Universidade de Lisboa

Faculdade de Ciências

Departamento de Biologia Animal

Environmental Impact and Sustainability of Portuguese Fisheries

Ana Filipa Ribeiro Baeta

Doutoramento em Biologia

Especialidade em Biologia Marinha e Aquacultura

2009

Universidade de Lisboa

Faculdade de Ciências

Departamento de Biologia Animal

Environmental Impact and Sustainability of Portuguese Fisheries

Tese orientada por:

Professora Catedrática Maria José Rosado Costa

Professor Auxiliar com Agregação Henrique Manuel Nogueira Cabral

Ana Filipa Ribeiro Baeta

Doutoramento em Biologia

Especialidade em Biologia Marinha e Aquacultura

2009

Table of contents

Abstract

Assess fishing impacts on marine ecosystem and fisheries sustainability is essential to achieve proper management of the sector and for the conservation of resources and marine ecosystem. The main fishing impacts (bycatch, namely of protected species, discards, and impacts on habitats and on marine trophic web) of seven Portuguese fisheries were assessed. The ecological impact requiring more urgent attention was bycatch, which in some cases led to significant amounts of discards. In particular, it was analyzed the elasmobranchs bycatch in trammel nets fishery, which constituted an important part of the total biomass caught and of the individuals discarded, and the impact of nets loss in the marine environment, which continue to fish for a relatively long periods of time, especially in rocky bottom. We also observed changes in the marine trophic web of Portuguese waters by analysis of the mean trophic level of national landings. The analysis of the sustainability of the national fisheries sector has shown that, in general, it has increased in recent years, although at a higher rate in economic and institutional dimensions than in ecological and social dimensions. The traditional fisheries of the Tagus estuary showed an intermediate sustainability, making clear the need for intervention. The Portuguese fisheries management measures were assessed considering their effects on commercial species, verifying that in general they have not the desired effects and that the current management model should be changed. Marine protected areas have been suggested as a tool for fisheries management. A methodology to assess their effectiveness in the small fisheries sustainability was developed and applied to the marine area of the Natural Park of Arrábida, for which there is only improvements in ecological and management areas.

Key-words: fisheries, impacts, sustainability, management, Portugal.

Resumo

Avaliar os impactos da pesca no ecossistema marinho bem como a sua sustentabilidade é fundamental para uma gestão adequada do sector e para a conservação dos recursos e do ecossistema marinho. Os principais impactos da pesca (capturas acessórias, em particular de espécies protegidas, rejeições, e impactos nos habitats e na teia trófica marinha) foram avaliados em sete pescarias portuguesas, verificando-se que o mais preocupante é a captura de espécies acessórias e as consequentes rejeições. Em particular, foi analisada a captura de elasmobrânquios pelas redes de tresmalho destinadas a outras espécies, constatando-se que constituem uma parcela importante da biomassa capturada e dos individuos rejeitados, e o impacto da perda destas artes no meio marinho, que continuam a pescar por um periodo de tempo relativamente longo, principalmente quando em fundo rochoso. Foram também observadas alterações na teia trófica marinha nas águas portuguesas mediante a análise do nivel trófico médio dos desembarques nacionais. A análise da sustentabilidade do sector das pescas nacional revelou que esta, de um modo geral, aumentou nos últimos anos, embora a uma taxa mais elevada nas dimensões económica e institucional do que nas dimensões ecológica e social. Já as pescarias tradicionais do estuário do Tejo apresentaram uma sustentabilidade intermédia, tornando-se evidente a necessidade de intervenção. As medidas de gestão das pescas portuguesas foram avaliadas considerando os seus efeitos nas espécies comerciais, tendo-se constatado que, de um modo geral, não alcançaram os resultados esperados e que o modelo de gestão actual deve ser alterado. As áreas marinhas protegidas têm sido sugeridas como ferramenta de gestão das pescas, pelo que se desenvolveu uma metodologia para avaliar o sua eficácia na sustentabilidade da pequena pesca. Esta foi aplicada à área marinha do Parque Natural da Arrábida, para a qual apenas se verificaram melhorias a nivel ecológico e de gestão.

Palavras Chave: pescas, impactos, sustentabilidade, gestão, Portugal.

Resumo alargado

Agiu-se durante anos como se os recursos vivos marinhos fossem ilimitados, mas com o aumento do conhecimento científico, o acentuado desenvolvimento das pescarias e o colapso de alguns stocks, percebeu-se que, embora renováveis, os recursos marinhos necessitavam de uma gestão adequada sob pena de comprometer a sua sustentabilidade. Tomou-se também consciência que os impactos da pesca não se limitam às espécies capturadas, mas que devem ser equacionados tendo em conta todo o ecossistema marinho.

Em resposta a esta situação foram feitos numerosos esforços no sentido de melhorar as medidas de conservação, gestão e exploração dos recursos e ecossistemas marinhos. A Política Comum de Pescas (PCP) foi o instrumento desenvolvido pela União Europeia em 1983 no sentido de gerir as pescas e aquacultura nas àguas dos estados membros. Não sendo suficientemente eficaz, foi reformulada em 2002, acentuando-se as preocupações ambientais e de desenvolvimento sustentável.

Sendo Portugal um país de ampla costa marítima, a pesca sempre foi uma actividade de grande importância socio-económica, com caracteristicas muito singulares e diversas. Contudo, tem sofrido grandes alterações nos últimos anos, não havendo muitos estudos que foquem quer os seus impactos no ambiente marinho, quer a sua sustentabilidade.

Assim, um dos objectivos deste trabalho é descrever e avaliar comparativamente os impactos ambientais das pescarias que operam nas águas nacionais, considerando as capturas acessórias e de espécies protegidas, as consequentes rejeições, os impactos no habitat e na teia trófica e o impacto da perda de artes de pesca no mar e, apresentar medidas para minimização dos mesmos, procurando um compromisso entre a actividade e a protecção do ecossistema marinho. O segundo objectivo é avaliar a sustentabilidade da actividade da pesca em Portugal nas suas múltiplas dimensões, tendo em conta as tendências evolutivas, e de um conjunto de pescarias artesanais a operar no estuário do Tejo. O último objectivo é a avaliação da eficácia ao nível ecológico das medidas de gestão das pescas em vigor em Portugal e, em particular, dos resultados sentidos na pequena pesca resultantes da implementação de áreas marinhas protegidas (AMP).

O presente trabalho é constituído por 10 capítulos, 8 deles correspondentes a manuscritos produzidos no decurso da investigação para responder aos objectivos propostos e que se encontram submetidos, em revisão ou já publicados em revistas científicas internacionais. Estes capítulos são precedidos de uma introdução geral (Parte I), e encontram-se agrupados em três secções correspondentes à avaliação dos impactos ambientais das pescas portuguesas (Parte II), à avaliação da sustentabilidade das mesmas pescarias (Parte III) e à análise dos efeitos das medidas de gestão da pesca (Parte IV). A discussão geral dos resultados e principais conclusões são apresentadas no último capítulo (Parte V).

Na introdução geral (Capitulo 1) são abordados os pricipais problemas da pesca, nomeadamente o crescimento desregrado que conduziu ao colapso de inúmeros stocks e os impactos da actividade nos ecossitemas marinhos, a necessidade de um desenvolvimento sustentável do sector e a sua gestão actual. O caso do sector da pescas Português é particularizado e as suas fragilidades evidenciadas.

Para que a gestão das pescas seja eficaz há que se conhecer os aspectos ambientais em risco de se tornarem ecologicamente insustentáveis. Assim, no capitulo 2 foi desenvolvido e utilizado um método semi-quantitativo para avaliar o impacto ambiental das pescarias portuguesas, tendo em conta as capturas acessórias e as rejeições, a captura de espécies protegidas e os impactos na teia trófica e nos habitats marinhos. Sete pescarias, abrangendo diversos tipos de artes, foram analisadas, verificando-se que impacto que precisa de mais atenção é a captura de espécies acessórias, o que em alguns casos conduz a elevadas taxas de rejeição. A captura de espécies protegidas é mais preocupante no palangre de superficie, enquanto que a pesca de arrasto tem o maior impacto nos habitats bentónicos. A falta de dados impediu a avaliação do impacto de cada uma das pescarias na teia trófica. O método permitiu estabelecer prioridades, evidenciando os problemas mais urgentes e as necessidades de pesquisa, pelo que foram sugeridas medidas de minimização dos impactos e directrizes de investigação.

O capítulo 3 é dedicado ao impacto da pesca artesanal com redes de tresmalho nos elasmobrânquios, uma componente importante das capturas acessórias de muitas pescarias em Portugal. Em cerca de 200 km de redes, foram capturadas 11 espécies de elasmobranquios, representando 4% do número total de individuos e 15% da biomassa capturada. As rejeições destas espécies, corresponderem apenas a 7,8% da biomassa das capturas, embora representem 24,8% dos indivíduos. Paralelamente estudaram-se aspectos da ecologia das espécies que podem ser utéis na sua gestão: verificou-se uma sazonalidade na ocorrência das espécies e preferências ao nível da profundidade para as espécies mais abundantes.

A pesca pode alterar a estrutura da teia trófica marinha pela remoção selectica de espécies. No capítulo 4 foram avaliadas as alterações na teia trófica marinha entre 1970 e 2006 com base em estimativas do nível trófico (TL) médio dos desembarques de Portugal continental, Açores e Madeira. Verificou-se que o TLm dos desembarques no continente decresceu, mas nas regiões autónomas aumentou, o que reflecte alterações na estrutura da teia trófica marinha nas águas portuguesas. Verificou-se também que as espécies de TL mais elevado se tornaram mais caras relativamente às espécies de TL mais baixo.

O quinto capítulo foca os impactos negativos da perda de artes de pesca nas comunidades marinhas, um fenómeno designado por “pesca fantasma”. Neste estudo foram fundeadas 10 redes de tresmalho, cinco em fundo arenoso e cinco em fundo rochoso, cuja evolução foi monitorizada em mergulho. Verificou-se que a área de pesca das redes se foi reduzindo gradualmente no fundo rochoso e muito rapidamente no fundo arenoso. Estimou-se que durante os 285 dias de duração da experiência, 541 e 257 individuos tenham sido capturados nas redes em fundo rochoso e arenoso, respectivamente. A eficiência da captura das redes decresceu de forma exponencial negativa, calculando-se que esta seria inferior a 1% em cerca de 10-11 meses nas redes de fundo rochoso e em 8 meses em fundo arenoso.

As pescas sofreram mudanças claras nos últimos anos em Portugal. A fim de descrever e avaliar o desenvolvimento da pesca em Portugal entre 1994 e 2004, no capítulo 6 foi criado um sistema de indicadores, agrupados nas dimensões ecológica, económica, social e institucional, e utilizadas duas metodologias para a sua agregação. Os dois métodos de agregação mostraram um elevado potencial como ferramentas de avaliação de sustentabilidade da pesca, podendo ser utilizados complementarmente e para decidir em que sentido a gestão e a investigação devem ser orientadas, permitindo analisar os resultados dessas alterações. No geral, a sustentabilidade da actividade das pescas em Portugal tem aumentado nos últimos anos, embora a uma taxa inferior nas dimensões ecológica e social, o que sugeri a necessidade de maior atenção nestas duas dimensões.

No capitulo 7 foi avaliada e comparada a sustentabilidade das pescarias mais importantes do estuário do Tejo, as quais têm grande importâcia social. Utilizou-se o método RAPFISH, que se baseia na quantificação de indicadores agrupados em cinco dimensões (ecológica, económica, social, tecnológica e ética), para avaliar a sustentabilidade das pescarias em cada uma das dimensões e numa abordagem interdisciplinar. As pescarias estudadas apresentaram uma sustentibilidade intermédia: os covos para polvo (*Octopus vulgaris*) apresentaram a maior sustentabilidade, seguidos pelas toneiras e piteiras também para cefalópodes. As pescarias com menor sustentabilidade foram as dragas para bivalves e o arrasto de vara. Os resultados obtidos permitiram identificar onde a intervenção é mais necessária a fim de melhorar a sustentabilidade destas pescarias.

No capítulo 8 foram avaliadas as medidas de gestão das pescas portuguesas após a adopção da PCP em 1986, considerando os seus efeitos em espécies exploradas comercialmente e a sua eficácia na prevenção da sua sobrepesca. De um modo geral as medidas de gestão não alcançaram os resultados esperados. Os totais admissíveis de capturas não limitaram as capturas, as quotas individuais de pesca, aplicadas na gestão dos stocks de sardinha e pescada, só funcionaram no primeiro caso, e os limites de captura diários, parecem funcionar, uma vez que apresentam benefícios económicos imediatos. As licenças, quotas individuais de esforço e restrições aplicadas a artes de pesca e embarcações limitam o esforço de pesca, embora tenha sido impossível reconhecer-lhes consequências directas. O efeito das medidas de selectividade foi também difícil de avaliar. Os defesos espácio-temporais parecem ter efeitos positivos para a sardinha e lagostim, mas não para a pescada. Os resultados evidenciaram a necessidade de um melhor sistema de gestão das pescas na Europa, que garanta a sustentabilidade dos recursos marinhos a longo prazo.

As áreas marinhas protegidas (AMP) têm sido amplamente sugeridas como ferramenta de gestão e conservação das pescas. No capítulo 9 foi desenvolvida uma metodologia baseada em indicadores multidimensionais para avaliar o papel das AMP na gestão e sustentabiliade da pequena pesca. A sua aplicação a um caso de estudo português, a área marinha do Parque

Natural da Arrábida, resultou numa classificação mediana, tendo em conta a escala utilizada, da performance da AMP quer nos momentos antes, quer depois da implementação da mesma. Verificou-se que as medidas implementadas nesta AMP melhoraram as dimensões ecológica e de gestão, mas resultaram numa diminuição da performance das dimensões social e económica, o que a manter-se compromete o futuro da MPA.

Finalmente, no capítulo 10 os resultados dos estudos descritos anteriormente são integrados numa discussão geral, destacando-se as conclusões mais importantes e são tecidas considerações finais acerca da sua relevância para o o sector das pescas. Também algumas questões deixadas em aberto são expostas bem como apresentadas possíveis direcções de pesquisa futura.

List of papers

This thesis comprises the papers listed below, each corresponding to a chapter, from 2 to 9:

Baeta, F., Costa, M.J., Cabral, H. (Submitted) An ecological risk assessment method and its use in the management of Portuguese fisheries. ICES Journal of Marine Science.

Baeta, F., Batista, M., Maia, A., Costa, M.J., Cabral, H. (Submitted) Elasmobranch bycatch in trammel nets fisheries in the Portuguese west coast. Fisheries Research.

Baeta, F., Costa, M.J., Cabral, H. 2009. Changes in the trophic level of Portuguese landings and fish market price variation in the last decades. Fisheries Research 97, 216-222.

Baeta, F., Costa, M.J. and Cabral, H. 2009. Trammel nets' ghost fishing off the Portuguese central coast. Fisheries Research 98,33-39.

Baeta, F., Costa, M.J., Cabral, H. (In review) Assessing sustainable development of Portuguese fisheries using two indicator aggregation methods. Fisheries Ecology and Management

Baeta, F., Pinheiro, A., Corte-Real, M., Costa, J.L., Almeida, P.R., Costa, M.J. and Cabral, H., 2005. Are the fisheries in the Tagus estuary sustainable? Fisheries Research 76, 243-251.

Baeta, F., Costa, M.J., Cabral, H. (Submitted) Are we using the appropriate fisheries management measures? The case of Portuguese fisheries. Marine Policy

Batista, M., Baeta, F., Costa, M.J., Cabral, H. (Submitted) MPA as management tools for small scale fisheries: the case study of Arrábida Marine Protected Area (Portugal). Ocean and Coastal Management.

The author of the thesis is first author in seven papers and co-author, with equal contribution to that of the first author, of one paper.

The author of the thesis was responsible for conception and design of the work, field surveys, sample collection and processing, data collection and analysis and manuscript writing of all the papers. Remaining authors collaborated in some or several of these tasks.

All papers published were included with publisher's agreement.

Part I

General introduction

CHAPTER 1

General introduction

Fisheries development
Fisheries impacts
Sustainability
Fisheries management in the European context
Portuguese fisheries
Aims and importance of this study
Structure of the thesis

General introduction

Fisheries development

Fishing is one of the most ancient human activities. Initially this activity simply represented a mean to get food, but rapidly acquired high interest as a commercial activity. Although marine living resources were long considered unlimited, the rise of fisheries as commercial activity and the development of industrial fisheries rapidly demonstrated the opposite.

Fisheries became industrialized in the early 19th century when English fishermen started operating steam trawlers, soon rendered more effective by the use of power winches and, after the First World War, also of diesel engines. The Second World War brought freezer trawlers, radar and acoustic fish finders to the industrialization of fishing (Pauly *et al.*, 2002) and after that the development of fisheries has been dramatic (Caddy and Cochrane, 2001; Watson and Pauly, 2001).

Throughout the 1950 and 1960 decades, the notable increase of global fishing effort led to an increase in catches, encouraging a generation of managers and politicians to believe that more boats would lead to higher catches (Pauly *et al.*, 2002). In the 1960s traditional fishing grounds of the North Atlantic and North Pacific became fully exploited and new fisheries were developed at lower latitudes and in the Southern Hemisphere (Watson and Pauly, 2001).

The first fisheries collapse with global repercussions, namely on global supply and prices of fishmeal, was that of the Peruvian anchoveta (*Engraulis ringens*) in 1971–1972 (Watson and Pauly, 2001). This collapse was considered to have been caused by an El Niño event, however, much of the available data suggests that overfishing was also implicated (Pauly *et al.*, 2002). Attributing the collapse of the Peruvian anchoveta to environmental effects allowed fisheries industry to continue and, by the mid-1970s, the beginning of a decline in total catches from the North Atlantic was observed (Pauly *et al.*, 2002). This decreasing trend aggravated in the late 1980 and early 1990 decades when most cod stocks off New England and eastern Canada collapsed, ending centuries old fishing traditions (Myers *et al.*, 1997).

Despite these collapses, fishing effort continued to expand globally (Garcia and Newton, 1997) and, according to official catch statistics, global catches seemed to continue increasing through the 1990s. This surprising result was recently explained when massive over-reporting of marine fisheries catches by a single country, the People's Republic of China, was uncovered (Watson and Pauly, 2001). A correction to such statistics showed that world fisheries landings have in fact been slowly declining since the late 1980s, at a rate of 0.36 million tonnes year^{-1} since 1988, rather than increasing at a rate of 0.33 million tonnes year^{-1}, as initially suggested by the uncorrected data. According to the latest statistics, marine capture fisheries supplied the world with about 82 million tonnes of fish (FAO, 2009).

Fisheries impacts

In the last decades fisheries effects on the marine ecosystem have been increasingly evident. Marine fisheries impacts on resources and their supporting ecosystems have been acknowledged to be much larger than commonly assumed (Christensen *et al.*, 2003; Jackson *et al.*, 2001; Myers and Worm, 2003), thus providing further support to the explanation of observed catch trends (Pauly *et al*., 2005).

Fisheries impacts on the marine ecosystem may be direct or indirect. Direct effects include fishing mortality exerted on target populations, which may lead to overfishing, fishing mortality affecting non-target populations (bycatch) and physical impacts caused by towed gears on benthic organisms and on the seabed. Indirect effects include impacts mediated by biological interactions, the environmental effects of dumping discards and organic detritus and the mortality caused by lost fishing gear (ghost fishing) (Goñi, 1998).

Effects on target species

The main direct impact of fishing is the reduction of the abundance of target species. However, establishing the links between overexploitation and the size of the targeted populations is not straightforward due to the difficulty in separating natural and fishing-related mortality as well as the lack of stock assessment studies prior to the beginning of exploitation (Goñi, 1998). Also fishing preferentially removes larger and older fish, modifying the size, age and genetic structure of exploited populations and reduce stock spawning potential (Goñi, 1998).

According to the United Nations Food and Agriculture Organization (FAO, 2009) the global state of exploitation of the world marine fishery resources has fluctuated with time, although with some trends in exploitation categories: while the proportion of underexploited or moderately exploited stocks declined linearly from 40% in the mid-1970s to 20% in 2007, the proportion of fully exploited stocks remained stable at about 50% in the same period. The proportion of overexploited, depleted or recovering stocks appears to have stabilized at values between 25% and 30% since the mid-1990s, after the increase observed in the 1970 and 1980 decades.

Effects on non-target species: bycatch

Most fishing methods have low selectivity, resulting in the incidental capture of non-target species or undersized individuals of target species. Many of the species captured unintentionally have little or no economic value and have been given low priority in research efforts, and consequently fishing effects on them remain poorly known (Pope *et al.*, 2000). Since most bycatch is discarded, this source of mortality, which is notable for some species and fisheries, is unaccounted for and fishing mortality is underestimated, which enhances the risk of stock overexploitation and depletion (Goñi, 1998).

Different fishing gears operating in the various fisheries lead to distinct types and rates of bycatch: trawling is a fairly unselective technique which captures any organism encountered in the path of the trawl not fast or small enough to escape; in purse-seine fisheries for small pelagics incidental catches are reduced; fixed gill nets are fairly size selective and the type and quantity of bycatch is largely dependent on the fishing area and season; longlines are moderately selective, although in some fisheries bycatch of non commercial and protected species may be important, such as marine turtles and sharks.

Many populations of marine megafauna, including seabirds, sea turtles, marine mammals, and elasmobranchs, have declined in recent decades due largely fisheries bycatch (Žydelis *et al.*, 2009). These species do not necessarily constitute a distinct group among bycatch species, although they differ in the public perception of their importance, especially in the Western Hemisphere, where conservation issues have tended to overtake resource exploitation considerations for them (Cook, 2001). In addition, large marine vertebrates are among those most vulnerable to the negative effects of bycatch because of their late age at maturity and low reproductive rates (Baum *et al.*, 2003; Heppell *et al.*, 1999; Lewison and Crowder, 2003).

Physical disturbance and habitat destruction

Amongst the physical impacts of fishing gears, those caused by towed gears on the seabed and on benthic organisms are the best studied (Goñi, 1998). Perhaps the most obvious change caused by trawling is in the sea bottom. The physical contact of fishing gear with the substratum can lead to reduction of topographic complexity, alteration of benthic community, ressuspension of the upper layers of sedimentary seabed habitats and fragmentation of rock and biogenic substrata, with implications on eutrophication processes and biogeochemical cycling (Kaiser *et al.*, 2002). Thus, towed gears can have direct effects in organisms, such as mortality, and indirect due to its habitat modification, changes in sedimentation pattern or benthic algal production or nutrient cycling (Trush *et al.*, 1998). Alterations to the benthic community can also indirectly influence associated species, which may have commercial importance (Kaiser *et al.*, 2000).

The magnitude of these effects has proven difficult to evaluate (Trush *et al.*, 1998), since the intensity of disturbance and its magnitude depends on the details of the gear, sediment type and water depth among other factors (Kaiser *et al.*, 2002).

Effects mediated by biological interactions

Fishing can alter the structure of marine communities since its effects can cascade along the entire food chain through competition and predation links (Goñi, 1998). In general, fisheries tend to extract organisms that are at the top of the food web. With fisheries development there is commonly a shift to smaller species with faster turnover (Jennings *et al.*, 1998; Pauly *et al.*, 1998; Pauly and Palomares, 2005). In the last decades, the mean trophic level (TL) of landed species declined from slightly more than 3.3 in the early 1950's to less than 3.1 in 1994 (Pauly *et al.*, 1998). A gradual transition in landings from long-living, high TL, piscivorous fish toward short-lived, low TL invertebrates and planktivorous pelagic fish has occurred, especially in Northern Hemisphere, which reflects changes in marine food webs (Pauly *et al.*, 1998). This process has been named fishing down marine food webs and has been documented globally (Pauly *et al.*, 1998; Pauly and Palomares, 2005) and regionally (e.g. Milessi *et al.*, 2005; Pauly *et al.*, 2001; Pinnegar *et al.*, 2002; Vivekanandan *et al.*, 2005).

Discards

Bycatch species with a low economic value or with a protection status are often thrown overboard as discards (the retained part of the catch constitutes the landings). The amounts of fish discarded are generally highly area- and gear-specific, but can be high, e.g., discards in tropical shrimp trawl fisheries may reach one order of magnitude higher than the retained catch (Zeller and Pauly, 2005). From an ecological perspective, the most critical discards impacts are represented by changes in the marine ecosystem structure and diversity, nevertheless these are poorly known (Borges *et al.*, 2001). Besides conducting to resource depletion, discards cause changes in food webs (Alverson *et al.*, 1994), contributing to the increase of necrophagous species and promoting decomposition processes (Cabral *et al.* 2002; Goñi, 1998). For most fisheries and species, organisms are already dead when discarded (FAO, 2002).

The total amount of fish discarded annually by marine fisheries throughout the world was recently estimated by FAO as 7.3 million tonnes (Kelleher, 2005). This estimate is considerably lower than previous estimates of 27 million tonnes pertaining to the late 1980s and early 1990s (Alverson *et al.*, 1994). The reduction of discards is usually attributed to the use of more selective gears and fishing practices, to the decline of some particularly wasteful fisheries, and especially to higher retention (Zeller and Pauly, 2005). However, this decline is also associated with the decline in total landings over the last decade (Zeller and Pauly, 2005).

Effects caused by lost gears: ghost fishing

Fishing activity produces litter through the accidental loss of gear or by the dumping or abandoning of gear, which continue to fish and capture individuals for some time after being discarded or lost. This incident is known as ghost fishing and has been confirmed to occur for traps, gill and trammel nets and small seine nets (Matsuoka *et al.*, 2005). Gill and trammel nets as well as traps may continue to fish with significant efficiency for a long time until they become physically damaged and colonized by fouling organisms (Bullimore *et al.*, 2001; Erzini *et al.*, 1997; Kaiser *et al.*, 1996). Data on the quantity of static fishing gears lost or knowledge on how long such gears continue to fish is scarce (Pawson, 2003) and, thus, the scale of the impacts of ghost fishing is poorly known.

Sustainability

Fisheries and conservation may often be seen as incompatible activities, however, it is widely recognized that both are fundamental elements of sustainable development (FAO, 2009). Fisheries are responsible for providing a significant share of the food supply for human consumption and, simultaneously, jobs and income for millions of people worldwide and have an important role in the economies of many countries. Ensuring that species and ecosystems that support these fisheries are maintained in healthy and productive states is essential if such benefits are to be sustained into the future (FAO, 2009).

The concept of sustainability has been brought to the center of socio-economic and environmental debate after the definition of sustainable development by World Commission on Environment and Development (WCED, 1987): the development that meets the needs of present generation without compromising the ability of future generations to meet their own needs. With declining stocks, the sustainability issue became very important and has been discussed as a central topic in fishery sciences.

Historically, fisheries have tended to be non-sustainable (Pauly *et al.*, 2002). Lack of good governance, inappropriate incentives, high demand for limited resources, poverty and lack of alternatives, complexity and lack of knowledge as well as the interactions of the fisheries sector with other sectors and the environment, have been identified as primary causes of non-sustainability (Greboval, 2002, 2004).

The need to view sustainability broadly, in an integrated perspective that includes ecological, economic, social and institutional aspects of the full fishery system, has been widely recognized. Ecological sustainability incorporates the long standing concern of ensuring that harvests are sustainable, by avoiding depletion of the fish stocks, and the broader concern of maintaining the resource base and related species at levels that do not foreclose future options (Charles, 1994, 2001). Socio-economic sustainability focuses on maintaining or enhancing overall long-term socio-economic welfare, which is based on the blend of economic and social criteria, recognizing that these are inseparable at the policy level (Adrianto *et al.*, 2005). Finally, institutional sustainability refers in particular to the sets of management rules and policy by which fisheries are governed and involves maintaining suitable financial, administrative and organizational capability in the long term, as a prerequisite for three components of sustainability described previously (Charles, 2001).

Fisheries management in the European context

The collapse of many important fish stocks around the world is currently acknowledged as an obvious example of a failure of management in sustaining natural resources (Steele and Hoagland, 2003). As a result, numerous international efforts have sought to improve management and prevent overexploitation, whist helping to maintain biodiversity and a sustainable food supply. Although these initiatives have received broad acceptance, the extent to which measures have been implemented and effective have not always been the desired.

The Common Fisheries Policy (CFP) is the instrument created in 1983 by the European Union (EU) for the management of fisheries, both inside and beyond Community waters, and aquaculture. But the first EU measures in the fishing sector date from 1970, when it was agreed that EU fishermen should have equal access to Member States' waters. Nevertheless, in order to ensure that smaller vessels could continue to fish near their home ports, a coastal band was reserved for local fishermen who have traditionally fished in these areas. Measures concerning the adoption of a common market in fisheries products and the coordination of the modernization of fishing vessels and on-shore installations were also adopted. These measures gained increased significance when, in 1976, Member States extended their rights to marine resources from 12 to 200 miles from their coasts, in line with international strategic tendencies.

To promote the sustainability of fishing activities in EU waters and protect a specific stock or a group of stocks the CFP established diverse conservation measures. These measures include: Total Allowable Catches (TAC) to limit the maximum amount of fish that can be caught from a specific stock over a given period of time; technical measures, such as mesh sizes, selective fishing gear, closed areas, minimum landing sizes, and by-catch limits; limiting fishing effort by reducing the number of fishing days at sea of fishing vessels; and fixing the number and type of fishing vessels authorized to fish.

CFP was reformed in 2002 to ensure the sustainable development of fishing activities from environmental, economic and social perspectives. This reform envisioned a more long-term approach to fisheries management and introduced a precautionary approach to protect and conserve living aquatic resources, and to minimize the impact of fishing activities on marine ecosystems. It aimed to progressively implement an ecosystem-based approach to fisheries management. It also aimed to improve the basis of the decision-making process through sound and transparent scientific advice and increased participation of stakeholders.

Despite these advances, attempts to manage fisheries sustainably have been unsuccessful due to several factors. The majority of commercial fish stocks in EU waters continue to represent cause for concern. In 2007, independent fisheries scientists assessed the condition of 33 of Europe’s most important commercial fish stocks, and concluded that 29 (ca. 88%) were overfished (European Commission, 2009). Yet, despite these warning signs, decisions on catch levels remain dominated by short-term goals, and the catching capacity of the European fleet remains more than twice the necessary to harvest our own fish stocks sustainably (European Commission, 2009).

Portuguese fisheries

In Portugal, coastal and maritime activities have traditionally been important to the national economy and to the historical, social and cultural identity. The country has long relied on fishing as a major means of subsistence, in particular for many coastal communities that depend almost exclusively on fisheries and related activities. Portuguese Exclusive Economic Zone (EEZ) is 18 times larger than its territory and, with a total area of ca. 1.7 million km^2, it is one of the largest EEZ of the EU member States. Fisheries importance is reflected in fish consumption over 60 Kg per capita per year, the largest in EU well above the average (Failler, 2007). Domestic output meets only one-half of market demand, thus fish products imports are extremely important.

