted bycatch, with minor losses of target species. This intensive work included studies on the codend size-selectivity of both diamond and square meshes for cephalopods (Fonseca *et al.*, 2002), fish (Campos and Fonseca, 2003; Campos *et al.*, 2003a) and crustacean species (Campos *et al.*, 2002, 2003b; Fonseca *et al.*, 2007); the use of square mesh windows alone (Campos and Fonseca, 2007) or associated to soft sorting panels (Campos and Fonseca, 2004); and the testing of rigid sorting devices (Nordmøre grids) in fish (Fonseca *et al.*, 2005a) and crustacean trawls (Campos *et al.*, 2006; Fonseca *et al.*, 2005b).

Portugal is one of the EU member states that, since 2002, has been subjected to collected discard data in the Atlantic waters of the Iberian Peninsula (Ices area IXa) by the Regulation (EC) No. 1639/2001 (´Data Collection Regulation´, DCR) (EC, 2001). However, the reports of the European Commission stated that Portugal has not provided the European Community with discards data (CEC, 2004, 2007c,d,e; EC, 2010), citing difficulties in the discard estimation procedure related to the short period of time of the discards sampling programme (EC, 2010) as well as in the discards database (CEC, 2008a). Only discards data from demersal long-line fishery targeting black scabbard fish were provided by Portugal to the European Community. These data were collected since 2005 through the ´Portuguese Discard

Sampling Programme´, which is included in the DCR/NP EU regulation and show that, for the period 2005-2008, the discard is unimportant (6.3% in number and 2.2% in weight of total catch, during 2005-2007, in Bordalo-Machado *et al.*, 2009) in this type of fishery (ICES, 2006a,b, 2008b, 2009b, 2010b). Meanwhile, Portugal did not provide the EU any further black scabbard fish discard data (ICES, 2011). Although more recent information (2004-2011) concerning the discard levels for certain species in Portugal has been published (ICES, 2012a-d; IEO/IPIMAR, 2010; Fernandes and Prista, 2012a,b; Fernandes *et al.*, 2009; Jardim and Fernandes, 2013; Prista, 2012; Prista and Fernandes, 2012; Prista *et al.*, 2012), complete and detailed data are still missing.

The fishing activity in Portugal

In Portugal, the fisheries activity has traditionally had a very important socio-economic role, especially for coastal communities which rely exclusively on fisheries and related activities as the main source of income (Dias, 2003; Pinho, 1999). According to the 2011 population census, 13,156 people are employed in the fisheries and aquaculture sector (18% less compared to 2001), representing about 0.3% of the Portuguese active population (INE, 2013).

The Algarve is considered one of the Portuguese regions economically most dependent on fisheries (Borges, 2010; Borges *et al.*, 1997, 2000; CEC, 1992a). Currently, the employed population in the fisheries sector in this region still represents a significant fraction of the mainland population (18.9%, 2011 data) (INE, 2013).

Portuguese fishing fleet

The Portuguese fishing fleet is quite diverse and employs a wide range of fishing gear and methods according to the characteristics of the vessels, the fishing zone and the exploited stocks (Borges *et al.*, 1997; Erzini, 2005; STECF, 2013a), operating mainly in the Portuguese Exclusive Economic Zone (EEZ) (STECF, 2013a), which is the most extensive EEZ of the European Community (Dias, 2003; Pinho, 1999) that currently covers an area of 1,727,408 km^2, equivalent to 18 times the Portuguese territorial area.

Currently, Portugal follows the global trend of decreasing fleet, both in number and in in fishing vessel activity, mainly as a result of the decommissioning of the older vessels. In 1999, the total number of registered national fishing vessels was 10933 (INE, 2001), of which 21% (n=2303) were registered in the Algarve (3745 fishing licenses) (ex-Direcção-Geral das

Pescas e Aquicultura, DGPA, unpublished data). In 2000, the national fishing fleet decreased by 1.7% in number of vessels (10 750 vessels, 21% in the Algarve), having suffered a decommissioning of 483 vessels (28.8% in the Algarve), of which 66% were demolished (INE, 2001). In 2001, the national fishing fleet was reduced by 2% to 10534 vessels (Anon., 2001).

Data referring to 2011, position Portugal as the member state with the highest number of inactive vessels (3691, 43.1% of vessels), representing 28.3% of the total inactive EU fleet, and as the fourth member state to report highest fishing days at sea (10%), followed by Italy (47%), France (13%) and the UK (11%) (STECF, 2013a). The official fishery statistics show that for 2012, the national fishing fleet comprised 8276 vessels (8283 *in* Anon., 2012; 8346 *in* DGRM, 2013) (22% in the Algarve), of which 56.2% had a fishing license and 1.5% of vessels (n=123) were decommissioned (65.8% demolished) (INE, 2013; DGRM 2013). For 2013, the national fishing fleet consisted of 8233 vessels (Anon., 2013).

Demersal trawling in Portugal and its legislative framework

In the Portuguese continental waters, the demersal trawl is part of a multispecies fishery (Campos *et al*., 2007) and is separated into two métiers (categories or segments), according to the target species: the crustacean trawl and the fish trawl (Campos *et al*., 2007; CEC, 1993a). In the Algarve coast, these vessels use the same fishing method throughout the year (Borges *et al.*, 1997). According to Portuguese law, demersal trawls cannot operate within 6 nautical miles counted from the coastline (DR, 1987, 2000, 2001a, 2003, 2006a,b, 2011).

Crustacean trawl métier

In the Algarve, the crustacean trawl became the most important métier of the trawling fleet during the 80s, increasing its activity since 1983 when the Spanish fleet trawling for crustaceans stopped operating in Portuguese waters (Campos *et al.* 2002). Compared to the extensive range of fishing gears used in this region, trawling for crustaceans is of highest socioeconomic importance (Cascalho *et al.*, 1984; DR, 1999; Pestana, 1991; Pita *et al.*, 2001). Its importance is also recognized by Fonseca *et al.* (2007), who associate it with both the high commercial value that the target species reach (15,372 x 10^3€, 1 176 tons in 2003) and the bycatch of a large number of commercial and non-commercial fish species.

The Portuguese fleet of the demersal crustacean trawl operates in the lower continental shelf and continental slope at depths between 150 and 800 meters (average depths of 400-500 meters) depending on the target species (Castro *et al.*, 2005; CEC, 1993a,b; Gordon, 1998; Moura *et al.*, 1998; Pestana, 1991; SEP, 1984). The main target species captured by this type of gear are the deep-water rose shrimp, *Parapenaeus longirostris* (Lucas, 1846), the Norway lobster, *Nephrops norvegicus* (Linnaeus, 1758) and the blue-and-red shrimp, *Aristeus antennatus* (Risso, 1816) (Campos and Fonseca, 2004; Campos *et al*., 2006; Castro *et al*., 2005; FAO, 2005; Fonseca *et al*., 2005a,b; Pestana, 1991). Many other species of crustaceans, fish, molluscs and other marine invertebrates are also part of the bycatch of this type of gear and most of them are discarded to the sea (Borges *et al.*, 1997, 2000-2002; Erzini *et al.*, 2002).

According to the fisheries legislation, the minimum legal mesh size allowed in crustacean trawls applied early in 1987 was 50 mm (CEC, 1993a; DR, 1987) and was in force until November 2000, by the time when minimum legal mesh sizes of 55 mm and 59 mm were allowed (DR, 2000). Since the beginning of 2003, a 70 mm minimum legal mesh size was imposed for those trawlers targeting Norway lobster, with the opportunity of acquiring simultaneously two types license, one for each type of mesh size (55-59 mm and ≥ 70 mm), given to crustacean trawlers licensed since 2002 (Campos *et al.*, 2007; DR, 2002, 2003, 2008, 2011). A minimum limit of 30% of target species and a maximum of 30% of bycatch species (fish and cephalopods, excluding blue whiting) is allowed for the crustacean trawlers using 55-65 mm mesh sizes; while for those using different mesh sizes, the catch of target species was reduced to 20% (DR, 2000, 2001, 2006a,b). Currently, this legislation still remains in force (DR, 2011) but in 2006, crustacean trawlers were banned from fishing between the 1st and the 31st of January (DR, 2006c).

Fish trawl métier

The Portuguese commercial fish trawling fleet operates on the continental shelf and upper continental slope to depths greater than 200 m (CEC, 1993a) and the most common target species are the Atlantic horse mackerel, *Trachurus trachurus* (Linnaeus, 1758), the Atlantic mackerel *Scomber scombrus* Linnaeus, 1758, and the Atlantic chub mackerel, *Scomber colias* Gmelin, 1789 (Campos *et al.*, 2007). Many other species of fish and marine invertebrates are also caught as bycatch, most of them being discarded (Borges *et al.*, 1997, 2000-2002; Erzini *et al.*, 2002). According to the fisheries legislation (dated on July 17th, 1987), fish trawlers were allowed to use a mesh with a 40 mm minimum legal size and to catch a minimum limit of 90% of target species (DR, 1987). In late 2000, the minimum legal mesh size had increased to 65-69 mm, and the minimum catch of target species suffered a reduction to 70% (DR, 2000). This legislation also allowed the absence of target species catch constraints in the cases where trawls use mesh sizes greater than 70 mm. Initially, a maximum limit of 20% of crustacean catches was imposed (DR, 2000, 2001a) but, since 2003, it was considered appropriate to allow fish trawlers using 65-69 mm and ≥ 70 mm mesh sizes the possibility of fishing up to 30% of crustaceans (DR, 2003, 2006a,b). Only since 2008, were trawl vessels licensed for a 65-69 mm mesh size given the possibility of licensing also for a ≥70 mm mesh size, maintaining the minimum percentage of target species set for such vessels (DR, 2008). This legislation is still in force since 2011 (DR, 2011).

Studies on the southern coast of Portugal show that the crustacean trawlers fish from 200 to 800 meters depth (Borges *et al.*, 1997, 2001, 2002; Erzini *et al.*, 2002; Castro *et al.*, 2005) using a 55 mm codend mesh size (Campos *et al.*, 2002, 2003b; Fonseca *et al.*, 2005b). Concerning fish trawls, these usually fish at depths between 100 and 200 m (Borges *et al.*, 2001; Erzini *et al.*, 2002) with a 65 mm minimum mesh size (Campos and Fonseca, 2003). Some studies also reveal that hake (*Merluccius merluccius* (Linnaeus, 1758)), horse mackerel (*Trachurus trachurus* (Linnaeus, 1758)), *T. mediterraneus* (Steindachner, 1868), *T. picturatus* (Bowdich, 1825)), and fish species belonging to the family Sparidae (*Diplodus* spp., and *Pagellus* spp.), are the most common target species of the fish trawlers in the Algarve coast (Borges *et al.*, 2000-2002).

Trawling fleet on the South coast of Portugal (Algarve)

According to information from the current Directorate-General for the Natural Resources, Security and Maritime Services Resources (DGRM) (former DGPA), in 1998, 62 trawl vessels were registered in the Algarvian trawl fishing fleet. During the sampling period of this study, the Algarve fleet has increased from 57 trawlers in 1999 to 66 trawlers in 2000, decreasing again to 59 trawlers in 2001, with the latter representing 53.1% of the national fleet trawling. Official fishery statistics reveal that in 2012, the national fishing fleet consisted of 83 trawlers (Anon., 2012; DGRM 2013) (82 *in* Anon., 2013). The situation of the national trawl fleet until the end of 2013 remains at a record of 82 vessels (Anon., 2013).

Framework of the study and its objectives

In 1996, the Research Group BIOPESCAS of the University of the Algarve carried out a scientific project on fisheries discards of five commercial fishing métiers in the Algarvian coast, named "Studies of the discards of commercial fisheries from the south coast of Portugal" (Borges *et al.*, 1997). The main goal of this project, in which I participated holding a scientific investigation grant, was determinant in my decision of carrying out this PhD study, was to evaluate and analyze both the bycatch and discards of commercial trawl fisheries (crustacean and fish trawls) in the south coast of Portugal.

To accomplish the goal of the present thesis the following objectives were outlined:

1. Analyse the species composition of the bycatch and quantify the catch rates of both target and bycatch species of fish and crustacean trawl métiers (Chapter 2);
2. Evaluate the discards both qualitatively and quantitatively, by means of discard ratios, abundances and biomasses of discarded species between and within crustacean and fish trawl métiers, species dominance in the discards and rates of discarded species in number and weight (Chapter 3); and
3. Analyse the discarding practices, check for variability in the discards and identify the underlying causes or reasons for discarding (Chapter 3).

Given the life history particularities of the elasmobranchs, I considered it important to evaluate and characterize this group at a biological level which, in this study, is represented by the species *Galeus melastomus* Rafinesque, 1810 (blackmouth catshark), pertaining to the Scyliorhinidae family. This particular species was chosen for being one of the deepwater elasmobranchs mostly caught as bycatch and largely discarded by trawlers, and about which the knowledge of the biology is limited in general, with no information regarding sexual maturity in Portuguese waters prior to this study. Therefore this study aimed also to:

4. Characterize *G. melastomus* in terms of reproductive biology, assessing the maturity of females and males, defining their maturity stages and the egg-deposition period, determining the size at first maturity and evaluating the reproductive activity of both males and females (Chapter 4).

The qualitative study of bycatch and discards enabled the scientific discovery of a new species of ray to which the name *Neoraja iberica* n. sp. (vernacular names: Iberian pygmy skate (En); raia pigmeia ibérica (P)) was assigned, justifying its inclusion in this study, with the purpose to:

5. Make known *Neoraja iberica* n. sp., explaining and describing the characteristics which make it a new species (Chapter 5).

My dedication to the study of the reproductive biology of elasmobranchs has also lead to the discovery of three cases of abnormal hermaphroditism in the Velvet belly *Etmopterus* *spinax* (Linnaeus, 1758) (Chondrichthyes: Etmopteridae), an extremely rare phenomenon within this group, and considered to be the first case of hermaphroditism reported in this species. This discovery came to justify its inclusion in this PhD study as well (Chapter 6), aiming to:

6. Describe the three *E. spinax* hermaphrodite specimens, explain their inclusion as a type of "abnormal hermaphroditism", and discuss this phenomenon in shark species.

This thesis is structured in seven chapters and comprises four papers published in peer-reviewed scientific journals[1] (Chapters 2, 4, 5 and 6) and one paper submitted to Reviews in Fisheries Science (part of Chapter 3), presented in five distinct main chapters following the standard structure of scientific papers. The general discussion of the most important results of these chapters, followed by some final remarks and suggestions for future research, are presented in the Chapter 7, followed by a compilation of all literature cited in all the previous chapters. This thesis also comprises 21 annexes that are compiled in a CD-ROM digital format.

[1] A copy of each published paper can be found in Annex XXI

Chapter 2

Bycatch of crustacean and fish bottom trawl fisheries from southern Portugal (Algarve)

Catch of a demersal crustacean trawler - photo from Borges (2010) adapted by Pedro Correia

Partially published in Scientia Marina (2008) 72(4): 801-814

Abstract

As part of two research projects for analysing bycatch and discards, we quantified catch composition, catch rates and bycatch in two important commercial bottom trawl fisheries (crustacean and fish trawls) off the southern coast of Portugal (Algarve). Stratified sampling by onboard observers took place from February 1999 to March 2001 and data were collected from 163 tows during 52 fishing trips. Commercial target species included crustaceans: blue-and-red shrimp (*Aristeus antennatus*), deep-water rose shrimp (*Parapenaeus longirostris*), Norway lobster (*Nephrops norvegicus*); and fishes: seabreams (*Diplodus* spp. and *Pagellus* spp.), horse mackerels (*Trachurus* spp.) and European hake (*Merluccius merluccius*). The trawl fisheries are characterised by considerable amounts of bycatch: 59.4% and 80.3% of the overall total catch for crustacean and fish trawlers respectively. A total of 255 species were identified, which belonged to 15 classes of organisms (137 vertebrates, 112 invertebrates and 6 algae). Crustacean trawlers had higher bycatch biodiversity. Bony fish (45.6% and 37.8%) followed by crustaceans (14.6% and 11.5%) were the dominant bycatch components of both crustacean and fish trawlers respectively. The influence of a number of factors (e.g. depth, fishing gear, tow duration and season) on bycatch is discussed.

Introduction

Although concern about bycatch in commercial and recreational fisheries can be found in the scientific literature from the mid-1970s, it became the most critical fisheries issue in the 1990s (e.g. Alverson and Hughes, 1996; Alverson *et al.*, 1994; Hall *et al.*, 2000; Kennelly, 1995; Perret *et al.*, 1995; Tillman, 1993). Given the over fished state of many of the world´s most important stocks (Pauly *et al.*, 2002), there has been a great interest in documenting and finding solutions to the economic, political, and ecological implications of bycatch and discarding. The worldwide interest has given rise to a significant number of research papers, reviews and conferences (e.g. Alverson and Hughes, 1996; FAO, 1996; Hall, 1996; 1998; Saila, 1983; Sánchez *et al.*, 2004; Zann, 2000; and many others). Furthermore, there is growing international concerns for the conservation of bycatch species (Nakano *et al.*, 1997). The first global estimate of bycatch was approximately 12 million tonnes (Mt), with 3 to 5 Mt a year concerning only shrimp trawl fisheries (Slavin, 1981; Saila, 1983). Later, Alverson *et al.* (1994) estimated an annual shrimp trawl bycatch of around 11.2 Mt worldwide and the global annual commercial fisheries bycatch was estimated to be an average of 28.7 Mt per year (FAO, 1996).

Most marine fisheries are mixed fisheries directed at only a few commercial target species; however a wide variety of bycatch species are captured along with the target species (Castriota *et al.*, 2001; FAO, 1996). Some of these species have economic value and can be retained and commercialised, while others are discarded overboard for a variety of reasons (Alverson *et al.*, 1994; Borges *et al.*, 2002; Saila, 1983; Stobutzki *et al.*, 2003).

Bycatch may include individuals of target species smaller than the legal minimum landing size, juveniles of commercial and/or recreational fisheries species, or individuals from threatened, endangered, or protected species (Alverson *et al.*, 1994; Kennelly, 1995; Lewison *et al.*, 2004a). Bycatch is by and large regarded as unavoidable, and it is not restricted to any particular region of the world or to a particular gear (Hall *et al.*, 2000). However, non-selective fishing gears such as trawls that catch almost everything in their path, are generally considered to have greater bycatch rates than more selective gears such as longlines and purse seines (FAO, 1996). Indeed, the issue of bycatch in bottom trawl fisheries is of particular concern in tropical shrimp fisheries, where the weight of bycatch can be 5 to 10 times greater than the weight of target species and many account for 8 to 16 Mt per year as a whole (Andrew and Pepperell, 1992).

The bycatch of commercial fisheries worldwide is of great concern to fisheries managers and environmental and conservation groups as it contributes to biological overfishing and to changing the structure of marine communities and/or ecosystems, with serious implications for marine populations and the overall health and sustainability of ecosystems (Alverson *et al.*, 1994; FAO, 1997; Rebecca *et al.*, 2004).

The first step towards understanding and solving bycatch problem is to identify and quantify bycatches (Alverson *et al.*, 1994; Borges *et al.*, 2002; Kennelly, 1995, 1997, 1998; Ye *et al.*, 2000). The most widely used approach for quantifying bycatches in commercial fisheries is to have onboard observers to record the required data during normal fishing operations (Alverson *et al.*, 1994; FAO, 1996; Kennelly, 1995, 1998; Liggins *et al.*, 1996; Saila, 1983).

In Portugal, the “trawling” category includes fleet components that trawl for both crustaceans and fish (C.E.C., 1993a). The most important fraction of the Portuguese commercial trawl landings comes from the Algarve, with the crustacean trawl fishery constituting a very important part of the fishing fleet in the region (DR, 1999; Pita *et al.*, 2001).

The present study is based on two research projects that analyse bycatch and discards and focus on the bottom (decapod crustaceans and fish) trawl fisheries of the southern Portuguese coast. We quantify here the composition and catch rates of the target and bycatch species of the fish and crustacean trawl fleets. While previous studies have focused on discarding

(Borges *et al*, 1997, 2000-2002; Monteiro *et al.*, 2001), this is the first study that specifically addresses the issue of bycatches of crustacean and fish trawlers. This research will increase our knowledge of the impacts of trawling on the area and will provide a useful point of departure and baseline for management and conservation and for present and future work in this field.

Material and methods

Data collection

The present study was carried out on commercial fishing vessels operating off the southern coast of Portugal (Algarve) (Figure 2.1) from February 1999 to March 2001, during two projects on fisheries bycatch and discards. Sampling was stratified by bottom trawl type (crustacean trawlers and fish trawlers) and season (four) per year. Given the larger quantities and diversity of crustacean trawlers, the sampling effort was 4 or 5 fishing trips per season for crustacean trawlers compared to 3 fishing trips per season for fish trawlers. Data were collected by onboard observers following the direct collection method, which consists in observers onboard commercial boats asking the skippers to identify the target species at the beginning of each trip.

On board the trawlers, observers recorded all the information needed to characterise the fishing vessel, fishing gears and fishing trips (number and duration of trips and tows), catch quantities (total catch, target catch, retained catch, total bycatch, commercial bycatch and discarded bycatch), species composition, and geographical and bathymetric location of the fishing area using onboard electronics. Catch estimates depended on the amounts caught per tow: if large amounts were caught, the size of the catch was estimated by the skipper of the fishing vessel. In the case of small amounts, the total catch was obtained by summing the weight of each commercial (target and bycatch species) species sorted into baskets by the fishermen. Commercial target species as well as bycatch species were measured on board, with cephalothorax length (mm) and total length (cm) recorded for crustaceans and fish respectively. All data collection was carried out by individual tow per fishing trip and all tows were conducted in a manner that reflected normal commercial practice.

Sampling was concentrated on trawlers based in Portimão and Olhão (Figure 2.1), which are the two main fishing ports in the Algarve, with the whole Algarve considered to be a single fishing ground (Borges *et al.*, 2000). Data on the technical characteristics of trawl vessels (year of construction, overall length in meters, gross registered tonnage (GRT), and engine power in Horsepower, hp, and Kilowatt, kw), and on the number of trawl licences for 1999, 2000 and 2001, were obtained from official archives.

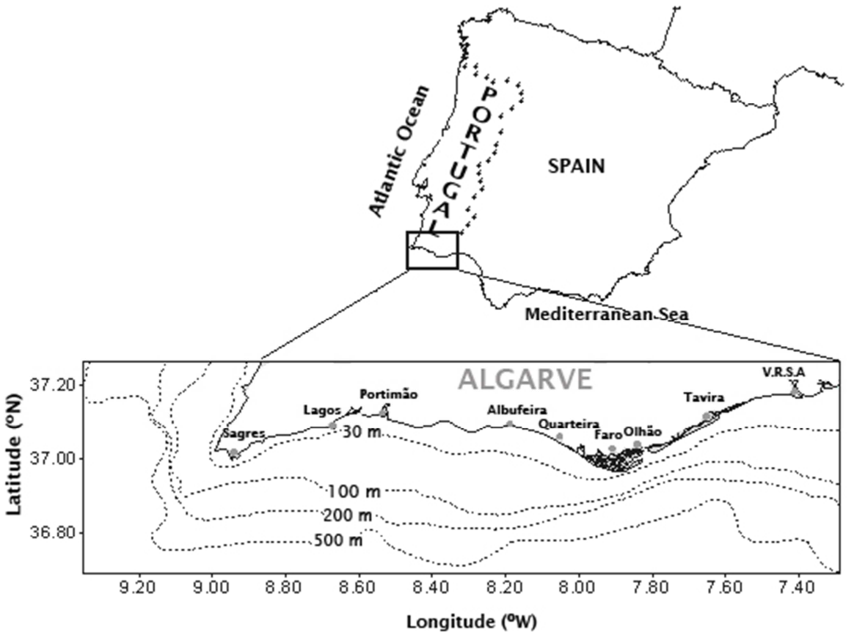


Figure 2.1 - Algarve region, showing the main fishing ports in the region.

Characteristics of fishing gears sampled

The crustacean trawl fisheries in the Algarve take place on the lower continental shelf and continental slope at depths from 150 to 800 m, depending on target species (SEP, 1984). The most important crustacean trawl target species are the decapod crustaceans, such as blue-and-red shrimp (*Aristeus antennatus*), deep-water rose shrimp (*Parapenaeus longirostris*), and Norway lobster (*Nephrops norvegicus*). As of November 22, 2000, the minimum legal mesh size was increased from 55 mm to a range of 55 to 59 mm. The total catch of crustacean trawlers that use this range of mesh size must consist of a minimum of 30% of target species and a maximum of 30% of bycatch species (fishes and cephalopods) (DR, 2000).

Fish trawlers operate on the continental shelf and upper continental slope, mainly at depths between 100 and 200 m (Borges *et al.*, 2001; Erzini *et al.*, 2002), and the most important target species are horse mackerel (*Trachurus* spp.), European hake (*Merluccius merluccius*) and seabreams (*Diplodus* spp. and *Pagellus* spp.). Since 2000, the minimum legal mesh size has been the range from 65 to 69 mm, and a minimum of 70% of the catch must consist of the target species. Trawlers using codend mesh sizes greater than 70 mm have no such restrictions regarding target species. However, the crustacean bycatch of fish trawlers must not exceed 20% of the total catch (DR, 2000). Crustacean and fish trawlers constitute two different fleets with vessels that do not switch between fishing.

Catch components definitions

In this paper we use the following terms and definitions: *total catch* is the quantity of all species brought on board; *target catch* is the fraction of the total catch which includes the species towards which the fishing effort is directed (target species); *retained (or landed) catch* is the part of the total catch that has economic value (i.e. the quantity of target and bycatch species that can be marketed); and *total bycatch* is the portion of the total catch which includes all the species caught accidentally (non-target species). Total bycatch may be retained if it has commercial value (commercial bycatch) and/or discarded at sea if it is not used for any purpose (discarded bycatch). In order to simplify, '*discarded bycatch*' will be referred to as '*discard(s)*' throughout this paper. It is also necessary to highlight that both the targeted and non-targeted species may be either marketable or discarded at sea.

Data analysis

The means and respective standard deviations of the different catch compositions were calculated according to trip and by tow. In order to determine if there are significant differences in the target, total bycatch, commercial bycatch and discard catches between seasons in each trawl type, non-parametric tests, which employ the ranks of the measurements instead of using the actual (raw) data, had to be applied since sample sizes were different between the seasons in each year. The two-sample Mann-Whitney test (U) (Zar, 1996), that is analogous to the two-sample t-test, was applied to spring, summer and autumn in the case of crustacean trawls and to all seasons in the case of fish trawls. For testing differences among groups where k (samples) > 2, non-parametric analyses of variance were applied by the means of the Kruskal-Wallis test (H), often known as "analysis of variance by ranks" (Zar, 1996).

Species diversity for target, bycatch and discard species was calculated by bottom trawl type. Mean catch rate of commercial target species from each type of trawl were calculated and standardized to hourly yields (kg/h), per season, and were compared with mean tow duration. Coefficients of variation (c.v.) were also calculated in order to understand the variability of catch rates among seasons. Size frequency distributions of the target species of the two types of trawl, as well as of the most important bycatch species captured by fish trawls for which there is legislation concerning legal minimum landing size (LMLS), were prepared. Legal minimum landing sizes for each species are reported following the Portuguese legislation published in Diário da República (DR) (2001).

Results

Fishing vessels and licences

Observers sampled 9 different trawlers of the 27 to 37 that were licensed in the Algarve from 1999 to 2001. Six crustacean trawlers were sampled, ranging in age from 7 to 44 years (mean=19.8) with total lengths ranging from 23 to 30 m (mean=25.8 m). The mean GRT was 144.9 ton (s.d.=29.26) and mean engine power was 441.3 kw (s.d.=80.63). The three fish trawlers that were sampled were older (mean=33.67 years) and slightly larger (mean=30.7 m) than crustacean trawlers. The mean GRT was 172.1 ton (s.d.=2.22) and their engine power mean was somewhat greater, with a mean of 504.7 kw (s.d.=72.17).

Crustacean trawlers fished at depths from 117 to 754 m (mean= 463.3 m; s.d.=150.0). Trip duration varied from 45.8 to 94.1 hours (mean=69.5 hours; s.d.= 16.876) and tow duration ranged from 2.25 to 10.22 hours (mean=5.78 h; s.d.=1.89). Fish trawlers normally fished at depths between 100 and 290 meters, but some hauls were as shallow as 41 m (mean= 105.3 m; s.d.=43.95). Fish trawler trip duration varied from 27.5 to 49 hours (mean=43.4 h; s.d.= 7.944) and tow duration ranged from 22.2 minutes to 2.85 hours (mean=1.45 h; s.d.=0.48).

Sampling effort

A total of 52 fishing trips were made (35 in crustacean trawlers and 17 in fish trawlers), during which 72 crustacean trawl tows and 91 fsh trawl tows were sampled, which totaled 163 fshing operations. There were less crustacean trawl fshing operations, with a maximum of 3 tows per trip (mean=2.06, s.d.=0.34) and 5 to 10 tows per season (mean=8.00, s.d.=1.73), compared with fsh trawls that had a maximum of 8 tows per trip (mean=5.47, s.d.=0.93) and 10 to 19 tows per season (mean=15.50, s.d.=3.83) (Table 2.1).

The trawl trajectories, by tow and season, are represented in Annex I, for crustacean trawls and in Annex II, for fish trawls.

Table 2.1- Estimates of the total, target and retained catches and of total, commercial and discarded bycatch, for the number of trips and fishing operations (tows).

Season	Métier	Boat (n)	Trips (n)	Tow (n)	Total Catch (kg)					Target Catch (kg)					Retained Catch (kg)				
					Total	m/trip	s.d.	m/tow	s.d.	Total	m/trip	s.d.	m/tow	s.d.	Total	m/trip	s.d.	m/tow	s.d.
Winter 1998	Crustacean trawl	2	4	8	2160	540	216.49	270	101.98	1117	279	54.60	140	105.93	1368	342	206.15	171	118.36
	Fish trawl	2	3	17	27957	9319	5613.41	1645	2124.97	2835	945	56.07	149	167.11	7298	2433	701.41	384	327.71
Spring 1999	Crustacean trawl	2	4	9	1755	439	44.79	195	72.46	540	135	18.96	60	28.41	1166	291	38.46	130	51.09
	Fish trawl*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Summer 1999	Crustacean trawl	3	5	10	2330	466	128.96	233	75.58	1057	211	39.11	106	38.29	1332	266	75.49	133	40.70
	Fish trawl	3	3	18	8720	2907	344.29	484	435.22	2648	883	61.82	147	103.93	4327	1442	529.95	240	136.28
Autumn 1999	Crustacean trawl	2	3	5	1322	441	460.83	264	203.49	336	112	10.21	67	12.83	370	123	14.15	74	21.39
	Fish trawl	3	3	19	8065	2688	766.39	424	341.84	2186	729	19.81	115	141.43	4769	1590	608.57	251	201.99
Winter 1999	Crustacean trawl	3	3	6	1320	440	115.33	220	92.74	682	227	44.33	114	61.30	811	270	119.78	135	71.82
	Fish trawl	2	2	10	3540	1770	410.12	354	191.44	970	485	60.99	97	71.15	2059	1030	130.81	206	81.42
Spring 2000	Crustacean trawl	3	4	7	1485	371	159.60	212	109.69	559	140	34.82	80	35.45	940	235	74.62	134	78.77
	Fish trawl	2	3	12	2970	990	523.74	248	99.01	1347	449	62.23	112	78.80	2109	703	290.79	176	89.04
Summer 2000	Crustacean trawl	2	5	9	1115	223	125.98	124	70.70	370	74	18.35	41	19.92	517	103	30.00	57	26.32
	Fish trawl	2	3	15	4030	1343	1099.74	269	331.90	847	282	28.80	56	58.48	1973	658	346.09	132	88.57
Autumn 2000	Crustacean trawl	2	3	8	700	233	87.37	88	70.46	316	105	20.34	40	28.39	385	128	30.07	48	30.81
	Fish trawl**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Winter 2000	Crustacean trawl	1	4	10	2800	700	261.41	280	58.69	1100	275	30.43	110	29.44	1141	285	108.12	114	29.15
	Fish trawl**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	Crustacean trawl	20	35	72	14987	428	224.66	208	108.76	6077	174	43.73	84	55.97	8029	229	118.87	112	68.16
	Fish trawl	14	17	91	55282	3252	3622.64	607	1068.03	10833	637	55.06	116	118.84	22535	1326	763.04	248	207.34

* no trips due to fish trawlers strike; **no trips due to bad weather conditions; m-mean; s.d.-standard deviation

Table 2.1 (cont.) - Estimates of the total, target and retained catches and of total, commercial and discarded bycatch, for the number of trips and fishing operations (tows).

Season	Métier	Boat (n)	Trips (n)	Tow (n)	Total Bycatch (kg)					Commercial Bycatch (kg)					Discarded Bycatch (kg)					Commercial bycatch (%)
					Total	m/trip	s.d.	m/tow	s.d.	Total	m/trip	s.d.	m/tow	s.d.	Total	m/trip	s.d.	m/tow	s.d.	
Winter 1998	Crustacean trawl	2	4	8	1043	261	62.37	130	55.29	251	63	11.38	31	17.76	792	198	12.03	99	56.49	18.3
	Fish trawl	2	3	17	25122	8374	1262.60	1322	2047.60	4463	1488	47.77	235	277.93	20659	6886	6122.23	1215	2082.89	61.2
Spring 1999	Crustacean trawl	2	4	9	1216	304	37.39	135	47.54	627	157	18.02	70	29.01	590	147	49.84	66	34.09	53.7
	Fish trawl*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Summer 1999	Crustacean trawl	3	5	10	1273	255	61.54	127	75.40	275	55	13.28	28	21.48	998	200	85.79	100	67.59	20.6
	Fish trawl	3	3	18	6072	2024	146.13	337	427.81	1679	560	52.30	93	74.46	4393	1464	782.45	244	396.05	38.8
Autumn 1999	Crustacean trawl	2	3	5	986	329	212.00	197	203.82	34	11	14.00	7	11.01	952	317	452.83	190	209.67	9.2
	Fish trawl	3	3	19	5879	1960	86.93	309	276.22	2583	861	50.11	136	93.70	3296	1099	497.10	173	256.80	54.2
Winter 1999	Crustacean trawl	3	3	6	638	213	27.49	106	40.02	129	43	15.60	22	16.22	509	170	58.62	85	40.03	15.9
	Fish trawl	2	2	10	2570	1285	42.13	257	179.99	1089	545	26.93	109	42.62	1481	741	540.94	148	197.88	52.9
Spring 2000	Crustacean trawl	3	4	7	926	232	88.28	132	85.25	381	95	77.99	54	60.44	546	136	124.70	78	65.81	40.5
	Fish trawl	2	3	12	1623	541	6.92	135	63.89	762	254	48.06	64	31.48	861	287	239.10	72	69.74	36.1
Summer 2000	Crustacean trawl	2	5	9	745	149	54.51	83	60.92	147	29	9.39	16	9.89	598	120	102.88	66	53.93	28.4
	Fish trawl	2	3	15	3184	1061	192.98	212	281.81	1127	376	40.99	75	53.17	2057	686	810.22	137	269.27	57.1
Autumn 2000	Crustacean trawl	2	3	8	384	128	40.14	48	43.11	69	23	2.71	9	4.45	315	105	64.97	39	42.15	17.9
	Fish trawl**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Winter 2000	Crustacean trawl	1	4	10	1700	425	31.91	170	52.49	41	10	1.81	4	2.33	1659	415	165.60	166	52.50	3.6
	Fish trawl**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	Crustacean trawl	20	35	72	8899	254	78.91	124	83.01	1941	55	34.92	27	31.54	6958	199	167.13	97	82.36	24.2
	Fish trawl	14	17	91	44400	2615	685.76	478	1028.27	11653	685	70.55	125	148.85	32747	1926	3263.38	360	1001.21	51.8

* no trips due to fish trawlers strike; **no trips due to bad weather conditions; m-mean; s.d.-standard deviation.

Catch composition

From the overall catch composition shown in Figure 2.2, it can be seen that total bycatch exceeded target catch in both types of bottom trawl, even though it is much higher in fish (80.3% in kg) than in crustacean (59.4% in kg) trawls. Crustacean trawls capture larger amounts of the target species (over 40% in kg) than fish trawls (less than 20% in kg), and fish trawls commercialize more bycatch (21%) and discards more (59%) compared to crustacean trawls (13% and 46% respectively).

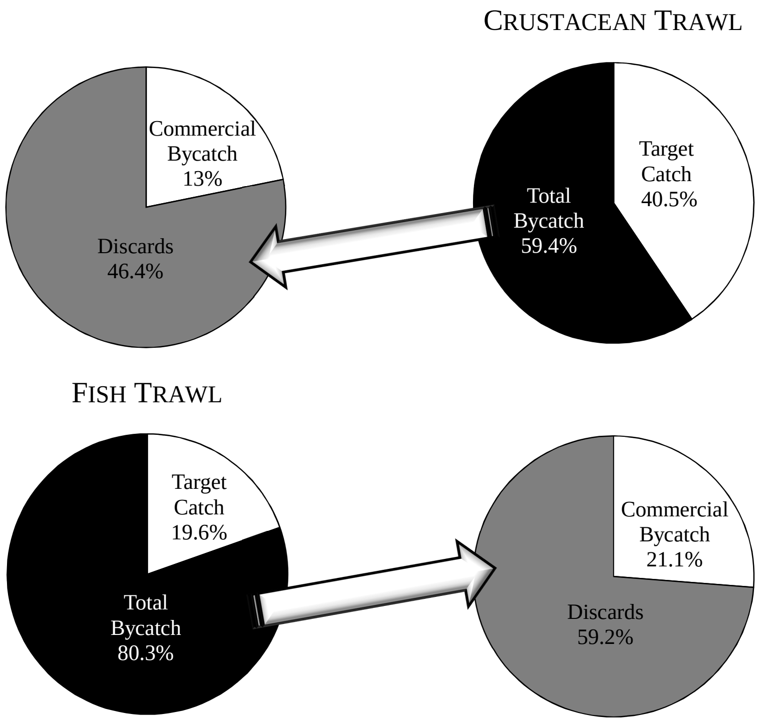


Figure 2.2 - Overall catch composition of the crustacean trawl and fish trawl.

During the study period, of the 3 crustacean trawl target species, deep-water rose shrimp accounted for the largest percentage (49.2% in kg) of the target catch, followed by blue-and-red shrimp (30.1% in kg). Norway lobster accounted for only 20.7% of the target catch in kg (Table 2.2). There are 14 crustacean trawl commercial bycatch species. We consider 9 of these to be the major bycatch species as they each accounted for at least 5% of the bycatch (Table 2.2). Cartilaginous fishes accounted for the largest percentage in kg (21.5%) and blue whiting the next most important commercial bycatch species (14.5%) (Table 2.2)

Table 2.2 - Target and commercial bycatch species caught by crustacean trawl off southern Portugal during 1999-2001 (per tow) (s.d.-standard deviation).

GROUP / SPECIES	COMMON NAME	MEAN WEIGHT (kg)	(s.d.)	(%)
TARGET				
Parapenaeus longirostris	Deep-water rose shrimp	60.7	57.59	49.2
Aristeus antennatus	Blue-and-red shrimp	37.2	32.72	30.1
Nephrops norvegicus	Norway lobster	25.5	32.13	20.7
Total				100.0
COMMERCIAL BYCATCH				
Chondrichthyes	Cartilaginous fish	14.3	13.65	21.5
Micromesistius poutassou	Blue whiting	9.7	3.21	14.5
Diverse		6.9	6.08	10.3
Lophius spp.	Angler	6.1	7.65	9.2
Merluccius merluccius	European hake	5.7	4.22	8.6
Phycis spp.	Forkbeard	4.5	2.87	6.7
Lepidopus caudatus	Silver scabbardfish	4.0	-	6.0
Conger conger	European conger	3.6	1.89	5.4
Cephalopoda	Cephalopodes	3.5	2.70	5.2
Maja squinado	Spiny spider crab	2.0	-	3.0
Trachurus spp.	Horse mackerel	2.0	-	3.0
Pagellus spp.	Seabream	2.0	1.41	3.0
Mullus spp.	Red mullet	1.8	1.66	2.6
Helicolenus dactylopterus	Blackbelly rosefish	0.8	0.35	1.1
Total				100.0

For the fish trawl, horse mackerel accounted for the highest percentage in kg (76%) of the target catch followed by European hake (11.6%) and seabreams (9.2%, for *Pagellus* spp. and 3.3% for *Diplodus* spp.). Fish trawl commercial bycatch species consisted of 27 species, of which 6 are considered as the major bycatch species, accounting for at least 5% of the bycatch in kg (Table 2.3). The most important fish trawl commercial bycatch species are chub mackerel (19.2% in kg) and European pilchard (18.8% in kg).

Table 2.3 - Target and commercial bycatch species caught by fish trawl off southern Portugal during 1999-2001 (per tow) (s.d.-standard deviation).

GROUP / SPECIES	COMMON NAME	MEAN WEIGHT (kg)	(s.d.)	(%)
TARGET				
Trachurus picturatus	Blue jack mackerel	142.5	143.96	30.2
Trachurus trachurus	Atlantic horse mackerel	132.3	96.49	28.0
Trachurus spp.	Horse mackerel	84.0	106.25	17.8
Merluccius merluccius	European hake	54.6	54.58	11.6
Pagellus spp.	Seabream	28.4	31.50	6.0
Pagellus acarne	Axillary seabream	15.0	-	3.2
Diplodus spp.	Seabream	10.3	10.94	2.2
Diplodus vulgaris	Common two-banded seabream	5.0	-	1.1
Total				100.0
COMMERCIAL BYCATCH				
Scomber colias	Atlantic Chub mackerel	96.9	176.52	19.2
Sardina pilchardus	European pilchard	94.6	98.65	18.7
Scyliorhinus canicula	Small-spotted catshark	50.0	-	9.9
Parapenaeus longirostris	Deep-water rose shrimp	35.9	36.14	7.1
Scomber scombrus	Atlantic mackerel	34.4	38.83	6.8
Boops boops	Bogue	23.5	25.61	4.6
Chondrichthyes	Cartilaginous fish	19.7	16.75	3.9
Cephalopoda	Cephalopodes	19.2	12.02	3.8
Triglidae	Gurnard	14.8	3.02	2.9
Pagrus spp.	Seabream	14.2	5.08	2.8
Diverse		13.7	11.20	2.7
Pagrus pagrus	Common seabream	10.0	-	2.0
Sarpa salpa	Salema	10.0	-	2.0
Xiphias gladius	Swordfish	10.0	-	2.0
Octopus vulgaris	Common octopus	9.8	8.04	1.9
Spondyliosoma cantharus	Black seabream	8.4	5.03	1.7
Serranus cabrilla	Comber	8.0	-	1.6
Zeus faber	John dory	7.8	10.25	1.5
Conger conger	European conger	5.0	-	1.0
Mullus spp.	Red mullet	4.8	3.78	0.9
Pleuronectes platessa	European plaice	4.0	-	0.8
Helicolenus d. dactylopterus	Blackbelly rosefish	4.0	-	0.8
Solea spp.	Sole	2.0	1.41	0.4
Lophius spp.	Angler	2.0	-	0.4
Trisopterus luscus	Pouting	1.5	-	0.3
Mullus surmuletus	Stripe red mullet	1.0	-	0.2
Phycis spp.	Forkbeard	1.0	-	0.2
Total				100.0

In crustacean trawls (Figure 2.3), the target catches account, in kg, for approximately 30 to 40% in spring and autumn and 40 to 46% in summer and winter of the total catch. The target catches were largest in winter (46%) and smallest in autumn (32%). Total bycatch follows the same trends, with approximately 50% in winter and summer and 60 to 68% in spring and autumn, with a minimum of almost 54% in winter and maximum of almost 68% in autumn. The lowest values of commercial bycatch are found in the autumn (7.5%) and winter (12.5%) and reach a maximum in spring (47%) but decrease to 20.9% in summer. There were more discards in crustacean trawl in autumn and winter (92.5% and 87.5% respectively) and less in the summer, although discards still had relatively high values (79.1%). Only in spring did the amount of discards decrease, reaching a value of a little over 50%.

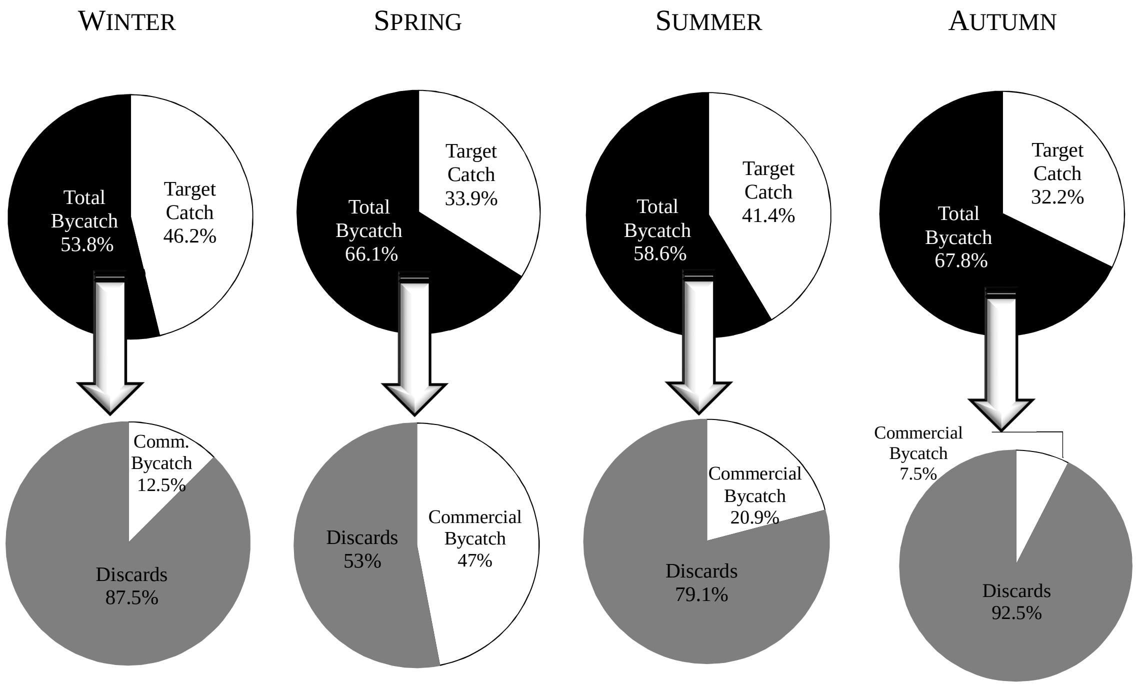


Figure 2.3 - Overall catch composition of the crustacean trawls according to season.

In all seasons, fish trawl total bycatch is greater than the target catch, especially in winter when it comprises almost 90% of the total catch (Figure 2.4). In summer and autumn, both target catch and total bycatch are very similar, approximately 27% and 72%, respectively. In spring, the target catch reached its highest value (45.4%) which, in turn, decreased the total bycatch (54.6%).Quantities of commercial bycatch (47% and 44%) and discards (53% and 56%) were quite similar in spring and autumn respectively. Discards were higher in winter (80%) and in summer (70%) and consequently lower in commercial bycatch (20% and 30% respectively).

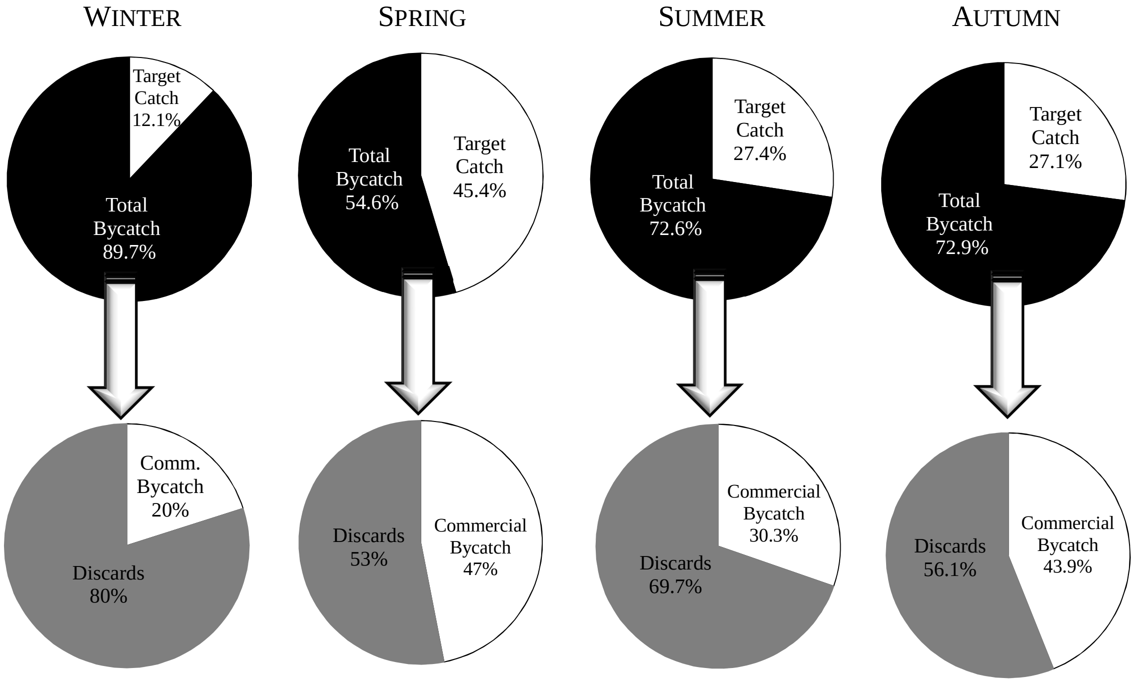


Figure 2.4 - Overall catch composition of the fish trawls according to season.

Mann-Whitney tests applied to data from both types of bottom trawls showed significant differences at a significance level (α) of 0.05 only for the target catch in summer. No significant differences were found for the rest of the seasons and the rest of the catch components. The Kruskal-Wallis test applied to crustacean trawl catches also showed that in winter there are no significant differences in the overall catch compositions.

The bycatch percentages, by tow and season, are represented in Annex I, for crustacean trawls and in Annex II, for fish trawls.

Species composition

Of the total number of species (n=255) identified during the present study, 137 (53.7%) are fish, 36 (14.1%) are crustaceans, 56 (22%) are molluscs and 26 (10.2%) are invertebrate species from ten different taxonomic groups (Table 2.4). Of the total species caught, 80.8% came from crustacean trawlers and 61.2% from fish trawlers, with 42% common to both trawl types. Target species represent a small portion of the total number of species (3.5%), 3.8% and 1.5% respectively for fish and crustacean trawlers. The vast majority of the species are in fact bycatch species: 98.5% for crustacean trawlers, 96.2% for fish trawlers and 96.5% overall for both types of trawler. This means that only 27.1% (n=55) and 34.7% (n=52) of bycatch species captured respectively by crustacean and fish trawls have commercial value, and the rest are discarded.

Table 2.4 - Species composition, in number, of the bottom trawl catches off southern Portugal from 1999 to 2001 (CT-crustacean trawl; FT-fish trawl; C&FT-coincident in both trawls).

TAXONOMIC GROUP	TOTAL SPECIES				TARGET SPECIES				BYCATCH SPECIES				DISCARDED SPECIES			
	CT	FT	CT&FT	Total	CT	FT	CT&FT	Total	CT	FT	CT&FT	Total	CT	FT	CT&FT	Total
VERTEBRATES																
Chondrichthyes	18	7	4	21	0	0	0	0	18	7	4	21	13	4	2	15
Osteichthyes	95	65	43	116	0	6	0	6	95	59	43	110	54	23	17	60
INVERTEBRATES																
Malacostraca	33	18	15	36	3	0	0	3	30	18	15	33	28	14	9	33
Cephalopoda	16	18	13	22	0	0	0	0	16	18	13	22	9	9	6	12
Bivalvia	12	10	7	15	0	0	0	0	12	10	7	15	12	10	7	15
Gastropoda	11	15	7	19	0	0	0	0	11	15	7	19	11	15	7	19
Anthozoa	4	4	4	4	0	0	0	0	4	4	4	4	4	4	4	4
Polychaeta	1	1	1	1	0	0	0	0	1	1	1	1	1	1	1	1
Ophiuroidea	2	3	2	3	0	0	0	0	2	3	2	3	2	3	2	3
Crinoidea	1	1	1	1	0	0	0	0	1	1	1	1	1	1	1	1
Holothuroidea	1	2	1	2	0	0	0	0	1	2	1	2	1	2	1	2
Asteroidea	2	3	2	3	0	0	0	0	2	3	2	3	2	3	2	3
Echinoidea	5	5	4	6	0	0	0	0	5	5	4	6	5	5	4	6
ALGAE																
Codiaceae	1	1	1	1	0	0	0	0	1	1	1	1	1	1	1	1
Dictyotaceae	1	0	0	1	0	0	0	0	1	0	0	1	1	0	0	1
Sargassaceae	3	3	2	4	0	0	0	0	3	3	2	4	3	3	2	4
Total	206	156	107	255	3	6	0	9	203	150	107	246	148	98	66	180

Both bottom trawl catches off southern Portugal appear to be very diverse (Figure 2.5). Osteichthyes stands out as the dominant group of bycatch species, as it represents almost 47% and slightly less than 39% of crustacean and fish trawl catches respectively.

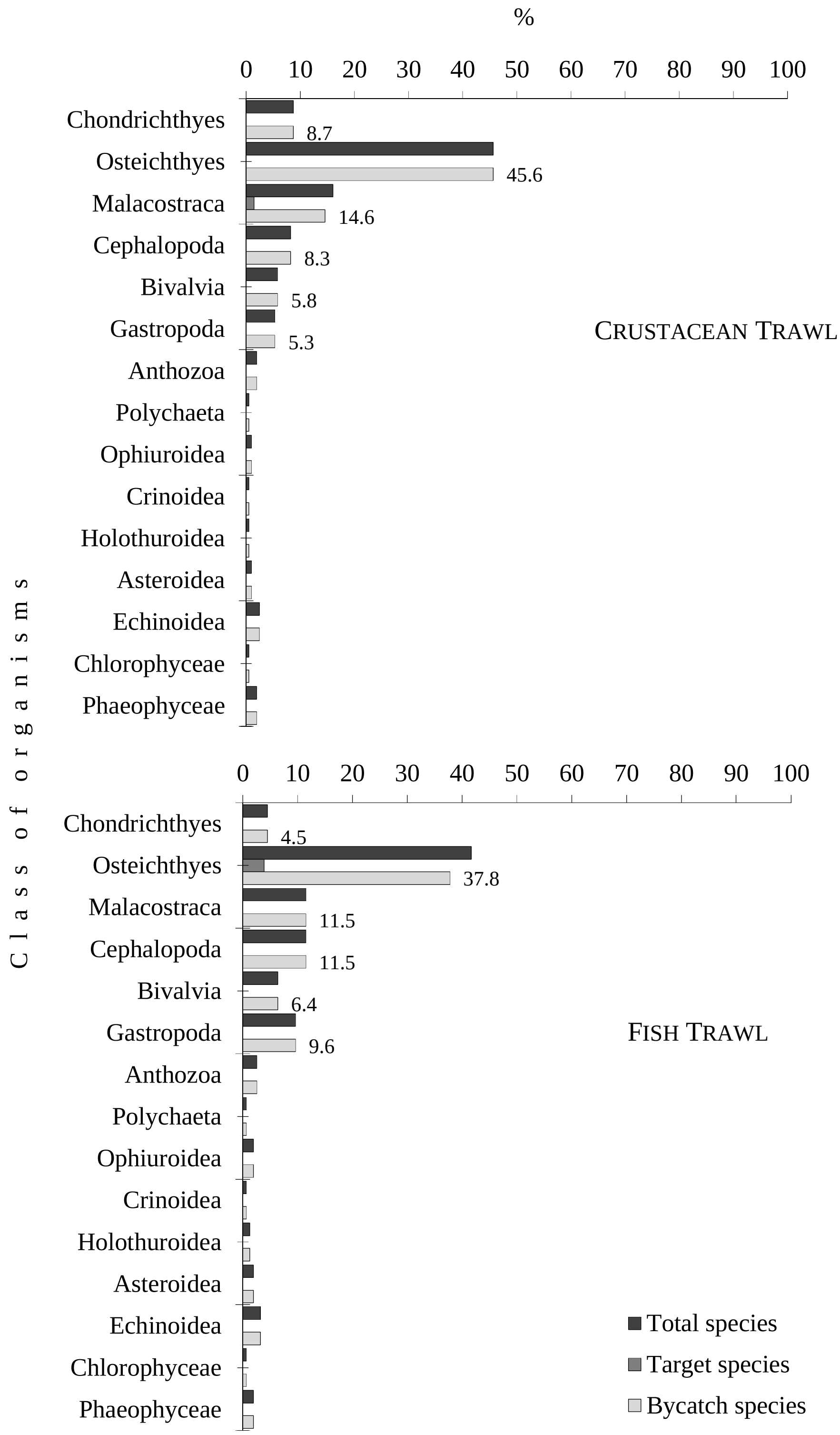


Figure 2.5 - Contribution of each class of organisms to the biodiversity of the total, target and bycatch catches in the two types of trawlers. Each bar represents the percentage of the species in that class in relation to the total number of species present.

The faunistic list of all species identified by métier is given in Annex III and the systematic classification of all species captured by crustacean and fish trawl métiers is presented in Annex IV.

Mean catch rates of target species

Mean catch rates (kg/h) were calculated from the overall commercial target catch for both types of bottom trawls (Tables. 2.5 and 2.6). For crustacean trawlers, the mean catch rate of the three commercial target species varied considerably in all seasons between winter 1998 and winter 2000 (Table 2.5). Mean catch rates of blue and red shrimp (*A. antennatus*) varied significantly in the winter 1999 (c.v.=137.6%) compared with other seasons. Deep-water rose shrimp (*P. longirostris*) is the crustacean target species which shows greater variations in mean catch rate over all seasons, being particularly high in winter 1998 (c.v.=141.2%). The target species that shows least variation is the Norway lobster (*N. norvegicus*), although it also shows high values of coefficient of variation, mainly in winter 1998 (99.9%) and spring 2000 (93.8%).

Of the four target species commercialized by fish trawlers, horse mackerels (*Scomber* spp.) and seabreams of the genus *Pagellus* show the highest coefficients of variation (143.2% and 141.2%, respectively) during summer 2000 (Table 2.6). The European hake (*M. merluccius*) is the target species that shows more consistency in the variation of the mean catch rate throughout all seasons, with the largest variation in summer 1999 (88.6%). The seabreams of the genus *Diplodus* are the target species with lowest mean catches but, even so, coefficients of variation in catch rate were considerably high (greater than 100%).

Table 2.5 - Mean catch (kg) and mean catch rate (kg/h) of commercial target species captured by crustacean trawl off southern Portuguese coast during the study period (c.v.= coefficiente of variation).

SEASON	Total tows (n)	Tow duration (mean, in hours)	MEAN CATCH (kg)									
			Aristeus antennatus	Tow (n)	c.v. (%)	*Nephrops norvegicus*	Tow (n)	c.v. (%)	*Parapenaeus longirostris*	Tow (n)	c.v. (%)	Mean
Winter 1998	35	7.60	46.3	6	99.1	10.3	8	102.0	115.4	7	115.6	55.6
Spring 1999	48	6.97	39.4	11	76.9	26.9	9	99.3	38.6	10	70.4	35.4
Summer 1999	63	6.88	32.2	10	90.6	33.0	10	74.3	48.2	10	44.0	40.2
Autumm 1999	10	5.66	21.0	1	-	6.0	1	-	63.0	5	16.5	56.0
Winter 1999	28	6.01	46.5	6	111.7	11.3	3	18.4	88.6	5	86.1	65.6
Spring 2000	27	6.87	32.4	7	57.4	60.3	7	100.0	38.6	7	31.5	35.5
Summer 2000	43	5.04	23.0	7	64.8	10.9	10	84.9	27.6	15	48.9	26.1
Autumm 2000	7	5.32	100.0	1		-	-	-	30.0	1	-	65.0
Winter 2000	19	3.84	-	-	-	-	-	-	110.0	10	26.8	110.0

SEASON	Total tows (n)	Tow duration (mean, in hours)	MEAN CATCH RATE (kg/h)									
			Aristeus antennatus	Tow (n)	c.v. (%)	*Nephrops norvegicus*	Tow (n)	c.v. (%)	*Parapenaeus longirostris*	Tow (n)	c.v. (%)	Mean
Winter 1998	35	7.60	5.4	6	96.3	1.3	8	99.9	22.5	7	141.2	9.6
Spring 1999	48	6.97	5.8	11	68.8	4.0	9	81.5	5.4	10	56.9	5.1
Summer 1999	63	6.88	4.8	10	94.0	4.8	10	75.7	7.1	10	44.3	5.9
Autumm 1999	10	5.66	2.6	1	-	0.8	1	-	14.8	5	38.1	12.8
Winter 1999	28	6.01	10.9	6	137.6	1.7	3	34.8	13.7	5	92.1	12.2
Spring 2000	27	6.87	5.0	7	68.7	8.9	7	93.8	5.8	7	39.0	5.4
Summer 2000	43	5.04	4.0	7	75.6	2.0	10	82.4	6.2	15	64.6	5.5
Autumm 2000	7	5.32	17.4	1	-	-	-	-	6.0	1	-	11.7
Winter 2000	19	3.84	-	-	-	-	-	-	28.8	10	25.1	28.8

Table 2.6 - Mean catch (kg) and mean catch rate (kg/h) of commercial target species captured by fish trawl off southern Portuguese coast during the study period (c.v., coeficiente of variation).

Season	Total tows (n)	Tow duration (mean, in hours)	MEAN CATCH (kg)												
			Diplodus spp.	Tow (n)	c.v. (%)	*Merluccius merluccius*	Tow (n)	c.v. (%)	*Pagellus* spp.	Tow (n)	c.v. (%)	*Trachurus* spp.	Tow (n)	c.v. (%)	Mean
Winter 1998	93	1.38	5.0	1	-	35.9	13	87.9	15.0	1	-	149.2	19	93.2	97.7
Summer 1999	115	1.59	-	-	-	91.0	23	97.1	25.8	6	78.2	43.5	15	120.2	65.9
Autumm 1999	100	1.24	6.5	2	119.7	46.4	18	56.1	45.0	4	82.2	131.5	13	111.9	74.0
Winter 1999	56	1.61	-	-	-	63.0	10	45.1	6.0	1	-	95.0	8	64.9	73.5
Spring 2000	71	1.47	14.0	2	111.1	46.8	12	73.2	4.0	1	-	69.8	12	79.0	53.0
Summer 2000	82	1.74	-	-	-	27.3	16	72.4	28.0	11	130.8	48.2	8	138.6	32.3

Season	Total tows (n)	Tow duration (mean, in hours)	MEAN CATCH RATE (kg/h)												
			Diplodus spp.	Tow (n)	c.v. (%)	*Merluccius merluccius*	Tow (n)	c.v. (%)	*Pagellus* spp.	Tow (n)	c.v. (%)	*Trachurus* spp.	Tow (n)	c.v. (%)	Mean
Winter 1998	93	1.38	3.6	1	-	26.9	13	83.6	11.5	1	-	133.0	19	99.8	85.1
Summer 1999	115	1.59	-	-	-	60.7	23	88.6	22.1	6	95.4	35.2	15	127.8	46.7
Autumm 1999	100	1.24	5.8	2	125.1	40.3	18	52.6	34.2	4	79.0	116.9	13	111.9	64.7
Winter 1999	56	1.61	-	-	-	39.4	10	34.2	4.9	1	-	68.2	8	88.7	49.7
Spring 2000	71	1.47	11.9	2	112.9	32.7	12	84.6	2.4	1	-	48.0	12	75.0	36.8
Summer 2000	82	1.74	-	-	-	14.1	16	63.3	16.2	11	141.2	30.3	8	143.2	18.5

Comparison of mean catch rates with fishing effort (mean tow duration), by season, for the crustacean trawl and fish trawl target species is shown in Figures 2.6 and 2.7, respectively. In general it can be seen that there is a more direct relationship between the mean catch rates of target species *A. antennatus* (blue and red shrimp) and *N. norvegicus* (Norway lobster) and mean tow duration for the crustacean trawlers. Exceptions to this are found in both spring seasons, for the blue and red shrimp, which decrease 8.3% in fishing effort and increase 7.4% in mean catch rate; and in spring and summer of the year 1999, for Norway lobster, with a 1998 to summer 1999 (Figure 2.6). In contrast, there seems to be no direct relation between mean catch rate and fishing effort in any season of the 3 years for deep-water rose shrimp. The exception seems to be in the first two seasons when a small decrease of 8.3% in fishing effort is associated with a sharp decrease of 76% in the mean catch rate. The highest value of mean catch rate does not correspond to the same season or to the maximum value of fishing effort for any of the three target species.

For the fish trawl target seabream species *Diplodus* spp., no relation between mean catch rate and fishing effort can be inferred for all years studied since no trips were made in intermediate seasons (Figure 2.7). However, it can be seen that mean catch rate rise from 3.6 kg/h in winter 1998 to 11.9 kg/h in spring 2000, which represents a large variation of 230.6%. Concerning European hake, there is a direct relation between1999 and summer 2000 where an increase of 29.8% and 18.4% of the fishing effort corresponds to a non-proportional decrease of 2.2% and 56.9% of mean catch rates, respectively. A similar situation can be observed for the *Pagellus* species of seabreams where there is an inverse relation between mean catch rate and fishing effort only in autumn and winter 1999. Although the highest value of mean catch rate (34.2 kg/h) is attained in autumn 1999, the increase of 54.8% of this rate corresponds to a decrease of 22% in fishing effort. In the next season, an increase in fishing effort (29.8%) was associated with an 85.7% decrease in mean catch rate. For horse mackerel (*Scomber* spp.) a direct relationship between mean catch rate and fishing effort can be seen only in spring 2000. From winter 1998, with the highest value of mean catch rate (133 kg/h) to winter 1999, fishing effort suffered a small variation of 16.7% while mean catch rate varied almost 50% (48.7%). From spring to summer of the year 2000, an increase of 18.4% in fishing effort was associated with a decrease of 36.9% in mean catch rate.

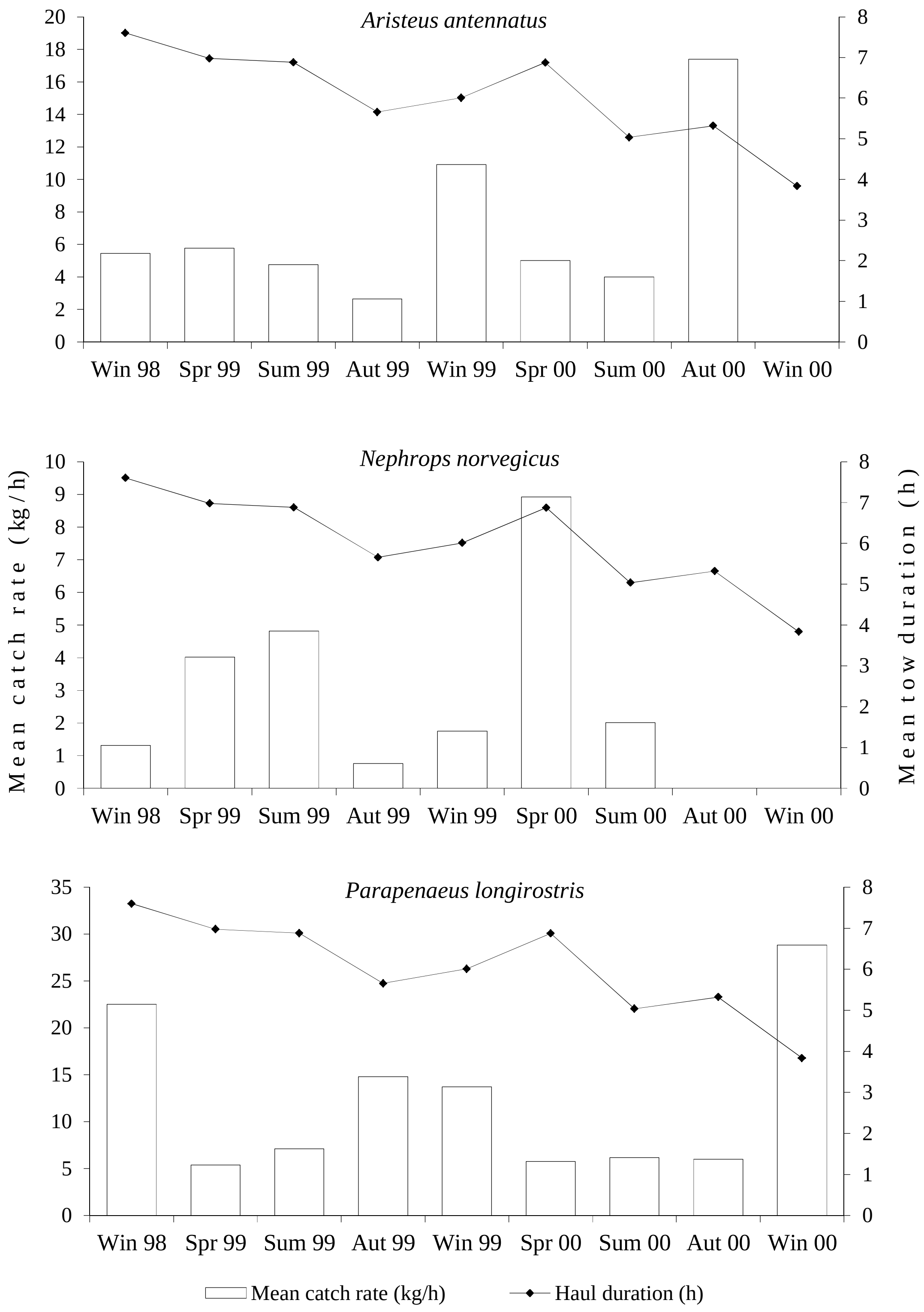


Figure 2.6 – Mean catch rates and mean tow duration for crustacean trawl target species.

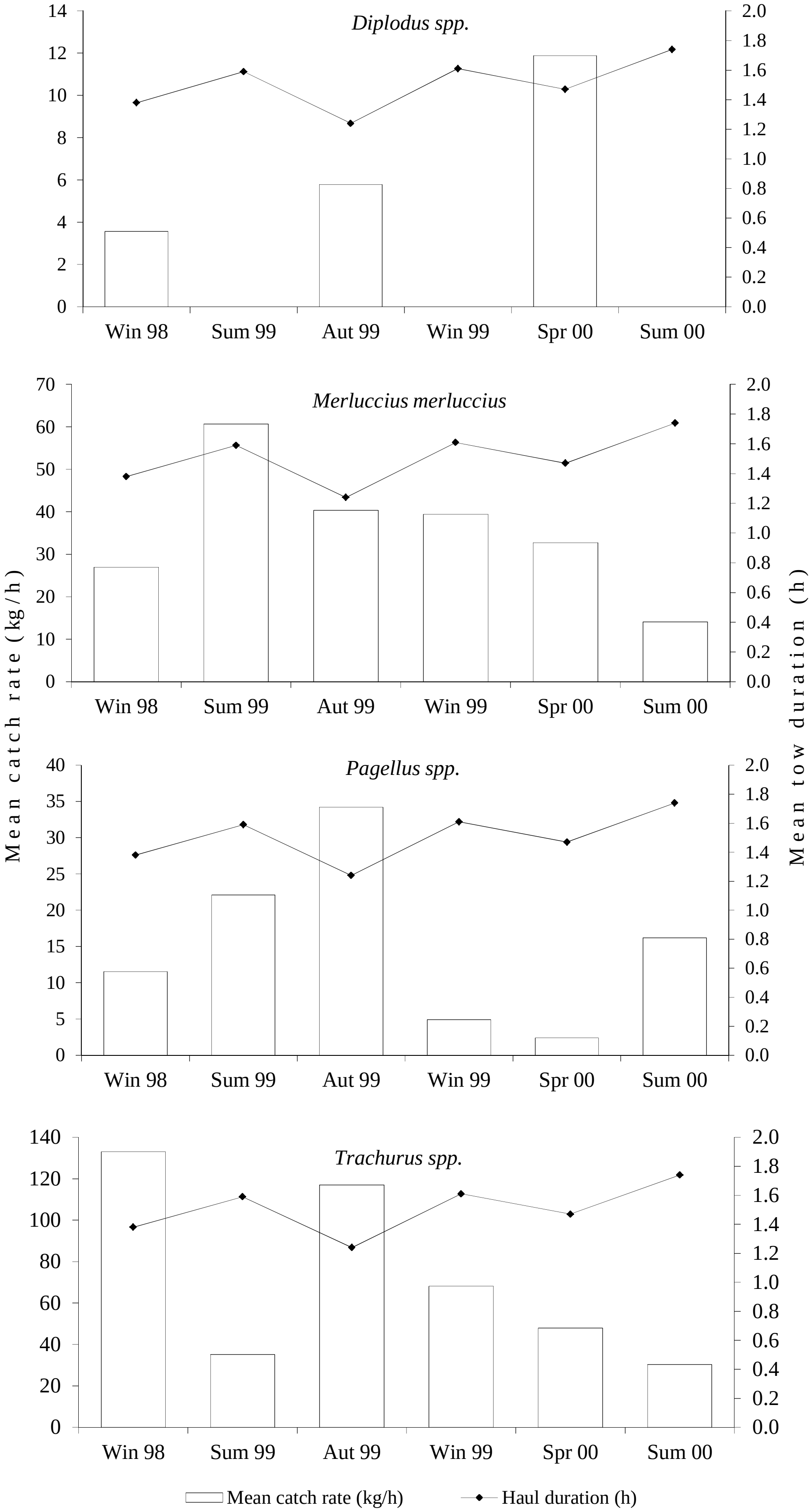


Figure 2.7 – Mean catch rates and mean tow duration for fish trawl target species.