After adhesion to the EU in 1986, the national fisheries sector has lost importance at different levels, namely in the national economy. Fleet dimension, number of fishermen and catches have decreased since then: landings reach values half of the values of 1980; the actual number of vessels is approximately half of the number in the 1980s but still mainly small wooden vessels with open decks, and the sector currently employs less than 0,35% of the active population, contrasting with the 1.44% in 1950.

Portuguese fisheries are highly diverse in their characteristics and present peculiarities in relation to other areas, but the knowledge of their effects on the marine environment is very fragmented.

The effect of fisheries on fish species, namely bycatch and discards have been focused in some studies. Borges *et al.* (2001) and Erzini *et al.* (2002b) compared bycatch and discards of several fisheries in the southern Portuguese coast. Gamito and Cabral (2003) evaluated discards of beam trawl fishery and its mortality in Tagus estuary and Cabral *et al.* (2002) addressed the effects of those discards on the ecosystem. Stratoudakis and Marçalo (2002) studied the purse seine slipping phenomenon. Cabral *et al.* (2003) assessed beach seine discards in Portuguese central coast. Palma *et al.* (2003) studied flatfish discarding practices in bivalve dredge fishing. Monteiro *et al.* (2001) analyzed the discards of crustacean trawl and Costa *et al.* (2008) the bycatch of both crustacean and fish trawl. Fernandes and Ferreira (2006) examined discards of black scabbardfish longline. Gonçalves *et al.* (2007) and Batista *et al.* (in press) studied discards of trammel nets, the first in southern Portuguese coast and the latter in central coast.

Regarding the bycatch of protected species, Sequeira and Ferreira (1994) and Sequeira *et al.* (1997) focused the impacts of Portuguese fisheries on cetaceans, Ferreira *et al.* (2001) the incidental capture of turtles by swordfish longline fishery, Santos *et al.* (2002) the shark bycatch by swordfish longline fishery and Coelho *et al.* (2003, 2005, 2008) the effects of fisheries on elasmobranchs.

Few studies analysed other environmental impacts of fishing activities. Influence of fishing gear on the benthic habitat was studied by Chícharo *et al.* (2002a,b), Falcão *et al.* (2003), Gaspar *et al.* (2001, 2002, 2003), focusing the impacts of dredge fishing, and Morais *et al.* (2007), which analyzed the impacts of trawl fishing. Ghost fishing was poorly studied: trammel nets ghost fishing was analyzed by Erzini *et al.* (1997) and Santos *et al.* (2003) and ghost fishing of octopus and fish traps was studied by Erzini *et al.* (2002a). All these studies were performed in the Portuguese southern coast.

Aims and importance of this study

Fishery sciences are progressively switching their attention from single species to ecosystem approach, from micro to macro perspectives, and are increasing the need for measuring the impact of fishing. One of the objectives of this work is to describe and assess comparatively the environmental impacts of the fisheries operating in Portuguese waters considering the catch of non-target and protected species, discards and impacts on habitat and on trophic interactions. Special attention was given to fisheries impacts in non target species that are often discarded, namely in such important species as elasmobranchs, its effects on marine trophic web and the impacts of fishing gear lost at sea. Measures to minimize them are provided, seeking a compromise between the activity and the protection of the marine ecosystem.

The need for measuring and evaluating the sustainability of fishery activities in a system perspective has acquired a high importance and should be undertaken at various levels involving all aspects of the fishery system. Considering the importance of the fisheries sector in Portugal, the analysis of its sustainability is of the utmost importance. In this work, the sustainability of fisheries in Portugal in its multiple dimensions is assessed and the obtained information can help the development of management policies for the long term sustainability of Portuguese fisheries. Also the sustainability of the artisanal fisheries operating in a confined area, the estuary of the Tagus, is assessed.

Awareness of the poor state of the world’s fisheries has led to efforts to improve management ultimately aiming reaching sustainability. However, the extent to which measures have been implemented and the objectives achieved are not always the expected. The present study aimed to evaluate the effectiveness of Portuguese fisheries management measures, determining which measures are effective in conserving marine resources. Taking into account the increasing importance of marine protected areas (MPA) as management tools, the magnitude and vulnerability of small-scale fisheries and the difficulty in assess the effectiveness of such management tools for small-scale fisheries, a methodology to assess whether a MPA is achieving its objectives, namely concerning small-scale fisheries, is developed.

Structure of the thesis

This thesis includes eight papers, published, in review or submitted for publication in peer-reviewed scientific journals, which are original contributions in three main subjects: fisheries impacts, sustainability and management. Each of these topics is here presented as separated part.

Chapter 1, which constitutes the Part I, introduced the general framework of this thesis.

Dedicated to the study of Portuguese fisheries impacts in the marine ecosystem, Part II consists of four chapters (2 to 5) each corresponding to a paper.

Efficient fisheries management plans require knowledge of which environmental components are at risk of becoming ecologically unsustainable. In order to accomplish the first objective proposed in this study, in chapter 2 a semi-quantitative risk assessment method was developed and applied to assess the environmental impacts of Portuguese fisheries. Risks posed by fisheries were analysed considering the catch of non-target and protected species, discards and impacts on habitat and on trophic interactions. Obtained results are very important to prioritize issues and research needs which should support future management interventions.

Elasmobranchs have an important role in marine ecosystems and are also significant components of bycatches of the Portuguese artisanal fisheries, but no assessment and management programs have yet been established. In the third chapter elasmobranch catches and discards in trammel nets fisheries in the Portuguese west coast were analyzed. Another objective of this work was to obtain management-relevant information on species characteristics, abundance and distribution, which is currently very scarce.

The mean TL of landings of a particular area can be used as an indicator of the fishery-induced impacts in food webs structure (Pauly *et al.*, 1998, 2001, 2002). In chapter 4 changes in marine food webs off Portuguese waters were evaluated based on estimates of the annual mean TL of mainland, Azores and Madeira marine fisheries landings for the period between 1970 and 2006. The relationship between these changes and the relative market price of living marine resources in Portuguese waters was also examined.

Knowledge on the effects of trammel nets ghost fishing in the Portuguese coast is scarce, with only a few studies conducted in the southern coast (Erzini *et al.*, 1997; Santos *et al.*, 2003). Chapter 5 aimed to evaluate the changes in gear structure and fishing capacity of lost trammel nets in rocky and sandy bottoms in the Portuguese central coast based on diving monitoring.

The third part addressed the sustainability of the Portuguese fisheries. It consists of two chapters (6 and 7) each corresponding to a paper.

Portuguese fisheries have suffered clear changes in the last decades. In order to describe and evaluate the sustainable development of Portuguese fisheries between 1994 and 2004, an indicator system was created and two methodologies that temporally track the sector's performance were used in chapter 6. Sustainability was analysed within four dimensions: ecological, economic, social and institutional, reflecting an integrated and interdisciplinary view of sustainability.

The traditional fisheries of the Tagus estuary are very important from a social perspective and can be quite profitable. In chapter 7 the comparative sustainability of seven fisheries of these fisheries - beam-trawl, boat dredge, nets for glass eel, gill nets, eel basket, squid jig and octopus traps - is analysed using RAPFISH, a multi-disciplinary rapid appraisal technique for evaluating the comparative sustainability of fisheries (Pitcher, 1999; Pitcher and Preikshot, 2001).

Part IV consists of two chapters (8 to 9), corresponding to two papers, and is dedicated to the assessment of the effectiveness of fisheries management measures.

Many important changes in Portuguese fisheries sector occurred with the adhesion to EU in 1986 and the adoption of CFP. In chapter 8 the biological effects of the present Portuguese management system was analysed, determining which measures are effective in conserving marine fisheries resources. Furthermore, it aimed to assess how well the various management measures have performed in terms of solving fishery problems and to identify fishery-management problems.

In chapter 9 a methodology to assess whether a MPA is achieving its objectives as a management tool, namely concerning multispecies small-scale fisheries was developed. This methodology was based in a simplified pool of indicators, regarding ecological, social, economic and management fields and was applied to a national case study, the Arrábida MPA.

Finally, a general discussion is presented in the tenth chapter (Part V), focusing the most important results of these papers and the major conclusions are delineated. Their importance and implications within the context of fisheries impacts and sustainability are also discussed, and some final remarks and guidelines for future research are also presented.

References

Adrianto, L., Matsuda, Y., Sakuma, Y., 2005. Assessing local sustainability of fisheries system: a multi-criteria participatory approach with the case of Yoron Island, Kagoshima prefecture, Japan. Mar. Policy 29, 9-23.

Alverson, D.L., Freeberg, M.H., Murawski, S.A., Pope, J.G., 1994. A global assessment of fisheries by-catch and discards. FAO Fisheries Technical Paper 339. FAO, Rome.

Batista, M.I., Teixeira, C.M., Cabral, H.N. (in press). Catches of target species and bycatches of an artisanal fishery: the case study of a trammel net fishery in the Portuguese coast. Fish. Res.

Baum, J.K., Myers, R.A., Kehler, D.G., Worm, B., Harley, S.J., Doherty, P.A., 2003. Collapse and conservation of shark populations in the Northwest Atlantic. Science 299, 389–392.

Borges, T.C., Erzini, K., Bentes, L., Costa, M.E., Gonçalves, J.M.S., Lino, P.G., Pais, C., Ribeiro, J., 2001. By-catch and discarding practices in five Algarve (southern Portugal) metiers. J. Appl. Ichthyol. 17, 104-114.

Bullimore, B.A., Newman, P.B., Kaiser, M.J., Gilbert, S.E., Lock, K.M., 2001. A study of catches in a fleet of “ghost-fishing” pots. Fish. Bull. 99, 247-253.

Cabral, H.N., Teixeira, C.M., Gamito, R., Costa, M.J., 2002. Importance of discards of a beam trawl fishery as input of organic matter into nursery areas within the Tagus estuary. Hydrobiologia 475/476, 449-455.

Cabral, H., Duque, J., Costa, M.J., 2003. Discards of the beach seine fishery in the central coast of Portugal. Fish. Res. 63, 63-71.

Caddy, J.F., Cochrane, K.L., 2001. A review of fisheries management past and present and some future perspectives for the third millennium. Ocean Coast. Manage. 44, 653-682.

Charles, A.T., 1994. Toward sustainability: the fishery experience. Ecol. Econ. 11, 201–211.

Charles, A.T., 2001. Sustainable fisheries system, Blackwell Sciences, London, UK.

Chícharo, L., Chícharo, A., Gaspar, M., Alves, F., Regala, J., 2002a. Ecological characterization of dredged and non-dredged bivalve fishing areas off south Portugal. J. Mar. Biol. Assoc. U.K. 82, 41-50.

Chícharo, L., Regala, J., Gaspar, M., Alves, F., Chícharo, A., 2002b. Macrofauna spatial differences within clam dredge-tracks and their implications for short-term fishing effect studies. Fish. Res. 54, 349-354.

Christensen, V., Guénette, S., Heymans, J.J., Walters, C.J., Watson, R., Zeller, D., Pauly, D., 2003. Hundred year decline of North Atlantic predatory fishes. Fish Fish. 4, 1–24.

Coelho, R., Bentes, L., Gonçalves, J.M.S., Lino, P.G., Ribeiro, J., Erzini, K., 2003. Reduction of elasmobranch by-catch in the hake semi-pelagic near bottom longline fishery in the Algarve (Southern Portugal). Fisheries Sci. 69, 293-299.

Coelho, R., Erzini, K., 2008. Effects of fishing methods on deep water shark species caught as by-catch off southern Portugal. Hydrobiologia 606,187-193.

Coelho, R., Erzini, K., Bentes, L., Correia, C., Lino, P.G., Monteiro, P., Ribeiro, J., Gonçalves, J.M.S., 2005. Semi pelagic longline and trammel net elasmobranch catches in Southern Portugal: catch composition, catch rates and discards. J. Northw. Atl. Fish. Sci. 35, 531-537.

Cook, R., 2001. The magnitude and impact of by-catch mortality by fishing gear. Reykjavik Conference on Responsible Fisheries in the Marine Ecosystem, Reykjavik, Iceland.

Costa, M.E., Erzini, K., Borges, T.C. 2008. Bycatch of crustacean and fish bottom trawl fisheries from southern Portugal (Algarve). Sci. Mar. 72, 801-814.

Erzini, K., Bentes, L., Lino, P.G., Ribeiro, J., Coelho, R., Monteiro, P., Correia, C., Gonçalves, J.M.S., 2002a. Ghost-fishing" of octopus and fish traps from the south coast of Portugal. ICES 2002 Annual Science Conference, Copenhaga, Denmark.

Erzini, K., Costa, M.E., Bentes, L., Borges, T.C., 2002b. A comparative study of the species composition of discards from five fisheries from the Algarve (southern Portugal). Fisheries Manage. Ecol. 9, 31-40.

Erzini, K., Monteiro, C.C., Ribeiro, J., Santos, M.N., Gaspar, M., Monteiro, P., Borges, T.C., 1997. An experimental study of gill net and trammel net `ghost fishing' off the Algarve (southern Portugal). Mar. Ecol. Prog. Ser. 158, 257-265.

European Commission, 2009. The Common Fisheries Policy – A user's guide. Office for Official Publications of the European Communities, Luxemburg.

Falcão M., Gaspar M.B., Caetano M., Santos M.N., Vale C., 2003. Short-term environmental impact of clam dredging in coastal waters (south of Portugal): chemical disturbance and subsequent recovery of seabed. Mar. Environ. Res. 56, 649-664.

Failler, P., 2007. Future prospects for fish and fishery products. 4. Fish consumption in the European Union in 2015 and 2030. Part 1. European overview. FAO Fisheries Circular. No. 972/4, Part 1. FAO, Rome.

FAO, 2002. The state of world fisheries and aquaculture. FAO, Rome

FAO, 2009. The state of world fisheries and aquaculture. FAO, Rome.

Fernandes, A.C. and Ferreira, A., 2006. First approach on Portuguese black scabbardfish longline fleet discards. Working document presented to the ICES Working Group on the

Biology and Assessment of Deep-sea Fisheries Resources (WGDEEP), Vigo, Spain, 2–11 May 2006.

Ferreira, R.L., Martins, H.R., Silva, A.A. and Bolten, A.B., 2001. Impact of swordfish fisheries on sea turtles in the Azores. Arquipélago. Life Mar. Sci. 18A: 75-79.

Gamito, R., Cabral, H., 2003. Mortality of brown-shrimp discards from the beam trawl fishery in the Tagus estuary, Portugal. Fish. Res. 63, 423-427.

Garcia, S.M., Newton, C., 1997. *in* Global Trends: Fisheries Management (ed. Sissenwine, M. P.) Am. Fish. Soc. Symp. 20, 3–27 (American Fisheries Society, Bethesda, MD).

Gaspar, M.B., Dias, M.D., Campos, A., Monteiro, C.C., Santos, M.N., Chicharo, A., Chicharo, L., 2001. The influence of dredge design on the catch of Callista chione (Linnaeus, 1758). Hydrobiologia 465, 153-167.

Gaspar, M.B., Leitão, F., Santos, M.N., Chícharo, L., Dias, M.D., Chícharo, A. , Monteiro, C.C., 2003. A comparison of direct macrofaunal mortality using three types of clam dredges. ICES J. Mar. Sci. 60, 733-742.

Gaspar, M.B., Leitão, F., Santos, M.N., Sobral, M., Chícharo, L., Chícharo, A. , Monteiro, C.C., 2002. Influence of mesh size and tooth spacing on the proportion of damaged organisms in the catches of the Portuguese clam dredge fishery. ICES J. Mar. Sci. 59, 1228-1236.

Gonçalves, J.M.S., Stergiou, K.I., Hernando, J.A., Puente, E., Moutopoulos, D.K., Arregi, L., Soriguer, M.C., Vilas, C., Coelho, R., Erzini, K., 2007. Discards from experimental trammel nets in southern European small-scale fisheries. Fish. Res. 88, 5-14.

Goñi, R., 1998. Ecosystem effects of marine fisheries: an overview. Ocean Coast. Manage. 40, 37-64.

Greboval, D.E., 2002. Report and documentation of the International workshop on factors contributing to unsustainability and overexploitation in fisheries. FAO Fisheries Report 672. FAO, Rome.

Greboval, D.E., 2004. International workshop on the implementation of international fisheries instruments and factors of unsustainability and overexploitation in fisheries. FAO Fisheries Report 700, FAO, Rome.

Heppell, S.S., Crowder, L.B., Menzel, T.R., 1999. Life table analysis of long-lived marine species, with implications for conservation and management. In: Life in the Slow Lane: Ecology and Conservation of Long-Lived Marine Animals (ed. Musick, J.A.). American Fisheries Society Symposium 23, Bethesda, MD, pp. 137-148.

Jackson, J.B.C., Kirby, M.X., Berger, W.H., Bjorndal, K.A., Botsford, L.W., Bourque, B.J., Bradbury, R.H., Cooke, R., Erlandson, J., Estes, J.A., Hughes, T.P., Kidwell, S., Lange, C.B., Lenihan,H.S., Pandolfi, J.M., Peterson, C.H., Steneck, R.S., Tegner, M.J., Warner, R.R., 2001. Historical overfishing and the recent collapse of coastal ecosystems. Science 293, 629–638.

Jennings, S., Reynolds, J.D., Mills, S.C., 1998. Life history correlates of responses to fisheries exploitation. Proc. R. Soc. Lond. B 265, 333-339.

Kaiser, M.J., Bullimore, B., Newman, P., Lock, K., Gilbert, S., 1996. Catches in “ghost fishing” set nets. Mar.Ecol.Prog. Ser. 145, 11-16.

Kaiser, M.J., Collie, J.S., Hall, S.J., Jennings, S., Poiner, I.R., 2002. Modification of marine habitats by trawling activities: prognosis and solutions. Fish Fish. 3, 114-136

Kaiser, M.J., Spence, F.E., Hart, P.J.B., 2000. Fishing-gear restritions and conservation of benthic habitat complexity. Conserv. Biol. 14, 1512-1525.

Kelleher, K., 2005. Discards in the world’s marine fisheries. An update. FAO Fisheries Technical Paper No. 470. FAO, Rome.

Lewison, R.L., Crowder, L., 2003. Estimating fishery bycatch and effects on a vulnerable seabird population. Ecol. Appl. 13, 743-753.

Matsuoka, T., Nakashima, T., Nagasawa, N., 2005. A review of ghost fishing: scientific approaches to evaluation and solutions. Fisheries Sci. 71, 691-702.

Milessi, A.C., Arancibia, H., Neira, S., Defeo, O., 2005. The mean trophic level of Uruguayan landings during the period 1990-2001. Fish. Res. 74, 223-231.

Monteiro, P., Araújo, A., Erzini, K., Castro, M., 2001. Discards of the Algarve (southern Portugal) crustacean trawl fishery. Hydrobiologia 449, 267-277.

Morais, P., Borges, T.C., Carnall, V., Terrinha, P., Cooper, C. and Cooper, R., 2007. Trawl-induced bottom disturbances off the south coast of Portugal: direct observations by the 'Delta' manned-submersible on the Submarine Canyon of Portimão. Mar. Ecol. 28, 112-122.

Morizur, Y., Berrow, S.D., Tregenza, N.J.C., Couperus, A.S., Pouvreau, S., 1999. Incidental catches of marine-mammals in pelagic trawl fisheries of the northeast Atlantic. Fish. Res. 41, 297-307.

Myers, R. A., Worm, B., 2003. Rapid worldwide depletion of predatory fish communities. Nature 423, 280-283.

Myers, R.A., Hutchings, J.A., Barrowman, N.J., 1997. Why do fish stocks collapse? The example of cod in Atlantic Canada. Ecol. Applic. 7, 91-106.

Palma, J., Reis, C., Andrade, J. P., 2003. Flatfish discarding practices in bivalve dredge fishing off the south coast of Portugal (Algarve). J.Sea Res. 50, 129-137.

Pauly, D., Christensen, V., Dalsgaard, J., Froese, R., Torres, F. Jr., 1998. Fishing down marine food webs. Science 279, 860-863.

Pauly, D., Christensen, V., Guénette, S., Pitcher, T.J., Sumaila, U.R., Walters, C.J., Watson, R., Zeller, D., 2002. Towards sustainability in world fisheries, Nature 418, 689-695.

Pauly, D., Palomares, M.L., 2005. Fishing down marine food web: it is far more pervasive than we thought. Bull. Mar. Sci. 76, 197-211.

Pauly, D., Palomares, M.L., Froese, R., Sa-a, P., Vakily, M., Preikshot, D., Wallace, S., 2001. Fishing down Canadian aquatic food webs. Can. J. Fish. Aquat. Sci. 58, 51-62.

Pauly, D., Watson, R., Alder, J., 2005. Global trends in world fisheries: impacts on marine ecosystems and food security. Phil. Trans. R. Soc. B 360, 5-12.

Pawson, M. G., 2003. The catching capacity of lost static fishing gear: introduction (Editorial). Fish. Res. 64, 101-105.

Pinnegar, J.K., Jennings, S., O'Brien, C.M., Polunin, N.V.C., 2002. Long-term changes in the trophic level of the Celtic Sea fish community and fish market price distribution. J. Appl. Ecol. 39, 377-390.

Pitcher, T.J., 1999. Rapfish, a rapid appraisal technique for fisheries, and its application to the code of conduct for responsible fisheries. FAO Fisheries Circular 947. FAO, Rome.

Pitcher, T.J., Preikshot, D., 2001. RAPFISH: a rapid appraisal technique to evaluate the sustainability status of fisheries. Fish. Res. 49, 255-270.

Pope, J.G., MacDonald, D.S., Daan, N., Reynolds, J.D., Jennings, S., 2000. Gauging the impact of fishing mortality on non-target species. ICES J. Mar. Sci. 57, 689-696.

Santos, M.N., Alexandra Garcia, A., Pereira, J.G., 2002. A historical review of the by-catch from the Portuguese surface long-line swordfish fishery: observations on blue shark (*Prionace glauca*) and short-fin mako (*Isurus oxyrinchus*). ICCAT Coll. Vol. Sc. Papers 54, 1333-1340.

Santos M.N., Saldanha, H.J., Gaspar, M.B., Monteiro, C.C., 2003. Hake (*Merluccius merluccius* L., 1758) ghost fishing by gill nets off the Algarve (southern Portugal). Fish. Res. 64, 119-128.

Sequeira, M., Ferreira, C., 1994. Coastal Fisheries and Cetacean Mortality in Portugal. Report of the International Whaling Commission 15, 165-174.

Sequeira, M., Inácio, A., Silva, M.A., 1997. Cetacean strandings in Portugal: 1993-1995. European Research on Cetaceans 10, 136-140.

Steele, J., Hoagland, P., 2003. Are fisheries “sustainable”? Fish. Res. 64, 1-3.

Stratoudakis, Y., Marçalo, A., 2002. Sardine slipping during purse-seining off northern Portugal. ICES J. Mar. Sci. 59, 1256-1262.

Vivekanandan, E., Srinath, M., Kuriakose S., 2005. Fishing the marine food web along the Indian coast. Fish. Res. 72, 241-252.

Watson, R., Pauly, D., 2001. Systematic distortions in world fisheries catch trends. Nature 414, 534-536.

WCED, 1987. Our Common Future. World Conference on Environment and Development. Oxford: Oxford University Press.

Zeller, D., Pauly, D., 2005. Good news, bad news: global fisheries discards are declining, but so are total catches. Fish Fish. 6, 156-159.

Žydelis, R., Wallace, B.P., Gilman, E.L., Werner, T.B., 2009. Conservation of Marine Megafauna through Minimization of Fisheries Bycatch. Conserv. Biol. 23, 608-616.

Part II

Impacts of Portuguese fisheries

CHAPTER 2

An ecological risk assessment method and its use in the management of Portuguese fisheries

Authors
Filipa Baeta[a], Maria José Costa[a,b], Henrique Cabral[a,b]

Authors' affiliation
[a]Instituto de Oceanografia, Faculdade de Ciências da Universidade de Lisboa, Campo Grande, 1749-016 Lisboa, Portugal
[b]Departamento de Biologia Animal, Faculdade de Ciências da Universidade de Lisboa, Campo Grande, 1749-016 Lisboa, Portugal

Submitted
ICES Journal of Marine Science

An ecological risk assessment method and its use in the management of Portuguese fisheries

Abstract: Efficient fisheries management plans require knowledge of which environmental components are at risk of becoming ecologically unsustainable. A semi-quantitative risk assessment method was developed and used to assess the environmental impacts of Portuguese fisheries. Risks posed by fisheries were analysed considering the catch of non-target and protected species, discards and impacts on habitat and on trophic interactions. Seven fisheries, covering a variety of gear types were analysed, namely crustacean trawl, fish trawl, pelagic purse seine, trammel nets for soles, octopus traps, swordfish longline and deepwater longline for black scabbardfish. Overall, the ecological impact requiring more urgent attention is bycatch, which in some cases generate significant rates of discards. The impact on protected species is more noticeable on swordfish longline fishery, while impacts on benthic habitats are higher in trawl activity. Insufficient data disabled the assessment of the fisheries impact on trophic interactions. Considering risk rankings obtained, applicable mitigation and management measures were identified. Risk assessment method was successful in identifying and quantifying effects of fishing activities on the environment and prioritizing issues and research needs, providing a decision tool which should leads to better management decisions.

Keywords: fisheries, impacts, risk analysis, ecosystem-based fishery management, Portugal.

Introduction

Ecosystem-based fishery management (EBFM) has been defined as a new direction for fishery management, essentially reversing the order of management priorities so that it starts with the ecosystem rather than a target species. EBFM aims to insure the sustainability of marine ecosystems and the fisheries they support (Pikitch *et al.*, 2004), considering not only impacts on target species, but also impacts on bycatch species and habitats, as well as indirect impacts of these catches on the broader ecosystem (Garcia *et al.*, 2003; Fletcher at al., 2005). However, undertake comprehensive EBFM is limited by the lack of adequate information and data (Livingston *et al.*, 2005). Although the impacts of commercial fishing in the environment are well described, their assessment is controversial since the analytical tools and data required proving cause and effect are frequently unavailable (Campbell and Gallagher, 2007).

Risk analysis has been acknowledged as a useful management tool to assess the ecological aspects of ecosystems when limited data are available (Campbell and Gallagher, 2007). It was suggested as a sensible approach as it considers the high number of issues necessarily evaluated in order to achieve an EBFM and the impossibility of gaining a perfect understanding for any of these (Fletcher, 2005). Moreover it can help prioritize issues and research needs in a cost effective manner (Campbell and Gallagher, 2007) leading to better management decisions (Fletcher, 2005). The use of risk analysis as a fisheries management tool as became more common with the recent work of Fletcher (2005); Ye *et al.* (2005) and Astles *et al.* (2006) for Australian fisheries and Campbell and Gallagher (2007) for New Zealand fisheries.

Risk analysis is comprised of two components: risk assessment, i.e. the process that evaluates possible consequences and estimates their likelihood of occurrence as a function of a decision taken and the probabilistic realization of the uncontrollable state dynamics of the system, and risk management, i.e. the process whereby decision makers use information from risk assessment to evaluate and compare decision alternatives (Lane and Stephenson, 1998).

Risk assessment may be quantitative or qualitative. Quantitative ecological risk assessment generally uses mathematical models to describe relationships between harvest levels and various parameters of the fish stocks and/or ecosystem. This type of risk assessment is only possible in data-rich fisheries (Astles *et al.*, 2006). On the other hand, qualitative risk assessment may be used for fisheries with lower availability of data. The main difficulty of both quantitative and qualitative ecological risk assessment methods is the complexity of the marine ecosystems to which they are applied (Cochrane, 1999). Therefore, making correct assessments of fishing activity impacts is difficult regardless of the amount of data available. A qualitative approach to risk analysis may not necessarily be less reliable than a quantitative approach (Astles *et al.*, 2006).

Subsequently, risk management involves: risk mitigation, which consists of the evaluation and implementation of regulatory and/or voluntary management responses to address issues raised by the risk assessment stage and mitigate the risks to ecosystem components, and risk monitoring, which aims to collect information to determine whether the initiatives implemented efficiently minimized the risk of the undesirable event (Astles *et al.*, 2006).

Portugal has an historical tradition in fisheries, relying on fishing as a major mean of subsistence in particular for coastal communities, and has one of the largest Exclusive Economic Zone (EEZ) in the European Union (EU). Portuguese waters include the EEZ sub-area of mainland Portugal and the two EEZ sub-areas of the Autonomous Regions of Azores and Madeira. All three areas are in the subtropical/boreal transition zone of the Eastern Atlantic. As a result of the high biodiversity in these areas, there are several distinct fleets (métiers) characterized by the use of different fishing gear types targeting different commercially important species. In mainland Portugal fisheries focus on a high diversity of resources in fishing grounds located a short distance from shore, whereas in the autonomous regions, due to their oceanic nature, pelagic species are the most exploited.

Portugal joined the EU in 1986 and has since implemented a fisheries policy within the framework of the EU Common Fisheries Policy, without prejudice to supplementary national legislation. The current Portuguese management system includes the establishment of annual total allowable catches (TAC) and quotas for some species and fishing areas, the application of technical conservation measures (minimum landing sizes, minimum mesh sizes, allowable percentages for by-catch species and target species, area closures and bans on the use of specific gear) and other restrictions to limit the fishing activity, such as prior administrative authorisation for the acquisition or construction of new fishing vessels and use of fishing gear, and annual fishing licences.

The present work aims to develop and apply a semi-quantitative risk assessment model to assess the ecological effects of some of the most important Portuguese fisheries on the marine environment. Results obtained were used to prioritize issues and research needs which should support future management interventions.

Material and Methods

A semi-quantitative risk assessment model was developed based on the models developed by Fletcher *et al.* (2005) and Campbell and Gallagher (2007). Risk was considered as an expected environmental loss and thus incorporated both the probability (likelihood) and outcome (consequence) of the undesirable event (e.g. Rosenberg and Restrepo, 1994), i.e. risk was defined as an impact. The risk assessment method can be summarized in four steps: establishing the context, identifying the sources of risk, assessing the risks and treating and/or mitigating the risks.

Establish the context

The semi-quantitative risk analysis model was developed to examine the impacts of commercial Portuguese fisheries on the marine ecosystem. Portuguese fisheries has three major fleet segments: the trawl fleet, which comprises two fleet components, namely the trawl fleet catching demersal fish and the trawl fleet directed at crustaceans; the purse seine fleet, which targets small pelagic species; and the artisanal multi-gear (polyvalent) fleet, the largest segment which uses a great variety of fishing gears (gill and trammel nets, hooks and longline, traps and pots) and targets a great diversity of benthic, demersal, and pelagic species (fish, cephalopods and crustaceans).