Size frequency distributions

Size distributions of the target species caught by the two types of bottom trawlers are presented in Figures 2.8 to 2.14. Legal minimum landing sizes (LMLS) according to Portuguese legislation are represented by a dotted line and individuals under the LMLS were all discarded, mainly due to their small (illegal) size and/or their poor quality.

Size distributions of the three crustacean target species are represented in Figure 2.8. The majority of blue and red shrimp (92.3%) and deep-water rose shrimp (88.6%) were over the LMLS. All Norway lobster specimens sampled were greater than the LMLS legislated for this species.

Most of the horse mackerel individuals (96.8%) were above the LMLS in both types of trawl (96.4% in crustacean trawl and 96.8% in fish trawl) (Figure 2.9). For European hake 68.1% and 57.7% of individuals caught in crustacean and fish trawls respectively were smaller than the LMLS (Figure 2.10). Overall, only 40.4% were large enough to be landed.

Figure 2.11 shows the size composition of the seabreams *Pagellus* spp., which is quite similar to the European hake situation, i.e., in both bottom trawls, only a few (19.3%) were greater than the LMLS of 18 cm (26.7%, in crustacean trawls and 18.9%, in fish trawls), and were landed. For seabreams of the *Diplodus* genus caught both by fish and crustacean trawls the majority were of legal size, with 87.7% of the specimens greater than the LMLS (Figure 2.12).

The two most important bycatch species captured by fish trawls and for which a LMLS is applicable, are the horse mackerel species (*Scomber colias* and *Scomber scombrus*, grouped together as *Scomber* spp.) and European pilchard, *Sardina pilchardus*. These species where chosen since their mean catch and mean catch rates were the highest (94.6 and 58.7 kg; 85.1 and 46.6 Kg/h, respectively) of the commercialized bycatch species, and were in fact between those of the two most important fish trawl target species, the horse mackerel and European hake.

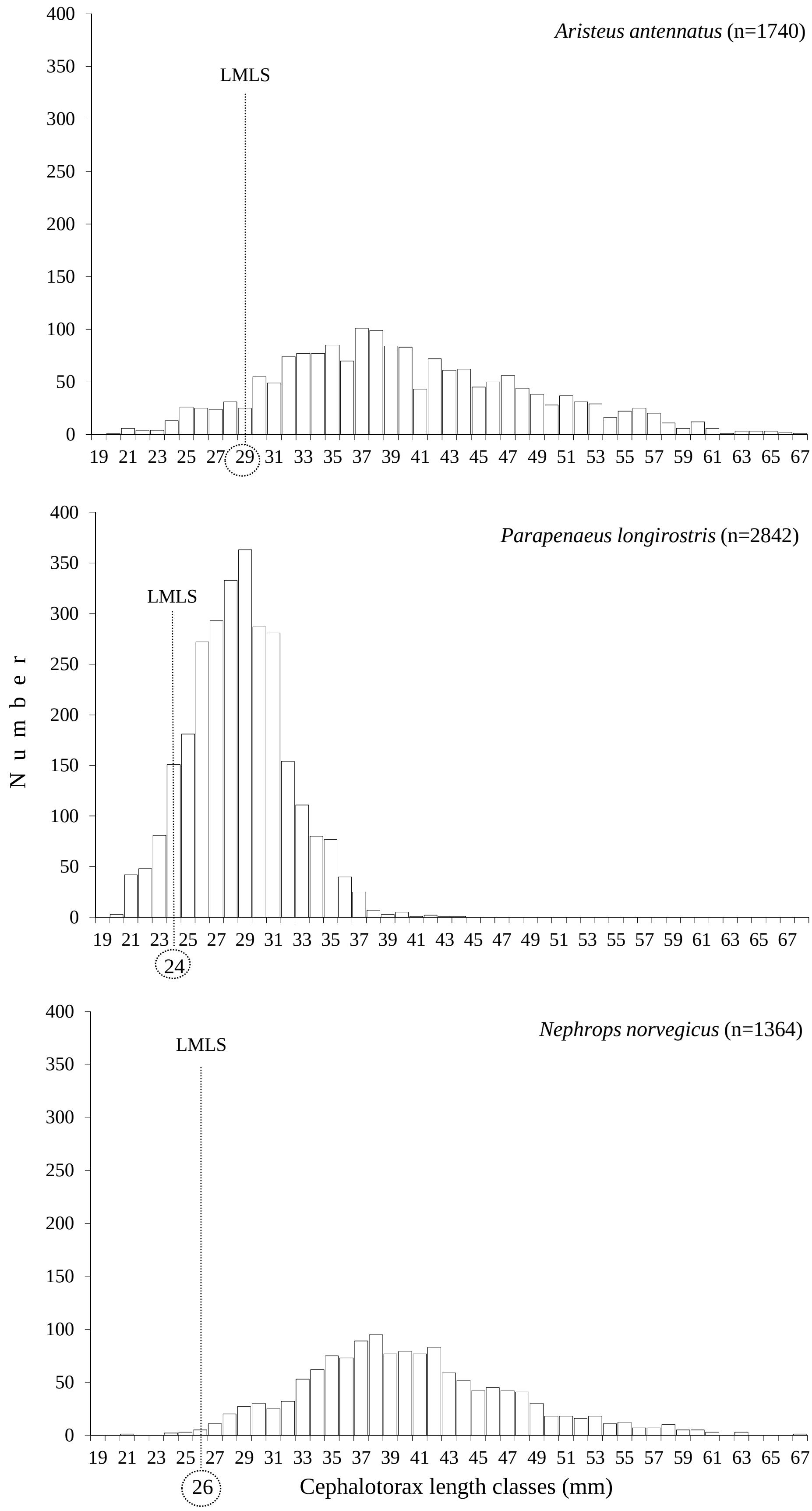


Figure 2.8 - Length frequency distribution of the crustacean trawl target species (LMLS-Legal Minimum Landing Size).

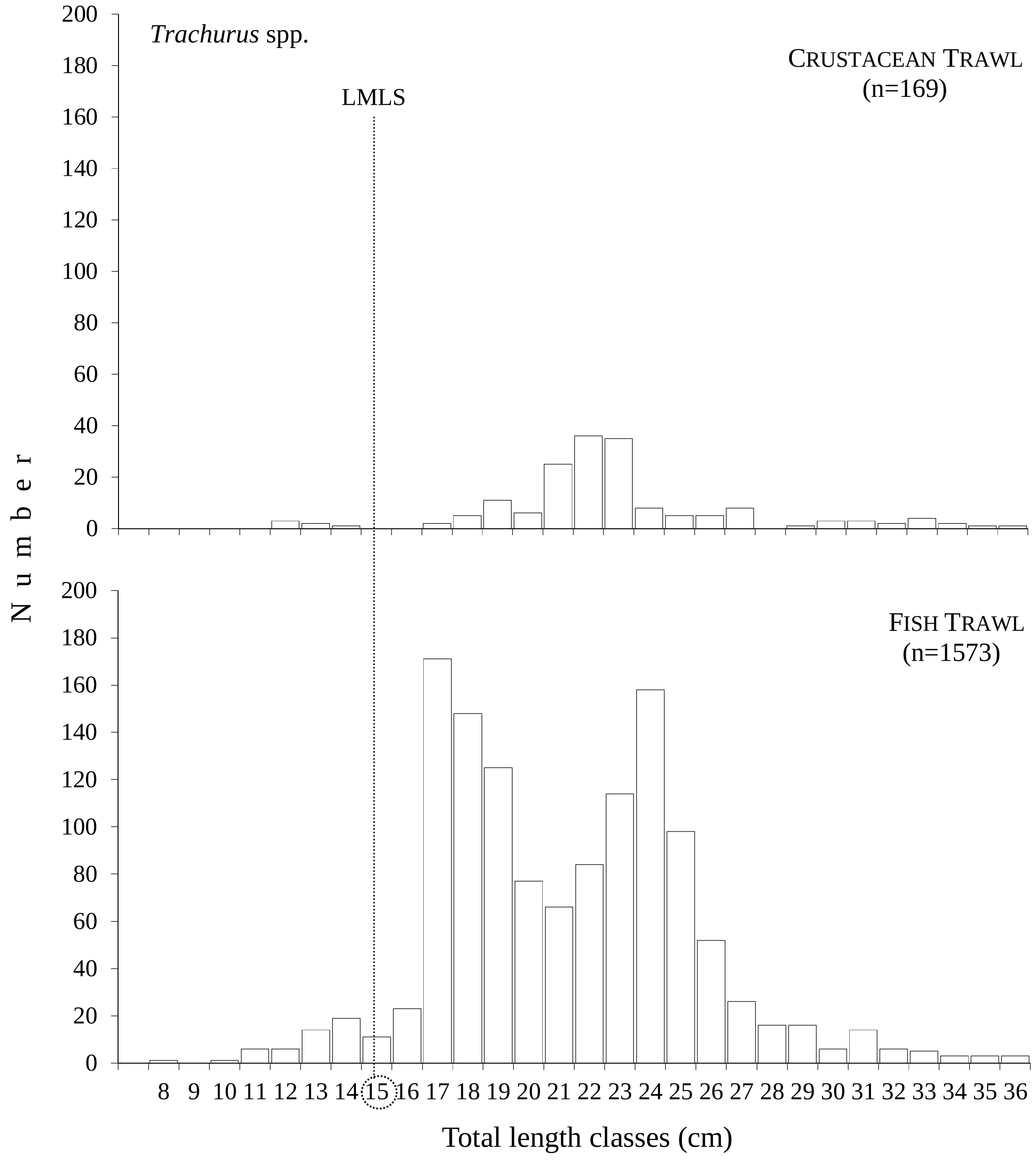


Figure 2.9 - Length frequency distribution of the fish trawl target species *Trachurus* spp. (Horse mackerels) (LMLS-Legal Minimum Landing Size).

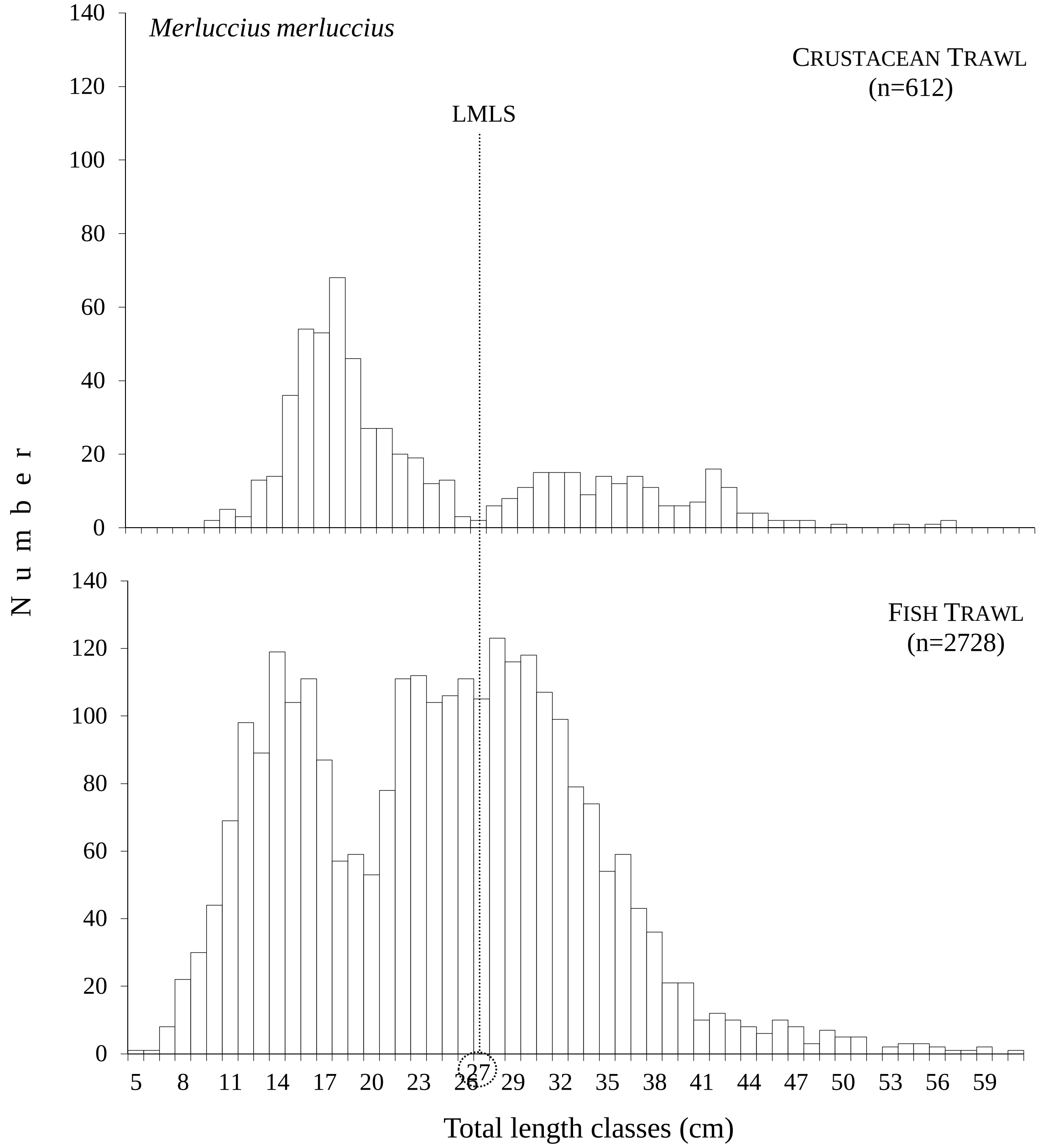


Figure 2.10 – Length frequency distribution of the fish trawl target species *Merluccius merluccius* (European hake) (LMLS-Legal Minimum Landing Size).

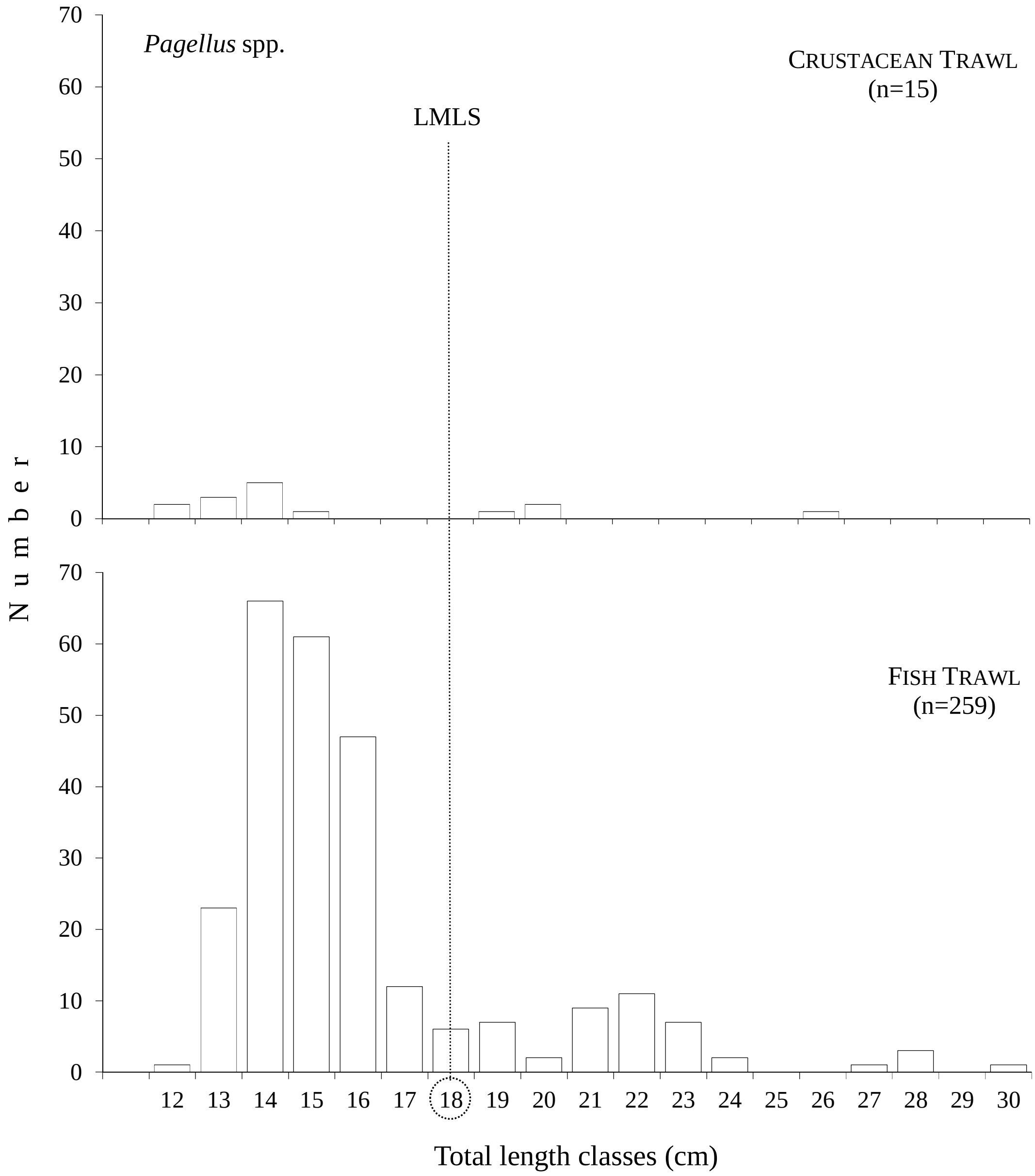


Figure 2.11 – Length frequency distribution of the fish trawl target species *Pagellus* spp. (Seabreams) (LMLS=Legal Minimum Landing Size).

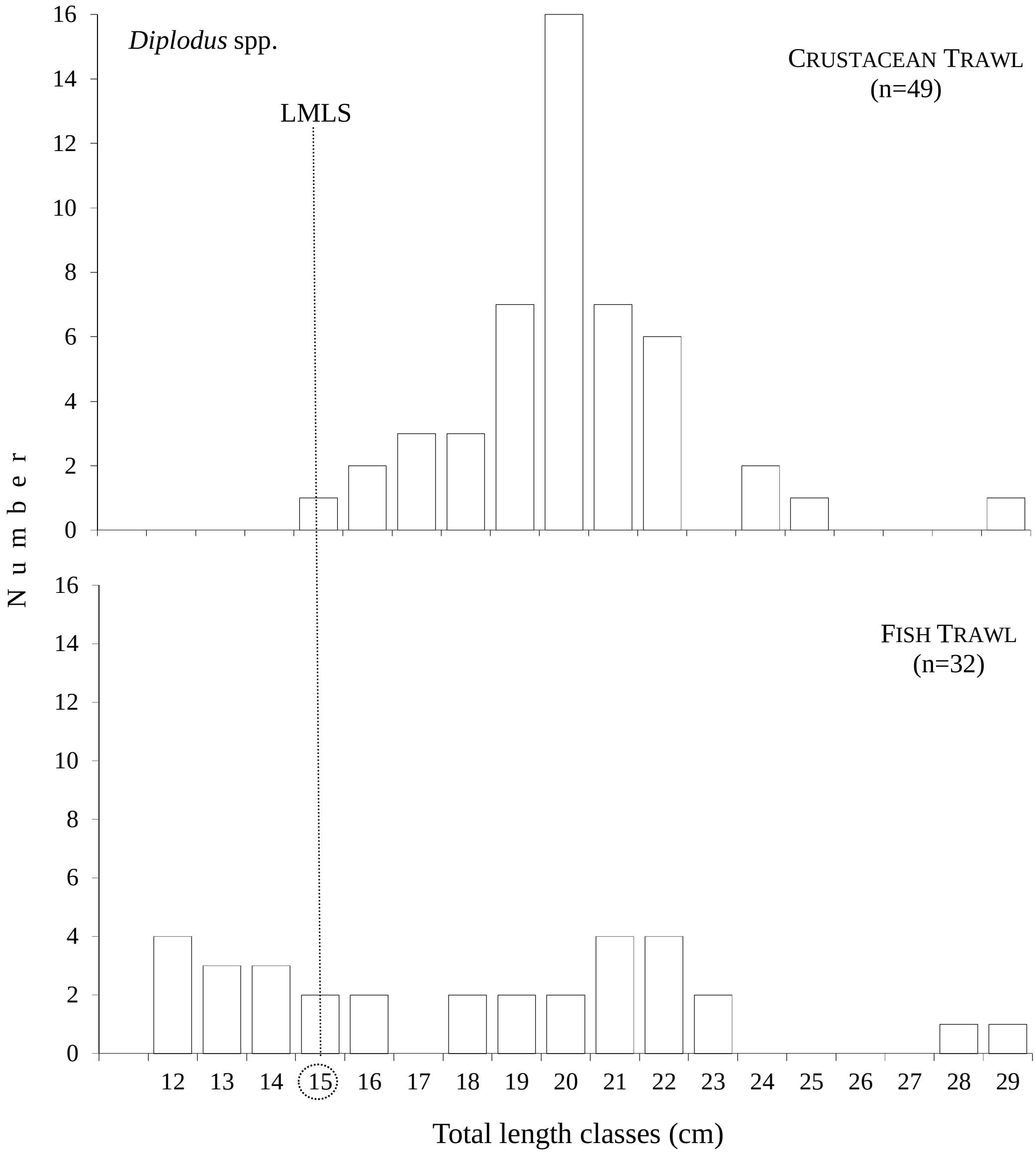


Figure 2.12 – Length frequency distribution of the fish trawl target species *Diplodus* spp. (Seabreams) (LMLS-Legal Minimum Landing Size).

Length data and the respective LMLS for horse mackerel and European pilchard bycatch species are presented in Figure 2.13 and Figure 2.14, respectively. For horse mackerels, almost every specimen sampled (98.7%) was greater than the 20 cm LMLS. Those captured by crustacean trawls were all above LMLS. For European pilchard, all specimens sampled were caught by fish trawlers and were greater than the LMLS.

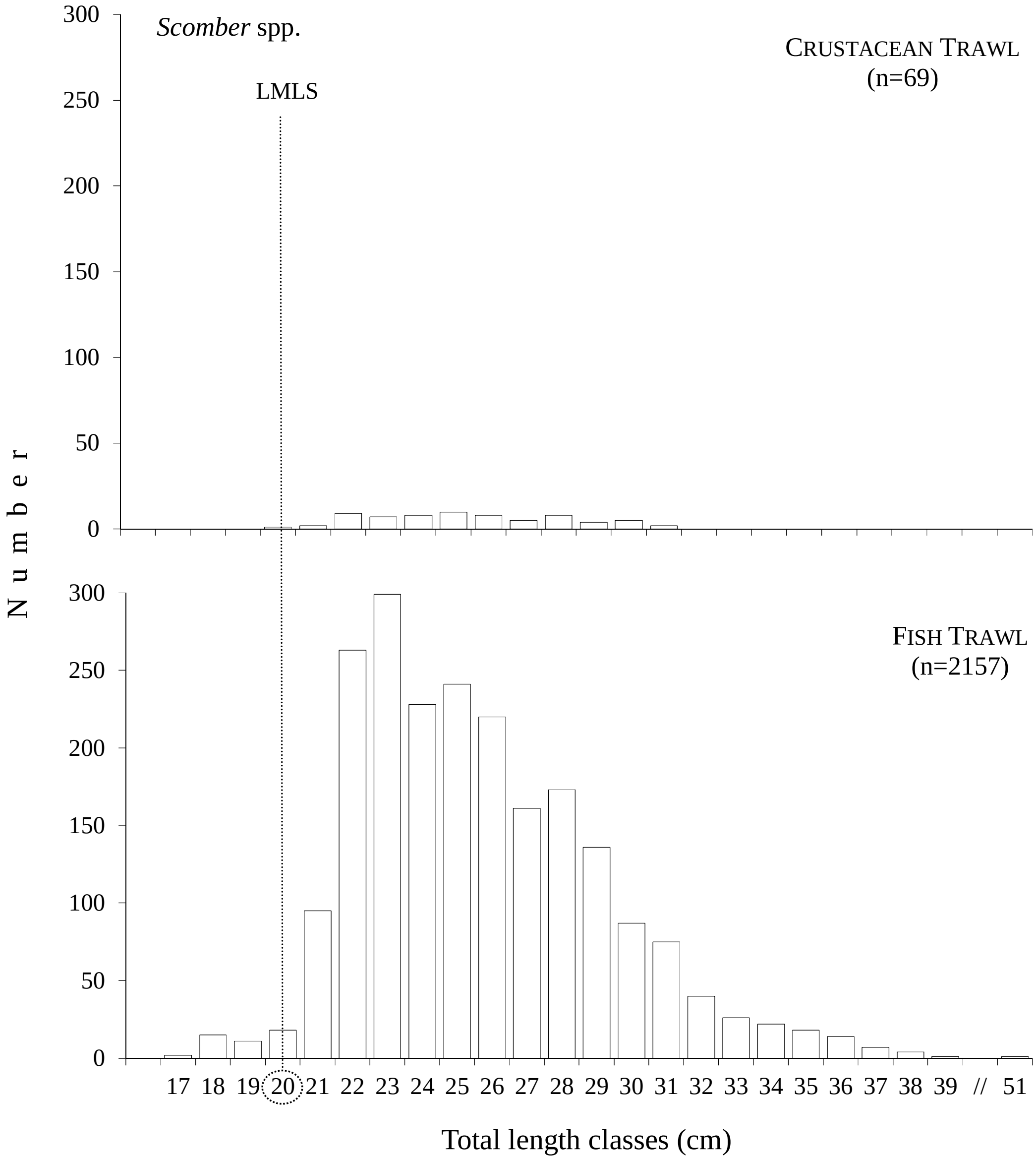


Figure 2.13 – Length frequency distribution of the fish trawl target species *Scomber* spp. (Mackerels) (LMLS-Legal Minimum Landing Size).

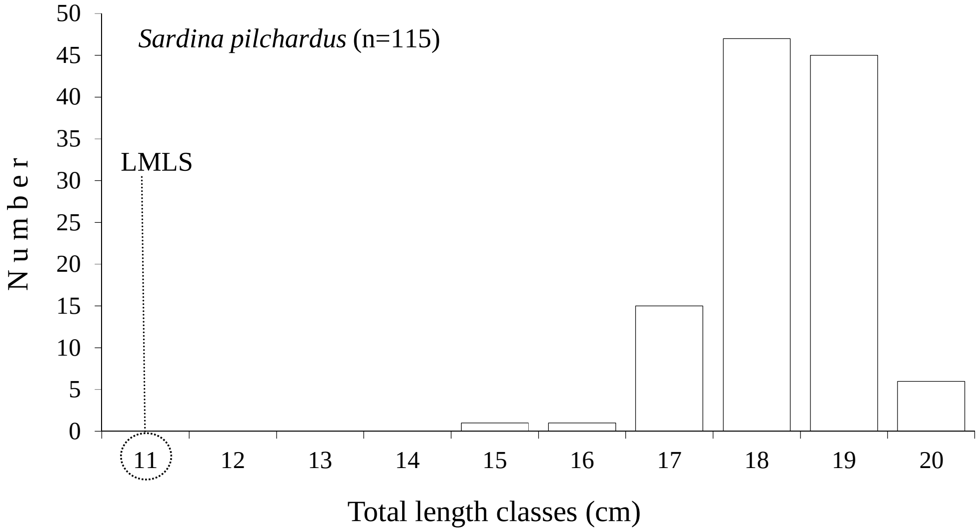


Figure 2.14 – Length frequency distribution of the fish trawl target species *Sardina pilchardus* (European pilchard) (LMLS-Legal Minimum Landing Size).

Discussion

Commercial bottom trawling (crustacean and fish trawls) is a very important activity in southern Portuguese waters, with approximately a third of the Portuguese trawl fleet based in the Algarve (DR, 1999). Bottom trawling off the southern coast of Portugal generates significant amounts of bycatch, with the great majority (80.3% for fish trawlers and 59.4% for crustacean trawlers) of the total catch captured accidentally (total bycatch). Part of the total bycatch includes non-target species of high commercial value, but a considerable portion consists of non-marketable target species, represented by undersized or poor quality specimens, and bycatch species with low or no commercial value that are discarded to the sea, in relatively higher percentages by fish trawls (59%) compared to crustacean trawls (46%). The other fraction of the total catch is made up of target species, and is clearly higher in decapod crustacean trawlers (40.6% compared to 19.7% in fish trawls).

Similar values of bycatch (about 80%) of the total catch were reported for the commercial bottom trawl fishery in the nearby western Mediterranean between 1995 and 1999 (Sartor *et al.*, 2003). The remaining fraction was also composed of target species, which represented a portion between 20% and 46% in all seasons. In contrast to our study, a significant portion of the bycatch consisted of commercial species, with higher values in summer.

Catch composition varies considerably according to a number of factors, including the nature of the fisheries stocks fished, the type of fishing gear used, gear selectivity, tow duration, target species and their price value, depth of capture, and the time of the year

(García-Rodriguez and Esteban, 1999; Larson *et al.*, 1996; Merella *et al.*, 1998; Oliver, 1993; Recasens *et al.*, 1998; Rochet *et al.*, 2002). The relatively non-selective nature of trawl nets in itself results in substantial quantities of bycatch (Monteiro *et al.*, 2001). In this study, only the summer target catches of both types of trawl differed significantly from those of the other seasons. This could be due to the fact that fishing effort was comparatively higher than during the other seasons, which leads to greater variability in the catches. Recasens *et al.* (1998) and García-Rodriguez and Esteban (1999), report that when there are temporal variations in the catches, it is important to consider the fluctuations in abundance and size range of the species studied.

Fishing trip duration is one of the most important factors influencing the proportion the of fish bycatch that is commercialised, and the quantity of bycatch landed inversely related to trip duration (Clucas, 1997). Considering that fish trawler trip duration is significantly shorter (mean=43.4 h) than that of crustacean trawlers (mean=69.5 h), the higher values of commercial bycatch are understandable.

Sbrana *et al.*, (2003) considers the variation in tow duration to be the main factor responsible for the seasonal variations in catches of the target species *A. antennatus* and *P. longirostris* in the western Mediterranean. According to Merella *et al.*, (1998), tow duration is greatest when the yields are highest or when market prices reach their maximum values. This was observed for the target species *N. norvegicus* (Merella *et al.*, 1998), and for *A. antennatus* and *M. merluccius* (Oliver, 1993) for Mediterranean waters. In our study, an inverse relationship between tow duration and target species catch rates in most cases compounds the non-selectivity of the trawl nets, which leads to more bycatch being capture as well as more undersized individuals of the most valuable species. Seasonal variations of tow duration could be attributed to targeting of different species being targeted during certain periods as well as catches being made at different times.

Great diversity in bycatch species composition is a common phenomenon in trawl fisheries (Andrew and Pepperell, 1992; Saila, 1983; Stergiou *et al.*, 2003). This was also the case in this study, with a total of 255 species recorded, 246 (96.5%) of which contributing to the total bycatch. The differences between the two types of trawlers can be explained by the fact that crustacean trawlers exploit greater depths that are richer in terms of biodiversity. In addition, longer crustacean trawl tow duration may decrease the size selectivity of the trawl net as the catch accumulates in the codend (Murawski, 1996), thereby increasing the number of species and consequently the bycatch.

The dominant bycatch species captured by both types of trawlers, belong to the class Osteichthyes followed by molluscs (mainly cephalopods) and crustaceans. This is in agreement with the findings of Monteiro *et al.* (2001), also for Algarve coastal waters and in the Mediterranean (Sartor *et al.*, 2003).

Of the crustacean trawl target species, the largest catches are of the deep-water rose shrimp (*P. longirostris*) followed by blue-and-red shrimp (*A. antennatus*). The deep-water rose shrimp prefers sandy and/or muddy bottoms between 150 and 550 m, while *Aristeus antennatus* (blue-and-red shrimp) is more common in muddy grounds beyond 500 m and extending to 750 m (Cascalho, 1995; CEC, 1993b). The third target species, *Nephrops norvegicus* (Norway lobster), which has an irregular distribution between 170-700 m (Cascalho, 1995; Ribeiro-Cascalho and Arrobas, 1987) and being limited primarily by bottom topography and sediment type due to its burrowing behaviour (De Figueiredo and Viriato, 1992), represented only 20.7% of the target catches in the trawls that took place at an average depth of 463 m. Due to the low power of their engines, crustacean trawlers do not often fish at the depths where this species is most abundant (CEC. 1993b).

In the demersal fish trawl fishery, horse mackerels (*Trachurus* spp.) followed by European hake (*M. merluccius*) were the main target species with highest mean catches (76% and 11.6%, respectively). Figueiredo *et al.* (1994) also reported European hake as a commercial bycatch species in the crustacean trawl fishery, which accounted for 8.6% of the catch in mean weight. Higher values are referred by Castriota *et al.* (2001) who found that European hake accounted for 28% for the commercial bycatch in the central Mediterranean and also by Monteiro *et al.* (2001), who reported that the European hake was the most landed bycatch species (91% of occurrence), with horse mackerel contributing only 3% to the commercial bycatch. The most important commercial bycatch species caught by fish trawls are *Scomber colias* and *Sardina pilchardus*. Whether these species are marketed or not depends on total amount caught and on the prices at auction.

Other groups of organisms taken as bycatch can also have some commercial value in fish markets, as is the case of the Chondrichthyes and cephalopods. Chondrichthyes are important only as bycatch and marketable fresh only at large sizes and/or if the fish quota established for the crustacean trawlers allows them to be commercialised. In this study, this group is the dominant component of commercial bycatches in crustacean trawlers, and is composed of 18 species that represent 21.5% in mean weight, which is even greater than that of the target species *A. antennatus* (13%). In fish trawlers, it is the third most important commercial bycatch group, and represents 13.8% in mean weight (7 species caught), of which 9.9% alone is the species *Scyliorhinus canicula*. Some species of cephalopods have high commercial value while others can be commercialised but only if they are caught in significant quantities. Like cartilaginous fishes, the commercial bycatch group of cephalopods is more representative in crustacean trawlers (17 species caught and 5.2%, in mean weight) than in fish trawlers (18 species caught and 3.8%, in mean weight).

The existence of legal minimum landing sizes (LMLS) for most exploited species demands higher lengths of marketable fish and, inevitably, leads to proportions of both target and/or commercial bycatch specie being discarded whenever they do not reach this size. Our results show that this is more significant for fish trawl catches. The clearest cases occur with the European hake and seabreams of the genus *Pagellus* spp. Moranta *et al.* (2000) suggests that this kind of situation could be due, in part, to poor size selectivity in the codend for these species, with potentially important implications in terms of juvenile mortality.

In addition to the LMLS, there are other regulations for conserving fisheries and/or reducing the bycatch in Portugal. These include minimum legal mesh sizes for crustacean and fish trawl nets of 55 to 59 mm and 65 to 69 mm and/or≥70 mm respectively, minimum catch percentages of legal-sized target species of 30% for crustacean trawlers and 70% for fish trawlers, and maximum permitted catch percentages of bycatch species of 30% for crustacean trawlers 20% for fish trawlers. In this study, the quantities traditionally kept and distributed by fishermen for personal consumption where not taken into account, which probably justifies the higher percentages shown in some occasions.

Other alternatives for reducing bycatch of bottom trawls include research on the development and evaluation of the performance of more selective gear and fishing practices, to permit juveniles to escape and to maximize the catch of target species. Research into reducing bycatch has been carried out in Portuguese waters since the 1990´s. Experiments using square-mesh codends windows (Campos and Fonseca, 2004; Campos *et al.*, 2002, 2003b; Fonseca *et al.*, 1998), diamond mesh codends (Campos *et al.*, 2002, 2003b), separator panels (Campos and Fonseca, 2004), and modified Nordmøre grids (Fonseca *et al.*, 2005a,b) were, and still are, being carried out. These studies have demonstrated the varying effectiveness of such sorting devices in reducing the amount of bycatches (and discards) in trawl fisheries, and in allowing a high percentage of undersized specimens and non-commercial bycatch species to escape. However, the use of these devices has not been adopted by the commercial fishermen due to the loss of part of the catch target and commercial bycatch species and the cost of implementing and operating such devices.

Knowing that the deep-sea fauna is quite diverse in the Algarve (Borges, 2010), and given the results of this particular study, it can be concluded that bycatch has important economic and ecological implications in this region. Removal of bycatch species by trawling can have a significant impact on marine trophic chains through predator-prey relationships and consequently on the whole ecosystem. This may be one of the reasons for the decrease of target species as well as overfishing.

Considering that both identification and quantification of bycatches are valuable pre-requisites to understanding the lesser known impacts of fishing and solving the problems, more attention should be paid to the bycatch issue in southern Portuguese waters. Efforts should be made to obtain information on the variables that influence the spatial and temporal distribution of bycatch, as well as on the biology of the species, including distribution, growth parameters, reproduction and feeding habits. This is essential for an effective management of this problem, as well as maintaining biodiversity and ecologic stability.

This study highlights the need for new and improved measures for mitigating the bycatch problem in Portuguese trawl fisheries. Although various bycatch reducing devices (BRDs) have been tested in Portuguese waters and size selectivity of both target and bycatch species has been studied (Campos and Fonseca 2003, 2004; Campos *et al.* 2002, 2003b; Fonseca *et al.* 1998, 2005a,b), there has been little progress in terms of practical applications in the fishery. Indeed, as emphasized by Rawson (1997), the management of fisheries bycatch should consider all approaches to finding solutions that stabilize fish populations and the ecosystem consequences, while taking into account the human requirements for the marine resources.

Chapter 3

Discards composition and rates from the coastal bottom trawl fisheries off the southern (Algarve) Portuguese waters

Catch of a demersal fish trawler - photo from Borges et al. *(2002) adapted by MECosta*

Partially submitted to Reviews in Fisheries Science

Abstract

Discarding is recognized as one of the major problems in world fisheries. Discards from crustacean and fish bottom trawl fleets in the southern coast of Portugal (Algarve) were analyzed to study the catch and species composition, the discarding practices and their underlying reasons. Sampling was carried out from February 1999 to March 2001, stratified by season, encompassing 163 tows from a total of 52 fishing trips. During this study a considerable amount (56.5%) of the total catch by weight was discarded by the two métiers. Average discard proportions (biomass discarded/biomass caught) ranged from 0.46 in crustacean trawlers to 0.59 in fish trawlers. A total of 255 species from 147 families were identified in the catches, of which about 69% were systematically discarded. The crustacean trawl métier captured a higher diversity of species (81%) and discarded more species (56%) compared to the fish trawl métier (61% of species; 37% discarded). The majority of the species captured by both métiers were bony fishes (46%), accounting for almost 79% of the biomass and 93% of the abundance of all fishes and cephalopods discarded. The great majority of discards (68.6%) are composed of unmarketable species. The most discarded species corresponded to fishes of low (blue whiting, *Micromesistius poutassou*; small-spotted dogfish, *Scyliorhinus canicula*, and blackmouth catshark, *Galeus melastomus*) or of no commercial value (snipefishes, *Macroramphosus scolopax*, and *M. gracilis*; boarfish *Capros aper*), species which are particularly relevant for the marine food chains. The blue whiting was the dominant species, both in abundance and biomass, discarded by crustacean trawlers, while for fish trawlers, the longspine snipefishes were the most discarded species in numbers, and the chub mackerel the most discarded in biomass. The reasons for discarding are fundamentally economic in nature (lack of commercial value) for bycatch species; and legal and administrative (legal minimum landing size) for commercially important species. In this study the abundances and biomasses of discarded species, between and within both métiers, the species dominance and the rates of discarded species, in terms of number and biomass, are also provided and the variability in the discards is discussed.

Introduction

Discarding of marine organisms resulting from fishing activities is widely recognized as one of the most serious problems in world fisheries (Anon., 2003; Alverson *et al.*, 1994; Connolly and Kelly, 1996; Margeirsson *et al.*, 2012; Saila, 1983). Therefore, this issue is receiving a growing global (public) awareness (Ulleweit *et al.*, 2010), leading to the adoption of management strategies of which the mandatory discard ban, included in the recent reform of the EU Common Fisheries Policy (CFP) (EU, 2013), constitutes an important part.

Discards are commonly defined as that part of the organisms in the total catch which, irrespective of the reason, is not retained on board during commercial fishing operations but returned back to the sea, often dead and/or dying (Kelleher, 2005; Saila, 1983). Several reasons can lead to the discarding of part or all of a species catch, even of the most commercially valuable ones, ranging from technical (e.g. lack of space on board or poor gear selectivity), economic (e.g. lack of or low commercial value) and regulatory (e.g. minimum landing size and quota restrictions) issues; to biological (e.g., species composition, poisonous/dangerous species) and ecological (overlapping habitats) constraints, as well as Skippers' decisions (Anon., 2003; Alverson, 1998; Clucas, 1997; Cotter *et al.*, 1995; Crean and Symes, 1994; Kelleher, 2005; Tsagarakis *et al.*, 2013).

Discards represent an important source of waste of natural resources (Alverson and Hughes, 1996; Alverson *et al.*, 1994; CEC, 2008a; EC, 2011c; Kelleher, 2005), leading to significant negative impacts, either economic (e.g. decreased fishers' income and food shortages), ecological (e.g. impact on non-commercial species affecting the food chain and inducing habitat modifications) or of commercial resources management (e.g. recruitment or growth overfishing, unquantifiable fishing mortality rates) (Bellido *et al.*, 2011; FAO, 2011a; Kelleher, 2005; Saila, 1983). The lack of supply and adequate discard information for many fisheries (FAO, 2010a, 2011a; Kelleher, 2005), precludes the inclusion of discards data in stock assessment models (Borges *et al.*, 2005a), resulting in a biased estimation of future biomasses and recruitment (Anon., 2003). This is particularly important in multispecies fisheries (Lema *et al.*, 2006; Rochet and Borges, 2006) where discards are more significant, further aggravated by the variation in their pattern over time (Anon., 2003).

Many fisheries around the world exhibit high spatial and temporal variability in the discarding (Alverson *et al.*, 1994; Andrew and Pepperell, 1992; Cotter *et al.*, 1995; Crean and Symes, 1994; Kelleher, 2005; Kennelly, 1995; Margeirsson *et al.*, 2012; Morizur *et al.*, 2004). Discards variability is highly dependent on the type of fishery (Kelleher, 2005; STECF, 2008), with a major contribution from bottom trawling (Hall, 1999; Stergiou *et al.*, 1998; Vázquez-Rowe *et al.*, 2011), given its low selectivity (Edelist *et al.*, 2011; Kumar and Deepthi, 2006; Macher *et al.*, 2008; Sacchi, 2008), particularly in mixed fisheries (Johnsen and Eliasen, 2011).

According to the most updated published study concerning discards in the world´s commercial fisheries, covering the 1992-2001 period, the FAO estimates point towards an annual global discards total of 6.8 million tonnes, equivalent to a discard rate of 8% of the total volume of fish caught worldwide (Kelleher, 2005). The Northeast Atlantic (FAO area 27) fisheries, where the majority of European Union fisheries are included, are responsible for generating around one-fifth (1.3 million tonnes) of total annual global discards, accounting for 19.5% of the annual global discards (Kelleher, 2005). Portugal, part of FAO area 27, ranks in the top 10 countries presenting the highest discards (total and rate) generated by shrimp trawl fisheries. In 1996, the latter amounted to over 35,000 tonnes (0.70 discard proportion) (Kelleher, 2005).

In Portugal bottom trawling is important at the national level and is one of the most intensively used fishing methods in the southern (Algarve) coast, the most fisheries dependent region, both as a source of food and livelihood (Borges, 2010; Borges *et al.*, 1997, 2000; CEC, 1992a). In the Portuguese continental waters, bottom trawling constitutes a mixed fishery targeting a wide variety of species, and is separated into two fleet segments, crustacean and finfish trawling, according to the main target species group (CEC, 1993a; Campos *et al.*, 2007). Crustacean trawling is directed to the exploitation of decapod crustaceans of high economic value, such as the deep-water rose shrimp, *Parapenaeus longirostris* (Lucas, 1846), the Norway lobster, *Nephrops norvegicus* (Linnaeus, 1758) and the blue-and-red shrimp, *Aristeus antennatus* (Risso, 1816) (Campos and Fonseca, 2004; Campos *et al.*, 2006, 2007; Cascalho *et al.*, 1984; Castro *et al.*, 2005; Fonseca *et al.*, 2005a; Pestana, 1991). On the other hand, the finfish trawl fleet targets a mixture of different fish (and cephalopod) species, like European hake, *Merluccius merluccius* (Linnaeus, 1758); horse mackerel, *Trachurus trachurus* (Linnaeus, 1758); Mediterranean horse mackerel, *Trachurus mediterraneus* (Steindachner, 1868); Blue jack mackerel, *Trachurus picturatus* (Bowdich, 1825); Atlantic Chub mackerel, *Scomber colias* Gmelin, 1789; Atlantic mackerel, *Scomber scombrus* Linnaeus, 1758; and seabreams of the genus *Diplodus* spp. and *Pagellus* spp. (Borges *et al.*, 2000, 2002; Campos *et al.*, 2007). The octopuses, *Octopus vulgaris* and *Eledone cirrhosa*, the European squid, *Loligo vulgaris*, and the common cuttlefish, *Sepia officinalis*, are the main cephalopod species captured by this fleet segment (Campos *et al.*, 2007; Fonseca *et al.*, 2008).

The issue of commercial fishing discards in Portuguese fisheries was first addressed by Borges *et al.* (1997, 2001), in 1996-1997, involving the identification and quantification of fisheries discards of five important fishing gears (crustacean and fish trawls, pelagic and demersal purse seines and trammel nets) in the southern Portuguese coast, generating the first comprehensive estimates of discards. These authors continued investigating discards from trawls and purse seines (Borges *et al.*, 2000, 2002), but several other studies on catch and composition of the discards followed, exclusively in the crustacean trawl (Monteiro *et al.*, 2001), beam trawl (Cabral *et al.*, 2002), trammel nets (Batista *et al.*, 2009; Gonçalves *et al.*, 2007, 2008b), demersal purse seine (Gonçalves *et al.*, 2004, 2008a) and beach seine (Cabral *et al.*, 2003) Portuguese fisheries. The impact of discards in trawl fisheries and their fate, namely their consumption along the trophic chain, have also been investigated in southern Portuguese waters (Castro *et al.*, 1999, 2005; Erzini *et al.*, 2003). These studies reveal that discards constitute a substantial and important component of commercial Portuguese catches and thus may have a significant impact on the structure and functioning of the marine ecosystem. Furthermore, even with the discard data collected since late 2003, under the early Data Collection Regulation (EC, 2000, 2001) conducted by the "Instituto Português do Mar e da Atmosfera" (Portuguese Sea and Atmosphere Institute) (IPMA), the national Portuguese institute responsible for fisheries research, complete and detailed discards data are still lacking.

The present study analyses discards from demersal crustaceans and fish trawl commercial fisheries from southern Portuguese (Algarve) waters, by quantifying and describing their composition, reporting their variability, and identifying the main reasons leading to the discarding practices. Data on discard proportions and rates, abundances and biomasses of discarded species between and within crustacean and fish trawl métiers, species dominance in the discards and rates of discarded species in number and weight are also provided, in order to complement the existing information and contribute to an increasing knowledge on the discards in Portuguese fisheries.

Material and methods

Data collection

The study was carried out off the southern coast of Portugal (Algarve), in an area between 36°36.990´N - 37°0.418´ N and 7°24.300´ W - 9°8.070´ W (Figure 3.1). Sampling took place during two years, from February 1999 to March 2001, aboard commercial bottom trawl fisheries during two research projects on fisheries bycatch and discards.

The sampling strategy was based on a random stratified sampling of the fishing vessels, by métier (crustacean trawl and fish trawl) and season (n=4), considered as four equal three-month periods, and data were collected by at least two scientific observers on board each commercial vessel. The vessels sampled were randomly selected but subjected to the willingness of skippers and owners to allow the presence of observers on board, as well as the time and resources available.

In the south coast of Portugal, crustacean and fish trawlers constitute two fishing fleets with vessels that do not switch between fishing methods (Chapter 2). Crustacean trawlers, targeting deep-water rose shrimp (*Parapenaeus longirostris*), Norway lobster (*Nephrops* *norvegicus*) and blue-and-red shrimp (*Aristeus antennatus*), use a stretched mesh codend between 55 to 59 mm and operate on the lower continental shelf and continental slope between 117 and 754 meters depth (mean=463.3 m; s.d.=150.0). Fish trawlers target European hake (*Merluccius merluccius*), horse mackerels (*Trachurus* spp.) and seabreams (*Diplodus* spp. and *Pagellus* spp.), on the continental shelf and upper continental slope at depths from 100 to 290 m, using a stretched mesh codend between 65 to 69 mm. Target species were defined by the skippers previously to the start of each tow.

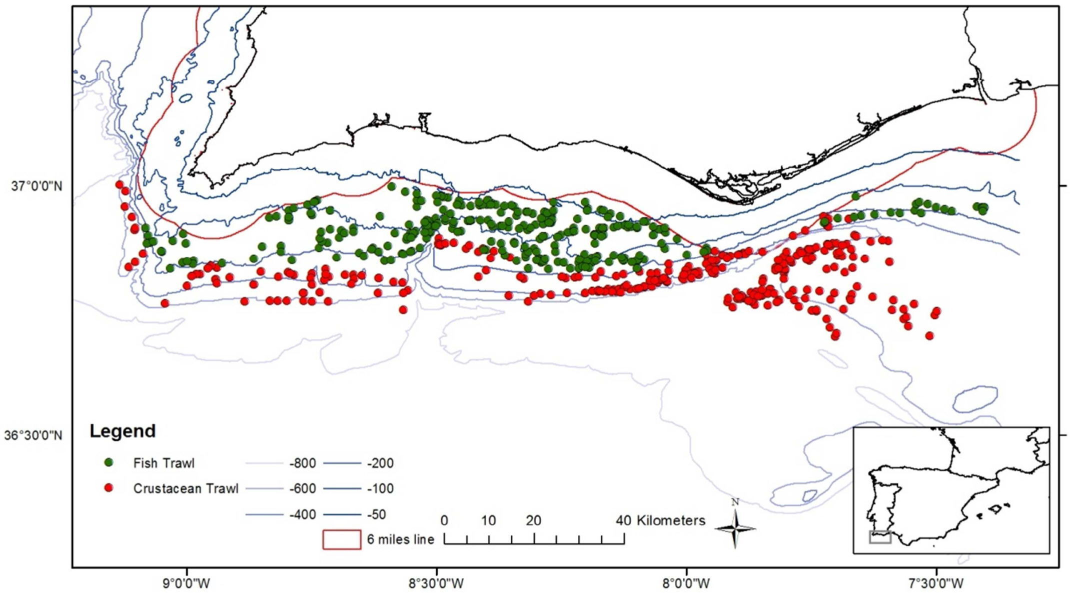


Figure 3.1 – Map of the southern Portuguese coast (Algarve) showing the trawling positions of the crustacean and fish trawl métiers, during the period of study.

All data collection was carried out by fishing operation (tow) per fishing trip, and was conducted in order not to interfere with the normal fishing practices of the crew. The sampling effort was based on nine different fishing vessels (6 crustacean trawlers and 3 fish trawlers) covering 25.7% of the active part of the Algarve coastal trawler fleet. On board, observers recorded data concerning the technical characteristics of the trawl vessel (e.g. overall length, gross registered tonnage) and the gear (e.g. mesh size), the fishing operations (date, hour and duration of the trip, number, geographical position, depth and duration of each tow), the composition of the catches (total, retained and discarded amounts), the faunistic composition of the retained and discarded catch, along with the main reasons for discarding.

In the case of large amounts caught, and mainly in situations where the whole catch is 'slipped' through an opening in the net, not making it possible to bring the catch on board, the skipper of the fishing vessel was asked to provide an estimate of the size of the total catch.

When the amount of discards was too large to weigh, sub-samples of approximately 30 kg were taken randomly, after all the commercial species were processed by the crew, and estimates of the total amount of discards were made. In the case of small quantities, the entire amount of discards was collected and brought to the laboratory. The total catch was obtained by adding the weight of the retained catch (separated in standard boxes, by species) to the weight of the discards.

Quantification and identification of the discards was largely carried out in the laboratory. The discards samples caught in each tow were sorted by taxonomic groups, weighed and identified to the lowest taxonomic (species) level, and all fish and cephalopods were counted and weighed individually.

This study follows the definition of *métier* mentioned in the first section of Chapter 1 and the definitions of *total catch* and *retained (or landed) catch* referred in Chapter 2. It also considers the *discarded catch* (abbreviated to *discards*) as the portion of the total catch which is returned to the sea, dead or alive, if it is not used for any purpose. Therefore this includes all the non-target and non-commercially valuable bycatch species, as well as the fraction of target or bycatch species with commercial value that cannot be legally landed.

Data analysis

Catch compositions (total, retained and discarded) were converted into rates (kg/h) and the means and respective standard deviations were calculated by tow and trip, on a seasonal basis for each métier.

The discard proportion (D_P)[2] measured on board a vessel is the proportion of the total catch that is discarded, expressed as the total weight of discarded species divided by the total weight of all species caught:

$$D_P = \frac{D}{D + L}$$

where, D is the total discard (kg), L is the total retained (or landed) (kg) and D+L gives the total catch (kg). The relationship between D_P and total catch was determined by means of linear regression.

All species caught by both métiers were classified by their frequency of discarding into three categories: (1) occasional (commercially valuable target species that are only

[2] In this study, the term *Discard Proportion* is considered to be more correct than *Discard Ratio* when referring to the amount discarded divided by the total catch, as in the formula D / (D + L) of FAO (1997) and Kelleher (2005).

occasionally discarded), (2) frequent (bycatch species with commercial value that are frequently discarded) and (3) systematic (species that are always discarded).

The species composition of the discards in terms of diversity was analysed for each métier by comparing the number of discarded species to the total number of species caught. The occurrence of each discarded species was studied based on the number of fishing operations in which the species occurred, by means of percentages, calculated as:

$$O = \frac{n}{N} X\, 100$$

where, O is the Occurrence, n is the number of tows in which a specific species occurred and N is the total number of tows done on a specific métier during the study period.

The numbers (n) and weights (w) of each discarded species in the samples (s) were multiplied by the ratio of total discard weight to the sample discard weight ($\frac{d_{wt}}{d_s}$) to give an estimate of the total amounts of discards of each species, in terms of abundance (dn_{ij}) and biomass (dB_{ij}), from each tow (j):

$$dn_{ij} = n_{ij} \times \frac{dw_j}{ds_j} \;;\; dB_{ij} = w_{ij} \times \frac{dw_j}{ds_j}$$

where n_{ij} is the number of species i in the sample from tow j, w_{ij} is the biomass of species i in the sample from tow j, ds_j is the weight of the sample of tow j, and dw_j is the total weight of discards of tow j.

The latter figures were divided by the tow duration in hours to determine the abundance (d_{nt}) and biomass (d_{Bt}) of fish discarded per hour, herein referred to as abundance and biomass discard rates.

Abundances and biomasses of discarded species were analysed by means of multivariate techniques based on Clarke and Warwick (2001), using the PRIMER package (Clarke and Gorley, 2006). For these analyses only fish (cartilaginous and bony fishes) and cephalopods species, herein referred to as fish, were considered. Crustaceans, as well as other invertebrate taxa, were not included in the analysis due to their very low contribution to discards both in abundance and biomass.

With the purpose of investigating the seasonal variation in species abundance and biomass of species discarded in each métier, as well to check for any differences between métiers, matrices of the estimated numbers and weights of each discarded species sampled by tow/season were constructed. Due to the data matrix size restrictions imposed by the PRIMER, and given the fact that a large number of species were discarded and that many species occurred in only a few tows, the species which contributed less than 0.1% to the total abundance or biomass were removed from the matrices.

The unstandardized abundance and biomass data were transformed using the double square root transformation in order to reduce the weighting of extremely abundant (or with high biomass) species against less dominant or even rare species (Field *et al.*, 1982; Carr, 1997; Clarke and Warwick, 2001) prior to analysis. To measure how close the abundance (or biomass) levels are for each species, triangular matrices of similarity coefficients were computed between every pair of samples (by season, between métiers and in each métier). The measurement of similarity was based on the Bray-Curtis coefficient:

$$S'_{il} = 100 \left\{ 1 - \frac{\sum_{j=1}^{n} |Y_{ij} - Y_{lj}|}{\sum_{j=1}^{n} (Y_{ij} - Y_{lj})} \right\}$$

where, Y_{ij} and Y_{lj} are the abundance (or biomass) values by discarded species j in samples i and l, respectively (Bray and Curtis, 1957). This enabled the classification of the data into groups of ranked similar entities. The coefficient of similarity takes values between zero, showing totally dissimilarity between two samples and 100, in the case of total similarity between two samples.

The resulting similarity matrices were subjected to two multivariate methods: (1) hierarchical clustering analysis (CLUSTER), applying the group-average linking in which samples are joined into hierarchical groups and the groups into clusters, at the average level of similarity between all members of one group and all members of the other, lowering the similarity levels, such that samples within a group are generally more similar to each other than samples in different groups (Field *et al.*, 1982, Clarke and Warwick, 2001); and (2) non-metric multidimensional scaling (MDS), in order to examine gradation trends in space and/or time without defining hierarchical groups. MDS is an ordination technique which attempts to place samples on a 'map' in two (or more) dimensions, in a manner that the rank order of the distances between samples on the map reflects the rank order of the matching relative similarities taken from the similarity matrix, i.e. samples that are closest together have similar community composition and vice versa (Clarke and Warwick, 1998; Clarke and Gorley, 2006). The suitability of the representation in two dimensions, rather than more than two, is expressed by a "stress (or distortion) coefficient", similar to R^2 in regression analyses, which reflects the extent to which the two sets of ranks do not agree (Clarke and Gorley, 2006). As a general rule, a stress coefficient of <0.1 indicates a good ordination with no possible misleading interpretation, and reveals a good representation of the underlying data in two dimensions. Excellent representations are given by stress values <0.05 and perfect representations by stress <0.01 (Clarke and Warwick, 2001).

The results of the cluster and MDS analysis are represented in the form of dendograms and as plots in two dimensions, respectively, with the most similar abundance and biomass compositions of discarded species closest together. When the two methods are in agreement, it can be assumed that the discontinuities between samples (métiers/season combinations) are realistic (Field *et al.*, 1982; Clarke and Green, 1988).

The variable tow mean depth was superimposed on the MDS configurations, with increasing diameters corresponding to increasing depth values (Clarke and Warwick, 1998, 2001). This approach is useful for providing knowledge about differences in the environmental variables between clusters and for identifying gradients in the ordination (Erzini *et al.*, 2002).

One-way analyses of similarity (ANOSIM), using permutation methods based on corresponding similarities between samples in the abundance and biomass similarity matrices, were performed to test whether the abundance (and biomass) of the discarded species differed significantly between seasons in each métier and between métiers. The contribution of individual discarded species, to the Bray-Curtis similarity (average dissimilarity between métiers and average dissimilarities by season within métiers), was analysed using similarity percentage (SIMPER) analysis (Clarke, 1993; Carr, 1997; Clarke and Warwick, 2001).

To check for differences in dominance patterns in both abundance and biomass of the discarded species, *k*-dominance curves were made by plotting the percentage cumulative abundance (and biomass) against log species ranks (k). In these kinds of curves, species are ranked from the most to the least common, and the logarithmic scale of the k species rank was used with the purpose to straighten and to separate the curves, making it easier to interpret and visualize the distribution of the most dominant species (Lambshead *et al.*, 1983; Platt *et al.*, 1984; Clarke, 1990; Carr, 1997). Dominance is inversely proportional to diversity and one group is considered more diverse than another if the *k*-dominance of one is less than or equal to the other for all values of k. Nevertheless, if the *k*-dominance curves of a set of groups intersect or cross with each other, then these groups cannot be compared in terms of intrinsic diversity (Lambshead *et al.*, 1983).

Results

Sampling effort

A total of 52 trips were made, of which 67.3% were on board crustacean trawlers and 32.7% on fish trawlers, corresponding to 890 hours at sea and 550 trawling hours. Fishing vessels characteristics and trip duration vary according to métier. Crustacean trawlers have the longest trips (70 h mean duration) and fish trawlers have the shortest trip duration (mean of 43 h). The former have an average tow duration of about 6 h while fish trawlers usually tow for about 1.5 h. Sampling effort was based on 163 fishing operations of which 72 tows were carried out by crustacean trawlers (2.06 tows/trip, s.d.=0.34) and 92 tows by fish trawlers (5.35 tows/trip, s.d.=0.93) (Tab 3.1) (more details can be found in Chapter 2, Results section).

The trawl trajectories, by tow and season, are represented in Annex I, for crustacean trawls and in Annex II, for fish trawls.

Catch composition and discard estimates

During the sampling period, both métiers yielded a total catch of 70.269 tons, of which 56.5% (39.705 t) were discarded. Crustacean and fish trawls contributed respectively with 21.3% and 78.7% to the total catch, 26.3% and 73.7% to the retained catch, and 17.5% and 82.5% to the discarded catch (Table 3.1).

Mean total, retained and discarded catches per tow were considerably higher in fish trawls (608 kg, 248 kg and 360 kg, respectively) than in crustacean trawls (208 kg, 112 kg and 97 kg, respectively) (Table 3.1). Fish trawlers caught between 154 and 1260 kg/h (447 kg/h average) and retained between 79 and 360 kg/h (189 kg/h average) of fish per tow; while crustacean trawls caught (20-74 kg/h, 40 kg/h avg.) and retained (10-30 kg/h, 20 kg/h avg.) less. Fish trawls discarded between 51 kg/h (spring 2000) and 900 kg/h (winter 1998), at a mean rate of about 258 kg/h per tow. Crustacean trawls discarded at a much lower mean rate (19 kg/h), varying from almost 9 kg/h (autumn 2000) to 55 kg/h (autumn 1999) per tow. No consistent seasonal patterns in the total, retained and discarded fractions were evident in each *métier*, with rates varying widely throughout the seasons. However, in some situations, the average discard rate was higher than the retained rate: in autumn 1999 (54.5 kg/h *vs.* 16.3 kg/h), mostly due to high amounts of cartilaginous fishes (*Chimaera monstrosa*, 174.7 kg; *Torpedo nobiliana*, 119.2 kg), in summer 2000 (11.3 kg/h *vs.* 10.4 kg/h) caused by greatest amounts of *Micromesistius poutassou* (243.9 kg) and in winter 2000 (43.8 kg/h *vs.* 29.9 kg/h) owing to high quantities of *M. poutassou* (439.4 kg), *Capros aper* (320.8 kg), and *Macroramphosus* spp. species (246.7 kg), in crustacean trawls; and in winter 1998 (900.2 kg/h *vs.* 360.2 kg/h) in fish trawls, due to highest amounts of *Scomber colias* (4627.0 kg), *Scyliorhinus canicula* (4083.1 kg), *M. scolopax* (1544.1 kg) and *Boops boops* (1401.4 kg) (Figure 3.2).

Table 3.1 – Estimates of quantities (kg) and rates (kg/h) of the total, retained and discarded catches and the discard proportion (D_P) for the number of trips and fishing operations (tows) for the crustacean trawl (CT) and fish trawl (FT).

Season	Métier	Trips (n)	Tow (n)	Tow duration (mean h)	Total catch (Kg)					Total catch rate (kg/h)				
					Total	by trip	s.d.	by tow	s.d.	Total	by trip	s.d.	by tow	s.d.
Winter 1998	CT	4	8	7.5	2160	540.0	216.5	270.0	102.0	36.1	42.8	18.1	42.0	28.2
	FT	3	17	1.3	27957	9319.0	5613.4	1644.5	2125.0	1238.9	1486.1	1271.4	1260.4	1540.2
Spring 1999	CT	4	9	6.7	1755	438.8	44.8	195.0	72.5	28.9	28.8	4.4	28.1	5.8
	FT[1]	-	-	-	-	-	-	-	-	-	-	-	-	-
Summer 1999	CT	5	10	6.8	2330	466.0	129.0	233.0	75.6	34.2	34.0	9.2	34.0	9.8
	FT	3	18	1.6	8720	2906.7	344.3	484.4	435.2	305.4	320.5	76.2	312.1	277.7
Autumn 1999	CT	3	5	4.7	1322	440.7	460.8	264.4	203.5	55.8	62.2	72.4	70.9	68.4
	FT	3	19	1.2	8065	2688.3	766.4	424.5	341.8	356.5	370.6	151.4	369.1	309.9
Winter 1999	CT	3	6	5.8	1320	440.0	115.3	220.0	92.7	37.6	41.2	13.3	41.2	24.0
	FT	2	10	1.6	3540	1770.0	410.1	354.0	191.4	221.1	219.2	16.2	221.5	85.8
Spring 2000	CT	4	7	6.9	1485	371.3	159.6	212.1	109.7	30.8	33.7	15.0	31.7	16.2
	FT	3	12	1.4	2970	990.0	523.7	247.5	99.0	171.0	165.6	43.9	173.4	74.7
Summer 2000	CT	5	9	5.4	1115	223.0	126.0	123.9	70.7	22.8	21.5	6.6	21.7	8.8
	FT	3	15	1.7	4030	1343.3	1099.7	268.7	331.9	158.0	181.4	181.1	181.4	224.8
Autumn 2000	CT	3	8	4.2	700	233.3	87.4	87.5	70.5	21.0	21.0	8.0	19.9	12.1
	FT[2]	-	-	-	-	-	-	-	-	-	-	-	-	-
Winter 2000	CT	4	10	3.8	2800	700.0	261.4	280.0	58.7	73.5	77.3	14.3	73.7	15.3
	FT[2]	-	-	-	-	-	-	-	-	-	-	-	-	-
1999 - 2001	CT	35	72	5.8	14987	428.2	224.7	208.2	108.8	36.0	40.3	18.7	39.5	28.6
	FT	17	91	1.5	55282	3251.9	3622.6	607.5	1068.0	416.8	457.2	510.4	451.4	788.7

s.d.-standard deviation; [1] no trips due to fish trawlers strike; [2] no trips due to bad weather conditions

Table 3.1 (cont.) – Estimates of quantities (kg) and rates (kg/h) of the total, retained and discarded catches and the discard proportion (D_P) for the number of trips and fishing operations (tows) for the crustacean trawl (CT) and fish trawl (FT).

Season	Métier	Trips (n)	Tow (n)	Tow duration (mean h)	Retained catch (kg)					Retained catch rate (kg/h)				
					Total	by trip	s.d.	by tow	s.d.	Total	by trip	s.d.	by tow	s.d.
Winter 1998	CT	4	8	7.5	1368	342.0	206.2	171.0	118.4	22.9	28.1	17.1	29.0	29.8
	FT	3	17	1.3	7298	2432.7	701.4	429.3	327.7	323.4	350.7	57.3	360.2	252.4
Spring 1999	CT	4	9	6.7	1166	291.4	38.5	129.5	51.1	19.2	18.8	2.7	18.6	4.7
	FT[1]	-	-	-	-	-	-	-	-	-	-	-	-	-
Summer 1999	CT	5	10	6.8	1332	266.4	75.5	133.2	40.7	19.5	20.4	5.2	20.4	5.7
	FT	3	18	1.6	4327	1442.3	529.9	240.4	136.3	151.6	162.9	23.8	162.9	99.1
Autumn 1999	CT	3	5	4.7	370	123.3	14.2	74.0	21.4	15.6	15.9	3.4	16.3	4.0
	FT	3	19	1.2	4769	1589.7	608.6	251.0	202.0	210.8	210.5	63.3	215.9	172.9
Winter 1999	CT	3	6	5.8	811	270.3	119.8	135.2	71.8	23.1	24.8	9.7	24.8	14.5
	FT	2	10	1.6	2059	1029.5	130.8	205.9	81.4	128.6	139.9	29.6	135.7	66.7
Spring 2000	CT	4	7	6.9	940	234.9	74.6	134.2	78.8	19.5	22.6	12.7	20.1	11.9
	FT	3	12	1.4	2109	703.0	290.8	175.8	89.0	121.4	121.6	29.0	122.1	64.1
Summer 2000	CT	5	9	5.4	517	103.4	30.0	57.4	26.3	10.6	10.7	1.5	10.4	2.6
	FT	3	15	1.7	1973	657.7	346.1	131.5	88.6	77.3	93.3	71.1	93.3	89.3
Autumn 2000	CT	3	8	4.2	385	128.3	30.1	48.1	30.8	11.5	11.6	2.9	11.4	6.3
	FT[2]	-	-	-	-	-	-	-	-	-	-	-	-	-
Winter 2000	CT	4	10	3.8	1141	285.3	108.1	114.1	29.2	29.9	31.8	7.6	29.9	7.1
	FT[2]	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	CT	35	72	5.8	8029	229.4	118.9	111.5	68.2	19.4	20.5	7.1	20.3	13.4
	FT	17	91	1.5	22535	1325.6	763.0	247.6	207.3	169.9	179.8	92.6	191.0	172.1

s.d.-standard deviation; [1] no trips due to fish trawlers strike; [2] no trips due to bad weather conditions

Table 3.1 (cont.) – Estimates of quantities (kg) and rates (kg/h) of the total, retained and discarded catches and the discard proportion (D_P) for the number of trips and fishing operations (tows) for the crustacean trawl (CT) and fish trawl (FT).

Season	Métier	Trips (n)	Tow (n)	Tow duration (mean h)	Discard (kg)					Discard rate (kg/h)					D_P
					Total	by trip	s.d.	by tow	s.d.	Total	by trip	s.d.	by tow	s.d.	
Winter 1998	CT	4	8	7.5	792	198.0	12.0	99.0	56.5	13.3	14.7	5.9	13.0	5.7	0.37
	FT	3	17	1.3	20659	6886.3	6122.2	1215.2	2082.9	915.5	1135.4	1271.7	900.2	1530.8	0.74
Spring 1999	CT	4	9	6.7	590	147.4	49.8	65.5	34.1	9.7	10.0	4.1	9.5	4.7	0.34
	FT[1]	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Summer 1999	CT	5	10	6.8	998	199.6	85.8	99.8	67.6	14.6	13.6	6.1	13.6	9.3	0.43
	FT	3	18	1.6	4393	1464.3	782.4	244.1	396.1	153.9	157.6	83.4	149.2	232.8	0.50
Autumn 1999	CT	3	5	4.7	952	317.3	452.8	190.4	209.7	40.2	46.4	69.0	54.5	65.4	0.72
	FT	3	19	1.2	3296	1098.7	497.1	173.5	256.8	145.7	160.0	106.0	153.2	228.5	0.41
Winter 1999	CT	3	6	5.8	509	169.7	58.6	84.8	40.0	14.5	16.4	8.4	16.4	12.0	0.39
	FT	2	10	1.6	1481	740.5	540.9	148.1	197.9	92.5	79.3	45.7	85.8	89.7	0.42
Spring 2000	CT	4	7	6.9	546	136.4	124.7	77.9	65.8	11.3	11.2	8.4	11.5	9.4	0.37
	FT	3	12	1.4	861	287.0	239.1	71.8	69.7	49.6	44.0	25.9	51.3	55.7	0.29
Summer 2000	CT	5	9	5.4	598	119.6	102.9	66.4	53.9	12.2	10.8	7.0	11.3	7.9	0.54
	FT	3	15	1.7	2057	685.7	810.2	137.1	269.3	80.6	88.1	112.1	88.1	174.0	0.51
Autumn 2000	CT	3	8	4.2	315	105.0	65.0	39.4	42.2	9.4	9.4	5.9	8.5	6.9	0.45
	FT[2]	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Winter 2000	CT	4	10	3.8	1659	414.8	165.6	165.9	52.5	43.5	45.5	8.4	43.8	13.8	0.59
	FT[2]	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	CT	35	72	5.8	6958	198.8	167.1	96.6	82.4	16.6	19.8	15.0	19.2	23.1	0.46
	FT	17	91	1.5	32747	1926.4	3263.4	359.9	1001.2	246.9	277.4	422.8	260.4	734.5	0.59

s.d.-standard deviation; [1] no trips due to fish trawlers strike; [2] no trips due to bad weather conditions

Average proportions of the catch discarded during the sampling period, were 0.46 in crustacean trawls and 0.59 in fish trawls. There is some seasonal variation in the average discards proportions in each métier, with most of the proportions between 0.3 and 0.7 (0.34-0.72, in crustacean trawls; 0.29-0.74 in fish trawls), but not in a consistent way (Figure 3.2). Linear regression showed a weak positive non-statistical significant increase of D_R with total catch (r=0.31 and r=0.57 in crustacean and fish trawl métiers, respectively).

The discard proportions (as percentages), by tow and season, are represented in Annex I, for crustacean trawls and in Annex II, for fish trawls.

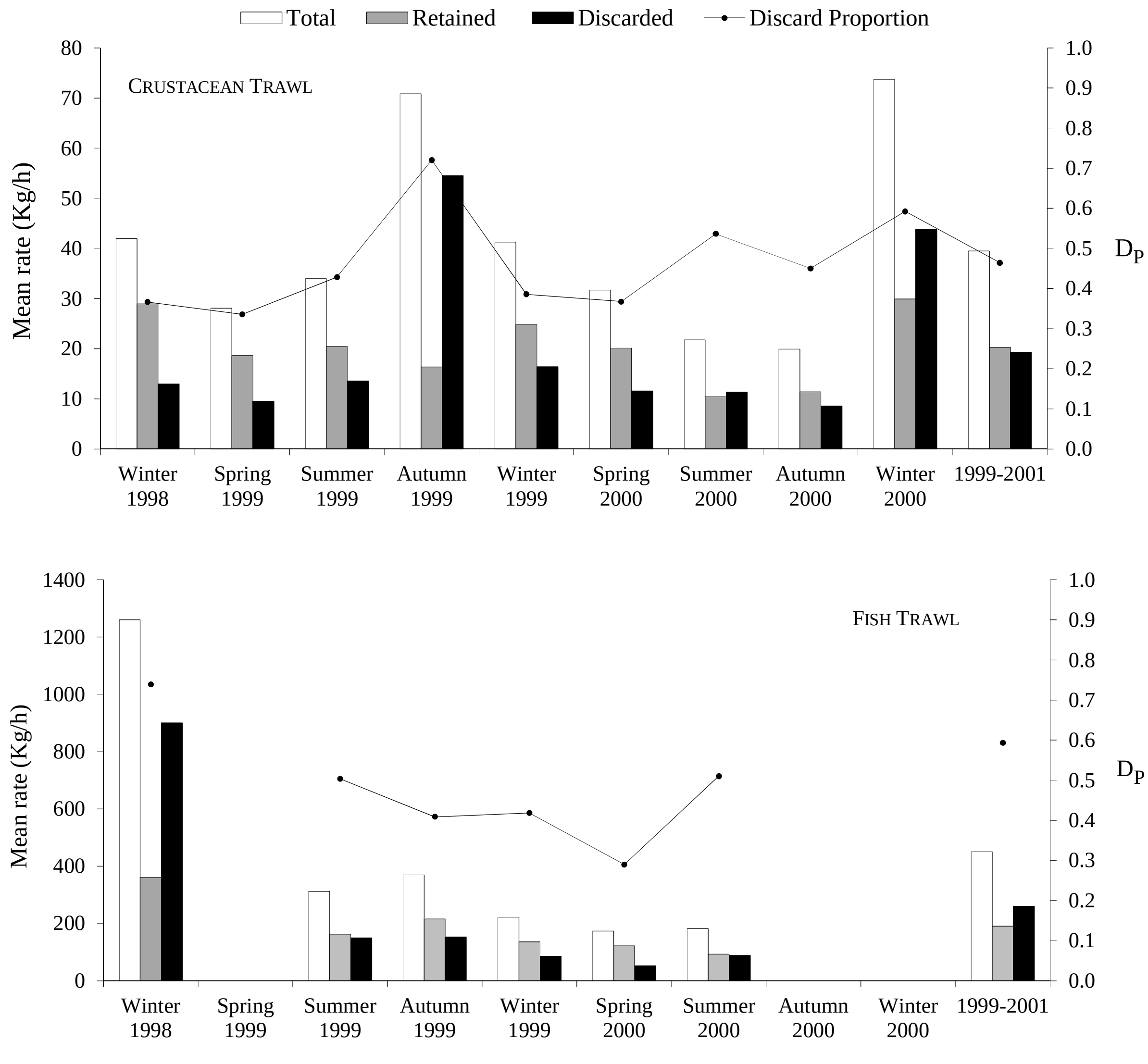


Figure 3.2 – Mean rate (kg/h) per tow of each fraction of the catch (total, retained and discarded) and discard proportions (D_P) by métier.

Species composition

Global analysis

During the present study, a total of 255species[3] from 16 different taxonomic groups were caught by both métiers, of which 53.7% were fish, 43.9% were invertebrates and 2.4% were algae. Of these, 31.4% had commercial value (11 target and 69 bycatch species), with the remaining majority (68.6%) consisting of non-commercial species. Overall, 4.3% of the species (8 bony fish and 3 crustacean species) were occasionally discarded, 27.1% (54 fish and 15 invertebrate species) were frequently discarded species and 68.6% (75 fish, 94 invertebrate and 6 algae species) were systematically discarded (Table 3.2). Of these, 4.3% of the species (8 bony fish and 3 crustacean species) were occasionally discarded, 27.1% (54 fish and 15 invertebrate species) were frequently discarded species and 68.6% (75 fish, 94 invertebrate and 6 algae species) were systematically discarded (Table 3.2). Of all the species, 30.6% had commercial value (11 target and 67 bycatch species), with the remaining majority (69.4%) consisting of non-commercial species. The faunistic list of all species identified and the frequency of discarding, by métier, is given in Annex III and the systematic classification of all species captured by crustacean and fish trawl métiers is presented in Annex IV.

The crustacean trawl was the métier with the greatest diversity (80.8%) of the total species (113 vertebrates, 88 invertebrates and 5 algae), of which 48.1% (65 vertebrate, 32 invertebrate and 2 algae species) were exclusively caught by this métier (Table 3.2and Annex III). Fish trawls captured a lower number of species (61.2%; 72 vertebrates, 80 invertebrates and 4 algae), of which 31.4% (24 vertebrate, 24 invertebrate and 1 algae species) were exclusively caught by this métier (Table 3.2and Annex III).

[3] At the time of this study, *Macroramphosus scolopax* and *M. gracilis* were considered to be two distinct species but, recently, a genetic study in Portuguese waters came to support the evidence of *M. scolopax* as the single *Macroramphosus* species (Robalo *et al.*, 2009). As this was acknowledged only after all statistical analyses had been completed and results discussed, there was no time to perform new analyses, so the two *Macroramphosus* species had to be maintained in this study.

Table 3.2 - Number of species caught in crustacean and fish trawls according to frequency of discarding (1-occasional, 2-frequent, 3-systematic). The number of species coincident in both métiers is in parentheses.

TAXONOMIC	CRUSTACEAN TRAWL				FISH TRAWL				BOTH MÉTIERS			
GROUP	1	2	3	Total	1	2	3	Total	1	2	3	Total
VERTEBRATES												
Chondrichthyes	0	5	13	18	0	3	4	7	0	6 (2)	15 (2)	21 (4)
Osteichthyes	6	39	50	95	6	36	23	65	8 (4)	48 (27)	60 (13)	116 (44)
INVERTEBRATES												
Crustacea	3	2	28	33	2	2	14	18	3 (2)	2 (2)	31 (11)	36 (15)
Cephalopoda	0	9	7	16	0	12	6	18	0	13 (8)	9 (4)	22 (12)
Bivalvia	0	0	12	12	0	0	10	10	0	0	15 (7)	15 (7)
Gastropoda	0	0	11	11	0	0	15	15	0	0	19 (7)	19 (7)
Anthozoa	0	0	4	4	0	0	4	4	0	0	4 (4)	4 (4)
Polychaeta	0	0	1	1	0	0	1	1	0	0	1 (1)	1 (1)
Ophiuroidea	0	0	2	2	0	0	3	3	0	0	3 (2)	3 (2)
Crinoidea	0	0	1	1	0	0	1	1	0	0	1 (1)	1 (1)
Holothuroidea	0	0	1	1	0	0	2	2	0	0	2 (1)	2 (1)
Asteroidea	0	0	2	2	0	0	3	3	0	0	3 (2)	3 (2)
Echinoidea	0	0	5	5	0	0	5	5	0	0	6 (4)	6 (4)
ALGAE												
Codiaceae	0	0	1	1	0	0	1	1	0	0	1 (1)	1 (1)
Dictyotaceae	0	0	1	1	0	0	0	0	0	0	1 (0)	1 (0)
Sargassaceae	0	0	3	3	0	0	3	3	0	0	4 (2)	4 (2)
TOTAL	9	55	142	206	8	53	95	156	11 (6)	69 (37)	175 (64)	255 (107)

Of all taxa, bony fishes (Class Osteichthyes) stand out as the dominant group of species caught by both métiers (45.5%), representing 46.1% in crustacean trawls and 41.7% in fish trawls (Figure 3.3). In crustacean trawls, the majority of bony fish species were regularly discarded (52.6%), followed by frequently discarded species (41.1%). Occasionally discarded species represent only 6.3% of all discarded bony fish species. In fish trawls, more bony fish species (55.4%) were frequently discarded than systematically discarded (35.4%) and 9.2% of the discarded species were occasional (Figure 3.4).

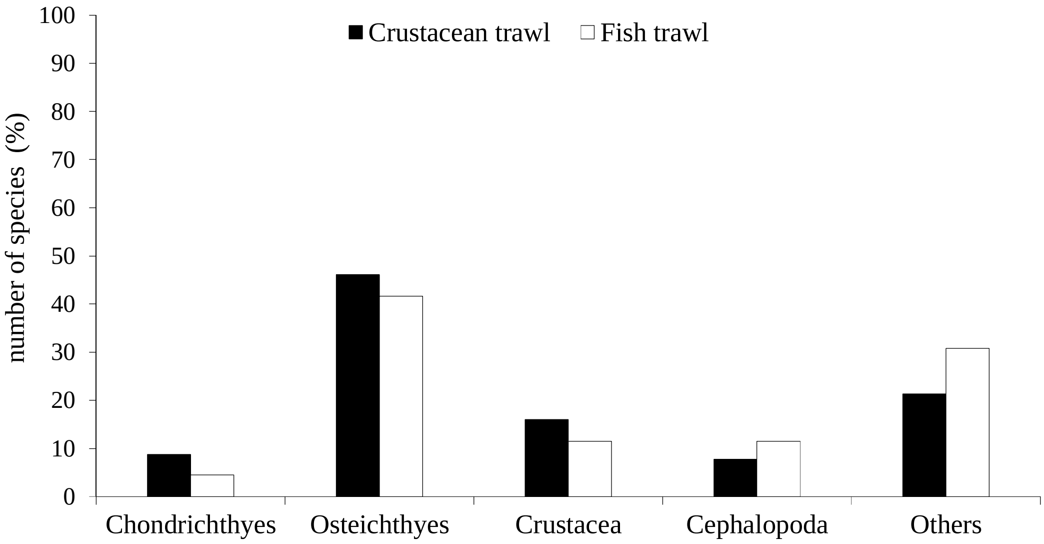


Figure 3.3 – Number of species (%), per taxa, discarded by crustacean and fish trawls.

Of the four most important groups, crustaceans (Class Crustacea) represent the next most diverse group in both métiers (14.1%), with more species caught by crustacean trawls (16%) than by fish trawls (11.5%) (Figure 3.3). In both métiers, the highest proportion of crustacean species is systematically discarded (84.8% in crustacean trawls and 77.8% in fish trawls). In crustacean trawls, the frequency of discarding is occasional for 9.1% of the crustacean species and frequent for 6.1%. In fish trawls crustacean species are occasionally and frequently discarded in equal proportions (11.1%) (Figure 3.4).

Cephalopods were the next most captured group of species, representing 8.6% of all species caught by both métiers, although in higher proportions in fish trawls (11.5%) than in crustacean trawls (7.8%) (Figure 3.3). In both métiers, more cephalopod species were frequently discarded followed by systematically discarded species, also in higher percentages in fish trawls (66.7% and 33.3%, respectively) compared to crustacean trawls (56.3% and 43.8%, respectively) (Figure 3.4).

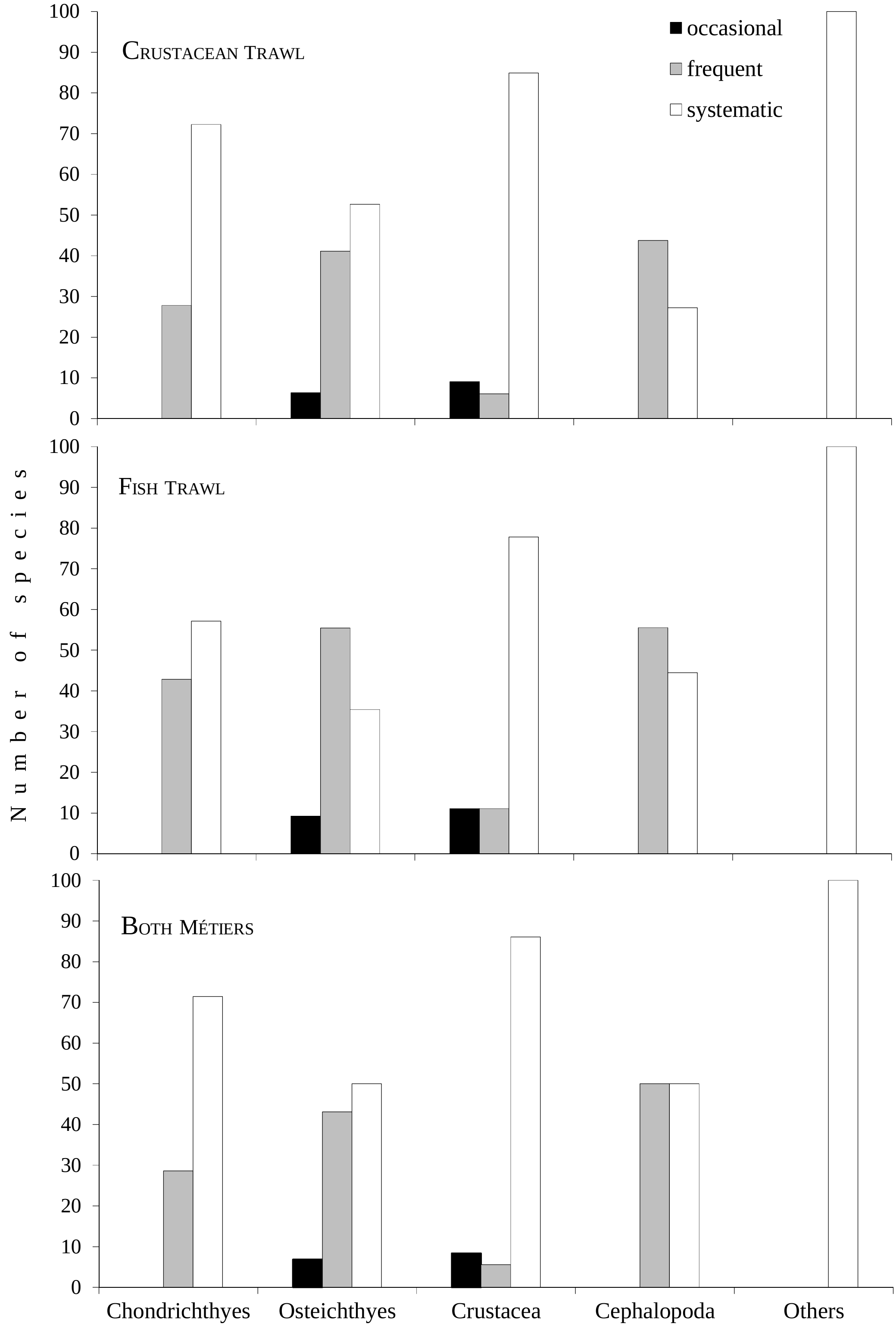


Figure 3.4 – Number of species (%), per taxa, discarded by crustacean and fish trawls, according to their frequency of discarding (occasional, frequent, systematic).

For both métiers combined, cartilaginous fish species accounted for 8.2% of the catch, 8.7% of crustacean trawl catches and 4.5% of fish trawl catches (Figure 3.3). In both métiers, the majority of the cartilaginous species were systematically discarded, 72.2% by crustacean trawls and 57.1% by fish trawls. Less than 28% and almost 43% of cartilaginous fish species were occasionally discarded by crustacean and fish trawls, respectively (Figure 3.4).

When grouped together in the “others” category, the remaining invertebrate and algae species were always discarded and contributed 23.5% to the biodiversity captured by both métiers, 21.4% in crustacean trawl and 30.8% in fish trawl (Figure 3.3). Bivalves (Class Bivalvia) and gastropods (Class Gastropoda) stand out in the “others” category with the greatest numbers of species, representing 7.5% and 5.9% of the biodiversity caught by both métiers, respectively. In crustacean trawls, bivalves and gastropods account for similar percentages of the discarded biodiversity, 5.8% and 5.3% respectively. In fish trawls, gastropod diversity (9.6%) was greater than that of bivalves (6.4%). In both métiers, each of the remaining invertebrate taxa represents between 0.9% and 2.4% of the total species diversity.

Species occurrence

The most frequently caught species by crustacean trawls (>40% of tows where the species were present) were the bony fishes *Micromesistius poutassou* (91.7%), *Conger conger* (70.8%) and *Nezumia sclerorhynchus* (66.7%), followed by the cartilaginous fish *Galeus melastomus* (63.9%). *Polybius henslowi* and *Illex coindetii* were the crustacean and cephalopod species which occurred most frequently, each in 43.1% of the tows carried out by this métier. The “other” invertebrate group is represented mostly by the anthozoan *Actinauge richardi*, which had a frequency of occurrence of slightly over 51% (Figure 3.5). Among target crustaceans, *Parapenaeus longirostris* was the species most frequently caught occurring in 30.6% of the tows. *Aristeus antennatus* and *Nephrops norvegicus* had lower frequencies of occurrence, (16.7% and 11.1%, respectively).

In fish trawls, the most frequently caught Osteichthyes were *Serranus hepatus* (in 81.5% of the tows), *Boops boops* (78.3%) and the target species *Merluccius merluccius* (73.9%), followed by *Scorpaena notata* (67.4%) and *Capros aper* (60.9%). *Alloteuthis subulata* (48.9%), *Eledone moschata* (42.4%) and *Sepia elegans* (40.2%) were the most caught cephalopod species of this métier. The bivalve *Venus nux* and the ophiurid *Ophiura ophiura* were, among the other invertebrate species, those which occurred more frequently in the catches (41.3%) (Figure 3.5). *Scyliorhinus canicula* was the most captured cartilaginous fish species (35.9%) and, with the exception of hake, the fish trawl target species occurred in lower percentages (*Pagellus acarne*, 20.7%; *Trachurus picturatus*, 15.2%; *Trachurus* *mediterraneus*, 9.7%; *Diplodus vulgaris*, 7.6%; *Trachurus trachurus*, 3.7%; *Pagellus bogaraveo*, 1.1%).

The species occurrence, in number and in percentage of trips and tows, by métier, along with the depth range is shown in Annex V.

Figure 3.5 – Most frequent (>40% of tows) species in crustacean and fish trawl métiers. Each bar shows the percentage of fishing operations where the species was present.

Abundance and biomass of discarded species

Abundance and biomass multivariate analysis of the species discarded by crustacean and fish trawls were based on 93 species (15 cartilaginous fishes, 63 bony fishes and 15 cephalopods) (Annex III).

Between métiers

Analysis by tow

The classification of the abundance matrix of the discards by species (two métiers and four seasons) indicated that, at the 13% similarity level, the 163 tow/season combinations falls into two main groups or clusters, and one isolated group stands out from the others. One main group consisted of the crustacean trawl métier and the other one corresponds to a mix of both (Figure 3.6). The isolated group corresponds to abundance values discarded in winter 1999 by fish trawl, where a high number of *Macroramphosus* spp. was caught.

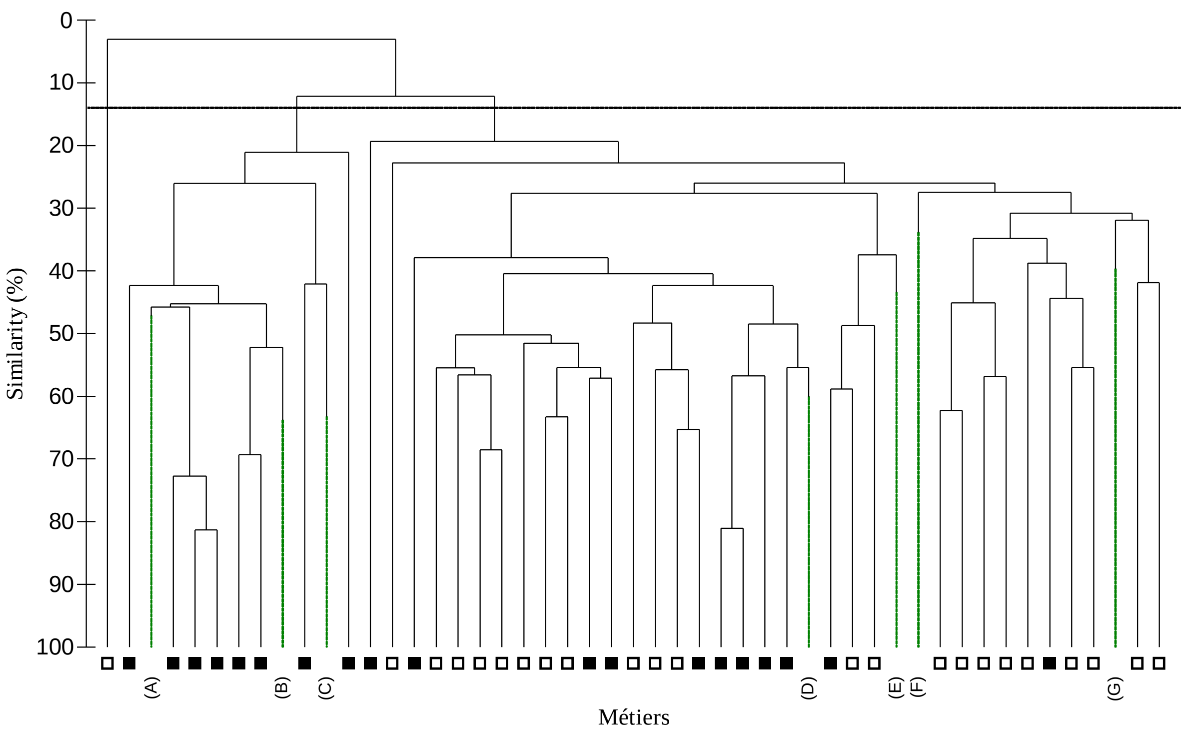


Figure 3.6 – Dendogram obtained by cluster analysis of the discarded species abundance for the crustacean trawl (■) and fish trawl (□) métiers (163 tows). The 3 groups defined at similarity level of 13% are indicated (dashed line). (■: A,B,C,D; □: E,F,G).

The classification of the biomass matrix of the discards by species (two métiers and four seasons) also indicated, at the same 13% similarity level, the two main groups with an overall correspondence to crustacean and fish trawls métiers, with two more distinct clusters (Figure

3.7). One of these isolated groups reflects the existence of a greater similarity in biomass values discarded by crustacean trawl in winter 2000 (high amounts of *Macroramphosus* spp. and *M. poutassou*) and by fish trawl in summer 2000 (high amounts of *M. poutassou*), and the remaining isolated cluster corresponds to biomass values discarded in summer 2000 by crustacean trawl (high amounts of *Macroramphosus* spp. and *C. aper*).

The results of the MDS ordination of both abundance (Figure 3.8) and biomass (Figure 3.9) matrices are in full agreement with those of cluster analyses. However, in both cases, the resulting stress values for the MDS plots were 0.16, indicating a useful two dimensional representation. As can be seen, the groups representing the trawling métiers are significantly different, both in terms of abundance (ANOSIM test, *R*= 0.774, *p*=0.1) and in biomass (ANOSIM test, *R*= 0.779, *p*=0.1).

The superimposition of depth onto abundance (Figure 3.10) and biomass (Figure 3.11) MDS plots shows a clear gradient of increasing depth, from the fish trawl cluster to the crustacean trawl cluster, in line with known activity of both métiers. This evidences that depth related species ecology and distribution strongly influence the observed grouping patterns.

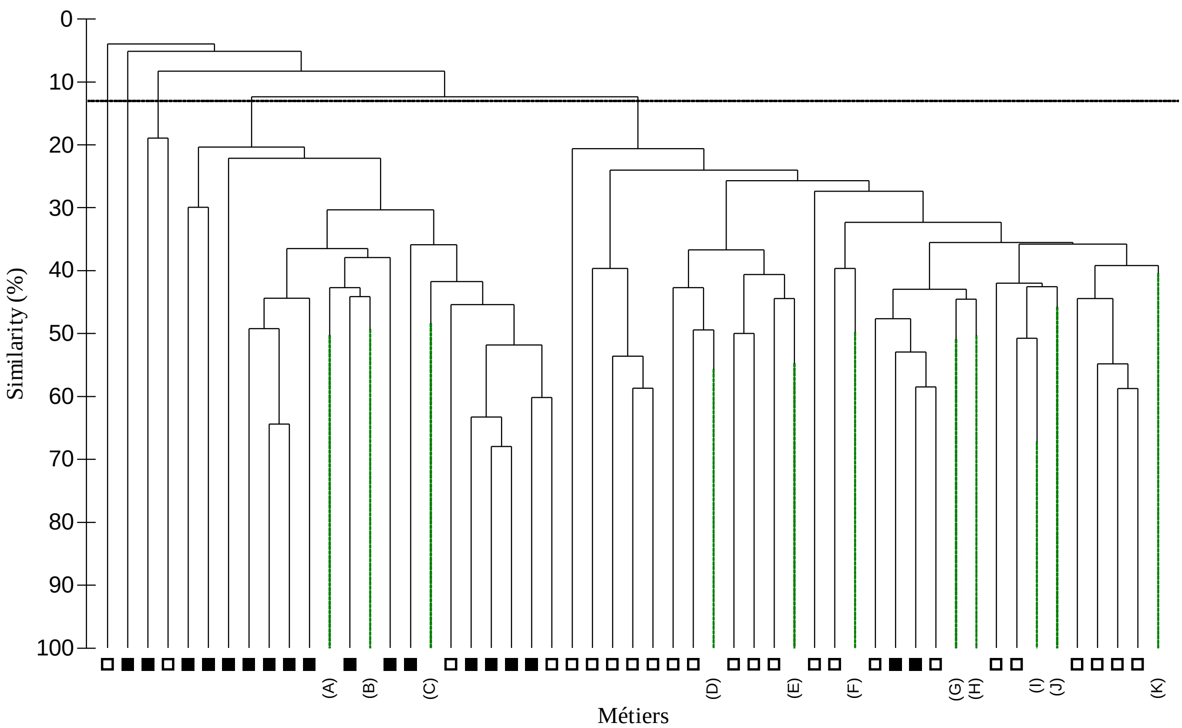


Figure 3.7 – Dendogram obtained by cluster analysis of the discarded species biomass for the crustacean trawl (■) and fish trawl (□) métiers (163 tows/métier combinations). The 5 groups defined at similarity level of 13% are indicated (dashed line). (■: A,B,C; □: D to K).

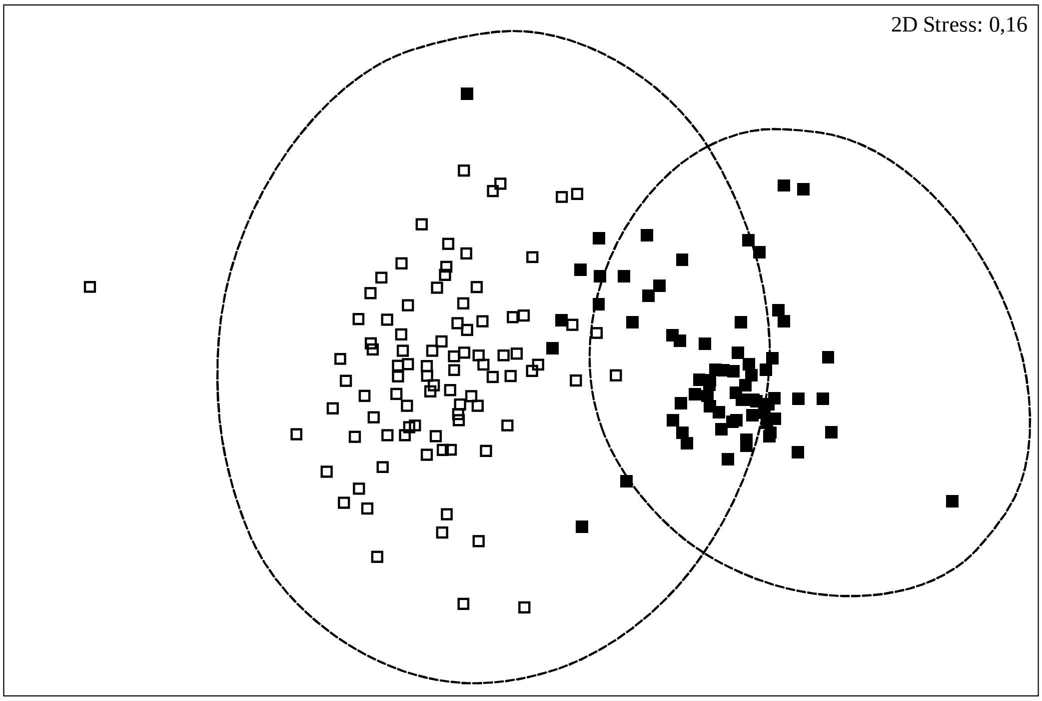


Figure 3.8 – MDS plot of the discarded species abundance for the crustacean trawl (■) and fish trawl (□) métiers (163 tows/métier combinations) with superimposed clusters at similarity levels of 13% (dashed line).

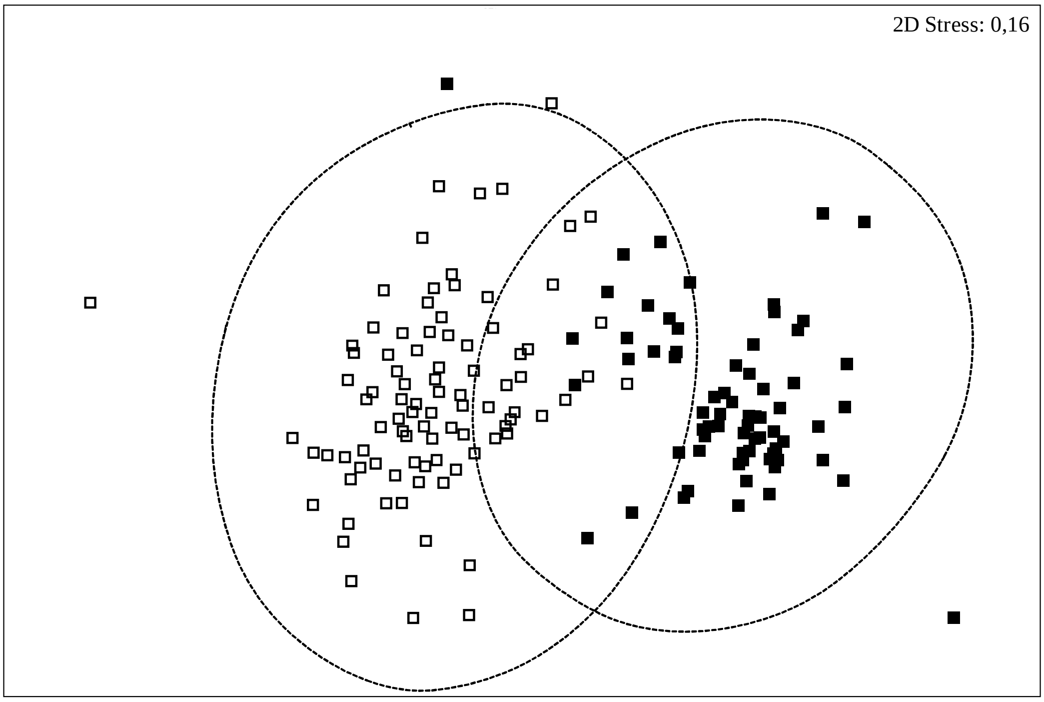


Figure 3.9 – MDS plot of the discarded species biomass for the crustacean trawl (■) and fish trawl (□) métiers (163 tows/métier combinations) with superimposed clusters at similarity levels of 13% (dashed line).

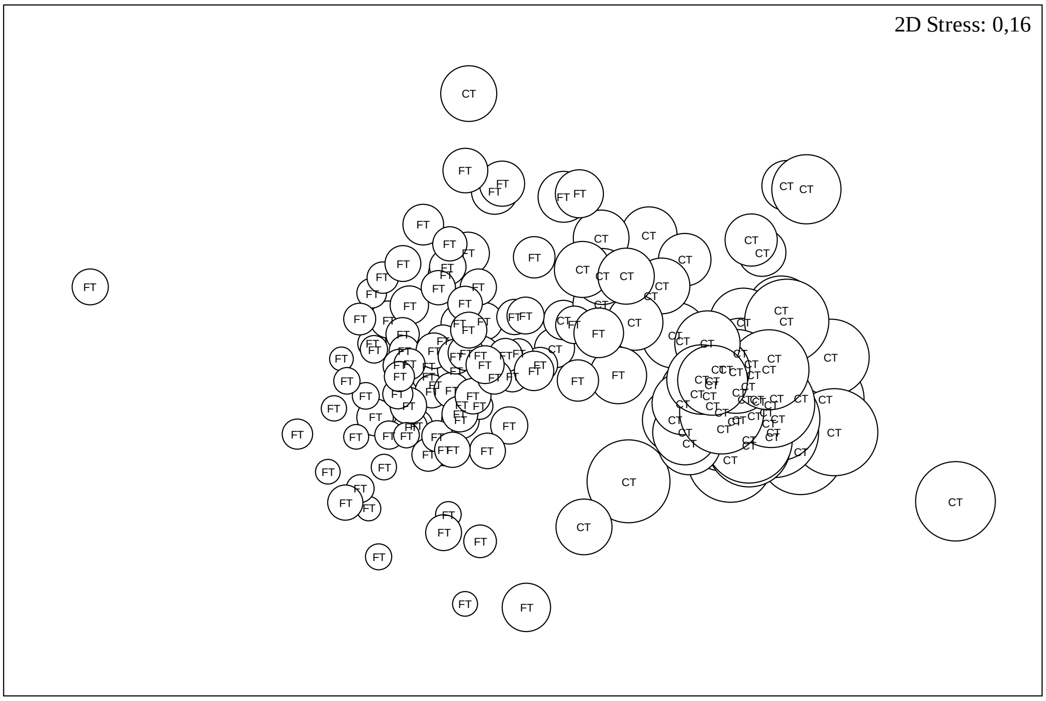


Figure 3.10 – MDS plot of the discarded species abundance for the crustacean trawl (CT) and fish trawl (FT) métiers (163 tows/métier combinations) with superimposed mean depth values (continuous line). The area of the circles is proportional to the average depth of the tows.

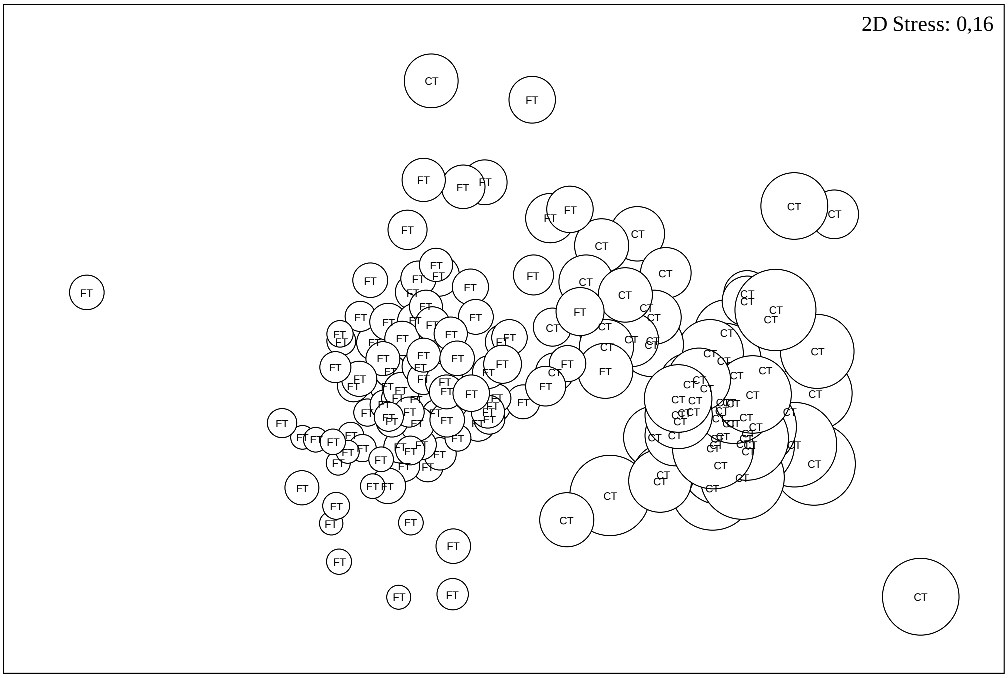


Figure 3.11 – MDS plot of the discarded species biomass for the crustacean trawl (CT) and fish trawl (FT) métiers (163 tows/métier combinations) with superimposed mean depth values (continuous line). The area of the circles is proportional to the average depth of the tows.

The average contribution of the discarded species to the dissimilarity between métiers, given by SIMPER analysis, was quite similar both in abundance (87.49%) and in biomass (87.90%). In terms of abundance, *Micromesistius poutassou* (5.44%), *Macroramphosus scolopax* (4.92%) and *Serranus hepatus* (4.39%) were the species most responsible for the dissimilarity between métiers, accounting for 14.75% of the total discarded abundance (Table 3.3). Concerning biomass, *M. poutassou* (5.75%), *Boops boops* (4.14%) and *S. hepatus* (3.79%), accounting for 13.68% of the total biomass discard, were the most influencing species to the dissimilarity between métiers (Table 3.4).

The average contribution of the discarded species to the similarity of the discarded species in terms of abundance and biomass between métiers is given in Annex VI-A and MDS plots of the main species which contributed most to the dissimilarities between crustacean and fish trawl metiers are given in Annex VI-B.

Table 3.3–SIMPER results for the abundance of the discarded species between crustacean (CT) and fish (FT) trawl métiers. Parameters include: average contribution to abundance (Av. Abund) and to dissimilarity (Av. Diss), dissimilarity/standard deviation (Diss/SD), contribution of the dominant species to the dissimilarity % (Contrib%) and cumulative dissimilarity % (Cum.%).

Species	CT Av.Abund	FT Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
CRUSTACEAN and FISH TRAWLS:			87.49			
Micromesistius poutassou	3.67	1.35	4.76	1.33	**5.44**	5.44
Macroramphosus scolopax	0.86	3.51	4.31	1.01	**4.92**	10.37
Serranus hepatus	0.22	3.13	3.84	1.71	**4.39**	14.75
Nezumia sclerorhynchus	2.32	0.00	3.30	1.12	3.77	18.53
Boops boops	0.03	2.53	3.27	1.45	3.73	22.26
Galeus melastomus	2.20	0.00	3.15	1.06	3.60	25.86
Capros aper	1.45	2.28	3.11	1.08	3.56	29.42
Merluccius merluccius	1.10	2.63	3.09	1.35	3.53	32.95
Macroramphosus gracilis	0.59	1.82	2.69	0.70	3.08	36.03
Sardina pilchardus	0.03	1.85	2.59	0.90	2.96	38.99
Scorpaena notata	0.09	1.90	2.57	1.23	2.94	41.93
Scomber colias	0.01	1.82	2.27	0.76	2.60	44.53
Etmopterus spinax	1.55	0.00	2.18	1.01	2.49	47.02
Conger conger	1.70	0.85	2.16	1.21	2.46	49.48
Citharus linguatula	0.16	1.71	2.06	1.12	2.36	51.84
Alloteuthis subulata	0.28	1.58	2.06	0.89	2.36	54.20
Hoplostethus m. mediterraneus	1.43	0.00	2.05	0.85	2.35	56.55
Gadiculus a. argenteus	1.44	0.17	2.00	0.91	2.29	58.84
Scomber scombrus	0.04	1.57	2.00	0.80	2.29	61.13
Lepidopus caudatus	1.01	0.88	1.90	0.87	2.18	63.31
Lepidotrigla cavillone	0.03	1.36	1.85	0.73	2.11	65.41
Scyliorhinus canicula	0.68	1.14	1.85	0.83	2.11	67.52
Illex coindetii	0.97	0.63	1.60	0.92	1.83	69.35
Malacocephalus laevis	1.16	0.04	1.60	0.96	1.83	71.18
Helicolenus dactylopterus	0.96	0.44	1.53	0.90	1.75	72.93
Etmopterus pusillus	1.07	0.00	1.49	0.77	1.71	74.64
Sepia elegans	0.15	1.90	1.35	0.83	1.54	76.19
Trachurus trachurus	0.22	0.99	1.33	0.79	1.52	77.70
Cepola macrophthalma	0.00	0.98	1.32	0.74	1.51	79.21
Eledone moschata	0.19	0.92	1.32	0.84	1.51	80.72
Arnoglossus imperialis	0.08	1.05	1.30	0.71	1.49	82.21
Callionymus lyra	0.09	0.98	1.30	0.81	1.49	83.70
Microchirus variegatus	0.04	1.17	1.29	0.81	1.47	85.17
Microchirus boscanion	0.00	1.06	1.19	0.69	1.37	86.53
Callionymus maculatus	0.09	0.87	1.06	0.69	1.22	87.75
Lepidotrigla dieuzeidei	0.00	0.85	1.05	0.56	1.20	88.95
Arnoglossus thori	0.02	0.86	0.99	0.61	1.13	90.08

Table 3.4 –SIMPER results for the biomass of the discarded species between crustacean (CT) and fish (FT) trawl métiers. Parameters include: average contribution to biomass (Av. Biom) and to dissimilarity (Av. Diss.), dissimilarity/standard deviation (Diss/SD), contribution of the dominant species to the dissimilarity % (Contrib%) and cumulative dissimilarity % (Cum.%).

Species	CT Av.Biom	FT Av.Biom	Av.Diss	Diss/SD	Contrib%	Cum.%
CRUSTACEAN and FISH TRAWLS:			87.90			
Micromesistius poutassou	1.92	0.57	5.06	1.44	**5.75**	5.75
Boops boops	0.01	1.36	3.64	1.47	**4.14**	9.89
Serranus hepatus	0.07	1.25	3.33	1.70	**3.79**	13.68
Macroramphosus scolopax	0.29	1.09	2.89	0.96	3.29	16.97
Conger conger	1.07	0.45	2.84	1.20	3.23	20.21
Scomber colias	0.01	1.08	2.81	0.81	3.20	23.40
Galeus melastomus	0.98	0.00	2.75	1.09	3.13	26.53
Merluccius merluccius	0.50	1.07	2.72	1.31	3.09	29.62
Sardina pilchardus	0.01	0.89	2.61	0.91	2.97	32.59
Scorpaena notata	0.04	0.88	2.53	1.24	2.88	35.48
Scyliorhinus canicula	0.42	0.73	2.39	0.87	2.72	38.20
Nezumia sclerorhynchus	0.81	0.00	2.36	1.07	2.69	40.89
Scomber scombrus	0.02	0.88	2.34	0.82	2.67	43.55
Capros aper	0.52	0.70	2.23	0.96	2.53	46.09
Etmopterus spinax	0.73	0.00	2.05	1.03	2.34	48.43
Illex coindetii	0.61	0.33	1.95	0.92	2.22	50.65
Macroramphosus gracilis	0.20	0.60	1.95	0.67	2.22	52.87
Lepidopus caudatus	0.52	0.37	1.89	0.87	2.15	55.02
Citharus linguatula	0.07	0.71	1.86	1.10	2.12	57.14
Malacocephalus laevis	0.56	0.02	1.59	0.98	1.81	58.95
Lepidotrigla cavillone	0.01	0.54	1.55	0.72	1.77	60.71
Helicolenus dactylopterus	0.49	0.20	1.54	0.90	1.75	62.47
Etmopterus pusillus	0.55	0.00	1.53	0.83	1.74	64.21
Eledone moschata	0.12	0.47	1.48	0.84	1.68	65.89
Phycis blennoides	0.53	0.00	1.46	0.80	1.66	67.56
Cepola macrophthalma	0.00	0.50	1.42	0.73	1.62	69.17
Trachurus trachurus	0.13	0.46	1.38	0.78	1.57	70.75
Hoplostethus m. mediterraneus	0.47	0.00	1.37	0.80	1.55	72.30
Gadiculus a. argenteus	0.46	0.05	1.35	0.90	1.54	73.84
Callionymus lyra	0.03	0.48	1.33	0.80	1.52	75.35
Microchirus variegatus	0.02	0.49	1.19	0.80	1.36	76.71
Alloteuthis subulata	0.07	0.40	1.17	0.88	1.33	78.04
Deania calceus	0.39	0.00	1.07	0.63	1.21	79.25
Raja clavata	0.16	0.29	1.06	0.59	1.20	80.45
Chimaera monstrosa	0.36	0.00	1.01	0.44	1.15	81.60
Arnoglossus imperialis	0.03	0.36	0.98	0.72	1.12	82.72
Microchirus boscanion	0.00	0.39	0.97	0.68	1.11	83.82
Sepia elegans	0.05	0.35	0.97	0.81	1.10	84.92
Chelidonichthys obscurus	0.01	0.34	0.95	0.56	1.09	86.01
Spondyliosoma cantharus	0.01	0.31	0.95	0.54	1.08	87.09
Pagellus acarne	0.07	0.31	0.94	0.52	1.07	88.16
Lepidotrigla dieuzeidei	0.00	0.32	0.85	0.55	0.97	89.12
Todaropsis eblanae	0.23	0.11	0.83	0.56	0.94	90.06

Within métiers

Analysis by tow/season

The results of the CLUSTER analyses based on the abundance and biomass matrices of the discarded species in each métier, per tow (72 tows in crustacean trawl; 91 tows in fish trawl) and season (four seasons), shows that neither crustacean trawl nor fish trawl samples form distinct clusters. Such unclear seasonal trends in the species composition can also be deduced in the MDS plots, at stress values >0.1 (0.16 and 0.22 for abundance; 0.17 and 0.23 for biomass, in crustacean and fish trawls respectively), for which the representation in two dimensions is not particularly adequate (Annexes VII and VIII). Similarity analyses revealed that season had no significant effect on both abundance and biomass of the species discarded by each métier (crustacean trawl ANOSIM test: abundance, R=0.251, p=0.1; biomass, R=0.246, p=0.1; fish trawl ANOSIM test: abundance, R=0.16, p=0.1; biomass, R=0.118, p=0.1).

In the crustacean trawl métier, the similarity percentage (SIMPER) analyses indicate that the highest average dissimilarities were found between the autumn season and both the spring (72.40% in abundance; 70.78% in biomass) and summer (70.74% in abundance; 70.16% in biomass) seasons. *Galeus melastomus* (7.27%), *N. scleorhynchus* (4.89%-8.05%) and *C. aper* (5.66%-6.21%) were the discarded species which contributed mainly to the seasonal dissimilarity, in terms of abundance. Similarly, *N. sclerorhynchus* (7.26%), *G. melastomus* (6.93%) and *C. aper* (4.90%), together with *E. pusillus* (4.34%), *C. conger* (4.90%) and *M. merluccius* (4.81%), were identified as those species which contributed mostly to the biomass differences found between seasons (Table 3.5).

Table 3.5 – Main species contributions (Contrib%) to the average dissimilarity (Av. Diss.%) on seasonal abundance and biomass of the discarded species in crustacean trawl métier (W-winter, S-spring, M-summer, A-autumn).

Groups (season)	ABUNDANCE			BIOMASS		
	Av.Diss. %	Species	Contrib%	Av.Diss. %	Species	Contrib%
A & M	70.74	*Galeus melastomus*	7.27	70.16	*Galeus melastomus*	6.93
A & S	72.40	*Nezumia sclerohrynchus*	8.05	70.78	*Nezumia sclerohrynchus*	7.26
M & S	52.27	*Nezumia sclerohrynchus*	4.89	54.66	*Etmopterus pusillus*	4.34
A & W	68.42	*Capros aper*	6.21	69.01	*Conger conger*	6.23
M & W	65.09	*Capros aper*	5.83	65.19	*Capros aper*	4.90
S & W	63.02	*Capros aper*	5.66	62.24	*Merluccius merluccius*	4.81

In the fish trawl métier, the average dissimilarities between seasons in the discarded species abundance and biomass were greater amongst winter and summer (70.37% and 71.0%, respectively) and summer and autumn seasons (69.05% and 68.87%, respectively). The species which contributed mostly to the dissimilarities found between seasons, identified by SIMPER analyses, were: *M. scolopax* (5.59-6.91%) and *L. cavillone* (4.63%), in terms of discarded abundance and *S. colias* (5.35-5.98%) and *S. scombrus* (4.92-5.38%), in terms of discarded biomass (Table 3.6).

The results of the similarity percentage analyses for the abundance and biomass of all the discarded species, by season, are shown in Annex IX, for crustacean trawls and in Annex X, for fish trawls.

Table 3.6 – Main species contributions (Contrib%) to the average dissimilarity (Av. Diss.%) on seasonal abundance and biomass of the discarded species in fish trawl métier (W-winter, S-spring, M-summer, A-autumn).

Groups (season)	ABUNDANCE			BIOMASS		
	Av.Diss. %	Species	Contrib%	Av.Diss. %	Species	Contrib%
W & S	67.85	*Macroramphosus scolopax*	6.56	68.13	*Scomber colias*	5.45
W & M	70.37	*Macroramphosus scolopax*	6.91	71.00	*Scomber colias*	5.98
S & M	65.27	*Macroramphosus scolopax*	5.80	66.90	*Scomber scombrus*	5.20
W & A	63.92	*Macroramphosus scolopax*	6.81	63.97	*Scomber colias*	5.35
S & A	59.46	*Lepidotrigla cavillone*	4.63	58.69	*Scomber scombrus*	4.92
M & A	69.05	*Macroramphosus scolopax*	5.59	68.87	*Scomber scombrus*	5.38

Species dominance in the discards

The dominance of a given species in the discards, in each métier, can be seen in the abundance and biomass *k*-dominance curves, shown in Figure 3.12. Dominance by a single species was more pronounced in terms of abundance for fish trawlers, heavily dominated by *M. scolopax* (35.4%), and in terms of biomass for crustacean trawlers, with *M. poutassou* accounting for almost 28%. When considering the 2nd to the 10th most dominant species, there is an evident clear change in dominance, more important in terms of abundance for crustacean trawls, dominated by *M. poutassou* (17.6%), *Macroramphosus* spp. (30.8%) and *C. aper* (11.9%), accounting for slightly more than 60% of all discarded species; and more important in terms of biomass for fish trawls, dominated by *S. colias* (16.2%), *S. canicula* (14.8%) and *M. scolopax* (10%), which accounted for almost 42% of all discards in weight (Table 3.7).

Dominance frequencies for the abundance and biomass values of all discarded species, for crustacean and fish trawl métiers, are given in Annex XI.

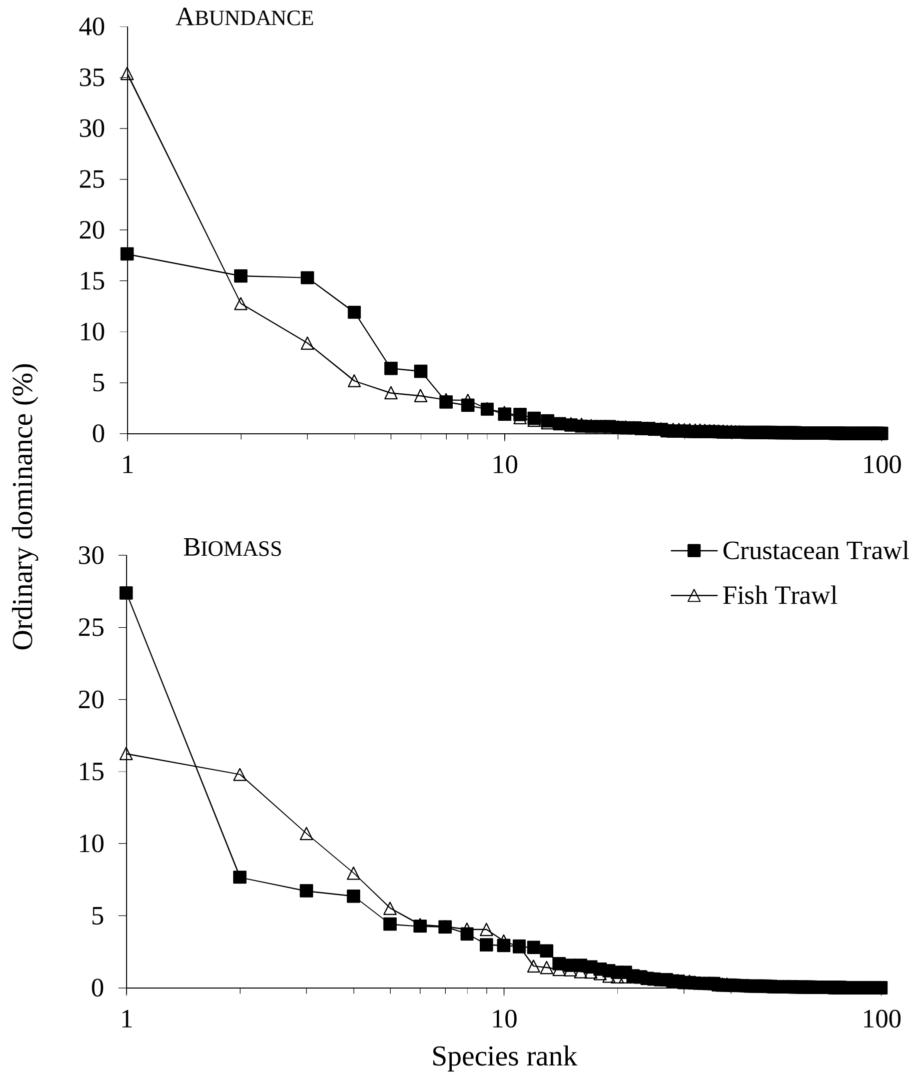


Figure 3.12 – *k*-dominance curves for the discarded species abundance and biomass, by métier.

Table 3.7 – Dominance frequencies for the abundance and biomass values of the most dominant (≥ 2%) discarded species for each métier.

SPECIES	CRUSTACEAN TRAWL Dominance (%)	SPECIES	FISH TRAWL Dominance (%)
ABUNDANCE:			
Micromesistius poutassou	17.6	*Macroramphosus scolopax*	35.4
Macroramphosus scolopax	15.5	*Macroramphosus gracilis*	12.8
Macroramphosus gracilis	15.3	*Capros aper*	8.9
Capros aper	11.9	*Serranus hepatus*	5.2
Nezumia sclerorhynchus	6.4	*Scomber colias*	4.0
Galeus melastomus	6.1	*Micromesistius poutassou*	3.7
Merluccius merluccius	3.1	*Merluccius merluccius*	3.3
Hoplostethus m. mediterraneus	2.8	*Scyliorhinus canicula*	3.3
Gadiculus a. argenteus	2.4	*Boops boops*	2.4
		Sardina pilchardus	2.0
Total	81.1		81.0
BIOMASS:			
Micromesistius poutassou	27.4	*Scomber colias*	16.2
Galeus melastomus	7.7	*Scyliorhinus canicula*	14.8
Capros aper	6.7	*Macroramphosus scolopax*	10.7
Conger conger	6.4	*Boops boops*	7.9
Chimaera monstrosa	4.4	*Macroramphosus gracilis*	5.5
Macroramphosus scolopax	4.3	*Capros aper*	4.4
Macroramphosus gracilis	4.2	*Scomber scombrus*	4.2
Torpedo nobiliana	3.7	*Serranus hepatus*	4.0
Scyliorhinus canicula	3.0	*Micromesistius poutassou*	4.0
Nezumia sclerorhynchus	2.9	*Sardina pilchardus*	3.2
Illex coindetii	2.9	*Merluccius merluccius*	2.8
Merluccius merluccius	2.8		
Etmopterus spinax	2.6		
Total	78.9		78.0

Seasonally, *k*-dominance curves show some variability in both abundance and biomass of the species discarded by each métier (Figure 3.13). In terms of abundance, seasonal dominance was more pronounced in autumn for crustacean trawls, heavily dominated by *M. poutassou* (63.8%), being also the most dominant species in summer (23.1%), while *N. sclerorhynchus* (25.0%) and *M. scolopax* (23.0%) were dominant in spring and winter seasons, respectively. In fish trawls, both summer and winter seasons were dominated by *M. scolopax* (44.1% and 34.9% respectively), while *L. cavillone* was more dominant in spring and autumn (Figure 3.13a,b; Table 3.8). For biomass values, differences in species dominance between seasons were less marked in either métier, mainly for fish trawlers (Figure 3.13d). In crustacean trawls, *M. poutassou* is the most dominant species in all seasons, accounting for

21.8% to 38.3% in biomass. Regarding fish trawlers, biomass was dominated by *S. scombrus* (22.5%) in spring and, to a lesser extent, in autumn (19.2%). In the remaining seasons, *S. colias* (23.5%) and *M. scolopax* (20.3%) are the species which dominate the discarded biomass in winter and summer, respectively (Table 3.9).

Seasonal dominance frequencies for the abundance and biomass values of all species discarded by crustacean and fish trawls are shown in Annexes XII and XIII, respectively.

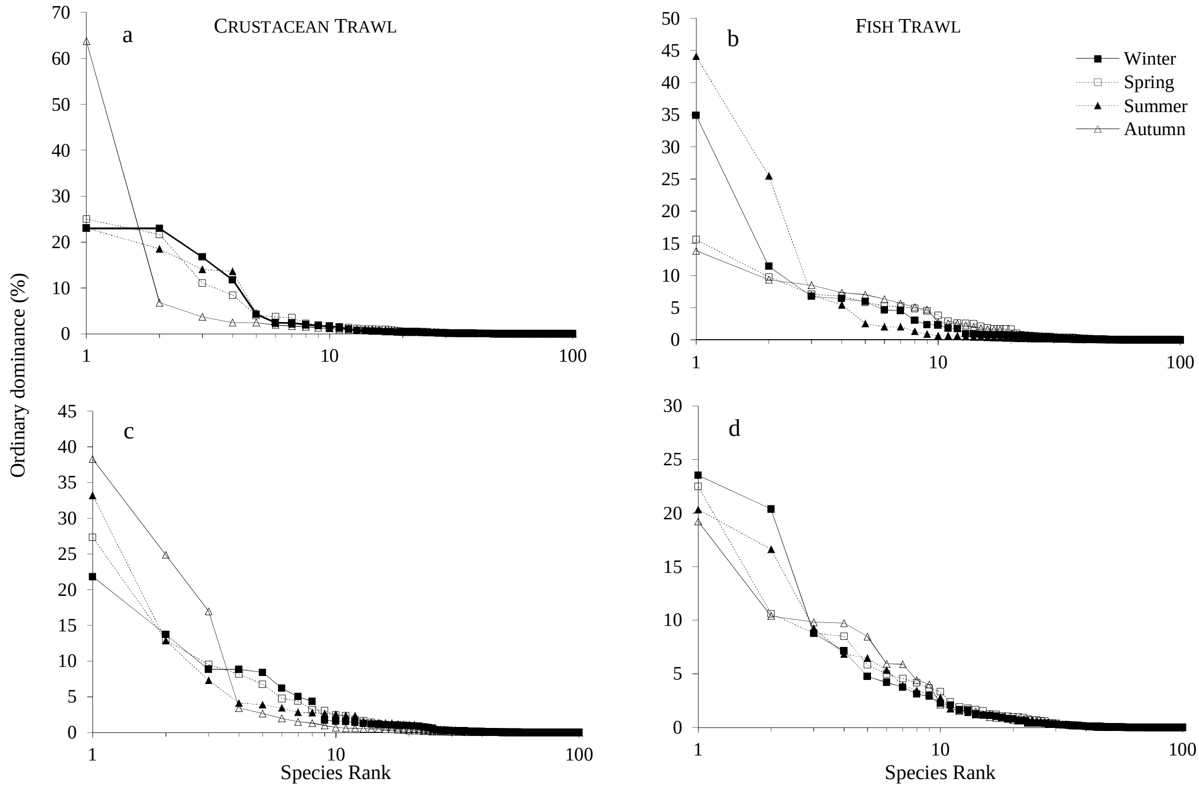


Figure 3.13 – *k*-dominance curves for the species abundance (upper) and biomass (lower) discarded by crustacean and fish trawl métiers, per season.

Table 3.8 – Dominance frequencies for the abundance values of the most dominant (≥2%) discarded species, by season, for each métier.

Species	WINTER Dominance (%)	Species	SPRING Dominance (%)	Species	SUMMER Dominance (%)	Species	AUTUMN Dominance (%)
CRUSTACEAN TRAWL:							
Macroramphosus scolopax	23.0	*Nezumia sclerorhynchus*	25.0	*Micromesistius poutassou*	23.1	*Micromesistius poutassou*	63.8
Macroramphosus gracilis	23.0	*Galeus melastomus*	21.7	*Galeus melastomus*	18.5	*Capros aper*	6.8
Capros aper	16.7	*Micromesistius poutassou*	11.1	*Hoplostethus m. mediterraneu*	14.0	*Gadiculus a. argenteus*	3.7
Micromesistius poutassou	11.7	*Etmopterus spinax*	8.4	*Nezumia sclerorhynchus*	13.6	*Chimaera monstrosa*	2.5
Merluccius merluccius	4.3	*Scyliorhinus canicula*	4.0	*Etmopterus spinax*	4.6	*Torpedo nobiliana*	2.5
Nezumia sclerorhynchus	2.4	*Etmopterus pusillus*	3.7	*Gaidropsaurus biscayensis*	2.4	*Galeus melastomus*	1.9
Gadiculus a. argenteus	2.4	*Gadiculus a. argenteus*	3.5	*Etmopterus pusillus*	2.2		
Conger conger	2.1	*Conger conger*	2.3	*Mora moro*	2.0		
Symphurus ligulatus	1.8			*Deania calceus*	1.9		
Total	87.3		79.7		82.3		81.2
FISH TRAWL:							
Macroramphosus scolopax	34.9	*Lepidotrigla cavillone*	15.6	*Macroramphosus scolopax*	44.1	*Lepidotrigla cavillone*	13.8
Capros aper	11.4	*Lepidopus caudatus*	9.8	*Macroramphosus gracilis*	25.5	*Serranus hepatus*	9.4
Scomber japonicus	6.8	*Macroramphosus scolopax*	7.1	*Capros aper*	6.9	*Scomber scombrus*	8.5
Serranus hepatus	6.4	*Scomber scombrus*	6.8	*Micromesistius poutassou*	5.4	*Merluccius merluccius*	7.3
Macroramphosus gracilis	6.0	*Sardina pilchardus*	5.9	*Serranus hepatus*	2.5	*Sardina pilchardus*	7.0
Merluccius merluccius	4.6	*Serranus hepatus*	5.3	*Scyliorhinus canicula*	2.0	*Lepidotrigla dieuzeidei*	6.3
Scyliorhinus canicula	4.6	*Boops boops*	5.2	*Boops boops*	2.0	*Pagellus acarne*	5.6
Micromesistius poutassou	3.0	*Capros aper*	4.8			*Alloteuthis subulata*	5.1
Sardina pilchardus	2.4	*Scorpaena notata*	4.5			*Boops boops*	4.7
Boops boops	2.3	*Macroramphosus gracilis*	3.8			*Alloteuthis media*	2.7
		Scomber japonicus	2.9			*Citharus linguatula*	2.6
		Merluccius merluccius	2.6			*Scomber japonicus*	2.5
		Lepidotrigla dieuzeidei	2.6			*Arnoglossus thori*	2.2
		Engraulis encrasicolus	2.5			*Sepia elegans*	2.0
		Trachurus trachurus	2.1				
Total	82.6		81.4		88.5		79.9

Table 3.9 – Dominance frequencies for the biomass values of the most dominant (≥ 2%) discarded species, by season, for each métier.

Species	WINTER Dominance (%)	Species	SPRING Dominance (%)	Species	SUMMER Dominance (%)	Species	AUTUMN Dominance (%)
CRUSTACEAN TRAWL:							
Micromesistius poutassou	21.8	*Micromesistius poutassou*	27.3	*Micromesistius poutassou*	33.2	*Micromesistius poutassou*	38.3
Capros aper	13.7	*Scyliorhinus canicula*	12.9	*Galeus melastomus*	12.9	*Chimaera monstrosa*	24.9
Macroramphosus scolopax	8.9	*Nezumia sclerorhynchus*	9.5	*Torpedo nobiliana*	7.3	*Torpedo nobiliana*	17.0
Macroramphosus gracilis	8.8	*Galeus melastomus*	8.2	*Conger conger*	4.1	*Dalatias licha*	3.4
Conger conger	8.4	*Conger conger*	6.7	*Etmopterus spinax*	3.9	*Galeus melastomus*	2.7
Galeus melastomus	6.2	*Etmopterus pusillus*	4.8	*Nezumia sclerorhynchus*	3.4	*Conger conger*	2.0
Merluccius merluccius	5.0	*Etmopterus spinax*	4.4	*Deania calceus*	2.8		
Illex coindetii	4.3	*Chimaera monstrosa*	3.1	*Sphoeroides pachygaster*	2.8		
		Phycis blennoides	3.1	*Hoplostethus m. mediterraneus*	2.7		
		Eledone cirrhosa	2.4	*Hexanchus griseus*	2.6		
		Illex coindetii	2.4	*Phycis blennoides*	2.4		
				Lepidopus caudatus	2.3		
Total	77.2		84.9		80.4		88.2
FISH TRAWL:							
Scomber japonicus	23.5	*Scomber scombrus*	22.5	*Macroramphosus scolopax*	20.3	*Scomber scombrus*	19.2
Scyliorhinus canicula	20.4	*Lepidotrigla cavillone*	10.6	*Macroramphosus gracilis*	16.6	*Lepidotrigla cavillone*	10.4
Macroramphosus scolopax	8.8	*Scomber japonicus*	8.8	*Boops boops*	9.3	*Boops boops*	9.8
Boops boops	7.1	*Boops boops*	8.5	*Scyliorhinus canicula*	6.9	*Sardina pilchardus*	9.7
Capros aper	4.8	*Sardina pilchardus*	5.8	*Micromesistius poutassou*	6.5	*Scomber japonicus*	8.5
Serranus hepatus	4.2	*Scorpaena notata*	5.0	*Capros aper*	5.3	*Pagellus acarne*	5.9
Micromesistius poutassou	3.8	*Lepidopus caudatus*	4.6	*Lepidopus caudatus*	3.9	*Serranus hepatus*	5.9
Merluccius merluccius	3.1	*Spondyliosoma cantharus*	4.2	*Scomber scombrus*	3.4	*Merluccius merluccius*	4.4
Sardina pilchardus	2.9	*Cepola macrophthalma*	3.7	*Serranus hepatus*	3.0	*Lepidotrigla dieuzeidei*	4.0
Trachurus picturatus	2.2	*Serranus hepatus*	3.3	*Balistes capriscus*	2.8	*Scyliorhinus canicula*	2.1
Macroramphosus gracilis	2.1	*Callionymus lyra*	2.4				
Total	82.8		79.3		78.1		80.0

Abundance and biomass discards and discard rate of species

Global analysis

The average estimated discards per tow of all fish and cephalopod species discarded by both métiers during the 1999-2001 sampling period, was 6900 individuals and 229.5 kg, of which 1799 individuals and 78.5 kg were discarded by crustacean trawls, and 10936 individuals and 348.9 kg were discarded by fish trawls.

Fish, in conjunction with cephalopods, accounted for 94.1% of the biomass of the discards of all the fishing operations in both métiers. The total estimated quantities of bony fishes, cartilaginous fishes and cephalopods discarded during the sampling period were 3703.9 kg (51.4 kg/tow), 1614.1 kg (22.4 kg/tow) and 336.6 kg (4.7 kg/tow), in crustacean trawls; and 25694.5 kg (282.4 kg/tow), 5341.8 kg (58.7 kg/tow) and 716.3 kg (7.9 kg/tow), in fish trawls, respectively. The total estimated discards of bony fishes, cartilaginous fishes and cephalopods, in terms of numbers, were 108722 (1510/tow), 17113 (238/tow) and 3680 (51/tow), in crustacean trawls; and 934577 (10270/tow), 32008 (352/tow) and 28631 (315/tow), in fish trawls, respectively.

The average estimated discard rates of all fish and cephalopod species discarded by both métiers (1999-2001) were 2050 n/h in abundance and 68.2 kg/h in biomass. Fish trawls discarded an average of 7505 n/h and 239.5 kg/h, substantially higher than crustacean trawls (311 n/h and 13.6 kg/h).

Analysis by species group

The total estimated abundance and biomass discard rates of bony fishes were greater than those of cartilaginous fishes and cephalopods in both métiers, but fish trawls discard more organisms at considerably higher rates compared to crustacean trawls (e.g. 41 n/h *vs.* 241 n/h cartilaginous fishes discarded) (Figure 3.14).

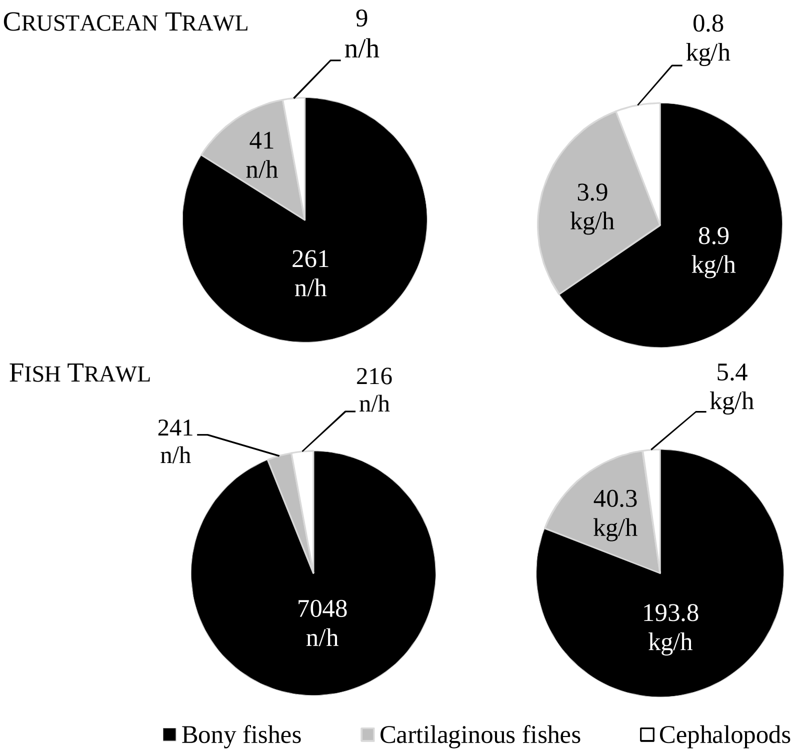


Figure 3.14 – Abundance (n/h) and biomass (kg/h) discard rates of fishes and cephalopods, by métier.