Identify the risk

Five categories were used to examine the environmental impact of a fishery, namely 1) non-target species, i.e. species caught but which are not target species; 2) discards, i.e. the portion of a catch which is not retained on board during commercial fishing operations and is returned to the sea; 3) protected species, i.e. species for which capture is prohibited, namely cetaceans, sea turtles and sea birds; 4) habitat, i.e. habitats impacted by fisheries; 5) trophic interactions, i.e. indirect impacts of fishing attributable to flow-on effects on the food web. This framework includes the main ecological components potentially impacted by a fishery thereby providing a broad ecosystem approach for assessing fishery impacts. The model does not analyse the effect of fisheries on target species but the effects of managing stocks or species on the rest of ecosystem, i.e. not the effects of stock removal, but the effects of fishing in the environment.

Assess the risk

This step can be divided into four substeps, namely determination of 1) the consequence, 2) its likelihood, 3) its risk and 4) its uncertainty.

Consequence measures the impact that the fishery may have on the environmental categories (Table 2.1). Each category has a different consequence matrix because each one may respond differently to the impact. Each of the matrices has also five ordinal levels of consequence ranging from insignificant (virtually no impact) to significant (irreversible). The consequence matrices can provide multiple examples of different levels of impact; however, only one example of impact is required to be met to achieve that level.

Likelihood is the probability of an event (impact) occurring and has also five ordinal levels, ranging from rare (event that will only occur in exceptional circumstances) to likely (expected to occur) (Table 2.2). To correctly assign these levels it is important to recognize likelihood as the probability of a particular level of consequence occurring.

The risk value for each issue was derived by combining likelihood level and the consequence level (Table 2.3) and can be classified into five risk categories ranging from negligible to extreme.

Assigning a level of risk carries with it the possibility of that risk being either higher or lower than the real risk, because of the uncertainty about exactly how a fishery might impact components of the ecosystem. Assigning a risk level higher than the real (type I error) may cause excessive expenditure of resources on unnecessary mitigation measures. Nevertheless, assigning a risk level lower than the real (type II error) could have worst consequences, since it could result in inadequate management action, leading to major damage to that fishery component, threatening its sustainability and requiring long-term remediation (Astles *et al.*, 2006). Thus, the present method addresses a lack of knowledge as a considerable consequence, emphasizing the precautionary principle. Assessing the data deficiencies in such a manner ensures that the analysis is risk averse to type II errors and prevents the collapse of a fishery through poor advice (Campbell and Gallagher, 2007).

Data used for risk assessment were drawn from previous scientific works, interviews to fishers and stakeholders, official information from public institutions and peer-reviewed and ‘grey’ literature.

Table 2.1. Consequence matrix for five categories: non-target species (bycatch), i.e. species captured but which are not target species; discards; protected species; habitat, i.e. habitats that influence fisheries or are impacted by fisheries; and ecosystem/trophic interactions, i.e. indirect impacts of fishing attributable to flow-on effects on the food web. The consequence category applies if one of the impact conditions is fulfilled.

	Non-target species (bycatch)				**Discards**	**Protected species**		
Level of consequence	Non-target species take in the fishery (% biomass of total catch)	Reductions in populations abundances	Species population take and the area of capture, compared with the area of distribution	Information on the distribution of species and on the susceptibility to capture or the vulnerability of life history stages.	Discards of the fishery (% biomass of total catch)	Threatened or protected species impacted	Reductions of populations abundances	Information on the distribution and behavior of those species and on the susceptibility to capture or their behavioral vulnerability
Insignificant	Small (<10%)	Not readily detectable			Reduced (<5%)	Almost none are impacted		
Minor	Small (<25%)	Insignificant (<10%)	Small (<20%)		Small (<10%)	Some, but there is no impact on stock and this is well below society's acceptable levels	Small (<1%)	
Moderate	Moderate (<40%)	Moderate (<20%)	Moderate (<20%)	Limited	Moderate (<30%)	At the maximum acceptable level	Moderate (<10%)	Limited
Major	Major (<70%)	Major (<70%)	Major (<70%); likely to cause local extinction	Very reduced	Major (<50%)	Above maximum acceptable level.	High (<20%)	Very reduced
Significant	Significant (>70%)	Significant (>70%)	Significant (>70%); likely to cause local extinction	No	Significant (>50%)	Well above maximum acceptable level.	Significant (>20%)	No

Table 2.1. Continuation.

	Habitat			Ecosystem / Trophic interactions	
Level of consequence	Changes in habitat area	Population of habitat-forming species	Information on the identity and distribution of habitat types, habitat-forming species and their susceptibility to fisheries activity.	Trophic web	Information on the species composition and abundance of trophic levels and on trophic interactions and basic ecosystem processes
Insignificant	Changes not measurable against background	Not affected		Changes in trophic interactions not measurable against background variability	
Minor	Measurable changes but localized	Small reduction (<10%)		No loss of keystone species populations; only minor changes in relative abundance of other constituents	
Moderate	More widespread changes but still acceptable; new habitat type(s) observed; possible loss of habitat type	Moderate reduction (<30%)	Limited	Measurable changes in the ecosystem components without there being a major change in function (i.e. no loss of components)	Limited
Major	Major changes; new habitat types observed; loss of most pre-existing habitat types.	High reduction (<70%); local extinction of at least one of these species	Very reduced	Ecosystem function altered measurably and some function or components missing/declining/increasing well outside historical acceptable range and/or allowed/facilitated new species to appear.	Very reduced
Significant	Significant changes; new habitat types observed; no pre-existing habitat types existing.	High reduction (>70%); local extinction of more than one of these species; global extinction of at least one species.	No	Major change in ecosystem structure and function. Different dynamics occur, with different species or groups now the major targets of the fishery.	No

Table 2.2. Likelihood of occurrence of each level of consequence.

Level of Likelihood	Description
Rare	Event will only occur in exceptional circumstances
Unlikely	Event could occur, but is not expected
Possible	Event could occur
Occasional	Event will probably occur in most circumstances
Likely	Event is expected to occur in most circumstances

Table 2.3. Risk matrix in which risk is denoted by N, negligible; L, low; M, moderate; H, high; E, extreme.

Likelihood	**Consequence**				
	Insignificant	Minor	Moderate	Major	Significant
Rare	N	L	L	M	M
Unlikely	N	L	M	H	H
Possible	N	L	M	H	E
Occasional	N	M	H	E	E
Likely	N	M	E	E	E

Treat and/or mitigate the risk

Depending on the risk category identified, a variety of actions can be defined to ameliorate or mitigate risk (Table 2.4). Possible management measures are reducing TAC, restricting fishing activities, developing fishing codes of practice or developing risk maps. In addition, scientific actions could be implemented, such as the improvement of fishing gears to reduce bycatch and other environmental impacts or the improvement of monitoring and data recording to ensure accurate representation of data.

Table 2.4. Actions that should be defined to ameliorate or mitigate risk.

Risk category	Likely scientific actions	Management Response
Negligible	Nil	No direct management needed
Low	None specific	No specific management actions needed, indirect management likely
Moderate	Specific scientific required	Specific management actions needed, some additions to current levels possible
High	Probably increases to scientific activities required	Increases to current management activities probably needed
Extreme	Additional scientific activities required	Significant additional management activities needed

Results

Establish the context

Seven Portuguese fisheries - crustacean trawl, fish trawl, pelagic purse seine, trammel nets for soles (*Solea* spp.), octopus (*Octopus vulgaris*) traps, swordfish (*Xiphias gladius*) longline and deepwater longline for black scabbardfish (*Aphanopus carbo*) - were selected for the assessment of the environmental impacts using the semi-quantitative risk-analysis model described (Table 2.5). These fisheries were selected because they are important fisheries which cover different fishing gears and with well defined target species.

Identify the risk

As described earlier, five fishing effects categories were identified as issues that need to be considered in the assessment of the ecological effects of the Portuguese fisheries on the environment. Globally they cover the main ecological components potentially impacted by a fishery.

Assess the risk

The risk results for the seven fisheries analysed are summarized in Table 2.6. Trophic interactions for all fisheries could not be assessed due to the inability to determine the consequence and the respective likelihood of such an event. Although it is known that the mean trophic level of landings from Portugal mainland waters has decreased in the last years (Baeta *et al.*, 2009), which may be interpreted as a result of a decrease in abundance of high trophic level species relative to low trophic level ones in the ecosystem, the impact of each of the fisheries studied on trophic web are not assessed. To account for this lack of knowledge in a precautionary approach, a rating of major consequence could be selected for the set of all fisheries. However, likelihood of this type of impact could not be determined. Thus, whereas likelihood can take any level, risk ranking is between moderate and extreme.

Table 2.5. Summary description of each of the seven fisheries examined.

Fishery	Fishing method	Target species	Main management methods
Crustacean trawl	deep-water otter trawl	Norway lobster (*Nephrops norvegicus)* rose shrimp (*Parapenaeus longirostris*) red shrimp (*Aristeus antennatus*)	TAC and recovery plan for Norway lobster; minimum landing sizes; gear restrictions, as mesh size.
Fish trawl	semi-pelagic otter trawl	horse mackerel (*Trachurus trachurus)* hake (*Merluccius merluccius)* anglerfishes (*Lophius piscatorius)* cephalopods (namely *Octopus vulgaris*)	TAC for some species; minimum landing sizes; gear restrictions, as mesh size.
Purse seine	pelagic purse seine	sardine (*Sardina pilchardus*)	Atlanto-Iberian sardine stock is managed by Portugal and Spain and, based on historical catches, an annual quota is defined; minimum landing size; fishing day limitations; gear restrictions, as mesh size, net size, etc.
Trammel nets	trammel nets	soles (*Solea* spp.)	TAC for soles; minimum landing sizes; gear restrictions, as maximum size of and minimum distance between nets, mesh size, maximum immersion time, etc.
Octopus traps	traps for moluscs	octopus (*Octopus vulgaris*)	Minimum landing sizes; gear restrictions, as number and size of traps, mesh size, type of construction materials, etc.
Deepwater longline	deepwater longline	black-scabbard fish (*Aphanopus carbo*)	TAC for black scabbardfish; minimum landing sizes; gear restrictions.
Swordfish longline	surface drifting longline	swordfish (*Xiphias gladius*)	TAC for swordfish; minimum landing sizes; gear restrictions.

Table 2.6. Ecological risk of the seven Portuguese fisheries analyzed.

Category		Crustacean trawl	Fish trawl	Purse Seine	Trammel nets	Octopus traps	Deepwater longline	Swordfish longline
Non-target species	Consequence	Major	Significant	Minor	Major	Moderate	Minor	Moderate
	Likelihood	Likely	Likely	Possible	Likely	Likely	Likely	Likely
	Risk	**Extreme**	**Extreme**	**Low**	**Extreme**	**Extreme**	**Moderate**	**Extreme**
Discards	Consequence	Major	Significant	Moderate	Moderate	Moderate	Minor	Minor
	Likelihood	Likely	Likely	Possible	Occasional	Occasional	Possible	Possible
	Risk	**Extreme**	**Extreme**	**Moderate**	**High**	**High**	**Low**	**Low**
Protected species	Consequence	Moderate	Moderate	Minor	Moderate	Minor	Minor	Moderate
	Likelihood	Possible	Possible	Possible	Possible	Unlikely	Unlikely	Occassional
	Risk	**Moderate**	**Moderate**	**Low**	**Moderate**	**Low**	**Low**	**High**
Habitat	Consequence	Moderate	Moderate	Insignificant	Minor	Insignificant	Insignificant	Insignificant
	Likelihood	Likely	Likely	Rare	Unlikely	Unlikely	Unlikely	Rare
	Risk	**Extreme**	**Extreme**	**Negligible**	**Low**	**Negligible**	**Negligible**	**Negligible**

Crustacean and fish trawl fisheries

Both trawl fisheries had extreme risk levels regarding non-target species and discards categories. Total bycatch exceeded target catch in both fisheries, even though it is much higher in fish trawl (80.4% in weight) than in crustacean trawls (59.5% in weight) (Costa *et al.*, 2008). Otherwise, discards are quite similar in the two trawl types: 78,1% and 73,8% of total weight of bycatch in crustacean and fish trawl fishery, respectively (Costa *et al.*, 2008).

There was a lack of information on the capture of protected species by these two Portuguese fisheries. Official data from Portuguese trawl fisheries, based on reports by skippers, recorded 12 cetacean bycatches in 1980; in 1981 capture and selling of marine mammals became illegal in Portugal and the capture of only six animals was reported between 1981 and 1994 (Sequeira and Ferreira, 1994). The interaction between trawl fisheries and protected species as marine mammals is under-reporting (López *et al.*, 2003). Records of a significant protected species bycatch could lead to constraints being imposed on fisheries, stimulating fishermen not to report it. To account for this lack of knowledge in a precautionary approach, a rating of moderate consequence was selected and likelihood of this type of impact was classified as possible given the reduced selectivity of such gears, resulting in a risk ranking in protected species category of high.

The risk of both trawl fisheries impacting habitat was also extreme. Even though it had a rating of moderate consequence, this type of impact always occurred. Crustacean trawl leads to variations in bottom type, the sedimentary framework and biological communities, suggesting a relatively widespread impact of the fishing activity as reported for the south coast of Portugal (Morais *et al.*, 2007). However, spatially detailed ecological or fisheries data is lacking and doubt exists on what has changed and when did it change: the macro and mega-epifauna described for the study area may already be a part of a shifting ecosystem, with changes in species composition and trophic structures (Borges *et al.,* 2001a).

Pelagic purse seine

Purse seine fishery is characterized by low levels of non-target species catch since skippers look for fish using an echosounder, which markings, despite not conclusive, are many times sufficient to the determination of the fish species. In 30 trips observed off northern Portugal, a total of 15 species were caught, with sardine (*Sardina pilchardus*) comprising 97% of total catch. The main part of bycatch was formed by chub mackerel (*Scomber japonicus*), horse mackerel (*Trachurus trachurus*) and anchovy (*Engraulis encrasicolus*) (Stratoudakis and Marçalo, 2002). Thus, non-target species category had a low risk ranking.

However, catch may be far different from the skipper prediction. Discard/catch ratio in purse seine fishery varies between 0.0 and 1.0 per set, with the latter ratio often corresponding to considerable quantities of discards (Erzini *et al.*, 2002). In 30 purse seine fishing trips observed 183 t were landed while 414 t were slipped, i.e. released after the drying-up of the net but without the fish being drawn aboard (Stratoudakis and Marçalo, 2002). In these trips about two-thirds of the total sardine catch was slipped, leading to unaccounted mortality. However, this phenomenon seems to present a strong seasonality and also regional variation. The fishing practice of the same fleet was clearly seasonality marked, with the frequency and magnitude of slipping being considerably smaller in spring and summer than in autumn. Also differences between the quantities landed and discarded/slipped between ports were reported (Wise *et al.*, 2005). Furthermore, Borges *et al.* (2001b) and Erzini *et al.* (2002) indicated that, although slipping is common in the purse seine fleet of southern Portugal (Algarve), sardine only constitute 15% of the slipped catch. Thus, discards category had a risk ranking of moderate.

Small cetaceans are frequently sighted within the operation area of the Portuguese purse-seine fishery but the capture of these individuals occurs very rarely (Wise *et al.*, 2007). Thus, risk ranking in protected species was low. A reduced number small cetacean bycatches by purse seine vessels (8 individuals caught in 3 of 65 fishing events) was reported by Wise *et al.* (2007). However, although individuals were released alive it is impossible to know whether they survived the interaction.

Due to its characteristics, pelagic purse seine fishery has is no impact on the bottom habitat and risk ranking in this category was negligible. This type of impact could only occur when water depth is lower than the seine net height during the fishing operations with the lower edge of the gear wiping the sea bottom, however this is not common.

Trammel nets for soles.

The most abundant species in catches of this fishery are soles, as would be expected since they are its target species, and cuttlefish (*Sepia officinalis*). However, an important part of the catch was composed of a variety of other demersal and small and medium sized pelagic species (Stergiou *et al.*, 2006), as skates (*Raja* spp.), octopus and chub mackerel (Batista *et al.*, in press). In the Portuguese central coast bycatch represented about 60% of total catches of this trammel net fishery (Batista *et al.*, in press), which contributed to an extreme risk ranking in bycatch category.

Concerning discards category, trammel nets fishery achieved a risk ranking of high. In the central coast of Portugal, it presented one of the highest values of discards percentage (21.9% in weight and 52.8% of the total number of individuals) (Batista *et al.*, in press). In the southern coast, discards represented 13% in weight of the catches of smaller boats fishing with trammel nets close to shore (Borges *et al.*, 2001a) and 49% in number of individuals (Gonçalves *et al.*, 2007).

Protected species category achieved a moderate risk ranking. Few information is available for this fishery, however, most of the incidental catch and mortality of cetaceans that occur in Portugal are considered to be due to gill and trammel nets (Sequeira and Ferreira, 1994; Sequeira *et al.*, 1997). Gillnets, with the trawl, were also identified as the leading cause of accidental capture of cetaceans in the waters of Galicia (López *et al.*, 2003).

Trammel nets cause relative little disturbance to seabed communities (Jennings and Kaiser, 1998). However, when bottom set nets are lost, other than uncontrolled catches, gears may also damage benthic habitats, becoming a source of litter or entanglement for birds and marine mammals, among other groups (Baeta *et al.*, 2009; Brown and Macfadyen, 2007). In the

Portuguese coast, the number of nets lost seems to be also low, since fishermen say they have a high rate of success in retrieving their lost nets. Thus, trammel net ghost fishing does not seem to be an important source of resources mortality and habitat damage and habitat category achieved a low risk ranking.

Octopus traps

Although the target species is the main catch of octopus traps fishery, bycatch still represents a significant fraction of the catch, so this fishery had a risk ranking of extreme in non-target species category. Octopus accounted for 54% of total catch in biomass and 47% of the number of individuals in octopus trap fishery in the central coast of Portugal (Batista, 2007). In discards category, octopus traps fishery had a high risk ranking. Discards represented 16% of the total catch, with octopus accounting for 84 % of discards biomass and 40% of total individuals discarded (Batista, 2007). However, the impact of the discard of these individuals in the octopus population seems to be very small, since individuals are generally returned to the sea still alive and able to continue its normal life cycle. Despite the little information available, traps did not seem to affect protected species and this fishery had a risk ranking of low in this category.

In habitat category traps fishery had a negligible risk ranking. This fishery is assumed to cause little physical damage to benthic habitat (Eno *et al.*, 2001). Traps are normally observed as static on the seabed. However, when insufficient line was deployed strong tides and large swell have been observed to cause them to bounce up and down on the seabed. Nonetheless, very few signs of impact on epifaunal species can be observed in these situations (Eno *et al.*, 2001). Also observations of pots and traps being dropped and hauled showed that these fisheries have little or no immediate effect on several benthic species that had previously been thought to be sensitive (Eno *et al.*, 2001) or on the abundance of the species in the areas where they are deployed (Eno *et al.*, 1996).

Deepwater longline

Deepwater longline for black scabbardfish achieved a moderate risk ranking in non-target species category, since catches were almost only composed by target species (89% in number and 84% in weight of total catch) (Fernandes and Ferreira, 2006). Other species are also caught frequently, namely deep-sea sharks as Portuguese dogfish, *Centroscymnus coelolepis*, leaf-scale gulper shark, *Centrophorus squamosus*), but mostly in reduced quantities (Bordalo-Machado and Figueiredo, 2009; Martins and Ferreira, 1995).

Discards category had a negligible risk ranking. Despite the little information, a very low percentage of discards (6% in number and 2% in weight of the total catch) is reported, which did not include black scabbardfish (ICES, 2006). Most discarded species was *Etmopterus pusillus*, followed by *Alepocephalus bairdii* and *A. carbo*. While the first two species are discarded because they have no commercial interest, the target species is discarded mainly because it's damaged due mostly to marine mammal predation (ICES, 2006). According to fishermen the capture of protected species happens very rarely, so protected species category had a low risk ranking.

Habitat category has a risk ranking of negligible, since given its characteristics deepwater longline fishery has is a very low impact on the bottom habitat.

Swordfish longline

Although the fishing effort primarily targets swordfish, some species of pelagic sharks are caught during some seasons or areas, increasing their importance especially when swordfish is less abundant (Santos *et al.*, 2002). Among these, blue shark (*Prionace glauca*) and the short-fin mako (*Isurus oxyrinchus*) are the most relevant. In the North Atlantic area, the ratio between blue shark and swordfish caught by the Portuguese longline swordfish fishery was constant (1.1-1.2) between 1990 and 1994, followed by an important increase from 1994 to 1997, reaching some stability from 1997 forward (2.8-3.1). Similar trends were observed for the ratio between the short-fin mako and swordfish, despite in this case the ratio had a much lower value (0.0-0.5) (Santos *et al.*, 2002). Given the importance of bycatch species in catches, this fishery achieved a risk ranking of extreme in non-target species category.

In discards category, this fishery achieved a low risk ranking. There is no quantification of the discards of this fishery, but considering fishermen testimony, it can be considered as reduced and mainly constituted by small swordfish that is often discarded still alive. Sharks, including blue shark, are always landed, despite its low market prices.

Bycatch from this fishery includes turtles, as loggerhead sea turtles (*Caretta caretta*) and, occasionally, leatherback sea turtles (*Dermochelys coriacea*), which are either hooked or entangled in the lines and sometimes released still hooked (Ferreira *et al.*, 2001). The mean turtle capture in the waters around Azores ranged from 0.04 turtles for 1000 hooks per month in May to 0.79 turtles for 1000 hooks per month in July (Ferreira *et al.*, 2001). Despite the scarcity of information, bycatch of marine birds, which is strongly discussed in the literature, seems to be low in this fishery (Cooper *et al.*, 2003). Therefore swordfish longline achieved a high risk ranking in protected species category.

Swordfish logline did not have any impact on the sea bed, therefore it achieved a negligible risk ranking in the habitat category.

Treat or mitigate the risk

Considering the risk rankings obtained for each category and fishery, a number of actions could be defined. Once an issue is rated as moderate or higher risk, it requires a more detailed assessment to determine what management measures, research and monitoring are necessary as defined in Table 2.4.

All fisheries had a risk ranking of extreme in non-target species category, with the exception of pelagic purse seine and deepwater longline, which makes it the most problematic issue. Since part of bycatch is discarded and never accounted for the official fisheries statistics, it is very difficult to gather information on the impact of commercial fisheries on fish populations.

Besides improving its quantification, the implementation of more adequate management measures and research aimed at identifying effective gear modifications to reduce bycatch could be very important to face this problem. Therefore, studies on fish behaviour patterns are needed to more accurately determine the best means to avoid the capture of or impact on untargeted species or undersized fish.

Discards, much related with bycatch, are also a fishery impact requiring attention. Both trawl fisheries presented very high rates of discards. Even though this fishing gear produces more damage on fish than others analysed, contributing to high quantities of fish returned to the sea, discards can only be effectively reduced with a reduction of the bycatch. The same applies to the trammel nets and octopus traps. On the other hand, purse seine has no large quantities of bycatch but discards, namely slipping, is the most problematic issue of this fishery. Some measures should be taken in order to reduce them, since the mortality associated to this phenomenon are unknown. In most European fisheries, management response to slipping has been setting up of monitoring schemes with shipboard observers obtaining catch data (ICES, 2000). Further work is necessary to obtain more accurate and detailed reporting of discard information in order to develop a database capable of supporting an EBFM, including the study of survival rates of discards to more accurately assess which species are most impacted. Awareness of commercial fishermen concerning the need for accurate catch and discard data, and the role this data plays in stock assessments and subsequent quota determinations is also important.

Concerning the catch of protected species, its real magnitude should be assessed in order to allow the developing and implementing of adequate management measures to prevent and reduce its impact. The introduction of bycatch reduction technologies has not always been successful (ICES, 2008). A framework in which managers and fishermen could co-operate to monitor and mitigate protected species interactions with fisheries and mortality, in a system that protects both fishing interests and protected species, can be a good strategy. The current system of fishery management in Portugal does not encourage such co-operation. Swordfish longline fishery in particular urgently needs management measures due to the high catches of turtles. FAO Guidelines specified that longline fisheries must develop and implement combinations of hook design, type of bait, depth, gear specifications and fishing practices that minimize sea turtle bycatch, incidental catch and mortality (FAO, 2005).

Impact on the bottom habitat differed among the two bottom trawl fisheries and to a large extent depends on the bottom conditions in the area fished (Valdemarsen *et al.*, 2007). Further research is still required on the impacts on habitats, including alteration of habitat structure and damage of benthic communities affected by fisheries, and on identifying effective gear modifications to reduce such impacts. Mitigation measures to reduce pressure on the bottom and minimize impacts during trawling should be implemented, which can include modifications in gears to reduce pressure on bottom or to improve of the efficiency of bottom trawls, reducing effort (e.g. Valdemarsen *et al.*, 2007). Moreover, also risk maps can be developed in order to restrict trawling activities within more sensitive areas. Concerning the other fisheries impacts in habitat, the risk rankings were either negligible or low and therefore did not require the development of specific additional management measures.

In order to assess the impact of fisheries on trophic interactions and supporting an EBFM, further research is required to achieve data that would allow the determination of such a risk, namely the impacts attributable to each fishery since the implementation of management measures will be made by fishery. A more detailed understanding of the life history of various species and interactions among species should be developed, as well as continued monitoring of environmental parameters in order to understand its influence on abundance and distribution of marine organisms.

Follow up monitoring of risks subsequently to the implementation of management measures is essential in order to determine whether the initiatives implemented in the strategy effectively minimised the risk of the undesirable event.

Discussion

Assessment of the historical, present and future states of marine ecosystems and the effects that humans and climate have on the state of an ecosystem are crucial to the scientific advice required to implement an EBFM (Livingston *et al.*, 2005). Effective management plans for fisheries requires knowledge of what parts of the environment are at risk of becoming ecologically unsustainable and an understanding of the specific issues causing that risk. Risk assessment is a primary means by which these needs are fulfilled (Astles and Green, 2005). The use of risk assessment in fisheries management is not new (e.g. Francis and Shotten, 1997; Lackey, 1994; Lane and Stephenson, 1998), however, it have been applied only to a limited number of contexts, such as Australian (Astles *et al.*, 2006; Fletcher, 2005; Ye *et al.*, 2005;) and New Zealand fisheries (Campbell and Gallagher, 2007), which are quite different from Portuguese fisheries.

While fish species commercially exploited are studied so that stocks can be managed, the impacts of fisheries on marine environment are much less known. The risk management method developed allowed to study the impacts of Portuguese fisheries beyond the effects on target species, namely the catch of non-target species and protected species, discards and the impacts on habitat and trophic interactions. It provided an overview of each fishery's impacts by bringing together data scattered in literature. Risk management method was successful not only in identifying and quantifying effects of fishing activities on the environment but also in prioritizing issues and research needs, providing a decision tool which can lead to better management decisions. Also it used a precautionary approach identifying issues with few or no information which are considered as considerable consequences.

The semi-quantitative risk assessment approach developed was the most suitable method for the Portuguese fisheries, which have considerable levels of data for their target species, but limited data for bycatch or ecosystem issues. This method proved to be relatively simple to apply and all issues could be assessed even with minimal data available. Data on the various impacts of each fishery was available as well as information on their likelihood. Risk assessment could be seen just as a first step in a process: once an issue is rated as moderate or higher risk, then it requires a more detailed assessment to determine what management, research and monitoring are necessary (Fletcher, 2005).

The seven fisheries studied covered a variety of gear types, including two trawl fisheries, a purse seine fishery, a trammel net fishery, a traps fishery and two longline fisheries. The issue needing more urgent attention is bycatch which was ranked as extreme risk in almost all fisheries, with the exception of purse seine and deepwater longline. Moreover, discards are also a problem in need of resolution. The fisheries impact on protected species is more preoccupant on surface longline fishery, since bycatch from this fishery often includes sea turtles. Concerning fisheries impacts on benthic habitats, trawl activity needs urgent action. Depending on the levels of risk found some actions have been suggested in order to reduce them. It is very important to ensure that the level of resources applied in the future management and/or monitoring of an issue are matched with the level of risk (Fletcher, 2005). Fisheries impact on trophic interactions could not be assessed given the lack of data as in Campbell and Gallagher (2007) for New Zealand fisheries. However, the need for data collection was highlighted.

The outcome of this study may provide the basis for future informed decision making by management, in addition to identifying issues requiring better information to ensure fisheries sustainability. Other environmental categories could not be included in the model described since data for such evaluations was many times limited. However, this method can be applied to the same fisheries in the future when more detailed and precise data are available, which will ensure a more realistic evaluation and reduce type II errors improving the efficacy of the model, or to different fisheries. Also model can be modified to assess other fisheries impacts on the environment or expanded to assess economic, social and/or cultural risks since ecology is only one of the components of the effective fisheries decision analysis framework required to a achieve a better fisheries management.

Acknowledgements

This study was co-funded by the European Union through the FEDER - Fisheries Programme (MARE), as well as by Fundação para a Ciência e a Tecnologia (FCT) through the grant attributed to F. Baeta (Grant SFRH/BD/19223/2004).

References

Astles, K., Green, M., 2005. How qualitative risk analysis contributes to management responses in management strategies for wild capture fisheries in Australia. Abstract of the oral presentation given at the 2005 Australian Society for Fish Biology Conference, 11-15 July 2005, Darwin, Australia.

Astles, K.L., Holloway, M.G., Steffe, A., Green, M., Ganassin, C., Gibbs, P.J., 2006. An ecological method for qualitative risk assessment and its use in the management of fisheries in New South Wales, Australia. Fish. Res. 82, 290-303.

Baeta, F., Costa, M.J., Cabral, H., 2009. Changes in the trophic level of Portuguese landings and fish market price variation in the last decades. Fish. Res. 97, 216-222.

Baeta, F., Costa, M.J., Cabral, H., 2009. Trammel nets' ghost fishing off the Portuguese central coast. Fish. Res. 98, 33-39.

Batista, M.I., 2007. Avaliação do impacto do plano de ordenamento da área marinha do Parque Natural da Arrábida na pesca comercial local. Master Thesis, Faculdade de Ciências da Universidade de Lisboa, Lisboa.

Batista, M.I., Teixeira, C.M. and Cabral, H.N., (in press). Catches of target species and bycatches of an artisanal fishery: the case study of a trammel net fishery in the Portuguese coast. Fish. Res.

Bordalo-Machado, P. and Figueiredo, I., 2009. The fishery for black scabbardfish (Aphanopus carbo Lowe, 1839) in the Portuguese continental slope. Rev. Fish Biol. Fisher. 19, 49-67.