From the total estimated discards of all fish and cephalopod species caught by both métiers, **cephalopods** represent 3.0% in abundance and 2.8% in biomass, being more significant in biomass (6%) in crustacean trawl (2.8% in abundance) and abundance (3%) in fish trawls (2.3% in biomass). The greatest number of discarded cephalopod species individuals was recorded for *Illex coindetii* (27.8%), *Alloteuthis subulata* (20.2%), *Todaropsis eblanae* (10.2%) and *Eledone cirrhosa* (9.8%), in crustacean trawls (Table 3.10, Figure 3.15); and for *A. subulata* (32.4%), *Sepia elegans* (13.7%), *S. orbignyana* (10.5%) and *I. coindetii* (10.2%), in fish trawls (Table 3.10, Figure 3.16). In crustacean trawls, *A. subulata* and *I. coindetii* were the two most abundantly discarded species, at low rates of 2 ind./h. In fish trawls, *A. subulata* was the species mostly discarded in numbers (65 ind./h), followed by *S. elegans* (31 ind./h), *S. orbignyana* (24 ind./h), *I. coindetii* (23 ind./h) and *A. media* (21 ind./h). In terms of biomass, the ommastrephid *I. coindetii* was the mostly discarded cephalopod species in both métiers, in higher amounts in fish trawls (194.9 kg) and at higher rates (1.5 kg/h) than in crustacean trawls (169.4 kg, 0.4 kg/h,), representing 27.1% and 50.3% of all cephalopod species caught by the corresponding métier, respectively (Table 3.10, Figure 3.15 and Figure 3.16). The octopodid *E. cirrhosa* (22.4%, 75.2 kg, 0.2 kg/h) was the next most discarded cephalopod species by crustacean trawls and *E. moschata* (15.4%, 111.1 kg, 0.8 kg/h) by fish trawls (Table 3.10, Figure 3.15 and Figure 3.16).

Table 3.10 – Total estimated discarded abundance and biomass and discard rates, in number (n/h) and weight (kg/h), for each cephalopod species discarded by crustacean trawl (CT) and fish trawl (FT) (% Ceph–percentage of all cephalopods; % All–percentage of all fish and cephalopod species).

Species	Métier	Abundance			Biomass			Discard Rate	
		n	% Ceph	% All	kg	% Ceph	% All	n/h	kg/h
Abralia veranyi	CT	120	3.3	0.1	0.3	0.1	<0.1	0.3	0.001
Alloteuthis media	CT	6	0.2	<0.1	0.0	<0.1	<0.1	<0.1	<0.001
	FT	2845	9.9	0.3	8.9	1.2	<0.1	21	0.067
Alloteuthis spp	FT	773	2.7	0.1	1.3	0.2	<0.1	6	0.010
Alloteuthis subulata	CT	744	20.2	0.6	2.7	0.8	<0.1	2	0.007
	FT	8574	29.9	0.9	37.9	5.3	0.1	65	0.286
Eledone cirrhosa	CT	362	9.8	0.3	75.2	22.4	1.3	1	0.181
	FT	114	0.4	<0.1	11.4	1.6	<0.1	1	0.086
Eledone moschata	CT	116	3.2	0.1	16.8	5.0	0.3	0.3	0.040
	FT	1480	5.2	0.1	111.1	15.4	0.3	11	0.838
Illex coindetii	CT	1022	27.8	0.8	169.4	50.3	3.0	2	0.407
	FT	3013	10.5	0.3	194.9	27.1	0.6	23	1.470
Loligo vulgaris	CT	2	0.1	<0.1	0.0	<0.1	<0.1	<0.1	<0.001
	FT	1019	3.6	0.1	24.0	3.3	0.1	8	0.181
Neorossia caroli	CT	188	5.1	0.1	6.6	2.0	0.1	0.5	0.016
Octopus salutii	CT	45	1.2	<0.1	10.7	3.2	0.2	0.1	0.026
	FT	32	0.1	<0.1	2.9	0.4	<0.1	0.2	0.022
Octopus vulgaris	FT	480	1.7	<0.1	54.3	7.5	0.2	4	0.410
Pteroctopus tetracirrhus	CT	1	<0.1	<0.1	0.1	<0.1	<0.1	<0.1	<0.001
Rossia macrosoma	CT	122	3.3	0.1	8.2	2.4	0.1	0.3	0.020
	FT	1178	4.1	0.1	59.4	8.2	0.2	9	0.448
Scaeurgus unicirrhus	CT	79	2.1	0.1	4.4	1.3	0.1	0.2	0.011
	FT	1041	3.6	0.1	59.6	8.3	0.2	8	0.449
Sepia elegans	CT	163	4.4	0.1	1.6	0.5	<0.1	0.4	0.004
	FT	4076	14.2	0.4	37.5	5.2	0.1	31	0.283
Sepia officinalis	FT	128	0.4	<0.1	3.2	0.4	<0.1	1	0.024
Sepia orbignyana	CT	146	4.0	0.1	3.8	1.1	0.1	0.4	0.009
	FT	3121	10.9	0.3	82.3	11.4	0.3	24	0.620
Sepietta obscura	FT	133	0.5	<0.1	0.2	<0.1	<0.1	1	0.001
Sepietta oweniana	CT	184	5.0	0.1	0.5	0.1	<0.1	0.4	0.001
	FT	257	0.9	<0.1	0.9	0.1	<0.1	2	0.007
Sepiola atlantica	FT	44	0.2	<0.1	0.2	<0.1	<0.1	0.3	0.002
Todarodes sagittatus	CT	4	0.1	<0.1	3.1	0.9	0.1	<0.1	0.008
Todaropsis eblanae	CT	375	10.2	0.3	33.2	9.8	0.6	1	0.080
	FT	324	1.1	<0.1	26.2	3.6	0.1	2.44	0.198

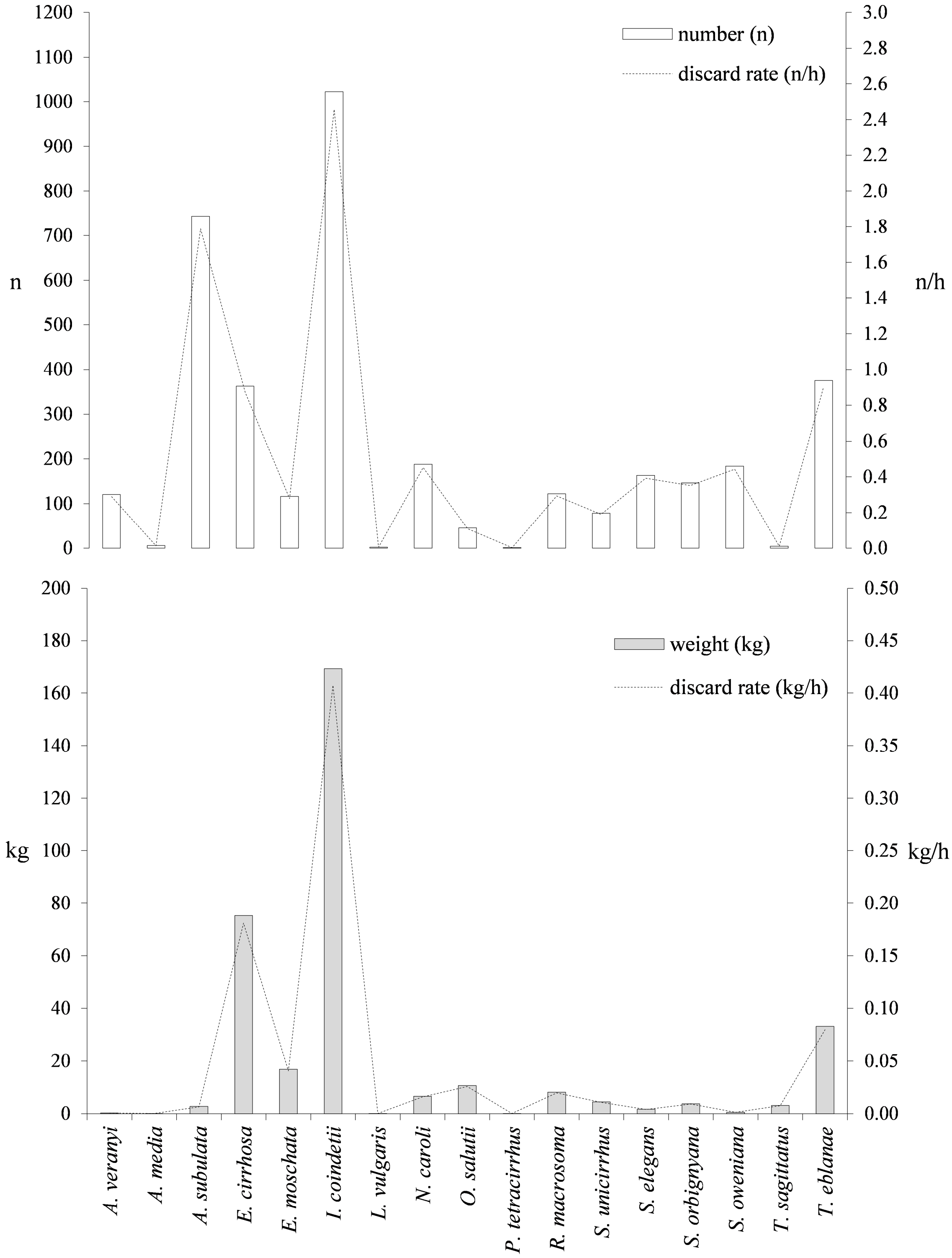


Figure 3.15 – Total estimated abundance (n), biomass (kg) and discard rates, in abundance (n/h) and biomass (kg/h), of cephalopod species discarded by crustacean trawls.

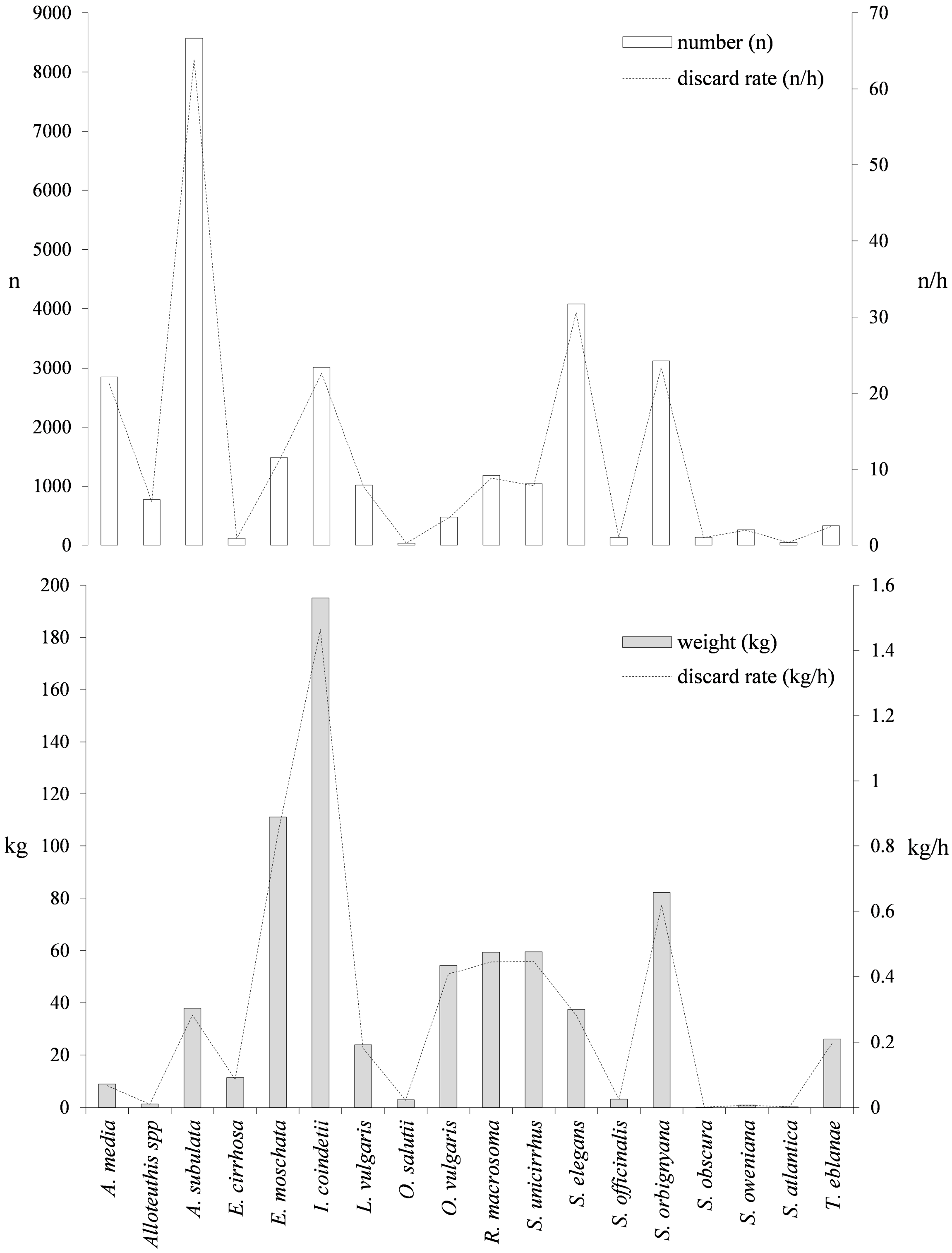


Figure 3.16 – Total estimated abundance (n), biomass (kg) and discard rates, in abundance (n/h) and biomass (kg/h), of cephalopod species discarded by fish trawls.

Chondrichthyes was the next most discarded class of organisms by both métiers, representing 4.4% in abundance and 18.6% in biomass of all fish and cephalopod species caught. Crustacean trawls discarded cartilaginous fishes in clearly higher percentages, both in abundance (13.2%) and in biomass (28.5%), compared to fish trawls (3.2% *vs.* 16.8%). The cartilaginous fish species mostly discarded by crustacean trawls, in terms of both number and weight, was the deep-sea shark *Galeus melastomus*, representing 54.7% and 28% of all discarded Chondrichthyes, at rates of 22 n/h and 1.1 kg/h. *Etmopterus spinax* (17%) and *E. pusillus* (8.4%) were the next most abundant deep-sea shark species discarded by this métier, at rates of 7 n/h and 3 n/h, respectively. In terms of biomass, *Chimaera monstrosa* (16.1%) and *Torpedo nobiliana* (13.6%) were the next most discarded chondrichthyan species, at rates of 0.6 kg/h and 0.5 kg/h, respectively. *Scyliorhinus canicula* is the fourth most discarded cartilaginous fish species, both in abundance (7.4%) and biomass (10.9%), at rates of 3 n/h and 0.4 kg/h (Table 3.11, Figure 3.17). In the fish trawl métier, *S. canicula*, the single demersal shark species caught by this métier, is the most discarded cartilaginous fish species, with extremely high percentages, not only in terms of number (91.4%) but also in weight (88%). Its discard rates were the highest (221 n/h; 35.5 kg/h) recorded among chondrichthyans. The remaining species, rays and torpedos, were discarded at rates less than 8 n/h and less than 2.7 kg/h (Table 3.11, Figure 3.18).

Table 3.11 – Total estimated discarded abundance and biomass and discard rates, in number (n/h) and weight (kg/h), for each cartilaginous species discarded by crustacean trawl (CT) and fish trawl (FT) (% Chon–percentage of all cartilaginous fishes; % All–percentage of all fish and cephalopod species).

SPECIES	MÉTIER	ABUNDANCE			BIOMASS			DISCARD RATE	
		n	% Chon	% All	kg	% Chon	% All	n/h	kg/h
Centrophorus granulosus	CT	15	<0.1	<0.1	27.8	1.7	0.5	<0.1	0.067
Chimaera monstrosa	CT	592	3.5	0.5	259.6	16.1	4.6	1	0.624
Dalatias licha	CT	32	<1.0	<0.1	62.6	3.9	1.1	0.1	0.150
Deania calceus	CT	839	4.9	0.6	85.0	5.3	1.5	2	0.204
Dipturus batis	CT	7	<0.1	<0.1	0.1	<0.1	<0.1	<0.1	<0.001
Dipturus oxyrhinchus	CT	136	0.8	0.1	17.4	1.1	0.3	0.3	0.042
Etmopterus pusillus	CT	1445	8.4	1.1	92.4	5.7	1.6	3	0.222
Etmopterus spinax	CT	2907	17.0	2.2	150.6	9.3	2.7	7	0.362
Galeus melastomus	CT	9354	54.7	7.2	451.4	28.0	8.0	22	1.085
Hexanchus griseus	CT	3	<0.1	<0.1	35.0	2.2	0.6	<0.1	0.084
Leucoraja naevus	CT	2	<0.1	<0.1	0.01	<0.1	<0.1	<0.1	<0.001
	FT	1042	3.3	0.1	345.8	6.5	1.1	8	2.607
Neoraja iberica n.sp.	CT	20	0.1	<0.1	0.9	<0.1	<0.1	<0.1	0.002
Raja asterias	FT	7	<0.1	<0.1	3.0	<0.1	<0.1	0.1	0.023
Raja clavata	CT	90	0.5	0.1	16.3	1.0	0.3	0.2	0.039
	FT	957	3.0	0.1	173.0	3.2	0.5	7	1.304
Raja miraletus	FT	92	0.3	<0.1	9.4	0.2	<0.1	1	0.071
Raja montagui	CT	17	0.1	<0.1	0.5	<0.1	<0.1	<0.1	0.001
	FT	487	1.5	<0.1	25.0	0.5	<0.1	4	0.189
Raja undulata	CT	15	<0.1	<0.1	4.7	0.3	<0.1	<0.1	0.011
	FT	107	0.3	<0.1	76.7	1.4	0.2	1	0.578
Scyliorhinus canicula	CT	1273	7.4	1.0	175.5	10.9	3.1	3	0.422
	FT	29257	91.4	2.9	4703.4	88.0	14.8	221	35.464
Scymnodon ringens	CT	14	<0.1	<0.1	10.3	0.6	0.2	<0.1	0.025
Torpedo marmorata	CT	2	<0.1	<0.1	3.7	0.2	<0.1	<0.1	0.009
	FT	61	0.2	<0.1	5.5	0.1	<0.1	0.5	0.042
Torpedo nobiliana	CT	348	2.0	0.3	220.3	13.6	3.9	1	0.530

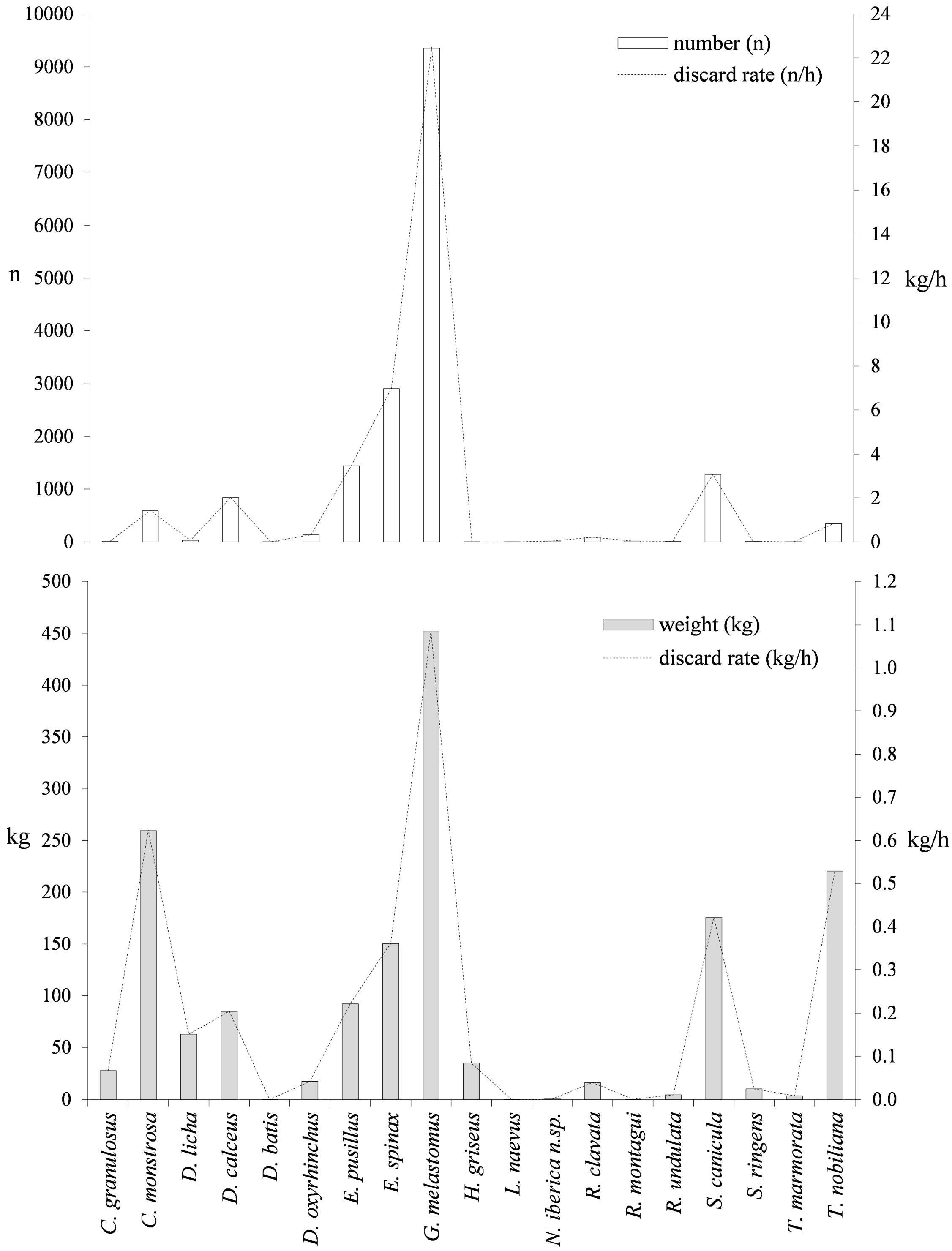


Figure 3.17 – Total estimated abundance (n), biomass (kg) and discard rates, in abundance (n/h) and biomass (kg/h), of cartilaginous fish species discarded by crustacean trawls.

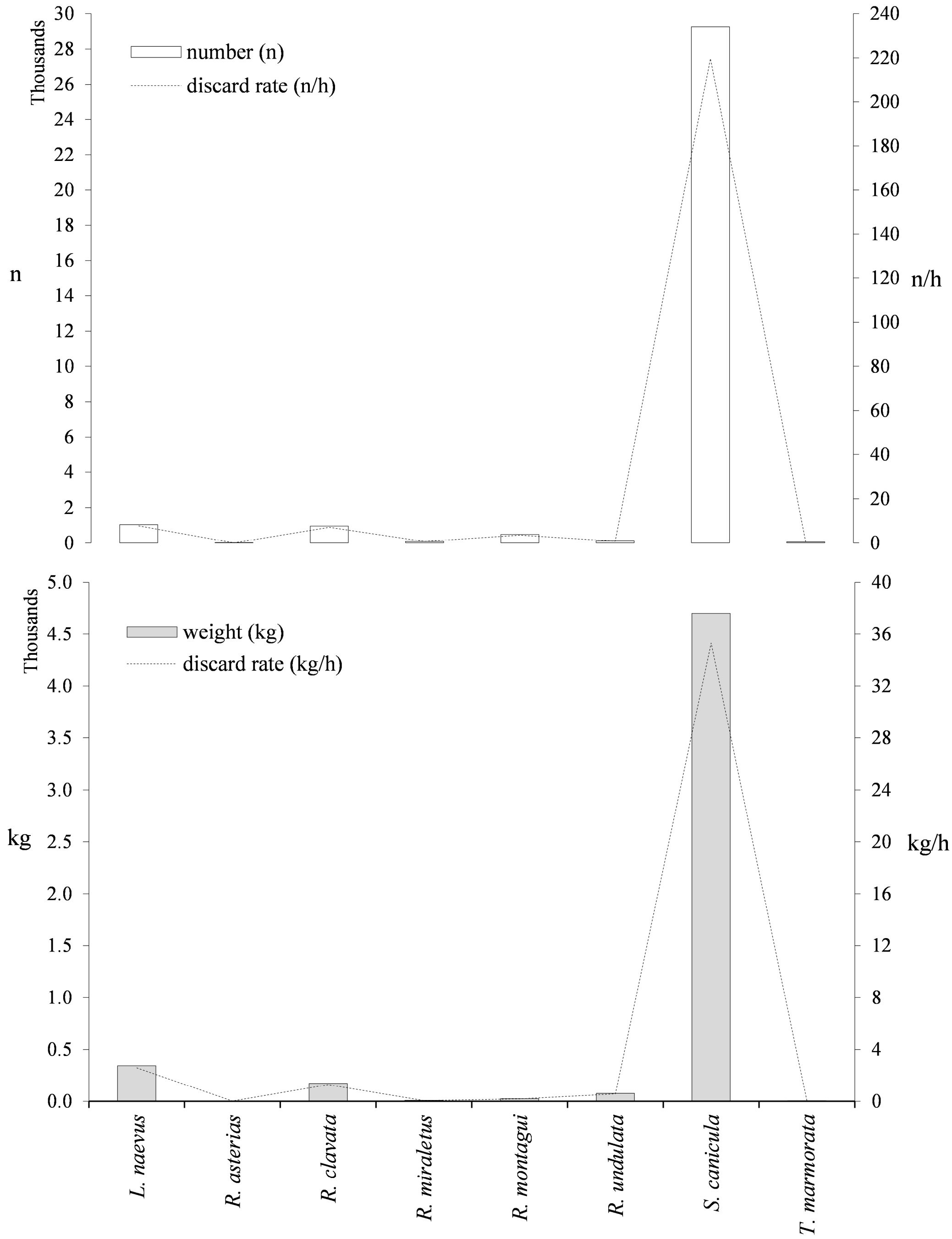


Figure 3.18 – Total estimated abundance (n), biomass (kg) and discard rates, in abundance (n/h) and biomass (kg/h), of cartilaginous fish species discarded by fish trawls.

Bony fishes are, undoubtedly, the organisms most discarded by both crustacean and fish trawl métiers, representing 92.7% in abundance and 78.6% in biomass of all fish and cephalopod species caught. Bony fish discards are more representative in fish trawls, both in terms of number (93.8%) and weight (80.9%), compared to crustacean trawls (83.9% and 65.5%, respectively).

There is a wide and varied catch for the discards of bony fish species, but the species most abundantly discarded by crustacean trawlers are *Micromesistius poutassou* (24.8%), *Macroramphosus* spp. (21.8%) and *Capros aper* (16.7%), at rates of over 43 individuals per hour (65 n/h, 82 n/h and 44 n/h, respectively) (Table 3.12, Figure 3.19). In fish trawls, *M. poutassou* is much less important in terms of discarded numbers (4%), but *Macroramphosus* spp. (51.3%) and *C. aper* (9.5%) are still the same most discarded bony fish species, at considerably higher rates (2925 n/h, 770 n/h and 673 n/h, respectively) than in crustacean trawls (Table 3.13, Figure 3.20).

Table 3.12 – Total estimated discarded abundance and biomass and discard rates, in number (n/h) and weight (kg/h), for the 25 bony fish species most discarded by crustacean trawl (% Ost–percentage of all bony fishes; % All–percentage of all fish and cephalopod species).

SPECIES	ABUNDANCE			BIOMASS			DISCARD RATE	
	n	% Ost	% All	kg	% Ost	% All	n/h	kg/h
Arnoglossus rueppelii	350	0.3	0.3	3.3	<0.1	<0.1	1	0.008
Benthodesmus elongatus	252	0.2	0.2	26.6	0.7	0.5	1	0.064
Capros aper	18193	16.7	14.0	396.4	10.7	7.0	44	0.953
Chelidonichthys lucerna	88	0.1	0.1	21.8	0.6	0.4	0.2	0.052
Conger conger	2873	2.6	2.2	374.6	10.1	6.6	7	0.900
Gadiculus argenteus	3640	3.3	2.8	33.6	0.9	0.6	9	0.081
Gaidropsaurus biscayensis	603	0.6	0.5	6.3	0.2	0.1	1	0.015
Helicolenus dactylopterus	829	0.8	0.6	48.2	1.3	0.9	2	0.116
Hoplostethus m. mediterraneus	4232	3.9	3.3	69.3	1.9	1.2	10	0.166
Lepidopus caudatus	2249	2.1	1.7	98.3	2.7	1.7	5	0.236
Macroramphosus gracilis	97	0.1	0.1	9.6	0.3	0.2	0.3	0.034
Macroramphosus scolopax	23639	21.7	18.3	251.4	6.8	4.4	82	0.877
Malacocephalus laevis	1032	0.9	0.8	62.1	1.7	1.1	2	0.149
Merluccius merluccius	4729	4.3	3.7	164.4	4.4	2.9	11	0.395
Microchirus azevia	282	0.3	0.2	3.4	<0.1	<0.1	1	0.008
Micromesistius poutassou	26967	24.8	20.8	1613.2	43.6	28.5	65	3.878
Mora moro	742	0.7	0.6	11.4	0.3	0.2	2	0.027
Nezumia sclerorhynchus	9790	9.0	7.6	173.3	4.7	3.1	24	0.416
Phycis blennoides	850	0.8	0.7	91.8	2.5	1.6	2	0.221
Ruvettus pretiosus	16	<0.1	<0.1	21.8	0.6	0.4	<0.1	0.052
Sphoeroides pachygaster	175	0.2	0.1	38.1	1.0	0.7	0.4	0.092
Symphurus ligulatus	1864	1.7	1.4	19.5	0.5	0.3	4	0.047
Synaphobranchus kaupii	1035	1.0	0.8	8.6	0.2	0.2	2	0.021
Trachurus trachurus	258	0.2	0.2	45.3	1.2	0.8	1	0.109
Venefica proboscidea	1091	1.0	0.8	17.4	0.5	0.3	3	0.042

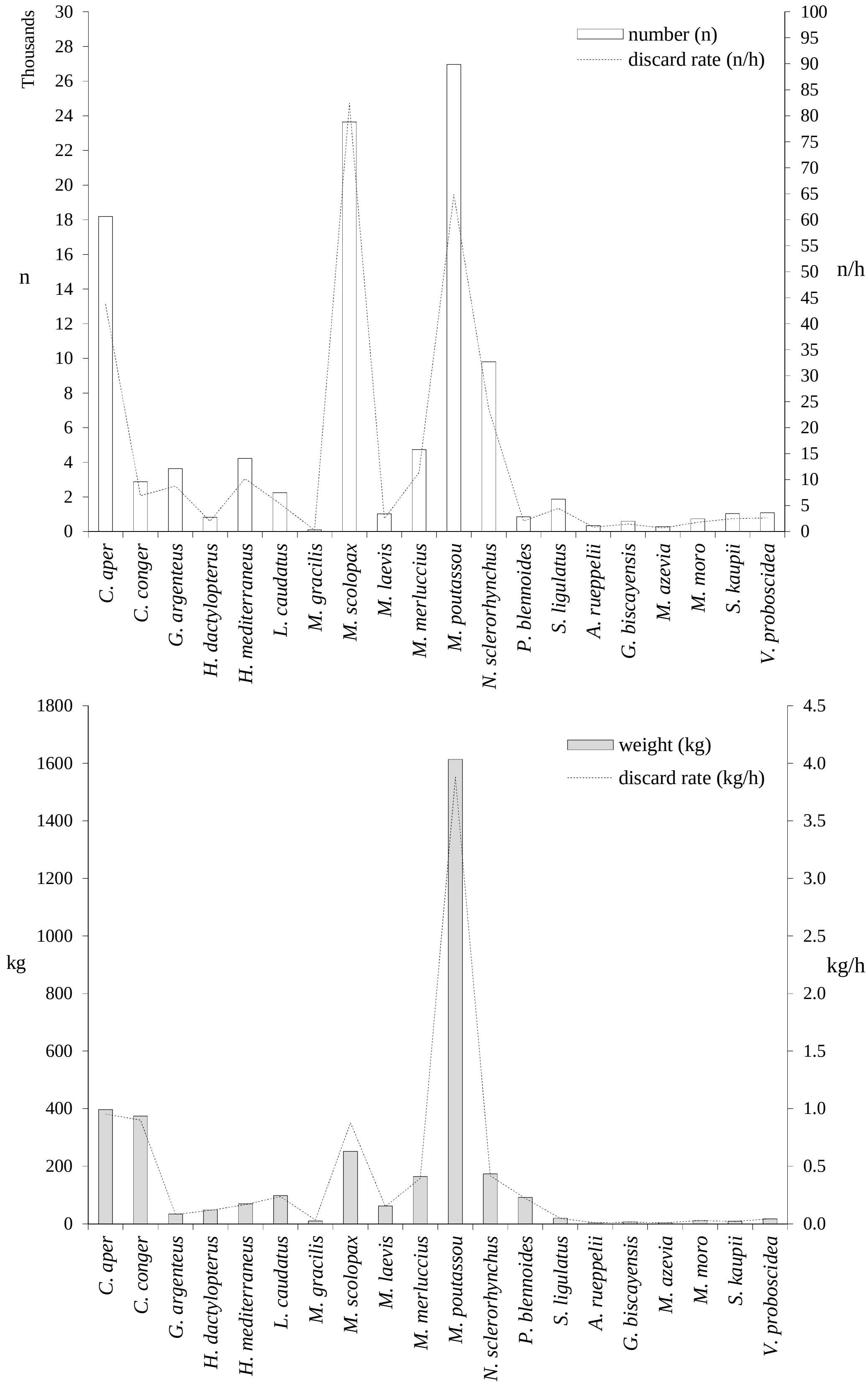
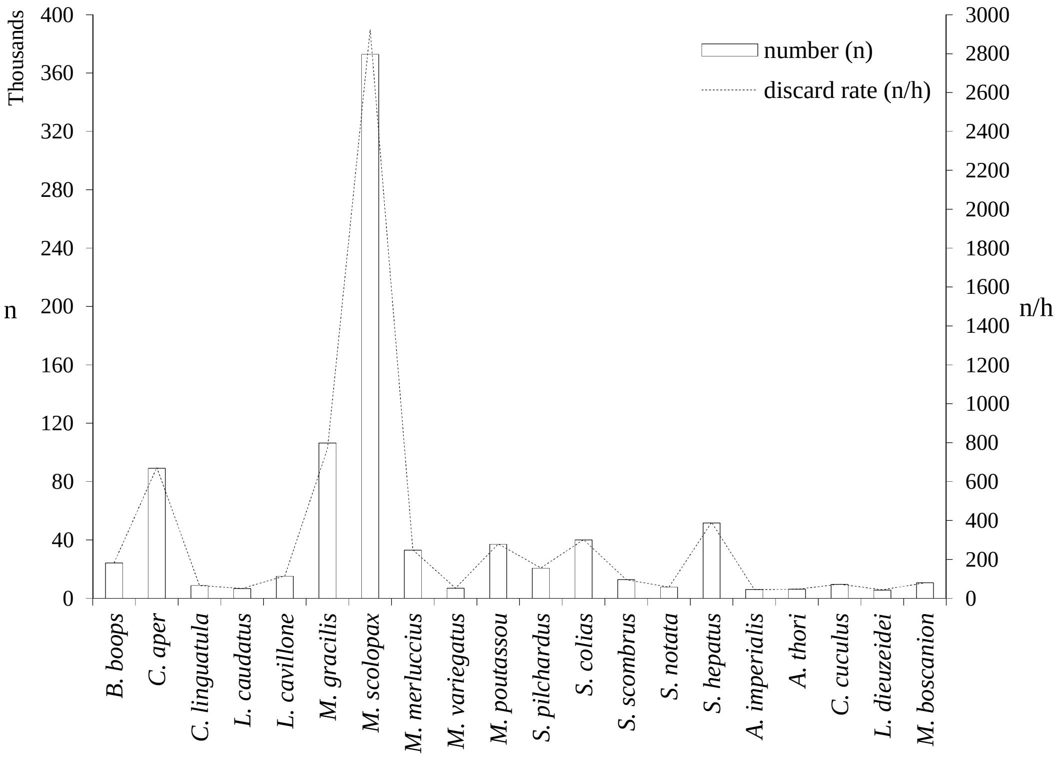


Figure 3.19 – Total estimated abundance (n), biomass (kg) and discard rates, in abundance (n/h) and biomass (kg/h), of the most discarded bony fish species in crustacean trawls.

Table 3.13 – Total estimated discarded abundance and biomass and discard rates, in number (n/h) and weight (kg/h), for the 25 bony fish species most discarded by fish trawl (% Ost– percentage of all bony fishes; % All–percentage of all fish and cephalopod species).

SPECIES	ABUNDANCE			BIOMASS			DISCARD RATE	
	n	% Ost	% All	kg	% Ost	% All	n/h	kg/h
Arnoglossus imperialis	6122	0.7	0.6	89.4	0.3	0.3	46	0.674
Arnoglossus thori	6279	0.7	0.6	60.2	0.2	0.2	47	0.454
Boop boops	24292	2.6	2.4	2527.8	9.8	8.0	183	19.059
Capros aper	89204	9.5	9.0	1391.4	5.4	4.4	673	10.491
Chelidonichthys cuculus	9609	1.0	1.0	222.0	0.9	0.7	72	1.674
Citharus linguatula	8811	0.9	0.9	243.8	0.9	0.8	66	1.838
Conger conger	4235	0.5	0.4	403.1	1.6	1.3	32	3.040
Helicolenus dactylopterus	3761	0.4	0.4	237.0	0.9	0.7	28	1.787
Lepidopus caudatus	6807	0.7	0.7	353.3	1.4	1.1	51	2.664
Lepidotrigla cavillone	15227	1.6	1.5	445.6	1.7	1.4	115	3.360
Lepidotrigla dieuzeidei	5784	0.6	0.6	144.3	0.6	0.5	44	1.088
Macroramphosus gracilis	106474	11.4	10.7	1229.3	4.8	3.9	770	8.721
Macroramphosus scolopax	372861	39.9	37.4	3887.5	15.1	12.2	2925	29.821
Merluccius merluccius	33118	3.5	3.3	904.6	3.5	2.8	250	6.820
Microchirus boscanion	10554	1.1	1.1	183.9	0.7	0.6	80	1.387
Microchirus variegatus	6984	0.7	0.7	237.4	0.9	0.7	53	1.790
Micromesistius poutassou	37043	4.0	3.7	1285.2	5.0	4.0	279	9.690
Pagellus acarne	5677	0.6	0.6	314.2	1.2	1.0	43	2.369
Sardina pilchardus	20772	2.2	2.1	1031.7	4.0	3.2	157	7.779
Scomber colias	39998	4.3	4.0	5163.0	20.1	16.3	302	38.929
Scomber scombrus	12823	1.4	1.3	1347.5	5.2	4.2	97	10.160
Scorpaena notata	7634	0.8	0.8	393.8	1.5	1.2	58	2.969
Serranus hepatus	51820	5.5	5.2	1286.7	5.0	4.1	391	9.702
Trachurus picturatus	4507	0.5	0.5	480.1	1.9	1.5	34	3.620
Trachurus trachurus	3450	0.4	0.3	257.0	1.0	0.8	26	1.938

The greatest bulk of discarded bony fish were accounted for by *M. poutassou* (43.6%, 1613 kg) in crustacean trawl, at a rate of 3.9 kg/h (Table 3.12, Figure 3.19); and by *Scomber colias* (20.1%, 5163 kg), *M. scolopax* (15.1%, 3887 kg) and *Boops boops* (9.8%, 2528 kg) in fish trawl, at rates of over 19 kg per hour (38.9 kg/h, 29.8 kg/h and 19.1 kg/h, respectively) (Table 3.13, Figure 3.20).



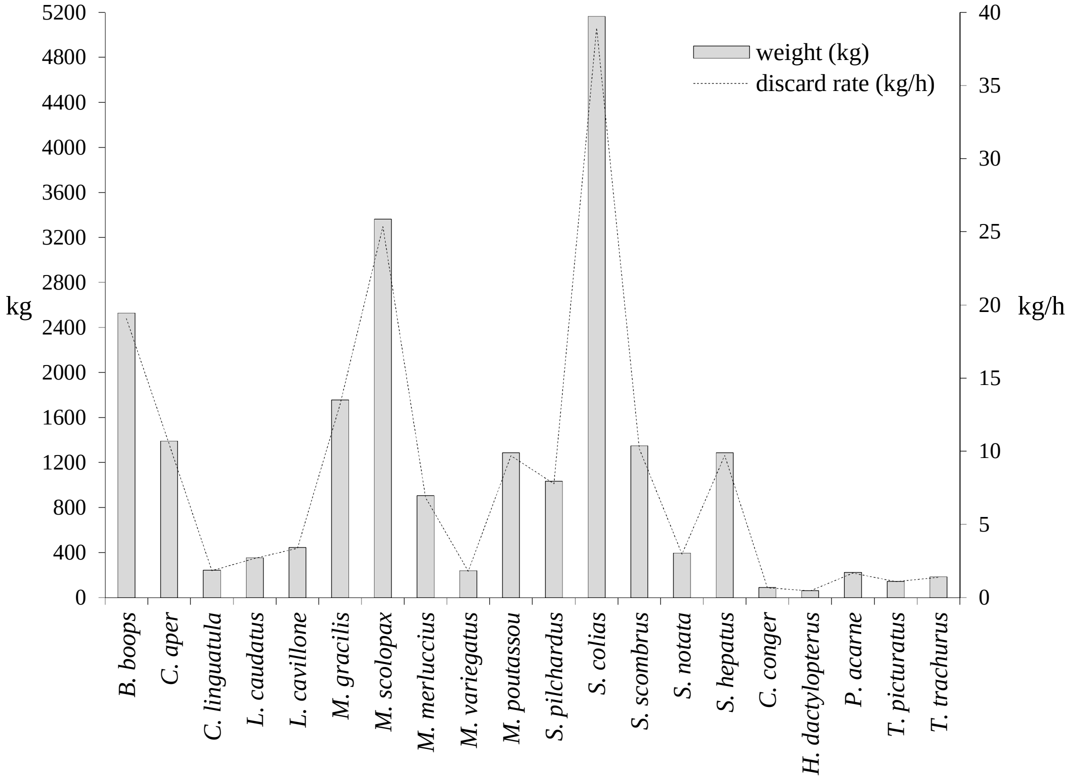


Figure 3.20 – Total estimated abundance (n), biomass (kg) and discard rates, in abundance (n/h) and biomass (kg/h), of the most discarded bony fish species in fish trawls.

Considering all fish and cephalopod species, *M. poutassou* stands out as the species most discarded by crustacean trawls, both in biomass (28.5%) and in abundance (20.8%), followed by *M. scolopax* (18.3%), *M. gracilis* (18.1%) and *C. aper* (14.1%) in number; and by *G. melastomus* (8%), *C. aper* (7%) and *C. conger* (6.6%) in biomass (Figure 3.21). In fish trawls, the most discarded species were *M. scolopax* (35.3%), *M. gracilis* (12.9%) and *C. aper* (9%) in abundance and *S. colias* (16.3%), *S. canicula* (14.8%), *M. scolopax* (10.6%) and *B. boops* (8%) in biomass (Figure 3.21). Target fishes were relatively unimportant in the discards, representing less than 2% (0.3-1.5% for horse mackerels and 1.2% for seabreams) in biomass and less than 1% (0.1-0.5 for horse mackerels and 0.6% for seabreams) in abundance. Only hake was discarded at slightly higher percentages (2.9% in weight and 3.7% in number).

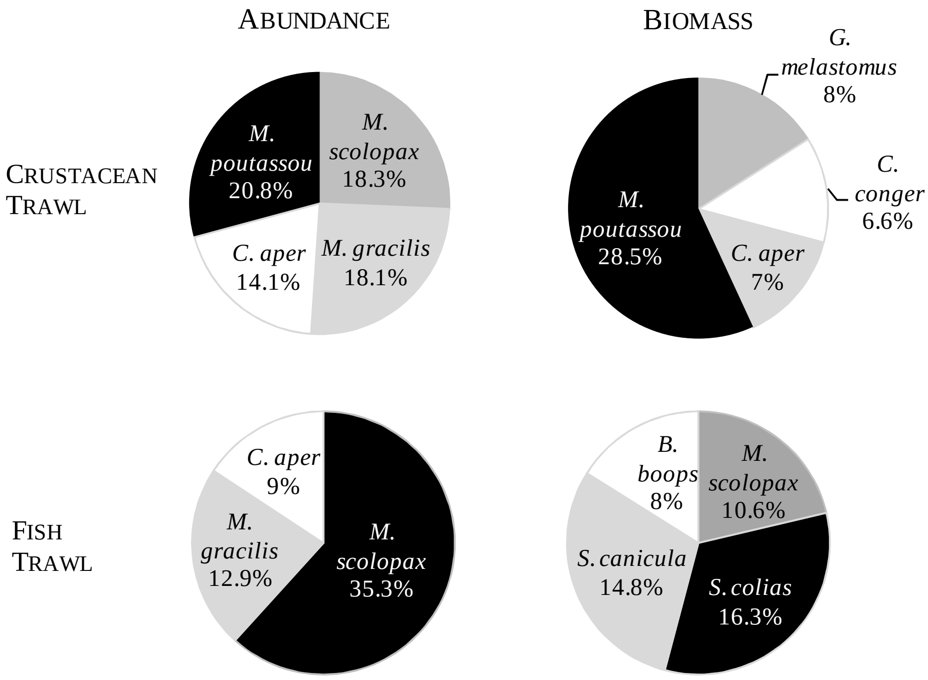


Figure 3.21 – Most discarded species of the crustacean and fish trawl métiers.

The total estimated discards and discards rates, both in abundance (n, n/h) and biomass (kg, kg/h), of each fish and cephalopod species discarded by crustacean and fish trawls, are given by métier and season in Annexes XIV and XV, respectively.

Reasons for discarding

The reasons for discarding identified in this study were: (1) economic reasons, such as low (LCV) or no commercial value (NCV), damaged or poor quality fish (DPQF) before gear retrieval, and no ready market available (NRMA) for commercial species; (2) legal and administrative (regulatory) demands, such as the minimum landing size (MLS) restriction; and (3) technical reasons, (e.g. gear damage and hauling capacity).

The majority of species were discarded because of NCV (68.6% of all species), whereas the least important reason was LCV (12.2% of species). Damage or poor quality of fish and MLS restrictions were the next most important reasons, responsible for discarding 24.7% and 26.3% of species, respectively. A total of 67 species (26.3%) were recorded as discards because there is no readily available market for them.

The fish trawl target species, *Diplodus vulgaris*, *Merluccius merluccius*, *Pagellus acarne, P. bogaraveo, P. erythrinus, Trachurus mediterraneus, T. picturatus* and *T. trachurus* were discarded mainly for regulatory (MLS) reasons, followed by the economic (DPQF) ones. However, for *M. merluccius* catches below MLS were the prime reason for discarding. The same reasons, in equal importance, were also responsible for discarding of the crustacean trawl target species, *Aristeus antennatus* and *Parapenaeus longirostris*.

For the most discarded cephalopod species, *A. subulata*, *Eledone* spp., *Illex coindetii* and *Sepia* spp., the foremost reason for discarding was the absence of a readily available market. However, for *I. coindetii*, MLS is another important reason for discarding, and *Eledone* spp. is quite often discarded also due to its damaged and poor quality after tows of long duration (Table 3.14).

For the great majority (71.4%) of the cartilaginous fishes, the main reason for discarding is purely economic since they have no commercial value (NCV). Nevertheless, and even though there is no readily available market for them, few (n=6) cartilaginous fish species that have some commercial value (e.g. *G. melastomus* and *S. canicula*) are discarded mainly for economic (LCV) reason. Although no MLS is applicable to *G. melastomus* and *S. canicula*, the smaller ones are discarded. The same reasons are valid for the rays *Raja clavata* and *R. undulata*[4] although it is mostly discarded for regulatory (MLS) reasons (Table 3.14).

[4] In 2009 the European Council required full protection of this species in ICES areas VIa-b, VIIa-k, VIII and IX, prohibiting its retention and landing (Shark Trust, 2009). However, recently ICES advised that "*There is no basis in the current or previous ICES advice for the listing of undulate ray as a prohibited species. Therefore it should not appear on the prohibited species list in either the Celtic Seas or the Biscay/Iberia ecoregion fisheries legislation (…). In view of the poor knowledge and patchy distribution of these populations, ICES recommends a precautionary approach to the exploitation of these populations of undulate ray*" (ICES, 2013).

Bony fishes were discarded fundamentally for economic reasons. The majority (52.6%) of these species were discarded due to no commercial value (e.g. *Macroramphosus* spp., *Capros aper*) and 22.4% because of low commercial value (e.g. *Micromesistius poutassou*, *Boops boops*). Damage or poor quality of fish was another reason for discarding a quite considerable percentage (43.1%) of marketable bony fish species (e.g. *Merluccius merluccius*, *Micromesistius poutassou*). The regulatory minimum landing size was the second most important reason responsible for discarding a high percentage (48.3%) of bony fish species (e.g. *Merluccius merluccius*, *Scomber colias*) (Table 3.14).

Retention of great amounts of mud, bolders or large man-made objects in the trawling net causing the breaking of the net, lead to the escape of the entire catch in 5.6% of the crustacean trawl tows and 2.2% of fish trawl tows. Other technical issues, like hauling capacity and bad weather during fishing operations in the crustacean trawl métier, were factors which have conditioned the fishing operations in 1.4% and 2.8% of tows, respectively.

The discards reasons found for each of the 255 discarded species are given in Annex XVI, and the discard reasons found on each trip, by tow and métier, can be seen in Annex XVII.

Table 3.14 – Discard reasons for the 93 fish and cephalopod species selected for statistical analysis, along with all cephalopod and cartilaginous fish species (T-Target; B-Bycatch; D-Discard; NCV-no commercial value; LCV-low commercial value; MLS-minimum landing size; DPQF-damaged or poor quality fish; NRMA-no readily market available). In bold are the main reasons for discarding.

SPECIES	TYPE	DISCARD REASONS
Alloteuthis media	B	NRMA
Alloteuthis subulata	B	NRMA
Argentina sphyraena	D	NCV
Arnoglossus imperialis	B	NRMA, **DPQF**, **MLS**
Arnoglossus laterna	B	NRMA, **DPQF**, **MLS**
Arnoglossus rueppeli	B	NRMA, **DPQF**, **MLS**
Arnoglossus thori	B	NRMA, **DPQF**, **MLS**
Balistes capriscus	D	NCV
Benthodesmus elongatus	D	NCV
Boops boops	B	NRMA, **LCV**, DPQF, **MLS**
Callionymus lyra	D	NCV
Callionymus maculatus	D	NCV
Capros aper	D	NCV
Centrophorus granulosus	B	NRMA, **LCV**
Cepola macrophthalma	D	NCV
Chelidonichthys cuculus	B	NRMA, **LCV**, DPQF, MLS
Chelidonichthys lucerna	B	NRMA, **LCV**, DPQF, MLS
Chelidonichthys obscurus	B	NRMA, **LCV**, DPQF, MLS
Chimaera monstrosa	D	NCV
Chlorophthalmus agassizi	D	NCV
Citharus linguatula	B	NRMA, **LCV**, **DPQF**, MLS
Coelorinchus caelorinchus	D	NCV
Conger conger	B	NRMA, **LCV**, DPQF, **MLS**
Dalatias licha	D	NCV
Deania calcea	D	NCV
Dipturus oxyrhinchus	D	NCV
Eledone cirrhosa	B	NRMA, DPQF
Eledone moschata	B	NRMA, DPQF
Engraulis encrasicolus	B	NRMA, **DPQF**, MLS
Etmopterus pusillus	D	NCV
Etmopterus spinax	D	NCV
Gadiculus a. argenteus	D	NCV
Gaidropsaurus biscayensis	D	NCV
Galeus melastomus	B	NRMA, **LCV**
Helicolenus dactylopterus	B	NRMA, **LCV**, DPQF, **MLS**

Table 3.14 (cont.) – Discard reasons for the 93 fish and cephalopod species selected for statistical analysis, along with all cephalopod and cartilaginous fish species (T-Target; B-Bycatch; D-Discard; NCV-no commercial value; LCV-low commercial value; MLS-minimum landing size; DPQF-damaged or poor quality fish; NRMA-no readily market available). In bold are the main reasons for discarding.

SPECIES	TYPE	DISCARD REASONS
Hexanchus griseus	B	NRMA, **LCV**
Hoplostethus m. mediterraneus	D	NCV
Illex coindetii	B	NRMA, DPQF
Lepidopus caudatus	B	NRMA, **LCV**, **DPQF**, **MLS**
Lepidotrigla cavillone	D	NCV
Lepidotrigla dieuzeidei	D	NCV
Lesueurigobius sanzi	D	NCV
Leucoraja naevus	D	NCV
Loligo vulgaris	B	NRMA, DPQF, **MLS**
Lophius budegassa	B	NRMA, DPQF, **MLS**
Lophius piscatorius	B	NRMA, DPQF, **MLS**
Macroramphosus gracilis	D	NCV
Macroramphosus scolopax	D	NCV
Malacocephalus laevis	D	NCV
Merluccius merluccius	T	DPQF, **MLS**
Microchirus azevia	B	NRMA, **LCV**, **DPQF**, MLS
Microchirus boscanion	B	NRMA, **LCV**, **DPQF**, MLS
Microchirus variegatus	B	NRMA, **LCV**, **DPQF**, MLS
Micromesistius poutassou	B	NRMA, **LCV**, **DPQF**
Mora moro	D	NCV
Myctophidae n.i.	D	NCV
Neorossia caroli	D	NCV
Nezumia sclerorhynchus	D	NCV
Notacanthus chemnitzii	D	NCV
Octopus salutii	D	NCV
Octopus vulgaris	B	NRMA, DPQF, **MLS**
Pagellus acarne	T	DPQF, **MLS**
Phycis blennoides	B	NRMA, **DPQF, MLS**
Polymetme corythaeola	D	NCV
Pontinus kuhlii	D	NCV
Raja clavata	B	NRMA, LCV, **MLS**
Raja undulata	B	NRMA, LCV, **MLS**
Rossia macrosoma	D	NCV
Ruvettus pretiosus	B	NRMA, **LCV**, DPQF, MLS
Sardina pilchardus	B	NRMA, **DPQF**, **MLS**

Table 3.14 (cont.) – Discard reasons for the 93 fish and cephalopod species selected for statistical analysis, along with all cephalopod and cartilaginous fish species (T-Target; B-Bycatch; D-Discard; NCV-no commercial value; LCV-low commercial value; MLS-minimum landing size; DPQF-damaged or poor quality fish; NRMA-no readily market available). In bold are the main reasons for discarding.

SPECIES	TYPE	DISCARD REASONS
Scaeurgus unicirrhus	D	NCV
Scomber colias	B	NRMA, DPQF, **MLS**
Scomber scombrus	B	NRMA, DPQF, **MLS**
Scorpaena notata	B	NRMA, **LCV**, DPQF, **MLS**
Scyliorhinus canicula	B	NRMA, **LCV**
Scymnodon ringens	D	NCV
Sepia elegans	B	NRMA, DPQF
Sepia orbignyana	B	NRMA, DPQF
Sepietta oweniana	D	NCV
Serranus cabrilla	B	NRMA, **LCV**, DPQF, **MLS**
Serranus hepatus	D	NCV
Sphoeroides pachygaster	D	NCV
Spondyliosoma cantharus	B	NRMA, DPQF, **MLS**
Symphurus ligulatus	D	NCV
Synaphobranchus kaupii	D	NCV
Todaropsis eblanae	B	NRMA, DPQF
Torpedo nobiliana	D	NCV
Trachurus mediterraneus	T	DPQF, **MLS**
Trachurus picturatus	T	DPQF, **MLS**
Trachurus trachurus	T	DPQF, **MLS**
Trigloporus lastoviza	B	NRMA, **LCV**, DPQF, MLS
Venefica proboscidea	D	NCV
Zeus faber	B	NRMA

Discussion

Commercial bottom trawling is a very important economic and social activity carried out in the Algarve that produces considerable amounts of bycatches (Chapter 2) which are discarded at sea. The outcomes of the present study highlight the importance of discarding by the southern Portuguese demersal trawl fisheries, which was significant in terms of amounts, species composition, abundance and biomass.

Although there is a relatively good representativeness of the randomly selected active part of the Algarve coastal trawler fleet, the discard estimates presented in this study should be viewed with some reservations since they do not represent the entire trawl fleet of the south coast of Portugal and refer only to a short period of two years. It should also be noted that vessels of the Spanish trawl fleet licensed to fish in Algarve waters were also not sampled since, due to differing consumption practices, it may be that discarding practices may also be different for the Spanish vessels. Given the degree of uncertainty that an extrapolation of data entails, raising discard data to fleet level has been avoided in this study. However, in our opinion, these estimates could reasonably point towards the possible order of magnitude of discards in trawl fisheries in this area.

Discard estimates

During the 1999-2001 sampling period studied, more than a half (~57%) of the total catch by weight was discarded at sea by the two trawl métiers, at average rates of about 154 kg/h. On average, fish trawls retained (248 kg) and discarded (360 kg) more fish and invertebrates per tow than crustacean trawls (112 kg and 96 kg, respectively), at a considerably higher discard mean rates (260 kg/h *vs.* 19 kg/h). A previous study on fisheries discards in the same studied area also reported higher mean amounts of discards per tow in fish trawls (1103 kg) compared to crustacean trawls (306 kg) (Erzini *et al.*, 2002). In 1996, Borges *et al.* (2001) estimated that trawl discards in the Algarve represented from 9,000 to 13,000 tonnes per year.

Our results point towards high mean discard proportions in both métiers, of about 0.46 (0.34-0.72) for crustacean trawls and 0.59 (0.31-0.74) for fish trawls. Other studies on bottom trawls in the Algarve reported higher mean values of proportions of the catch discarded by crustacean trawls of 0.70 (0.36-0.91) (Borges *et al.* 2001) and 0.51 (0.33-0.89) (Borges *et al.* 2002) in comparison to fish trawls, which discarded between 0.59-0.91 (0.62 avg.) (Borges *et al.* 2001) and 0.27-0.75 (0.35 avg.) (Borges *et al.* 2002). Considering that higher discard proportions in trawls results from longer tows, as a consequence of the reduction of the selectivity of the net (Castriota *et al.*, 2001; Murawski, 1996; Tamsett *et al.*, 1999; Tudela, 2004), this consistent difference in discarding between both métiers (higher for fish trawls, trawling for a shorter period of time), is related with the preferential catch of small pelagics (e.g. *Macroramphosus* spp.) whose depth distribution overlaps the depth range exploited by fish trawlers.

Erzini *et al.* (2002) also considers depth as determinant in the distinction between métiers. Sánchez *et al.* (2004) and Tamsett *et al.* (1999) refer that the higher discard proportions found in shallower waters, which is the case of our studied fish trawls, were associated with the presence of small fish closer to the coast. The data collected in the present study are not sufficient to corroborate this assumption, as it was not initially addressed, but it would be quite important to consider it in futures studies concerning discards.

A further study on the crustacean trawl métier in southern Portuguese waters carried out by Monteiro *et al.* (2001), reported considerably lower mean discard proportions (range 0.05-0.76, mean 0.37). Additionally, a discards monitoring program for the entire Portuguese coast is underway under the responsibility of the IPMA (Portuguese Institute for the Ocean and Atmosphere) since late 2003 (Anon., 2006). This program, carried out within the scope of the European Union Data Collection Framework is intended to cover the main groups of fishing gears, including trawls. Discard estimates, dating back to 2009 data, corroborates our own data evidencing high discard proportions, both for crustacean (~0.35-0.64) and fish trawl (~0.17-0.62) métiers (Prista, 2012).

The differences among the discard proportions found in our study and those reported by others are certainly related to either temporal or spatial quantitative and qualitative changes in fish communities, as pointed out by Monteiro *et al.* (2001), Erzini *et al.* (2002) and Anon. (2010).

In Portugal, discard proportions higher than those characteristically produced by crustacean and fish trawl fisheries have only been reported for the beam trawl fishery within the Tagus estuary, targeting brown-shrimp (*Crangon crangon*) and soles (*Solea solea* and *S. senegalensis*), which are in the order of 0.90 (Cabral *et al.*, 2002); classified by Kelleher (2005) as one of the world's non-shrimp trawl fisheries with the highest discard proportions.

Discards are not restricted to trawl fisheries. Very close to the average results of this study, relatively high proportions of discards were also reported in Portugal for some trammel net (0.49 and 0.74) (Gonçalves *et al.*, 2007, 2008b), demersal purse seine (0.51) (Gonçalves *et al.*, 2004, 2008a) and beach seine (0.44) (Cabral *et al.*, 2003) fisheries. These proportions are uncharacteristically high for small-scale fisheries, not only in Portugal (which are between 0.03 and 0.27) and in the Mediterranean (0.01-0.30) but around the world (0.05-0.075) (Table 3.15), in which the total amount of discards is known to be much lower than those of bottom trawls (Kelleher, 2005), given the higher selectivity of their gears.

Table 3.15 – Discard proportions in small scale fisheries[5].

FISHING ZONE	FISHING AREA	MÉTIER	DISCARD RATIO	REFERENCE
Portugal	southern coast, Algarve	pelagic purse seine	0.03	Borges *et al.* (2000)[1]
		pelagic purse seine	0.27	Borges *et al.* (2001)[2]
		demersal purse seine	0.07	Borges *et al.* (2000)[3]
		demersal purse seine	0.20	Borges *et al.* (2001)[4]
		demersal purse seine	0.51	Gonçalves *et al.* (2004, 2008a)[5]
		purse seine	0.06	Borges *et al.* (2002)[6]
		trammel	0.13	Borges *et al.* (2001)[7]
		trammel	0.49	Gonçalves *et al.* (2007)[8]
		trammel	0.74	Gonçalves *et al.* (2008b)[9]
		trammel	0.22	Batista *et al.* (2009)[10]
		gillnet	<0.03	Santos *et al.* (2002)[11]
		longline	<0.03	Santos *et al.* (2002)[12]
	central coast, south Lisbon	beach seine	0.44	Cabral *et al.* (2003)[13]
Spain		purse seine, gillnet, longline	0.13-0.15	Kelleher (2005)
Mediterranean	Patraikos Gulf, western Greece	trammel	0.01-0.06	Tzanatos *et al.* (2007)[14]
		gillnet	0.30	Tzanatos *et al.* (2007)
		combined nets	<0.02	Tzanatos *et al.* (2007)
		longline	0.06	Tzanatos *et al.* (2007)
		all fisheries	0.10	Tzanatos *et al.* (2007)[15]
	eastern Adriatic Sea	seine	0.29	Cetinić et al. (2011)[16]
	north-central western Aegean Sea	pelagic purse seine	0.05	Tsagarakis *et al.* (2012)
	eastern Ionian Sea	pelagic purse seine	0.02	Tsagarakis *et al.* (2012)
World	global	small pelagic seine	0.016	Kelleher (2005)[17]
		beach seine	0.044	Kelleher (2005)[18]
		gillnet	0.005	Kelleher (2005)[19]
		bottom longline	0.075	Kelleher (2005)[20]

[1] 0.001-0.07 range, 3,080 kg; [2] 5,509 kg/trip average; [3] 0.005-0.24 range, 3,075 kg; [4] 1,129 kg/trip average; [5] 8,266 kg, 49% mean/tow, percentages of total number discarded; [6] 0.01-0.10 range, 685 kg, 171 kg/tow average; [7] 9.4 kg/trip average; [8] percentages of total number discarded; [9] average percentages discarded numbers per 1000 m of net; [10] ca. 170 t/year (amounts in g/10,000 m of net), 53% in number; [11] non-commercial species (43% hake discards); [12] non-commercial species (10% hake discards); [13] 605 t/year; [14] with a single record of 0.44; [15] 114 kg; 16 319 kg, 44% in number; [16] 319 kg, 44% in number; [17] weigthed global average (351,111 t); [18] weigthed global average (1,068 t); [19] weigthed global average (29,004 t); [20] weigthed global average (10,988 t).

In spite of the differences in species′ composition and abundance, the discards generated by nearby foreign coastal bottom trawl fisheries also constitute an important fraction of the total catch. Several studies conducted in Mediterranean waters also reported high and variable discard proportions of 0.20-0.67 in the western part, 0.42-0.72 in the central part of the Mediterranean and 0.20-0.63 in the eastern part (Table 3.16). Similarly, comparable high discard levels have been described for demersal trawl fisheries in the Northeast Atlantic: 0.30-0.59 in northern Spain, 0.24-0.55 in the Celtic Sea, 0.60-0.84 in the Clyde Sea, 0.20-0.67 in western waters of British Isles and 0.25-0.95 in the North Sea (Table 3.17). According to

[5] For the purpose of comparison with the values of this study, the discard percentages presented by the authors were transformed to proportions.

Kelleher (2005), the existence of few trawl grounds justifies the slightly lower discard proportions in the Mediterranean compared to northern Atlantic areas. According to Machias *et al.* (2001), these differences are due both to biological factors (different target fishing communities) and market factors (higher number of species landed and commercialization of small sized fish). Our values are in line with the weighted global average discards for trawls (>0.50) referred by Kelleher (2005), either targeting shrimp (0-0.96) or demersal finfish (0.05-0.83), considered as the two major types of fisheries that contribute most to discards. The particularly high discard proportions found in trawl fisheries are universally attributable to the inherently low species and size selectivity of the gear (e.g. Alverson *et al.*, 1994; Catchpole *et al.*, 2005b; Kelleher, 2005; Tingley *et al.*, 2000), but Pravoni *et al.* (2001) also believe that it is largely attributable to the low density of target species due to over-exploitation.

Table 3.16 – Discard proportions in Mediterranean trawl fisheries[6].

FISHING AREA	FISHING ZONE	MÉTIER	DISCARD RATIO	REFERENCE
Eastern	Saronikos Gulf, Thracian Sea, Cyclades Islands and Ionian Sea	bottom trawl	0.45	Stergiou *et al.* (1998)
	Aegean Sea, Cyclades	bottom trawl	0.59-0.63	Vassilopoulou and Papaconstantinou (1998)
	off Israel	otter trawl	0.28	Edelist *et al.* (2011)[1]
Northeastern	Ionian Sea, Thracian Sea and Cyclades Islands	bottom trawl	0.44	Machias *et al.* (2001)[2]
Eastern-Central	Ionian Sea	bottom trawl	0.20-0.50	D´Onghia *et al.* (2003)
Central	Straits of Sicily	shrimp trawl	0.49	Castriota *et al.* (2001)
		bottom trawl	0.42	Ragonese *et al.* (2001)
	Sicilian Channel	shrimp trawl	0.45	Campagnuolos *et al.* (2001)
	Sicily	trawl	0.44-0.72	Charbonnier (1990 in Tudela, 2004)[3]
Western	Spain and Italy	trawl	0.13-0.67	Carbonell *et al.* (1998)
	Southeast Spain	bottom trawl	0.35	Soriano and Sánchez-Lizaso (2000 in Tudela, 2004)
	Balearic Islands	shrimp trawl	0.42	Moranta *et al.* (2000)
	Northern Tyrrhenian Sea	bottom trawl	0.20	Sartor *et al.* (2003)
North-western	Catalan coast	bottom trawl	0.33	Sánchez *et al.* (2004)[4]
	Adriatic Sea and Catalan Sea	otter trawl	0.39-0.48	Sánchez *et al.* (2007)[5]
Mediterranean and Black Sea	FAO statistical area 37	shrimp trawl	0.86	Kelleher (2005)[6]
		all fisheries	0.05	Kelleher (2005)[7]

[1] range of 400-700 t/year and 3.7-9.9 kg/h; [2] range of 39-49%; [3] 70,000 t/year; [4] range of 17-34% (3.7 -164.8 kg/h average); [5] range of 7.8-24.61 kg/h; [6] weighthed discard rate, 70,000 t *Nephrops* and deepwater shrimps; [7] 17,954 t (1992-2001 average discards).

[6] For the purpose of comparison with the values of this study, the discard percentages presented by the authors were transformed to proportions

Table 3.17 – Discard proportions in the Northeast Atlantic trawl fisheries[7].

FISHING ZONE	MÉTIER	DISCARD RATIO	REFERENCE
Galicia, Spain	demersal fish and crustacean trawls	0.35-0.59	Perez *et al.* (1996 in Valeiras, 2003)[1]
	demersal fish trawl (coastal)	0.42	Vázquez-Rowe *et al.* (2011)[2]
	demersal fish trawl (offshore)	0.43	Vázquez-Rowe *et al.* (2011)[3]
Bay of Biscay (ICES Divisions VIIIa,b), Spain	*Nephrops* trawl	0.30	ICES (2006 in Macher *et al.*, 2008)[4]
Celtic Sea, France	benthic trawl	0.24	Rochet *et al.* (2002)[5]
	gadoid trawl	0.26	Rochet *et al.* (2002)[6]
	Nephrops trawl	0.55	Rochet *et al.* (2002)[7]
	Trawl fleet	0.32	Rochet *et al.* (2002)[8]
Firth of Clyde (west), Scotland	*Nephrops* trawl	0.60	Stratoudakis *et al.* (2001)[9]
Clyde Sea (north), Scotland	*Nephrops* trawl	0.84	Bergmann *et al.* (2002)[10]
Clyde Sea (south), Scotland	*Nephrops* trawl	0.71	Bergmann *et al.* (2002)[11]
British Isles, West coast	demersal fish trawl	0.52	Allain *et al.* (2003)[12]
	bottom trawl	0.20-0.40	CEC (2007a)
England and Wales (ICES sub-area VII)	beam trawl	0.42	Enever *et al.* (2007)[13]
	otter trawl	0.36	Enever *et al.* (2007)[14]
Ireland	demersal trawl	0.32	Connolly & Kelly (1996)[15]
Ireland (ICES Divisions VIa,b; VIIa-c,g,j)	beam trawl	0.67	Borges *et al.* (2005a)[16]
	otter trawl	0.20-0.60	Borges *et al.* (2005a)[17]
North Sea (ICES sub-area IV)	flatfish beam trawl	0.05-0.75	Van Beek *et al.* (1998)

[1] 42,000 tons/year;[2] 36,066 t/year (487 t/year average);[3] 13,064 t/year (321 t/year average);[4] *Nephrops* discards, 1,875 t, 60% in number;[5] 5,469 t;[6] 12,083 t;[7] 13,566 t;[8] 29,773 t;[9] 1,761 t/year average, as percentage of the fish bycatch;[10] range of 0.46-0.98;[11] range of 0.47-0.86;[12] 17 423 t/year, 0.024–0.824 range, 0.485 per haul;[13] 12,356 t/year average, in number: 71%, 313 fish/hour [14] 8,931 t/year average, in number: 64%, 180 fish/hour;[15] 7,520 t;[16] 1,806 t/year; [17] 285-4,966 t/year;[18] 0.25 average, 100 kt/y.

[7] For the purpose of comparison with the values of this study, the discard percentages presented by the authors were transformed to proportions

Table 3.17 (cont.) –Discard proportions in the Northeast Atlantic trawl fisheries[7].

FISHING ZONE	MÉTIER	DISCARD RATIO	REFERENCE
North Sea (ICES sub-area IV)	flatfish beam trawl	0.71-0.95	Lindeboom and Groot (1998 in Catchpole *et al.*, 2005a)
	Nephrops otter trawl	0.45	Catchpole *et al.* (2002)
	roundfish otter trawl	0.20-0.65	Cotter *et al.* (2002 in Catchpole *et al.*, 2005a)[19]
	Nephrops trawl	0.45	ICES (2006 in Catchpole *et al.*, 2008)
	flatfish beam and otter trawl	0.38-0.54	Panten *et al.* (2003 in Ulleweit *et al.*, 2010)
	Nephrops trawl	0.45	Catchpole *et al.* (2008)
	flatfish beam trawl	0.77	Catchpole *et al.* (2008)[20]
	otter trawl	0.18	Enever *et al.* (2009)[21]
	demersal fish beam trawl	0.31	Enever *et al.* (2009)[22]
	Nephrops trawlers	0.36	Enever *et al.* (2009)[23]
	Trawl fleet	0.25	Enever *et al.* (2009)[24]
North Sea, NE England	White fish, pair, seine and *Nephrops* trawls	0.15-0.59	Tamsett and Janacek (1999)[25]
	Nephrops trawl	0.57	Catchpole *et al.* (2005c)[26]
	Nephrops trawl	0.43	Catchpole *et al.* (2005c)[27]
North Sea, German Bight and off the Dutch coast	beam trawl	0.56-0.72	Ulleweit *et al.* (2010)
	bottom trawl	0.46-0.64	Ulleweit *et al.* (2010)
North Sea	beam trawl	0.40-0.60	CEC (2007a)
	bottom trawl	0.40	CEC (2007a)
FAO statistical area 27	all fisheries	0.13	Kelleher (2005)[28]

[19] expressed in number, cod (20-48%), haddock (30-41%), whiting (51-65%); [20] 6,850 kg/vessel/day; [21] mean annual estimates, 2,109 t average, 44% in number; [22] 1,962 t average, 59% in number; [23] 1,344 t average, 22% in number; [24] 36% in number; [25] average ratiosrates, cod (15-34%), haddock (18-59%), whiting (18-59%); [26] 4,890 t, including Nephrops heads; [27] 3,682 t, 74 kg/h average,excluding Nephrops heads, 57% and 85% of Nephrops discards; [28] 1,332,212 t (1992 -2001 average).

Discards variability

Regardless of the geographic location, high temporal and spatial variability of the discards proportions and amounts is recognized in different fisheries around the world (Alverson *et al.*, 1994; Andrew and Pepperell, 1992; Cotter *et al.*, 1995; Crean and Symes, 1994; Kelleher, 2005; Kennelly *et al.*, 1998; Margeirsson *et al.*, 2012; Morizur *et al.*, 2004; Murawski, 1996). Discards variability is highly dependent on the type of fishery (Kelleher, 2005; STECF, 2008), being reported from small-scale (e.g. Cetinić *et al.*, 2011; Tsagarakis *et al.*, 2012; Tzanatos *et al.*, 2007; Welch *et al.*, 2008) to trawl (e.g. Edelist *et al.*, 2011; Lema *et al.*, 2006; Sánchez *et al.*, 2007; Ulleweit *et al.*, 2010; Walmsley *et al.*, 2007) fisheries.

There is a multiplicity of factors, pointed out by several authors, that influence the variability of discards: from technical characteristics of the vessels (e.g. type, size, performance) and gears (e.g. type, characteristics, mesh size), fishing strategies (e.g. haul/trip duration, catch size and composition), environmental variables (e.g. season, area, depth, distance from shore, ground/bottom type, landing port) and species (e.g. spatial distribution, abundance, recruitment, biology, migration), to fishers behaviour (e.g. personal skills and decision makings concerning fishing strategies), market constraints (e.g. local demands, prices), and regulation issues (e.g. quota, minimum landing size, mesh size) (Table 3.18).

Table 3.18 – Factors conditioning the variability in discards.

Reference	Season	Area	Depth	Species	Landing port	Vessel	Gear	Fishing effort	Catch	Market	Legislation
Allain *et al.* (2003)		X	X	X				X			
Alverson *et al.* (1994)	X		X				X	X			
Blasdale and Newton (1998)			X	X						X	X
Borges *et al.* (2005b)								X			
Cabral *et al.* (2003)	X										
Carbonell *et al.* (1998)		X	X						X	X	
Castriota *et al.* (2001)								X			
Catchpole *et al.* (2005c)										X	
Cetinić *et al.* (2011)		X		X							
Connolly and Kelly (1996)	X	X	X				X				
Crean and Symes (1994)		X					X	X			
D´Onghia *et al.* (2003)		X	X						X		
Edelist *et al.* (2011)									X		
Erzini *et al.* (2002)		X	X	X	X		X				
Feekings *et al.* (2012)	X	X		X		X					
García-Rodriguez and Esteban (1999)				X							
Gonçalves *et al.* (2007)	X						X				
Gonçalves *et al.* (2008b)	X		X								
Gray *et al.* (2005)	X	X					X				
Howell and Langan (1987)		X		X		X	X		X		X
Kelleher (2005)	X	X			X		X	X	X	X	X
Kennelly *et al.* (1998)	X	X									
Lema *et al.* (2006)		X		X			X			X	
Machias *et al.* (2001)	X	X	X					X			
Machias *et al.* (2004)	X			X						X	
Monteiro *et al.* (2001)				X							
Moranta *et al.* (2000)									X		
Morizur *et al.* (1999)		X		X			X				X
Murawski (1996)							X		X		
Pálsson (2003)		X					X				
Pravoni *et al.* (2001)				X				X			
Recasens *et al.* (1998)				X							
Rochet *et al.* (2002)				X			X	X	X	X	
Saila (1983)	X	X		X	X		X		X	X	
Sánchez *et al.* (2004)									X		
Sánchez *et al.* (2007)		X							X		
Sartor *et al.* (1999 in Tudela, 2004)	X								X		
Stergiou *et al.* (1998)	X	X									
Stratoudakis *et al.* (1998 in Trenkel and Rochet, 2001)							X		X		
Tamsett (1995)	X	X			X		X			X	X
Tamsett and Janacek (1999)		X	X			X	X				
Tamsett *et al.* (1999)								X			X
Tsagarakis *et al.* (2012)		X		X					X	X	
Tsitsika and Maravelias (2006 in Tsagarakis *et al.*, 2012)											
Tudela (2004)		X	X								
Tzanatos *et al.* (2007)				X					X	X	
Ulleweit *et al.* (2010)								X		X	X
Van Beek (1998)	X			X							X
Walmsley *et al.* (2007)				X							
Welch *et al.* (2008)				X				X			

In southern Portugal, type of gear (Erzini *et al.*, 2002), season (Cabral *et al.*, 2003; Gonçalves *et al.*, 2007, 2008b), area (Erzini *et al.*, 2002), depth (Erzini *et al.*, 2002; Gonçalves *et al.*, 2008b), landing port (Erzini *et al.*, 2002) and species´ abundance and distribution (Borges *et al.*, 2000; Erzini *et al.*, 2002; Monteiro *et al.*, 2001) are identified as influencing discard variability. Borges *et al.* (2000) also consider that the inter-annual differences in biological and environmental conditions, as well as economic and marketing reasons, are possible explanations that might be in the origin of the variability found in the discard proportions.

Although there are a number of fisheries displaying evidence of proportionality between the total catches or landings and the amount of discards (Feekings *et al.*, 2012; Machias *et al.*, 2001), our analysis did not find any statistically significant proportionality between total catches and the amount of discards. Also no seasonal patterns in the discards rates and proportions were evidenced. Similarly, D´Onghia *et al.* (2003) and Tsagarakis *et al.* (2012) also did not find any significant seasonal patterns among the highly variable discards in the Eastern Mediterranean Sea. The former authors rely on the Stergiou *et al.* (1998) explanation, that the increase in discards with the total catch could be related to the decreased selectivity of codends. For Tsagarakis *et al.* (2012), this situation is possibly explained by the different recruitment periods of the species, an opinion shared by Gonçalves *et al.* (2008a) for a trammel net fishery discard study in southern Portugal, and also by Cabral *et al.* (2003) for a beach seine fishery discard study in the central coast of Portugal. In the Northwest Atlantic Newfoundland coast, Ibarrola and Paz (2011) also found no seasonal variability pattern in the discards generated by bottom trawls targeting Greenland halibut, alleging that discards were probably more associated to the fishing vessel's strategy, such as the exceeding of the available quota or of the onboard storage capacity. Tsagarakis *et al.* (2012) also considers the variability of the fishing and discarding practices as determinant in the seasonal variations of discards. For Feekings *et al.* (2012), the seasonality of the discards found in the Danish Kattegat demersal trawl fisheries is also ascribed to both the species and targeting behaviour´s seasonality of the fishermen.

Non-linear increases of discards with total catch or weak relationship between discards and landings are reported by some authors (Rochet and Trenkel, 2005; Rochet *et al.*, 2002; Tsagarakis *et al.*, 2012; Trenkel and Rochet, 2001), which consider this non-linearity as a reflection of the complexity of the factors that affects discards. Tamsett *et al.* (1999) also calls into question that the discarding proportion is a function of catch size. A result also reported by Cetinić *et al.* (2011) state that both catch amounts and season have no influence on the discard rates.

In our study, the rates of the retained catches varied considerably within métiers from 1.4 kg/h to 3.9 kg/h in crustacean trawls and from 5.2 kg/h to 12.9 kg/h in fish trawls always exceeding the discard rates (1.1-2.4 kg/h *vs.* 4.5-9.3 kg/h). Discards in excess of landings were found only for particular seasons/years, associated to the sporadic presence of high amounts of *Micromesistius poutassou* (summer 2000, winter 2000, autumn 1999), *Capros aper* (winter 2000) and cartilaginous fishes (*Chimaera monstrosa, Torpedo nobilian*a and *Galeus melastomus,* autumn 1999) in crustacean trawls; and of *Scomber colias, Scyliorhinus canicula, Macroramphosus* spp., *Boops boops, C. aper, M. poutassou* and *Merluccius merluccius* (winter 1998) in fish trawls. The highest discards took place in autumn (1999) and winter (2000) for crustacean trawls and in winter (1998) for fish trawls, contrasting with the summer (2000 in fish trawl and 2001 in crustacean trawl) in the study of Borges *et al.* (2002). These results are thought to be partially associated with the decrease of the local market prices of some commercial bycatch species otherwise retained. Similarly, fluctuations in the market demands and in the catch compositions are referred by Stergiou *et al.* (1998) as factors potentially influencing the seasonal variation in the discards.

Large variability in the seasonal relevance for discarding are also reported in the Mediterranean Sea. The summer (Castriota *et al.*, 2001), spring (Moranta *et al.*, 2000; Machias *et al*., 2001, 2004) and autumn (Machias *et al*., 2001, 2004) seasons are those where the highest discard rates were observed. The discards in the spring season are associated with the spring/summer recruitment season of most of the species (Machias *et al*., 2001, 2004) and with the seasonal nature of the fish species' abundances (Moranta *et al.*, 2000).

Species composition

The species composition of discards found in this study reflects the existing fish assemblages off the southern Portuguese coast as identified by Gomes *et al.* (2001) and Sousa *et al.* (2005). A high number (n=255, 147 families) of vertebrate and invertebrate species were caught in trawl fisheries, of which only 4% were occasionally discarded and 27% were frequently discarded, with the majority (~69%) of the species systematically discarded. Species diversity was higher in crustacean trawls (n=206) of which 48% were exclusively caught therein and ~69% were systematically discarded, compared to fish trawls (n=156, 31% exclusively caught and ~61% systematically discarded). Only a rather small percentage (17%) of the species had commercial value and was therefore retained (landed).

High species diversity in trawl fisheries in the Algarve coast is also reported by Borges *et al.* (2001) and Erzini *et al.* (2002) who noted that the majority of species were also systematically discarded (59%) while some were frequently (33%) and occasionally (8%)

discarded. However, and in contrast to our results, these authors found that the species diversity found in fish trawl catches was greater (64%) than in crustacean trawls (59%). In the same way, crustacean trawls captured exclusively more species (59%) than the fish trawls (64%) (Borges *et al.*, 2001). Lower number of species (n=91) were reported by Monteiro *et al.* (2001) for the crustacean trawl, which is certainly related with the much shorter (4 months) sampling period of the latter study. Since the area prospected by the trawlers in the Borges *et al.* studies is the same as that of our study, reflecting the same species assemblages characteristic of the southern Portuguese coast, the fluctuations verified over the years in the species composition of the discards and how frequently they are discarded, could only be associated to the temporal fluctuations in species abundance.

The waters of the Algarve, as part of Gulf of Cadiz are subject to a strong Mediterranean influence, resulting in a close similarity of species composition and overall biodiversity. However, most of the studies carried out in the western part of Mediterranean report a much higher number of species (609 species *in* Carbonell *et al.*, 1998; 424 species *in* Sánchez *et al.*, 2004; 155 species *in* Sartor *et al.*, 2003) compared to the eastern (281 species *in* Machias *et al.*, 2001; 162 species *in* D´Onghia *et al.*, 2003; 145 species *in* Edelist *et al.*, 2011) and central (194 species *in* Campagnuolos *et al.*, 2001; 170 species *in* Castriota *et al.*, 2001; 132 species *in* Ragonese *et al.*, 2001) parts of the Mediterranean.

The greater species diversity found in crustacean trawls is not unexpected since fishing is carried out over a greater depth range (117-754 meters) and a broader area, compared to fish trawls (100-290 meters) which operate mainly in the shallower waters of the continental shelf. The relevance of the bathymetric range, and consequently the various demersal assemblages fished, is also reported by several authors as being determinant in the differences in the species composition found between métiers (Bergman *et al.*, 2002; Blasdale and Newton, 1998; Edelist *et al.*, 2011; Erzini *et al.*, 2002; Gomes, 2001; Lema *et al.*, 2006; Pravoni *et al.*, 2001). Moreover crustacean trawlers spent more time at sea, carrying out tows with an average of 6 hours duration (*vs.* mean tow duration of 1.5 h in fish trawls), thus increasing the possibility of retaining the less abundant species. The association of the species diversity to the sampling effort is also supported by Tsagarakis *et al.* (2012).

The high diversity of species caught and discarded by both trawl métiers corroborates the findings of Borges (2010), revealing the extreme richness and diversity that can be found off the southern Portuguese waters, and also reinforcing the multi-species nature of the catches of the trawl gear and, together with the high discard amounts, the poor species selectivity of the trawls. Borges *et al.* (2001) also consider that the high diversity of species present in the discards has important implications in terms of conservation, management and sustainable use of living resources.

The majority of the species captured by both crustacean and fish trawls were from the class Osteichthyes (45%) followed by Crustacea (14%), with Cephalopoda (9%) and Chondrichthyes (8%) constituting the smaller components of the discards. This is in agreement with the findings of Borges *et al.* (2000-2002) and Monteiro *et al.* (2001) for the same fisheries. A similar ranking of the major groups of species was found for the Mediterranean (e.g. Carbonell *et al.*, 1998; D´Onghia *et al.*, 2003; Sánchez *et al.*, 2004), although with higher percentage of Osteichthyes species (73% *in* Moranta *et al.*, 2000; 76% *in* Castriota *et al.*, 2001; 85% *in* Edelist *et al.*, 2011) and of crustaceans (19% *in* Campagnuolos *et al.*, 2001; 19% *in* Ragonese *et al.* 2001; 22% *in* Machias *et al.*, 2001; 27% *in* Sartor *et al.*, 2003). The frequency with which bony fishes were discarded was distinct in the two métiers; more species were systematically discarded by crustacean trawls while more species were frequently discarded during trawling for fish. The majority of cartilaginous fishes and non-commercial crustaceans were systematically discarded, while most of the cephalopods were frequently discarded.

Discards abundance and biomass

Fishes and cephalopods accounted for about 94% of the discarded biomass of all fishing operations of which 79% were bony fishes. The latter group of species was more representative in the fish trawls compared to crustacean trawls, both in terms of abundance (94% *vs.* 84%) and of biomass (81% *vs.* 66%). This is comparable with Borges *et al.* (2001), who found analogous fish and cephalopods discard biomass percentages (90%), but not with the Monteiro *et al.* (2001) study in which both bony and cartilaginous fishes, discarded by crustacean trawls, accounted for 82% in biomass (*vs.* 94% in our study) and 85% in abundance (*vs.* 99% in our study). In the Mediterranean, Machias *et al.* (2001) reported lower discard biomass percentages for fishes (34-44%) but higher for cephalopods (11-31%).

Discards from trawl fishing activity in the Algarve were dominated in abundance by three bony fish species: the frequently discarded bycatch species, *Micromesistius poutassou* (blue whiting), and by the systematically discarded species *Macroramphosus scolopax*[8] (longspine snipefish) and *Capros aper* (boarfish), all accounting for more than 60% of the discards in

[8] Herein *Macroramphosus scolopax* includes also the individuals initially identified as *M. gracilis*.

crustacean trawls, and by the latter two in fish trawls, representing 57% of the discards. Concerning biomass, crustacean trawl discards were made up primarily by the blue whiting, the boarfish, and by the frequently discarded low-valued commercial species, *Galeus melastomus* (blackmouth catshark, cartilaginous fish) and European conger (*Conger conger*, bony fish). Fish trawl discards were dominated by the snipefishes and the three frequently discarded commercial bycatch species, *Scomber colias* (Atlantic chub mackerel), *Scyliorhinus canicula* (small-spotted catshark), and *Boops boops* (bogue) in biomass.

A limited number of species contributing to high levels of discards were also reported in the southern Portuguese coast. Monteiro *et al.* (2001) found that four bony fish species, blue whiting, silvery pout (*Gadiculus a. argenteus)*, Mediterranean slimehead (*Hoplostethus m. mediterraneus*) and roughtip grenadier (*Nezumia sclerorhynchus*), accounted for 60% of all crustacean trawl discards in number and 70% in weight. This difference in the composition of the main discarded species is certainly related to the fact that most tows carried out in this study were carried out in deeper waters in the Norway lobster fishing grounds. On the other hand, the Borges *et al.* (2001) study identified four species as the main contributors of crustacean trawls discards in biomass (46%): the cartilaginous fishes *Torpedo nobiliana* (Atlantic torpedo) and small-spotted catshark, along with the European conger and the boarfish. For fish trawl métier, longspine snipefish, chub mackerel and boarfish accounted for 70% of the discards in weight. Notwithstanding the overall coincidence in the main discard species among the studies carried out in the same area, their ranking varied considerably evidencing both temporal changes in the relative compositions of the fish assemblages and the depth range of fishing tows.

Combining the studies of Borges *et al.* (2001) and Monteiro *et al.* (2001) and ours, blue whiting, longspine snipefish, boarfish, European conger and small-spotted catshark were wherefore found to be the most dominant species coincident in the discards of over almost 3 years of study (June 98-March 2001), although with differences in the ranking order of discards dominance, either in biomass or in biomass (e.g. *M. poutassou* mas the most abundant discarded in our study while it ranked 4th in the Monteiro *et al.* (2001)´s study).

Multivariate analyses and dominance plots indicated variations with no clear seasonal trend in the overall species abundance and biomass discard rates, which may be indicative of no changes in the fishing behaviour, since fishing operations are conducted in the manner to take advantage of the availability of the most important (target) species.

Micromesistius poutassou (Blue whiting)

Blue whiting is regarded as the dominant species in the deep-northern (southwest Portugal) and deep-southern (off Algarve) assemblages, of the upper slope of the Portuguese continental waters at depths from 150/200 to ~700 m (Gomes *et al.*, 2001; Marques *et al.*, 2005; Sousa *et al.*, 2005), representing 70% to 90% of total biomass (Gomes *et al.*, 2001), being much less abundant or even absent in shallow assemblages (Sousa *et al.*, 2005, 2007). The southern NE Atlantic waters, in particular those of the Iberian Peninsula, which are recognized as nursery grounds due to their warmer and more saline waters, are far more abundant in blue whiting compared to the northern waters (Reid, 2001). In Portugal, this species is usually caught as bycatch by bottom trawl fleets (ICES, 2012e) and, in spite of the large catches, it is frequently discarded due to the low or null market price, especially for the smaller sizes (Fonseca *et al.*, 2005a). For Fonseca *et al.* (2005a) blue whiting is also considered one of the most discarded fish species, which is discarded mainly due to market-driven issues (restricted landings) (Borges *et al.*, 2001). In our study, the reasons for discarding blue whiting are fundamentally economic (low commercial value and poor body quality due to damage caused during trawling). This situation is rather different in NW Mediterranean waters where this species constitutes a higher proportion (80%) of the retained catch because of its small size (Sánchez *et al.*, 2004). As a consequence, it is discarded at a significantly lower rates (0.73 kg/h) compared to this study (3.9 kg/h and 9.7 kg/h in crustacean and fish trawls, respectively). However, blue whiting discard rates reported by Borges *et al.* (2002) were far higher (22 kg/h) in crustacean trawls but lower (6 kg/h) in fish trawls, in the same studied area. According to the Prista (2012)´ extrapolations for the Portuguese trawl fleet (ICES Division IXa), the highest blue whiting discards were recorded in 2004 and 2006 for the crustacean trawls (2498 t vs. 2252 t) and in 2004 for the fish trawls (1080 t), having decreased in 2009 down to 368 t in crustacean trawls, and in 2006 down to 240 t in fish trawls. The most recent estimates point towards a slight increase to 690 t (2011) in crustacean trawls, although still higher than landings (603 t; ICES, 2012e), and down to 491 t (2010) in fish trawls (Prista *et al.*, 2012). According to Anon. (2010), blue whiting discard proportions are in the order of 0.11-0.16 when fishing is directed to a single (e.g. Atlantic horse mackerel) or two (e.g. Atlantic horse mackerel and blue jack mackerel) target fish species and can reach 1.0 when targeting multiple fish species. In crustacean trawl métier, discard proportions varied widely between 0.23 and 0.96 (Anon., 2010b). Considering its abundance on the Portuguese coast, its discard proportions and its key role in the trophic chain as prey for important commercial valuable species, such as hake and horse mackerel (Cabral and Murta, 2002), blue whiting discards may represent a major bycatch problem.

Capros aper (Boarfish)

Boarfish is a small very abundant pelagic fish species in Portuguese waters (Lopes *et al.*, 2006), distributed approximately between 200 and 500 meters depth (Cardador and Chaves, 2010). It is characteristic of the deep-southern assemblage as referenced by Gomes *et al.* (2001), although Marques *et al.* (2005) refer higher abundances in the outer continental shelf (100-200 m). In a more recent study, Sousa *et al.* (2005) refers the shallow-southern assemblage (40-180 m), as the one displaying the highest numbers. The highest boarfish occurrences (>80%) are reported during summer, usually associated with the spring–summer bloom, when the prey species availability is higher (Lopes *et al.*, 2006; Sousa *et al.*, 2005). This species is caught as bycatch in crustacean and fish trawl fisheries off the southern Portuguese coast and, as verified in our study, it is always discarded due to its no commercial value (Borges *et al.*, 2000-2002). Boarfish discard estimates in the Portuguese trawl fisheries (ICES Division IXa) available only from 2004 onwards, point to higher values in fish trawls (222-281 t) compared to crustacean trawls (23- 97 t). The highest estimate was recorded in 2009 for crustacean trawls (167 t) and in 2006 for fish trawls (154 t). The most recent estimates point towards a significant decrease to 8 t (2011) in crustacean trawls, and to 154 t (2009) in fish trawls (Prista *et al.*, 2012). Contrarily to what happens in the ICES Subareas VI (Ireland), VII (UK-Scotland) and VIII (Bay of Biscay), where there is a target fishery for this species being regulated and managed under the quota system of total allowable catches (TACs) since 2011, in Portuguese waters it is systematically discarded both in crustacean and fish trawl métiers (Anon., 2010b; Prista *et al.*, 2012). Although the ecological impact of its discarding on the ecosystem is not fully understood, the boarfish is recognised as an important link in the trophic chain in the Portuguese waters (Lopes *et al.*, 2006), as prey for commercial fish species like European hake, mackerel (Cabral and Murta, 2002), European conger, monkfish (*Lophius* spp.) and blackmouth catshark (Santos and Borges, 2001).

Macroramphosus scolopax (longspine snipefish)

Longspine snipefish is among the most abundant fish species, mostly in shallow grounds (100-200 m) of the outer Portuguese continental shelf, partially overlapping boarfish and blue whiting distribution (Marques *et al.*, 2005; Lopes *et al.*, 2006). As for the boarfish, its highest occurrences are also reported in the summer on the south coast, a time when, due to the greater availability of prey, each species seek different kind of preys (mysids for longspine snipefish *vs.* copepods for boarfish) (Lopes *et al.*, 2006). In Portugal, this species used to be commercially exploited by purse seiners as bycatch, as an alternative for the shortage of European pilchard (*Sardina pilchardus*) in the early 1970s, and by demersal trawls in the late 1970s, time of major longspine abundance, and was used exclusively for the production of fishmeal and fish oil. However, during the 80s, the increase of fishing for crustaceans lowered its market value, causing a decrease in their captures and subsequent landings, which compromised the further exploration of this resource in the industrial sector of fishmeal and fish oil (Morais, 1981). Currently, longspine snipefish is a bycatch species in Portuguese demersal trawl fisheries and, as found in the present study, is systematically discarded due lack of commercial value (Borges *et al.*, 2001, 2002). Our data indicate that longspine snipefish is discarded at rates of 0.9 kg/h in crustacean trawls and of 29.8 kg/h in fish trawls, higher than those reported by Borges *et al.* (2002) (<0.1 kg/h in crustacean trawls; 14 kg/h in fish trawls). Similarly to boarfish, it is a relevant component of the marine ecosystem as prey for commercially valuable fish species (Cabral and Murta, 2002; Lopes *et al.*, 2006; Marques *et al.*, 2005; Santos and Borges, 2001). Taking into consideration its high abundance on the Portuguese coast, Fonseca *et al.* (2005a) considers that, like blue whiting and longspine snipefish represent a major bycatch problem and that the best solution to this problem is to avoid the dense schools of longspine snipefishes, instead of changing the near gear size which results in the loss of significant amounts of target species.

Boops boops (bogue) and *Conger conger* (European conger)

As a sparid, the bogue is a species characteristic of the Portuguese shallow southern assemblage, attaining values up to 10% of the assemblage biomass (Gomes *et al.*, 2001; Sousa *et al.*, 2005). European conger is another species present in Portuguese waters although far less abundant (Gomes *et al.*, 2001; Sousa *et al.*, 2005). Both species have a low commercial value, although higher for the European conger. For the year 2009, according to extrapolations for the overall trawl fleet made by Prista (2012), 133 tons of European conger were discarded by crustacean trawlers and 342 tons of bogue were discarded by fish trawlers. The European conger discard rates found in this study attained values of 0.9 kg/h in crustacean trawls and of 3.0 kg/h in fish trawls while for bogue 19 kg/h were discarded by fish trawlers. European conger discard rates are higher than those reported by Borges *et al.* (2000) (200 kg in each métier) but more similar to those found by Borges *et al.* (2002) (0.92 kg/h in crustacean trawls; 2 kg/h in fish trawls). Similarly, bogue discard rates were higher than those described by Borges *et al.* (2002) (11 kg/h). In our study, the reasons for discarding both of these species were the low commercial value and the minimum landing size restrictions (580 mm for European conger; 150 mm for bogue) (DR, 2001a). Borges *et al.* (2001, 2002) reports the low commercial value as the main reason for their discarding. The European conger is a top predator, preying on the Atlantic mackerel, horse mackerel and blue whiting (Gomes and Olim, 2010) while bogue is a prey of highly valuable commercial species, such as the European hake (Cabral and Murta, 2002) and John Dory (*Zeus faber*) (Silva, 1999). Taking also into account the fact that due to their reproductive characteristics conger eel is highly susceptible to commercial exploitation (Cau and Manconi, 1984 *in* Morato *et al.*, 1999), high discard amounts of this species may have important implications on this resource.

Scyliorhinus canicula (small-spotted catshark) and *Galeus melastomus* (blackmouth catshark)

The small-spotted catshark is a deepwater cartilaginous species well represented in the Portuguese continental shelf most frequently at 200-400 m depth and over 500 m in southern Portugal (Algarve) (Costa, 2010, ICES, 2012b). The blackmouth catshark is distributed between approximately 200-900 m depth, occurring more frequently at 600-800 m (Costa, 2010), and is especially abundant in the southwest (Alentejo) and south (Algarve) regions (Sanches, 1986). These two elasmobranch species are common bycatch in mixed demersal trawl and small-scale fisheries (Coelho and Erzini, 2008; ICES, 2012b), making up the landings of demersal elasmobranchs in Portugal (mostly small-spotted catshark) (ICES, 2012b). Although no MLS is established for these species (Fonseca *et al.*, 2005a), only larger specimens are marketable, but at low prices (Coelho and Erzini, 2008; Costa, 2010). They are commonly discarded due to their low commercial value (Borges *et al.*, 2001; Coelho and Erzini, 2008; Costa, 2010), as supported by our study, in which most of the discards also consisted in small and immature specimens (Chapter 4). For the year of 2009, Anon. (2010) estimated the discard proportions of small-spotted catshark of 0.53-0.75 in crustacean trawls and 0.26-0.36 in fish trawls, while the blackmouth catsharks discard proportion was found to be 1. Our data points to a mean discard proportion of 0.4 kg/h in crustacean trawls and 35.3 kg/h in fish trawls for small-spotted catshark, and of ~1.1 kg/h in crustacean trawls for blackmouth catshark. These values are comparable to those reported in the same studied area by Borges *et al.* (2002) but are much higher considering the small-spotted catsharks discarded by fish trawls (0.6 kg/h in fish trawls). The existing discard estimates in the Portuguese trawl fisheries (ICES Division IXa) refer to the period 2004-2011, and values of about 133 tonnes of small-spotted catsharks (121.7 t in crustacean trawls, 11.3 t in fish trawls) (*vs.* landings close to 2900 t) and 134 tonnes of blackmouth catsharks (49.5 t in crustacean trawls; 84.6 t in fish trawls) (*vs.* landings of 490 t) are reported, believing that these discards have increased (ICES, 2012b). Solely in 2009, small-spotted and blackmouth catsharks´ estimated discard amounts were set at 48 tons and 24 tons, respectively (Prista, 2012). Between the period corresponding to the present study (1999-2001), 2373 tons (ICES, 2012b), in an average of 154.8 t/year (Ellis *et al.*, 2009) of small-spotted catsharks, and 86-95 tons of blackmouth catsharks were landed (ICES, 2002, 2012b). Currently, no management measurements are defined for deepwater sharks in ICES division IXa (TAC was set to zero since 2010 due to the depletion of the main commercial species) and since 2012 there is no allowance for bycatch (ICES, 2012b, EU, 2010, 2012). In 2013, ICES continued to not advise that an individual TAC be set for skate and rays individual stocks (ICES, 2013).

Nearby to Portuguese waters, in the Eastern (Damalas and Vassilopoulou, 2011), Western (Carbonell *et al.*, 2003; Fanelli *et al.*, 2009) and Northwestern (Sánchez et al., 2004) Mediterranean Sea, and in the British Isles (Ellis *et al.*, 2005; Revill *et al.*, 2005), small-spotted and blackmouth catsharks are also important bycatch species in trawl fisheries, with the majority of them being discarded due to no commercial value. In the central Aegean Sea, significantly high proportions of the catch of small-spotted catsharks are discarded (0.86-0.94 by weight; 0.94-0.99 by number) and well as blackmouth catsharks (1.0) (Damalas and Vassilopoulou, 2011). Off the Balearic Islands, small-spotted and blackmouth catsharks are sufficiently abundant to be recorded in the landings, but still are discarded at rates of 0.03-5.6 kg/h and 0.2-2.4 kg/h, respectively (Carbonell *et al.*, 2003), slightly higher than those reported by Sánchez *et al.* (2004) in the Catalan coast (0.1 kg/h vs. 0.6-1.4 kg/h).

Taking into consideration that small-spotted and blackmouth catsharks, as chondrichthyans, a) are far more susceptible to overexploitation than teleosts, given their specific K-selected life-history strategy (slow growth, long gestation, low fecundity, late maturing and long lifespans) (Camhi *et al.*, 1998, 2009; Compagno and Musick, 2005; Hoening and Gruber, 1990; Holden, 1974), which makes them slow to recover from large declines in their populations (Musick, 2005; Stevens *et al.*, 2000); b) have an important ecological role as predators near or at the top of the marine trophic chains (Cailliet *et al.*, 2005; Stevens *et al.*, 2000); and c) are considered as indicators of the state of the fishery (Stevens *et al.*, 2000), their discarding, even if in small amounts, may have a higher impact than high discards of marketable species (Alverson *et al.*, 1994). However, Serena *et al.* (2009) believe that the recent declines in traditional target species may lead to a decrease in discards of these catsharks as, to compensate for this decline, higher amounts of “alternative” bycatch species are being retained.

Target species

Concerning commercially valuable target fishes, these were not relevant in the discards, neither in biomass (<2%) nor in abundance (<1%) but, among them, European hake (*Merluccius merluccius*) was the most discarded (3% in weight and 4% in number). This species is one of the most abundant and ubiquitous species occurring along the Portuguese continental shelf, caught both in the deep- (4-9% of total biomass, 150-400 m) and shallow-southern assemblage (1-10%; 20-120 m) (Gomes *et al.*, 2001). For the purpose of the European hake stock assessment, Portuguese European hake discard estimates are available since 1992, when the minimum value of 330 tons was registered, followed by periods of slight increases to 1,200 t in 1997 (ICES, 2012a). During the present study period (1999-2001), the European hake discard rates were of 0.4 kg/h in crustacean trawls and of 6.8 kg/h in fish trawls, higher than those reported by Borges *et al.* (2002) (1 kg/h *vs.* 4 kg/h) in the same studied area. For the same period, Jardim and Fernandes (2013) estimated overall discards ranging from 1,170 t to 1,290 t. These authors found a maximum absolute discard estimate of 1,956 t in 2009 and a minimum of 580 t in 2010. On the other hand, Prista (2012) estimates for the year 2009 were considerably lower (of 381 tons, 0.64-0.93 discard proportion in crustacean trawls; 908 tons, 0.35-0.61 discard proportion, in fish trawls). For the year 2011, overall European hake discards were estimated by Prista and Fernandes (2012) at 169 tons and 570 tons in crustacean and fish trawl métiers, respectively.

In the present study, the catch below the minimum landing size restrictions (27 mm; DR, 2001b) was the main reason for the European hake discards but the damaged/poor quality of the individuals, also have influenced their discarding. These three same reasons were reported by Borges *et al.* (2001) during their 1996-1997 study. Regarding a) European hake’s importance in the food chain as one of the most important top predators of commercial fish, such as blue whiting (Cabral and Murta, 2002; ICES, 2012e), small hake (Cabral and Murta, 2002), sardine (ICES, 2012e), bogue (Cabral and Murta, 2002), and also the very abundant non-commercial boarfish (Prista and Fernandes, 2012) and snipefish (Cabral and Murta, 2002; ICES, 2012e), b) its high abundance on the Portuguese coast (Cabral and Murta, 2002), and the fact that c) decisions on hake management will have an impact on the trophic chain

(ICES, 2012e), high discard amounts of this species may have significant effects on this highly valuable resource. It is of utmost importance to incorporate the discards in the assessment and management of the European hake stock, with the same applying for other (commercially or not) important stocks.

Long-term studies of groundfish assemblages in the Portuguese continental shelf (Gomes *et al.*, 2001; Sousa *et al.*, 2005) revealed that these assemblages tend to be persistent in composition over time and with no major changes in their geographical limits. However, it may happen that, in a given year or season, the assemblages may show quite uncommon patterns in the proportions of the individuals and/or that they can be displaced from their usual geographic boundaries (Gomes *et al.*, 2001; Sousa *et al.*, 2005). Taking also into consideration that, a) depth is a major factor which accounts for the most important changes in the composition of the demersal communities (Allain *et al.*, 2003; Gomes *et al.*, 2001), b) the existence of a faunistically distinct area depends on the relative abundance of the species (Gomes *et al.*, 2001), and that c) changes in the abundance of some species may result in temporal variations of these species (Colloca *et al.*, 2003), the differences found in the species discards' compositions and proportions between the studies of Borges *et al.* and ours, may be related, not with the assemblages themselves, since these studies were conducted in the same geographical area targeting the same groundfish assemblage, but rather to the depth at which trawlers operated and to the variations in the abundance of some species in the different years of study.

Discard reasons

In this study the main reason for discards is economic, since the majority of species caught have no commercial value (e.g. longspine snipefish, boarfish, most of cartilaginous fishes and invertebrates). In the case of high value commercial species the main reason for discarding is legal and administrative, since most are below the legal minimum landing sizes (e.g. hake, mackerels, seabreams), being also largely discarded because of damaged condition and/or the poor (bad) quality of the individuals (e.g. hake, target crustaceans) as a result of long tows. The same happens with other marketable bycatch species, in particular with those species that are quite fragile, therefore less resistant to deterioration (e.g. blue whiting, European pilchard, flatfishes, forkbeards). Discarding was also influenced by the inexistence of readily available markets for many commercial bycatch species (e.g. triglids, most of cephalopods) and by the low commercial value of some bycatch species (e.g. blue whiting, small-spotted catshark, blackmouth catshark, triglids). Technical problems, like gear damage, hauling capacity and bad weather conditioned the fishing practice but were not meaningful in the discards context.

Final considerations

Portuguese fisheries are managed under the quota system of total allowable catches for some species and licence schemes, and regulated through technical measures, such as minimum landing sizes, minimum codend mesh sizes, limits for relative percentage of target and bycatch species accordingly to métier and prohibition of trawling within 6 miles of the coastline. However these measures have been insufficient to prevent the decline of resources, since *88% of the European Community fish stocks are being fished beyond MSY* and *30% are outside safe biological limits* (2008 ICES Assessments) (CEC, 2009). The existence of high levels of discards in European waters, as further highlighted by this study, supports the known low species- and size-selectivity of the bottom trawls, especially in a multi-species and multi-size ecosystem such as the Portuguese, and supports the need for using more selective gears. The fact that most discards are composed of undersized individuals proves that the current technical measurements are far from being an effective way of reducing the unwanted bycatch which is therefore discarded. This latter issue is corroborated by Campos *et al.* (2003a) who consider that 55 cm crustacean trawls codend mesh size is not compatible with MLS of 27 cm for hake, and also by Fonseca *et al.* (2005a) who suggest that the 65 mm fish trawls codend mesh size is too small for the adequate management of most commercial fish and cephalopods. Stephen and Harris (2010) also take the view that, since most of the discarded fish do not survive (mostly those caught by trawl gears, as it was observed in this study) size limits may not be an effective measure to reduce discards.

It is certain that the low selectivity of most fishing gears, together with spatial and temporal changes in species composition and age structure, makes it impossible to eliminate the discards completely, as stated by Crean and Symes (1994): "*discards are one of the seemingly prices to be paid for a modern, sophisticated and highly capitalized industry developed within a common use rights system of exploitation*". It is also certain that, with the current levels of discarding, the maintenance of biodiversity, the functioning of the ecosystem and the long-term sustainability of the fisheries (intensified by the non-inclusion of the discards in the stock assessment of the status of the fishery and by the lack of implementation of relevant management plans) will be threatened (CEC, 2007b; Elliston *et al.*, 2005; FAO, 2011a). This is especially true, if we consider that the discarding of fish and other marine organisms by fishers may have a negative ecological (e.g. changes to the food web and alterations to the habitat), economical (e.g. loss of present and future incomes) and biological (e.g. reduce spawning stock biomass) impacts on the management of commercial fisheries (Alverson *et al.*, 1994; Anon., 2003; CEC, 2007b; Clucas, 1997; FAO, 2010a, 2011a; Kelleher, 2005; Kumar and Deepthi, 2006).

In 2009, the increasing worldwide concern about the importance and the consequences of discarding, led to the creation of International Guidelines on Bycatch Management and Reduction of Discards by the FAO Committee on Fisheries (COFI). Within that scope, measures towards more effective management of bycatch and reduction of discards (e.g. fishing capacity and effort controls, improvement of fishing gear design, bycatch mitigation devices, spatial and temporal closures, limits and/or quotas on bycatches) have been proposed (FAO, 1995, 2010, 2011a). Technical improvements in the selectivity of trawl nets, such as changes in the codend mesh size or mesh configuration and installation of bycatch reduction devices (BRDs) (e.g. sorting grids, square mesh panels, selection panels, escape windows), have been tested worldwide and have proved to be efficient in reducing catches of non-commercial and undersized fish, thus lowering the discards levels (Anon., 2000; Enever *et al.*, 2009; Hall and Mainprize, 2005; Kelleher, 2005; Suuronen and Sardà, 2007). However, technical measures are not enough by themselves (Macher *et al.*, 2008; Sacchi, 2008) and should be combined with quota and/or effort limitation so as to compensate more the high short-term losses in the revenue (Macher *et al.*, 2008).

Since the early 1990's, an intense research effort on the improvement of size and species selection of bottom trawls has been carried out in Portuguese continental waters. This work has encompassed the codend size-selectivity of both diamond and square meshes for cephalopods (Fonseca *et al.*, 2002), fish (Campos and Fonseca, 2003; Campos *et al.*, 2003a) and crustacean species (Campos *et al.*, 2002, 2003b; Fonseca *et al.*, 2007). At the same time, the feasibility of separation between target and bycatch species was evaluated by using square mesh windows alone (Campos and Fonseca, 2007) or associated to soft sorting panels (Campos and Fonseca, 2004). In a later phase, rigid sorting devices (Nordmøre grids) were tested, both for size- and species-selectivity optimization, in fish (Fonseca *et al.*, 2005a) and crustacean trawls (Campos *et al.*, 2006; Fonseca *et al.*, 2005b). Although these technical improvements in the selectivity of trawl nets have proved to be effective in reducing the capture of unwanted species and undersized commercial fish species, with minor losses and an increase in quality of target species, their implementation has not yet been considered in Portuguese fisheries.

In conclusion, it can be stated that both crustacean and fish demersal trawl fisheries in the southern Portuguese coast capture an extraordinary diversity of species and generate significant amounts of discards, most of which are fishes of no commercial value. Notwithstanding, among the discarded species are also undersized individuals of the most commercially important fisheries resources, currently subject to strong European Community regulations (e.g. hake), or that are particularly relevant to the marine food webs (e.g. blue whiting, longspine snipefish, catsharks). The discarding of fish is due fundamentally to economic reasons (lack of commercial value) for bycatch species, and for legal and administrative reasons (legal minimum landing size) for high valuable target species. These aspects, allied to the spatial and temporal variability in the discard proportions and rates found in this study, and the known implications that discards have on the management of commercial fisheries and in the ecosystem functioning, reveals that discarding should not be neglected in Portuguese fisheries since they constitute a major source of unaccounted mortality. Therefore it is essential to continue with the quantification of discards in order to incorporate the data in the landings database of the national institutions, so that more accurate estimates of stock abundance can be obtained.

Even recognizing that bycatch and discards mitigation measures are often most favourable to a particular species rather than others (FAO, 2011a), their adoption should still be encouraged in the multispecies demersal trawl Portuguese fisheries. The adoption of bycatch reduction devices, the development of alternative commercial markets for species currently discarded, and the harnessing of some systematically discarded species (e.g. longspine snipefish and boarfish), fostering the reutilization of the old but still existing fishmeal and fish oil factories, will contribute to the promotion of the sustainable use of the living resources.

Chapter 4

Reproductive biology of the blackmouth catshark, *Galeus melastomus*, (Chondrichthyes: Scyliorhinidae) off the south coast of Portugal

Tendril-lacking egg cases of Galeus melastomus *Rafinesque, 1810 - photo by @ MECosta*

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Abstract

The reproductive biology of 1045 female (9.5-67 cm TL) and 1007 male (9.4-64.3 cm TL) blackmouth catsharks, *Galeus melastomus*, was investigated. The sharks were caught off southern Portugal by bottom crustacean trawlers at depths from 209 to 754 m. The sex ratio was 1:1 and this species is sexually dimorphic with males approaching maturity at smaller sizes than females. Sexual segregation appears to be given for the stock within the study area. Sexual maturity was reached at a total length above 49 cm in males and above 56 cm in females. Mating and egg-deposition take place all year round, with two reproductive peaks of activity, in winter and summer. Egg capsules are, on average, 54 mm long and 21 mm wide, with a maximum of 63x25 mm encountered. Morphometric measurements of claspers, testes, ovaries, and oviducal glands were suitable for determining sexual maturity of blackmouth catshark.

Introduction

The blackmouth catshark, *Galeus melastomus* Rafinesque, 1810, belongs to the family Scyliorhinidae and is a common deepwater bottom-dwelling shark, not listed in the International Union for the Conservation of Nature and Natural Resources Red list (http://www.fishbase.org; http://www.redlist.org; ICN, 1993). It is found on the continental slope at 200-1200 m (mainly between 200 and 500 m), but occasionally at depths of 55 to 200 m also on the outer shelf. It is distributed in most parts of the north-eastern Atlantic Ocean, northward to the Faeroes and Trondheim (Norway), from the British Isles and Ireland southward to Senegal, in Madeira and Canaries archipelagos and is present throughout the Mediterranean (Bannister, 1998; Cadenat and Blache, 1981; Compagno, 1984a; http://www.fishbase.org; http://shark-gallery.netfirms.com; Quéro, 1984; Mojetta, 1997; Moreno, 1995; Muus and Nielsen, 1998; Pivnička and Černý, 1990; Sanches, 1986; Steel, 1992). This small catshark feeds on bottom-living and midwater invertebrates (cephalopods, crustaceans, gastropods), benthic and also small pelagic bonyfish (e.g. lanternfish) and, occasionally, on other small elasmobranchs. Its mode of reproduction is oviparity, with litters of up to 13-14 depending on the number of eggs present in the oviduct of a female at one time, and with tendrillacking egg cases measuring 60x30 cm, or smaller in the Mediterranean population (Cadenat and Blache, 1981; Compagno, 1984a; http://www.fishbase.org; http://shark-gallery.netfirms.com; Moreno, 1995; Mojetta, 1997; Muus and Nielsen, 1998; Quéro, 1984; Steel, 1992). Deposition of egg capsules attains a maximum during the hydrologic warm season. In the Mediterranean, egg deposition occurs throughout the year, with a peak of activity in the spring and the summer (Cadenat and Blache, 1981;

http://www.fishbase.org; http://shark-gallery.netfirms.com; Moreno, 1995; Quéro, 1984; Tursi *et al.*, 1993).

The blackmouth catshark is a species of limited interest to fisheries, although in some parts of its distribution it is caught as trawl bycatch at bathyal depths. In the eastern North Atlantic this species is caught in bottom trawls and utilized fresh and dried-salted for human consumption, and for leather (Compagno, 1984a; http://www.fishbase.org; Moreno, 1995; Quéro, 1984; Tursi *et al.*, 1993). According to Tursi *et al.* (1993), *G. melastomus* abundances and biomasses make this species particularly important to the marine ecosystem.

Galeus melastomus is a very common species off Portugal at depths of 400-800m, being especially abundant in the Alentejo and Algarve regions (Figueiredo and Correia, 1996; Figueiredo *et al.*, 1995; Moura, 1995) and around Madeira Island, where it is caught mainly between 150 and 500 m depth (Sanches, 1986). In Portugal, the blackmouth catshark is included in the offcial landing statistics even though only the largest individuals are marketable. There is no minimum legal size set for fisheries (Figueiredo *et al.*, 1994; Moura, 1995).

Like other deepwater shark species, the blackmouth catshark is strongly affected by trawling, being caught as bycatch and largely discarded. The limited fisheries management measures in place do not take into consideration this unaccounted mortality. Regarding this aspect and also because knowledge of the biology of this species is limited in general, with no information regarding sexual maturity in Portuguese waters, this study aims to contribute to the conservation and management of the blackmouth catshark by providing information on its reproductive biology.

Materials and methods

Sampling

The specimens for this study were collected aboard commercial crustacean bottom trawlers (mesh size of 55 to 65 mm) targeting blue-and-red shrimp (*Aristeus antennatus*), deep-water rose shrimp (*Parapenaeus longirostris*) and Norway lobster (*Nephrops norvegicus*). Sampling operations were conducted, on a seasonal basis, between February 1999 and March 2001 off the south coast of Portugal (Algarve), during two scientific projects on discards. Blackmouth catshark was captured between 36º41´N-36º56´N and 7º24´W-9º02´W and at depths of 209 to 754 m. Sub-samples of the *G. melastomus* catch were taken randomly by scientific observers in most cases, but the whole catch was sampled on some occasions.

Measurements

Specimens were taken to the laboratory where they were frozen whole for later study and processed after thawing. Identification was confirmed based on Compagno (1984a), Cadenat and Blache (1981) and Quéro (1984). The following was recorded for each individual: total length (TL), to the lowest 0.1 cm; total weight (TW), gonad (left and right testes for males and right ovary for females) weight (GW), liver weight (LW), and eviscerated weight (EW), to an accuracy of 0.01 g; sex and maturity stage were ascertained macroscopically. The EW was recorded because it is recommended for study of certain aspects of reproduction (Mellinger, 1996 *in* Peres and Vooren, 1991).

Total length (TL), used throughout this paper, is defined as the length, on a horizontal line, from the snout tip to the posterior tip of the caudal fin, depressed along the anterior-posterior axis of the fish (Compagno, 1984b).

For males clasper lengths (inner, CLi and outer, CLo) of both left and right claspers and length, width and weight of both left and right testicles were recorded. Inner clasper length was measured from the point of insertion at the cloaca to the distal tip of the clasper and CLo were measured from the point of outside insertion at the pelvic fin to the tip of the clasper (Compagno, 1984b). For females, the following data were collected: maximum length and width of oviducal (nidamental or shell) gland, maximum length and width and total weight of right (single functional) ovary and maximum width of uterus. Reproductive organs were measured to the nearest 0.01 mm using Vernier callipers, weighed to the nearest 0.01 g and were recorded in order to examine changes in these structures during the maturation process.

Assessing maturity

Sexual maturity was determined following a scale described for all chondrichthyan species by Stehmann (2002). For males, a four-scale maturity scale (from A or 1 to D or 4) takes into account the size and flexibility or rigidity of claspers, size of testes, width and the occurrence of coiling of sperm ducts (epididymes) and absence or presence of sperm in the seminal vesicle (ampullae ductus deferens) (Annex XVIII). For females, a six-scale maturity scale (from A or 1 to F or 6) is divided in two reproductive activity subcycles: the ovarian and the uterine. In the ovarian stage, size of ovary, absence or presence and size of oocytes and width of oviducts (uterus) are determinant, while in the uterine stage, presence of large yolk-egg in fallopian tubes and formation and rigidity of egg capsules are considered (Annex XIX).

Sex ratio

The sex-ratio (♀:♂) for the whole sample was analysed considering the variation of sex-ratio by seasons, throughout the year. The χ^2 goodness-of-fit test (α = 0.05; Zar, 1996) was used to examine the differences between observed sex-ratios and the expected ratio of an equal sex ratio.

Maturity stages and Spawning period

Distribution of maturity stages for females and males of *Galeus melastomus*, was analysed according to size, and the egg deposition period was determined by analysing the seasonal evolution of the maturity stages as percentages by sex.

Size-at-maturity

Size-at-first-maturity is usually determined by either analysing the growth of reproductive organs relative to size, or by fitting a maturity ogive. Reproductive organ measurements described above were used for analysing length at first maturity.

In order to determine which of the internal reproductive organs measurements (variables) are more important for discriminating between maturity stages (groups), ranking them in order of importance given by the naive rank, Discriminant Analyses (DA) were performed using Brodgar (http://www.brodgar.com). These analyses were applied to a sample of 778 males and 683 females of *G. melastomus* and the variables considered were: clasper lengths (CLi and CLo) of both left and right claspers and length, width and weight of both left and right testicles, for males; and the length, width and total weight of the ovary, for females.

Males

One method to determine the size-at-first-maturity for male elasmobranchs is using clasper length measurements, because there is a known correlation between the development of secondary sex characters and the reproductive organs, and maturity (Conrath, 2004). The length of the clasper as a proportion of the total length is plotted against the corresponding length. This usually results in a plot where maturity is indicated by a sharp increase in the slope (Holden and Raitt, 1974; Pratt, 1979; Teshima, 1981; Yano, 1993). While clasper length is most commonly used, the size or weight of other reproductive structures like the testis and siphon sac are often also used and plotted in the same manner (Teshima, 1981; Yano, 1993). In this study, the length-at-maturity in *G. melastomus* male was estimated by the relation between clasper length and total length, and also from the relationships between, testis length, width and weight, and total length.

Females

In females, size of the oviducal gland or other structures of the female reproductive tract are often used to assess the size-at-first maturity. The size or weight of the single functional ovary (right), or the size of the oviducal gland, uterus, or other reproductive structure is often plotted against the length of the animal to determine if there is a size-range at which the structure in question begins to develop very quickly before getting thinner again (Castro *et al.*, 1988; Wass, 1973 *in* Conrath, 2004; Yano, 1993).

As the length range at which the adolescent part of elasmobranch population matures is determined by a change in the slope of the plot, for the purpose of establishing size at which blackmouth catshark females become mature, we used the length and width of oviducal gland; length, width and total weight of ovary; and width of uterus *vs.* total length plot, in a similar way to that discussed above for the males.

Size-at-first maturity for *Galeus melastomus* males and females (defined as the size at which 50% of all individuals sampled are mature - L_{50}), was also determined through the fitting of maturity ogives. The specimens in stages A/1 and B/2 were considered as "immature" and the specimens in other stages were considered as "mature", as suggested by Conrath (2004).

Once all individuals had been classified, the proportion of mature specimens by 1 cm size-classes was calculated. A maturity curve was determined using the logistic curve - $P_i = 1 / [1 + e^{(a+b*TL)}]$, where P_i is the proportion of mature individuals in length class *i* and *a* and *b* are fitted parameters which can change during the life cycle. A logarithmic transformation was applied to the equation in order to calculate the parameters *a* and *b* by means of linear regression and L_{50}, the length at the point of the curve corresponding to 50% often used as an indicator of the size as the specimens mature, could be calculated as $L_{50}=(a/b)$ (Sparre and Venema, 1992).

Reproductive activity

The cyclic manifestations of the reproductive activity in marine fish concerns the evolution of the gonadosomatic indices (GSIs) as an indicator of notable weight variations (Lahaye, 1981). For each sex, the reproductive cycle of blackmouth catshark was analysed in terms of seasonal changes of the GSIs, calculated by using the weight of the gonads as a percentage of the eviscerated body weight. In each index, the means and respective standard deviations were calculated by season.

Correspondence analysis (CA) was performed using SAS (SAS, 1989) in order to identify possible relations between the variables sex, maturity stage and season. This analysis was applied to a sample of 2052 *G. melastomus* (1045 females and 1007 males), cross-classified by season, sex and maturity stage and data were pooled across seasons for all years, since there were insufficient data for a monthly analysis or for seasonal analysis per year.

Results

Length frequency distributions

Length data for *Galeus melastomus* were collected for 2052 specimens in total, captured in 25 trips (45 tows) during the period study (Table 4.1). The length-frequency distributions for both sexes are shown in Figure 4.1. Specimens ranged in size from a minimum of 9.5 cm TL (2.62 g TW) to a maximum of 67 cm TL (1013.6 g TW) for females and 9.4 cm TL (1.99 g TW) to 64.3 cm TL (733.2 g TW) for males. Average TL for females is slightly larger (23.2 cm) than for males (22.5cm). The most frequent sizes, for both sexes, were from 12 to 32 cm TL representing about 87 % of the sharks examined.

Table 4.1 – Summary data for *Galeus melastomus* examined in each season (N-number; Min.-minimum; Max.-maximum; SD-standard deviation).

Season	Trips (N)	Tows (N)	Sex	N	TL range (cm)			Tow depth range (m)		
					Range	Mean	SD	Min.	Mean	Max.
Winter	7	12	♀	148	13.6 - 63.5	30.9	15.969	300	567	680
			♂	144	12.0 - 64.3	26.6	13.009	300	584	680
			♀ + ♂	292	12.0 - 64.3	28.8	14.723	300	575	680
Spring	8	15	♀	400	11.2 - 62.2	19.2	6.365	405	558	754
			♂	353	10.8 - 59.2	19.3	5.313	350	553	754
			♀ + ♂	753	10.8 - 62.2	19.3	5.891	350	555	754
Summer	8	16	♀	374	9.5 - 67.0	22.9	10.408	430	587	750
			♂	393	9.4 - 59.5	22.0	8.719	430	585	750
			♀ + ♂	767	9.4 - 67.0	22.5	9.584	430	586	750
Autumn	2	2	♀	123	15.7 - 59.8	27.4	7.245	610	622	635
			♂	117	15.2 - 49.5	28.6	7.111	209	618	635
			♀ + ♂	240	15.2 - 59.8	28.0	7.191	209	620	635
Total	25	45	♀	1045	9.5 - 67.0	23.2	10.623	300	577	754
			♂	1007	9.4 - 64.3	22.5	8.928	209	578	754
			♀ + ♂	2052	9.4 - 67.0	22.8	9.831	209	577	754

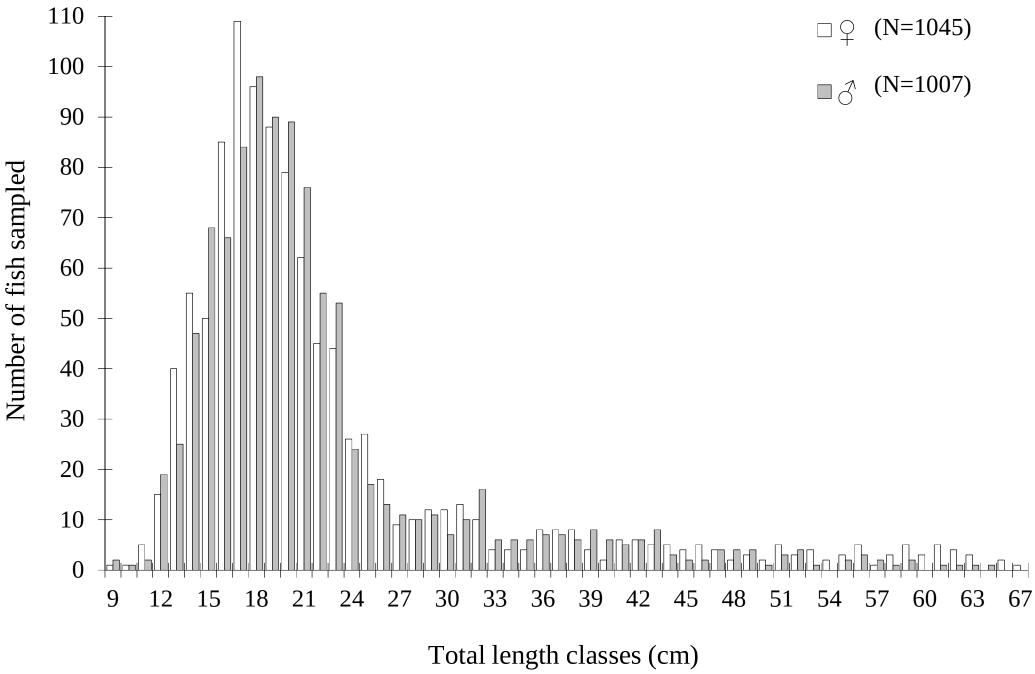


Figure 4.1 – Length distributions of *Galeus melastomus*.

Sex ratio

Of the total specimens examined, 1045 (51%) were females and 1007 (49%) were males. The overall ratio of females to males was 1.04:1 and χ^2 goodness-of-fit tests showed no significant differences (χ^2=0.7, p>0.05) in the proportion of sexes for the whole period analysed. The same result was obtained for the each of the four seasons for both sexes.

Maturity stages and egg-deposition period

The distributions of maturity stages of *G. melastomus* females and males, according to size are shown in Figure 4.2. The smallest immature (stage A) specimens were 9 cm TL, with males reaching 44 cm TL and females 45 cm TL, and representing 95% and 93% of the total, respectively. Both males and females start maturing (stage B) at 42 cm with females of this stage being larger (55 cm TL) than males (51 cm TL). Males attained maturity (stage C) sooner (44 cm TL) than females (52 cm TL), reaching a maximum at 59 cm and 62 cm TL, respectively. Males began to become active (stage D) above 49 cm TL, and no active males were found (Stage D) above 64 cm TL. No active females were found but those that reached the advanced stage (stage E) attained a size-range from 56 to 62 cm TL, with the exception of one specimen of 45 cm TL. Females start to appear in the extruding phase (stage F) with sizes above 56 cm to a maximum of 67 cm TL.

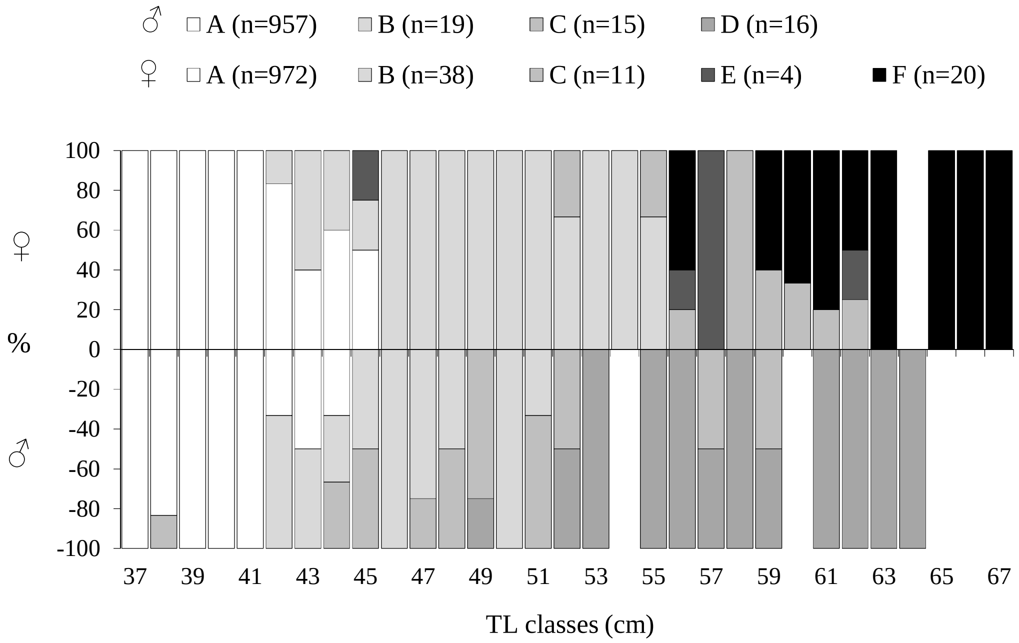


Figure 4.2 – Frequency distributions of *Galeus melastomus* by sex and maturity stages. Specimens between 9 and 36 cm total length (TL) are not represented because they were all immature.

Egg-deposition period could be inferred by analysing the seasonal evolution of the percentages of maturity stages (i.e. mature specimens) of *G. melastomus*. Mature males (Stages C and D) are present all year round, occurring most frequently in summer (17.6%)

and winter (70.6%), when four active males (Stage D) showed copulating signals, such as opened claspers frequently with sperm. The same seems to happen with mature (Stages C to F) females although less frequently (10.5%) in summer and with much higher percentages (79%) in winter. Throughout the reproductive period, mature and immature (A) stages occurred simultaneously, the latter showing a decrease towards winter. In fact, the smallest individuals (9-12 cm TL) were caught almost exclusively in spring and summer. Females attain first sexual maturity in spring, and neither maturing males nor extruding females appeared in spring.

Size at maturity

Male

The internal reproductive organs' measurements taken of *G. melastomus* males are given in Table 4.2. The inner clasper length of the left clasper ranged from 1 to 29 mm for juvenile specimens with non-calcified claspers, from 26 to 51 mm for maturing specimens with calcifying claspers and from 42.7 to 90 mm (mean=67.8, SD=13.52, N=30) for adult (Stages C and D) specimens with calcified claspers.

Table 4.2 – Internal reproductive organ measurements of *Galeus melastomus* males in each maturity stage (N-number of specimens; SD-standard deviation).

Characteristic	A			B		
	Range (N)	Mean	SD	Range (N)	Mean	SD
Inner clasper length (mm) – Right	1.0–29.0 (728)	9.52	5.21	26.0–51.0 (20)	35.98	8.60
Inner clasper length (mm) – Left	1.0–29.0 (728)	9.49	5.18	26.0–51.0 (20)	35.80	8.41
Outer clasper length (mm) – Right	1.0–30.0 (728)	4.65	2.82	13.0–33.0 (20)	20.40	7.38
Outer clasper length (mm) – Left	1.0–30.0 (728)	4.64	2.81	13.0–33.0 (20)	20.40	7.37
Length of testicle (mm) – Right	7.48–61.35 (567)	19.09	9.36	38.77–78.08 (20)	56.73	13.23
Length of testicle (mm) – Left	7.29–52.22 (567)	16.53	7.24	32.75–80.80 (20)	46.68	10.88
Width of testicle (mm) – Right	0.40–6.26 (568)	1.61	1.04	4.37–11.31 (20)	7.57	2.17
Width of testicle (mm) – Left	0.09–5.63 (568)	1.45	0.93	4.32–9.96 (29)	7.21	1.84
Weight of testicle (g) – Right	0.01–0.19 (569)	0.02	0.03	0.14–0.89 (20)	0.47	0.27
Weight of testicle (g) – Left	0.01–0.15 (569)	0.02	0.02	0.12–0.83 (20)	0.40	0.25
Total length of specimens (cm)	9.4–44.0 (730)	21.95	6.59	42.0–51.8 (20)	45.66	2.78
	C			D		
	Range (N)	Mean	SD	Range (N)	Mean	SD
Inner clasper length (mm) – Right	43.3–81.0 (14)	58.44	11.99	65.0–90.0 (16)	76.52	7.29
Inner clasper length (mm) – Left	42.7–81.0 (14)	52.83	16.54	65.0–90.0 (16)	76.58	7.73
Outer clasper length (mm) – Right	27.0–57.0 (14)	38.71	9.58	45.0–67.0 (16)	56.03	7.42
Outer clasper length (mm) – Left	27.0–57.0 (14)	38.34	9.44	43.2–7.0 (16)	55.63	7.69
Length of testicle (mm) – Right	47.1–91.77 (14)	70.46	15.94	59.35–103.86 (16)	74.11	12.39
Length of testicle (mm) – Left	41.8–69.48 (14)	59.09	7.64	32.1–81.54 (16)	67.78	11.66
Width of testicle (mm) – Right	6.96–14.97 (14)	11.21	2.17	10.31–20.22 (16)	14.54	2.83
Width of testicle (mm) – Left	7.13–15.79 (14)	10.69	2.33	10.21–19.86 (16)	14.12	2.96
Weight of testicle (g) – Right	0.57–2.72 (14)	1.42	0.69	0.99–4.46 (16)	2.69	1.03
Weight of testicle (g) – Left	0.56–2.69 (14)	1.29	0.67	1.16–4.14 (16)	2.57	0.90
Total length of specimens (cm)	38.8–59.2 (14)	49.96	5.03	49.2–64.3 (16)	57.23	4.32

Globally, clasper length (CL) increased with total length and, according to the calcification of the clasper, three groups can be noted (Figure 4.3). In *G. melastomus*, 778 specimens were analysed and the size of claspers ranged from 1 to 90 mm (mean=12.33, SD=13.00). The first group of CL range corresponds to immature males (93.6%), ranging in size from 9.4 to 44.0 cm TL, with small, non-calcified claspers, of less than 29 mm length. The second range of clasper size corresponds to maturing males (2.6%), ranging in size from 42.0-51.8 cmTL, with claspers attaining larger sizes (26 to 51 mm) and already calcifying, while the third is composed of mature and active males (3.9%) ranging in size from 38.8-64.3 cm TL, with completely developed sexual organs, including fully calcified and rigid claspers (42.7 to 90 mm). When claspers of 42.7 to 54 mm, 58.3% of males are mature and about 83.3% of the male specimens had claspers that were 42.7 to 90 mm long. A noticeable increase in clasper length occurs when specimens attain 49 cm TL, which indicates that male maturation has begun. At this size, claspers are longer than 54 mm and all of the specimens are mature. Following this rapid growth, the claspers continue to grow but at a slower rate.

Like clasper length, left testis weight, length and width also increased with total body length with onset of maturity. With testes weight ranging from 1.13 g (38 cm TL) to 1.97 g (49 cm TL), 46.2% of males are mature. From 49 cm TL onward, testes weight starts to increase and there is a marked further increase (2.04-3.87 g) from 52 cm TL onward, when all of the specimens are mature. Following this rapid growth, the claspers continue to grow at an even higher rate (Figure 4.4A).

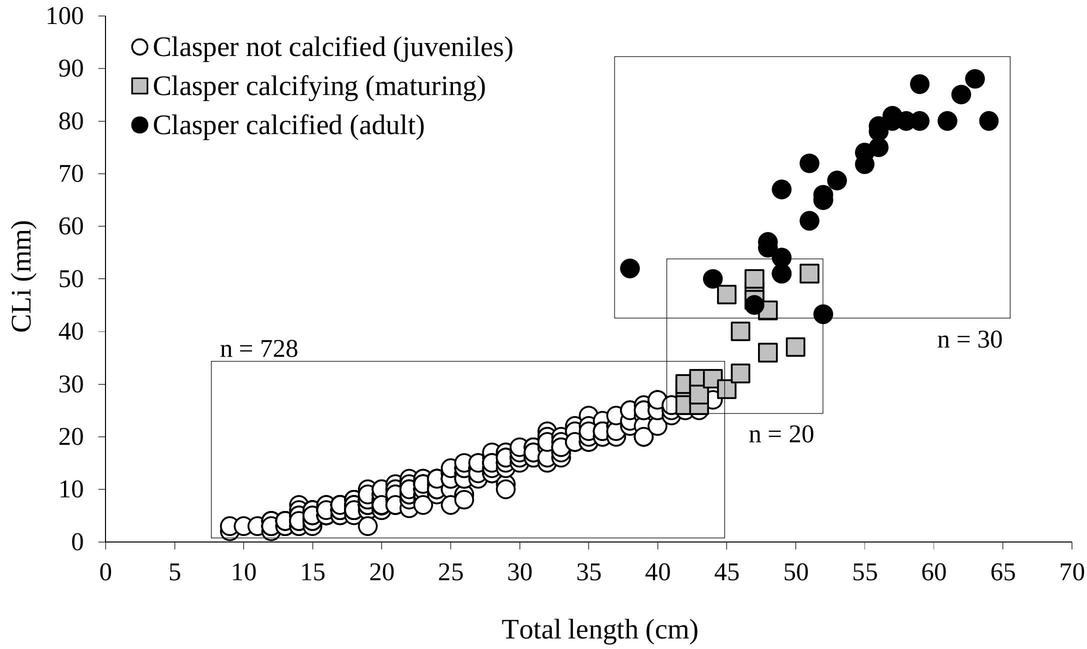


Figure 4.3 – Relationship between total length and inner (left) claspers length (CLi) for males of *Galeus melastomus* across stages of maturity.

Length of the left testes (Table 4.2) does not increase with total length as do the other two testes measurements and the data are more disperse (Figure 4.4B). Even so, testes increased in size more rapidly at a length above 48 cm TL, oscillating between 59.73 to 81.54 mm in length, above which all specimens are mature. As for all other testes measurements, all males greater than 52 cm were mature (Figure 4.4B). Testes also started to grow in width rapidly at a total length of 48 cm (11.35 mm) to 51cm TL (14.23 mm). For testes width ranging from 7.13 mm (38 cm TL) to 10.54 mm (44 cm TL), 36.8% of males are mature, and above 11.35 mm (48 cm TL), all males are mature. No immature or maturing adolescent males less than 52 cm TL were found (Figure 4.4C).