Borges T.C., Costa M.E., Erzini K., Gonçalves I., Malaquias M., Olim S., Pais C., 2001. Análise e avaliação do efeito do arrasto nas espécies demersais da costa do Algarve: quantificação e estudos bioecológicos (REG 21). Relatório final: INTERREGII. Project No. 21/REG II/6/96. Fundação para a Ciência e Tecnologia, Portugal.

Borges, T.C., Erzini, K., Bentes, L., Costa, M.E., Gonc¸alves, J.M.S., Lino, P.G., Pais, C., Ribeiro, J., 2001b. By-catch and discarding practices in five Algarve (southern Portugal) métiers. J. Appl. Ichthyol. 17, 104-114.

Brown, J., Macfadyen, G., 2007. Ghost fishing in European waters: Impacts and management responses. Mar. Policy 31, 488-504

Campbell, M.L., Gallagher, C., 2007. Assessing the relative effects of fishing on the New Zealand marine environment through risk analysis. ICES J Mar. Sci. 64, 256-270.

Cochrane, K.L. 1999. Complexity in fisheries and limitations in the increasing complexity of fisheries management. ICES J. Mar. Sci. 56, 917-926.

Cooper, J., Baccetti, N., Belda, E.J., Borg, J.J., Oro, D., Papaconstantinou, C., Sánchez, A., 2003. Seabird mortality from longline fishing in the Mediterranean Sea and Macaronesian waters: a review and way forward. Sci.Mar. 67, 57-64.

Costa, M.E., Erzini, K., Borges, T.C., 2008. Bycatch of crustacean and fish bottom trawl fisheries from southern Portugal (Algarve). Sci. Mar. 72, 801-814.

Eno, N.C., MacDonald, D.S., Amos, S.C., 1996. A study on the effects of fish (Crustacea/Mollusc) traps on benthic habitats and species. Report to the European Commission Directorate General XIV, Study Contract No. 94/076.

Eno, N.C., MacDonald, D.S., Kinnear, J.A.M., Amos, S.C., Chapman, C.J., Clark, R.A., Bunker, F.S.P.D., Munro, C., 2001. Effects of crustacean traps on benthic fauna. ICES J. Mar. Sci. 58, 11-20.

Erzini, K., Costa, M.E., Bentes, L., Borges, T.C., 2002. A comparative study of the species composition of discards from five fisheries from the Algarve (southern Portugal). Fish. Manage. Ecol. 9, 31-40.

FAO, 2005. Report of the Technical Consultation on Sea Turtles Conservation and Fisheries. FAO Fisheries Report 765, FAO, Rome.

Ferreira, R.L., Martins, H.R., Silva, A.A., Bolten, A.B., 2001. Impact of swordfish fisheries on sea turtles in the Azores. Arquipélago. Life and Marine Sciences 18A, 75-79.

Fletcher, W.J., 2005. The application of qualitative risk assessment methodology to prioritize issues for fisheries management. ICES J. Mar. Sci. 62, 1576-1587.

Fletcher, W.J., Chesson, J., Sainsbury, K.J., Fisher, M., Hundloe, T., 2005. A flexible and practical framework for reposting on sustainable development for wild capture fisheries. Fish. Res. 71, 175-183.

Fonseca, T., Campos, A., Afonso-Dias. M., Fonseca, P., Pereira, J., 2008. Trawling for cephalopods off the Portuguese coast—Fleet dynamics and landings composition. Fish. Res. 92, 180-188.

Francis, R.I.C.C., Shotten, R., 1997. ‘‘Risk’’ in fisheries management: a review. Can. J. Fish. Aquat. Sci. 54, 1699-1715.

Garcia, S.M., Zerbi, A., Aliaume, C., Do Chi, T., Lasserre, G., 2003. The ecosystem approach to fisheries: issues, terminology, principles, institutional foundations, implementation and outlook. FAO Fisheries Technical Paper 443, FAO, Rome.

Gonçalves, J.M.S., Stergiou, K.I., Hernando, J.A. , Puente, E., Moutopoulos, D.K., Arregi, L., Soriguer, M.C., Vilas, C., Coelho, R., Erzini, K., 2007. Discards from experimental trammel nets in southern European small-scale fisheries. Fish. Res. 88, 5-14.

ICES, 2000. Report of the Study Group on Discard and By-catch Information. ICES CM 2000/ACFM.

ICES. 2006. Report of the Working Group on the Biology and Assessment of Deep-Sea.Fisheries Resources (WGDEEP). ICES CM 2006/ACFM:28.

ICES. 2008. Report of the ICES Advisory Committee, 2008. ICES Advice, 2008. Books 1 - 10. ICES, Copenhagen.

Jennings, S., Kaiser, M.J. 1998. The effects of fishing on marine ecosystems. Adv. Mar. Biol. 34, 11-16.

Lackey, R.T.,1994. Ecological Risk Assessment. Fisheries 19, 14-19.

Lane, D.E., Stephenson, R.L., 1998. A framework for risk analysis in fisheries decision-making. ICES J. Mar. Sci. 55, 1-13.

Livingston, P.A., Aydin, K., Boldt, J., Ianelli, J., Jurado-Molina, J., 2005. A framework for ecosystem impacts assessment using an indicator approach. ICES J. Mar. Sci. 62, 592-597.

López, A., Pierce, G.J., Santos, M.B., Gracia, J., Guerra, A., 2003. Fishery bycatches of marine mammals in Galician waters: results from on-board observations and an interview survey of fishermen. Biol. Conserv. 111, 25-40.

Martins, R., Ferreira, C., 1995. Line fishing for black scabbardfish (*Aphanopus carbo* Lowe,

1839) and other deep water species in the eastern mid-Atlantic to the north of Madeira. In Deep-water fisheries of the North Atlantic Oceanic slope, pp. 323–335. Ed. By A.G. Hooper. Kluwer Academic Publishers, Dordrecht.

Morais, P., Borges, T.C., Carnall, V., Terrinha, P., Cooper, C., Cooper, R., 2007. Trawl-induced bottom disturbances off the south coast of Portugal: direct observations by the 'Delta' manned-submersible on the Submarine Canyon of Portimão. Mar. Ecol. 28, 112-122.

Pikitch, E.K., Santora, C., Babcock, E.A., Bakun, A., Bonfil, R., Conover, D.O., Dayton, P. Doukakis, P., Fluharty, D., Heneman, B., Houde, E.D., Link, J., Livingston, P.A., Mangel, M., McAllister, M.K., Pope, J., Sainsbury, K.J., 2004. Ecosystem-Based Fishery Management. Science 305, 346-347.

Rosenberg, A.A., Restrepo, V.R., 1994. Uncertainty and risk evaluation in stock assessment advice for U.S. marine fisheries. Can. J. Fish.Aquat. Sci. 51, 2715-2720.

Santos, M.N., Alexandra Garcia, A., Pereira, J.G. 2002. A historical review of the by-catch from the Portuguese surface long-line swordfish fishery: observations on blue shark (*Prionace glauca*) and short-fin mako (*Isurus oxyrinchus*). Collective Volume of Scientific Papers ICCAT 54, 1333-1340.

Sequeira, M., Ferreira, C., 1994. Coastal Fisheries and Cetacean Mortality in Portugal. Report of the International Whaling Commission 15, 165-174.

Sequeira, M., Inácio, A., Silva., M.A., 1997. Cetacean strandings in Portugal: 1993-1995. European Research on Cetaceans 10, 136-140.

Stergiou, K.I., Moutopoulos, D.K., Soriguer, M.C., Puente, E., Lino, P.G., Zabala, C., Monteiro, P., Errazkin, L.A., Erzini, K., 2006. Trammel net catch species composition, catch rates and métiers in southern European waters: a multivariate approach. Fish. Res. 79, 170-18.

Stratoudakis, Y., Marçalo, A., 2002. Sardine slipping during purse-seining off northern Portugal. ICES J. Mar. Sci. 59, 1256–1262.

Valdemarsen, J.W., Jørgensen, T., Engås, A., 2007. Options to mitigate bottom habitat impact of dragged gears. FAO Fisheries Technical Paper 506. FAO, Rome.

Wise, L., Ferreira, M., Silva, A., 2005. Caracterização da Pesca de Cerco na Costa Oeste Portuguesa. Relat. Cient. Téc. IPIMAR, Série digital 24.

Wise, L., Silva, A., Ferreira, M., Silva, M.A., Sequeira, M., 2007. Interactions between small cetaceans and the purse-seine fishery in western Portuguese waters. Sci. Mar. 71, 405-412.

Ye, Y., Loneragan, N., Die, D., Watson, R., Harch, B., 2005. Bioeconomic modeling and risk assessment of tiger prawn (Penaeus esculetus) stock enhancement in Exmouth Gulf, Australia. Fish. Res. 73, 231-249.

CHAPTER 3

Elasmobranch bycatch in trammel nets fisheries in the Portuguese west coast

Authors
Filipa Baeta[a], Marisa Batista[a], Anabela Maia[b], Maria José Costa[a,c], Henrique Cabral[a,c]

Authors' affiliation
[a]Instituto de Oceanografia, Faculdade de Ciências da Universidade de Lisboa, Campo Grande, 1749-016 Lisboa, Portugal
[b]University of Rhode Island, Department of Biological Sciences, 120 Flagg Road, Kingston, RI, USA
[c]Departamento de Biologia Animal, Faculdade de Ciências da Universidade de Lisboa, Campo Grande, 1749-016 Lisboa, Portugal

Submitted
Fisheries Research

Elasmobranch bycatch in trammel nets fisheries in the Portuguese west coast

Abstract: Elasmobranchs are an important component of bycatches of the Portuguese artisanal fisheries, but no assessment and management programs have yet been established. Elasmobranch catches have been decreasing in Portugal, which might indicate that these species are being overexploited. This study analysed elasmobranch catches in trammel nets fisheries in the Portuguese west coast. Thirty seven sampling surveys were conducted aboard commercial fishing vessels, on a seasonal basis between October 2004 and August 2005. A total of 11 elasmobranch species were caught (seven Rajiformes, two Torpediniformes and two Carchariniformes), representing 4% of the total fish catches and 15% of the total weight. Raja *clavata* was the most important species in number (7.4 ind 10000 m-1 of net) and *Raja undulata* the most important in weight (8512.4 g 10000 m-1 of net). Despite only 7.8% in weight, discards represented 24.8% of specimens caught in number, with seven of 11 caught elasmobranch species discarded. A marked seasonality was noticed, being the lowest value of species richness registered in spring (four species) and the highest in autumn (11 species). These seasonal variations could be related to the migratory habits of these species. For the most abundant species it was also possible to outline depth range preferences.

Keywords: elasmobranch, trammel nets, bycatch, discards, Portuguese artisanal fisheries.

Introduction

Worldwide, there is increasing concern over the capture of elasmobranchs as bycatch and the need for management advice. According to FAO statistics, the global elasmobranch landings are currently about 760000 tons; however, a similar amount may be unreported bycatch (Bonfil, 1994). This bycatch is unmanaged in most fisheries and elasmobranchs are less able to sustain their populations under fisheries regimes designated to sustain the target teleosts or invertebrates (Heuter, 1998) because of their slow growth, late maturity, long life spans, low fecundity and the close relationship between recruitment and parental stock of elasmobranchs (Stevens *et al.*, 2000). These characteristics make them extremely vulnerable even to modest levels of fishing (Megalofonou *et al.*, 2005). Skates and sharks also play a fundamental role in the ecosystem trophic relationships and most of them are predators at, or near, the top of marine food webs (Stevens *et al.*, 2000). All these aspects make it very important to increase knowledge and to ensure proper management of these species.

The main problem in the assessment and management of the elasmobranch fisheries is the lack of basic biological information and appropriate fisheries databases (Pawson and Vince, 1999). Castro *et al.* (1999) conducted a preliminary evaluation of the status of shark species worldwide and determined that there had been severe population declines for almost all the 26 shark species for which catch or landing data had been available for more than 10 years. Once over-fished many elasmobranch populations would take several years to recover (Stevens *et al.*, 2000).

One additional difficulty in management is that there are still problems with the correct identification of these less known species, mainly due to their low economic value (Stevens *et al.*, 2000). FAO statistics showed that less than 15% of total chondrichthyan landings were identified to species level in 1998, and 45% of total landings, were only identified as 'chondrichthyans'. In addition, a total of over 10 million tons of world fisheries landings were identified as miscellaneous marine fish of which some are likely to be sharks (FAO, 2002).

Elasmobranchs are a significant component of bycatches of the artisanal fisheries in Portugal (Coelho *et al.*, 2005; Correia and Smith, 2003; Erzini *et al.*, 2002; Machado *et al.*, 2004). Since part of this bycatch is discarded and never accounted for the official fisheries statistics, it is very difficult to gather information on the impact of these fisheries on elasmobranch populations and no management or monitoring programs have been established yet.

Trammel nets are highly represented in the Portuguese artisanal fisheries. This fishing gear is included in various métiers which are characterized by different combinations of mesh sizes, fishing grounds, fishing time, season, markets and consequently target species (Borges *et al.*, 2001; Stergiou *et al.*, 2006). Although trammel nets are fairly selective, they capture a high diversity of species, being most of them non-target species. Amongst these non-target species (bycatches), there are both non-commercial species, that are discarded, and commercial species, that are retained and landed.

Discarding can affect biodiversity and community structure (Goñi, 1998). With the increasing emphasis on conservation and management at the multi-species and ecosystem levels, there is an urgent need to evaluate discarding practices and to quantify discard composition and mortality in order to understand the impacts at the population, trophic and ecosystem levels (Borges *et al.*, 2001; Hall *et al.*, 2000) and contribute to a better definition of technical measures (Gonçalves *et al.*, 2007).

Not many studies have been done in Portugal on the impact of trammel net fisheries and these were mainly concentrated on the southern coast of mainland (Borges *et al.*, 2001; Erzini *et al.*, 1997, 2002, 2006; Gonçalves *et al.*, 2007, 2008). Bycatch and discards of elasmobranchs have been studied worldwide (e.g. Carbonell *et al.*, 2003; Fernandez *et al.*, 2005; Mckinell and Seki, 1998; Revill *et al.*, 2005; Shepherd and Myers, 2005), but in Portugal few works have been conducted (Coelho *et al.*, 2005; Coelho and Erzini, 2008). In the past few years, elasmobranch catches have been decreasing in Portugal, which might indicate that these species are being over-exploited (Coelho *et al.*, 2005). This article presents the results of the research carried out by observers onboard trammel net fishing vessels working in Portuguese west coast. The main objective of this study was to analyse elasmobranch catches and discards and to add to management-relevant information on species characteristics, abundance and distribution.

Material and Methods

Samplings were carried out in commercial fishing vessels from two of the most important fishing harbours of the Portuguese west coast, Setúbal and Sesimbra, between October 2004 and August 2005. Data from a total of 37 fishing trips, 18 in Sesimbra and 19 in Setúbal, were collected in a seasonal basis - 9 in autumn, 8 in winter, 10 in spring and 10 in the summer.

The sampling area is located off the Portuguese central coast, within 38º and 39º North and 8º and 10º West, from 0.25 to 6 nautical miles off the coast at depths range between 10 m and 115 m, approximately (Figure 3.1). Winds were predominantly from North and Northeast quadrants, ranging on average from 8 to 20 knots.

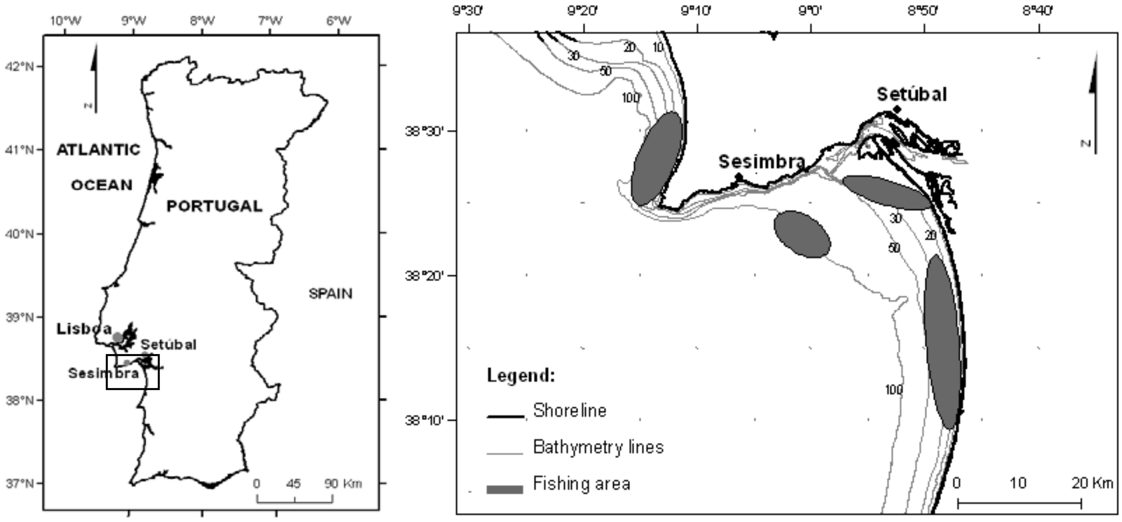


Figure 3.1. Map of the study area with the location of the fishing area of the vessels surveyed.

Vessels were randomly chosen and fishers' participation in this study was voluntary. Ten vessels were sampled, 4 from Sesimbra and 6 from Setúbal (overall length between 10 and 14 m, crew from 3 to 5 fishermen). In each survey, observers accompanied commercial fishers during one full-day fishing trip, which lasted on average ca. 10 h. Vessels left the fishing harbour before sunrise and travelled to the fishing grounds where nets were set during the last fishing trip. Fishermen usually began to retrieve their nets at sunrise.

A total of 136 bottom trammel net sets were sampled, which corresponded to 204 km in length. All trammel nets sampled had the same characteristics: 3 panels made of polyethylene, 1.5 to 2.5 m deep and ca. 40 m long and mesh size of the inner panel equal to 100 mm (minimum allowed by Portuguese legislation). Trammel net sets were usually composed of a large number of these sheets (usually more than 2000 m long), with a gap of ca. 1 m between consecutive sheets. Net sets were anchored at each end on the sea bottom. Senegalese sole, *Solea senegalensis* Kaup, 1858, common sole, *Solea solea* (Linnaeus, 1758) and cuttlefish, *Sepia officinalis* Linnaeus, 1758 are the target species of this fishery. These species have high importance in Portuguese landings and acquire special relevance in the central coast, since near 60% of total soles landings occur in this area being almost all from trammel nets' fishery (source: DGPA).

When each net was retrieved, specimens were untangled from the net by fishers who decide whether they are retained or discarded. Those retained were identified and their total length (to the nearest millimetre) and weight (to the nearest 5 grams) registered and separated in specimens for sell and for fishers' personal consumption. As most of the individuals were dead when they were untangled from the nets, discards were preserved in ice and brought to the laboratory to be identified, measured and weighed. The individuals discarded that remained alive were processed on board and returned to the sea. Additional data, as net length, haul location and depth, fishing time (total immersion time of nets) and number of sheets in each set were also collected.

For elasmobranch species, total catches and catch per unit of effort (CPUE) per species (number and weight per 10000 m of net) were determined. Estimates of the discards, retained portion of catches for sale and for the fishermen's own consumption were also analysed for each species. For the most important species in number, the existence of significant differences in the length of the individuals retained and discarded was analysed using analysis of variance (α=0.05).The total annual amount of elasmobranch discards from this trammel nets fishery was estimated based on mean number of individuals and mean weight discarded per vessel in each fishing day and fishing effort in the sampled area (fishing days per year and total number of vessels).

Catches by season were calculated for the most abundant elasmobranchs' species in catches. Also for the most important species in number, depth range preferences were outlined and the existence of significant differences in the depth at species level in each season was analyzed with analyses of variance (α=0.05). The depth range considered is limited to 0-125 m, given that 125 m was the maximum depth to which the nets sampled were set.

Results

A total of 11 elasmobranch species (428 specimens; 479 kg) were caught, seven Rajiformes, two Torpediniformes and two Carchariniformes, accounting for 4% of the total catches in number and 15% in weight. All elasmobranchs caught were identified to the species level, except for three individuals that could only be identified as *Raja* spp., due their high degradation level. *Raja clavata* Linnaeus, 1758 was the most abundant species comprising 35.0% of all elasmobranchs (7.4 ind 10000 m-1 of net), followed by *Raja undulata* Lacepède, 1802 (20.1%; 4.2 ind 10000 m-1) and *Raja miraletus* Linnaeus, 1758 (19.4%; 4.1 ind 10000 m-1), as described in table 3.1. However, considering values of biomass caught, *R. undulata* was the most important species (comprising 34.9% of total elasmobranch weight; 8512.4 g 10000 m-

1), followed by *R. clavata* (27.2%; 6403.7 g 10000 m-1) and *Raja brachyura* Lafont, 1873 (24.8%; 5846.7 g/ 10000 m-1) (Table 3.1).

The main fraction of elasmobranch caught was retained (75.5% in number; 92.3% in weight) (Table 3.1). Amongst retained captures, an insignificant part was for fishermen own consumption (3.1% in number; 3.6% in weight), with the remaining fraction landed at the fishing docks. Elasmobranchs discarded represented 24.8% of total number of individuals caught, but only 7.8% in weight, with 7 of 11 caught species being discarded (Table 3.1). *Dasyatis pastinaca* (Linnaeus, 1758), *Mustelus mustelus* (Linnaeus, 1758), *Raja montagui* Fowler, 1910 and *Torpedo marmorata* Risso, 1810 were always retained, while species with low or no commercial value, such as *Myliobatis aquila* (Linnaeus, 1758) and *Torpedo torpedo* (Linnaeus, 1758) were always discarded. More than a half of *Scyliorhinus canicula* (Linnaeus, 1758) individuals were also discarded.

The main reasons found for discards were the low or inexistent species commercial value and their damage condition when disentangled. Captures with poor condition, i.e., individuals entangled showing higher degradation signs, were found especially after storming days (which lead to higher soak times since fishermen failed to retrieve nets during those periods). Although less important, fish size also seemed to contribute to the discards: specimens discarded had in general lower dimensions than the ones retained (Table 3.2). For *R. brachyura* there were differences in the lengths of the individuals retained and of the individuals discarded, presenting the latest smaller dimensions. The estimation of total annual amount of elasmobranch discarded from this trammel net fishery was ca. 9900 kg per year, which corresponds to 4250 individuals.

A marked seasonality was noticed, with the lowest value of species richness registered in spring (4 species; 70 individuals) and the highest in autumn (10 species; 233 individuals) (Figure 3.2). For some species that seasonality is quite clear. *R. clavata* presented its highest abundance in autumn, showing considerable lower values in the remaining seasons, especially in winter. *R. undulata* abundance presented a slight increasing trend between the coldest and warmer months. *R. miraletus* was present in the study area only in colder months, with highest abundance in winter. *M. aquila* was more abundant in summer, whereas *T. torpedo* was captured only in winter.

Table 3.1. Elasmobranchs' catches in a trammel net fishery. Catches and respective percentage, catches per unit of effort (per 10000 m of net) and fate (in percentage) in number (N) and weight (W).

	Number				Weight			
Species	**N (%)**	**N 10000 m^{-1} net**	**Retained (commercial) (%)**	**Discarded (%)**	**W (%) (g)**	**g 10000 m^{-1} net**	**Retained (commercial) (%)**	**Discarded (%)**
Dasyatis pastinaca	1 (0.2)	0.05	100.0 (100.0)	0.0	4400.0 (0.9)	216.54	100.0 (100.0)	0.0
Myliobatis aquila	14 (3.3)	0.69	0.0 (0.0)	100.0	6449.3 (1.3)	317.39	0.0 (0.0)	100.0
Mustelus mustelus	4 (0.9)	0.20	100.0 (100.0)	0.0	6975.0 (1.5)	343.26	100.0 (100.0)	0.0
Raja brachyura	56 (13.1)	2.76	83.9 (80.4)	16.1	118803.3 (24.8)	5846.71	95.9 (94.9)	4.1
Raja clavata	150 (35.0)	7.38	82.0 (80.7)	18.0	130121.3 (27.2)	6403.70	93.9 (89.1)	6.1
Raja miraletus	83 (19.4)	4.08	63.9 (60.2)	36.1	23403.8 (4.9)	1151.78	70.0 (65.8)	30.0
Raja montagui	4 (0.9)	0.20	100.0 (100.0)	0.0	1860.0 (0.4)	91.54	100.0 (100.0)	0.0
Raja undulata	86 (20.1)	4.23	94.2 (90.7)	5.8	167260.4 (34.9)	8231.44	99.0 (94.6)	1.0
Raja spp	3 (0.7)	0.15	33.3 (33.3)	66.7	3135.9 (0.7)	154.32	79.7 (79.7)	20.3
Scyliorhinus canicula	14 (3.3)	0.69	42.9 (21.4)	57.1	4952.4 (1.0)	243.72	57.4 (26.8)	42.6
Torpedo marmorata	2 (0.5)	0.10	100.0 (100.0)	0.0	4740 (1.0)	233.27	100.0 (100.0)	0.0
Torpedo torpedo	11 (2.6)	0.54	0.0 (0.0)	100.0	6705.6 (1.4)	330.00	0.0 (0.0)	100.0
Total	428	21.06	75.5 (72.4)	24.8	478806.81	23563.68	92.3 (88.7)	7.8

Table 3.2. Average lengths and size ranges for retained and discarded elasmobranchs.

		Retained		Discarded	
Species	**Nt**	**Average lenght (cm)**	**Size-range (cm)**	**Average lenght (cm)**	**Size-range (cm)**
Dasyatis pastinaca	1	80.0*			
Myliobatis aquila	14			51.9	19.2 - 70.0
Mustelus mustelus	4	74.9	56.0 - 99.5		
Raja brachyura	56	63.3	36.9 - 79.0	43.8	38.2 - 50.2
Raja clavata	150	45.0	20.4 - 101.0	41.8	30.5 - 71.0
Raja miraletus	83	40.2	35.5 - 47.5	39.4	25.5 - 49.5
Raja montagui	4	42.4	35.0 - 46.8		
Raja undulata	86	61.9	37.0 - 96.5	40.4	28.6 - 45.5
Scyliorhinus canicula	14	51.6	48.9 - 56.0	47.5	40.5 - 55.9
Torpedo marmorata	2	45.7	42.3 - 49.0		
Torpedo torpedo	11			32.4	23.7 - 40.4

* length of the specimen caught

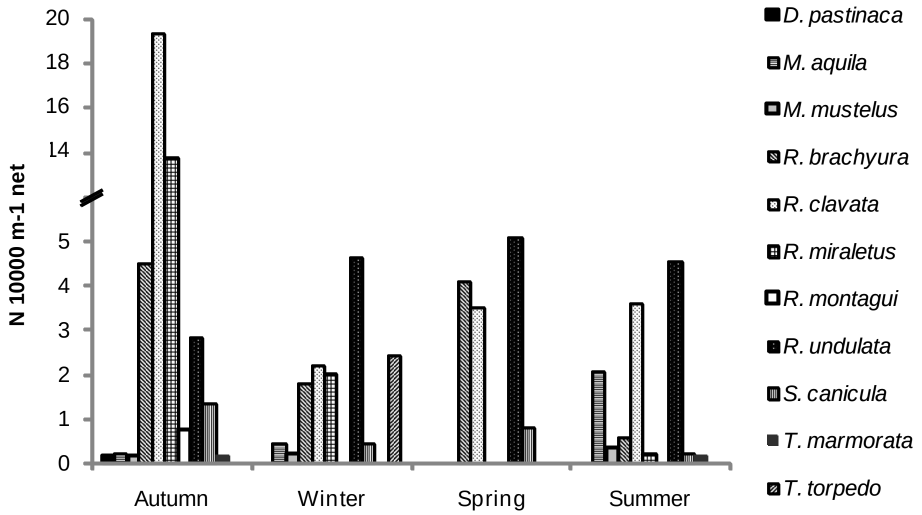


Figure 3.2. Catches in number of individuals of elasmobranchs species according to season.

For the most abundant species, it was possible to outline depth range preferences (Figure 3.3). *R. clavata* were captured within the entire depth range analysed (5-120 m depth), however, this species seemed to prefer deeper water during the coldest months. For *R. undulata*, which appeared down to about 50 m depth, a decreasing trend in captures was noticed with increasing depth. For this species there was no clear relationship between depth and season. For *R. brachyura*, which was captured within the same depth range, the opposite pattern was observed, with the highest catches obtained in deeper waters, and in this case the deeper water also seemed to be preferred during the coldest months. *R. miraletus* were found only upper than 50 m depth. Statistical tests showed that there were significant differences amongst depths where each skate's species mostly occurred in each season. For *R. undulata* there were significant differences between the depths where the species occurred in summer and the depths where occurred in autumn and spring. *R. clavata* occurred in autumn at depths significantly different from the depths where this species occurred in the other seasons. For *R. miraletus* there were significant differences in the depths where the species occurs in autumn and winter. Also *R. brachyura* occurred in winter at depths significantly different from where occurred in spring and summer.

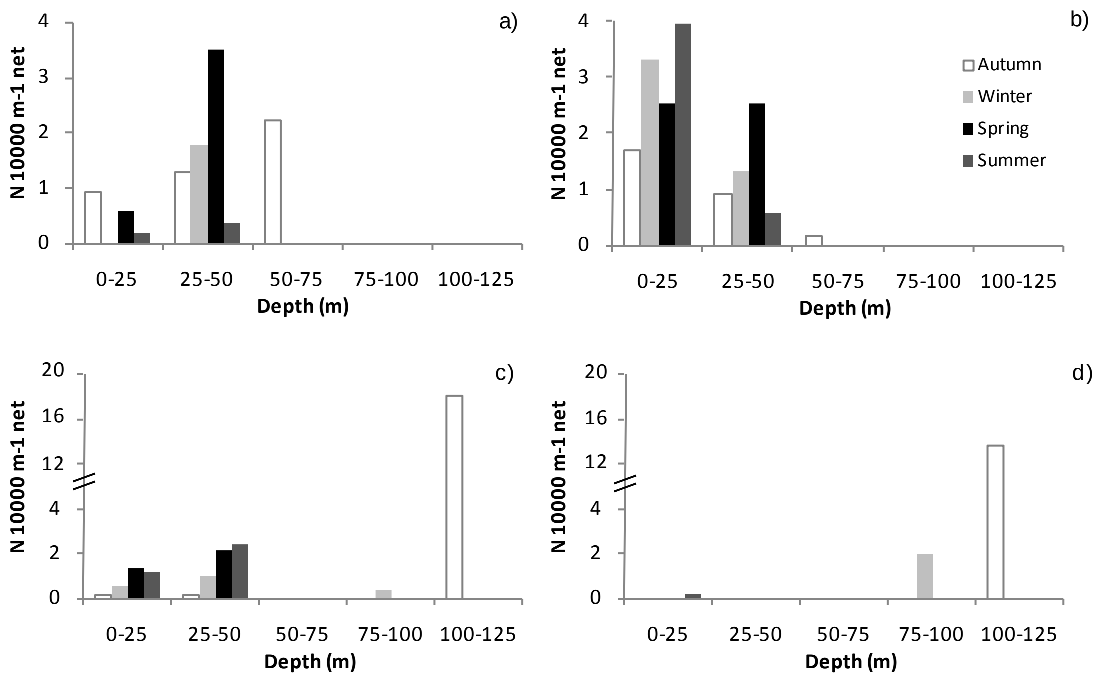


Figure 3.3. Catches in number of individuals of the most abundant elasmobranchs species according to depth and season: a) *Raja brachyura*; b) *Raja undulata*; c) *Raja clavata*; d) *Raja miraletus*.