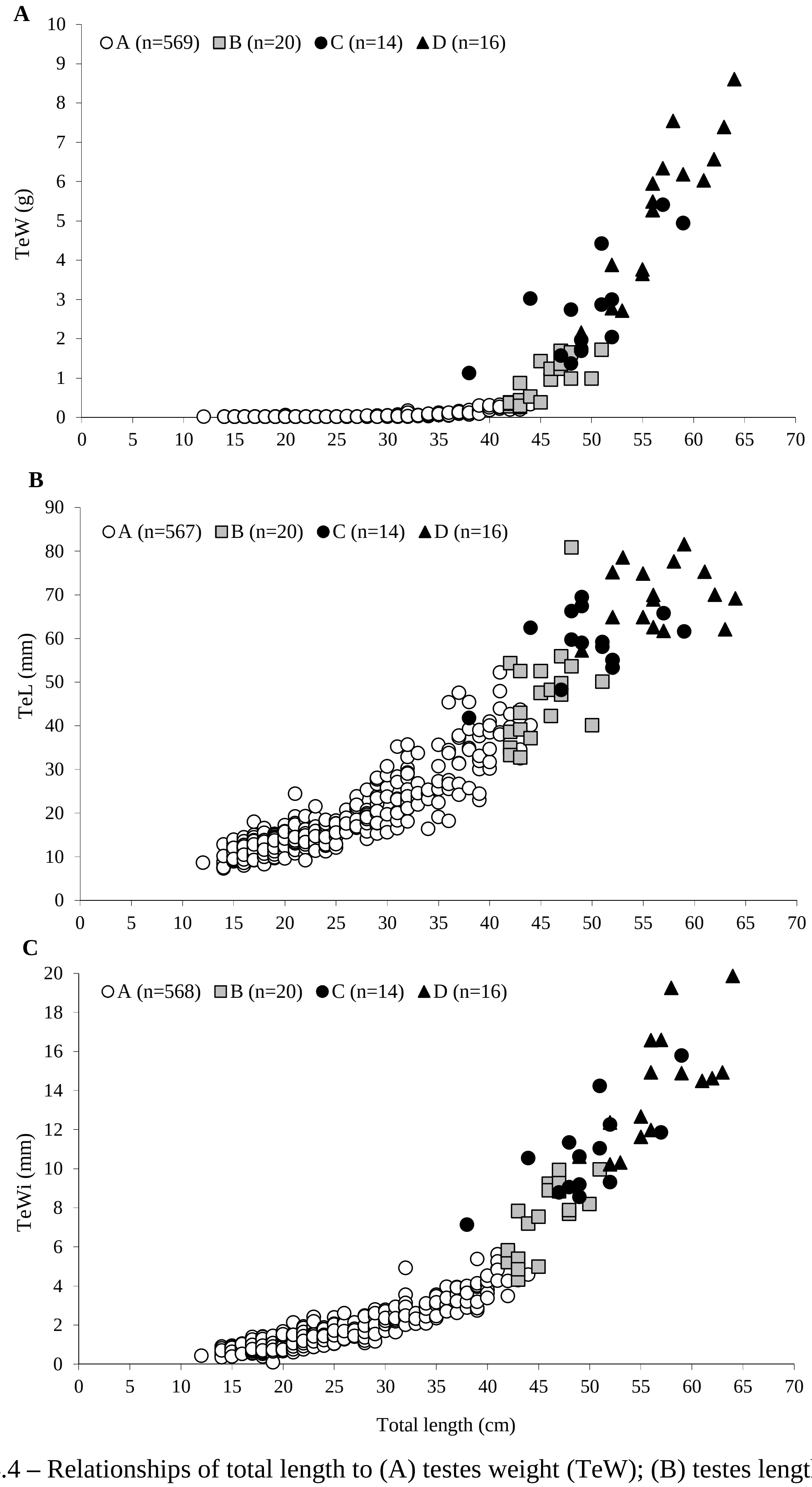


Figure 4.4 – Relationships of total length to (A) testes weight (TeW); (B) testes length (TeL); and (C) testes width (TeWi), in *Galeus melastomus* males, according to maturity stages.

As clasper length and left testis measurements showed rapid increases with the increment in total length, relationships between clasper length and each of the testis measurements were pooled and plotted against total length, but in this case not considering maturity stages (Figure 4.5). As expected, the relationship between the clasper length and the total length is very similar to that between the testes weight (TeW), length (TeL) and width (TeWi). An increase in both clasper and testis occurs at approximately 44 cm TL and this may indicate that male *G. melastomus* reaches maturity about this size.

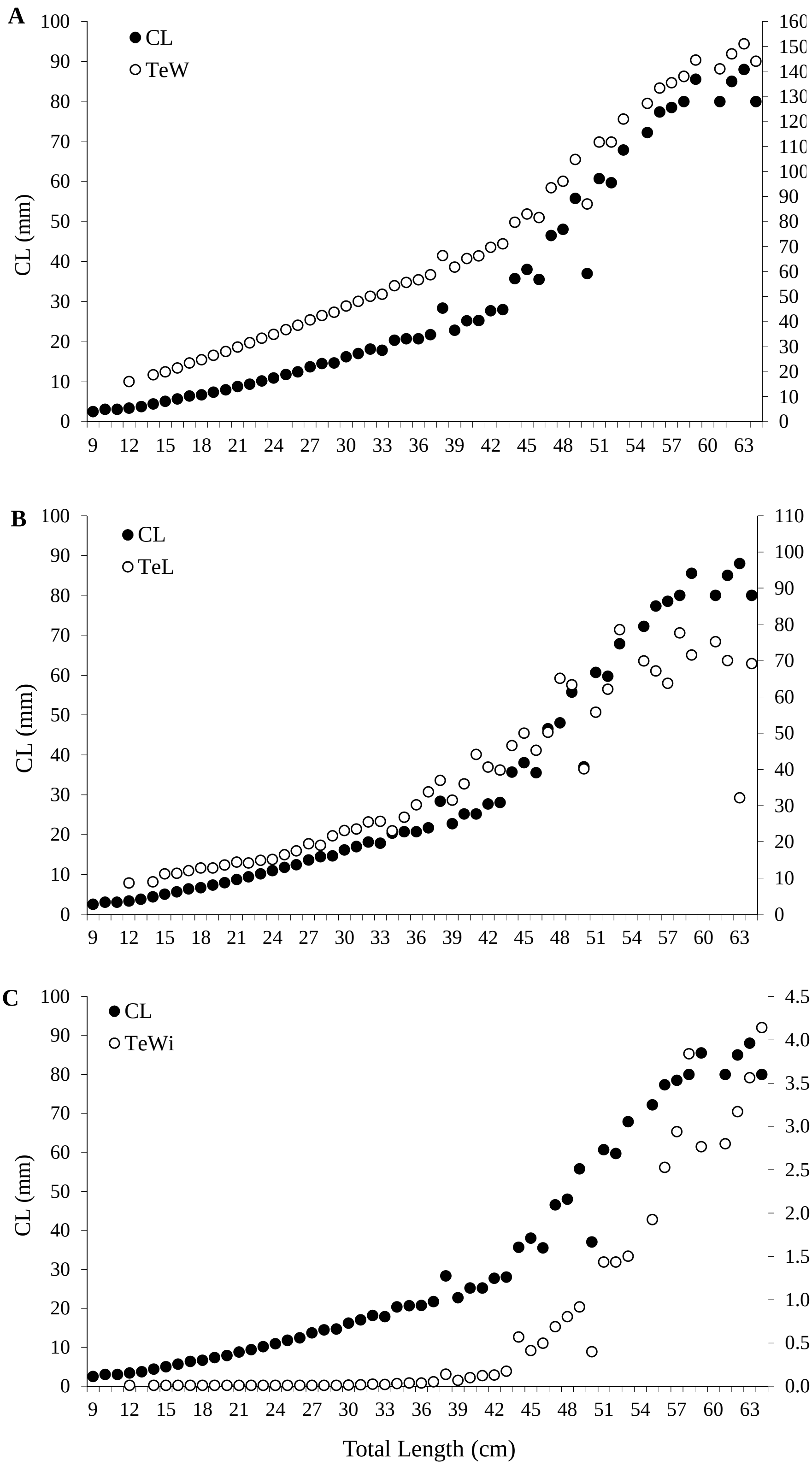


Figure 4.5 – Relationships between total length and (A) clasper length (CL) and testis weight (TeW), (B) CL and testes length (TeL) and (C) CL and testes width (TeWi) in *Galeus melastomus* males.

Size-at-first-maturity (L_{50}) for *G. melastomus* males was determined from 31 mature specimens and was estimated to be 49.37 cmTL. The logistic curve was:

$$P_i = 1 / [1 + e^{(7.6374 + 0.1547 * TL)}]. \quad (1)$$

Discriminant analyses results shows a good separation between the four maturity stages (groups 1 to 4) of males (Figure 4.6) and reveals that, in addition to total length, length of left clasper and measurements of left testis are the most important variables to define stage of maturity in males (Table 4.3).

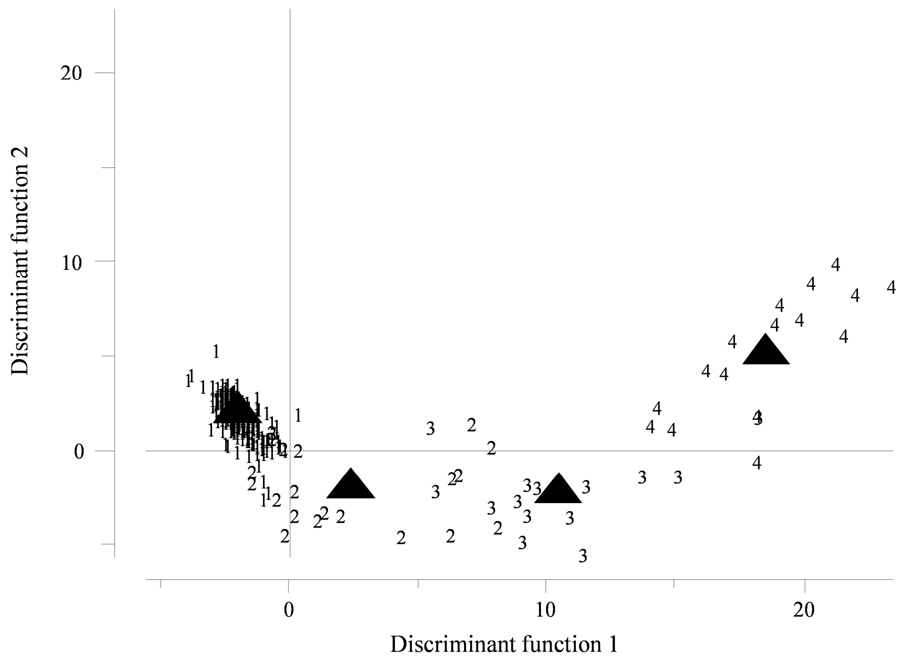


Figure 4.6 – Scores of maturity stages (groups 1 to 4) for the two discriminant functions axes of the DA for *Galeus melastomus* males. Triangles represent mean values.

Table 4.3 – Discriminant Analysis (DA) output for *Galeus melastomus* males.

naive rank	Mahalanobis distance	Variable
1	984.683	Total Length
2	1017.903	Inner Clasper Length Left
3	1089.717	Weight Testis Left
4	1130.083	Inner Clasper Length Right
5	1131.533	Length Testis Left
6	1135.230	Weight Testis Right
7	1147.460	Width Testis Left
8	1150.166	Outer Clasper Length Right
9	1151.574	Length Testis Right
10	1161.241	Outer Clasper Length Left
11	1162.580	Width Testis Right

Total sum of Mahalanobis distances between group means = 1166.59

Female

The internal reproductive organ measurements taken on ovaries of *G. melastomus* females are given in Table 4.4. Ovary width ranged from 0.5 to 13.74 mm for immature (Stage A), from 5.73 to 20.9 mm for maturing (Stage B), and from 15.11 to 59.83 mm (mean=38.59, SD=9.85, N=35) for mature (Stages C, E, F) specimens. Ovary weight ranged from 0.01 to 0.80 g for immature, from 0.09 to 1.68 mm for maturing, and from 1.03 to 45.57 mm (mean=18.26, SD=10.07, N=35) for mature specimens. Ovary length varied from 6.22 to 97.08 mm for immature, from 55.53 to 108.47 mm for maturing and from 77.10 to 155.85 mm (mean=114.26, SD=19.50, N=35) for mature specimens.

Table 4.4 – Internal reproductive organ measurements of *Galeus melastomus* females in each maturity stage (N-number of specimens; SD-standard deviation).

Characteristic	A			B			C		
	Range (N)	Mean	SD	Range (N)	Mean	SD	Range	Mean	SD
Length of nidamental gland (mm)				8.63–21.11 (21)	13.63	2.86	17.7–31.43 (10)	24.53	4.73
Width of nidamental gland (mm)				3.67–12.24 (21)	6.24	2.66	11.13–19.89 (10)	15.92	2.74
Length of ovary (mm)	6.22–97.08 (612)	26.29	16.50	55.53–108.47 (36)	87.06	10.43	77.10–120.92 (11)	105.49	12.89
Width of ovary (mm)	0.50–13.74 (612)	4.26	2.65	5.73–20.90 (36)	13.56	2.87	15.11–46.76 (11)	30.52	10.51
Weight of ovary (g)	0.01–0.80 (612)	0.04	0.08	0.09–1.68 (36)	0.77	0.32	1.03–27.72 (11)	10.13	8.36
Width of uteri (mm)				2.24–14.30 (22)	5.54	3.26	7.71–19.37 (11)	13.62	3.11
Total length of specimens (cm)	12.7–47.8 (614)	22.87	6.82	43.6–55.1 (36)	49.52	3.57	52.7–62.2 (11)	58.42	2.66
	E			F					
	Range (N)	Mean	SD	Range (N)	Mean	SD			
Length of nidamental gland (mm)	21.82–31.15 (4)	25.14	4.33	24.34–35.43 (17)	28.45	2.96			
Width of nidamental gland (mm)	12.76–20.06 (4)	17.46	3.28	16.58–25.92 (17)	19.97	2.38			
Length of ovary (mm)	73.55–128.74 (4)	101.87	22.60	88.16–155.85 (20)	121.56	19.47			
Width of ovary (mm)	26.41–43.81 (4)	37.70	7.96	34.25–59.83 (20)	43.21	6.72			
Weight of ovary (g)	9.72–19.5 (4)	13.94	4.17	14.98–45-57 (20)	23.60	8.35			
Width of uteri (mm)	14.05–26.02 (4)	19.21	5.24	22.55–28.26 (7)	25.28	2.18			
Total length of specimens (cm)	45.5–62.0 (4)	55.23	6.95	56.0–67.0 (20)	61.42	2.97			

In general, width, weight and length of right ovary of *G. melastomus* females also increased with total body length with onset of maturity, as was also the case for males (Figure 4.7). With an ovary width (OWi) from 15.11 mm (52 cm TL) to 24.15 mm (55 cm TL), only 30.8% of females are mature (Figure 4.7A). Ovary width in relation to total length increased rapidly from a TL of about 56 cm onward, above which all specimens are mature, varying from a minimum of 27.79 mm to a maximum of 59.83 mm width. Following this rapid growth, the ovary continues to grow in width but at a slower rate. Exceptionally, one female of 45 cm TL was in the advanced stage of maturity, with an ovary width of 26.41 mm. The relationship between total length and ovary weight (OWe) also demonstrates that ovaries started to get noticeably heavier from a total length of 56 cm onward, above which all specimens are mature, varying from 5.74 to 33.28 g (Figure 4.7B). Following this growth, the ovary continues to grow in weight at an even higher rate. Female specimens from 12 to 55 cm TL were all immature and maturing, with the exception of one mature (Stage C) female of 52 cm TL (OWe=1.03 g) and another one in an advanced stage (E) at 45 cm TL (OWe=0.72 g). Concerning the ovary length (OL), an increase with total length is not as evident as for the other two ovary measurements, with data that are more disperse (Figure 4.7C). Even so, ovaries seemed to start to grow more rapidly at 59 cm TL, continuing to increase in size with higher total lengths. With ovary lengths ranging from 73.55 mm (45 cm TL) to 108.47 mm (50 cm TL), few females are mature (28.3%) and, similar to other two ovary measurements, females above 56 cm TL are all mature.

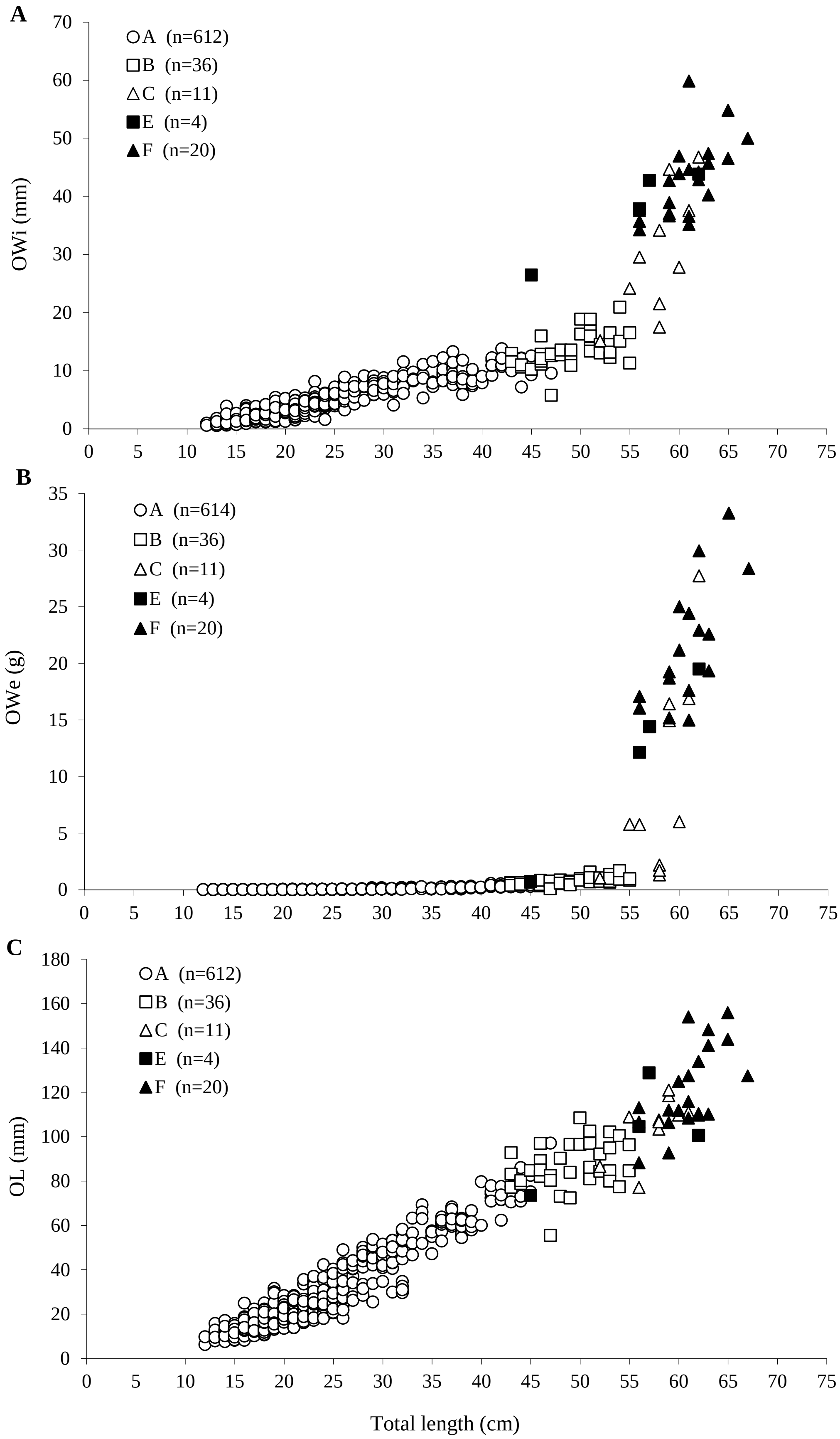


Figure 4.7 – Relationship between total length and (A) ovary width (OWi); (B) ovary weight (OWe); and (C) ovary length (OL), in *Galeus melastomus* females, across stages of maturity.

Nevertheless, relationships between total length and width and length of oviducal gland (Figure 4.8) and total length and uterus width (Figure 4.9) were explored in order to see if there is an increase in these organ measurements with total body length, with onset of maturity. Both oviducal gland width (OgWi) and length (OgL) in relation to total length, increased rapidly at a TL from about 56 cm onward, above which all specimens are mature. For mature females, OgWi varied from a minimum of 11.88 mm to a maximum of 25.92 mm, and OgL ranged from 17.72 to 35.43 mm. Following this rapid growth, the oviducal gland continues to grow in width but rather gradually, while it seems to continue growing in length but even less gradually. Also, in both kinds of measurements of the oviducal gland, females less than 55 cm are not mature, with the exception of one mature female (Stage C) of 52 cm TL (OgWi=11.13 mm, OgL=17.7 mm) and outstandingly, one female in the advanced stage of maturity (Stage E), measuring 45 cm TL, had a smaller oviducal gland, of 12.76 mm in width and of 21.82 mm in length, being more similar to females in the maturing (B) stage (Figure 4.8).

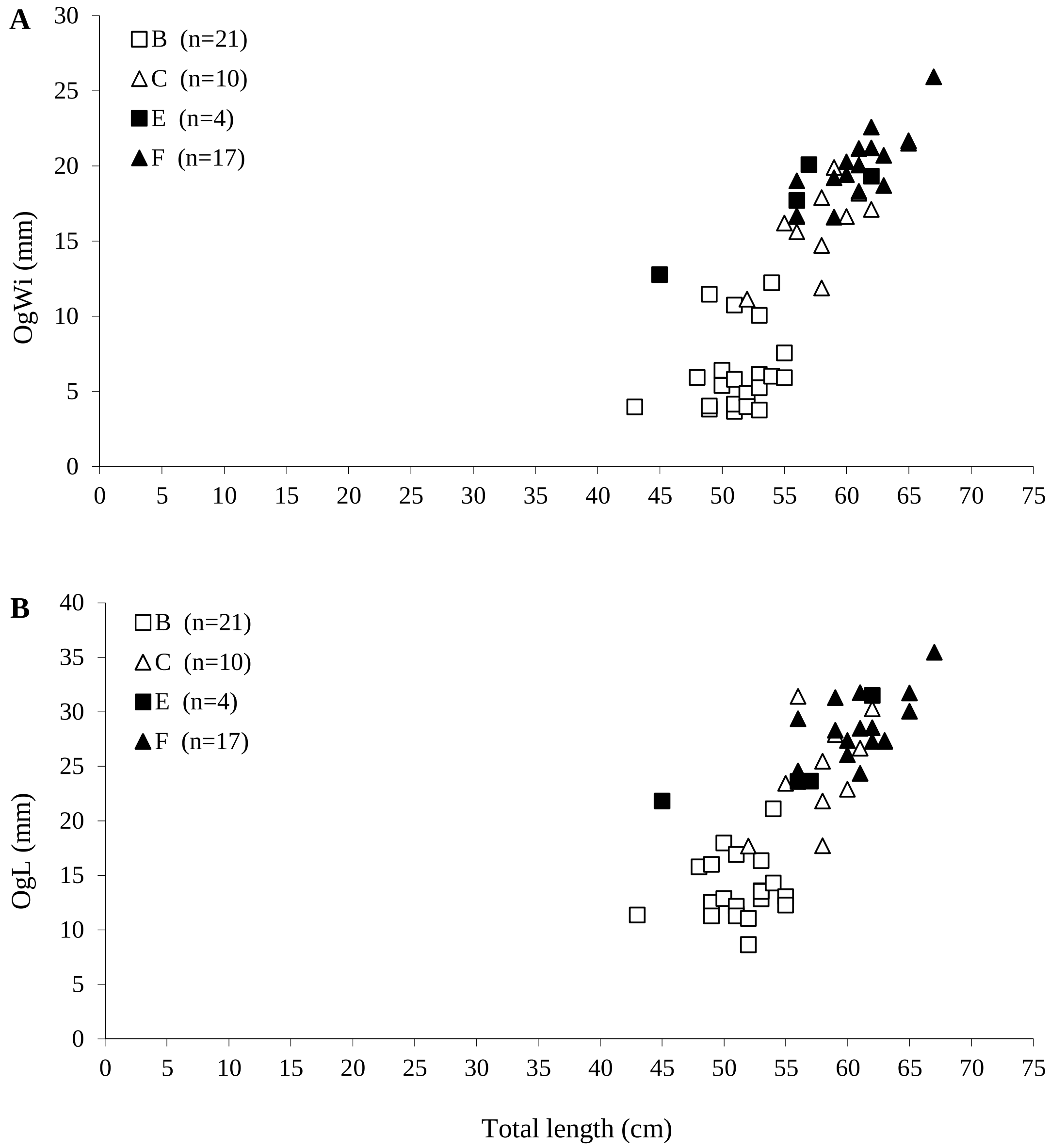


Figure 4.8 – Relationship between (A) oviducal gland width (OgWi) and total length and (B) oviducal gland length (OgL) and total length, in *Galeus melastomus* females, across stages of maturity.

Width of uterus (UWi) follows exactly the same pattern as oviducal gland. A rapid increase appears when females attain 56 cm TL, with all females above this size being mature. Nonetheless, after this increment uterus width only grows 2.24 mm more, attaining a maximum of 28.26 mm at 62 cm TL. The rest of the mature females have uteri that range from 11.27 to 26.02 mm in width (Figure 4.9).

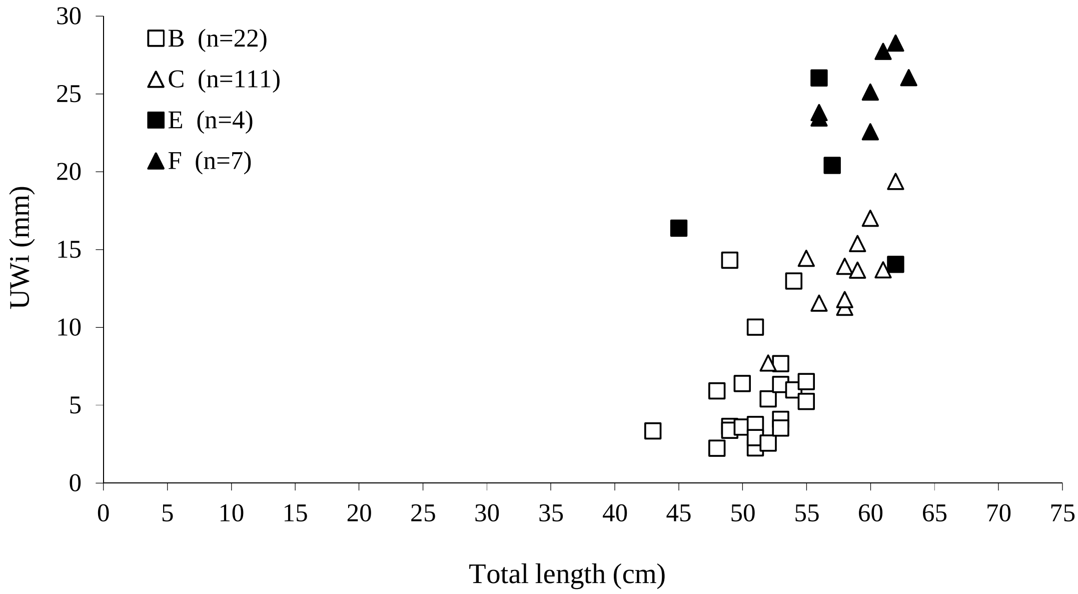


Figure 4.9 – Relationship between uterus width (UWi) and total length, in *Galeus melastomus* females, across stages of maturity.

Egg capsules were found in 24 *G. melastomus* females, with three females in advanced stage (E) and 21 females in the extruding stage (F). No marked difference was found in the number of egg capsules between the right and left uterus. The number of egg capsules ranged from 1 to 4 in each uterus (oviducts) and of the 24 litters examined, 18 had equal number of egg capsules in each uterus, one had one more egg capsule on one side or the other and five had only one egg capsule, all in the right uterus. The 100 egg capsules ranged from a minimum of 35x14 mm to a maximum of 63x25 mm in length and width (mean=54x21 mm; SD=4.66x1.78), respectively. Females carrying egg capsules appeared all year round but the majority of them were captured in the winter (70.83%) and in the summer (20.83%). Single females bearing egg capsules were captured in spring and in autumn. Although no relation between female size and the number of eggs was found, larger females seem to have slightly larger egg capsules.

Size-at-first-maturity (L_{50}) for *G. melastomus* females was determined from 35 mature specimens and was estimated to be 69.69 cmTL. The logistic curve was:

$$P_i = 1 / [1 + e^{(3.0387 + 0.0436 * TL)}]. \quad (2)$$

Discriminant analyses results shows a good separation between the five maturity stages (groups 1 to 5) of females when considering the mean values, although it is closer in groups 1 and 2 than that of the remaining groups (Figure 4.10). DA also reveals that ovary width is the most important variable to define stage of maturity in females, followed by ovary weight (2[nd] naive rank) and ovary length (3rd naive rank). Total length of the specimen is the least important variable (Table 4.5).

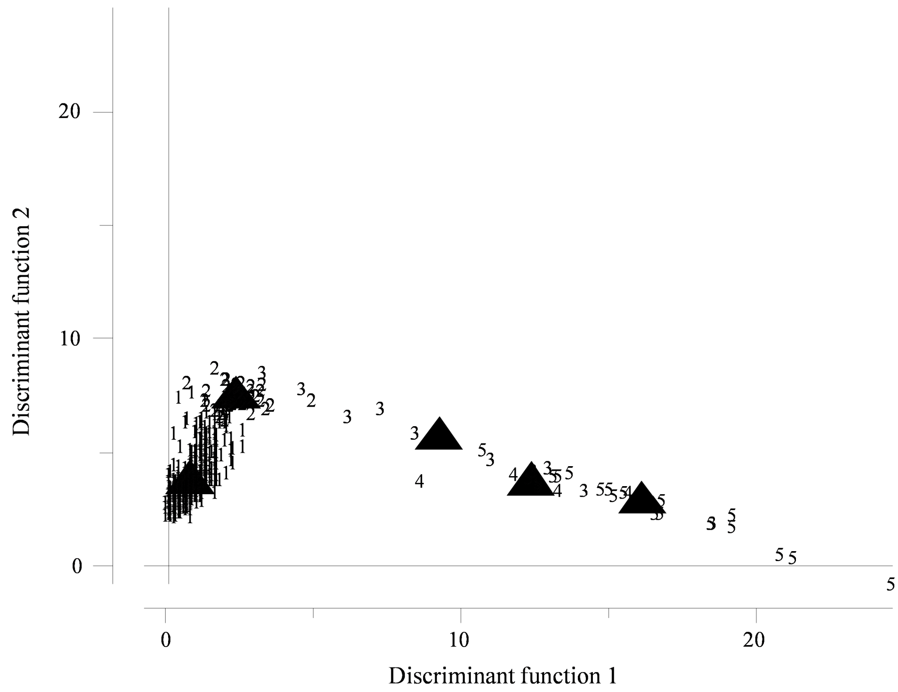


Figure 4.10 – Scores of maturity stages (groups 1 to 4) for the two discriminant functions axes of the DA for *Galeus melastomus* females. Triangles represent mean values.

Table 4.5 – Discriminant Analysis (DA) output for *Galeus melastomus* females.

naive rank	Mahalanobis distance	Variable
1	710.180	Width Ovary (Right)
2	834.235	Weight Ovary (Right)
3	968.187	Length Ovary (Right)
4	975.858	Total Length

Total sum of Mahalanobis distances between group means = 1166.59

Reproductive activity

The seasonal evolution of the gonadosomatic index (GSI) of *G. melastomus* is similar in both sexes with higher values for females than males. The analysis of GSI shows that gonads reach their maximum weight in winter (egg laying peak) (mean=15.3, SE=2.695, for females and mean=9.6, SE=1.922, for males) and a minimum in the spring (mean=2.7, SE=0.445, for females and mean=3.2, SE=0.233, for males) and autumn (after and before egg deposition, respectively) (mean=2.2, SE=0.426), in females, and in the autumn (resting period) (mean=1.0, SE=0.08), in males. These findings generally agree with those obtained by the seasonal analysis of maturity stages.

Correspondence analysis (CA) result shows a good separation between females and males, according to maturity stage and season (Figure 4.11). Immature individuals are well distinguished from maturing and mature ones, with immature females closer to spring and autumn and males closer to summer season. Mating season and egg-deposition periods occur more markedly during the winter season.

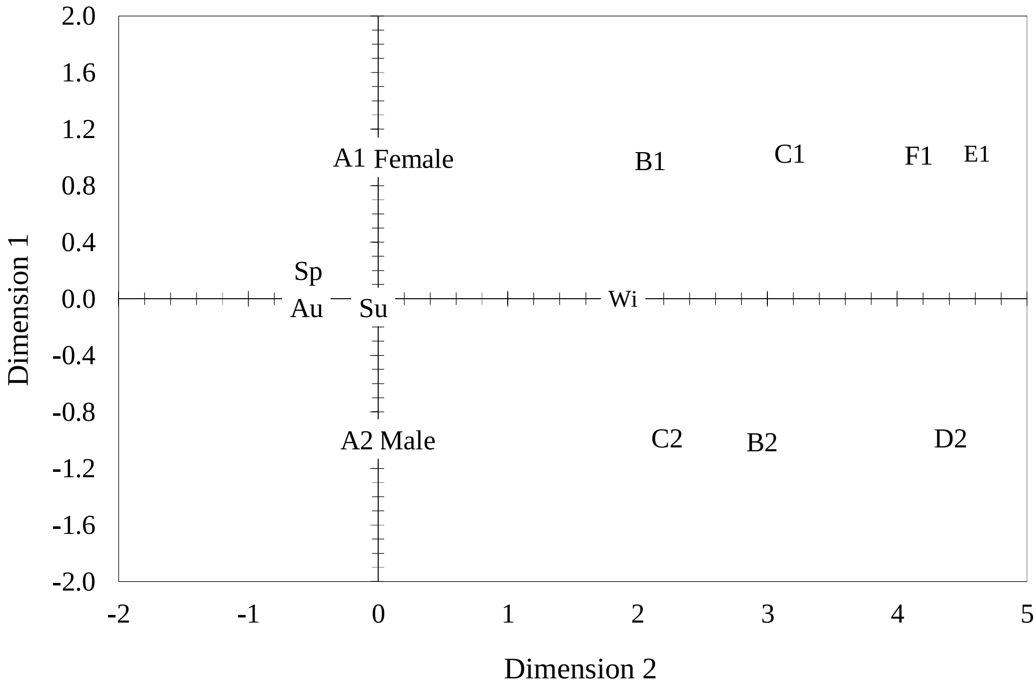


Figure 4.11 – Correspondence analysis (CA) plot displaying variable scores in the first two dimensions for *Galeus melastomus*. Letters A to F represent maturity stages, numbers 1 and 2, associated with maturity stages, correspond to sex (1-♀, 2-♂) and seasons are represented by Wi-winter, Sp-spring, Su-summer and Au-autumn.

Discussion

The population of *Galeus melastomus* off the south coast of Portugal was found to consist mostly of young individuals. This could be due to the non-selective gear characteristics of crustacean trawlers and/or to overfishing effects at bathyal depths (200 to 800m) by the fishery targeting valuable species such as *Aristeus antennatus*, *Parapenaeus longirostris* and *Nephrops norvegicus*.

The biological and reproductive aspects of *G. melastomus* from Algarve waters differ only slightly from those of Mediterranean specimens. According to Capapé and Zaouali (1977), Mediterranean blackmouth catshark specimens attain smaller maximum total lengths than those from the Atlantic. The maximum total length of the specimens caught off the south coast of Portugal corroborates this statement, as can be seen in Table 4.6.

Table 4.6 – Comparison of maximum total length (TL) and size at first maturity by sex of *Galeus melastomus* for various geographical subareas.

Author	Maritime sector	Maximum TL (cm) ♂	Maximum TL (cm) ♀	Size at maturity ♂	Size at maturity ♀
Joensen and Taning (1970) in Cadenat and Blache (1981)	Faeroe Archipelago			70–79	
Capapé (1974) in Cadenat and Blache (1981)	Tunisian coasts (Mediterranean)		63	50–70	
Capapé and Zaouali (1977)	Tunisian waters (Mediterranean)	42	47	>42	39–42
Cadenat and Blache (1981)	Mediterranean and Atlantic (occidental coast of Africa)	40 (mean)			
Capapé and Brahim (1984)	Tunisian waters (Mediterranean)	62	66		
Compagno (1984b)	Eastern North Atlantic and Mediterranean	61	90	33–42	38–45
Quéro (1984)	Eastern North Atlantic and Mediterranean	61	90	34–42	39–45
Sanches (1986)	Portuguese coast and Madeira Island	90			
Tursi *et al.* (1993)	Ionian Sea (Mediterranean)	51	55	45	49
Pivnička and Černý (1990)	European coasts	70			
Figueiredo *et al.* (1995)	Portuguese south and southern west coasts	80			
Moreno (1995)	Iberian waters, north-eastern Atlantic and Mediterranean	60–70		40	40
Mojetta (1997)	Eastern Atlantic and Mediterranean	90			
Bannister (1998)	Eastern Atlantic	100			
Muus and Nielsen (1998)	Eastern Atlantic and Mediterranean	60	90		
Our data	Portuguese south coast	64	67	49	56–59

According to Figueiredo and Correia (1996), in Portugal there are no relevant studies on growth of *G. melastomus*. Figueiredo *et al.* (1994) reported that this species displays a clear increase in size with depth, being well represented in the Algarve at depths from 400 to 800 m, with mean total lengths ranging between 26.12 cm to 56.73 cm. The lack of larger specimens in the present study (mainly females in the last reproductive stages), could be a characteristic of the local population or may be due to the tendency for larger specimens to be found in even deeper waters.

The overall distribution of length-frequencies and maturity stages indicates that the blackmouth catshark presents a sexual dimorphism by size in the studied area, with females growing larger than males and also reaching maturity at a larger size. Capapé and Brahim (1984), in the Mediterranean (Tunisia) also found that females were slightly bigger than males.

No variation in the sex ratio throughout the year was found. Capapé and Zaouali (1977) also found that schools of blackmouth catshark inhabiting bathyal zones in the Ionian Sea were made up of females and males in equal proportion.

The blackmouth catshark has been confirmed as an oviparous species (Cadenat and Blache, 1981; Compagno, 1984a; http://www.fishbase.org; http://shark-gallery.netfirms.com;

Mojetta, 1997; Moreno, 1995; Quéro, 1984), with eggs that are enclosed within an egg capsule, without tendrils at the corners, and that are deposited on the bottom. Oviparity in *G. melastomus* is a case of retained oviparity, with multiple egg capsules retained within the oviducts (the same as in the uterus of viviparous sharks), but in which the development proceeds for a longer period before the egg capsules are released into the environment (Compagno, 1988 and Compagno, 1990 *in* Conrath, 2004).

Wourms (1977) characterized three basic types of reproductive cycle for chondrichthyan fish: (1) reproduction continuously throughout the year; (2) a prolonged and partially defined annual cycle with one or two peaks; and (3) a well defined annual or biennial cycle.

The results of seasonal percentages of males and females by maturity stages, the existence of males that showed copulation signals, the seasonal evolution of the GSI and the correspondence analysis results, suggest that the mating season and egg-deposition period occurs mainly in winter and, to a lesser extent, in summer. The fact that females carrying egg capsules appeared in all seasons could suggest egg-deposition all year round in the studied area. Therefore, *G. melastomus* could have an extended breeding season, reproducing continuously all year round, with eggs continuing to develop throughout the year, but with two reproductive activity peaks occurring during the winter and summer.

Egg-deposition of *G. melastomus* attains a maximum during the hydrologic warm season and, in the Mediterranean, occurs throughout the year, with a peak of activity in the spring and the summer (Capapé and Zaouali, 1977; Quéro, 1984; Tursi *et al.*, 1993; Moreno, 1995; Bannister, 1998). Capapé and Zaouali (1977) reported that vitellogenic activity is constant all year round and that all adult females have numerous oocytes inside their ovary ready to be fertilized in the uterus. Tursi *et al.* (1993) added that the active reproductive cycle of mature blackmouth catshark occurs at the shallowest depths at which the species is found, whilst juveniles are widely distributed on the bathyal slope (Orsi and Wurtz, 1977), probably due to different feeding requirements compared with those of the adults (Tursi *et al.*, 1993) and, over time, they move successively into shallower depths, reproducing (copulating and fertilizing the eggs) and concluding its life cycle (by gestation, egg-deposition and hatching of the egg-capsules). According to Muñoz-Chápuli (1984), the phenomenon of segregation of deep-sea sharks into aggregations of the same sex and size was already studied by Ford (1921) for the genus *Scyliorhinus*, and by Bullis Jr (*in* Gilbert, 1967) for *Galeus arae* (Nichols, 1927).

Length of left clasper and measurements of left testis are considered a good measure to define stage of maturity of males, with marked changes in growth rate from 49 to 52 cm TL for clasper length, testis weight, width and length. Size at first maturity (L_{50}) was estimated to be 49.37 cm TL. These results suggest that the size at maturity for males could fall between 48 and 52 cm TL.

Oviducal gland measurements can also be potential indices of maturity, although not so important as the ovary, which is, probably, the best reproductive organ for defining the state of maturity of *G. melastomus* females. On the other hand, uterus width does not seem to be as important for defining female maturity stage. The ovary width and weight increased noticeably at about 56 cm TL (27.79-59.83 mm and 5.74-33.28 g, respectively) and ovary length, although not as clearly as the other two measurements, increased rapidly at 59 cm TL (92.57-120.92 mm). The smallest advanced (Stage E) and extruding (Stage F) females were 56 cm TL. Size-at-first-maturity (L_{50}) was estimated to be 69.69 cm TL. This value is probably overestimated since the sample size of the proportion of mature females used to estimate L_{50} was small. These results suggest that the size-at-first-maturity for females is probably above 56 cm or could fall between 56 and 59 cm TL. Nevertheless, our size at first sexual maturity data is greater than for the Mediterranean, as can be seen in Table 4.6. Tursi *et al.* (1993) also found that sexual maturity in *G. melastomus* would be reached around the third or fourth year of life and Capapé (1977) *in* Capapé and Brahim (1984) states that maximum total lengths and size-at-first-maturity are random in some species of selachians and, notably, that there could be very important variations within the family Scyliorhinidae.

The dimensions of egg capsules vary according to geographic area, with those of specimens from the Atlantic being larger than those from the Mediterranean (Capapé and Zaouali, 1977). Capapé and Zaouali (1977) stated that the reproductive cycle of *G. melastomus* in Mediterranean waters is different from that of other oviparous selachians in certain points: the egg-deposition is permanent all year round and the seasonal fluctuations (egg capsules production was more important in the autumn) are less marked than in *Scyliorhinus canicula* and in Rajidae. The egg capsule dimensions studied off the south coast of Portugal (from 35x14 to 63x25 mm) are, in fact, larger than those of the Mediterranean and, closer to our study are the egg capsule dimensions reported by Moreno (1995) (Table 4.7).

A relatively small proportion (9%) of *G. melastomus*, off the Algarve, of total lengths greater than 38 cm TL is marketed. If we consider that the size at first sexual maturity for this species is in fact over 38 cm TL, we suggest that a minimum landing size should be established: above 56 cm, for females and above 48 cm, for males.

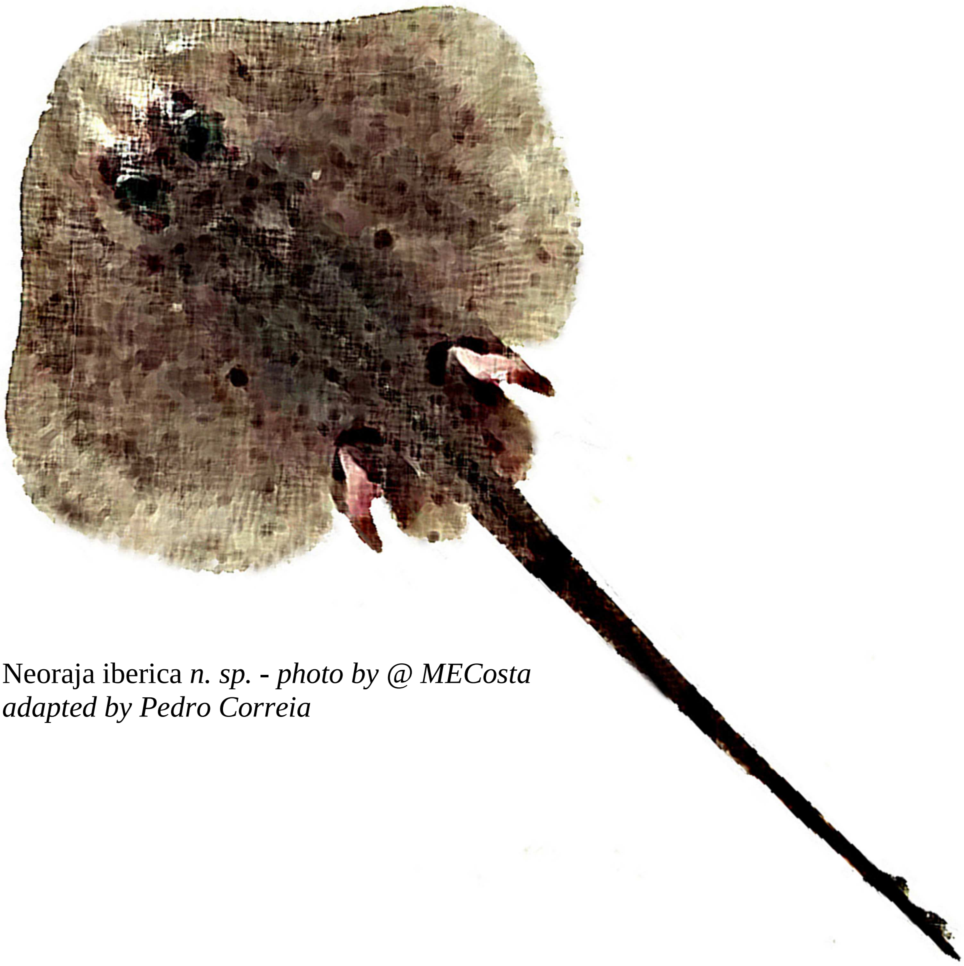
Table 4.7 – Comparison of egg capsules dimensions of *Galeus melastomus* for various geographical subareas.

Author	Maritime sector	Egg capsules Dimension (mm)
Lo Bianco (1909) in Capapé and Zaouali (1977)	Italian seas	45x18
Le Danois (1913) in Capapé and Zaouali (1977)	Manche (eastern Atlantic)	60x30
Tortonese (1956) in Capapé and Zaouali (1977)	Italian seas	45x18
Wheeler (1969) in Capapé and Zaouali (1977)	British Isles (eastern Atlantic)	60x30
Capapé (s/d) in Capapé and Zaouali (1977)	Tunisian waters (Mediterranean)	46x21
Smith (1893) in Cadenat and Blache (1981)	Occidental coast of Africa	45x18–65x20
Capapé and Zaouali (1977)	Tunisian waters (Mediterranean)	42x18–48x25
Compagno (1984b)	Eastern North Atlantic and Mediterranean	60x29
Quéro (1984)	Eastern North Atlantic and Mediterranean	60x30
Tursi *et al.* (1993)	Ionian Sea (Mediterranean)	45x17–55x20
Moreno (1995)	Iberian waters, north-eastern Atlantic and Mediterranean	50x20–55x20
Bannister (1998)	Eastern Atlantic	60x30
Our data	Portuguese south coast	35x14–63x25

However, these results should be considered as preliminary and further research into relevant life history characteristics, growth, distribution, spatial segregations of mature individuals and, particularly, gestation period, fecundity studies and histological examinations of the gonads are required in order to carry out an assessment of the *G. melastomus* population off the South coast of Portugal.

Chapter 5

Neoraja iberica n. sp., a new species of pygmy skate (Elasmobranchii, Rajidae) from the southern upper slope of the Iberian Peninsula (Eastern North Atlantic)



Neoraja iberica *n. sp. - photo by @ MECosta adapted by Pedro Correia*

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Abstract

Neoraja iberica n. sp. is described from the Portuguese and Spanish sector of the Iberian Peninsula south coast slope, based on a series of 50 type specimens representing all sizes of both sexes. This pygmy skate species was found with a maximum total length of 316 mm for females and 327 mm for males. The smallest specimens were a 55 mm TL neonate female and a 67 mm TL male. This new species is easily distinguished externally from four named congeners *N. stehmanni*, *N. caerulea*, *N. africana* and *N. carolinensis* by: upper side ochre to medium greyish-brown and dark greyish in ground colour with a lively ornamentation in smaller specimens of dark brown dots and spots all over disc and posterior pelvic lobes to the extreme margins, plus frequently a few pairs of whitish spots and dots on inner pectorals; 7-8 blackish cross-bars or asymmetrically paired saddle blotches along tail, which pattern fades with growth and becomes reduced in adults to a few pairs of larger dark, pale edged spots plus mostly 1-2 pairs of the whitish dots, and cross-bars or saddle blotches along tail become less distinct; underside of disc, pelvics and tail white, at most a faint greyish margin to posterior disc and pelvic lobes, but occasionally a cloud of merging brownish spots appears on each pectoral centre. A mature male specimen in poor condition of about 260 mm TL from the southern Bay of Biscay, originally identified by Vaillant (1888) as *Raja fullonica* Linnaeus 1758, is now reallocated to *Neoraja*, based mainly on features of its nearly skeletonised claspers. The similar patchy and very limited distributional range of each species all along the Eastern Atlantic from off South Africa to off Scotland is briefly discussed, with four or five species occurring in the Eastern and only one species in the NW Atlantic.

Introduction

Bigelow and Schroeder (1948) established the genus *Breviraja* for soft-snouted pygmy skates first found in the Western North Atlantic and assigned their new species *B. colesi* (generotype) and *B. plutonia* (Garman, 1881) to this genus. These authors diagnosed their genus by "Rajidae with a rostral cartilage, but with the latter falling considerably short of the extremities of the anterior rays of the pectorals and hence short of the tip of the snout; the anterior pectoral rays of the two sides are either close together anteriorly or are farther separated. Characters otherwise as in *Raja*." Six more Western North Atlantic species were subsequently described by Bigelow and Schroeder (1950): *B. cubensis*, *B. atripinna*, *B. sinusmexicanus*, *B. spinosa*, *B. yucatanensis*; and Bigelow and Schroeder (1962): *B. ishiyamai*. Other authors added to this number by describing or assigning further species from other ocean localities to *Breviraja*, based primarily on the soft-snouted rostral condition (e.g. Bigelow and Schroeder, 1965; Forster, 1967; Ishiyama, 1958, 1967; Krefft, 1968a), although in external appearance and size most differed considerably from the eight species initially assigned to the genus *Breviraja* by Bigelow and Schroeder (*loc. cit.*).

Ishiyama and Hubbs (1968) compared rostral cartilages and claspers of *Breviraja colesi*, with those of soft-snouted Western North Pacific skates described by Ishiyama (1958, 1967), and found considerable differences. Consequently, they rediagnosed *Breviraja* based on its type species *B. colesi* and assigned all species, other than the original eight from the Western North Atlantic, to the genus *Bathyraja* Ishiyama, 1958 by elevating it from subgeneric rank *Breviraja* (*Bathyraja*) to a defined genus. Following this revision, various authors reallocated many species previously assigned to *Breviraja* to *Bathyraja* (e.g. Hulley, 1970; Menni, 1972; Stehmann, 1970, 1978).

Based on the revised diagnosis of *Breviraja* by Ishiyama and Hubbs (1968), further species were described mainly from the Eastern Atlantic: *B. stehmanni* Hulley, 1972, *B. caerulea* Stehmann, 1976b. Stehmann (1976a) also reallocated two Indian Ocean species of *Raja* to *Breviraja*, namely *B. mamillidens* (Alcock, 1889) and *B. sibogae* (Weber, 1913) and commented on a third unnamed one Weber (1913) had collected and assigned to *Raja mamillidens* Alcock, 1889. McEachran and Compagno (1982) analysed and disentangled the interrelationships of and within *Breviraja* with a detailed revision of the 11-12 species resulting in: *Breviraja* Bigelow and Schroeder, 1948 was restricted to two *B. colesi* and *B. spinosa*, a new genus *Neoraja* was erected with two subgenera *Neoraja* and *Fenestraja*; to the former subgenus were assigned *B. stehmanni*, *B. caerulea* and an unnamed third species, to the latter subgenus the majority of species, i.e. *sinusmexicanus*, *sibogae*, *ishiyamai*, *cubensis, plutonia*, *atripinna*, and finally was *B. yucatanensis* reallocated to *Raja*.

Three more Western Atlantic species of *Breviraja* were newly described after the genus revision by McEachran and Compagno (1982): *B. claramaculata* McEachran and Matheson, 1985, *B. nigriventralis* McEachran and Matheson, 1985, *M. mouldi* McEachran and Matheson, 1995. A fourth one *B. marklei* McEachran and Miyake, 1987, from off Nova Scotia, however, is a junior synonym of *Rajella fyllae* (Lütken, 1888).

Appearance of the McEachran and Compagno (1982) revision had overlapped with the manuscript submission by Stehmann and Séret (1983) describing a third Eastern Atlantic species, *Breviraja Africana*. McEachran and Stehmann (1984) thus described a fourth species already as *Neoraja carolinensis* from the Western North Atlantic and placed *B. africana* also in *Neoraja* presently comprising three Eastern and only one species.

McEachran and Dunn (1998), after a phylogenetic analysis of relevant character complexes, finally elevated all former rajoid subgenera of several genera to generic rank and rediagnosed the genus *Neoraja* for mainly features like: without oronasal pits; individual thorns on nape/shoulder regions, no thorn triangle; median thorns along trunk and tail in a single row; anterior pelvic lobes about ¾ of length of posterior lobes; tail length distinctly more than 60% of TL; caudal fin with hypochordal lobe; cranium without nasobasal fenestrae, with narrow anterior fontanelle, and feeble rostral shaft almost reaching rostral node; low number of trunk vertebrae, less than 29; clasper tip with external components terminal bridge and dike; clasper skeleton with large dorsal terminal 1 and ventral terminal cartilages which firmly fused distally around axial; accessory terminal 1 cartilage U-shaped and with distal extension.

The present paper describes the fifth species of *Neoraja* and the fourth one from the Eastern Atlantic, based on 50 specimens covering both sexes and all sizes. Stehmann and Séret (1983:921) had discussed this Iberian species briefly in their interspecific comparison of *B. africana*.

Materials and methods

Institutional acronyms follow Leviton *et al.* (1985).

External morphometric measurements were taken from 70% ethanol preserved specimens by dial callipers to 1/10 of a millimetre largely following the scheme of Bigelow and Schroeder (1953), i.e. between perpendiculars, to allow direct comparison with previously described congeners, except for: ventral head length after Ishiyama (1958); nasal curtain and head length (= dorsal HL) measurements after Hubbs and Ishiyama (1968), length of anterior and posterior pelvic lobes according to Stehmann (1985), which all also taken between perpendiculars. Skeletal morphometric measurements of cranium and scapulocoracoid follow McEachran and Compagno (1979) and vertebral counts Krefft (1968b). Skeletal meristics were counted from soft x-rays films: for pectoral radials, the anteriormost propterygium was not counted but only the first laterally attached real radial, as well as on the last metapterygium the last laterally attached one was counted as a radial but not radial-like extension (at times bifurcated) at the rear surface. For pelvic fin (V) radial counts, the thick first one was counted as first one.

The Portuguese samples were taken during M.E. Costa's research period for her PhD under the auspices of the projects DISCALG (Borges *et al.*, 2000), BYDISCARD (Borges *et al.*, 2002) and BIOFISH (Borges *et al.*, 2007) on board chartered commercial crustacean trawlers using nets specified only by their overall length, with mesh size between 55 and 59 mm.

Two damaged Portuguese paratype specimens, juvenile female (ZMH 25427) and juvenile male (ZMH 25428), were used for skeletal dissections of crania, scapulocoracoids and pelvic girdles and these elements kept at the Zoological Museum Hamburg University (ZMH). Alcian blue staining and dissections from underside of snout of another specimen (ZMH 25435) were done to confirm shape of rostral node and its long appendices. In addition, left scapulocoracoids of two more female and male paratypes (MNHN 2007-0124 and MNHN 2007-0125) were dissected in order to confirm variation range found in the two ZMH paratypes specified above and for confirming sexual dimorphism. The holotype male was not at all dissected, only its opened glans clasper with external components is illustrated here, and clasper skeleton was dissected of the mature male paratype ZMH 25429.

Photographs of the original Spanish specimens (1982) of Málaga University, and of all new Portuguese and Spanish specimens were taken by the senior author, who also prepared the drawings of Figures 5.4, 5.5-9 and 5.15. ZMH ichthyology staff assisted with radiographs of all specimens. The map of Figure 5.1 was prepared by João Sendão of the CCMAR, University of the Algarve, Faro. The 50 type specimens have been split and distributed to various European and an U.S. collection as specified in the list of material.

NEORAJA IBERICA N. SP.

Proposed vernacular names: Iberian pygmy skate (En), raie pygmée ibérique (F), raya pigmea ibérica (ES), raia pigméia ibérica (P), Iberischer Zwergrochen (De)

Material examined

Holotype: MB (Museu Bocage, Portugal) 4869, mature male 322 mm TL; FV ‘Porto Amboim’, trawl #1, 3 Jun. 2006; 36º50.7’ – 36º54.3’ N, 07º44.8’ – 07º39.1’ W at 558-531 m depth; 23 m crustacean trawl; collectors Patrícia Calixto and Gonçalo Carvalho.

49 paratypes - Portuguese specimens: MB 4870; adolescent female 253 mm TL; FV ‘Crustáceo’, trawl #2, 8 Jun. 2000; 36°47.8-36°50.5 N, 07°39.6’-07°48.5’ W at 520-620 m; 23.6 m crustacean trawl; collectors M. Esmeralda Costa and Sónia Olim. – MB 4871; juvenile male 249 mm TL; FV ‘Aurora Boreal’, trawl #1, 8 May 2005; 36º48.5’ N–07º59.1’ W (start position only) at 538 m depth (mean); 26.5 m crustacean trawl; collectors Inês Figueiredo and Jorge Encarnação. – MB 4872; juvenile male 244 mm TL; FV ‘Aurora Boreal’, trawl #1, 9 May 2005; 36º46.9’ N–08º10.3’ W (start position only) at 531-540 m depth; 26.5 m crustacean trawl, collectors Inês Figueiredo and Jorge Encarnação – MB 4873a-d; adol.

female 235 mm (a), juv. female 129 mm (b), juv. male 200 mm (c), juv. male 221 mm TL (d); FV 'Porto Amboim'; trawl #2, 29 May 2006; 36º49.8'–36º51.0' N, 07º39.4'–07º35.0' W; at 529-512 m depth; 23 m crustacean trawl; collectors Patrícia Calixto and Gonçalo Carvalho. – MB 4874, mature female 314 mm TL; FV 'Porto Amboim'; trawl #1, 3 Jun. 2006; 36º50.7' – 36º54.3' N, 07º44.8'–07º39.1' W at 558-531 m depth; 23 m crustacean trawl; collectors Patrícia Calixto and Gonçalo Carvalho. – MNCN (Musée Nationale de SCiences Naturelles, Paris) 259.151; juvenile male 216 mm TL; FV 'João Pinto', trawl not numbered, 1 May 1999; no precise locality data, off Faro; 24.5 m crustacean trawl. – MNCN 259.152; juv. female 192 mm TL; data as for MB 4871. – MNCN 259.153: juv. male 167 mm TL; FV 'Porto Amboim', trawl #3, 25 Sep. 2005; 36º57.3'–36º54.1' N, 07º34.3'–07º46.2' W at 172-403 m depth; 23 m crustacean trawl, collectors Gonçalo Carvalho and Jorge Encarnação. – MNHN (Musée Nationale de Histoire Naturelle, Paris) 2007-0013; juv. female 228 mm TL; FV 'Gamba', trawl #3, 11 May 1999; 36°53.1'-36°45.7' N, 07°42.3'-07°54.2' W at 172-670 m; 30 m crustacean trawl; collectors M. Esmeralda Costa and Sónia Olim. – MNHN 2007-0014: juv. male 270 mm TL; data as views for MNCN 259.151 – MNHN 2007-0015; juv. female 239 mm TL; data as for MB 4870. – MNHN 2007-0016; juv. male 183 mm TL; FV 'Aurora Boreal', trawl #1, 10 May 2005; 36º46.9' N–08º10.2' W (start position only) at 530 m depth (mean); 26.5 m crustacean trawl, collectors Inês Figueiredo and Jorge Encarnação. – TCWC (Texas Cooperative Wildlife Collection, Texas A&M University, i.e. McEachran) 13204.01; juv. female 262 mm TL; data as for MB 4870. – ZMH (Zoological Museum of Hamburg) 25427; juv. female 230 mm TL; FV 'Crustáceo', trawl #1, 8 Jun. 2000; off Faro on the slope, no precise locality data taken) (skeletal parts only), 23 m crustacean trawl; collectors M. Esmeralda Costa and Sónia Olim. – ZMH 25428; juv. male, 252 mm TL (skeletal parts only); data as for MNCN 259.151. – ZMH 25429; mature male 318 mm TL; FV 'Aurora Boreal', trawl #1, 8 May 2005; 36º48.5'N–07º59.1' W (start position only) at 538 m depth (mean); 26.5 m crustacean trawl; collectors Inês Figueiredo and Jorge Encarnação. – ZMH 25430, immature female 200 mm TL; data as for MB 4873a-d. – ZMH 25431, immature female 191 mm TL; data as for MB 4873a-d. – ZMH 25432, immature male 142 mm TL; data as for MB 4873a-d. –ZMH 25433, immature male 209 mm TL; data as for MB 4873a-d. – ZMH 25434, mature female 316 mm TL; data as for MB 4874.

Initial Spanish specimens: 7 immature females (170.5-206.4 mm TL) and 3 immature males (184.2-187.5 mm TL) taken by commercial trawlers from the Isla Cristina, Gulf of Cadiz, fishing fleet in 1982 by otter trawl on fine and coarse sand bottom within an area delimited by approximately 36°30-45’ N, 07°05-20’ W and within a depth range of about 270-315 m; collector J. Baro: MB 4875, juv. female 170.5 mm TL. – MB 4876, juv. female 170.5 mm TL. – MNCN 259.154, juv. female 202.6 mm TL. – MNCN 259.155, juv. female 206.4 mm TL. – MNCN 259.156, juv. female 192.7 mm TL. – MNCN 259.157, juv. male 187.5 mm TL. – MNHN 2007-1024, juv. female 202 mm. – MNHN 2007-1025, juv. male 186.4 mm TL. – ZMH 25435, juv. female 203.4 mm TL. – ZMH 25436, juv. male 184.2 mm TL.

New Spanish specimens: From 1994-2004, collector J. Baro: MB 4877, mature male 297 mm TL; RV ‘Cornide de Saavedra’ cr. ARSA 0302, haul 19, 2 Mar. 2001; 36°21.25’ N, 06°54.75’ W, 522 m; ‘baka’ bottom trawl. – MB 4878, juv. female 112 mm TL; RV ‘CdS’ cr. ARSA 0301, haul 35, 8 Mar. 2001; 36°21.40’ N, 07°07.06’ W, 679 m; ‘baka’ bottom trawl.—MNCN 259.158 mature female 294 mm TL, MNCN 259.159 adol. male 278 mm TL; RV ‘CdS’ cr. ARSA 0394, haul 18, 6 Mar. 1994; 36°36.62’ N, 07°03.87’ W, 494 m; ‘baka’ bottom trawl. – MNCN 259.160, neonate female 55 mm, MNCN 259.161, juv. female 97 mm, MNCN 259.162 juv. male 202 mm TL; RV ‘CdS’ cr. ARSA 197, haul 12, 22.II.1997; 36°47.55’ N, 07°16.80’ W, 484 m; ‘baka’ bottom trawl. – MNCN 259.163, mature male 315 mm TL; RV ‘CdS’ cr. ARSA 1199, haul 8, 5 Nov. 1999; 36°37.89’ N, 07°04.26’ W, 496 m; ‘baka’ bottom trawl. – MNCN 259.164, mature male 327 mm TL; RV ‘CdS’ cr. CALIMA 00, haul 25, 16 Nov. 2000; 36°42.61’ N, 07°06.89’ W, 478 m; ‘baka’ bottom trawl. – NMHN 2007-0017, mature male 298 mm TL; data as for MB 4877. – MNHN 2007-0018, juv. female 157 mm TL; RV ‘CdS’ cr. ARSA 0304, haul 37, 13 Mar. 2004; 36°21.35’ N, 06°55.52’ W, 522 m; ‘baka’ bottom trawl. – MNHN 2007-0019, mature female 299 mm, data as for MNHN 2007-0018. – TCWC 13205.01 mature male 312 mm TL, data as for MNHN 2007-0018. – ZMH 25437, mature male 305 mm TL, data as for MB 4877. –ZMH 25438, juv. male 67 mm TL, data as for MB 4878.

Diagnosis

Disc inverse heart-shaped, with short, triangular projection at shout tip; tail length about 62% (mean) of TL; lateral folds only along posterior half or 1/3 of tail length; caudal fin with hypocordal lobe; anterior pelvic lobes about 3/4 of length of posterior lobes; ochre to greyish-brown or dark greyish disc and posterior pelvic lobes distinctly ornamented dorsally by many dark brown spots and dots and frequently a few paired whitish spots in small and half-grown specimens, all often reduced in larger sized specimens to few pairs of larger symmetrically placed brown, pale edged spots, plus 1-2 pairs of pale spots or dots; tail with 7-8 more or less distinct dark cross-bars or asymmetrically placed saddle blotches; underside of disc and tail white, at most pale greyish margin to pectoral corners and posterior margins, and occasionally a cloud of merged pale brownish spots centrally on each pectoral. Upper side of disc, posterior pelvic lobes and back of tail totally and densely covered with fine dermal denticles, sides of tail with several rows of hooked thornlets. Individual thorns on nape/shoulder regions, no thorn triangle; median thorns along trunk and tail in a single row almost disappearing in posterior half or 1/3 of tail. Dorsal thorns appear irregularly mixed in various stages of development, shape and size in all their locations, resulting particularly in midline thorns (about 60 posterior to shoulder girdle to first dorsal (D1) being set at irregular interspaces. Underside totally smooth, except for extreme edges of tail set with erect dermal denticles which in dorsal and caudal fin section are embedded. Cranium without nasobasal fenestrae, with narrow anterior fontanelle and delicate, thin rostral shaft almost reaching rostral node. Low number of less than 29 trunk vertebrae. Glans clasper with external components terminal bridge, dike and newly defined component ribbon; clasper skeleton with large dorsal terminal 1 and ventral terminal cartilages which firmly fused distally around axial; accessory terminal 1 cartilage U-shaped and with distal extension.

Description of the holotype

(Figures 5.1-5.4, 5.10A, 5.12A) Detailed morphometric and meristics measurements are given in Tables 5.1–5.3 and 5.5.

External morphology (Figs. 5.1-5.3): Disc inverse almost heart-shaped, 1.2 times as broad as long, with axis of maximum disc width at about 60% of disc length somewhat posterior to level of shoulder girdle. Anterior disc margins of this mature male strongly undulated, i.e. concave opposite short projection at snout tip, strongly convex at snout sides to level with eyes, strongly concave to level of spiracles and nape, and convex again toward to the broadly rounded outer corners continuous with the evenly convex posterior disc margins. Inner pectoral corners narrowly rounded, with pectoral axils deeply incised to origin of anterior pelvic lobes. Snout bluntly rounded, snout angle 122°, with short triangular projection at tip. Snout very short, preorbital length 3.1 times the very narrow interorbital width and nearly 6 times in disc width. Orbits large, horizontal diameter 1.8 times the interorbital width and 57% of preorbital snout length. Spiracle length 54% of orbit diameter, interspace between spiracles 2.2 times the interorbital width. Eight pseudobranchial folds in each spiracle. Pelvic fins large, with deep notch separating both lobes. Anterior lobes long and broad, distal third narrowing slightly and with bluntly rounded tip. Posterior lobes elongated, with pointed tip, angular outer margin moderately convex over distal two thirds. Anterior lobe is 64.5% of length of the posterior lobe. Claspers fully developed, evenly elongated, with sharply pointed tip marked off and relatively short terminal region only little widened (Figure 5.1B); postanal clasper length 34% of tail length from mid-vent. Tail very long, slender, gradually tapering toward tip, length nearly 62% of the total length; depressed over its entire length but less so on posterior third; lateral folds restricted to posterior third of tail and terminating about mid-postdorsal tail length. Dorsal fins low and elongated, 2.6 times (first dorsal, D1) and 3 times (second dorsal, D2) as long as high, D1 slightly larger than D2, their bases connected by a transparent membrane above tail surface, D2 and upper caudal (C) confluent. Both dorsal fins of similar shape, with long, almost straight anterior margin rising at about 45° and continuous with short, rounded upper margin, with maximum height over posterior third of base length, then sloping a little toward pointed apex widely overhanging origin of either D2 or upper C, resp.; rear margin strongly inclined forward. Postdorsal tail section long, 60% of D2 base length, with almost equally high upper C fold of 1/4 of D2 height; lower C fold shorter and only half height of the upper.

Preoral snout length 1.4 times the mouth width; mouth width 31% of ventral head length, and the latter 3.6 times the internarial width. Distance between fifth gill slits 48% of distance between first gill slits, and the latter distance 1.9 times the internarial space. Mouth width 1.1 times the distance between nostrils. Anterior nasal flaps not well developed, cone-shaped, with fine fringes along outer edge. Outer margins of nasal curtain strongly undulated, with a triangular lobelet at proximal third, nearly square-shaped apices with angular outer corners and transverse, almost straight rear edges set with coarse, mostly bifurcated fringes; isthmus a steeply arched (Figure 5.1A). Oronasal pits underneath nasal curtain apices absent. Jaws nearly straight, upper jaw distinctly indented medially, with a median lower jaw protrusion accordingly. Jaw teeth in 41 upper and 37 lower rows, in close set parallel in outer thirds of band but in quincunx arrangement medially. Individual teeth have rhombic crown bearing short, conical cusp on inner corner in median rows, with cusp gradually becoming shorter toward mouth corners. Anterior pectoral (P) radials and propterygial elements extended over entire rostral length and almost abutting rostral node at snout tip.

Squamation: Entire upper disc densely set with fine dermal denticles, except for extreme posterior margins, eyes with fine prickles; denticles coarser, to thornlet size, in malar regions and along sides of trunk. Anterior pelvic lobes smooth, posterior lobes with central patch of fine denticles. Edges of clasper groove over full length densely set with very fine denticles, as well as externally on entire terminal region, and smooth only the proximal half of dorsal clasper stem (Figure 5.1B). Dermal denticles sparse directly alongside and between median thorns from nape to 2/3 tail length, but from there rearward more densely set also on back of tail. Laterally along back of tail, a stripe of densely set fine denticles on each side, lower sides of tail densely set with several rows of much larger, hooked thornlets attaining nearly the size of median tail thorns (Figure 5.1B-C). Both dorsal fins and upper caudal also set with fine denticles. Underside of disc and pelvic fins smooth; outer and inner edges and part of terminal surface of claspers set with fine denticles; underside of tail smooth along broad midline, only extreme tail edges with narrow stripe of fine, erect denticles which embedded below dorsal-caudal fin section.

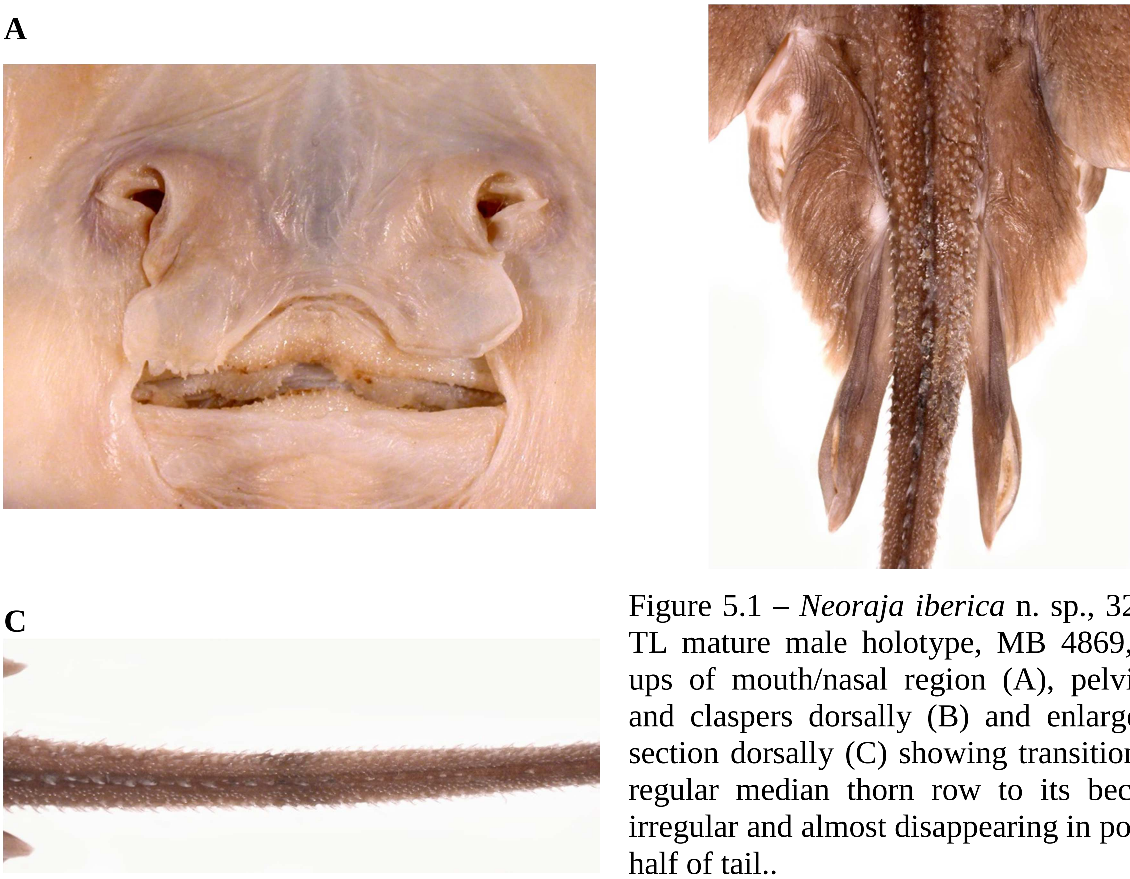

Figure 5.1 – *Neoraja iberica* n. sp., 322 mm TL mature male holotype, MB 4869, close ups of mouth/nasal region (A), pelvic fins and claspers dorsally (B) and enlarged tail section dorsally (C) showing transition from regular median thorn row to its becoming irregular and almost disappearing in posterior half of tail..

Dorsal thorns appear in various stages of development, shape and size in all areas of their location. The initial ones are evenly cone-shaped, ribbed and on a circular basal plate, with the tip erect and placed centrally; later added or replaced thorns have oval basal plate with low base and long, rearward curving long and pointed tip overhanging rear base end; the latter type of thorns also appearing in early development stages, i.e.being whitish, with the low base not yet formed and the long pointed tip being still soft and often embedded under the integument. All three kinds of thorns do appear at orbits, on nape and midline of trunk and tail irregularly mixed resulting in mainly midline thorns set at irregular interspaces.Patch of 7/5 preorbital and 3/2 postorbital thorns on left/right side, respectively, separated by a gap supraorbitally. Pair of small, conical interspiracular thorns at level of occipital joint, only slightly larger than surrounding erect dermal denticles with rearward curving tip. Five median nuchal thorns in a regular line, one in suprascapular position and 1/2 on left/right shoulder (Figure 5.2A). Regular mid-row of 12 thorns along back of trunk between shoulder girdle and level of pectoral axils, but these thorns of differing sizes and set at varying interspaces; this median row of thorns continued onto tail with approximately 50 more thorns of different size and shape to near D1, but this row becoming very irregular in posterior half of tail with regard to much smaller size of and much wider spaces between thorns, so that median thorns appear to rather disappear in posterior half of tail length (Figure 5.1C). Alar thorns of the permanently erect, hooked, non-erectile type, which form a rather narrow and short stripe inward on left and right wing tip of 2/10 and 2/9 longitudinal/transverse thorn rows, respectively (Figure 5.2B).

A B

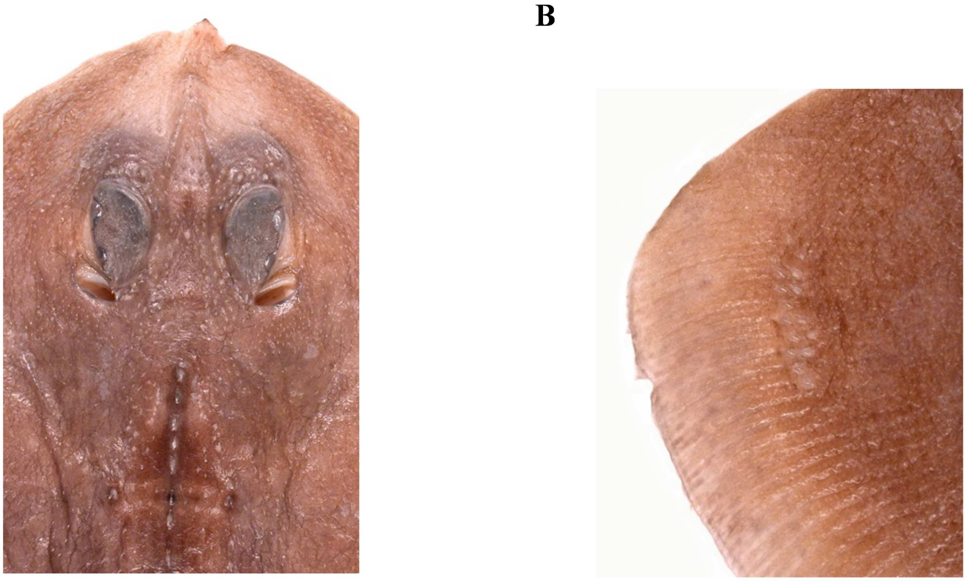

Figure 5.2 – *Neoraja iberica* n. sp., 322 mm TL mature male holotype, MB 4869, close ups of head dorsally (A) and of left wing tip with alar thorn field (B).

Table 5.1 – *Neoraja iberica* n.sp., morphometrics 40 type specimens: holotype in mm and % TL; mature female, small juvenile female and male paratypes as % TL; all 40 types with min-max-mean values % TL.

Collection	HT	MB	PT-ZMH	PT-MNCN	PT-ZMH	min.	max.	mean	notes
Coll. No.		4869	25434	259,161	25438				as values
Sex		mat. male	mat. fem.	juv. fem.	juv. male	18 females and 22 males			at times for
			316 mm TL	97 mm TL	67 mm TL				less than
	mm	%	%	%	%				40 spec.
TL, mm	322.0	100.0	100.0	100.0	100.0	55.0	327.0	229.9	mm
Disc, width	170.0	52.8	54.1	49.5	41.8	25.5	55.0	50.4	-
Disc, length	140.0	43.5	44.0	41.2	43.3	36.4	44.6	42.0	-
Snout length, preorbital	28.8	8.9	10.1	9.3	9.4	7.6	10.8	9.0	-
Snout length, preoral	30.4	9.4	10.8	10.0	11.6	7.9	16.6	10.0	-
Snout length, prenasal	21.5	6.7	7.7	8.2	9.0	4.5	9.0	7.1	-
Orbit, horizontal diameter	16.5	5.1	5.1	5.1	6.3	4.3	6.3	5.1	-
Eyeball, horiz. diameter	13.5	4.2	4.4	-	4.8	3.9	5.1	4.4	37 spec.
Interorbital width	9.2	2.9	3.0	4.4	5.2	2.6	5.2	3.2	-
Spiracle length	9.0	2.8	3.3	2.8	3.0	2.3	3.4	2.9	39 spec.
Interspiracular width	20.5	6.4	6.2	7.4	9.3	5.7	9.3	6.5	-
Orbit + spiracle length	18.3	5.7	5.7	6.5	7.5	5.3	7.5	5.9	-
D1, height	7.3	2.3	2.2	-	1.5	0.8	2.3	1.3	36 spec.
D1, base length	18.8	5.8	6.3	5.2	3.7	3.5	6.4	4.9	39 spec.
D2, height	5.8	1.8	2.1	-	1.2	0.6	2.1	1.3	37 spec.
D2 , base length	17.2	5.3	4.8	5.3	3.9	3.4	6.5	5.0	39 spec.
Interdorsal space	0.0	0.0	0.0	0.0	0.0	0.0	1.7	0.1	-
C, base length	10.4	3.2	1.8	5.2	2.5	1.3	5.2	2.7	39 spec.
C, height epichordal lobe	1.5	0.5	0.5	-	0.6	0.3	1.2	0.6	36 spec.
C, height hypochordal lobe	0.8	0.2	0.3	-	-	0.1	0.3	0.2	30 spec.
Tail, postdorsal length	10.4	3.2	1.9	5.2	2.5	1.7	5.2	2.8	39 spec.
Tail, height at V-tips	6.0	1.9	2.2	3.0	2.7	0.5	3.6	2.3	39 spec.
Tail, width at V-tips	10.5	3.3	3.6	3.8	3.3	2.0	4.4	3.4	39 spec.
Tail, height at D1-origin	2.5	0.8	0.9	0.9	1.2	0.7	1.2	0.8	39 spec.
Tail, width at D1-origin	3.4	1.1	1.2	1.2	1.6	0.8	1.6	1.1	39 spec.
Tail, lateral fold length	75.0	23.3	26.7	-	-	13.8	31.2	23.4	34 spec.
Head length, ventrally	70.3	21.8	22.2	20.6	24.2	8.4	24.2	21.5	39 spec.
Head length, dorsally	50.5	15.7	16.6	16.8	19.0	6.5	19.0	15.8	-
Mouth width	21.9	6.8	6.5	7.0	8.2	6.2	9.3	7.0	-
Internarial width	19.5	6.1	5.9	6.9	6.3	5.4	7.3	6.1	-
Nasal curtain, length	13.5	4.2	4.1	4.0	4.0	3.1	5.5	4.0	37 spec.
Nasal curtain, width each lobe	7.8	2.4	2.2	2.4	3.0	1.8	3.6	2.4	37 spec.
Nasal curtain, space between lob	10.0	3.1	3.1	3.0	3.1	2.3	3.9	3.2	37 spec.
Gill slit length, 1st	2.7	0.8	1.3	1.5	1.5	0.8	1.6	1.3	39 spec.
Gill slit length, 3rd	3.2	1.0	1.3	1.5	1.9	1.0	1.9	1.3	39 spec.
Gill slit length, 5th	2.5	0.8	1.0	1.3	1.0	0.7	1.3	0.9	38 spec.
Interspace first gill slits	37.4	11.6	12.6	14.4	14.6	10.7	14.6	12.5	-
Interspace fifth gill slits	18.0	5.6	7.4	8.2	9.0	4.1	9.0	6.6	39 spec.
V-length, ant. lobe	39.0	12.1	11.7	10.7	14.3	9.2	14.3	11.1	39 spec.
V-length, post. lobe	60.5	18.8	15.8	11.5	12.5	11.5	18.8	14.7	39 spec.
Clasper, postanus length	67.7	21.0	-	-	6.3	5.7	22.2	12.8	22 spec.
Clasper length	57.3	17.8	-	-	-	2.6	19.7	10.1	21 spec.
Snout tip to mid-anus	119.0	37.0	38.9	36.8	38.1	34.5	40.0	37.6	-
Snout tip to 1st hemal spine	127.0	39.4	41.1	40.0	-	36.9	41.1	39.4	38 spec.
Snout tip to axis max. disc width	84.0	26.1	26.9	24.7	28.4	22.2	28.4	25.3	39 spec.
Mid-anus to D1	153.5	47.7	48.1	50.0	44.0	44.0	51.1	49.1	39 spec.
Mid-anus to D2	171.0	53.1	53.6	55.2	47.8	47.8	56.7	54.0	39 spec.
Mid-anus to tail tip	198.5	61.6	60.3	65.7	61.8	59.6	65.7	61.7	39 spec.

Colouration (after preservation in formalin and ethanol) (Figure 5.3A-B): Upper side medium greyish-brown, slightly darker along midline of body and on tail. Rostral triangle semitransparent pale whitish, with rostrum marked off brown. Eyes dusky bluish, broad margins of outer corners and posterior disc semitransparent lighter. Two pairs of circular dark brown spots with pale outer ring on inner pectorals, anterior pair smaller and level with anterior nape, posterior pair larger and level with anterior trunk. Anterior pelvic lobes as disc, with outer margin white only in basal half, whereas inner margin totally edged white; posterior lobes as disc, with white blotch at axils between tail and claspers and narrow pale outer edge. Dorsal side of claspers greyish-brown somewhat darker than disc, except for proximal inner half being paler brown, and also outer edge of the ventral lobe dark brown along clasper groove and its broader terminal region. About seven indistinct dark cross-bars along tail length, with last three through D1, D2 and C, respectively, marking the three fins dusky, respectively. Lateral tail folds nearly transparent, only at dorsal and caudal fins partly dark. Underside milky-white, with short projection at snout tip brown, broad pale greyish margin to outer corners and posterior pectorals, speckled with pale brown spots, as well as outer margin posterior pelvic lobes. Cloud of largely merged pale brown spots on each pectoral centre. Claspers white, with some brown encroaching from dorsal side at terminal outer margin. Underside of tail only in posterior half, irregularly coloured with few pale brown spots at edges, and extreme tail tip dusky. Mouth cavity white.

Figure 5.3 – *Neoraja iberica* n. sp., 322 mm TL mature male holotype, MB 4869, in total dorsal (A) and ventral (B).

Clasper components (Figure 5.4): Clasper with very elongated but narrow and shallow pseudosiphon (ps) along entire stem section of outer dorsal lobes from about level of apopyle to begin of terminal region (Figure 5.4), but ps formed entirely by a dorsal dilatator muscle without direct relation to and not formed by the dorsal terminal 1 (dt1) cartilage of the clasper skeleton. Inner dorsal lobe with deep longitudinal proximal and shallower distal cleft (cf), separated diagonally by a terminal bridge (tb). Proximally, integumental slit (sl) spans between axial and dt1-cartilages over and across upper end of the proximal cleft. A new component 'ribbon' (rb) is defined here: integumental ribbon-like fold located very proximally along midline of glans clasper, originating at base of inner dorsal lobe about level with slit (sl), running diagonally across axial into clasper groove and terminating level with about half length of proximal cleft. Predominant component on inner ventral lobe is the elongated trough-like shield (sh) over nearly entire length of terminal region, with a cutting outer edge of free cartilage and an inward curving dike (di) as a plate-like extension at inner distal end, whereas distal extension as funnel (fn) is poorly developed. Along the proximal inner wall of ventral lobe and to proximal end of shield stretches the rhipidion (rh), an integumental fold with porous outer surface. From underneath proximal end of shield extends diagonally inward a short, finger-like sentinel (st) to half length of terminal region, and originating underneath shield and tip of sentinel curves up a spoon-shaped spike (sp) transversally into the opened glans. Only four among eight mature males showed distally on axial cartilage the rather rudimentary integumental component 'flag' (MNCN 259.163, MNHN 2007-0017, ZMH 25437, MNHN 2007-0017) not present in glans clasper of holotype and a paratype illustrated here.

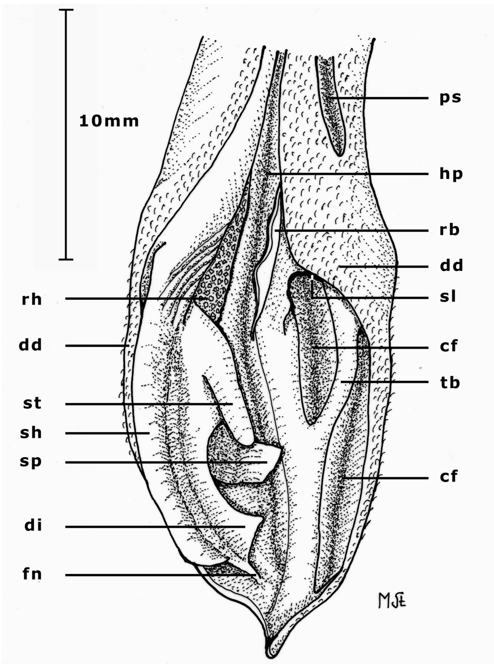

Figure 5.4 – *Neoraja iberica* n. sp., 322 mm TL mature male holotype, MB 4869, opened left glans clasper showing components and coverage with dermal denticles. Abbreviations: cf=cleft, dd=dermal denticles, di=dike, fn = funnel, hp = hypopyle, ps = pseudosiphon, rb = ribbon, , rh = rhipidion, sh = shield, sp = spike, st = sentinel, sl = slit, tb = terminal bridge.

Internal meristics: Trunk vertebrae (Vtr): 24, Predorsal tail vertebrae (Vprd): 71, Pectoral radials (P radials): 65/65, Pelvic radials (V radials): 19/19 (Table 5.2).

Table 5.2 – *Neoraja iberica* n. sp.: snout angle and meristics of the holotype and 35-37 paratypes as min-max-mean values.

	Holotype	min.	max	mean	n
Snout angle	122°	119°	145°	132.3°	36
Pseudobranchial folds	8	9	10	9.1	37
Trunk vertebrae Vtr	24	20	27	23.9	37
Predorsal tail vertebrae Vprd	71	67	78	71.5	37
Pectoral radials	65	64	69	65.6	37
Pelvic radials	19	16	20	17.7	35
Upper jaw tooth rows	41	40	52	43.1	37
Lower jaw tooth rows	37	35	48	41.2	35

Squeletal anatomy: Proportional measurements of skeletal elements are given in Tables 5.3-5.5.

Table 5.3 – *Neoraja iberica* n. sp.: cranial morphometrics of the holotype (X-ray), two dissected juveniles and three more paratypes (X-rays) as per cent of the nasobasal length.

Specimen	Holotype MB 4869	ZMH 25427	ZMH 25428*	ZMH 25431	ZMH 25434	ZMH 25429
	x-ray	dissected	dissected	x-ray	x-ray	x-ray
Sex & maturity	mature male	immature female	immature male	immature female	mature female	mature male
TL / DW in mm	322 / 170	230 / 118	252 / 127	191 / 98	316 / 171	318 / 168
Cranium TL (x-ray)	178.70	151.30	ca. 144.0	202.00	182.10	172.30
Nasobasal length	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**
Max. ethmoidal width	121.70	103.10	98.40	122.70	112.90	120.80
Min. dorsal interorbital width	33.10	30.50	28.00	38.00	30.10	34.60
Min. internasal width	17.10	17.70	16.00	22.70	16.10	17.30
Min. basal plate width	27.00	26.50	24.80	31.30	29.40	28.50
Max. width otic region	73.00	59.30	58.00	70.00	70.60	78.10
Max. width jugular	59.70	58.40	56.00	62.70	60.90	65.40
Rostral shaft length (x-ray)	64.60	51.30	48.00	76.00	71.70	60.80
Rostrum base width	22.10	17.70	17.60	18.70	19.00	21.20
Postnasal length orbit region	30.40	37.20	39.60	30.70	29.00	28.80
Length otic region	30.40	19.50	22.00	29.30	24.40	30.80
Postoccipital length jugal arches	0.00	0.00	0.00	0.00	0.00	0.00
Tip rostrum to tip ant. fontanelle	43.30	24.30	-	55.30	49.50	36.50
Tip rostrum to end ant. fontanelle	91.30	77.90	-	113.30	99.60	84.60
Tip rostrum to tip post. fontanelle	96.20	79.60	-	120.00	106.10	90.00
Tip rostrum to end post. fontanelle	144.10	126.10	-	169.30	154.10	138.50
Tip rostrum to level ant. propterygia	11.40	-	-	6.70	5.70	3.80
Tip rostrum to level max. ethmoidal v	88.20	66.40	-	98.00	93.20	78.80
Tip rostrum to symphysis upper jaw	117.10	91.20	-	133.30	118.30	121.90
Ant. fontanelle length	44.50	40.70	47.20	57.30	50.50	45.80
Ant. fontanelle max. width	20.50	14.60	16.00	22.70	21.90	21.20
Space betw. ant.&post. fontanelles	6.50	8.80	10.80	6.70	7.20	7.70
Post. fontanelle length	49.40	42.50	45.20	52.00	48.70	50.00
Post. fontanelle min. width	1.90	0.40	3.60	4.70	5.00	3.80
Post. font. max. width anteriorly	8.70	4.40	4.80	6.70	7.20	5.80
Post. font. max. width posteriorly	19.00	13.30	12.00	20.00	15.10	15.40
Max. cranial height	-	31.00	28.00	-	-	-
Max. height rostral shaft	-	14.60	14.00	-	-	-
Angle post. edge nasal capsules	79°	80°	80°	70°	71°	75°

Table 5.4 – *Neoraja iberica* n. sp.: scapulocoracoid morphometrics as per cent of maximum length of left and right dissected elements of two immature paratypes.

Specimen	ZMH 25427		ZMH 25428	
Sex & maturity	immature female		immature male	
TL / DW in mm	230 / 118		252 / 127	
	left	right	left	right
Max. length	**100**	**100**	**100**	**100**
Max. height	86.9	79.6	79.8	80.7
Height at rear corner	61.7	63.9	56.1	57
Pre-mesocondyle-length	42.1	43.5	52.6	49.1
Post-mesocondyle-length	49.5	50.9	44.7	48.2
Anterior fenestra height	26.2	25	28.1	26.3
Anterior fenestra length	15	16.7	7	11.4
Postdorsal fenestra height	9.3	10.2	19.3	17.5
Postdorsal fenestra length	13.1	18.5	26.3	22.8
Postventral fenestra height	14	15.7	14.9	14.9
Postventral fenestra length	15	17.6	27.2	24.6
Total number of postdorsal fenestrae	1	1	1	1
Total number of postventral fenestrae	1	1	1	1

Table 5.5 – *Neoraja iberica* n. sp.; pelvis morphometrics of the holotype (X-ray), a juvenile paratype couple (dissected and X-rays) and three more paratypes (X-rays), and relation max. width shoulder girdle / pelvis. (*: from level of max. width / from level of ant. contour. **: from level of max. width).

Specimen	ZMH 25427		ZMH 25428		MB 4869 holotype	ZMH 25431	ZMH 25434	ZMH 25429
Sex & maturity	immature female		immature male		mature male	immature female	mature female	Mature male
TL / DW in mm	230 / 118		252 / 127		322 / 170	191 / 98	316 / 171	318 / 168
	dissected	x-ray	dissected	x-ray	x-ray	x-ray	x-ray	x-ray
Pelvis max. width	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**
Median transverse thickness	13.8	13.9	13.6	11.4	10.6	11.8	13.1	13.4
Prepelvic processes length *	25.6 /9.2	19.8/8.9	tips broken	19.1/5.0	18.4/5.7	14.1/2.9	15.6/4.7	17.0/7.6
Iliac processes length**	19	18.3	23.3	15	10.6	5.9	15.6	14.5
Depth posterior arc	13.8	14.4	13.1	15.9	13.1	8.8	11.3	17
Number iliac foramina	2		2		2	2	2	2
Shoulder girdle max. width, mm		26		26.5	29.7	22	41.5	31
Pelvis max. width, mm	19.5	20.2	20.6	22	28.2	17	32	27.6
Relation shoulder girdle / pelvis max. width		**1.3**		**1.2**	**1.1**	**1.3**	**1.3**	**1.1**

Clasper (Figs. 5.5-5.7): Both marginal cartilages do not possess any extended distal process. The large dt1 with pointed proximal process, and with long distal extension curving around the axial to the ventral side, where firmly fused with the distal tip of the large vt cartilage; plate-like elongated dt2 and dt3 cartilages connect distal end of dorsal marginal with tip of axial cartilage, with the distal part of dt2 forming terminal bridge by connecting to the axial at half length of terminal region; ventrally, the elongate ventral terminal forms the outer edge, and it is linked with its medial process with the medio-distal notch of the U-shaped at1, which itself is attached with its proximal notch around the outer 2/3 of the ventral marginal; at the inner end of the vm attaches the elongated, club-shaped aT2. Figure 5.6A illustrates the entire clasper of the mature male paratype ZMH 25429 in dorsal view mainly for showing the full extension of the pseudosiphon and the coverage with dermal denticles; Figure 5.6B which represents the opened left glans clasper, shows components being identical in kind and position with those of the holotype. Abbreviations in Figure 5.6 are as in Figure 5.5. The clasper skeleton displays, in dorsal (Figure 5.6A) and ventral views (Figure 5.6B), the genus-typical composition and characteristic dominating cartilages: dorsally. Figure 5.7 provides enlarged the isolated relevant cartilages, namely the distally fused dt1 and vt, with the latter's outer lamella forming externally the component shield, and with the inward curving process near distal end the component dike, whereas an extension as funnel at distal end is rudimentary; further forms of the U-shaped at1 forms with its distal process external component sentinel, and the club-shaped at2 is the external component spike with its spoon-shaped curved distal end.

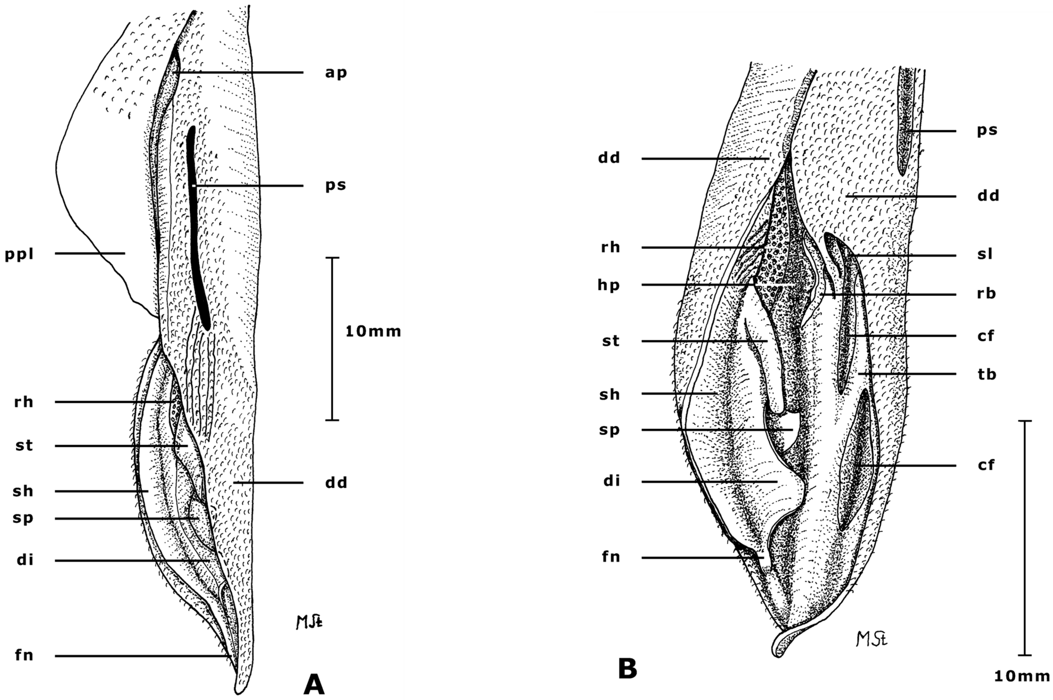

Figure 5.5 – *Neoraja iberica* n. sp., 318 mm TL mature male paratype ZMH 25429, dorsal view of left clasper showing extension of pseudosiphon and coverage with dermal denticles (A), and opened left glans clasper (B). Abbreviations as in Fig. 5, and ap = apopyle, = posterior pelvic lobe.

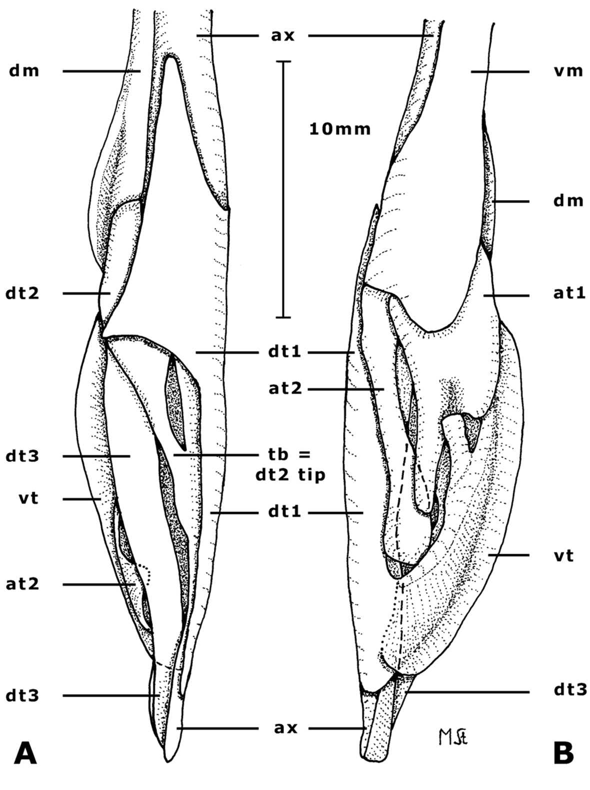

Figure 5.6 – *Neoraja iberica* n. sp., 318 mm TL mature male paratype ZMH 25429, left clasper skeleton in dorsal (A) and ventral (B) views. Abbreviations for cartilages: at1-at2=accessory terminals 1 and 2, ax=axial, dm=dorsal marginal, dt1-dt2-dt3= dorsal terminals 1, 2, 3 resp., tb=terminal bridge, vm=ventral marginal, vt=ventral terminal.

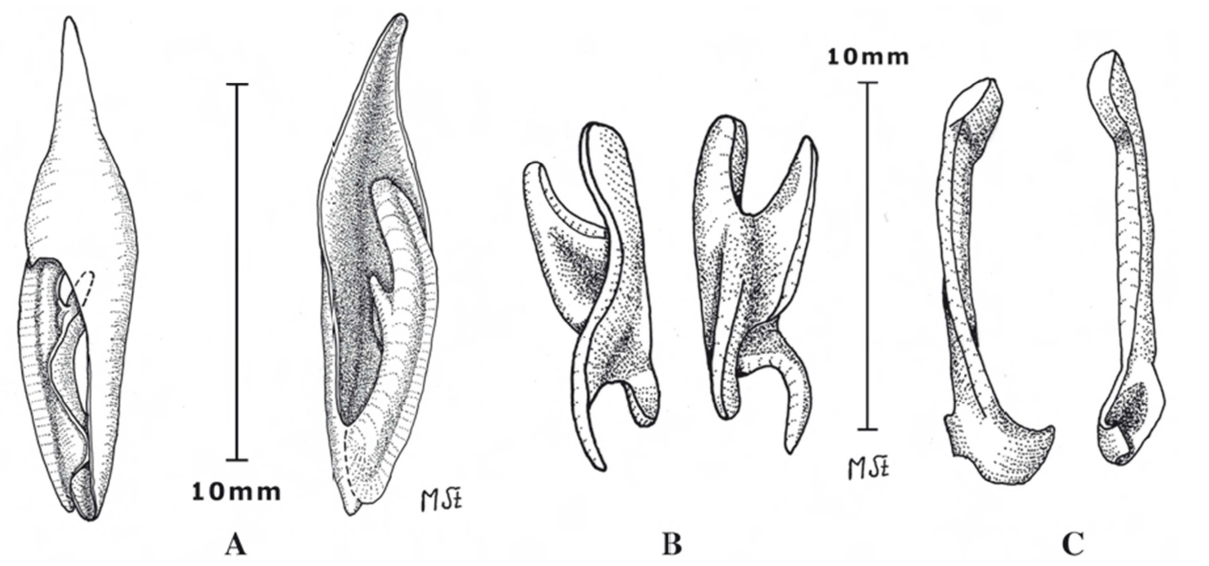

Figure 5.7 – *Neoraja iberica* n. sp., 318 mm TL mature male paratype ZMH 25429, individual cartilages of left clasper in dorsal and ventral views (left and right, resp.): distally fused dorsal terminal 1 and ventral terminal cartilages (A), accessory terminal 1 (B) and at2 (C) cartilages.

*Cranium of holotype from x-ra*y (Figure 5.8; Table 5.3): Rostral base forms moderately broad triangle, base width 18.1% of maximum cranial width; rostral cartilage tapers abruptly at about 2/3 of length to thread-like, non-calcified rostral filament extending to near rostral node. Anterior cranial fontanelle forms elongated narrow triangle with rounded anterior and straight transverse posterior margins; its length 36.6%, its maximum width 16.9% of cranial width. Posterior cranial fontanelle long and club-shaped with the posterior part being much wider; its length 1.1 times that of anterior fontanelle and 40.6% of cranial width. Fontanelles separated by solid, broad cartilaginous bridge. Nasal capsules very large, with bulging anterior, straight to weakly concave posterior margins and marked preorbital processes; capsules slightly angled forward at 79° to longitudinal axis of cranium. Nasobasal fenestrae absent. Orbital region long, strongly constricted as evenly deep arc; minimum interorbital width dorsally 27.2% of maximum cranial width. Minimum width of basal plate and internasal space are 22.2% and 14.1% of cranial width, resp. Otic region relatively long and wide, postorbital processes well marked and separated by notch from smaller pterotic processes. Jugal arches small and delicate, not exceeding the contours of occiput. Rostral node is thin and plate-like, with two large perforations, and long, thin appendices not fused with rostral shaft; length of appendices about 43% of rostral length.

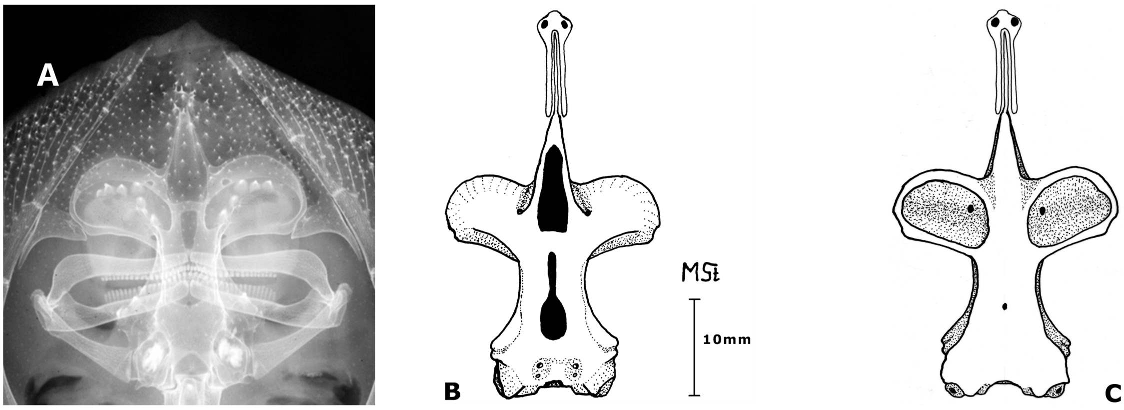

Figure 5.8 – *Neoraja iberica* n. sp., X-ray of cranium of 322 mm TL mature male holotype (MB 4869) (A) and dissected cranium of 230mm TL juv. female paratype (ZMH 25427) in dorsal (B) and ventral (C) views different in size and shape in left and right element of the male.

Scapulocoracoid (Figure 5.9, Table 5.4): Figure 5.9 illustrates the dissected left and right scapulocoracoids of immature female and male paratypes (ZMH 25427 + 25428) to demonstrate obvious sexual dimorphism in general shape and in size of fenestrae already at sexually immature stage, as well as the fact that left and right elements of one and the same specimen are not necessarily 100% identical. Left scapulocoracoids of another immature paratype couple (MNHN 2007-1024 and 2007-1025) were additionally dissected to confirm sexual dimorphism. One large, vertically to somewhat diagonally oval anterior fenestra is situated nearly completely in the dorsal part of the element above a horizontal line through all three condyles. Post-mesocondyle length of the element is only a bit larger than pre-mesocondyle length, except for the left element of the immature male (ZMH 25428) with a little longer pre-mesocondyle (msc)-section. A moderately large to very large, and more or less horizontally oval postdorsal and postventral fenestra close to horizontal midline, resp.. In the female (Figure 5.9A), the scapulocoracoid shows a rectangular, rather low overall shape with angular contours, with maximum length being 1.6 times the height at rear corner; the dorsal margin is horizontally concave, with very well marked angular rear corner, the postdorsal margin slopes steeply to metacondyle, as well as the postventral margin from this condyle; ventral margin horizontally nearly straight. In its left element both, postdorsal (pdf) and postventral (pvf) fenestrae are equally rather small and of the same size, their length is 87.5 and 100.0%, resp., of that of the anterior fenestra (af); in its right element, however, pdf and pvf are almost twice as large as in the left element and their length is 111.0 and 105.6% of the af, resp. In the male (Figure 5.9B), the element rather displays a more compact, relatively higher and ovoid overall shape with rounded contours, with maximum length being

1.8 times the height at rear corner; dorsal margin is more or less horizontally straight to weakly concave, the rear corner widely angled to rounded but not sharply angular, and postdorsal margin slopes at about 45° angle diagonally to métacondyle (mtc), as also does the postventral margin from mtc, so that the rear contour appears triangular or trapezoid, rather than rectangular as in the female. The large, oval anterior fenestra is equal in size and shape in left and right element, and corresponds well with the af of the female. However both, postdorsal and postventral fenestrae are about twice as large in the male than in the female, and further are both fenestrae

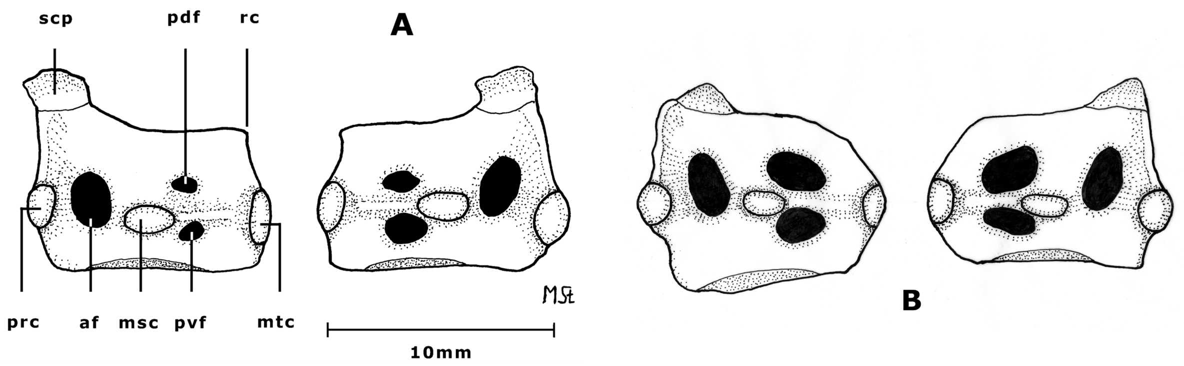

Figure 5.9 – *Neoraja iberica* n. sp., left and right scapulocoracoids of 230 mm juv. female (ZMH 25427) (A) and 252 mm TL juv. Male (ZMH 25428) (B) paratypes in lateral views. Abbreviations: af = anterior fenestra, msc = mesocondyle, mtc = metacondyle, pdf = postdorsal fenestra, prc = procondyle, pvf = postventral fenestra, rc = rear corner, scp = scapular process.

Pelvic girdle of Holotype from X-ray (Figure 5.10, Table 5.5): Figure 5.10 illustrate in dorsal view x-rays the element of the holotype male (Figure 5.10A) and an adolescent female paratype (Figure 5.10B), to likewise demonstrate sexual dimorphism. Prepelvic processes are very short, solid conical and outward inclined; two obturatorial foramina in each iliac region; pelvic bar weakly angled only, more so in the female (Figure 5.10B); posterior contour an evenly rounded deep arc in the male, with transition to iliac regions as well marked angles, whereas in the female the rounded arc is much shallower, with transition to iliac regions hardly marked. Iliac processes are massive and longer in the male than in the female. Proportionally, the female pelvis is apparently wider than that of the male, whose iliac regions also are more massive, as is shown as well by the relation of maximum width of shoulder girdle to that of the pelvis, resp. (Table 5.5).

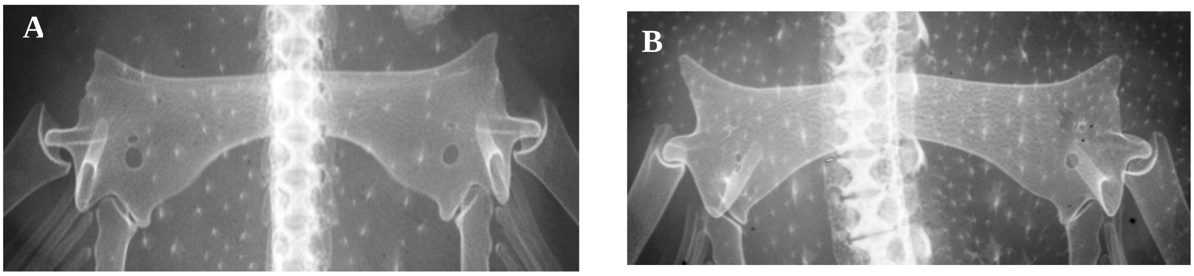

Figure 5.10 – *Neoraja iberica* n. sp., X-rays of pelvic girdles in dorsal views of 322 mm TL mature male holotype (MB 4869) (A) and juv. female of 262 mm TL (TCWC 13204.01) paratype (B).

Variation in paratypes

Proportional morphometrics are given in Table 5.1 as range and mean.

Like in most rajid species, the shape of disc differs in young and females from that of mature males, in that the latter have a strongly undulated anterior disc margin, whereas in young of both sexes and also larger females it is at most weakly undulated to evenly convex. As a rule the bases of dorsal fins are confluent in this species, but exceptionally do specimens show a more or less distinct interspace separating both dorsals. Only four immature males (ZMH 25428, MNHN 2007-0014, MB 4873c, ZMH 25433) among the Portuguese samples and only one male (MNCN 259.159) among the new Spanish samples had dorsal fins separated. As is demonstrated by the values in Table 5.1, there is no obvious sexual dimorphism in proportional morphometrics, and values present in general only a moderate range.

There is little variation in shape and density of dermal denticles on dorsal surface of disc, posterior pelvic lobes, on eyes, tail and on dorsal and upper caudal fins. All specimens are smooth ventrally, except for prickles along the extreme outer edges of the tail. Sides of tail in small juveniles possess only one or two less irregular rows of enlarged thornlets. In all specimens, the median row of thorns begins directly posterior to shoulder girdle, or at most on anterior trunk, and appears more regular in young in shape of and distance between thorns. However, from smallest specimens onward, median thorns become rapidly much smaller from about half tail length to D1, to become very insignificant, irregularly spaced and apparently disappearing with growth. The drastic reduction of median thorns in posterior half to one third of tail is a natural condition and does neither display a late development of thorns in this section with growth, nor a reduction or absorption of existing normal thorns as specimens grow. Thus there is some variation in number of median thorns in small and large specimens. Likewise is some variation displayed in number of orbital, nuchal and scapular thorns, as these appear to be replaced rather often and so vary in number and shape. Also scars are present where thorns have been lost, and have been counted especially in the median row series.

Preorbital thorns of different developmental stages were found in a patch of 2-8, mostly 4-6, on each side. Supraorbitally usually no thorns but a gap separating pre- and postorbital thorns, only very exceptionally may a small supraorbital thorn appear. Postorbital thorns, again differing in development, were found in the range of 2-5, mostly 2-4, each side. Only in about 50% of the specimen was a small supraspiracular thorn present on each side, but regularly was found a pair of small, conical interspiracular thorns with a very few exceptions. Thorns along midline of nape are mostly large and appear in the range of 2-7, mostly 4, with the maximum numbers resulting from few cases with paired thorns anteriorly, and in one specimen was also a pair of smaller lateral nuchal thorns present. On mid-shoulder mostly a single thorn, but in one third of specimens a second one located usually over rear edge of shoulder girdle. Thorns on shoulders vary from 0-4 on each side, often differing on both sides in number and also in arrangement, i.e. side by side, or in triangular position, but mostly were only one or two thorns found on each shoulder. Median thorns from anterior trunk to level of pectoral axils, mostly in rather regular line and at equally short interspaces, numbered 7-17, mainly in the range of 10-15. Much greater range is shown in number of median tail thorns for reasons mentioned above, with extremes from 25 to about 60, if obvious scars and very tiny thorns in posterior half of tail to D1 are included; about 35-40 is the most frequent count, which however all rather relative due to the uncertainty with counting the tiny median thorns along posterior half of tail. Apparent large thorns from posterior to shoulder girdle to about midlength of tail are in the range of 28-51.

Most obvious in this species is the change in dorsal ground colour from ochre-brown in young to rather medium greyish-brown in larger specimens, along with lively colour pattern in young fading toward mature stages. Figure 5.1A and Figure 5.11A show the regular appearance in adult males and females, i.e. of the lively ornamentation of juveniles and half-grown ones remain one or a few pairs of the larger dark spots and eventually one or two pairs of the pale or whitish dots, or specimens may even appear nearly plain brownish. Figure 5.12 shows the dorsal appearance of small juvenile specimens MB 4873b and ZMH 25432, namely the disc, incl. rostral area and eyeballs, and posterior pelvic lobes are scattered to the extreme outer edges with dark brown oval to circular dots and spots, and of the latter several symmetrical pairs on inner parts of both pectorals are larger and pale edged; mostly two pairs of circular whitish spots are found on inner pectorals level with posterior nape (the larger) and level with posterior trunk (the smaller) and, although fading with growth, these do often also remain in larger specimens. Occasionally are nuchal and scapular thorns pigmented dark, and few specimens showed a dark transverse bar over shoulder girdle, including the darkly pigmented thorns, and others display dark edging at pectoral axils and/or a dark blotch on pelvic origin. Further are the usually eight blackish-brown cross-bars or somewhat asymmetrically paired saddle blotches along tail more apparent in small specimens. The white underside of disc displays seemingly in smaller specimens with very thin disc margins dark spots and dots, which however are translucent from the dorsal pattern. The intensity of the broad greyish margin to outer disc corners and posterior margins, as well as that to posterior pelvic lobes, varies but becomes indistinct rather in larger specimens. Further variation is shown by the appearance in several specimens (e.g., in the holotype and paratype female ZMH 25434, see Figure 5.1B, Figure 5.11B) of variously large clouds on inner ventral pectorals of more or less distinct medium brown spots merging to various degrees.

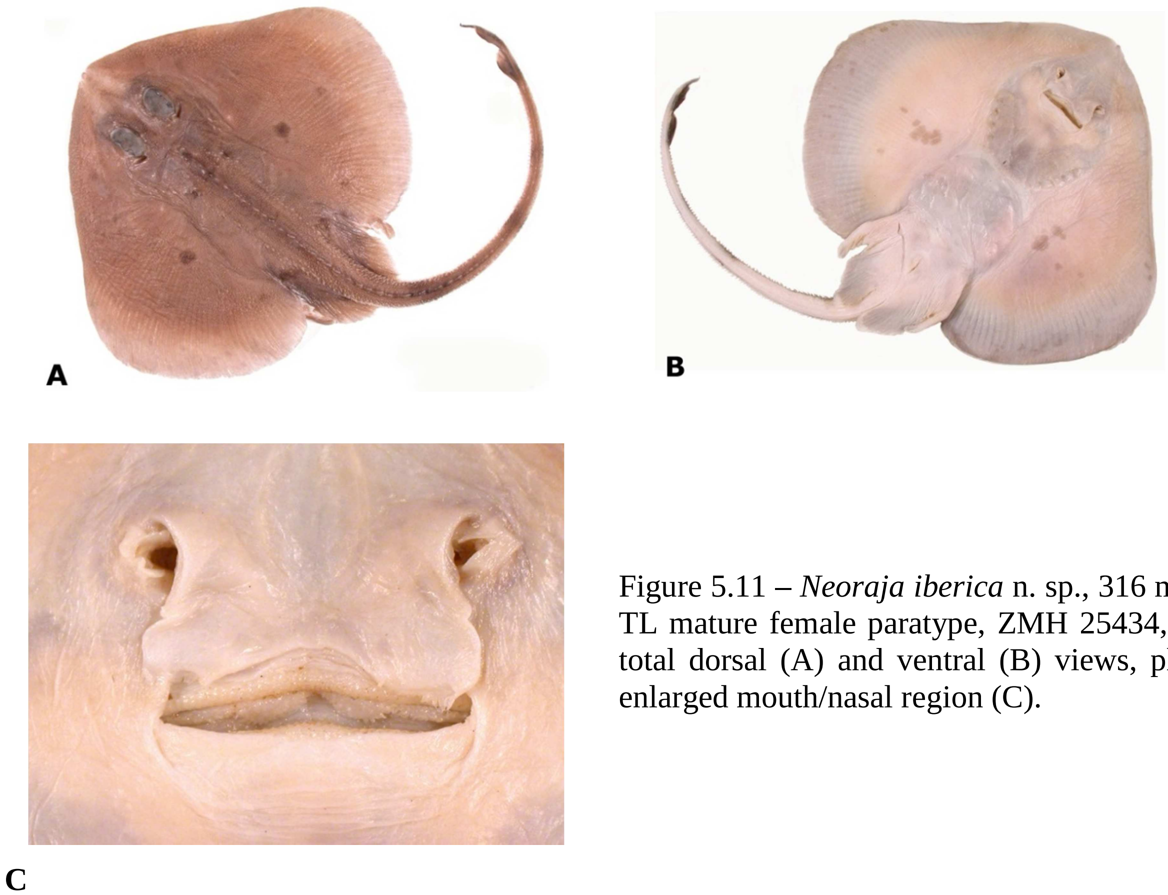

Figure 5.11 – *Neoraja iberica* n. sp., 316 mm TL mature female paratype, ZMH 25434, in total dorsal (A) and ventral (B) views, plus enlarged mouth/nasal region (C).

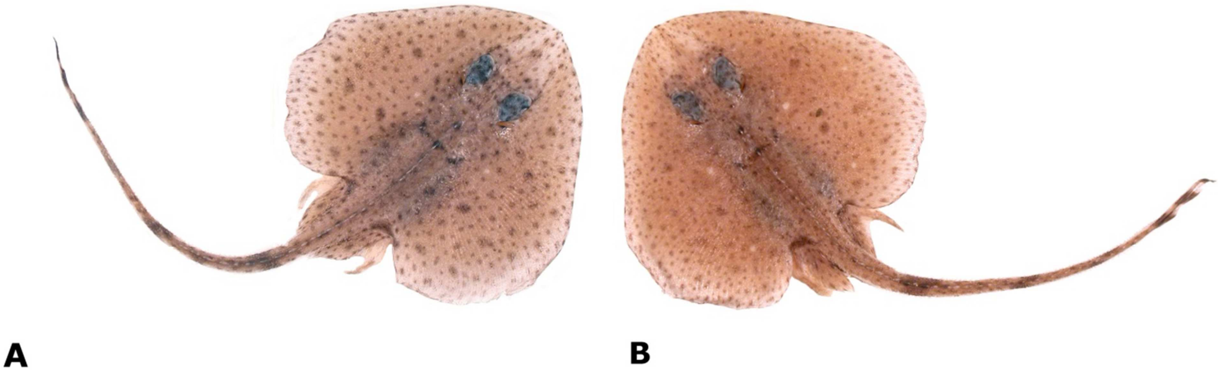

Figure 5.12 – *Neoraja iberica* n. sp., 129 mm juv. female (MB 4873b) (A) and 143 mm TL juv. male (ZMH 25432) (B) paratypes showing distinct juvenile dorsal colour pattern.

Internal meristics: Trunk vertebrae (Vtr): 20/27, Predorsal tail vertebrae (Vprd): 67/78, Pectoral radials (P radials): 64-69, Pelvic radials (V radials): 16-20 (Table 5.2).

Size

Minimum-maximum sizes of the material are 55 (neonate)-327 mm TL, with 327 mm for the largest male and 316 mm TL; largest adolescent male was 278 mm, smallest mature male was 295 mm TL. Males appear to mature between about 280-290 mm TL.

Distribution

Upper south slope of Iberian Peninsula within Bay of Cadiz at 270-670 m depth. One oblique haul from 172-414 m (ZMH 25427) presumably took the specimen at the deeper part of the haul. Bottom temperature and salinity, if taken, at capture stations were approximately between 12.76 and 13.95° C and 36.18 and 37.20 psu, resp., according to data obtained by J. Baro. Regarding bottom substrate, which was not specifically registered during trawl operations, J. Baro's colleague V. Diaz del Rio provided the following summary for the general condition: "Sediments become progressively finer-grained with increasing depth of water and distance from the sea shore. On the upper slope, there is a strong dominance of contourite deposits composed of fine and very fine, occasionally muddy, sands created by the contour-flowing of the strong outflow current of Mediterranean water through the Strait of Gibraltar" (

Figure 5.13).

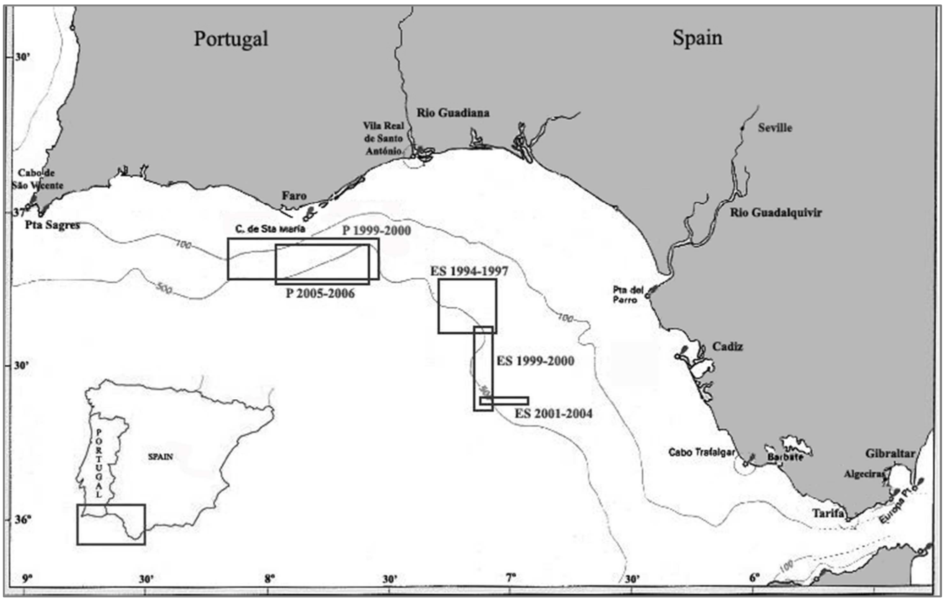

Figure 5.13 – Atlantic south coast of the Iberian Peninsula from Strait of Gibraltar to Cabo de São Vicente, with 100 m and 500 m continental slope isobathic lines. Rectangles indicate capture areas of the Portuguese *Neoraja iberica* samples off Faro during the 1999-2000 and 2005-2006 project periods and the Spanish samples within the Gulf of Cadiz during 1994-1997, 1999-2000 and 2001-2004 surveys.

Etymology

Named for the type localities which are a very restricted area of the eastern North Atlantic along south-western slope of the Iberian Peninsula, in both the Portuguese and Spanish sectors.

Interspecific comparison

N. iberica is already clearly distinguished from its four congeners by its relatively light ochre to medium greyishbrown dorsal ground colour (*vs* plain dark ground colour, or bluish in *N. caerulea*) and by its pattern of largely symmetrically arranged dark brown dots and spots plus a few pairs of small whitish spots on pectorals and posterior pelvic lobes (*vs* no dorsal colour pattern at all). *N. iberica* has an almost totally white underside with at most faint greyish broad margins to outer corners and posterior pectoral margins, as well as to posterior pelvic lobes, and as a rule is its underside of tail plain white. The four congeners, in contrast, show distinctlydark to even blackish broad margins ventrally at least at outer corners and along posterior pectorals, as well as to posterior pelvic margins, and hardly ever a plain white underside of tail. Head and the centre of disc ventrally are usually plain white in *N. iberica*, with at most a cloudy blotch of pale brown, partly merging spots on inner pectoral centres in few specimens. In contrast, as a rule congeners display more or less large dark areas also on underside of head, interbranchially, along line of gills slits, on belly and inner pectorals to at times almost totally dark discs, as well as their underside of tail is always marbled light and dark, largely blotched dark, or even totally dark in anterior half or two thirds of length.

The four congeners resemble each other and *N. iberica* in further external aspects like: general shape, squamation and even morphometric proportions, tooth row counts and internal meristics (Vtr, Vprd, P and V radials), as well as their scapulocoracoids and pelvic girdles are very similar, as largely demonstrated by McEachran and Compagno (1982). Even claspers, except for *N. carolinensis* with no mature males yet known, show externally and in their skeleton a very similar aspect, in that outer surfaces display a rather intensive coverage of fine dermal denticles, and the ‘pseudosiphon’ groove on outer dorsal lobe is either lacking (*N. stehmanni*, *N. caerulea*), or present but formed as a longitudinal, very proximally located groove largely (*N. africana*) or totally (*N. iberica*) within the dorsal dilatator muscle. All congeners with mature males known show externally and in their clasper skeleton the component ‘terminal bridge’ separating two distinct ‘clefts’ on inner dorsal lobe (not labeled by Hulley, 1972, Figure 5.3, as neither external components ‘dike’ and ‘funnel’, but likely present according to skeleton Figure 5.4), and the lateral ‘dike’ and distal ‘funnel’ extensions of ventral terminal cartilage in its distal third. The large clasper cartilages dorsal terminal 1 and ventral terminal – each of characteristic shape, and dt1 curving around axial distally – are firmly fused with their distal tips on inner ventral side, with (*N. stehmanni*, *N. africana*, *N. iberica* but rudimentary in the latter) or without (*N. caerulea*) distal extension of vt forming external component ‘funnel’, depending on whether the dt1 or the vt is the longer element at distal fusion, and if the vt shows a more or less distinct distal extension. Further differences are due to presence (*N. stehmanni*, *N. africana*) or absence (*N. caerulea*, *N. iberica*) of a distal extension of the dorsal marginal cartilage and so a more or less distinct external component ‘pseudorhipidion’. The accessory terminal 1 and 2 cartilages are in all species, with mature males known, of genus-typical U-shape, with Z-shaped distal lateral extension, or straight club-shaped with spatulate, curved tip, resp. The number of dorsal terminal cartilages, other than dt1, may vary from mostly three (*N. stehmanni*, *caerulea*, *iberica*) to four (*N. africana*) as a sequence connecting as dorsal lobe support the distal end of dorsal marginal with the terminal bridge to the axial and the very tip of the axial cartilage. To a degree, presence or absence, or distinctiveness of external components supported by cartilages, as well as clasper cartilages themselves may depend on age of a mature male specimen, in that continued growth of cartilage extensions and the increasing degree of skeletal calcification may make up some of the interspecific differences. This may also hold true for integumental components in the glans, as was found in *N. iberica*. Of eight mature males, only three (MNCN 259.163, MNHN 2007-0017, ZMH 25437) showed a rudimentary component flag (fg) in both claspers as a low integumental flap on distal end of the axial cartilage, but a flag showed only in the right glans clasper of MNHN 2007-0017. Such natural variation demonstrates the apparent gradual development of the flag, if it shows at all?, as mature males grow larger and become older.

Based on the revision by McEachran and Compagno (1982) and availability of better species specific information, a final conclusion can now be drawn regarding the generic identity of the *Breviraja* sp. (*Raja fullonica* of Vaillant, 1888, non Linnaeus; Figure 5.14C) as mentioned and commented on in CLOFNAM (Stehmann, 1973 and 1979 [Suppl.]) and in FNAM (Stehmann and Bürkel, 1984), which appears to have been taken at 614 m depth on the continental slope off northern Spain, i.e. in the southern Bay of Biscay. This single, badly disintegrated, partly skeletonised mature male of approximately 260 mm TL (MNHN 83-149) has been re-investigated to the still possible details by the senior author, incl. radiographs. It can be assigned now to the genus *Neoraja*, based on mainly the following features: cranium without nasobasal fenestrae and with obviously broad basal rostral triangle narrowing abruptly to a delicate rostral shaft being disintegrated like rostral node and its appendices, but with anterior propterygia and pectoral radials apparently extending forward to nearly snout tip. Totally skeletonised claspers, no more providing any indication of integumental components in the terminal region, do however show all *Neoraja*typical features of the terminal skeleton (Figure 5.14A,B): large dt1 with proximal extension and distally curving around axial onto ventral surface; elongated vt with anterior notch and medial extension linking with ventral surface of at1 but distally (? no more due to disintegration) not fused to and longer than dt1, further with distal, inner dorsal platelike, upward curving extension (dike); dt2 to dt4 sequence of dorsal terminal cartilages linking distal end of dm, which has an outer distal extension (pseudorhipidion), with tip of axial, and dt2 with its distal end fused with axial (terminal bridge) and head of dt3; at1 and at2 typically of U-shape with Z-shaped lateral extension and club-shape with spatulate tip, resp.. Internal meristics fall well into the range for congeners: Vtr 25, Vprd 73, P radials approximately 65, and tooth rows approximately 40 in each jaw. Further external characters also fit well the generic diagnosis: individual thorns but no thorn triangle on nape/shoulder region (2 median nuchal, none suprascapular, probably one on each shoulder) and about six small orbital thorns each side;

from directly posterior to shoulder girdle one median row of about 50 thorns to D1 (10 on trunk, about 39 on tail) but almost disappearing after two thirds of tail length a fair distance in front of D1. Upper side totally spinulose. Lateral tail folds only in posterior third of tail length.

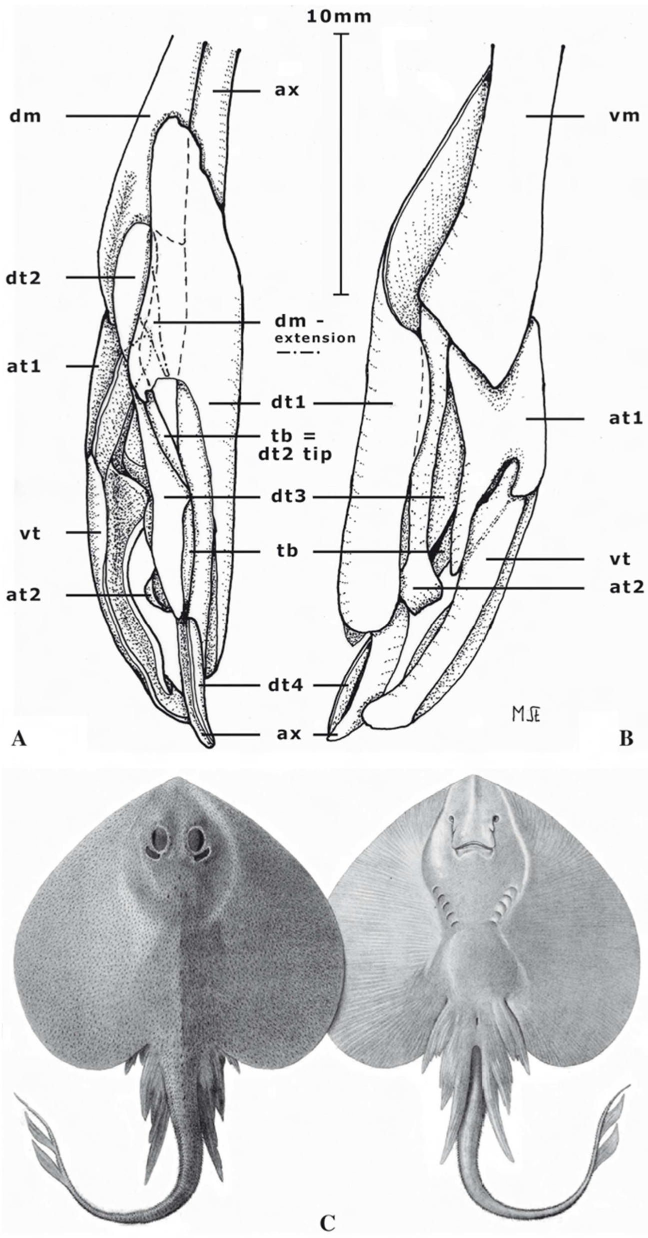

Figure 5.14 – *Raja fullonica* of Vaillant (1888) (non Linnaeus); mature male about 260 mm TL (MNHN 83-149) = *Neoraja* sp.; skeletonised left clasper in dorsal (A) and ventral (B) views. Abbreviations as in figure 9; plus dt4 = dorsal terminal 4. Vaillant's original plate 4 illustrations (C) of this specimen.

However, several distinct features distinguish this *Neoraja* sp. from its five congeners: disc of this mature male very evenly inverse heart-shaped, without obvious undulation of anterior margins as is typical in mature males (correctness of pl. 4 in Vaillant, 1888, assumed); colour (in present bad condition and preserved) dorsally and ventrally sort of plain medium brown, without any indication or remains of dorsal colour pattern; dorsal fins widely separated by space of about two times D1 base length, both very short-based and fanshaped much higher than long, with probably interdorsal thorns between both; this mature male shows a strikingly long postdorsal tail section, which is about twice as long as the distance from D1 origin to D2 base end, bearing a long, low epichordal C lobe terminating a bit anterior to tip of tail. If the locality in the southern Bay of Biscay at a depth of 614 m has been interpreted correctly, it is surprising that no additional specimens have been discovered. Hence doubts remain concerning the locality of the specimen. The poor condition of the specimen also recommends to not yet formally name this species.

Discussion

One may wonder, why *N. iberica* has been only recently discovered, although European slope waters are among the best investigated for a long time, and this moderately rare species lives at upper to middle slope depths having been commercially fished on the bottom for fish and crustaceans again for a long time by local fishermen. The very small size of this pygmy skate species may mainly be responsible, that is has been overlooked probably and/or been discarded at sea or mistaken on a first glance for juveniles of not marketable size of one of the well know, larger growing skate species landed regularly for human consumption. Its very small size eventually also prevented its being caught by trawls, or made it easier for specimens to escape from a trawl. Such circumstances may also have delayed the discovery of *N. caerulea* within the Rockall Trough to the west of Scotland and Irelanduntil the 1970s, despite its exceptional blue dorsal colour making it indeed obvious in any catch, in particular because commercial deep water fishing there has been carried out by large factory stern trawlers using trawls with large mesh size – unlike the small local fishing boats along the Iberian Peninsula south coast.

Species of the genus *Neoraja* show at least in the Eastern Atlantic mostly an unusually localized, very limited distribution not only compared with other offshore deep water but likewise shelf species of skates. However, their small size is an apparent reason for them being unable to migrate over long distance, and they may have occupied particular ecological niches within their restricted habitat areas, where they have been found living sympatrically with larger species of other deep water skates. Knowledge of their biology is still too limited for confirming the latter assumption. According to Compagno *et al.* (1991) is *N. stehmanni* an endemic off the west coast of South Africa from mainly about Saldanha Bay to south of Agulhas Bank, with so far only one more northern record south west of Orange River mouth at 292-1025 m depth. It is said (*loc. cit*.) to have been caught in considerable numbers of mostly adults off Cape Town and Saldanha Bay in limited areas below 600 m depth. *N. caerulea* has only been found at about 600-1260 m depth within the Rockall Trough to the west of Scotland and Ireland on the continental slope and slopes of surrounding submarine banks, with occasional records also on the outer slopes of the latter banks delimiting the Trough to the north and west. Bottom water temperatures at capture localities were between 6.41° and 9.102°C, mostly between 6.4° and 6.9°C, and salinities between 35.171 psu and 35.326 psu. The species thus appears to live within the NEAtlantic water mass characterised by temperatures higher than 6°C and salinity of more than 35 psu. If this holds true, the depth range of *N. caerulea* will be limited to a maximum of about 1300 m (Stehmann, 1976; Stehmann and Bürkel, 1984). *N. africana* was so far found with three type specimens on the Central West African continental slope off Gabon at 900-1030 m and 4.35° to 4.66°C (Stehmann and Séret, 1983) and with one postembryonic female off Mauritania/Rio de Oro at 1490-1640 m depth (Stehmann, 1995). With these two widely separated localities and apparently greater depth range, *N. africana* shows a wider geographical distribution within the Eastern Atlantic than its congeners. *N. iberica* with its very limited distribution, eventually sharply restricted by the outflow of high salinity Mediterranean water through the Strait of Gibraltar, is geographically intermediate between *N. africana* and *N. caerulea*, and the *Neoraja* sp. of Vaillant (1888) from off the north coast of Spain – correctness of its locality given – is intermediate between *N. iberica* and *N. caerulea*. The only NW Atlantic congener, *N. carolinensis*, was found with all but one of six type specimens off North Carolina at 695-1010 m, 4.18-4.56°C and 34.929-34.958 psu, only one paratype off Florida at 1000-1008 m, 6.09°C and 35.035 psu (McEachran and Stehmann, 1984).

Chapter 6

Cases of abnormal hermaphroditism in velvet belly *Etmopterus spinax* (Chondrichthyes: Etmopteridae) from the southern coast of Portugal

Etmopterus spinax *(Linnaeus, 1758) specimen - photo by @ MECosta*

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Abstract

The authors described in this note three hermaphroditic specimens of the Velvet belly *Etmopterus spinax* (Linnaeus, 1758) captured off the southern coast of Portugal (Algarve), during commercial trawl fisheries. The concomitant presence of a pair of claspers and a normal and complete female reproductive system allowed considering these specimens as hermaphrodites. These three specimens are the first cases of hermaphroditism recorded in *E. spinax* to date and the second reported case of hermaphroditism in chondrichthyan species in Portuguese waters. The authors summarized and comment the different records of hermaphroditism known to date in sharks, pointing out that such a phenomenon is extremely rare within this group.

Introduction

Velvet belly lantern shark *Etmopterus spinax* (Linnaeus, 1758) is a small to medium-sized common shark, well known in the eastern Atlantic, from Iceland and Norway to Portugal (Quéro *et al.*, 2003). South Strait of Gibraltar, the species is reported off Morocco (Lloris and Rucabado, 1998), Mauritania (Maurin and Bonnet, 1970), Senegal (Capapé *et al.*, 2001a, b), Guinea Bissau (Sanches, 1991), Azores (Sanches, 1986; Santos *et al.*, 1997), Madeira (Sanches, 1986) and the Cape Verde Islands (Menezes *et al.*, 2004), also in southern Africa (Compagno, 1984a). *E. spinax* is reported in both Mediterranean Basins (Capapé, 1989; Golani, 2005), in waters between 150-200 m to 400 m, and probably more (Quignard and Capapé, 1971), however, it has been recorded down to 2200 m in the Ionian Sea (Sion *et al.*, 2004).

Previous studies on the reproductive biology of *E. spinax* showed that it is a viviparous aplacental species, with a gestation period not exceeding one year. Sexual maturity is reached at similar sizes for specimens from off the British Isles (Hickling, 1963) and those from the Tunisia coast (Capapé *et al.*, 2001b). Additionally, in each area, males matured at a smaller size than females, 350 mm and 380 mm resp., with 460 mm the maximum size recorded for both sexes. However, Compagno (1984) noted that the maximum size observed was 600 mm. Capapé *et al.* (2001b) recorded near term embryos, having 126 mm total length and weighing 6.03 g in pregnant females. Lo Bianco (1909), Hickling (1963) and Capapé *et al.* (2001b) considered that the gestation period did not exceed a year. Food composition and feeding habits of *E. spinax* have been studied from different marine areas of the eastern Atlantic and Mediterranean. Stomach contents were analyzed and showed that the species feeds on crustaceans, teleosts and cephalopods (Capapé *et al.*, 2003; McPherson, 1980; Relini Orsi and Wurtz, 1977).

Off the southern Portuguese coast (Algarve), *E. spinax* is commonly caught as a bycatch by bottom trawls, being always discarded at sea since it has no commercial value (Borges *et al.*, 2002). Thus, in order to obtain information on fisheries discards, research was carried out on board commercial bottom trawl fisheries trawlers targeting red shrimp, *Aristeus antennatus* (Risso, 1816), deep-water rose shrimp *Parapenaeus longirostris* (Lucas, 1847) and Norway lobster *Nephrops norvegicus* (Linnaeus, 1758) operating off the southern coast of Portugal (Algarve). Of the 629 specimens of *E. spinax* sampled during the survey, three revealed an abnormal genital apparatus, and constituted new cases of hermaphroditism; the first recorded to date in this species, to the best of our knowledge.