Discussion

The impact of fishing on chondrichthyan stocks around the world is currently the focus of considerable concern (Stevens *et al.*, 2000). When taken as bycatch, they are often subject to high fishing mortality direct at teleosts' target species. Consequently, some elasmobranch species have been practically eliminated from large regions (Stevens *et al.*, 2000). Moreover bycatches constitute a high amount of unreported data that could be of great importance in stocks evaluation or in the development of recovery programs applied to species that are bycatch of other fisheries. Evaluating the impact of trammel nets fisheries in elasmobranchs, this study contributes to the management of these bycatch species.

Most studies on bycatch and discards of elasmobranchs consider trawl and longline fisheries (Carbonell *et al.*, 2003; Clarke *et al.*, 2005; Coelho and Erzini, 2008; Megalofonou *et al.*, 2005; Stobutzki *et al.*, 2002). Erzini *et al.* (2002) studied discards from the most important fisheries in southern Portugal and found that, despite a great diversity of species caught, including seven chondrichthyes species, trammel nets were those with lower discards. Another study from southern Portuguese coast confirmed that trammel nets have the lower value of mean discard rate per trip of the analysed fisheries (Borges *et al.*, 2001). Also for a trammel net fishery in southern Portugal, Coelho *et al.* (2005) found that 16 elasmobranch species were caught, accounting for 4.3% of the total catch. Our results showed that 11 elasmobranch species were caught, accounting for 4% of the total catches in number and 15% in weight, which was similar to results obtained by Coelho *et al.* (2005).

However, results obtained by Coelho *et al.* (2005) concerning discards were quite different than those obtained in our study. In trammel net fisheries from southern Portugal discards were low, accounting for only 5.4% of the elasmobranch catch; most of the elasmobranchs were either landed for sale or consumed by the fishermen themselves. In our study, discarding was important in terms of the number of species and number of individuals: despite only 7.8% in weight, discards represented 24.8% of specimens caught in number, with seven of the 11 caught species discarded. Differences between discarded rates using the same gear could be related to local species diversity, environmental constrains, social-economic aspects or simply due random factors (pers. observation).

D. pastinaca, *M. mustelus*, *R. montagui* and *T. marmorata* were always retained. It was expected that at least *D. Pastinaca*, dangerous to fishers due to its poisonous spine, and *T. Marmorata*, that can produce electric discharges, were discarded. The reduced catches of these species probably contributes to their retention on board. The other dangerous species were always discarded: *M. aquila*, which is also dangerous due to its poisonous spine, and *T. torpedo*, capable of inflicting a severe shock of up to 200 volts (Froese and Pauly, 2008). Fishers retained all species that have some commercial value. When few individuals of these species were captured, fishers kept them for personal consumption, due to the low selling value they would have at the fishing dock. This was also concluded by Gonçalves *et al.* (2007) for a similar fishery in the southern Portuguese coast. When the principal resources have lower catch rates, fishers avoid the decline in revenues trying to take greater advantage of bycatch species, such as skates, which can have a high relevance in revenues, and thus maintaining their activity economically sustainable. Since 1990, skates and rays annual landings have been around 1500 tons with high market price values, ca. 2.5 euros per kg currently.

Bycatch reduction devices have been tested in various types of fishing gear, but apart from some selectivity experiments (e.g. Erzini *et al.*, 2006), there has been no research on trammel net bycatch reduction. Nevertheless, choice of fishing ground, reduction in the number of fleets and soak time as well as the use of larger mesh sizes in the inner panel may reduce bycatches and discards (Gonçalves *et al.*, 2007). To reduce discards of the trammel net fishery existing regulation should be enforced, namely in which respects to nets soak time in order to minimize the amount of damage fishes, allowing them to be sold (Gonçalves *et al.*, 2007). A decrease in soak time during the warmer months could also contribute to higher quality of the landings since at higher water temperatures fish and invertebrates degrade faster and this small fleet does not have refrigerated storage on board. The release of smaller individuals could also be positive, however, even though most of these specimens are discarded, they are returned to sea either dead or with severe injuries that probably affect their survival. It is generally considered that none or very few of the discarded animals survive when returned to the sea (Mesnil, 1996). Studies on post-release survival show that capture by trammel nets is quite traumatic: stress and injuries incurred during encounter and subsequent escape may result in an unaccounted level of fishing mortality (Chopin *et al.*, 1996).

The seasonal variations of species abundance, with lowest species richness registered in spring and the highest in autumn, and the significant differences in the depth at which the most abundant species seasonally occurred could be related to the reproductive or latitudinal migratory habits of these elasmobranch species. Spawning migrations have been suggested for several rajid species. It is known that females of several species of skates tend to move inshore at shallow depths to lay eggs (e.g. Cox and Koob, 1993; Rydland and Ajayi, 1984; Walker and Hensen, 1996). Also nursery areas of elasmobranchs were typically in shallower water than adult habitats, an evident pattern for *R. brachyura*, *R. clavata* and *R. montagui* (Ellis *et al.*, 2005). However, despite the economic importance of rajids in the North-east Atlantic, their reproductive biology remains poorly known. Also, a bathymetric separation between species was suggested by results, which might be related to niche partitioning and/or competition between them.

The abundance of *R. clavata* is strongly correlated with depth, seabed sediment type, prey availability and suitable egg laying substrata (Martin *et al.*, 2005). This species is known to lay eggs in shallow waters and once the egg laying season is completed they segregate into single sex shoals in deeper water (Walker and Hessen, 1996). Classic mark-and-recapture data have shown that juveniles tend to remain in deeper waters for several years, whereas adults show seasonal movements, from deeper waters in winter, to shallower waters in the spring, where they are presumed to mate and lay the eggs (Walker *et al.*, 1997). In this study, this species was captured year round and across the whole depth range, although the highest values of abundance occurred in autumn at higher depths (>100 m). This could indicate a return of the adults to deeper waters after the egg laying season in shallow waters or food or temperature related migrations. Similarly, in bottom trawl fisheries of western Mediterranean its maximum values of abundance were reached between 100 and 300 m depth (Massutí and Moranta, 2003).

R. miraletus is also much more abundant in captures during the autumn season and about 100 m depth. Similar reasons might be at play here. In bottom trawl fisheries of western Mediterranean the bathymetric distribution of this species reach their maximum values at depths less than 100 m (Massutí and Moranta, 2003), which is similar to that found in the central Mediterranean, where it is mainly concentrated between depths of 50 and 150 m (Serena *et al.*, 2005).

R. undulata occurred in the fishing area throughout the year without major changes in abundance. In the south coast of Portugal, the gonadosomatic index for females of this species was higher during the winter, meaning that this species reproduces during this season, despite some specimens started reproducing earlier during the autumn (Coelho and Erzini, 2006). Our results do not allow us to infer about the reproductive season. In the catches of *R. undulata*, which appeared always below 60 m deep, a decreasing trend was noticed according to depth. In the trammel net fishery of southern Portuguese coast, this species reached depths exceeding 90 m but the highest catch rates were in the shallower depths with a progressive decrease with depth (Coelho *et al.* 2005). In the English Channel the maximum observed depth for this species was 72 m (Ellis *et al.*, 2005).

R. brachyura is a shallow water species living mainly on sandy and sand-rock bottoms (Catalano *et al.*, 2007). The available information on reproduction of this species in Portuguese waters suggests that its reproductive period is quite limited, with females sexually active only sampled in March (Serra-Pereira *et al.*, 2005). In our study seasonal migrations were not obvious, since *R. brachyura* abundance was so high in autumn as in spring. This species appeared down to about 60 m depth with the highest catches in the higher depths. Similarly, in western Mediterranean most of these animals were caught between 25 and 40m depth (Catalano *et al.*, 2007).

Elasmobranchs captured by trammel net fishery may be considered a reduced proportion of total trammel net captures, but its impact must be taken into account, especially for Rajidae. Our study pointed out that discards represented about 25% of elasmobranch specimens caught, which in our view is a very significant amount. The assessment of elasmobranchs bycatch and discards in order to understand the impact of fisheries on these species is an important step towards the development of a management program to ensure the sustainability of these resources, especially in multispecies fisheries as trammel net fishery.

Current conservation measures for elasmobranchs in Portuguese waters principally involve stipulating a minimum landing size. Since elasmobranchs are mainly caught as a bycatch, the establishment of a TAC may result in additional discards without necessarily reducing fishing mortality. The survival rate of discards is a relevant management consideration, which for some species it is believed that is high (e.g. lesser-spotted dogfish), but for other species it is unknown (ICES, 2008).

In mixed fisheries and without species discrimination, as the studied trammel net fishery, elasmobranch species may face abundance variations that could put their population in an unstable situation: involving a drastic decline of some species and an abnormal increase of others. Thus, the stability on Portuguese commercial landings of the generic group Raja spp. could be masking species decline (Figueiredo *et al.*, 2007). In recent years an increase on landed species diversity was obvious as an increase of species relative importance and changes on species abundance: *R. brachyura* and *R. clavata* relative importance decreased and at the same time *Leucoraja naevus* (Müller & Henle, 1841) relative importance showed a small increased (Figueiredo *et al.*, 2007). This shows that it is urgent to have better identification of elasmobranch species caught in order to obtain more information about such fragile species and to develop protective measures that allow its sustainable management.

The results obtained increased the amount of management-relevant information on elasmobranch species characteristics, abundance and distribution, suggesting, among other aspects, a spatial segregation between species, which could be very important in the development of management measures. More studies are needed to promote a more sustainable management of these species.

Acknowledgements

We thank the crews of the vessels sampled for their help on board. We are also grateful to all the volunteers that helped with sampling work. This study was co-funded by the European Union through the FEDER - Fisheries Programme (MARE), as well as by Fundação para a Ciência e a Tecnologia (FCT) through the grant attributed to F. Baeta (Grant SFRH/BD/19223/2004).

References

Bonfil R., 1994. Overview of world elasmobranch fisheries. FAO Fisheries Technical Paper 341, FAO, Rome.

Borges, T.C., Erzini, K., Bentes, L., Costa, M.E., Gonçalves, J.M.S., Lino, P.G., Pais, C., Ribeiro, J., 2001. By-catch and discarding practices in five Algarve (southern Portugal) métiers. J. Appl. Ichthyol. 17, 104-114.

Carbonell, A., Alemany, F., Merella, P., Quetglas, A., Románc, E., 2003. The by-catch of sharks in the western Mediterranean (Balearic Islands) trawl fishery. Fish. Res. 6, 7-18.

Castro, J.I., Woodley, C.M., Brudek, R.R., 1999. A preliminary evaluation of the status of shark species. FAO FisheriesTechnical Paper 380, FAO, Rome.

Catalano, B. , Dalu, M., Scacco, U., Vacchi, M., 2007. New biological data on Raja brachyura (Chondrichthyes, Rajidae) from around Asinara Island (NW Sardinia, Western Mediterranean). Ital. J. Zool. 74, 55-61.

Chopin, F.S., Arimoto, T., Inoue, Y., 1996. A comparison of the stress response and mortality of sea bream Pagrus major captured by hook and line and trammel net. Fish. Res. 28, 277-289.

Clarke, M.W., L. Borges, Officer, R.A., 2005. Comparisons of trawl and longline catches of deepwater elasmobranchs west and north of Ireland. J. Northw. Atl. Fish. Sci. 35, 429-442.

Coelho, R., Erzini, K., Bentes, L., Correia, C., Lino, P.G., Monteiro, P., Ribeiro, J., Gonçalves, J.M.S., 2005. Semi-pelagic longline and trammel net elasmobranch catches in southern Portugal: catch composition, catch rates and discards. J. Northw. Atl. Fish. Sci. 35, 531-537.

Coelho, R., Erzini, K., 2006. Reproductive aspects of the undulate ray, Raja undulata, from the south coast of Portugal. Fish. Res. 81, 80-85.

Coelho, R., Erzini, K., 2008. Effects of fishing methods on deep water shark species caught as by-catch off southern Portugal. Hydrobiologia 606, 187-193.

Correia, J.P.S., Smith, M.F.L., 2003. Elasmobranch landings for the Portuguese commercial fishery from 1986 to 2001. Mar. Fish. Rev. 65, 32-40.

Cox, D.L., Koob, T.J., 1993. Predation on elasmobranch eggs. Environ. Biol. Fish. 38, 117-125.

Ellis, J.R., Cruz-Martínez, A., Rackham, B.D., Rogers, S.I., 2005. The distribution of Chondrichthyan fishes around the British Isles and implications for conservation. J. Northw. Atl. Fish. Sci. 35, 195-213.

Erzini, K., Gonçalves, J.M.S., Bentes, L., Moutopoulos, D.K., Casal, J.A.H., Soriguer, M.C., Puente, E., Errazkin, L.A., Stergiou, K.I., 2006. Size selectivity of trammel nets in southern European small-scale fisheries. Fish. Res. 79, 183-201.

Erzini, K., Costa, M.E., Bentes, L., Borges, T.C., 2002. A comparative study of the species composition of discards from five fisheries from the Algarve (southern Portugal). Fish. Manag. Ecol. 9, 31-40.

Erzini, K., Monteiro, C.C., Ribeiro, J., Santos, M.N., Gaspar, M., Monteiro, P., Borges, T.C., 1997. An experimental study of gill net and trammel net 'ghost fishing' off the Algarve (southern Portugal). Mar. Ecol. Prog. Series 158, 257-265.

FAO, 2002. FAO Yearbook: Fishery Statistics: Capture Production 2000. FAO Fisheries Series 90/1. FAO, Rome.

Fernandez, L., Salmerón, F., Ramos, A., 2005. Change in elasmobranchs and other incidental species in the Spanish deepwater black hake trawl fishery off Mauritania (1992–2001). J. Northw. Atl. Fish. Sci. 35, 325-331.

Figueiredo, I., Moura, T., Bordalo-Machado, P., Neves, A., Rosa, C., Gordo, L.S., 2007. Evidence for temporal changes in ray and skate populations in the Portuguese coast (1998-2003) - its implications in the ecosystem. Aquat. Living Resour. 20, 85-93.

Froese, R., D. Pauly. Editors. 2008.FishBase. World Wide Web electronic publication. www.fishbase.org, version (12/2008).

Gonçalves, J.M.S., Bentes, L., Coelho, R., Monteiro, P., Ribeiro, J., Correia, C., Lino, P.G., Erzini, K., 2008. Non-commercial invertebrate discards in an experimental trammel net fishery. Fish. Manag. Ecol. 15, 199-210.

Gonçalves, J.M.S., Stergiou, K.I., Hernando, J.A., Puente, E., Moutopoulos, D.K., Arregi, L., Soriguer, M.C., Vilas, C., Coelho, R., Erzini, K., 2007. Discards from experimental trammel nets in southern European small-scale fisheries. Fish. Res. 88, 5-14.

Goñi, R., 1998. Ecosystem effects of marine fisheries: an overview. Ocean. Coast. Manage. 40, 37-64.

Hall, M.A., Alverson, D.L., Metuzals, K.I., 2000. By-catch: problems and solutions. Mar. Poll. Bull. 41, 204-219.

Heuter, R.E., 1998. Science and managementof shark fisheries – introduction. Fish. Res. 39, 105.

ICES. 2008. Report of the ICES Advisory Committee, 2008. ICES Advice, 2008. Book 7. ICES, Copenhagen.

Machado, P.B., Gordo, L.S., Figueiredo, I., 2004. Skate and ray species composition in mainland Portugal from the commercial landings. Aquat. Living Resour. 17, 231-234.

Martin, C., Vaz, S., Ernande, B., Ellis, J.R., Eastwood, P., Coppin, F., Harrop, S., Meaden, G., Carpentier, A., 2005. Spatial distributions (1989-2004) and preferential habitats of thornback ray and lesser-spotted dogfish in the Eastern English Channel. ICES CM 2005/N:23.

Massutí, E., Moranta, J., 2003. Demersal assemblages and depth distribution of elasmobranchs from the continental shelf and slope off the Balearic Islands (western Mediterranean) ICES J. Mar. Sci. 60, 753-766.

McKinnell, S., Seki, M.P., 1998. Shark bycatch in the Japanese high seas squid driftnet fishery in the North Pacific Ocean. Fish. Res. 39, 127-138.

Megalofonou, P., Yannopoulos, C., Damalas, D., De Metrio, G., Deflorio, M., de la Serna, J.M., Macias, D., 2005. Incidental catch and estimated discards of pelagic sharks from the swordfish and tuna fisheries in the Mediterranean Sea. Fish. Bull. 103, 620-634.

Mesnil, B. 1996. When discards survive: Accounting for survival of discards in fisheries assessments Aquat. Living Resour. 9, 209-215.

Pawson, M., Vince, M., 1999. Management of shark fisheries in the Northeast Atlantic. In: Case studies of the management of elasmobranch fisheries. R. Shotton (ed.). FAO Fish. Techical Paper 378, 1-46.

Revill, A. S., K. Dulvy, N. K., Holst, R., 2005. The survival of discarded lesser-spotted dogfish (Scyliorhinus canicula) in the Western English Channel beam trawl fishery. Fish. Res 71, 121-124.

Rydland, J. S., Ajayi, T. O., 1984. Growth and population dynamics of three species of Rajidae (Batoidei) in Carmarthen Bay, British Isles. ICES J. Mar. Sci. 41, 111-120.

Serena, F., Mancusi, C., Barone, M., Abella, A. J., 2005. Abundance and distribution of rays in South Ligurian and North Tyrrhenian Sea. ICES CM 2005/N:20.

Serra-Pereira, B., Figueiredo, I., Bordalo-Machado, P., Farias, I., Moura, T., Serrano Gordo, L., 2005. Description of Portuguese mixed-fisheries with positive landings of *Raja brachyura* Lafont, 1873 and *Raja montagui* Fowler, 1910. ICES CM 2005/N:18.

Shepherd, T. D., Myers, R. A., 2005. Direct and indirect fishery effects on small coastal elasmobranchs in the northern Gulf of Mexico. Ecol. Lett. 8, 1095-1104.

Stergiou, K. I., Moutopoulos, D.K., Soriguer, M.C., Puente, E., Lino, P.G., Zabala, C., Monteiro, P., Errazkin, L.A., Erzini, K., 2006. Trammel net catch species composition, catch rates and métiers in southern European waters: A multivariate approach. Fish. Res. 79, 170-182.

Stevens, J.D., Bonfil, R., Dulvy, N.K., Walker, P.A., 2000. The effects of fishing on sharks, rays, and chimaeras (chondrichthyans), and the implications for marine ecosystems. ICES J. Mar. Sci. 57, 476-494.

Stobutzki, I.C., Miller, M., Heales, D.S., Brewer, D.T., 2002. Sustainability of elasmobranch caught as bycatch in a tropical prawn (shrimp) trawl fishery. Fish. Bull. 100, 800-821.

Walker, P.A. Hessen, H.J.L., 1996. Long-term changes in ray populations in the North Sea. ICES J. Mar. Sci. 53, 1085-1093.

Walker, P.A., Howlett, G., Millner, R., 1997. Distribution, movement and stock structure of three ray species in the North Sea and eastern English Channel. ICES J. Mar. Sci. 54, 797-808.

CHAPTER 4

Changes in the trophic level of Portuguese landings and fish market price variation in the last decades

Authors
Filipa Baeta[a], Maria José Costa[a,b], Henrique Cabral[a,b]

Authors' affiliation
[a]Instituto de Oceanografia, Faculdade de Ciências da Universidade de Lisboa, Campo Grande, 1749-016 Lisboa, Portugal
[b]Departamento de Biologia Animal, Faculdade de Ciências da Universidade de Lisboa, Campo Grande, 1749-016 Lisboa, Portugal

Published
Fisheries Research (2009) 97, 216-222.

Changes in the trophic level of Portuguese landings and fish market price variation in the last decades

Abstract: Fishing can alter the structure of marine food web by selective removal of some species. Changes in marine food webs in Portuguese waters were evaluated based on estimates of the annual mean trophic levels (TLm) and fishing-in-balance index (FiB) of mainland, Azores, Madeira and total Portuguese marine fisheries landings for the period between 1970 and 2006. The log-relative-price-index (LRPI), that translates the relationship between the logarithm of prices of low and high trophic level species, was also calculated for each year. TLm of mainland landings showed a decreasing trend, reflecting changes in the structure of marine food webs, whereas in Azores and Madeira TLm increased. FiB index also showed a downward trend and negative values in mainland waters, which may be associated with unbalanced fisheries. In the period studied LRPI increased, indicating that high trophic level species had become more valuable in relation to species feeding at lower trophic levels. It is likely that the persistence of present trends will compromise the sustainability of fisheries. A better management is needed in order to reverse this decreasing trend in TLm in the long-term using an ecosystem-based approach.

Keywords: trophic level; landings; fishing-in-balance index; log-relative-price-index; fishing down the food web; Portugal

Introduction

Since fishing can alter the structure of marine ecosystems by selectively removing some species and by changing the physical support for the communities (Goñi, 1998), analysing its effects on the ecosystem has become a thrust area of investigation in recent years (Vivekanandan *et al.*, 2005). An ecosystem-based approach has been suggested as a complement to the traditional fisheries stock assessment and management (Sinclair *et al.*, 2002; Pauly *et al.*, 2003; Pikitch *et al.*, 2004). Ecosystem indicators (Rochet and Trenkel, 2003; Trenkel and Rochet, 2003) and ecosystem models have, therefore, been proposed to detect and describe the effects of fishing in marine ecosystems (Hollowed *et al.*, 2000; Shannon *et al.*, 2000).

Fisheries tend to first remove large, slow growing long-lived predatory fish. As the fishery develops there will be a shift to smaller species with faster turnover (Jennings *et al.*, 1998; Pauly *et al.*, 1998a; Pauly *et al.*, 1998b; Pauly and Palomares, 2005). Consequently, the mean trophic level (TLm) of the fish communities remaining in the system is reduced, eventually leading to declining trends of TLm in the catches extracted from an ecosystem, a process known as “fishing down marine food webs” (Pauly *et al.*, 1998a). Because the number of links in marine food webs is finite, and because few commercially attractive species are positioned near the base, Pauly *et al.* (2000b) argued that current practices will lead to the collapse of fisheries in many areas.

The TLm of landings of a particular area has been proposed as an indicator of the fishery-induced impacts in food webs structure (Pauly *et al.*, 1998a; Pauly *et al.*, 1998b; Pauly *et al.*, 2001; Pauly *et al.*, 2002; Rochet and Trenkel, 2003). This indicator is a useful way of describing the state of fisheries because: it reflects complexity; it is largely related to the size of target species, which is linked to their fecundity and thus to their scope for recruitment; it tends to reflect other types of stress, such as pollution; it allows the development of new approaches to the analysis of aquatic food webs and to obtain a series of TLm values of fish and invertebrates landed by fisheries that can be used to evaluate their impacts on marine ecosystems (Stergiou and Polunin, 2000).

TLm of fisheries landings (total marine and freshwater landings) appear to have globally declined in recent decades at a rate of about 0.1 per decade, without the landings themselves increasing substantially. At a regional, ocean-specific scale this decreasing trend was also observed, especially in the Northern Hemisphere. According to Pauly *et al.* (1998a), TLm of landings in the Northeast Atlantic has declined since the late 1960s. The “fishing down marine food webs” hypothesis triggered fisheries scientists to start searching for similar patterns at smaller scales and several studies have confirmed this theory at regional and local scales (Laurans *et al.*, 2004; Milessi *et al.*, 2005; Pauly *et al.*, 2001, Pinnegar *et al.*, 2002; Sala *et al.*, 2004; Sánchez and Olaso, 2004; Stergiou and Koulouris, 2000; Vivekanandan *et al.*, 2005).

Changes in fishery preferences are often driven by economic reasons. The value of a species will determine the investment that fishermen are willing to make in order to catch it, and thus how heavily it is targeted even at low abundance (Pinnegar *et al.*, 2002; Pinnegar *et al.*, 2006). In general, large fish species with a high trophic level command higher prices in the market than small low trophic level fishes or invertebrates (Pinnegar *et al.*, 2006). In general average market price of a species will increase as it becomes scarce (Murawski and Serchuk, 1989).

Portuguese waters include the Exclusive Economic Zone (EEZ) sub-area of mainland Portugal and the two EEZ sub-areas of the Autonomous Regions of Azores and Madeira. All three areas are in the subtropical/boreal transition zone of the Eastern Atlantic. As a result of their high biodiversity, there are several distinct fleets (métiers) characterized by the use of different fishing gear types targeting different commercially important species. In mainland Portugal fisheries focus on a high number of resources existing in fishing grounds located a short distance from shore, whereas in the autonomous regions, due to their oceanic nature, pelagic species are the most exploited.

The Portuguese fishing fleet can be divided in three segments: seine, trawl and multigear. The purse seine fishery targets mainly small pelagics like sardines *Sardina pilchardus*

(Walbaum, 1792), the most important species in terms of total landings in Portugal, Atlantic horse mackerel *Trachurus trachurus* (Linnaeus, 1758) and chub mackerel *Scomber japonicus* (Houttuyn, 1782). Trawl fisheries comprise two distinct fleets: one that targets fish such as Atlantic horse mackerel and European hake *Merluccius merluccius* (Linnaeus, 1758), and cephalopods, whilst the other targets crustaceans. The multigear fleet is the largest segment and catches a wide variety of species as it is made up of boats that are usually licensed to operate with gillnets, trammel nets, longlines and traps.

The impact of Portuguese fisheries in biological interactions, especially along the food web, remains poorly understood. The present study describes changes in Portuguese landings over time, analyses whether the TLm of landings is declining as a function of time and examines if these changes are reflected in the relative market price of living marine resources in Portuguese waters. The result of this study should provide valuable information for the future management of the Portuguese marine ecosystems.

Material and Methods

Landings in Portuguese waters and fleet composition between 1970 and 2006 were obtained from the National Statistical Institute database (INE). For the period between 1992 and 2006 statistics were also obtained from the General-Directorate for Fisheries and Aquaculture (DGPA) since these present a better taxonomic resolution. The DGPA data is comprised of 389 species or groups of species (316 fish, 31 crustaceans, 41 molluscs, 1 equinoderms) whilst the INE data aggregated the same data but only for 60 species or groups of species (42 fish, 6 crustaceans, 12 molluscs). For an enhanced interpretation of possible trends and patterns in the data and subsequent analysis, Portuguese waters were divided in mainland Portugal (hereafter referred to as mainland), Azores and Madeira. Also the evolution of Portuguese fishing fleet composition and landings by fleet segment were analysed.

Trophic level (TL) of each species was obtained from information in feeding studies and FishBase (Froese and Pauly, 2008), in the case of fish, and from TrophLab (Pauly *et al.*, 2000b), in the case of invertebrates. When available, data for Portuguese waters were used primarily; otherwise, data for neighbour areas or for the species in general were used. Landings and trophic levels of each species were subsequently used to calculate the annual mean trophic level (TLm) of landings as follows:

$$TLm = \frac{\sum TLijYij}{\sum Yij}$$

where TLm is the mean trophic level of landings in year j, Yij denotes the landing of species i in the year j and TLij is the trophic level of species i in the year j. The rate of TLm increase or decrease over time was calculated as the slope of a linear trend line.

Landings composition was analysed considering the species or groups of species with higher landings individually – sardine, horse mackerel, chub and Atlantic mackerels *Scomber scombrus* Linnaeus, 1758, silver *Lepidopus caudatus* (Euphrasen, 1788) and black scabbardfishes *Aphanopus carbo* Lowe, 1839 – and the other species grouped into ISCAAP (International Standard Statistical Classification of Aquatic Animals and Plants).

Moving down the food web may be the result of a deliberate choice, for which justification may be found in the ever-increasing, worldwide demand for animal protein. As biological production increases about 10 times as one moves down one trophic level in typical marine ecosystems (Pauly and Christensen, 2002), a fair evaluation of the impacts of a fishery should not be based on an index that declines as a fishery moves down the food web of a particular ecosystem. A good evaluation index should only decline when catches do not increase as expected, and, therefore, an index that allows us to assess whether a fishery is balanced in ecological terms or not (Pauly *et al.*, 2000a) was used in the present paper. The fishing-in-balance index (FiB) for any year i in a time series is defined by:

$$FiB = \log\left(Yi\left(\frac{1}{TE}\right)^{TLi}\right) - \log\left(Yo\left(\frac{1}{TE}\right)^{TLo}\right)$$

where Yi corresponds to landing in year i, TLi is the mean TL of the landing in year i, TE the trophic efficiency (here set at 0.10 following Pauly *et al.*, 2000a), and Y0 and TL0 the landing and mean TL, respectively, of the first year of the series. The FiB index changes its value only when a decrease in TL is not matched by a corresponding increase in catch, and conversely for increasing TL. Values of FiB < 0 may be associated with unbalanced fisheries, i.e. a lower catch than that theoretically predicted based on the productivity of the food web (Pauly *et al.*, 2000a). An increase in FiB indicates expansion of a fishery (geographically, or expansion beyond the initial ecosystem to stocks not previously exploited, or only lightly exploited) or that bottom-up effects have occurred, e.g. increased primary production. Conversely, a decrease indicates geographic contraction of the fisheries, a collapse of the underlying food web (impairing the ecosystem functioning) (Pauly and Palomares, 2005; Pauly and Watson, 2005). A decrease in FiB will also be observed if discarding takes place that is not reflected in the reported catches (Pauly and Watson, 2005).

Within each year the relationship between log price (€ kg^{-1}) and TL of each fish species was calculated using linear regression, considering the slope of the regression as the log-relative-price-index (LRPI; Pinnegar *et al.*, 2006) for that particular year. For this analysis only fish species that had a complete time series of price estimates for the period between 1970 and 2006 were used. The logarithm of fish prices was used because inflation acts non-linearly, which results in larger absolute increases in the price of high-value species compared to lower-value species. If the LRPI decreases, then the relative price of high TL species has declined or low TL species are becoming relatively more valuable and conversely if the LRPI increases then the price of high TL species has increased (above inflation) or the price of low TL species has declined. If the LRPI remains constant then this infers that there has been no significant redistribution of prices and that the price of each species has simply increased in line with inflation. The rate of the LRPI increase or decrease over time was calculated as the slope of a linear trend line.