The aims of the paper are to describe each specimen, define the kind of hermaphroditism, normal or abnormal, and comment and discuss hermaphroditism in shark species. Of the three categories of abnormalities reported by Dawson (1964, 1966, 1971) and Dawson and Heal (1971) in chondrichthyans, hermaphroditism is probably the most interesting due to the fact that it directly concerns reproductive organs and reproduction.

Material and Methods

The whole sample including three abnormal specimens was collected during fishing carried out between February 1999 and September 2000, mostly on muddy and sandy bottoms, using a minimum codend mesh size of 50 mm. Specimens were taken to the laboratory where they were frozen whole for later study and processed after thawing. Identification to species level was confirmed from Compagno (1984b) and McEachran and Branstetter (1984).

During the study, all measurements were recorded to the nearest lowest millimeter. Total length was measured in a straight line from the tip of the snout to the posterior tip of the caudal fin, depressed along the anterior-posterior axis of the fish (Compagno, 1984b, 2001). Total body weight, eviscerated weight, the weights of the ovaries and the liver after being excised were recorded to the nearest lower centigram. Lengths of left and right male claspers were recorded, and state of the claspers (flexibility or rigidity) was noted. Inner clasper lengths were measured from the point of insertion at the cloaca to distal tip of clasper and outer clasper lengths were measured from the point of outside insertion in the pelvic fin to tip of clasper (Compagno, 1984b, 2001).

Additionally, maximum oviduct widths, right oviducal gland, length and width, ovaries length, width and weight, oocyte diameters and uteri width were recorded. All measurements of reproductive organs were taken with a digital caliper with 0.01 mm precision and weights with a digital scale to an accuracy of 0.01 g. Sexual maturity was ascertained macroscopically and was determined following the maturity scale proposed by Stehmann (2002) for viviparous chondrichthyan species. Test for significance was performed by chi-square test with $p < 0.05$ following the methodology of Schwartz (1963).

Results

The first specimen was caught in March 1999, at depths ranging from 561 to 650 meters, between 36° 46´ 04´´N - 36° 53´ 15´´ N and 7° 37´ 55´´ W - 7° 53´ 08´´ W (Figure 6.1). It measured 320 mm in total length and weighted 130.71 g. Eviscerated and liver weights were 85.33 g and 20.49 g, respectively. Claspers were soft, flexible and longer than extreme tips of posterior pelvic fins lobes, but the left clasper was rather smaller, 3 mm outer length; 19 mm inner length, than the right one, 6 mm outer length; 22 mm inner length. Both left (LO) and right (RO) ovaries were transparent and almost equally of the same length, 46.59 mm in LO and 46.80 mm in RO, and weight, 0.13 g in LO and 0.14 g in RO. The right ovary was slightly wider, 5.58 mm, than the left ovary, 4.78 mm. Some small-sized transparent ovarian eggs (oocytes) in the ovaries were visible, but not macroscopically measurable. Oviducal glands (OG) appeared to be in a developing stage, measuring 12.06 mm in length and 4.58 mm in width (right OG). Oviducts were widened posteriorly forming the uterus, and the widths of right and left sides were 5.36 mm and 5.53 mm, respectively (Figure 6.2). Measurements and weights of the internal female reproductive organs were within the range of values observed in normal maturing females of similar total length, with exception of a wider uterus. The state of these organs allowed us to classify this specimen as a maturing female, according to Stehmann (2002).

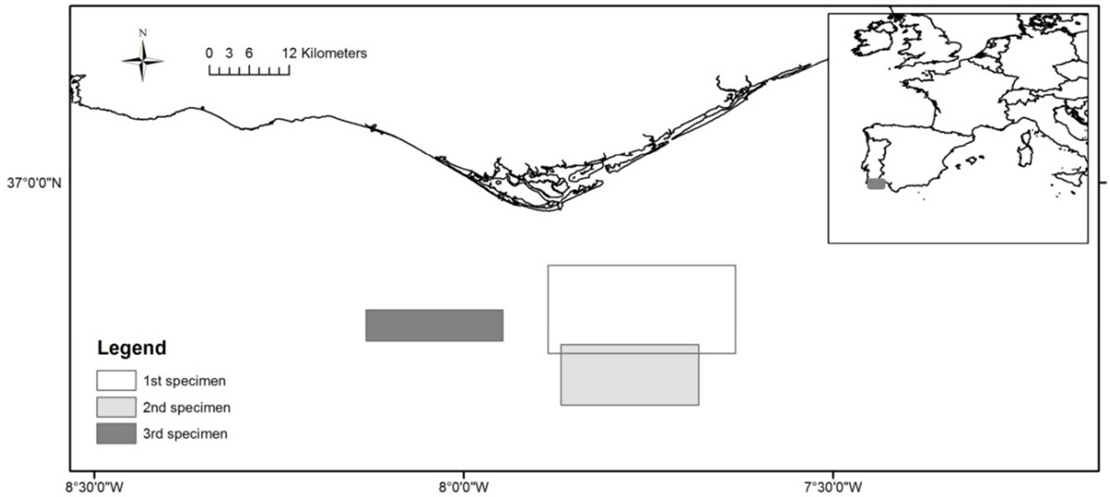

Figure 6.1 – *Etmopterus spinax*. Map of southern Portugal showing the capture areas of the three abnormal hermaphroditic specimens.

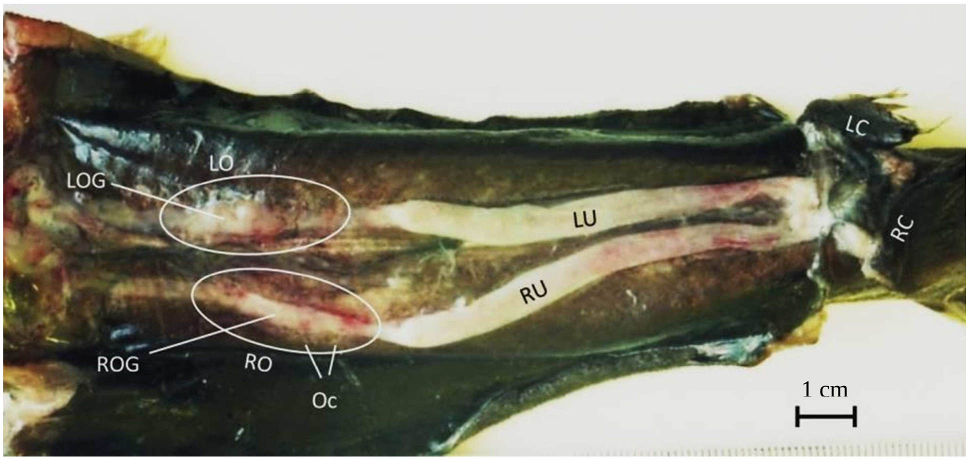

Figure 6.2 – *Etmopterus spinax*. Ventral view of the abdominal cavity of the first abnormal hermaphroditic specimen, showing normal female reproductive organs and claspers. LC, left clasper; RC, right clasper; LOG, left oviducal gland (underneath the ovary); LO, left ovary; RO, right ovary; Oc, oocyte; LU, left uterus; RU, right uterus.

The second specimen was caught in September 1999, at depths ranging from 595 to 640 meters, between 36° 41´ 53´´N - 36° 46´ 47´´ N and 7° 40´ 55´´ W - 7° 52´ 05´´ W (Figure 6.1). It had a total length of 319 mm and a total weight of 132.90 g. The eviscerated body weight and liver weight were 84.56 g and 25.65 g respectively. Both claspers were soft, flexible and extended beyond the extreme tips of posterior pelvic fins lobes, being the left clasper quite smaller, 3 mm outer length; 22 mm inner length, than the right clasper, 7 mm outer length; 26 mm inner length. The left ovary was rather smaller, 41.03 mm and wider, 10.60 mm, but also heavier, 0.22 g, than the right ovary, which was 45.16 mm in length, 7.25 mm in width and 0.15 g in weight. Both ovaries exhibited translucent oocytes having different small sizes, 5.15 mm maximum diameter, easily recognizable by naked eye. The right oviducal gland measured 12.81 mm in length and 5.40 mm in width. Oviducts were still narrow, 2.40 mm in left side and 3.38 mm in right side, posteriorly widened forming the uterus, with widths quite similar on both left and right sides, 9.51 mm and 9.91 mm, respectively (Figure 6.3). The description of the internal female reproductive organs fits the criteria of a maturing female defined by Stehmann (2002). Measurements and weights of the internal female reproductive organs were comparable to those of normal maturing females of the same size, and only the inner right clasper length presented a size similar to this of maturing males having the same total length.

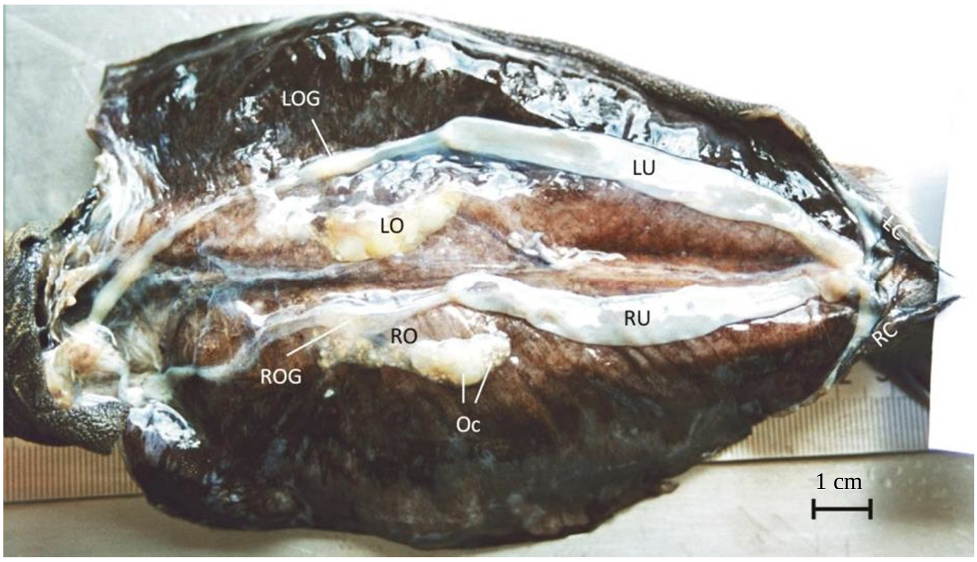

Figure 6.3 – *Etmopterus spinax*. Ventral view of the abdominal cavity of the second abnormal hermaphroditic specimen, showing normal female reproductive organs and claspers. LC, left clasper; RC, right clasper; LOG, left oviducal gland; ROG, right oviducal gland; LO, left ovary; RO, right ovary; Oc, oocyte; LU, left uterus; RU, right uterus.

The third specimen was caught in September 1999, at depths ranging from 465 to 590 meters, between 36° 47´ 05´´ N - 36° 49´ 38´´ N and 7° 56´ 49´´ W - 8° 07´ 55´´ W (Figure 6.1). The total length of this specimen was 376 mm and the total weight was 238.57 g. The eviscerated body and liver weighed 147.04 g and 59.78 g, respectively. Both left and right claspers were of the same size, 10 mm outer length; 29 mm inner length, and were rigid and longer than the extreme tips of the posterior pelvic fin lobes. Ovaries were large, well rounded and measured 63.10 - 74.63 mm in length, 15.71 - 19.82 mm in width and 2.45 - 4.23 mm in weight, on the left and right side, respectively. The specimen contained enlarged yolked oocytes, easily counted and measured, and almost all about the same size, with a maximum diameter of 13.48 mm. The right oviducal gland measured 15.28 mm in length and 5.40 mm in width. Oviduct width ranged from 3.28 mm in left side to 5.30 mm in right side. The uterus was rather wider on the right side, 10.01 mm, than on the left side, 9.06 mm (Figure 6.4). The condition of both ovaries and uterus allowed us to classify this specimen as a mature female according to Stehmann (2002). The internal female reproductive organs measurements and weights are typical of those found in the same range size of normal mature females, with the exclusion of the uterus (narrower) and the oviducts (wider). As no normal mature male more than 330 mm in total length was sampled, it was not possible to verify if the claspers of this specimen approached the length of normal mature males.

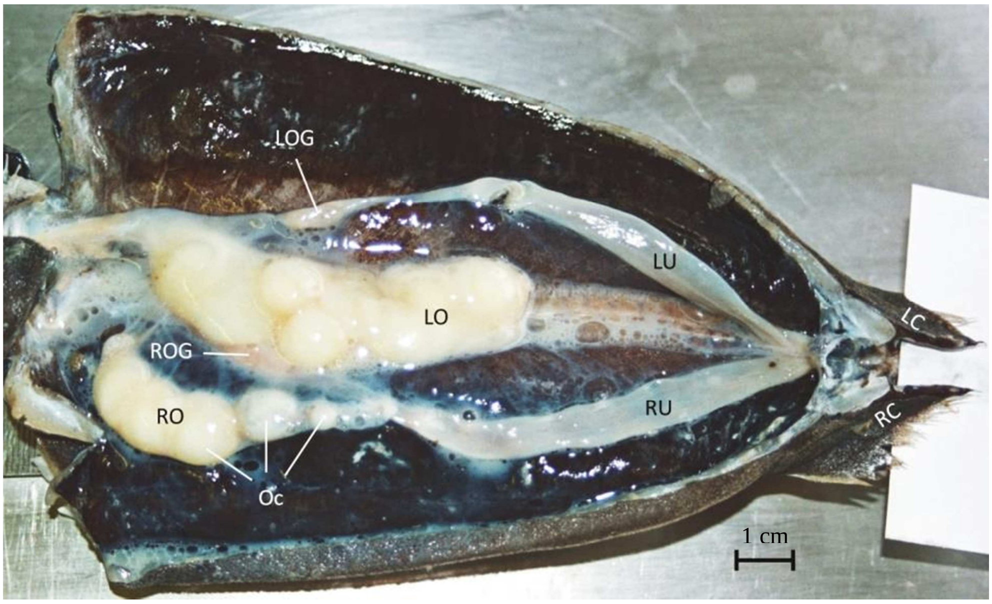

Figure 6.4 – *Etmopterus spinax*. Ventral view of the abdominal cavity of the third abnormal hermaphroditic specimen, showing internal normal female reproductive organs and male claspers. LC, left clasper; RC, right clasper; LOG, left oviducal gland; ROG, right oviducal gland; LO, left ovary; RO, right ovary; Oc, oocyte; LU, left uterus; RU, right uterus.

Discussion

Although *Etmopterus spinax* has been the subject of studies concerning some aspects of its reproductive biology and diet and feeding habits, no case of hermaphroditism has to date been reported for the species. Thus, the three *E. spinax* described in the present paper constitute the first cases of hermaphroditism ever recorded for the species, and the second for chondrichthyans in Portuguese waters; the first one was described in the Portuguese dogfish *Centroscymnus coelolepis* (Bocage and Capello, 1864) by Veríssimo *et al.* (2003). Consequently, the low occurrence of *E. spinax* hermaphroditic specimens highlights the rarity of such an abnormality, in agreement with Atz (1964), and the reports of Dawson (1964, 1966, 1971) and Dawson and Heal (1971).

Two types of hermaphroditism are generally reported in chondrichthyans such as ‘abnormal hermaphrodite’ and ‘normal hermaphrodite’ following Atz (1964) and Iglesias *et al.* (2005), and defined also as ‘pseudo-hermaphrodite’ and ‘true hermaphrodite’ by Irvine *et al.* (2002). Normal hermaphrodites or true-hermaphrodites exhibit internally both sexes with claspers and when mature the individual could assume both male and female functions; while all other cases of hermaphroditism would be defined as abnormal or pseudo-hermaphroditism (Irvine *et al.*, 2002; Iglesias *et al.*, 2005). Additionally, Atz (1964) and Bortone and Davis (1994) noted that intersexuality is considered when primary or secondary characters of both sexes are present in a same specimen. The presence of claspers characteristic of males and a normal and complete female reproductive system in the three *Etmopterus spinax* specimens described, allowed us to state that they are abnormal or pseudo-hermaphrodite sharks, following the definitions cited above.

In Table 6.1, we have summarized reports of the 30 hermaphroditism cases available to date in the literature; it appears that number of normal hermaphrodite cases, 16, did not significantly differ from that of abnormal hermaphrodites, 14, with $\chi^2 = 2.00$, df = 1, p = 0.31. Conversely, of the 14 hermaphroditism cases reported in batoid species by Ribeiro-Prado *et al.* (2009), only 4 were normal hermaphrodites, the 10 other cases were abnormal hermaphrodites; with this difference being statistically significant ($\chi^2 = 50.00$, df = 1, $p < 0.05$). This phenomenon, especially normal hermaphroditism, seems to be more characteristic of sharks than batoids. Normal hermaphroditism is evident in both aplacental and viviparous species. Although such abnormality is considered very rare in chondrichthyans (Atz, 1964), a high percentage of normal hermaphrodites were observed in the brown lantern shark *Etmopterus unicolor* (Engelhardt, 1912) by Yano and Tanaka (1989), and the black dogfish *Centroscyllium fabricii* (Reinhardt, 1825) by Yano (1995), while Iglesias *et al.* (2005) stated that hermaphroditism is the normal condition of reproduction in the longhead catshark *Apristurus longicephalus* Nakaya 1975.

The causes of hermaphroditism in chondricthyan species still remain difficult to explain (Atz, 1964; Ribeiro-Prado *et al.*, 2009). As in other vertebrates, hermaphroditism may have different origins, probably genetic and/or hormonal. Unfavorable environmental conditions such as radio-activity contamination could play an important role (Yano and Tanaka, 1989; Scenna *et al.*, 2007), and other pollutants may be implicated in the wild (Ribeiro-Prado *et al.*, 2009). The large variations of hermaphroditism cases in different chondrichthyan species reported to date, especially the recent observations of Iglesias *et al.* (2005), support the need of further and more detailed studies on this subject.

Table 6.1 – *Etmopterus spinax*. Normal and abnormal cases of hermaphroditism recorded in shark species from different marine regions including the specimens described in this note.

FAMILY	SPECIES	HERMAPHRODITISM	REPRODUCTIVE MODE	CAPTURE SITE	AUTHORS
Hexanchidae	*Notorynchus cepedianus*	Normal*	Yolk-sac viviparous	?	Daniel (1928)
Etmopteridae	*Etmopterus baxteri*	Normal	Yolk-sac viviparous	Southern Australia	Irvine (2004, in Jones *et al.*, 2005)
Etmopteridae	*Etmopterus granulosus*	Abnormal	Yolk-sac viviparous	Eastern New Zealand	Wetherbee (1996)
Etmopteridae	*Etmopterus granulosus*	Normal	Yolk-sac viviparous	South-east Tasmania	Irvine et al. (2002)
Etmopteridae	*Etmopterus unicolor*	Abnormal*	Yolk-sac viviparous	Suruga Bay, Japan	Yano & Tanaka (1989)
Etmopteridae	*Centroscyllium fabricii*	Abnormal*	Yolk-sac viviparous	Western Greenland	Yano (1995)
Etmopteridae	*Etmopterus spinax*	Abnormal	Yolk-sac viviparous	Southern Portugal	This study
Somniosidae	*Centroscymnus coelolepis*	Normal	Yolk-sac viviparous	Central Portugal	Veríssimo *et al.* (2003)
Somniosidae	*Centroscymnus owstonii*	Abnormal	Yolk-sac viviparous	Suruga Bay, Japan	Yano (1985, in Irvine *et al.*, 2002)
Squalidae	*Centrophorus lusitanicus*	Abnormal	Yolk-sac viviparous	Coast of Senegal	Cadenat (1960)
Squalidae	*Squalus acanthias*	Abnormal	Yolk-sac viviparous	Western Canada	Rowan (1929)
Squalidae	*Squalus acanthias*	Abnormal	Yolk-sac viviparous	?	Gelsleichter *et al.* (1997, in Irvine *et al.*, 2002)
Squalidae	*Squalus megalops*	Abnormal	Yolk-sac viviparous	South-eastern Australia	Braccini (2009)
Heterodontidae	*Heterodontus portusjacksoni*	Normal	Yolk-sac viviparous	South-western Australia	Jones et al. (2005)
Heterodontidae	*Heterodontus portusjacksoni*	Normal	Oviparous	South-western Australia	Jones & Potter (2009)
Carcharhinidae	*Prionace glauca*	Normal	Placental viviparous	Central Long Island, USA	Pratt (1979)
Scyliorhinidae	*Apristurus longicephalus*	Normal *	Oviparous	New Caledonia	Iglésias *et al*. (2005)
Scyliorhinidae	*Apristurus longicephalus*	Normal	Oviparous	West Australia	Iglésias *et al*. (2005)
Scyliorhinidae	*Apristurus longicephalus*	Normal*	Oviparous	South-western Japan	Iglésias *et al*. (2005)
Scyliorhinidae	*Scyliorhinus canicula*	Abnormal	Oviparous	France	Borcea (1904)
Scyliorhinidae	*Scyliorhinus canicula*	Normal	Oviparous	British waters	Bamber (1917)
Scyliorhinidae	*Scyliorhinus canicula*	Abnormal	Oviparous	British waters	Murray & Baker (1924)
Scyliorhinidae	*Scyliorhinus canicula*	Normal*	Oviparous	British waters	Arthur (1950)
Scyliorhinidae	*Scyliorhinus canicula*	Normal	Oviparous	British waters	Fuller and Zacharov (1960)
Scyliorhinidae	*Scyliorhinus canicula*	Normal	Oviparous	Coast of Tunisia	Capapé & Zahnd (1974)
Scyliorhinidae	*Scyliorhinus canicula*	Abnormal	Oviparous	Bristol Channel, UK	Ellis & Shackley (1997)
Scyliorhinidae	*Scyliorhinus stellaris*	Normal	Oviparous	Southern France	Vayssière & Quintaret (1914)
Scyliorhinidae	*Scyliorhinus stellaris*	Normal	Oviparous	Coast of Tunisia	Capapé et al. (1979)
Triakidae	*Iago omanensis*	Abnormal	Placental viviparous	Northern Arabian Sea	Compagno & Springer (1971)
Triakidae	*Iago omanensis*	Abnormal*	Placental viviparous	Madras coast, India	Devadoss & Batcha (1997)

* Several specimens were observed by authors.

Chapter 7

General Discussion and Final Remarks

Finding a way to ´fish better´…

Hauling of a trawl net with a BRD - photo by @ Paulo Fonseca adapted by MECosta

Neither bycatch (the portion of the unintentional catch of non-targeted species) nor discards (the portion of the catch not retained and thrown overboard) are new issues of international concern. However, since the recent inclusion of a ‘landing obligation’ (hereafter referred to as ‘discards ban’), addressed in the reform of the European Union Common Fisheries Policy, bycatch and discards issues have gained a tremendous attention from the economic, scientific, political and social point of view.

The present work provides results on bycatch and discards in the Portuguese commercial trawl fisheries, specifically on the southern coast (Algarve), which are relevant to other high discarding multi-species and multi-sized fisheries. These include:

☑ The crustacean and fish trawl fisheries are characterised by considerable amounts of bycatch, largely exceeding the target catch (Chapter 2) and also of discards, both in abundance and biomass (Chapter 3), commonly attributable to the inherently non-selective nature of the trawl gear;

☑ Both bycatch and discards are much higher in the fish trawl than in the crustacean trawl métier (Chapters 2 and 3); these bycatches are more related with the non-selective nature of trawl nets and the discards are more connected with the catch of small pelagic organisms (e.g. *Macroramphosus* spp.), whose depth distribution overlaps the depth range exploited by trawlers;

☑ The biomass of target species caught by crustacean trawls is considerably higher than those caught by fish trawls, but the inverse applies concerning commercial bycatch species (Chapter 2), which can be attributable to longer tow durations of crustacean trawlers and shorter trip durations of fish trawlers;

☑ No significant seasonal patterns in the target, bycatch (total and commercial), retained and discarded catch components were found (Chapters 2 and 3), most likely due to the persistence of groundfish assemblages composition over time; also no seasonal trends in the overall species abundance and biomass discard rates were found (Chapter 3), which may indicate no changes in the fishing behaviour, since fishing operations are conducted in order to take advantage of the availability of the most important (target) species;

☑ The highest amount of discards found in a specific season/year, in each métier, is probably related to the increase of the local market prices of some commercial bycatch species otherwise discarded;

☑ Demersal trawl fisheries in this region capture an extraordinary diversity of species from a large number of taxonomic categories (Chapters 2 and 3), reinforcing the multispecies nature of the trawl fisheries;

☑ Both bycatch and discard biodiversity is far greater in crustacean trawls, which is expected since fishing is carried out over a greater depth range and a broader area and with four times longer mean tow durations than in fish trawls; target species, selected by the skippers represent a very small fraction of the biodiversity in both métiers (Chapters 2 and 3);

☑ Bony fishes were dominant in both bycatches and discards, followed by cephalopods in the bycatches and by crustaceans in the discards (Chapters 2 and 3);

☑ Most species caught by crustacean trawls were systematically discarded while most of the caught in fish trawls were frequently discarded (Chapter 3);

☑ Fishes and cephalopods are retained and discarded at considerably higher mean rates in fish trawls when compared to crustacean trawls, with the retained ones always exceeding the discards; discards in excess of landings were only found in specific seasons and years, associated to the sporadic presence of high amounts of certain bony and cartilaginous fish species in each métier, which could only be a reflection of a temporal variation in their abundances (Chapter 3);

☑ Deep-water rose shrimp (*Parapenaeus longirostris*), in crustacean trawls, and horse mackerels (*Trachurus* spp.), in fish trawls, were the species which accounted for the largest fraction of the target catch (Chapter 2);

☑ The species that contributed most to the commercial bycatch were the cartilaginous fishes in the crustacean trawl métier, and the Atlantic chub mackerel (*Scomber colias*) and European pilchard (*Sardina pilchardus*) in the fish trawl métier, whose commercialization depends on the total amount of catch and on the market prices (Chapter 2);

☑ In both métiers, bony fishes alone account for an extremely high percentage of the discards abundance and biomass, although being higher in the fish trawl métier (Chapter 3);

☑ A limited number of fish species, of low or no commercial value and particularly relevant to the marine food webs, contributes to high levels of discards in each métier, both in abundance and in biomass. The main species discarded by crustacean trawls are *Micromesistius poutassou* (blue whiting), *Macroramphosus scolopax* (longspine snipefish) and *Capros aper* (boarfish) in abundance, and blue whiting, boarfish, *Galeus melastomus* (blackmouth catshark) and *Conger conger* (European conger) in biomass. The species most discarded by fish trawls are longspine snipefish and boarfish in abundance, and snipefishes, Atlantic chub mackerel, *Scyliorhinus canicula* (small-spotted catshark) and *Boops boops* (bogue) in biomass (Chapter 3);

☑ The reasons for discarding are fundamentally of an economic nature for bycatch species, since the majority of them have no commercial value (e.g. longspine snipefish, boarfish, and most of the cartilaginous fishes and invertebrates) (Chapter 3), and of legal and administrative nature for commercially important target species, as most are below the legal minimum landing sizes (e.g. hake, seabreams of the genus *Pagellus* spp., deep-water rose shrimp) (Chapters 2 and 3). Both target and bycatch species are also discarded because of damaged condition and/or poor (bad) quality of individuals as a result of long tows, particularly those less resistant to deterioration (e.g. hake, blue whiting, forkbeards) (Chapters 2 and 3). Other important economic reasons that lead to discarding of bycatch species are the inexistence of readily available markets for many commercial bycatch species (e.g. triglids, most of cephalopods), and the low commercial value (e.g. blue whiting, catsharks) (Chapter 3).

The results of these studies come to reinforce the increasing concern about bycatch and discards that we have been assisting recently worldwide and highlight the urgent need to search for solutions towards addressing this problem. Due to the lack of selectivity of the trawl nets and the multispecies nature of trawl fisheries, of which the southern Portuguese trawl fisheries is a good example, some bycatch will always occur making it impossible to completely eliminate the discards, however there is no doubt that the current levels of bycatch and discards of non-target species and undersized individuals can be significantly decreased.

The concern to investigate and take appropriate measures for the minimization of bycatch and discards is not recent (Alverson *et al.*, 1994) and, since 1995, it is referred in the FAO Code of Conduct for Responsible Fisheries (CCRF) (FAO, 1995). In light of the management goal to '*maintain or restore stocks at levels capable of producing maximum sustainable yield*' (Article 7.2.1), the CCRF specifies that '*discards, catch of non-target species, both fish and non-fish species, and impacts on associated or dependent species*' should be minimized by means of appropriate '*selective, environmentally safe and cost-effective fishing gear and techniques*' (Article 7.2.2 g), including '*technical measures related to fish size, mesh size or gear, discards, closed seasons and areas and zones reserved for selected fisheries*' with the foremost purpose to '*protect juveniles and spawners*' (Article 7.6.9) (FAO, 1995).

The mitigation of bycatch and consequent reduction of discards can be achieved by a broad range of technical, regulatory and socio-economic measures, which are presented in

Table 7.1. These possible measures will not be discussed in detail in this chapter as this belongs to a much wider context and is beyond the scope of this study. Nevertheless, those measures found to be most pertinent in the context of Portuguese trawl fisheries, and taking into account the main outcomes of this study, will be discussed in a more generic way.

The most recent and most feasible approach used to reduce catches of bycatch and undersized species, thus decreasing discards levels of bottom trawls, is the **development and adoption of more selective fishing gears and practices** (Table 7.1), where only one or a few target species are captured and others, such as juveniles, are allowed to escape during the catching process. A large number of gear modifications (e.g. increasing mesh sizes) and technical improvements in the selectivity of trawl nets, both in size and species-selection (e.g. Bycatch Reduction Devices, BRDs)[9], have been tested worldwide and some have proven to be very successful in some fisheries for many important marketable species. However, as these gear-based technical measures allow the escapement of some of the commercially valuable target species from trawl nets, reducing the catching efficiency or even a potential loss of landings and incomes in a short term, the fishers, whose main concern is to maximize catches of target species, do not accept them easily. This is further aggravated in multi-size and multi-species fisheries as the improvement of the selectivity by the gear-based technical measures cannot be achieved for all species. On the other hand, the additional work that fishers have to face, associated to inserting, handling, repairing and maintaining BRDs, as well as the high economic costs of manufacturing these devices, makes them and the fishing industry more reluctant to adopt this type of measures.

In order to achieve a minimization of bycatch and reduction of discards, it is also of utmost importance that fishers, as major stakeholders and knowers of fisheries, adopt appropriate measures that best respond to this objective, either by implementing the technical measures referred above or by **finding new fishing techniques** or **changing to more selective fishing gears** that induce lower bycatch/discards levels (Table 7.1). To make them realize that they can benefit from the adoption of new improvements and measures, and feel encouraged to, i.e. to perceive that the cost involved in the technical modifications will compensate their profit in a long-term, a **incentive-based system**, whether economic and/or social, (Table 7.1) is also a vital measure to be considered. Some possible incentives could be given to those fishers who are receptive to the use of more selective fishing gears generating lower bycatches, such as granting of fishing permits to the best fishing grounds and/or

[9] See Suuronen and Sardà, 2007 for a comprehensive review on this subject.

extended seasons (e.g. in Norwegian shrimp fisheries), extra fishing days (e.g. in English *Nephrops* fishery), higher catch limits/extra quotas, economic subsidies (e.g. loans or grants) for initial costs associated to technological modifications of fishing gear and installation of BRDs, and lower taxes/fees on investment. A system of individual penalty (or '*individual shame'*), where the worst performing fishers in terms of bycatches are placed on a list, is also considered a clear incentive. One example of this system is the 'dirty dozen' list used in some Alaskan fisheries where being on the list is an incentive for fishers to improve their fishing behavior. However, to be effective, these or any other incentives should not be exclusive to a single fishery, but rather applied to all fisheries targeting the same stocks, because fishermen need to have confidence that resulting measures are fair.

The minimization of bycatch and reduction of discards can also be achieved effectively by **spatial and/or temporal fisheries closures**, either on a permanent or on a temporary basis (Table 7.1), banning or limiting fishing to all or selected fishing gears where and when there are relatively high levels of bycatch and high concentrations of juvenile undersized fish. Besides helping in the reduction of gear impacts on the habitat, fisheries closures can also be used to reduce fishing intensity, and consequently fishing mortality, on not only unwanted or less valuable bycatch species and on target species, but also on immature and spawning aggregations, therefore protecting nursery areas and spawning grounds. Likewise, the rare, endangered, threatened and/or protected species populations can also benefit from the fisheries closures. Temporary, and in real-time closures, adapted to occurrences of high/low bycatches (e.g. exchanging fishing grounds when encountering significant bycatch levels), are thought to be more useful and effective than permanent closures. However, a problem with the fishery closures is that at the boundaries or adjacent areas of the closures or in periods outside the closure, the fishing effort may increase, adversely influencing the desired effect. The identification and establishment of where and when fishing should be closed to the use of all or certain less selective fishing gears, should be carried out without significantly compromising the retained catch to the point of making the fishery economically viable.

Although the current lack of detailed information on the stock distribution in their habitats, spawning seasons and biological condition of fish, allied to the spatio-temporal variability in the population structure, hampers the identification of such closures, making the limitation of these areas/periods difficult to implement (e.g. Hall and Mainprize, 2005; Kennelly, 1997; Walker, 2005), the access to fishing grounds that otherwise should be closed due to excessive bycatches (as happens e.g. in Irish Sea *Nephrops* fisheries and in the

Norwegian roundfish fishery), along with thorough analysis of bycatch records, is considered an effective incentive for the development and use of selective devices (BRDs) in trawl fishing nets. As it has been widely accepted by fishermen, this could be a promising approach to minimize bycatch and reduce discards in other fisheries, but always taking into account the nature of those fisheries.

Another alternative to minimize bycatch and reduce discards includes a thoroughgoing **utilization of bycatch** (Table 7.1) by making it a harvested resource instead of a wasted discard. The development of new economically viable local markets for bycatch species that are currently discarded, the commercialization of certain bycatch species to countries which developed a market for these species (e.g. sardines discarded by Italian fisheries could be exported to supply Spanish markets), the use of bycatch species with low commercial value for animal feed and aquaculture (e.g. fishmeal and fish wafers), and the development of products either for human consumption (e.g. frozen, smoked and/or salted and dried fish; minced fish and canned products, *inter alia*) or for application in cosmetic (e.g. collagen to skin treatments), pharmaceutical (e.g. fish oil) and biomedical (e.g. bacteriological peptone to produce antibiotics and vaccines; chitosan to treat obesity, cholesterol and kidneys, blood and dental diseases; hyaluronic acid with anti-inflammatory properties) industries, are possible ways by which discarded waste can be transformed into exploitable catch, thereby contributing to a more rational use of marine resources. Although not considered by many as the most satisfactory measure to use the resources (Hall *et al.*, 2000), the utilization of discards has proven to be an extremely effective measure to reduce bycatch in many African and Asian (e.g. India) fisheries generating significant economic and social revenues to the populations[10]. However, one of the main problems that could arise from this measure is that fishermen can increase fishing effort on the bycatch species with potential future market value. Overcoming this situation (e.g. not allowing the market value of bycatch species to be very high) and the costs involved in the technical improvements necessary to the transportation, preservation and/or processing of bycatch species to be used, as well as in the investments needed to promote the sale of new fishes and/or products, the utilization of bycatch could be indeed a great improvement to minimize the impacts of discards.

[10] Kumar and Deepthi (2006), Lobo *et al.* (2010) and Raffi (2011)'s articles are good reviews on this subject.

Table 7.1 – Measures to minimize bycatch and reduce discards[11].

TECHNICAL MEASURES	
IMPROVE SELECTIVITY OF FISHING GEAR	**Fishing gear modifications / changes of gear design**[1,2,4,7-10,14-17,19,20,24,28] e.g. changes in mesh configuration, fishing gear dimensions and codend mesh sizes, in trawls; changes in hook size, in longlines.
	Development and instalation of selectivity devices (Bycatch Reduction Devices, BRD´s)[1,2,4-10,14-22,28,29] **to improve:** **Size-Selectivity –** e.g. Codend Mesh Size, Square-Mesh Codends, Square-meshed Panels (SMPs), Turned Mesh Codend (T-90), Selection Panels and Escape Windows (e.g. Square mesh panels, Bacoma panel, Danish/Swedish exit windows), (Rigid) Size Sorting Grids, for active gears. **Species-Selection** – e.g. Nordmøre Grid, Modified Nordmøre Grids and Other Excluding Grids, Selective Ring Device, Horizontal Separator Panel, Inclined Separator Panel, Sieve Net, Set-back Headline (Cut-Away-Trawl), Large Mesh Top Panel Net, Selective Ground-gear modification, Benthic Release Panels, Electric Stimuli, for active gears.
CHANGE FISHING METHODS / PRACTICES [4-6,8-9,13]	e.g. handling and release practices, changing the time of day of fishing operations, the immersion time of nets, the fishing depth.
BANNING FISHING GEARS/METHODS [5-7]	**Non-selective fishing gears**, that induce the highest bycatch/discards levels (e.g. beam trawl and single trawl)
IMPROVING DETECTION TECHNIQUES [4,7,9]	**Identify shoal composition (target/bycatch species) before its capture** Geoglobal Positioning Systems (GPS) Automated image analysis (e.g., Geographic Information Systems, GIS).
USE OF ALTERNATIVE FISHING GEARS	**More selective fishing gears**[4-6,8,14,32] e.g. gillnets, trammel nets, longlines, fixed gears.
SPATIAL/TEMPORAL CLOSURES [1,2,4-7,9-10,18,21,26,28-30]	**Permanent** **Temporary**

[11]Compiled from: [1]Crean and Symes (1994), [2]FAO (1996), [3]Clucas (1997), [4]FAO (2011b), [5]Hall (1996), [6]Hall *et al.* (2000), [7]Elliston *et al.*, (2005), [8]Hall and Mainprize (2005), [9]Walker (2005), [10]Catchpole *et al.* (2006), [11]Branch *et al.* (2006), [12]Kilimnik *et al.* (n/d), [13]Kumar and Deepthi (2006), [14]Broadhurst *et al.* (2007), [15]Suuronen and Sardà (2007), [16]Campbell and Cornwell (2008), [17]Catchpole and Revill (2008), [18]Fuller *et al.* (2008), [19]Macher *et al.* (2008), [20]Matsuoka (2008), [21]Anon. (2009b), [22]Enever *et al.* (2009), [23]Alonso *et al.* (2010), [24]Catchpole and Gray (2010), [25]Lobo *et al.* (2010), [26]Dunn *et al.* (2011), [27]Raffi (2011), [28]Gilman *et al.* (2012), [29]Johnsen and Eliasen (2011), [30]Harrington *et al.* (2005), [31]Zhou (2008), [32]Jenkins and Garrison (2013).

Table 7.1 (cont.) – Measures to minimize bycatch and reduce discards[11].

REGULATORY MEASURES	
INPUT CONTROLS	**Limit fishing effort or overall capacity**[1,2,5-6,8-10,16,19,21,28-30] e.g. reduction of vessels number, decommissioning grants, limits on trips, fishing days, tow duration.
OUTPUT CONTROLS[1] (to limit catch)	**Size restrictions**[2,7,9-10,21,28] e.g. increasing Minimum Landing Size (MLS)
	Limits and/or quotas on allowable bycatches[4-6,9,18,19,28,30] e.g. Maximum Acceptable Bycatch (MAB), limits on the bycatch:target catch proportion, trip limits.
	Transfers of quotas[2,7,9,11] e.g. Individual Transferable Quotas (ITQs)
	Ban on discards[1-4,8,10,21,28,29]
UTILIZATION OF BYCATCH[4,10]	**Human consumption**[2,3,5,8-9,13,23,25,27] e.g. frozen fish, salted and dried fish, fish paste, fish sausages, fish jam, fish noodles, fish pickles, fish spirals, fish pappads, surimi, fish protein concentrate, fish gelatine, canned and breaded products, etc.
	New potential uses[2,3,5,12,13,20,23,25,27] for aquaculture (e.g. fishmeal and fish wafers) and cosmetics (e.g. collagen, bioactive compounds), pharmaceutical (e.g. fish oil, chondroitin sulphate) and biomedical (e.g. hyaluronic acid, bacteriological peptone, chitosan, chitin) industries.
	New markets[3,5,8,10,13,25,27]
	Fish trade[13,25,27]
SOCIO-ECONOMIC MEASURES	
INCENTIVES TO FISHERS	**Compensation mechanisms to encourage technological development and according to the fishers performance (lowest/highest bycatches)**[2,4,11,32] Access to or restrictions to fishing opportunities[5,10,24] Positive (rewarding) *vs.* negative (penality) system[5-8,10,24,28,32] Economic (e.g. fundings, subsidies, lower taxes)[4-6,10,24,28]

The perception and the non-acceptance of the currently high levels of discards in European fisheries by the European Commission, allied to the increasing awareness of the negative impacts that the practice of discarding exerts on fish stocks and in the marine ecosystem, made the European Community prepare in 2007 a policy proposal which addresses the problem of bycatch and discards as a matter of priority, establishing the procedures to be taken in order to reduce unwanted bycatch and eliminate discards in European fisheries (CEC, 2007a,b). The instruments of this policy proposal includes the introduction of a **discard ban** as a regulatory measure (Table 7.1) with a combination of several other measures to mitigate bycatch, such as the improvement in the selectivity of fishing gear, real-time closures in areas of high bycatches, flexibility and transferability in the use of quotas, obligation to move to other fishing grounds when significant bycatch levels are encountered, imposition on fees on unwanted bycatches and/or their expropriation, introduction of preferential access to fisheries granted on the basis of low bycatch track records, alternative utilization of bycatches of low or no commercial value with the possible creation of new markets of previously discarded species and the implementation of information systems that allow fleets to identify a priori where the bycatch risk is lowest.

The inclusion of a discards ban, in the latest Proposal for a Regulation of the European Parliament and of the Council on the Common Fisheries Policy (CFP)[12], where all individuals of commercial stocks that are caught will have to be landed (citing *Article 15* paragraph 1*:* "*All catches of species which are subject to catch limits (…) shall be brought and retained on board the fishing vessels (…)*"), thought as an incentive to improve the selectivity of the fisheries, to decrease the capture of potential discards and to avoid food waste (EC, 2011a), constitutes one of the most emblematic and demanding proposals in terms of implementation, within the scope of the CFP reform. After some years of debates (Borges (2013) provided an excellent review article on evolution of the European Union's discard policy), the reforms to the new European CFP were finally agreed on December 11, 2013 and applicable from 1st January 2014 (EU, 2013). The new regulation of the CFP contemplates the introduction of a mandatory discard ban (referred to as '*landing obligation*') limited to species that are subject to catch limits (i.e. species under TACs and/or minimum sizes) (Article 15(1)), which will be gradually introduced on a fishery-by-fishery basis (Art. 2) and with specific start dates for each fishery (pelagic species in 2015, most valuable demersal species in 2016 and other species in 2019) (Art. 15(1a)), with the main purpose to allow fishermen to adapt to the change. These catches will be counted against the quotas of the target species (Art. 15(1)), which can be transferred between Member States according to a certain percentage (Art. 15(8,9)), and the complete phase out of discarding is planned for 2019 (Art. 15(1c,1d)). The EU Regulation also addresses the issue of the utilization of the catches of regulated species under minimum conservation reference sizes, but only for purposes that do not involve human

[12] A comprehensive review on this subject can be found in STECF (2013b).

consumption (Art. 15(11)), and also considers improvement of the selectivity of fishing gears in order to avoid and reduce bycatch (Art. 7 1(d)) and the possibility of granting increasing fishing opportunities (Art. 16(2)) as priorities. Derogations from this legislation (Art. 15(4) onwards), shall apply to those regulated species for which it is demonstrated there are high survival rates after capture and when released into the sea[13] (regarding this point, more studies on survival in different fisheries need to be carried out), as well as on those (non-commercial) species not considered subject to the 'landing obligation' and under the minimum conservation reference size, which must be now discarded at sea (Art. 15(5)). Although not excluding the full consultation of the document (Annex XX), an extract of the most recent EU Regulation on the CFP, pertaining to bycatch minimization measures and ban on discarding, is presented in Table 7.2.

[13] A complete review of survival rates of discards, for species for which a landing obligation has been proposed, can be found in Santurtún *et al.* (2014).

Table 7.2 – Extract of the most recent EU Regulation of the European Parliament and of the Council on the Common Fishery Policy (EU, 2013).

REGULATION (EU) No 1380/2013
OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL

of 11 December 2013

on the Common Fisheries Policy, amending Council Regulations (EC) No 1954/2003 and (EC) No 1224/2009 and repealing Council Regulations (EC) No 2371/2002, (EC) No 639/2004 and Council Decision (EC) No 2004/585

THE EUROPEAN PARLIAMENT AND THE COUNCIL OF THE EUROPEAN UNION,

Having regard to the Treaty on the Functioning of the European Union, and in particular Article 43(2) thereof,

Having regard to the proposal from the European Commission, (…)

Whereas:

(…)

(13) An ecosystem-based approach to fisheries management needs to be implemented, environmental impacts of fishing activities should be limited and unwanted catches should be avoided and reduced as far as possible.

(26) Measures are needed to reduce the current high levels of unwanted catches and to gradually eliminate discards. Unwanted catches and discards constitute a substantial waste and negatively affect the sustainable exploitation of marine biological resources and marine ecosystems and the financial viability of fisheries. An obligation to land all catches ("the landing obligation") of species which are subject to catch limits and, in the Mediterranean Sea, also catches of species which are subject to minimum sizes, made during fishing activities in Union waters or by Union fishing vessels should be established and gradually implemented and rules that have so far obliged fishermen to discard should be repealed.

(27) The landing obligation should be introduced on a fishery-by-fishery basis. Fishermen should be allowed to continue discarding species which, according to the best available scientific advice, have a high survival rate when released into the sea.

(28) In order to make the landing obligation workable and to mitigate the effect of varying yearly catch compositions, Member States should be allowed to transfer quotas between years, up to a certain percentage.

(29) In the management of the landing obligation, it is necessary that Member States do their utmost to reduce unwanted catches. To this end, improvements of selective fishing techniques to avoid and reduce, as far as possible, unwanted catches must have high priority. It is important for Member States to distribute quotas between vessels in a mix that reflects as far as possible the expected composition of species in the fisheries. In the event of a mismatch between available quotas and actual fishing pattern, Member States should consider adjustments through quota swaps with other Member States, including on a permanent basis. Member States should also consider facilitating the pooling by vessel owners of individual quotas, for example at the level of producer organisations or groups of vessel owners. Ultimately, Member States should consider counting by-catch species against the quota of the target species, depending on the conservation status of the by-catch species.

(30) The destination of landings of catches of fish under the minimum conservation reference size should be limited and should exclude sale for human consumption.

Table 7.2 (cont.) – Extract of the most recent EU Regulation of the European Parliament and of the Council on the Common Fishery Policy (EU, 2013).

(31) In order to cater for unwanted catches that are unavoidable even when all the measures for their reduction are applied, certain *de minimis* exemptions from the landing obligation should be established for the fisheries to which the landing obligation applies, primarily through multiannual plans.

(32) Subject to scientific advice and without jeopardising the objectives of maximum sustainable yield or increasing fishing mortality, where the landing obligation, including the obligation to document catches, applies, an increase of related fishing opportunities should be possible, in order to take into account the fact that fish previously discarded will be landed. (…)

HAVE ADOPTED THIS REGULATION:

PART I GENERAL PROVISIONS

(…)

Article 2 - Objectives

(…)
5. The CFP shall, in particular:

(a) gradually eliminate discards, on a case-by-case basis, taking into account the best available scientific advice, by avoiding and reducing, as far as possible, unwanted catches, and by gradually ensuring that catches are landed;

(b) where necessary, make the best use of unwanted catches, without creating a market for such of those catches that are below the minimum conservation reference size;
(…)

PART III MEASURES FOR THE CONSERVATION AND SUSTAINABLE EXPLOITATION OF MARINE BIOLOGICAL RESOURCES
TITLE I CONSERVATION MEASURES

(…)

Article 7 - Types of conservation measures

1. Measures for the conservation and sustainable exploitation of marine biological resources may include, *inter alia*, the following: (…)

(d) incentives, including those of an economic nature, such as fishing opportunities, to promote fishing methods that contribute to more selective fishing, to the avoidance and reduction, as far as possible, of unwanted catches, and to fishing with low impact on the marine ecosystem and fishery resources; (…)

(j) technical measures as referred to in paragraph 2.

2. Technical measures may include, *inter alia*, the following: (…)

(b) specifications on the construction of fishing gear, including:

(ii) modifications or additional devices to reduce the incidental capture of endangered, threatened and protected species, as well as to reduce other unwanted catches;

(c) limitations or prohibitions on the use of certain fishing gears, and on fishing activities, in certain areas or periods; (…)

Table 7.2 (cont.) – Extract of the most recent EU Regulation of the European Parliament and of the Council on the Common Fishery Policy (EU, 2013).

(d) requirements for fishing vessels to cease operating in a defined area for a defined minimum period in order to protect temporary aggregations of endangered species, spawning fish, fish below minimum conservation reference size, and other vulnerable marine resources;

(e) specific measures to minimise the negative impact of fishing activities on marine biodiversity and marine ecosystems, including measures to avoid and reduce, as far as possible, unwanted catches.

TITLE II SPECIFIC MEASURES

(…)

Article 10 - Content of multiannual plans

1. As appropriate and without prejudice to the respective competences under the Treaty, a multiannual plan shall include: (…)

(f) objectives for conservation and technical measures to be taken in order to achieve the targets set out in Article 15, and measures designed to avoid and reduce, as far as possible, unwanted catches; (…)

2. A multiannual plan may also include:

(a) other conservation measures, in particular measures to gradually eliminate discards, taking into account the best available scientific advice, or to minimise the negative impact of fishing on the ecosystem, to be further specified, where appropriate, in accordance with Article 18; (…)

(…)

Article 14 - Avoidance and minimisation of unwanted catches

1. In order to facilitate the introduction of the obligation to land all catches in the respective fishery in accordance with Article 15 ("the landing obligation"), Member States may conduct pilot projects, based on the best available scientific advice and taking into account the opinions of the relevant Advisory Councils, with the aim of fully exploring all practicable methods for the avoidance, minimisation and elimination of unwanted catches in a fishery.

2. Member States may produce a "discard atlas" showing the level of discards in each of the fisheries which are covered by Article 15(1).

Article 15 - Landing obligation

1. All catches of species which are subject to catch limits and, in the Mediterranean, also catches of species which are subject to minimum sizes as defined in Annex III to Regulation (EC) No 1967/2006, caught during fishing activities in Union waters or by Union fishing vessels outside Union waters in waters not subject to third countries' sovereignty or jurisdiction, in the fisheries and geographical areas listed below shall be brought and retained on board the fishing vessels, recorded, landed and counted against the quotas where applicable, except when used as live bait, in accordance with the following time-frames:

(a) From 1 January 2015 at the latest:
– small pelagic fisheries (i.e. fisheries for mackerel, herring, horse mackerel, blue whiting, boarfish, anchovy, argentine, sardine, sprat);
– large pelagic fisheries (i.e. fisheries for bluefin tuna, swordfish, albacore tuna, bigeye tuna, blue and white marlin);

Table 7.2 (cont.) – Extract of the most recent EU Regulation of the European Parliament and of the Council on the Common Fishery Policy (EU, 2013).

– fisheries for industrial purposes (inter alia, fisheries for capelin, sandeel and Norwegian pout);
– fisheries for salmon in the Baltic Sea.

(b) From 1 January 2015 at the latest for species which define the fisheries and from 1 January 2017 at the latest for all other species in fisheries in Union waters of the Baltic Sea for species subject to catch limits other than those covered by point (a).

(c) From 1 January 2016 at the latest for the species which define the fisheries and from 1 January 2019 at the latest for all other species in:

(i) the North Sea
– fisheries for cod, haddock, whiting, saithe;
– fisheries for Norway lobster;
– fisheries for common sole and plaice;
– fisheries for hake;
– fisheries for Northern prawn;

(ii) North Western waters
– fisheries for cod, haddock, whiting, saithe;
– fisheries for Norway lobster;
– fisheries for common sole and plaice;

– fisheries for hake;

(iii) South Western waters
– fisheries for Norway lobster;
– fisheries for common sole and plaice;
– fisheries for hake;

(iv) other fisheries for species subject to catch limits.

(d) From 1 January 2017 at the latest for species which define the fisheries and from 1 January 2019 at the latest for all other species in fisheries not covered by point (a) in the Mediterranean, in the Black Sea and in all other Union waters and in non-Union waters not subject to third countries' sovereignty or jurisdiction. (…)

4. The landing obligation referred to in paragraph 1 shall not apply to:

(a) species in respect of which fishing is prohibited and which are identified as such in a Union legal act adopted in the area of the CFP;

(b) species for which scientific evidence demonstrates high survival rates, taking into account the characteristics of the gear, of the fishing practices and of the ecosystem;

(c) catches falling under *de minimis* exemptions.

5. Details of the implementation of the landing obligation referred to in paragraph 1 shall be specified in multiannual plans referred to in Articles 9 and 10 and, where relevant, further specified in accordance with Article 18, including:

(a) specific provisions regarding fisheries or species covered by the landing obligation referred to in paragraph 1;

Table 7.2 (cont.) – Extract of the most recent EU Regulation of the European Parliament and of the Council on the Common Fishery Policy (EU, 2013).

(b) the specification of exemptions to the landing obligation of species referred to in point (b) of paragraph 2;

(c) provisions for *de minimis* exemptions of up to 5 % of total annual catches of all species subject to the landing obligation referred to in paragraph 1. The *de minimis* exemption shall apply in the following cases:

(i) where scientific evidence indicates that increases in selectivity are very difficult to achieve; or
(ii) to avoid disproportionate costs of handling unwanted catches, for those fishing gears where unwanted catches per fishing gear do not represent more than a certain percentage, to be established in a plan, of total annual catch of that gear.

Catches under the provisions referred to in this point shall not be counted against the relevant quotas; however, all such catches shall be fully recorded.

For a transitional period of four years, the percentage of the total annual catches referred to in this point shall increase:

(i) by two percentage points in the first two years of application of the landing obligation; and

(ii) by one percentage point in the subsequent two years;

(d) provisions on documentation of catches;

(e) where appropriate, the fixing of minimum conservation reference sizes in accordance with paragraph 10. (…)

8. By way of derogation from the obligation to count catches against the relevant quotas in accordance with paragraph 1, catches of species that are subject to the landing obligation and that are caught in excess of quotas of the stocks in question, or catches of species in respect of which the Member State has no quota, may be deducted from the quota of the target species provided that they do not exceed 9 % of the quota of the target species. This provision shall only apply where the stock of the non-target species is within safe biological limits.

9. For stocks subject to the landing obligation, Member States may use a year-to-year flexibility of up to 10 % of their permitted landings. For this purpose, a Member State may allow landing of additional quantities of the stock that is subject to the landing obligation provided that such quantities do not exceed 10 % of the quota allocated to that Member State. Article 105 of Regulation (EC) No 1224/2009 shall apply. (…)

11. For the species subject to the landing obligation as specified in paragraph 1, the use of catches of species below the minimum conservation reference size shall be restricted to purposes other than direct human consumption, including fish meal, fish oil, pet food, food additives, pharmaceuticals and cosmetics.

12. For species that are not subject to the landing obligation as specified in paragraph 1, the catches of species below the minimum conservation reference size shall not be retained on board, but shall be returned immediately to the sea.

13. For the purpose of monitoring compliance with the landing obligation, Member States shall ensure detailed and accurate documentation of all fishing trips and adequate capacity and

Table 7.2 (cont.) – Extract of the most recent EU Regulation of the European Parliament and of the Council on the Common Fishery Policy (EU, 2013).

means, such as observers, closed-circuit television (CCTV) and others. In doing so, Member States shall respect the principle of efficiency and proportionality.

(…)

Article 16 - Fishing opportunities

(…)

2. When the landing obligation in respect of a fish stock is introduced, fishing opportunities shall be fixed taking into account the change from fixing fishing opportunities that reflect landings to fixing fishing opportunities that reflect catches, on the basis of the fact that, for the first and subsequent years, discarding of that stock will no longer be allowed.

(…)

PART XIII FINAL PROVISIONS

(…)

Article 51 - Entry into force

This Regulation shall enter into force on the day following that of its publication in the *Official Journal of the European Union*.

It shall apply from 1 January 2014.

This Regulation shall be binding in its entirety and directly applicable in all Member States.

Done at Strasbourg, 11 December 2013.

Although chondrichthyan fisheries give only a relatively small contribution to the overall fisheries production (0.8% in 2010) and in spite of the decrease in their catches worldwide (from 847,982 t in 2004 to 738,924 t in 2010) (FAO, 2012), the **bycatch of elasmobranchs** (sharks and rays), and consequently the discards, has also been gaining a high and increasingly concern at an international level. Elasmobranchs bycatch accounts for a significant part (e.g. ~50% in large-scale high-sea longline and driftnet fisheries) of the total elasmobranch reported world landings (Bonfil, 2002; Fowler *et al.*, 2002; Worm *et al.*, 2013), but it is expected to be much higher if the elasmobranchs caught as bycatch in other fisheries directed at more productive and highly valued teleost species, which are unknown and never documented in the official statistics of world fisheries (Anon., 2007; Bonfil, 2002; Compagno and Musick, 2005; Fowler *et al.*, 2002; Walker, 2002), could be included.

The most recent information on the current status of shark populations found in the literature is provided by Worm *et al.* (2013). These authors gathered all the information available up to now (1961-2011) on global shark reported landings, illegal, unregulated and unreported (IUU) landings and shark finning and, together with their own and first worldwide estimates of shark discards, have reached to a global shark catch and mortality estimate of

1.412 million tons in 2010 (*vs.* 1.445 Mt in 2000) which, converted into number of sharks, gives an estimate of between 97 to 267 million individuals in 2010 (*vs.* 69 to 100 million in 2000). Despite the uncertainty of data, which is mentioned by the authors, who also advised care in interpretation of their calculations, a conservative value of 1.135 Mt of sharks discarded has been estimated for the year 2000. Albeit uncertain, this estimate illustrates the magnitude of the discards problem and by itself clearly justifies the rising concern that falls on this particular group of species. The elasmobranch K-selected life-history characteristics, among which the particular reproductive strategies (e.g. long gestation periods, low fecundity and late age at maturity), renders them far more vulnerable to fishing pressure compared to most r-selected, prolific, bony fishes, and makes recovery after major declines in their populations difficult (Bonfil, 1994, 2002; Bradley and Gaines, 2014; Stevens *et al.*, 2005; Fowler *et al.*, 2002; Musick, 2005; Myers and Worm, 2005; Stevens *et al.*, 2000, 2005). This is further aggravated in deepwater chondrichthyans as their reproductive potential is even lower (e.g. slower growth and reproductive rates, higher age at maturity) than most other coastal and pelagic shallow-water elasmobranch species (Compagno and Musick, 2005; Fowler *et al.*, 2002; García *et al.*, 2008; Stevens *et al.*, 2005; Walker, 2002).

As shown in chapters 2 and 3 of this study, the cartilaginous fishes contribute to the existing high biodiversity in coastal waters off southern Portugal and are an important component of commercial bycatches and discards of the trawl fisheries, of which *Galeus melastomus* (blackmouth catshark) in crustacean trawls, and *Scyliorhinus canicula* (small-spotted catshark) in fish trawls, are the deepwater shark species that stand out most. Considering the low reproductive potential of the elasmobranchs and the limited, or even inexistent, reproductive biological studies for most of these species in Portugal, the reproductive biology of the deepwater shark *G. Melastomus*, the second fish species most discarded in biomass by trawlers fishing for crustaceans, was investigated. Addressed in chapter 4, it was found that:

☑ The sex ratio of *G. melastomus* does not vary throughout the year and there appears to be a sexual segregation for the stock within the studied area;

☑ This species presents a sexual dimorphism by size, with females growing larger than males and reaching first maturity at larger sizes than males;

☑ An extended breeding season with eggs developing throughout the year, and with two reproductive activity peaks during winter and summer, is suggested for this species;

☑ In this region of the Atlantic, blackmouth catsharks attain greater maximum total lengths, reach first sexual maturity at larger sizes and produce larger egg capsules, compared to those reported for the Mediterranean;

☑ Morphometric measurements of the left clasper and testis of males, and the oviducal glands of females, were suitable for determining sexual maturity of blackmouth catsharks; females uterus width is not a good potential indicator of maturity, but the ovary is considered to be the best reproductive organ to define maturity stages of females;

☑ The lack of larger specimens, mostly females in the last reproductive stages, could be either a characteristic of the local population or a tendency of larger specimens to be found at even deeper waters.

☑ The population of *G. melastomus* was found to consist mostly of young individuals, and the non-selectivity of the crustacean trawl gear and/or the overfishing effects at bathyal depths, are pointed out as possible reasons;

☑ Only small proportions of individuals greater than 38 cm TL are marketed but, considering that length at which this species attains first sexual maturity is far greater, a minimum legal landing size should be considered and established, for this and other deepwater elasmobranch species.

The knowledge of the reproductive biology of a species is a fundamental key in the stock assessments and management of any fishery (Holden and Raitt, 1974; Cailliet *et al.*, 2005; Lowerre-Barbieri, 2009; Morgan, 2008). Reproductive parameters, such as sex ratio, fecundity, age and size at sexual maturity and spawning time and location, can be used to determine the size, recruitment and the reproductive potential of a stock, to assess the optimum age of first capture of a species and the time and grounds of spawning (Holden and Raitt, 1974; Morgan, 2008). This kind of information is extremely useful to fishery managers to the extent that it enables them to make important decisions in the management of the stocks. Changing the fishing practice, delineating new fishing strategies, proposing fishing temporal/area closures, or restricting specific fishing gears or even fishing of stocks in which recruitment is compromised (Holden and Raitt, 1974; Morgan, 2008), are some of the examples of the decisions that can be taken.

The incorporation of the biological reproductive parameters into fisheries management has been applied to stocks of the most commercially valuable teleosts (Cailliet *et al.*, 2005). In contrast, the elasmobranch fisheries are, in general, largely unmanaged and unregulated (Fowler *et al.*, 2002; Pawson and Vince, 1999; Stevens *et al.*, 2005). In effect, the lack of data pertaining to both (reproductive) biological aspects and catch components (landings, bycatch and discards) and of information on the size and distribution of the stocks, coupled with the small numbers of species targeted and the lack or low market value of most of the elasmobranchs, makes it impossible to manage this group of species in an accurate and efficient way (Fowler and Cavanagh, 2005; Pawson and Vince, 1999; Stevens *et al.*, 2005; Walker, 2005). Regarding the specific life-history characteristics and reproductive strategies of the elasmobranchs and the lack of adequate data, a more rigorous and specialized management of this group is nevertheless, required to ensure the sustainability of their stocks (Anderson and Teshima, 1990; Bonfil, 1994; Cailliet *et al.*, 2005; Camhi *et al.*, 1998; Musick *et al.*, 2000; Stevens *et al.*, 2005). In this context, particular attention should be given to the elasmobranchs caught as by-catch and discarded in multispecies trawl fisheries since this type of fishery has been responsible for the reduction of many demersal elasmobranch stocks (e.g. Squaliformes, batoids) (Musick *et al.*, 2000; Walker, 2005).

Basic biological information (e.g. age and growth, size composition, distribution and habitat, ecology, length by maturity stage, *inter alia*) is still considered insufficient or missing for most elasmobranch, especially with regards to deepwater species (Cailliet *et al.*, 2005; Ellis *et al.*, 2008; Fowler and Cavanagh, 2005; Hoff and Musick, 1990; Martin and Treberg, 2002; Stobutzki *et al.*, 2002). It is therefore of utmost importance to carry out studies on the biology of these species (Ellis *et al.*, 2008; Jones *et al.*, 2008) and improve research and monitoring on the elasmobranchs bycatch (Cavanagh and Claudine, 2007) in order to not only properly assess the status of stock condition and make a rational management of the elasmobranchs populations, but also for the conservation management of this vulnerable group of fishes.

From the aforementioned, the reproductive biology information provided in this particular study (chapter 4) is considered to be a valuable contribution both to the management and conservation of the *G. melastomus* population off the southern coast of Portugal. However, further detailed and demanding research on relevant biological and other life-history characteristics of this species, as well as on other equally important deepwater elasmobranch species, are compulsory.

The life-history traits of elasmobranchs is also reflected in the degree of extinction risk of their species, which is higher than that of teleosts and other vertebrates (Dulvy *et. al.*, 2000, 2014; Field *et al.*, 2009; García *et al.*, 2008; Hutchings *et al.*, 2012). Maximum reproductive rates and particularly age at maturity are considered excellent indicators of the extinction risk

(Hutchings *et al.*, 2012; Myers and Worm, 2005), and the reproduction mode of the elasmobranchs is considered by García *et al.* (2008) as a crucial factor of this risk, asserting that it increases according to the complexity and specialization of the reproductive organs (i.e. lowest in oviparous, increased in yolk-sac viviparous and highest in aplacental viviparous species).

This subject leads us to chapter 6 where reference is made to the hermaphroditism cases recorded in the deepwater velvet belly shark, *Etmopterus spinax*, discarded by the crustacean trawl métier. From this study it was found that:

☑ Hermaphroditism was observed in three specimens, representing around 0.5% of the studied sample, in which the presence of claspers and a normal and complete female reproductive system allowed us to state that they are abnormal or pseudo-hermaphrodite sharks;

☑ These are the first cases known to date of hermaphroditism recorded in this species and the second reported in chondrichthyan species in Portuguese waters;

☑ Although normal and abnormal (or pseudo) hermaphroditism was recorded in some of other yolk-sac viviparous (aplacental) shark species, as well as in oviparous and placental viviparous species, hermaphroditism in chondrichthyans is still considered a very rare phenomenon, which let us consider that the low occurrence of velvet belly hermaphroditic specimens emphasizes the rarity of such abnormality;

☑ The causes of hermaphroditism in chondricthyan species still remain difficult to explain but genetic and/or hormonal causes and unfavorable environmental conditions (e.g. radio-activity contamination, other pollutants) are the possible explanations found in the literature.

Although no reference to hermaphroditism as a reproductive feature that makes elasmobranch species prone to an additional increased risk of population extinction was found in the literature, it should be important to study because of the possible implications for conservation of endangered species and populations. The large variations of hermaphroditism cases in different chondrichthyan species reported to date supports the need of further and more detailed studies on this subject.

At the time when the high levels of bycatch and discards, the overexploitation of fish stocks, the ecological impact of fishing (particularly trawlers) on the marine environment, threatening the marine biodiversity and placing some species, particularly sensitive species such as the elasmobranchs, at risk of extinction, are a matter of great concern, leading to an increasing need to ensure the long-term sustainability of marine resources, the discovery of the new pygmy skate species, *Neoraja iberica* n. sp., during this study (Chapter 5) could not be more gratifying. The study of *Neoraja iberica* n. sp., based on a complete and detailed description of 50 specimens, half of which were caught as bycatch and discarded by commercial crustacean trawlers in the southern Portuguese coast and the remaining in Gulf of Cadiz, reveals that the Iberian pygmy skate is a moderately rare species, with a very limited geographic distribution in the upper slope, and it is easily distinguished from four other congeners (*N. stehmanni*, *N. caerulea*, *N. africana* and *N. carolinensis*), both by the external characteristics as by specific internal features of the cranium, scapulocoracoid and clasper skeleton. Its recent discovery could be associated to its very small size (TL max. of 316 mm for females and 327 mm for males) to the extent that it might have been overlooked, discarded at sea or mistaken as juveniles of other commercial skate species of non-marketable size, or because they escape more easily by trawl nets. Its inability to migrate over large distances, as a result of their small size, is pointed out as a reason to the unusually localized, very limited, distribution when compared to other species of skates. The discovery of *N. iberica* n. sp., is of great importance to the extent that is a major contribution not only to the local marine biodiversity of Portuguese waters but also to the global biodiversity.

In conclusion I would like to express that, in spite of the overall potential benefits of the adoption of a discard ban in the European fisheries, and taking into consideration the economic and social complexity inherent in this ‘landing obligation’, care must be taken regarding its implementation. Although the implementation of the discard ban is to be phased-in, in Portugal, this issue is bound to raise additional difficulties due to the multigear and multispecies nature of its fisheries, in contrast to the more single-species fisheries of northern Europe (e.g. Norway, Iceland), by increasing both technical (e.g. lack of space on board, more time spent sorting unwanted catch, increase of the overall number of trips, etc.) and logistic (e.g. onshore management, preparation of land infrastructures to receive discards, increased of fuel consumption and associated costs, etc.) constraints.

The ideal way to address the problem of bycatch and discards is, and paraphrasing Hall *et al.* (2007), by *finding ways to fish "better"*, instead of merely banning the practice of discarding which, although being the most direct way of controlling discards, will not improve the very high current levels of discards generated by European fisheries. Agreeing with Borges and O´Dor (2010), stating "*more important than to forbid is to study ways of mitigating discards*", the best approach to apply in the southern Portuguese multispecies trawl fisheries should be the minimization of the bycatch before implementing a discard ban, primarily centered on the adoption of the technical measures via gear modification and implementation of selectivity devices to increase selectivity of trawl nets, which has been already been carried out in Portuguese coastal waters (referred in Chapters 2 and 3) and have proved to be effective in reducing the amount of bycatch, allowing the escapement of a high percentage of undersized specimens and non-commercial bycatch species, and with minor losses and an increase in quality of target species. However, to compensate more the high short-term losses in the revenue, the combination of these technical measures with other available bycatch mitigation regulatory (e.g. individual quotas/licenses on allowable bycatch, limits on fishing effort, market controls) and socio-economic (e.g. incentives to fishers in the adoption of technical modifications in the gear) measures must be also considered, since the formers are not effective as a single measure (e.g. Macher *et al.*, 2008; Sacchi, 2008; Suuronen and Sardá, 2007; *inter alia*) to reduce discards. Other approaches that can be used in conjunction with the technical measures, in the context of Portuguese trawl fisheries, could be the development of alternative commercial markets for species currently discarded and the exploitation of some systematically discarded species (e.g. longspine snipefish and boarfish), fostering the reutilization of the old but still existing fishmeal and fish oil factories (Chapter 3). In effect, fishing mortality of the concerned fish stocks can only be reduced with a significant reduction in bycatches, therefore contributing to an optimization of the yield of these stocks and to the promotion of the sustainable use of the living resources.

The lack of information and the difficult access and lack of transparency of data on discards resulting from the Data Collection Framework by the Portuguese institution responsible for monitoring and managing fisheries, greatly hampered a more detailed and comparative study on this subject. To comply with the new EU CFP regulated ´landing obligation´ in Portuguese fisheries, it is vital to conduct new long-term studies to enhance and improve the necessary scientific research (e.g. biological and ecological) and technical knowledge, and a close and honest cooperation between all those directly involved in fisheries (from the simple fisherman, represented by the ship-owners, through the fishing industry, scientists, fishery managers, environmental policy-makers and government), always having in regard the hedonistic principle, i.e., promote fishermen's interest in adopting the necessary available measures to minimize bycatch and reduce discards and their compliance with regulations, and by showing them the profits they can obtain (e.g. in the particular case of a 'landing obligation', the costs of such landing need to be lower than the cost of discarding in order to maximize their economic gains). Moreover, there should be an adequate, extensive and well-developed system of scientific and technical monitoring (e.g. self-sampling, regular onboard observer programs, electronic monitoring systems), control (e.g. vessel monitoring systems (VMS)) and surveillance (e.g. closed circuit (CCTV) cameras) of fishing practices that result in discarding, for effective enforcement and compliance to the obligation to land all catches. Irrespective of the measures to be adopted or implemented, a balance between the human needs in a socio-economic context (e.g. in terms of consumption, markets and employability), the state of the marine fishery resources and the ecological impacts on the marine ecosystem must always be sought.

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