Results

In the last decades total landings from Portuguese waters have shown a downward trend (Figure 4.1a). Nowadays, its values (145593 tons) represent no more than half the value of the landings in 1970 (298756 tons). During the analysed period, landings from the Azores were always higher than those of Madeira, however, the overall contribution of these two autonomous regions to the total Portuguese landings was small, in such a way that mainland landings made up more than 85% of the total landings. In effect, the mainland landings showed a decreasing trend, which was only inverted between 1983 and 1986, whilst landings from the Azores and Madeira were very similar in the beginning and in the end of the analysed period.

The TLm of the landings from Portuguese waters during 1970–2006 is shown in Figure 4.1b. Despite the observed fluctuations, TLm of mainland landings presented an overall decreasing trend in the order of 0.005 units per year (s.e. 0.035). In 1970 TLm of landings from mainland attained approximately 3.37. This maximum value was reached once more in 1987, subsequent to the increase verified between 1985 and 1987. After that TLm continued to show a downward trend, although, in the last three years, this trend appeared to be slightly inverted, attaining the value of 3.19 in 2006.

Contrary to what succeeded in mainland, TLm of landings of both autonomous regions landings increased between 1970 and 2006, more pronouncedly in Madeira (0.007 per year; s.e. 0.091) than in the Azores (0.003 per year; s.e. 0.125). Values of TLm attained in these regions, and their variations over time, were larger than those from mainland. In 1970 TLm of Azores' landings was 3.82, reaching its maximum value (4.04) in 1988. Between 1998 and 2001 it showed a marked decrease, followed by an increase until reaching 3.94 in 2006. TLm of Madeira's landings decreased from 4.15 in 1970 to 3.76 in 1980, increasing again to its maximum value in 2002 (4.30) and attaining 4.21 in 2006.

Considering the DGPA data for the period between 1992 and 2006 (Figure 4.1b), TLm for all considered regions' landings showed the same trend, however, TLm obtained with these data were lower for mainland waters and higher for both autonomous regions than those obtained with INE data.

A clear decrease in FiB index was observed for mainland landings between 1970 and 2006 with values always below zero (Figure 4.1c). The exception was only between 1984 and 1987. FiB index of the Azores' landings showed wide variations over time but rarely attained values below zero. In the 1980s FiB increased whilst at the end of the 1990s it decreased sharply to negative values; in the recent years FiB index has had an increasing trend. FiB index for Madeira's landings also presented a high variability during the analysed period: after a marked decrease at the end of 1970s, when it reached less than zero, an upward trend has been observed until now, with positive FiB values since 1987.

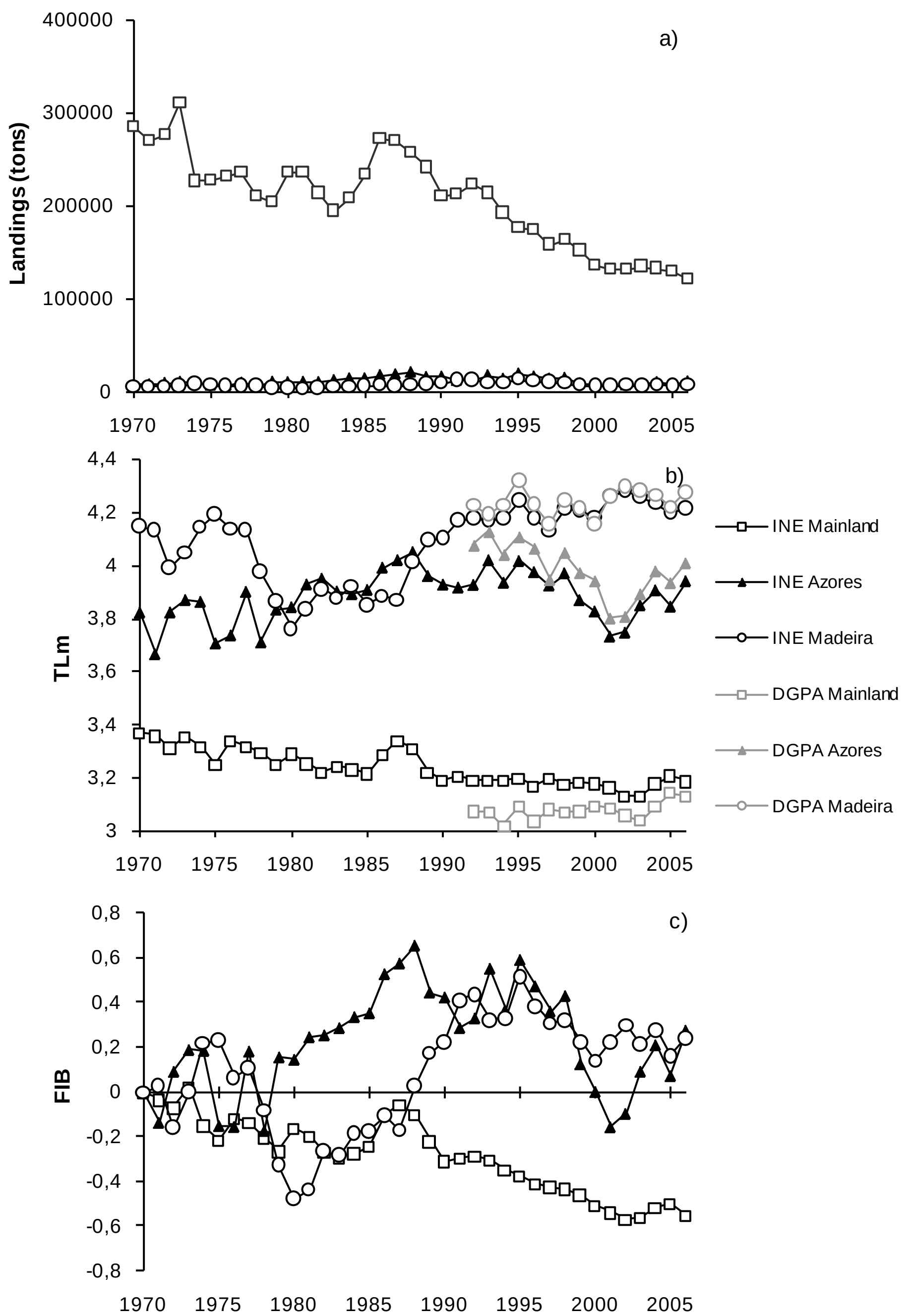


Figure 4.1. a) Annual landings, b) mean trophic level of landings and c) FiB index from Portuguese waters for the period between 1970 and 2006.

There was a concordant trend between TLm and landings in all analysed areas (Figure 4.2) with the highest values of TLm associated to the highest landings values. During the analysed period, TL versus landings plot for mainland presented a decline of TL accompanied by a decline in catches. For the Azores there is an increase both in catches and TL until 1990, after which both decline until 2000 when they start to rise again. In Madeira, despite landings not showing a significant increase, TL increased since 1980 until nowadays.

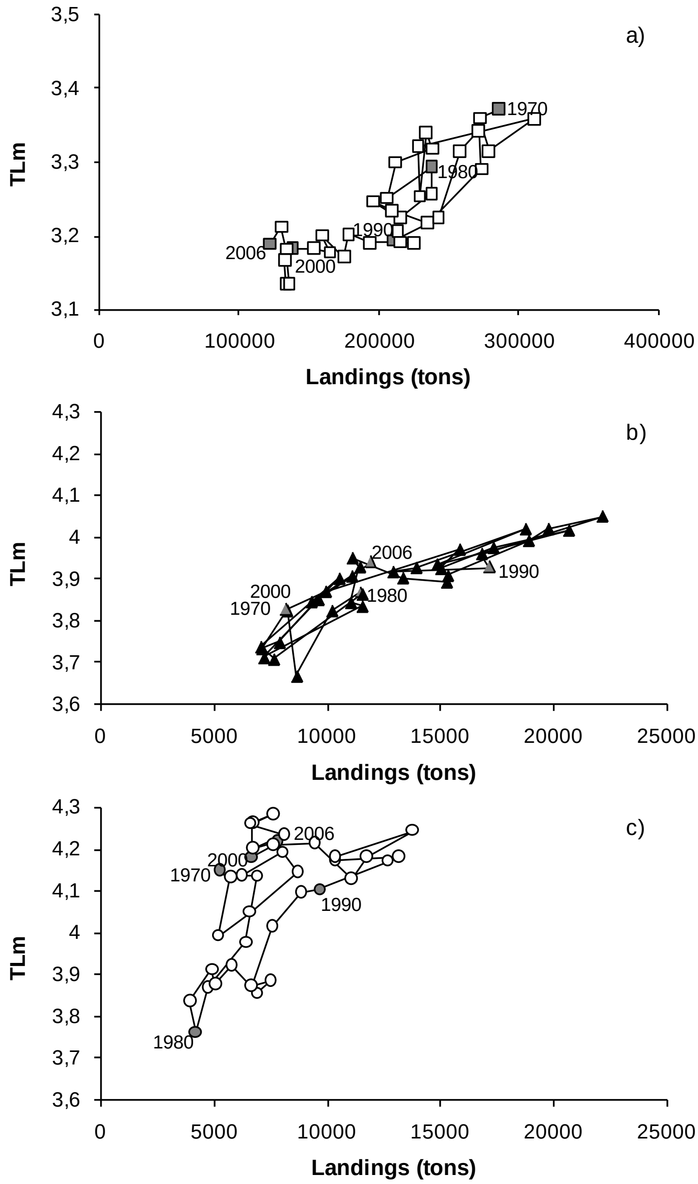


Figure 4.2. Mean trophic level of landings versus landings for a) mainland Portugal, b) Azores and c) Madeira, for the period between 1970 and 2006.

The decrease in TLm in mainland waters coincided with changes in landings' composition (Figure 4.3). Sardine was the most caught species in mainland waters, with highest landing values attained in the mainland. In 1970, this resource represented approximately 24% of total mainland landings (69158 tons). Its importance increased in the next years, attaining a maximum value of 48% of total landings in 1981 (113572 tons). After 1985, sardine catches decreased, with the minimum value achieved in 2006, even though its relative importance in the national landings increased (48021 tons; 39% of total landings). From 1970 to 2006, the most caught resources in both autonomous regions were tunas; Madeira also had high landing values of black scabbard fish. In all the three analysed regions, horse mackerel and chub and Atlantic mackerels occupied top positions in landings.

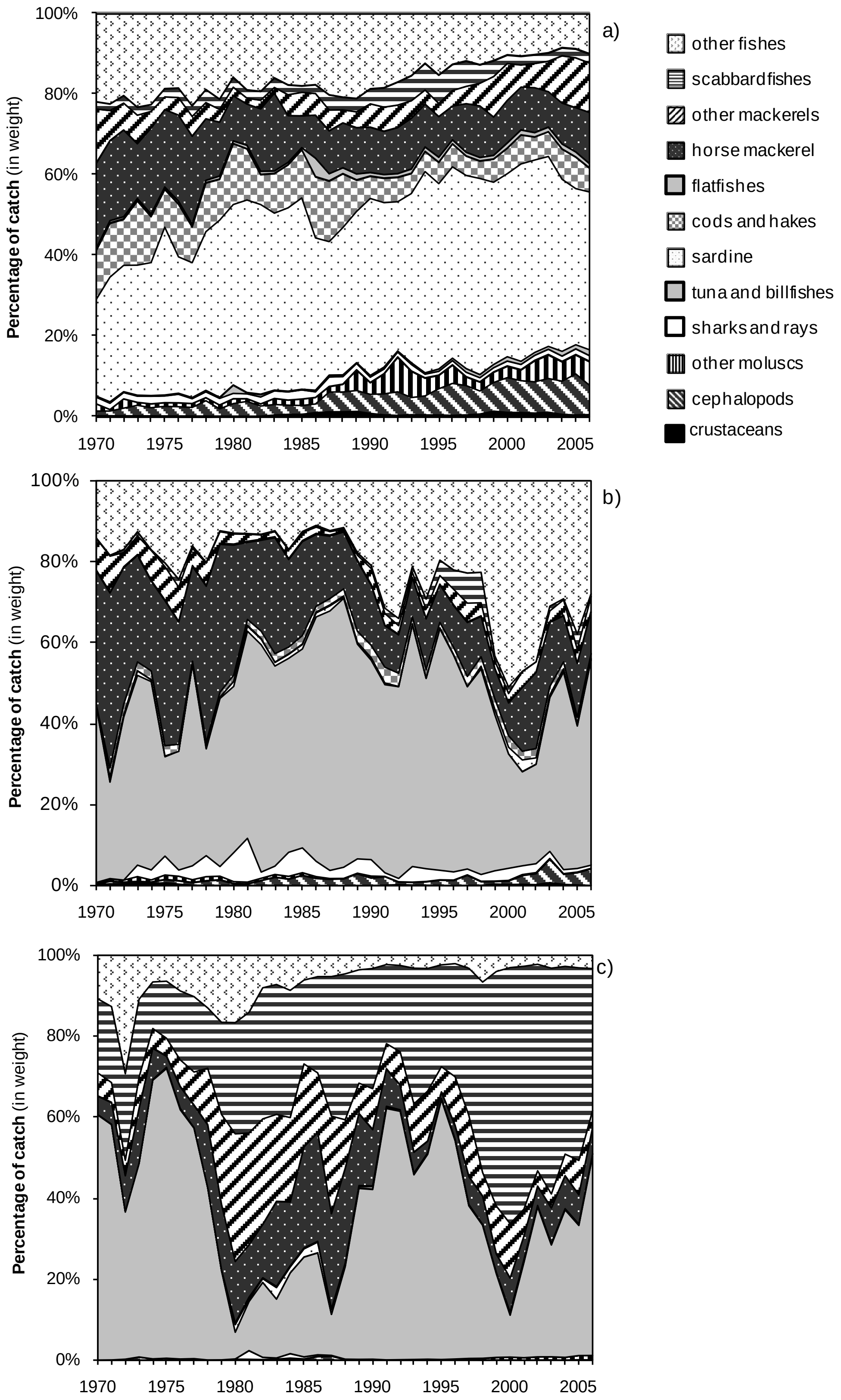


Figure 4.3. Landings composition for a) mainland Portugal, b) Azores and c) Madeira between 1970 and 2006. Landings were divided considering the species or groups with higher landings – sardine, horse mackerel, chub and Atlantic mackerels, silver and black scabbardfishes – and the other species grouped into ISCAAP (International Standard Statistical Classification of Aquatic Animals and Plants)—crustaceans, mollusks subdivided into cephalopods and other mollusks, sharks and rays, tuna and billfishes, cods and hakes, flatfishes and other fishes.

Between 1970 and 2006 the Portuguese fleet was reduced to almost half the vessels, however, the three segments of the fleet kept their relative proportions (Table 4.1). In mainland, where the reduction was greater, the three segments of the fleet can be effectively identified throughout the studied period, although the multigear was always the most important segment. This was also the only region where there is a trawling fleet. The proportion of landings correspondent to each of the segments in the mainland did not change much over time (Figure 4.4). In the 1970s catches from the trawl fleet corresponded to around 20%, decreasing over time to around 15%; seine and multigear fleets' contributions have remained at around 55% and 30%, respectively. In the Azores, multigear is the only segment present and even though in Madeira there was a seine fleet the number of vessels is reduced.

Along the analysed period LRPI increased at 0.004 per year (s.e. 0.051), although between 1976–1979 and 2001–2005 it decreased (Figure 4.5).

Table 4.1. Fishing fleet composition in mainland Portugal, Azores and Madeira.

Year	Total (number of vessels)	Mainland				Azores			Madeira			
		Multigear (%)	Seine (%)	Trawl (%)	Total (number)	Multigear (%)	Tuna	Total (number)	Multigear (%)	Tuna	Seine (%)	Total (number)
1970	17583	96.59	2.51	0.90	15375	100.00	2.46	1708	100.00	7.80	0.00	500
1980	19326	98.18	0.91	0.91	16772	100.00	1.66	1623	99.46	2.90	0.54	931
1990	16582	98.21	0.82	0.97	13988	100.00	1.96	1892	99.29	19.09	0.71	702
2000	10750	96.80	1.96	1.23	8601	100.00	1.03	1649	99.00	25.60	1.00	500
2006	9603	96.94	1.80	1.26	7551	100.00	0.76	1584	98.93	19.44	1.07	468

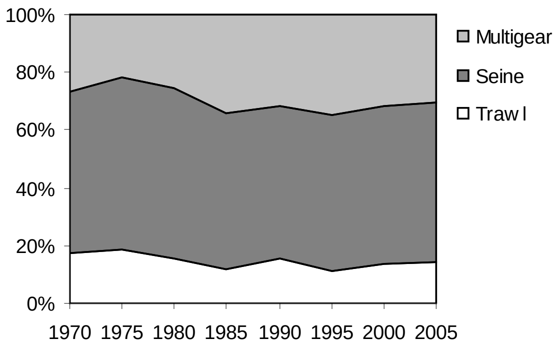


Figure 4.4. Landings by fleet segment – multigear, seine and trawl – in mainland Portugal between 1970 and 2006.

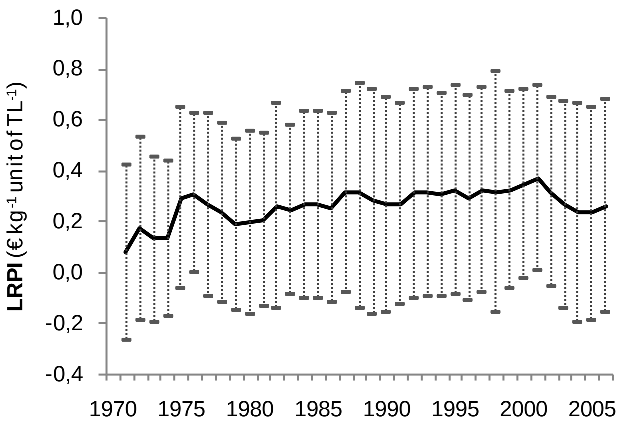


Figure 4.5. Log-relative-price-index (LRPI), that translates the relationship between log price (€ kg^{-1}) and mean trophic level of fish species, and respective confidence intervals for the period between 1970 and 2006.

Discussion

Although short-term fisheries management objectives may be partially fulfilled in the absence of ecosystem information, long-term strategies necessarily require placing fisheries in their ecosystem context (Christensen *et al.*, 1996; Sinclair *et al.*, 2002). The analyses carried out in the present paper, using an ecosystem indicator which describes a major aspect of the complex interactions between fisheries and marine ecosystems (Pauly and Watson, 2005), demonstrated marked changes in the structure of fisheries landings and fish communities from Portuguese waters in the past 36 years.

In the last decades, Portuguese landings have shown a downward trend, mainly due to the decrease of mainland's landings. Upon joining the European Union in 1986, Portuguese fisheries' management became based on the Common Fisheries Policy (CFP) and the policies and management measures undertaken since then seem to be the most important factors that contributed to this trend. At the same time TLm of landings from Portugal mainland waters has also decreased at a rate of about 0.005 per year, whilst the TLm of landings registered in the autonomous regions showed an upward trend (0.003 per year in Azores and 0.007 per year in Madeira). In the three areas the highest landings were not associated with the lowest trophic levels, as the "fishing down marine food webs" theory would predict; instead TLm declines were accompanied by declining catches.

Based on Pauly *et al.* (1998a) hypothesis that landings data can be used as ecosystem indicators, with changes in TLm of the catch a reflex of the changes in the ecosystem, the decreasing trend found in the mainland data may be interpreted as a result of a decrease in abundance of high trophic level species relative to low trophic level ones in the ecosystem. Since mainland fleet works not only in its EEZ but in the whole national EEZ, this decrease in TLm can be seen as representative of the entire national EEZ. Our results support the statement of Pauly *et al.* (1998a) that there have been great changes in fish communities in all marine areas, including the northeast Atlantic, although the decrease observed in our data (0.05 per decade) was lower than that estimated by these authors for northeast Atlantic (about 0.2 per decade) or on a global scale (0.1 per decade).

Decreasing trends in TLm of landings and fish communities, due to fishing, have been described for different locations: Aegean Sea marine communities (Stergiou and Koulouris, 2000), Canadian landings (Pauly *et al.*, 2001), Celtic Sea (Pinnegar *et al.*, 2002), Senegal and Guinea (Laurans *et al.*, 2004), Gulf of California (Sala *et al.*, 2004), Cantabrian Sea (Sánchez and Olaso, 2004), Uruguayan waters (Milessi *et al.*, 2005), Indian coastal communities (Vivekanandan *et al.*, 2005) and Argentinian–Uruguaian Common Fishing Zone (Jaureguizar and Milessi, 2008). On the contrary, Pérez-España *et al.* (2006) showed that the TLm in Mexican fisheries has increased in the last decades. Jennings *et al.* (2002), after analysing two long time series, concluded that there was no trend in the TLm of the demersal community of the North Sea. The observed changes differ both in direction and intensity, suggesting that responses of marine communities to exploitation or habitat degradation are the result of complex interactions and feedback mechanisms (Goñi, 1998).

The “fishing down marine food webs” phenomenon observed in mainland landings is also supported by the decreasing trend observed in FiB index, which suggests that the functioning of the foodweb that underlies fisheries is impaired. The application of FiB index to the North Atlantic (Pauly *et al.*, 2000a) indicated that the observed decrease in TLm, though initially matched by an increase in catches, eventually led to decreasing FiB indices, i.e. the decrease in catches did not compensate for the decrease in TLm. Pauly and Watson (2005) considered that this effect also occurs in world catches as a whole.

The positive values of FiB in autonomous regions and its increase during the 1980s suggest an expansion in fisheries beyond its traditional fishing area (or ecosystem) and that fisheries would not have yet reached their maximum catch level. Subsequently the decrease in FiB observed for Azores could be pointing out a heavy withdraw of biomass from the ecosystem, impairing its functioning. Madeira's FiB remained more or less constant, highlighting that TLm changes were accompanied by “ecologically correct” changes in the catch (Pauly and Watson, 2005).

The lack of “taxonomic resolution”, i.e. the over-aggregation of species under a higher taxonomic unit, also influences the estimation of TLm: whereas mainland's TLm values were lower when the landing statistics used were more detailed, the opposite occurred for the autonomous regions. According to Pauly *et al.* (1998b), the better the taxonomic resolution, the stronger the effect of “fishing down the marine food web” phenomenon. However, data of the present study suggest that finer taxonomic resolution contributes to higher accuracy of trends, whether they are increasing or decreasing.

The composition of historical landings may be affected by phenomena such as natural oscillations in species abundance, changes in fishing technology and economic factors which are likely to have influenced TLm of the landings (Caddy *et al.*, 1998; Caddy and Garibaldi, 2000).

The influence of environmental factors on abundance and distribution of marine organisms is not quite clear in Portuguese waters (Santos *et al.*, 2001b). Sardine has been presenting fluctuations in its abundance with consequences in the catch level (Mendes and Borges, 2006) that are believed to be associated with environmental factors and climatic changes. Since 1970s sardine population has been decreasing as a result of a winter upwelling phenomenon with negative consequences to the primary productivity and juveniles' survival (Borges *et al.*, 2003; Dickson *et al.*, 1988; Santos *et al.*, 2001a). This change on primary productivity can also influence other species of lower trophic levels, since these react more rapidly to environmental changes (Laurans *et al.*, 2004), and then propagate the effect up the foodweb. Despite this, species with low trophic level have gained importance in Portuguese landings.

Despite the reduction of the Portuguese fishing fleet to almost half the number of vessels between 1970 and 2006, the three fleet segments kept their relative proportions throughout the analysed period. Even if the reduction in the number of vessels was accompanied by a maintenance or even increase of the fishing power, the proportion of total landings for each fleet segment did not change much over time. Portuguese fishing practices have suffered few changes in the last decades and the fishing fleet is an aging fleet: nowadays about 62% of mainland vessels and 42% of trawlers are over 20 years old.

Also the establishment of TACs, mainly set on higher trophic level species, could have resulted in changes in landings composition. Most of the species landings declined in the last decades, however, this reduction does not appear to have been greatest for species subject to TAC in comparison to those that are not. Despite fluctuations, landings for many of these species have remained at similar levels to those recorded before the entry into the EU with some even increasing, namely blue whiting *Micromesistius poutassou* (Risso, 1827), Atlantic mackerel, monkfishes (*Lophius* spp.) and tunas. Thus, changes in landings TLm seem more related to changes in the exploited fishing community than to changes in fishing practices.

Fish prices are significantly influenced by changes in consumer income and preferences, the price of alternative products, their availability in the environment, catch restrictions, technologic innovation as well as weather (Ludicello *et al.*, 1999) and fuel prices (Pinnegar *et al.*, 2006). The present study revealed that the relative distribution of fish market prices in Portugal has changed over the past decades, with high TL species experiencing greater price rises than lower TL species. As species of higher TL become less abundant, their prices increased. At the same time for species of lower TL landings increased. Similar results were obtained by Pinnegar *et al.* (2002, 2006) for the Celtic Sea fish community. In the Italian fish market the LRPI remained remarkably stable but as a result of widespread expansion in fin-fish aquaculture (Pinnegar *et al.*, 2006). Sumaila (1998) suggested that globally, low TL species have become more valuable in relation to high TL species over the past 50 years, since markets are good at giving value to previously undesirable fish when target species become unavailable, therefore masking the real economic effects of changing trophic levels in marine ecosystems.

Results obtained in this study can be considered as good indicators of fishery-induced impacts on the marine community structure of Portuguese waters, highlighting the unsustainability of Portuguese fisheries resources. Achieving sustainable use of marine fisheries and ecosystems is not easy, but it can be enhanced by a better recognition of the scope and magnitude of the problems to be solved, to which this study presents a significant contribution. However, more studies on the ecosystem's structure and functioning are still required to promote better management solutions to address and attempt to reverse in the long-term the decreasing trend found in TLm through ecosystem-based approaches.

Acknowledgements

This study was co-funded by the European Union through the FEDER - Fisheries Programme (MARE), as well as by Fundação para a Ciência e a Tecnologia (FCT) through the grant attributed to F. Baeta (Grant SFRH/BD/19223/2004).

References

Borges, M.F., Santos, A.M.P., Crato, N., Mendes, H., Mota, B., 2003. Sardine regime shifts off Portugal: a time series analysis of catches and wind conditions. Sci. Mar. 67, 235-244.

Caddy, J.F., Garibaldi, L., 2000. Apparent changes in the trophic composition of world marine harvests: the perspective from the FAO capture database. Ocean. Coast. Manag. 43, 615-655.

Caddy, J.F., Csirke, J., Garcia, S.M., Grainger, R.J.R., 1998. How pervasive is “fishing down marine food webs?” Science 282, 1383-1385.

Christensen, N.L., Bartuska, M., Brown, J., Carpenter, S., D’Antonio, C., Francis, R., Franklin, J., MacMahon, J., Noss, R., Parsons, D., Peterson, C., Turner, M., Woodmansee R., 1996. Report of the Ecological Society of American Committee on the scientific basis for ecosystem management, Ecol. Appl. 6, 665–691.

Dickson, R.R., Kelly, P.M., Colebrook, J.M., Wooster, W.S., Cushing, D.H., 1988. North winds and production in the eastern North Atlantic. J. Plankton Res. 10(1), 151-169.

Froese, R., Pauly, D., Editors, 2008. FishBase. World Wide Web electronic publication. (www.fishbase.org, version 09/2008)

Goñi, R., 1998. Ecosystems effects of marine fisheries: an overview. Ocean. Coast. Manag. 40, 37-64.

Hollowed, A.B., Bax, N., Beamish, R., Collie, J., Fogarty, M., Livingston, P., Pope, J., Rice, J.C., 2000. Are multispecies models an improvement on single-species models for measuring fishing impacts on marine ecosystems? ICES J. Mar. Sci. 57, 707-719.

Jaureguizar, A., Milessi, A., 2008. Assessing the sources of the fishing down marine food web process in the Argentinean-Uruguayan Common Fishing Zone, Sci. Mar. 72, 25-36.

Jennings, S., Greenstreet, S.P.R., Hill, L., Piet, G.S., Pinnegar, J.K., Warr, K.J., 2002. Long-term changes in the trophic structure of the North Sea fish community: evidence from stable-isotope analysis, size-spectra, and community metrics. Mar. Biol. 141, 1085-1097.

Jennings, S., Reynolds, J.D., Mills, S.C., 1998. Life history correlates of responses to fisheries exploitation. Proc. R. Soc. London B 265, 333-339.

Laurans, M., Gascuel, D., Chassot, E., Thiam, D., 2004. Changes in the trophic structure of fish demersal communities in West Africa in the three last decades. Aquat. Living Resour. 17, 163-173.

Ludicello, S., Weber, M., Wieland, R., 1999. Fish, Markets and Fishermen: The Economics of Overfishing. Earthscan, London.

Mendes, H., Borges, M., 2006. A sardinha no século XX: capturas e esforço de pesca. Relat. Cient. Téc. IPIMAR 32, Série digital (http://ipimar-iniap.ipimar.pt).

Milessi, A.C., Arancibia, H., Neira, S., Defeo, O., 2005. The mean trophic level of Uruguayan landings during the period 1990-2001. Fish. Res. 74, 223-231.

Murawski, S.A., Serchuk, F.M., 1989. Mechanized shellfish harvesting and its management: the offshore clam fishery of the eastern United States. In: J.F. Caddy (Ed.), Marine Invertebrate Fisheries: Their Assessment and Management. John Wiley & Sons, New York, pp. 479–506.

Pauly, D., Christensen, V., 2002. Primary production required to sustain global fisheries. Nature 374, 255-257.

Pauly, D., Palomares, M.L., 2005. Fishing down marine food web: it is far more pervasive than we thought. Bull. Mar. Sci. 76, 197-211.

Pauly, D., Watson, R., 2005. Background and interpretation of the ‘Marine Trophic Index’ as a measure of biodiversity. Phil. Trans. Roy. Soc. Lond. B 360, 415-423.

Pauly, D., Alder, J., Bennett, E., Christensen, V., Tyedmers, P., Watson, R., 2003. The future for fisheries. Science 302, 1359-1361.

Pauly, D., Christensen, V., Froese, R., Palomares, M.L., 2000b. Fishing down aquatic food webs. Am. Sci. 88, 46-51.

Pauly, D., Christensen, V., Dalsgaard, J., Froese, R., Torres, F., 1998a. Fishing down marine food webs. Science 279, 860-863.

Pauly, D., Christensen, V., Guénette, S., Pitcher, T.J., Sumaila, U.R., Walters, C.J., Watson, R., Zeller, D., 2002. Towards sustainability in world fisheries. Nature 418, 689-694.

Pauly, D., Christensen, V., Walters, C., 2000a. Ecopath, ecosim and ecospace as tools for evaluating ecosystem impact of fisheries. ICES J. Mar. Sci. 57, 697-706.

Pauly, D., Froese, R., Christensen, V., 1998b. Response to Caddy, *et al.*, 1998. How pervasive is “fishing down marine food webs”? Science 282, 1383-1385.

Pauly, D., Froese, R., Sa-a, P., Palomares, M.L.D., Christensen, V., Rius, J., 2000b. The TrophLab Manual. (www.fishbase.org)

Pauly, D., Palomares, M.L., Froese, R., Sa-a, P., Vakily, M., Preikshot, D., Wallace, S., 2001.

Fishing down Canadian aquatic food webs. Can. J. Fish. Aquat. Sci. 58, 51-62.

Pérez-España, H., Abarca-Arenas, L.G., Jiménez-Badillo, M.L., 2006. Is fishing-down trophic web a generalized phenomenon? The case of Mexican fisheries, Fish. Res. 79, 349-352.

Pikitch, E.K., Santora, C., Babcock, E.A., Bakun, A., Bonfil, R., Conover, D.O., Dayton, P., Doukakis, P., Fluharty, D., Heneman, B., Houde, E.D., Link, J., Livingston, P.A., Mangel, M., McAlister, M.K., Pope, J., Sainsbury, K.J., 2004. Ecosystem-based fishery management. Science 305, 346-347.

Pinnegar, J.K., Hutton, T.P., Placenti, V., 2006. What relative seafood prices can tell us about the status of stocks. Fish Fish. 7, 219-226

Pinnegar, J.K., Jennings, S., O'Brien, C.M., Polunin, N.V.C., 2002. Long-term changes in the trophic level of the Celtic Sea fish community and fish market price distribution. J. Appl. Ecol. 39, 377-390.

Rochet, M.J., Trenkel, V.M., 2003. Which community indicators can measure the impact of fishing? A review and proposals. Can. J. Fish. Aquat. Sci. 60, 86-99.

Sala, E., Aburto-Oropeza, O., Reza, M., Paredes, G., López-Lemus, L.G., 2004. Fishing down coastal food webs in the Gulf of California. Fisheries 29, 19-25.

Sánchez, F., Olaso, I., 2004. Effects of fisheries on the Cantabrian sea shelf ecosystem, Ecol. Model. 172, 151-174.

Santos, A.M.P., Borges, M.F., Groom, S., 2001a. Sardine and horse mackerel recruitment and upwelling off Portugal. ICES J. Mar. Sci. 58, 589-596.

Santos, F.D., Forbes, K., Moita, R., 2001b. Mudança Climática em Portugal. Cenários, Impactes e Medidas de Adaptação – SIAM. Sumário Executivo e Conclusões, Gradiva, Lisboa.

Shannon, L.J., Cury, P., Jarre, A., 2000. Modeling effects of fishing in the southern Benguela ecosystem. ICES J. Mar. Sci. 57, 720-722.

Sinclair, M., Arnason, R., Csirke, J., Karnicki, Z., Sigurjonsson, J., Rune Skjoldal, H., Valdimarsson, G., 2002. Responsible fisheries in the marine ecosystems. Fish. Res. 58, 255-265.

Stergiou, K.I., Koulouris, M., 2000. Fishing down the marine food webs in the Hellenic Seas. In: Stergiou, K.I., Polunin, N. (Ed.) Fishing down the Mediterranean food webs, CIESM Workshop Series 12, 73-78.

Stergiou, K.I., Polunin, N., 2000. Executive Summary. In: Stergiou, K.I., Polunin, N. (Ed.) Fishing down the Mediterranean food webs, CIESM Workshop Series 12, 7-15.

Sumaila, U.R., 1998. Markets and the fishing down marine food webs phenomenon. EC Fish. Coop. Bull. 11(3-4), 25-28.

Trenkel, V.M., Rochet, M.J., 2003. Performance of the indicators derived from the abundance estimates for detecting the impact of fishing on a fish community. Can. J. Fish. Aquat. Sci. 60, 67-85.

Vivekanandan, E., Srinath, M., Kuriakose, S., 2005. Fishing the marine food web along the Indian coast. Fish. Res. 72, 241-252.

CHAPTER 5

Trammel nets' ghost fishing off the Portuguese central coast

Authors

Filipa Baeta[a], Maria José Costa[a,b], Henrique Cabral[a,b]

Authors' affiliation

[a]Instituto de Oceanografia, Faculdade de Ciências da Universidade de Lisboa, Campo Grande, 1749-016 Lisboa, Portugal

[b]Departamento de Biologia Animal, Faculdade de Ciências da Universidade de Lisboa, Campo Grande, 1749-016 Lisboa, Portugal

Published

Fisheries Research (2009) 98, 33-39

Trammel nets' ghost fishing off the Portuguese central coast

Abstract: The loss of fishing gear has negative consequences to marine communities if the gear preserves its catching abilities for a significant period, a phenomenon called "ghost fishing". The present study assessed the impact of lost trammel nets in both sandy and rocky bottoms in the central area of the Portuguese coast. Twelve trammel nets, each 50 m long and corresponding to the most common type used by the local commercial fleet, were allowed to fish continually for 285 days. During this time, changes in the structure and catching ability of each net were monitored by scuba divers in regular time intervals (1, 5, 10, 15, 20, 30, 40, 60, 80, 120, 250 and 285 days). Three control nets were also set in each bottom type the day before each monitoring dive. Irrespective of bottom type, nets' fishing area decreased to about 40% during the first 30 days, and then gradually (rocky bottoms) or sharply (sandy bottoms). It was estimated that during the experiment 541 and 257 individuals were caught per 100 m of net in rocky and sandy bottoms, respectively. Catching efficiency decreased in a negative exponential manner in parallel with the nets deterioration. The nets' effective fishing lifetime, when catching efficiency became lower than 1%, was 10–11 months in the rocky bottom and 8 months in the sandy bottom.

Keywords: ghost fishing; trammel nets; rocky bottom; sandy bottom; fishing efficiency; Portugal.

Introduction

Defined as the capacity of a fishing gear to continue to fish after it has been lost and/or the fisher has lost control of it (Erzini *et al.*, 1997; Kaiser *et al.*, 1996), ghost fishing has been identified as a potential source of significant unaccounted mortality of commercially important species, especially in fisheries where substantial amounts of gear are lost. Other than uncontrolled catches, ghost gears may also damage benthic habitats, becoming a source of litter or entanglement for birds and marine mammals, among other groups, and potentially posing safety risks for fishers by entanglement with active fishing gear and vessel propulsion systems (Brown and Macfadyen, 2007).

This issue first gained global recognition at the 16th Session of the Fisheries and Agriculture Organization (FAO) Committee on Fisheries in April 1985, although the International Maritime Organisation Convention for the Prevention of the Pollution from Ships (1973) already specifically prohibited the abandonment or dumping of fishing gear. The FAO Code of Conduct (1995) later recognised the impact of lost gears, stating that states should take appropriate measures to minimise catch by lost or abandoned gear. Under the 'basic' Regulation of the

Common Fisheries Policy (CFP) of the European Union (EU), member states should undertake measures for marine resources conservation and management purposes and for the limitation of the environmental impact of fishing activity.

Static fishing gear, such as gill and trammel nets and traps, may be considered environmental friendly given that are highly selective for target species and cause relative little disturbance to seabed communities (Jennings and Kaiser, 1998). However, when bottom set nets or traps are lost, due to, for example, bad weather conditions or interaction with other gears or with the sea bed (Kaiser *et al.*, 1996), they may continue to fish for several years (Pawson, 2003) before becoming physically damaged or heavily colonised by incrusting biota, thus losing their catching ability (Bullimore *et al.*, 2001; Carr *et al.*, 1992; Erzini *et al.*, 1997; Kaiser *et al.*, 1996;). Because modern gears are mostly made of non-biodegradable synthetic fibres, they can persist in the environment for longer periods possibly contributing to an increase in ghost fishing and its impacts, depending on the rate of gear loss, gear catching efficiency and evolution of lost gear and on the species present, their abundance and vulnerability (Brown and Macfadyen, 2007).

Information about the quantity of static fishing gears lost or for how long such gears continue to fish is scarce, possibly due to the reluctance of fishers to report such incidents and to the difficulty of conducting long-term studies on the subject (Pawson, 2003). Early research has concentrated on estimates of net loss (e.g. Carr and Cooper, 1987), on the effects of using degradable materials (Carr *et al.*, 1992) and on the impacts of lost nets on endangered animals such as mammals (Henderson, 1984) and turtles (Carr, 1987). In recent years, catch rates and the evolution of lost gill and trammel nets have been studied by diving observations (Akiyama *et al.*, 2007; Ayaz *et al.*, 2006; Erzini *et al.*, 1997; Kaiser *et al.*, 1996; Revill and Dunlin, 2003,) and by comparative fishing experiments (Humborstad *et al.*, 2003; Sancho *et al.*, 2003; Santos *et al.*, 2003; Tschernij and Larsson, 2003) but only few have evaluated the effects of ghost fishing (Erzini *et al.*, 1997; Santos *et al.*, 2003).

More than 90% of the Portuguese fishing vessels are included in the multigear segment, which works with nets, longlines and traps (INE, 2008). Most of these fishing vessels use various fishing gears simultaneously, in different combinations that frequently include gill and trammel nets. In fact, fishing licenses for operating with nets were the second most attributed licences in the central area of the Portuguese coast, where the present study was conducted (1153 in a total of 3739) (INE, 2008). Within this area, traps were the most commonly used fishing gear, followed by trammel nets; longlines and gill nets were used less frequently (Batista, 2007). Given that little is known about the effects of trammel nets ghost fishing in the Portuguese coast, with only a few studies conducted in the southern coast (Erzini *et al.*, 1997; Santos *et al.*, 2003), the present case study aimed to evaluate the structural evolution and changes in fishing capacity of lost trammel nets in rocky and sandy bottoms in the Portuguese central coast based on direct measurements made by scuba divers.

Material and Methods

Twelve experimental trammel nets were deployed in rocky and sandy bottoms off the Portuguese central coast, on a traditional fishing ground inserted in a marine protected area near Sesimbra, one of the most important fishing harbours of this coastal sector (Figure 5.1). The target species of this type of net in the selected fishing ground are soles (*Solea solea* and *Solea senegalensis*). The usual procedure of commercial fisheries was followed in nets deployment and the two sets (6 trammel nets in each bottom type) were located as close as possible in order to maximize the resemblance in environmental conditions. Water depths at both locations ranged between 15 and 25 m for the two sets and the twelve experimental nets were monitored by scuba divers for 285 days (9.5 months), from 22 June 2007 to 5 April 2008.

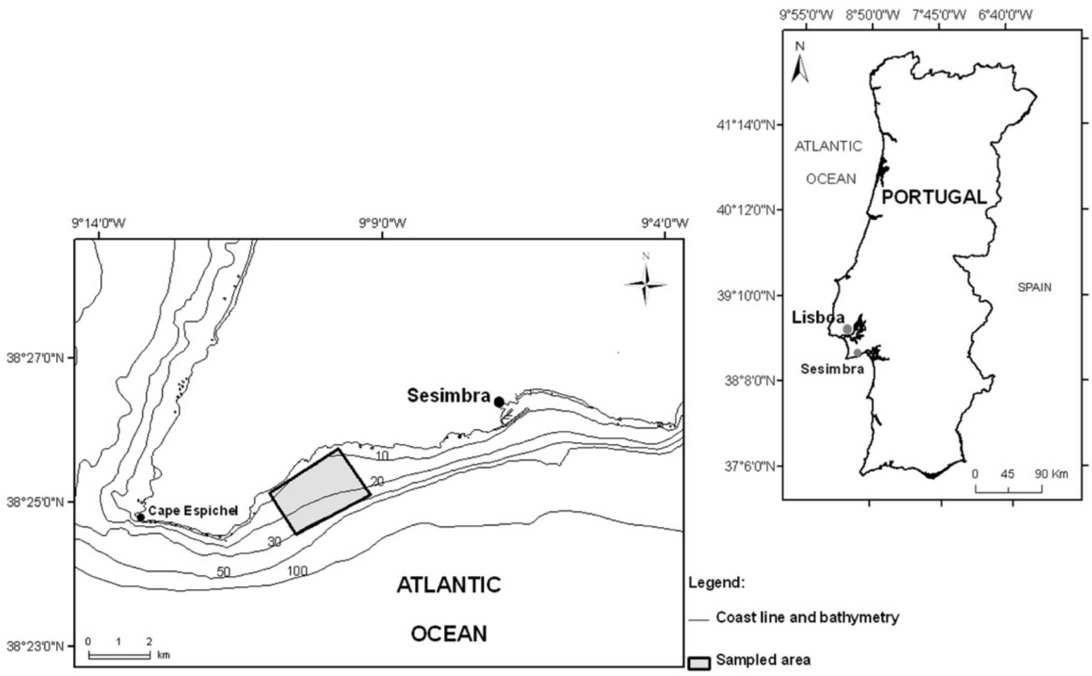


Figure 5.1. Geographical location of the experimental area in the Portuguese central coast.

Each trammel net, corresponding to the most common type used by the commercial fleet, was constructed of monofilament nylon; inner mesh dimensions were100 mm and outer mesh dimensions 600 mm. Nets were approximately 50 m long, 1.75 m height, and were marked at about 5.5 m intervals with neutrally buoyant floats. Nets of each set were fastened to each other with a 25 m rope, which helped lead the scuba divers to the nets during underwater observations, and an anchor was placed in the middle of that distance. Surface marker buoys were used at each end of both sets. This design allowed simulating the loss of large net sets or their non-retrieval due to inability in finding their exact location (e.g. from loss of surface buoy markers).

Scientific scuba divers surveyed the experimental nets at regular time intervals (1, 5, 10, 15, 20, 30, 40, 60, 80, 120, 250 and 285 days after nets' deployment), recording their structural changes and catches. At each 5.5 m interval, corresponding to the floats spacing, net height was measured as the vertical distance between the leadline and the headline. Each animal caught in each net sector (i.e. between float number i and i + 1) was identified to the species level, whenever possible and measured in situ by the scuba divers. Its preservation status was also recorded according to the scale: (1) still alive; (2) recently dead; (3) decomposed but identifiable; (4) unidentifiable remains. All enmeshed (day 1) or newly enmeshed (following days) animals were tagged with plastic bracelets to avoid record duplication.

Since many individuals caught in between surveys were not recorded, total catches of each net, expressed as the number of individuals recorded per 100 m of net during the 285 days of the experiment, were estimated by the sum of expected catch off all experiment days (determined separately for each of the intervals between surveys using recorded 24 h catches of lost nets).

In order to evaluate the evolution of catching efficiency over time, three control nets with the same characteristics as the experimental nets were set in each bottom type and in the vicinity of the experimental nets. These control nets were deployed 24 h prior to each diving survey of the "lost gear". Only fish judged to have been caught in the experimental nets during the past 24 h, i.e. either alive or dead but in good condition (stages 1 and 2), were used to evaluate the lost nets' catching efficiency over time.

The fishing area of each net was estimated as:

$$A_{i,i+1} = D \; x \; (H_i + H_{i+1}) / 2,$$

where Ai,i+1 is the area between floats i and i + 1, D is the distance between floats (5.5 m) and Hi and Hi+1 are the net heights, measured from the leadline and the headline at floats i and i + 1, respectively. The effective fishing area was obtained by summing all the Ai,i+1 for each net.

The catching efficiency of experimental nets, in terms of the number of individuals caught, was determined in relation to the corresponding catches of the control nets, and calculated as Efficiency = Experimental nets catches/Control nets catches. To evaluate the long-term evolution of the experimental nets catching efficiency, exponential models were fitted to the efficiency data: Effic (Nt) = a e−bt,where Effic (Nt) is the relative efficiency in number over time, a the intercept that corresponds to the theoretical maximum catching efficiency, b the catching efficiency decrease rate and t the number of days after deployment.

Results

Similar variation patterns in structure were observed in the nets set at both bottom types (Figure 5.2): within the first few weeks after deployment net height decreased sharply and then gradually until it finally stabilised near the bottom, this occurring faster in the nets set in the sandy bottom. When nets were set they were not fully stretched and, therefore, the distance between the leadline and the headline never reached the maximum net height, which was particularly evident in the patterns displayed by rocky bottom nets in the first days of scuba diving survey, since these nets were trapped in rocks (Figure 5.2). There was little net movement, except at one of the fixed ends of rocky bottom net, which probably was lifted accidentally or deliberately by fishermen.

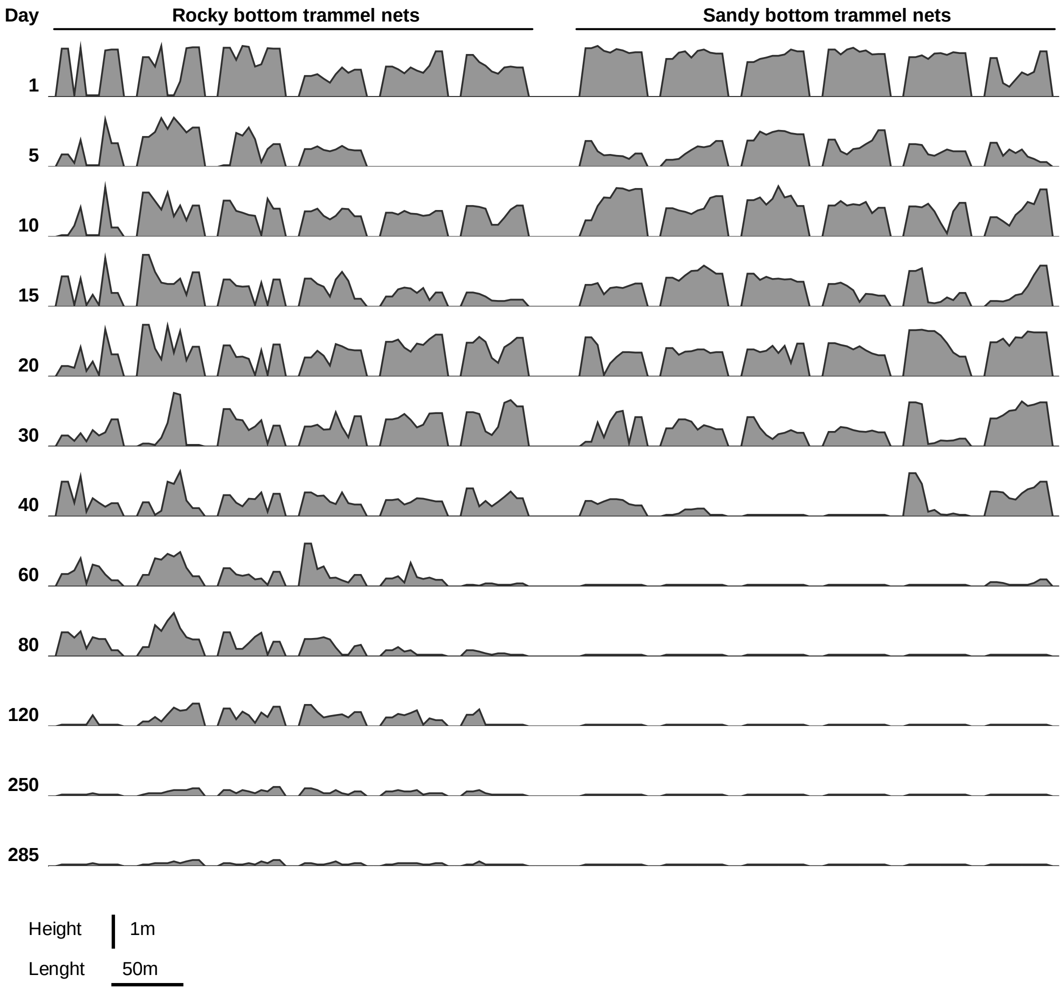


Figure 5.2. Physical deterioration of the rocky bottom and sandy bottom trammel nets over a period of 285 days. Sketches were based on measurements of nets height. Note different ordinate and abscissa scales.

Total fishing area of all trammel nets declined over time (Figure 5.3), with the accumulation of detritus, biofouling and damages such as broken meshes. It was also noted that nets acted as a substratum for many colonising plants and animals, increasing net visibility and providing a complex habitat that was attractive to many organisms (personal observations). In both bottom types, fishing area decreased to about 40% of their original area in approximately 30 days after their deployment. During this first month simultaneous ascent and descent movements of the trammel nets in both bottoms were observed (Figure 5.2) with corresponding increases and decreases of their fishing areas (Figure 5.3). After that the fishing area of sandy bottom nets showed a marked decrease, and 60 days after deployment all nets were completely collapsed and fishing area was reduced to about 3.5%: float line, the lead line and the net were almost completely torn and colonised by biota (personal observations); on the other hand, the fishing area of nets deployed in rocky bottom showed gradual decreases and after 60 days it was still 23.5%. The lower part of rocky bottom nets, which came into contact with the bottom, became overgrown and blended into the background. In the last survey, after 285 days of immersion, the fishing areas of both sandy and rocky bottom nets were 2.9% and 5.0%, respectively (Figure 5.3).

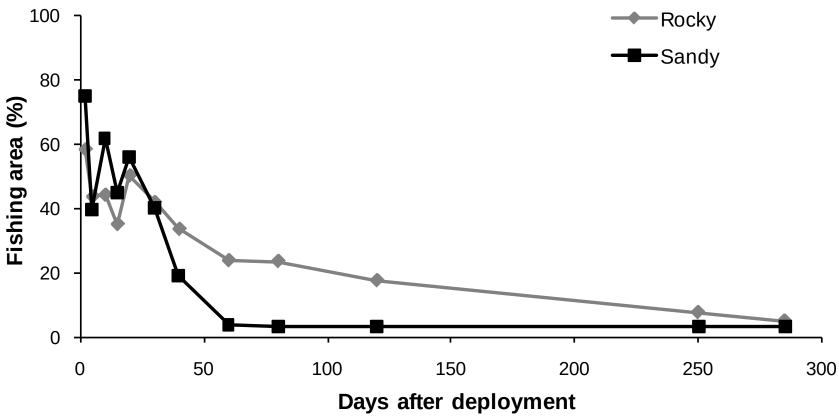


Figure 5.3. Average fishing area (in percentage of total) of trammel nets in rocky (a) and sandy (b) bottoms over the study period (285 days).

More than 33 marine species (3 crustaceans, 1 gastropod, 2 cephalopods and more than 28 fish) were recorded by divers in the experimental trammel nets (Table 5.1), totalling 61 and 41 individuals per 100 m of net in rocky and sandy bottoms, respectively. The species presenting higher catch levels in the experimental nets set in the sandy bottom were *Scomber japonicus* (10.3%), *Solea lascaris* (4.7%), *S. senegalensis* (3.7%) and *Raja undulata* (3.0%). In the rocky bottom the most captured taxa were *Labrus* spp. (9.3%), *Symphodus* spp. (7.3%), *Balistes capriscus* (6.0%) and *Scomber japonicus* (5.3%), all considered bycatch of this fishing gear. The crustacean *Maja squinado* was also highly captured: 3.3% in rocky bottom and 2.3% in sandy bottom. Considering the target species of this fishing gear, lost nets, and particularly those deployed in the sandy bottom, continued to catch soles and skates for 30 and 40 days, respectively.

Relationships between the deployment time of each experimental set and the number of enmeshed animals of each taxonomic group are shown in Figure 5.4: in the first surveys, fishes constituted the majority of the catches in both bottom types but crustaceans became more important during the experiment; in the last surveys they were as important as fishes in the rocky bottom and more important than fishes in the sandy bottom.

Catches declined in parallel with the decline in fishing area and the increasing of net visibility, with the higher number of catches registered in the first days after the nets had been deployed. It was estimated that during the experiment 541 and 257 individuals were caught per 100 m of net in rocky and sandy bottoms, respectively.

Table 5.1. Mean number of individuals of each species caught per 100 m of net in experimental trammel nets and their respective percentage in relation to total catches.

Group	**Family**	**Species**	**Rocky bottom**		**Sandy bottom**		**Total**	
			N/100m net	%	N/100m net	%	N/100m net	%
Crustaceans								
	Majidae	*Maja squinado*	3.33	5.46	2.33	5.69	5.67	5.56
	Nephropidae	*Homarus gammarus*	0.67	1.09	-	-	0.67	0.65
	Portunidae	*Necora puber*	0.33	0.55	-	-	0.33	0.33
Gastropods								
	Ranellidae	*Charonia lampas*	0.33	0.55	1.00	2.44	1.33	1.31
Cephalopods								
	Sepiidae	*Sepia officinalis*	0.33	0.55	0.33	0.81	0.67	0.65
	Octopodidae	*Octopus vulgaris*	1.33	2.19	-	-	1.33	1.31
Chondrichthyes								
	Rajidae	*Raja clavata*	-	-	0.67	1.63	0.67	0.65
		Raja undulata	0.67	1.09	3.00	7.32	3.67	3.59
		Raja sp.	0.33	0.55	0.33	0.81	0.67	0.65
	Torpedinidae	*Torpedo marmorata*	0.67	1.09	-	-	0.67	0.65
Osteichthyes								
	Balistidae	*Balistes capriscus*	6.00	9.84	1.67	4.07	7.67	7.52
	Bothidae	*Bothus podas*	0.67	1.09	1.00	2.44	1.67	1.63
	Callionymidae	*Callionymus lyra*	-	-	0.33	0.81	0.33	0.33
	Carangidae	*Trachurus trachurus*	1.33	2.19	2.00	4.88	3.33	3.27
	Clupeidae	*Sardina pilchardus*	-	-	0.33	0.81	0.33	0.33
	Gadidae	*Physis phycis*	2.00	3.28	-	-	2.00	1.96
	Labridae	*Labrus bergylta*	1.67	2.73	-	-	1.67	1.63
		Labrus sp.	7.67	12.57	-	-	7.67	7.52
		Symphodus sp.	7.33	12.02	-	-	7.33	7.19
	Merlucciidae	*Merluccius merluccius*	-	-	0.67	1.63	0.67	0.65
	Mugilidae	*Liza sp.*	0.67	1.09	0.00		0.67	0.65
	Mullidae	*Mullus sp.*	-	-	0.33	0.81	0.33	0.33
	Scombridae	*Scomber japonicus*	5.33	8.74	10.33	25.20	15.67	15.36
		Scomber scombrus	1.00	1.64	-	-	1.00	0.98
	Scopaenidae	*Scorpaena sp.*	0.33	0.55	-	-	0.33	0.33
	Serranidae	*Serranus hepatus*	0.33	0.55	-	-	0.33	0.33
		Serranus sp.	0.67	1.09	-	-	0.67	0.65
	Soleidae	*Solea lascaris*	0.33	0.55	4.67	11.38	5.00	4.90
		Solea senegalensis	0.67	1.09	3.67	8.94	4.33	4.25
		Solea sp.	-	-	0.67	1.63	0.67	0.65
	Sparidae	*Boops boops*	-	-	0.33	0.81	0.33	0.33
		Diplodus sp.	0.33	0.55	0.33	0.81	0.67	0.65
		Diplodus vulgaris	0.67	1.09	-	-	0.67	0.65
		Pagrus pagrus	0.33	0.55	-	-	0.33	0.33
		Sarpa salpa	2.33	3.83	-	-	2.33	2.29
		Sparus aurata	-	-	0.67	1.63	0.67	0.65
	Trachinidae	*Trachinus sp.*	0.33	0.55	0.67	1.63	1.00	0.98
	Triglidae	*Chelidonichthys lucernus*	1.00	1.64	-	-	1.00	0.98
		Chelidonichthys sp.	0.33	0.55	1.33	3.25	1.67	1.63
		Trigla lyra	0.33	0.55	0.33	0.81	0.67	0.65
	Not identified		11.33	18.58	4.00	9.76	15.33	15.03
	Total		61.00	100.00	41.00	100.00	102.00	100.00

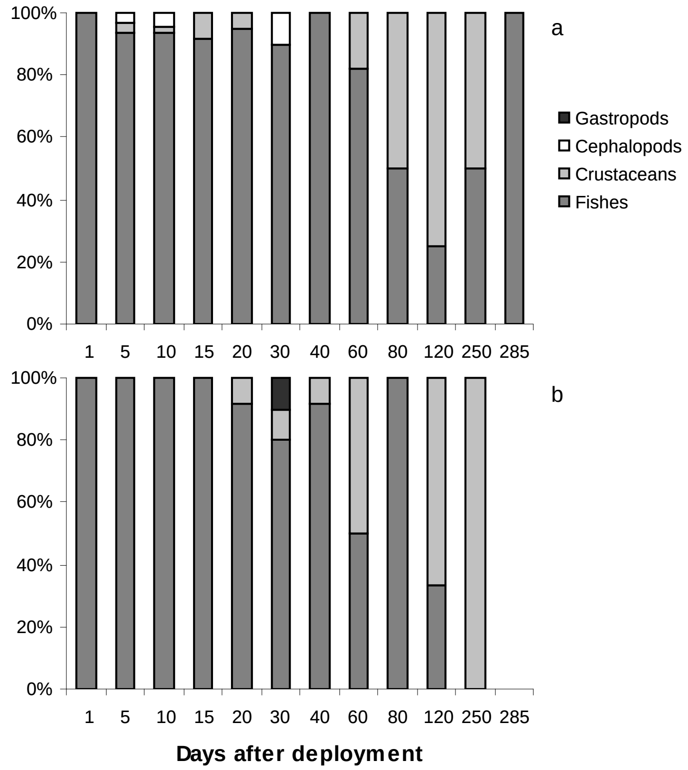


Figure 5.4. Trammel nets catches per taxonomic group over the study period, in rocky (a) and sandy (b) bottoms.

Nets' catching efficiency in both bottom types showed a negative exponential decrease pattern over time, which was more pronounced in the nets set in the sandy bottom (Figure 5.5). Initial catch rates were comparable to those of control nets. Considering catching efficiencies of experimental trammel nets in both bottom types, maximum values were attained at the fifth day of immersion (rocky bottom 96.7%; sandy bottom 86.7%). Over the first 15 days, the catching efficiency was reduced to about 46.2% (rocky bottom) and 41.1% (sandy bottom), followed by an increase reaching 73.3% in the case of trammel nets set in the rocky bottom. After 60 days, catching efficiency of both groups of nets was similar: 17.9% for rocky bottom nets and 13.3% for sandy bottom nets. The reduction of the relative catching efficiency was then less strong, presenting values near 0 at the end of the experiment for nets set in the sandy bottom. Concerning nets set in the rocky bottom, and after an increase at 80th day, catching efficiency decreased again stabilising at about 2.2%.

According to the fitted exponential models (Figure 5.5), catching efficiency was lower than 1%, i.e. catches were nil, 317 days after nets deployment, in the case of rocky bottom, and 237 days after nets deployment, in the case of sandy bottom.

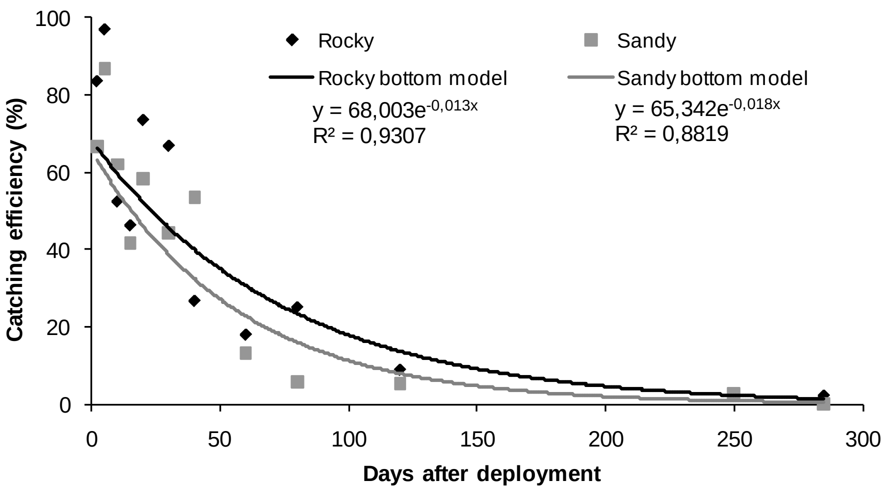


Figure 5.5. Changes in catching efficiency of rocky bottom and sandy bottom trammel nets in terms of the number of specimens, over the study period. Exponential models fitted to the data are also shown.

Discussion

The scale of the ghost fishing problem is difficult to assess given the uncertainties regarding the amount and the circumstances of gear loss and the effect of environmental conditions on the deterioration of fishing gears in sea beds upon their loss. Rates of permanent net loss in European waters are typically below 1% of the nets deployed, which seems to be related to the costs of losing the gear and to the use of GPS to aid self recovery of nets (Brown and Macfadyen, 2007). Compared to other regions, the extent of lost fishing nets in the Southern Portuguese coast is low: less than 1800 nets per year (Santos *et al.*, 2003). In the Portuguese central coast, the number of nets lost seems to be also low, since fishermen say they have a high rate of success in retrieving their lost nets. Although trammel net ghost fishing does not seem to be an important source of resources mortality given this information, the number of individuals caught in each 100 m of net estimated in the present study (541 in the nets set in the rocky bottom and 257 in the nets set in the sandy bottom) point to the need to consider some countermeasures to minimise the effects of such losses.

The assessment of the fishing capacity of nets by physical rather than by biological parameters seems to be important as such measurements are independent of variations in the abundance of the local fish populations (Revill and Dunlin, 2003). In the present experiment, net height decreased sharply within the first 2 months after deployment, and then gradually until it finally stabilised near the bottom. Nets fishing area was also greatly reduced during the study period, especially for those set in sandy bottoms where values lower than 5% were attained in only 2 months. Authors who have set experimental nets in inshore waters reported similar trends of lost trammel nets evolution and lifetime (Erzini *et al.*, 1997; Kaiser *et al.*, 1996).

The decline of fishing area exhibited some oscillations probably mainly due to water currents since simultaneous ascent and descent movements of the trammel nets were detected in both types of bottoms. Still, nets did not recover to the heights observed in the beginning of the experiment, what might be related to the accumulation of biofouling (Ayaz *et al.*, 2006), and to permanent damages caused in the nets by water currents.

Just after deployment, the average height of the trammel nets set in the rocky bottom was lower than that of those set in the sandy bottom given that parts of the nets were immediately trapped in rocks and thus limited in height. Moreover, the higher number of individuals caught by rocky bottom nets in the early stages contributed to decrease their average height. Whereas the rocky bottom nets remained in their original position for a long time, being held by rocks and protected by them from the effects of water currents, wave energy caused the spiralling and loss of fishing capacity of sandy bottom nets. However, rocky bottom nets, although first favoured by their location, ended up disintegrating as a consequence of their abrasive contact with rocks.

Results obtained clearly showed that the catch rate of the rocky bottom trammel nets was greater than that of the sandy bottom trammel nets. This difference is not only related with the fact that rocky bottom nets showed almost always a higher fishing area but also with species higher abundance in the rocky habitat. Overall, results suggest that the impact of lost trammel nets on the local faunal community depends on species abundance and community composition, habitat type and topography, and environmental conditions such as tidal currents and weather.

In both rocky and sandy bottom types, there was a similar trend in the succession of species caught: fish constituted the largest portion of the catches in the first days but crustaceans acquired an increasing importance over time, probably related to the dead and decomposing individuals trapped in the nets that served as food to this group of organisms. Similar trends in catches composition have been reported by other authors (Erzini *et al.*, 1997; Kaiser *et al.*, 1996; Revill and Dunlin, 2003). However, no data were available to quantify the scavenging due to gastropods, since these species rarely become entangled in the nets. Thus, only the relationship between the catch rates of fish and crustaceans was observed. The fact that crustaceans move in close proximity to the bottom being easily caught by nets can also contribute to the increase of crustaceans catches even after nets present a reduced fishing area and no longer catch roundfish (Revill and Dunlin, 2003).

The vertical profile and invisibility of nets seem to be the main features determining their effectiveness since catching efficiency decreased in a negative exponential manner in parallel with the deterioration of the nets' structure and the consequent decline in fishing capacity. However, sea bottom type, depth and the exposure to environmental factors and biofouling are also important in determining the catching efficiency of ghost nets (Bullimore *et al.*, 2001; Erzini *et al.*, 1997; Kaiser *et al.*, 1996).

Accordingly to the exponential models fitted to the net efficiency data, the time at which catching efficiency became lower than 1% was between 10 and 11 months, for nets set in the rocky bottom, and 8 months, for nets set in the sandy bottom. However, both these periods are much higher than those necessary for the nets to reach only 5% of their fishing area. Our results also strongly suggest that rocky bottom trammel nets continued to fish beyond the observed 285 days, which is in agreement with the several years longevity referred for monofilament lost nets (May, 1976).

Kaiser *et al.* (1996) stated that lost trammel nets at bottoms with sand and rocks almost ceased to catch fish 22 days after deployment but continue to catch crustaceans for at least 9 months. Erzini *et al.* (1997) reported a 15–20-week effective fishing lifetime for gill and trammel nets lost in a rocky bottom and considered that after 8–11 months nets were completely destroyed. These results are similar to ours, although the fishing lifetime for the lost trammel nets estimated in our study is longer than that of the previous studies. These differences could be related with differences in experimental design, since our nets were attached at both ends and in the referred studies they had one end free.

Nevertheless, most studies were performed using gill nets, and among them experimental designs similar to ours can be found and also longer fishing lifetimes. Gillnets fastened to each other with a 30 m rope and deployed in a bay in Turkey captured fish until 112 days of immersion and lost their fishing ability by the end of 1 year (Ayaz *et al.*, 2006). In Japan lost gill nets with lead sinkers at each end continued to fish 561 days after deployment in an artificial reef and 200 days after deployment in a sandy bed (Akiyama *et al.*, 2007). An exception to these rapid declines in catching rates was reported for cod gill nets lost in the Baltic Sea where catch rates of 4–5% of commercial fishing rates were still being recorded after 27 months (Tschernij and Larsson, 2003).

Also in the case of gillnets, the experimental design in which one net end is free seems to result in a shorter fishing lifetime. The maximum fishing lifetime of a lost gill net in the Southern Portuguese coast was 248 days, although it showed negligible catches after 3 months (Santos *et al.*, 2003). In UK coastal waters, trammel nets abandoned in open fishing grounds were washed ashore after 58 days, while gill nets abandoned over wrecks continued to fish over 2 years (Revill and Dunlin, 2003).

Our study, as well as all others mentioned above, was carried out in a depth range narrower than that of commercial fishing, as the logistics of diving observations need the use of sites with easy access in relatively shallow water. These circumstances and environmental conditions clearly differ from those experienced in many commercial fisheries where nets may be lost. The relatively low depths at which nets were set may have important implications concerning changes in net structure and catch characteristics because of light penetration and consequent biofouling. In addition, sea conditions and bottom currents may have a greater influence here than at greater depths (Santos *et al.*, 2003). Different studies showed that nets set in very deep waters continued to fish for many years. In the case of the Greenland halibut fishery on the Norwegian continental slope, catch rates in lost nets were about 20–30% of commercial catch levels after 45 days at depths between 537 m and 851 m and net retrieval programmes in the area have hauled nets that have been fishing for more than 8 years (Humborstad *et al.*, 2003). Also our nets were set in the very beginning of summer, a period of good weather conditions. Thus, we were not able to evaluate the effect of rough weather conditions soon after deployment, which will certainly lead to different results regarding the evolution of the nets and, therefore, catches. Despite this, the results obtained give an indication of the likely sequence of events after losing the nets, although timescales and catch composition will vary according to location.

Some authors considered that lost/abandoned nets in exposed coastal waters are an insignificant source of unaccounted fishing mortality (Carr *et al.*, 1992; Erzini *et al.*, 1997; Kaiser *et al.*, 1996; Revill and Dunlin, 2003). It is technically difficult, and therefore costly, to simulate gear loss and net evolution and to retrieve lost gears. Ghost fishing mortality rates and total ghost catches estimates are, therefore, limited and approximate (Brown and Macfadyen, 2007). However, in most of the fisheries that have been examined the losses of commercial species attributable to lost static gears were small compared to that commercial catches. Estimated ghost catches are generally believed to be well under 1% of landed catches (Brown and Macfadyen, 2007). Hake ghost catch was estimated to be between 1.67 and 2.25 tonnes of hake per year by the Algarve fleet, which is equivalent to a maximum of 0.5% of the total annual catches (Santos *et al.*, 2003). Higher values were reported for the ghost catch of monkfish in tangle nets in the Cantabrian region, which constituted 1.46% of the total commercial landings in the area (Sancho *et al.*, 2003). The magnitude of ghost fishing for soles and rays, the target species of the fishery evaluated in the present study, is impossible to assess accurately because there is no estimate for the amount of lost nets in this fishing area. Although lost trammel nets continued to catch soles for a significant period, fishermen commonly refer that few nets are effectively lost and thus trammel nets ghost fishing may be considered as a small source of mortality of these species in this area part of the Portuguese coast.

Ghost fishing has many costs and/or negative impacts at the environmental, social and economic levels. Therefore, reducing ghost fishing through management measures will have benefits (Brown and Macfadyen, 2007) if measures are based on the prevention of fishing gear loss, on the retrieval or dysfunction of lost gear, and on the development of designed degradation of fishing gear when lost (Matsuoka *et al.*, 2005).

The absolute and relative impacts of gear loss on fish stocks and on the marine environment remain uncertain and misunderstood and information on the economic and social impacts is still lacking (Brown and Macfadyen, 2007). Determining the amount of lost nets, in order to estimate the real effects of ghost fishing on stock levels, and clarifying changes in the ghost fishing function over time are perhaps the most urgent aspects to study. Technical measures and legislation against ghost fishing should also be developed, especially on a local scale.

Acknowledgements

The authors thank all the participants involved in field work. This study was co-funded by the European Union through the FEDER - Fisheries Programme (MARE), as well as by Fundação para a Ciência e a Tecnologia (FCT) through the grant attributed to F. Baeta (Grant SFRH/BD/19223/2004).

References

Akiyama, S., Saito, E., Watanabe, T., 2007. Relationship between soak time and number of enmeshed animals in experimentally lost gill nets. Fisheries Sci. 73, 881–888.

Ayaz, A., Acarli, D., Altinagac, U., Ozekinci, U., Kara, A., Ozen, O., 2006. Ghost fishing by monofilament and multifilament gillnets in Izmir Bay, Turkey. Fish. Res. 79, 267–271.

Batista, M., 2007. Avaliação do impacto do plano de ordenamento da área marinha do Parque Natural da Arrábida na pesca comercial local. Master Thesis, Faculdade de Ciências da Universidade de Lisboa, Lisboa.

Brown, J., Macfadyen, G., 2007. Ghost fishing in European waters: Impacts and management responses. Mar. Policy 31, 488-504

Bullimore, B.A., Newman, P.B., Kaiser, M.J., Gilbert, S.E., Lock, K.M., 2001. A study of catches in a fleet of “ghost-fishing” pots. Fish. Bull. 99, 247-253.

Carr, H.A., 1987. Impact on non-biodegradable marine debris on the ecology and survival outlook of sea turtles. Mar. Pollut. Bull. 18, 352-356.

Carr, H.A., Cooper, R.A., 1987. Manned submersible and ROV assessment of ghost gillnets in the Gulf of Maine. In: Proceedings of the Oceans’87, the Ocean – An International Workplace, Vol.2, Halifax, NS, pp. 622-624.

Carr, H.A., Blott, A.J., Caruso, P.G., 1992. A study of ghost gillnets in the inshore waters of southern New England. In: Proceedings of the MTS’92: Global Ocean Partnership. Marine Technology Society, Washington, DC, pp. 361-367.

Erzini, K., Monteiro, C.C., Ribeiro, J., Santos, M.N., Gaspar, M., Monteiro, P., Borges, T.C., 1997. An experimental study of gill net and trammel net 'ghost fishing' off the Algarve (southern Portugal). Mar. Ecol. Prog. Ser. 158, 257-265.

FAO, 1995. Code of Conduct for Responsible Fisheries. FAO, Rome.

Henderson, J.R., 1984. Encounters of Hawaiian monk seals with fishing gear at Lisianski Island, 1982. Mar. Fish. Rev. 46, 59-61.

Humborstad, O.B., Løkkeborg, S., Hareide, N.-R., Furevik, D.M., 2003. Catches of Greenland halibut (Reinhardtius hippoglossoides) in deepwater ghost-fishing gillnets on the Norwegian continental slope. Fish. Res. 64, 163-170.

INE, 2008. Estatisticas da Pesca 2008. Instítuto Nacional de Estatística, Lisboa.

International Convention for the Prevention of Pollution from Ships, 1973, as modified by the Protocol of 1978 relating thereto (MARPOL 73/78) Annex V, Regulation 3.

Jennings, S., Kaiser, M.J., 1998. The effects of fishing on marine ecosystems. Adv. Mar. Biol. 34, 11-16.

Kaiser, M.J., Bullimore, B., Newman, P., Lock, K., Gilbert, S., 1996. Catches in “ghost fishing” set nets. Mar. Ecol. Prog. Ser. 145, 11-16.

Matsuoka, T., Nakashima, T., Nagasawa, N., 2005. A review of ghost fishing: scientific approaches to evaluation and solutions. Fish. Sci. 71, 691–702.

May, E.W., 1976. Lost gill-net Retrieval Experiment. Environment Canada, Fisheries and Marine Service, Industrial Development Branch, St Johns, Newfoundland

Pawson, M.G., 2003. The catching capacity of lost static fishing gear: introduction (Editorial). Fish. Res. 64, 101-105.

Revill, A.S., Dunlin, G., 2003. The fishing capacity of gill nets lost on wrecks and on open ground in UK coastal waters. Fish. Res. 64, 107-113.

Sancho, G., Puente, E., Bilbao, A., Gomez, E., Arregi, L., 2003. Catch rates of monkfish (*Lophius* spp.) by lost tangle nets in the Cantabrian Sea (northern Spain). Fish. Res. 64, 129-139.

Santos, M.N., Saldanha, H.J., Gaspar, M.B., Monteiro, C.C., 2003. Hake (*Merluccius merluccius* L., 1758) ghost fishing by gill nets off the Algarve (southern Portugal). Fish. Res. 64, 119-128.

Tschernij, V., Larsson, P.-O., 2003. Ghost fishing by lost gill nets in the Baltic Sea. Fish. Res. 64, 151-162.

Part III

Sustainability of Portuguese fisheries

CHAPTER 6

Assessing sustainable development of Portuguese fisheries using two indicator aggregation methods

Authors

Filipa Baeta[a], Maria José Costa[a,b], Henrique Cabral[a,b]

Authors' affiliation

[a]Instituto de Oceanografia, Faculdade de Ciências da Universidade de Lisboa, Campo Grande, 1749-016 Lisboa, Portugal

[b]Departamento de Biologia Animal, Faculdade de Ciências da Universidade de Lisboa, Campo Grande, 1749-016 Lisboa, Portugal

In review

Fisheries Management and Ecology

Assessing sustainable development of Portuguese fisheries using two indicator aggregation methods

Abstract: Portuguese fisheries have suffered clear changes in the last decades. In order to describe and evaluate the sustainable development of Portuguese fisheries between 1994 and 2004, an indicator system was created and two methodologies that temporally track the sector's performance were used. Sustainability was analysed within four dimensions: ecological, economic, social and institutional. In the first approach, indicators were aggregated into sustainability sub-indices, related to each dimension, and finally composed into an overall index. The rate of sustainable development was also determined. The second approach consisted of Traffic Light method which allowed the comparison of the same indicators temporal evolution and between each dimension. The two methods showed a high potential as tools for fisheries sustainability assessment and may be used complementarily. Portuguese fisheries sustainability has increased in the last years, though at a lower rate in ecological and social dimensions, which indicates that special attention should be paid to these two dimensions, besides the continuous improvement of the others.

Keywords: fisheries, sustainable development, indicators, index, Traffic Light method, Portugal.

Introduction

Sustainable development can be characterized by improving the welfare of the present generations, without sacrificing that of future ones (WCED, 1987). The need for balancing present and future yields and for preserving the renewal capacity of resources has concerned fisheries scientists since the 1950's (Garcia and Staples, 2000a). However, only with the increasing problems in fisheries, especially the collapse of a considerable number of fish stocks, sustainability related issues become more discussed. In 1995, Food and Agriculture Organization (FAO) elaborated the Code of Conduct for Responsible Fisheries, providing a framework for the creation of management policies and strategies (Garcia *et al.*, 1999) for ensuring sustainable exploitation of aquatic living resources and in 1999 created guidelines regarding the development and use of indicators of fisheries sustainable development (FAO, 1999).

Indicators allow the assessment of fisheries development and management performance in the four dimensions that any sustainability system comprises, i.e. ecological, economic, social and the one related to the institutions and governance systems in which fisheries operate (FAO, 1999). The importance of developing indicator systems for sustainable development of marine fisheries has been acknowledged worldwide and several countries have devoted tremendous efforts to establish and develop them (Liu and Ou, 2007). Different regions require different indicators to suit their needs, considering local targets and definitions of sustainability (Dahl, 2000).

It is not easy to understand the interaction of a large number of trends from different indicators and it is even more complicated to transmit their meaning to policy-makers and to the general public (Garcia and Staples, 2000a). There is a need for the development of aggregate indices that integrate different dimensions of sustainable development (Dahl, 2000; Garcia and Staples, 2000a; Malkina-Pykh, 2002), which could promote new policy guide instruments and better integration of decision-making, as well as public participation in sustainability discussions (Krajnc and Glavič 2005). In recent years, international research has focused on the development of composite indicators to be applied in a wide variety of fields, for instance concerning the environment, e.g. pilot environmental performance index (WEF, 2002), index of environmental friendliness (Statistics Finland, 2003), the economy, e.g. composite leading indicators (OECD, 2002), and sustainability, e.g. Dow Jones sustainability index (DJSI, 2003).

The analysis and evaluation of fisheries sustainability has been addressed through several methods, such as the FAO Code of Conduct Compliance (Garcia *et al.*, 1999; Pitcher, 1999), the International Instrument Compliance (Alder *et al.*, 2001), the RAPFISH method (Baeta *et al.*, 2005; Pitcher and Preikshot 2001), the Traffic Light method (Caddy, 1998, 1999), and the method developed by Liu *et al.* (2005). Also, Chuenpadgee and Alder (2001) described a scaling method that aggregated the first three cited methods.

Owner of one of the largest exclusive economic zone (EEZ) in the European Union (EU), Portugal has a historical tradition in fisheries and has always relied on fishing as a major mean of subsistence, in particular for coastal communities. The social importance of this sector is amplified by the related sectors that use fisheries products or whose products are used in fisheries related activities. However, Portuguese fisheries still present an artisanal character with reduced interest for younger generations.

Portugal joined the EU in 1986 and has since implemented a fisheries policy within the framework of the EU Common Fisheries Policies (CFP), without prejudice to supplementary national legislation. According to the Commission of the European Communities (2002), one of the main objectives of the CFP is to maintain responsible and sustainable fisheries. Considering the importance of the fisheries sector in Portugal, the analysis of its sustainability is of the utmost importance. In this study, a set of specifically chosen indicators along with two adapted aggregation methods were used to assess the trends in sustainable development of Portuguese marine fisheries between 1994 and 2004, reflecting an integrated and interdisciplinary view of sustainability. Furthermore, the obtained information will help the development of management policies for the long term sustainability of Portuguese fisheries.

Material and Methods

The assessment of sustainable fishery development was divided into ecological, economic, social and institutional dimensions (FAO, 1999). The selection of adequate indicators for the Portuguese fisheries sector was done based on both FAO guidelines (FAO, 1999) and the Portuguese National Strategic Plan for Fisheries (DGPA, 2006), which sets out the specific goals and national priorities for implementing the EU's Common Fisheries Policy (Table 6.1). The fisheries sector considered included the catches sub-sector as well as the aquaculture and fisheries products processing industry. Statistics and data series for the period between 1994 and 2004 were collected from national and European public institutions.

Integrating indicators involves normalization, in which indicators are scaled to be comparable, and the application of a method to summarize the results from many indicators (Halliday *et al.*, 2001). The normalization process used was adapted from Krajnc and Glavič (2005). For each dimension indicators were classified either as positive indicators (I^+), indicators whose increasing value have a positive impact in the fisheries sustainability, or as negative indicators (I^-), indicators whose increasing value contribute to the decrease of sustainability (Table 6.1). Subsequently, each type of indicators was normalized using the following equations:

$$I^+_{N,ijt} = (I^+_{ijt} - I^+_{\min,jt})/(I^+_{\max,jt} - I^+_{\min,jt}) \ , \qquad (1)$$

$$I^-_{N,ijt} = 1 - ((I^-_{ijt} - I^-_{\min,jt})/(I^-_{\max,jt} - I^-_{\min,jt})) \, , \qquad (2)$$

where I^+_{ijt} is the positive indicator i from dimension j for time (year) t, $I^+_{N,ijt}$ is the standardized positive indicator i and $I^+_{\min,jt}$ and $I^+_{\max,jt}$ are, respectively, the minimum and the maximum values attained by the indicator in the time period considered. Concerning the negative indicators, the nomenclature is the same. Thus the values of the indicators were all between zero and one.

The integration of normalised indicators was performed using two different methods. Both methods, for any given year, reveal the sustainability of the fisheries sector compared to the best and the worst years of the analysed period.

The first model used for integration of indicators was also adapted from Krajnc and Glavič (2005) which consists in averaging indicators into dimension sub-indices and finally in averaging sub-indices into a final index. For each dimension j a sub-index ($I_{S,j}$) was derived using the equation:

$$I_{S,jt} = \sum_{ji}^{n} (1/n_{ij}) I^+_{N,ijt} + \sum_{ji}^{n} (1/n_{ij}) I^-_{N,ijt} \, , \qquad (3)$$

where $I_{S,jt}$ is the sustainability sub-index for the dimension j in time (year) t and n_{ij} is the number of indicators of j dimension. $I_{S,ECL}$, $I_{S,ECN}$, $I_{S,SOC}$ and $I_{S,INS}$ represent the ecological, economic, social and institutional sub-indices, respectively.

Table 6.1. Sustainable fishery development indicator system in Portugal.

Dimension	**Indicator**	**Definition**	**Sustainability**[a]
Ecological	Trophic level	Weighted average of trophic level of harvested species	I^+
	Catch per Unit of Effort	Ratio between landings and number of vessels	I^+
	Protected areas	Fishing protected areas as a percentage of exclusive economic zone (EEZ)	I^+
	Landings from nacional waters	Production in weight of fisheries marine products from national waters	I^-
	Aquaculture production	Production in weight of fisheries marine products by aquaculture	I^+
	Aquaculture species	Number of species produced by aquaculture	I^+
Economic	Landings	Production in value of fisheries marine products	I^+
	Mean value of fish landed	Average market price per weight of species landed	I^+
	Fisheries contribution to National Economy	Fisheries Gross Value Added (GVA) as a percentage of National GVA	I^+
	Fishers income	Earnings obtained by each fisheries employee	I^+
	Fishers enterprises income	Profits obtained by vessels owners once the operating costs have been deduced	I^+
	Fisheries commercial balance	Difference between imports and exports of fisheries products	I^-
	Aquaculture units	Number of aquaculture units	I^+
	Fish processing companies	Number of fish processing companies	I^+
	Fish processing industry production	Production in weight of seafood products by processing industry	I^+
	Investment	Public expenditure in subsidies for fisheries sector	I^-
Social	Fishers	Number of fishers	I^-
	Aging	Average fishers age	I^-
	Education level	Percentage of fishers with more than the mandatory education level	I^+
	Training courses	Number of fishermen that attended training courses	I^+
	Weight of consumed fish per inhabitant	Weight of consumed fish per capita	I^-
	Security level	Number of injured and deceased people in fishing activities	I^-
Institutional	Fishing TACs	Number of species regulated by total allowable catches (TACs)	I^+
	Expenditure in RandD	Public expenditure for research and development (RandD) in natural sciences	I^+
	Compliance with management regime	Infractions detected as a percentage of inspections	I^-
	Producers’ organizations	Number of producer's organizations	I^+
	Species with recovery plans	Number of endangered species to which recovery plans was developed	I^-

[a] I^+ and I^-: Indicators whose increasing values have a positive and negative impact, respectively, in Portuguese fisheries sustainability.

Finally, the sustainability sub-indices were combined into a composite sustainable development index (I_C):

$$I_{C,t} = \sum_{jt}^{n} (1/n_j) I_{s.jt} \quad , \tag{4}$$

where n_j denote the number of dimensions.

I_C and sub-indices can show in what direction, and at what rate, the fisheries sector is moving either towards or away from sustainable development. The parameter rate of sustainable development is calculated as the slope of a linear trend line through the values of I_C (r_C) and sub-indices ($r_{S,j}$) in the time period considered. The higher the value, the greater the improvement of the fisheries sector towards sustainability.

The second method, the Traffic Light method (TL) (Caddy, 1998, 1999) was first proposed as a system of red (dangerous values), yellow and green (safe values) lights to categorise multiple indicators of the state of a fishery and ecosystem in relation to defined Limit Reference Points (Halliday *et al.*, 2001). In this study, instead of the basic or "Strict" TL method, it was adapted the Fuzzy TL method (Halliday *et al.*, 2001), which has transitions zones between colours that are fractions of the neighbouring colours. In these transition zones a given value of an indicator belongs, to some degree, to more than one colour set. In addition, red, yellow and green colours were substituted by black, grey and white colours, respectively.

In the absence of external criteria that would convert the colour boundaries into formal reference points, the range of normalized indicators was divided into three equal sectors (Caddy *et al.*, 2005), being the transition zones intervals whose average values are the 33rd and 67th percentiles: the black-grey transition was from 0,28 to 0,38 and the grey-white from 0,62 to 0,72. Normalized indicators were compared to this set of decision levels.

Indicators from each dimension were integrated by a simple integration of colours: the total area of each colour of the various indicators was added and renormalized to sum to 1 (Halliday *et al.* 2001).

Results

In the studied period (1994-2004), the ecological sustainability of the fisheries sector had a slight increase from 0.401 to 0.463 ($r_{S,ECL}$ =0.007, p<0.05, R^2= 0.062) (Figure 6.1a). $I_{S,ECL}$ attained its lowest sustainability value in 1995 (0.333), and increased in the following years until 1998 attaining its highest value (0.658). After that $I_{S,ECL}$ has been showing a decreasing trend.

Considering the TL method (Figure 6.1b), ecological dimension tended to sustainability until 1998 with the white fraction increasing and attaining 50% and the black one decreasing to zero. In the following years, the black fraction increased, i.e. sustainability decreased, and in

2002 and 2003, white and black fractions were equivalent. In 2004, the grey fraction was the highest. Results for each of the indicators showed that three indicators tended to sustainability ("Protected areas", "Landings from national waters" and "Aquaculture production"), while the other three showed the opposite trend ("Trophic level", "Catch per Unit of Effort" and "Aquaculture species") (Figure 6.1c).

Economic dimension showed a higher rate of sustainable development ($r_{S,ECN}$ =0.025, $p<0.05$, R^2= 0.676) than ecological one (Figure 6.2a). $I_{S,ECN}$ ascended from 0.417, in 1994, to 0.629, in 2004, attaining an all-time low in 1999 (0.380) and a peak in 2003 (0.700).

TL method became evident that economic sustainability decreased until 1999, despite a slight increase in 1997 (Figure 6.2b). Both black and white fractions became smaller in this period, whereas the grey fraction occupied a greater proportion. In the following years sustainability increased and in 2003 the white fraction attained 70%. In 2004 sustainability showed a slight decrease. From the ten indicators used, five evolved towards sustainability ("Landings", "Mean value of fish landed", "Fishers income", "Fisheries enterprises income" and "Aquaculture units"), and three had the inverse trend ("Fisheries contribution to national economy", "Fisheries commercial balance" and "Processing companies") (Figure 6.2c).

Social sustainability increased in the ten-year period ($r_{S,SOC}$ =0.008, $p<0.05$, R^2= 0.111) from 0.559, in 1994, to 0.580, in 2004 (Figure 6.3a). Following an initial decreasing trend, $I_{S,SOC}$ increased from 0.362, in 1997, to 0.617, in 2000, the maximum value attained, after which it decreased until 2003.

According to the TL method (Figure 6.3b), social sustainability decreased until 1996: the decrease in the white fraction was accompanied with an increase in the grey. This trend was reverted in 2000, although in the next years both white and black fractions increased. Only in 2004 social sustainability showed a little improvement. During the analysed decade two indicators ("Fishers" and "Education level") tended in the direction of sustainability and two in the inverse direction ("Aging" and "Training courses") (Figure 6.3c).

The highest rate of sustainable development was obtained in the institutional dimension ($r_{S,INS}$ =0.070, $p<0.05$, R^2= 0.960), which increased from 0.200 to a maximum of 0.867 (Figure 6.4a), with the lowest value being attained in 1995 (0,100).

Results of the TL method revealed the same trend. Overall, the white fraction increased and the black one decreased (Figure 6.4b), which resulted from the fact that all indicators in this dimension tended to sustainability in the analysed period, except for one that showed some oscillations ("Compliance with management regime") (Figure 6.4c).

Overall, between 1994 and 2004, the Portuguese fisheries sector progressed towards sustainable development in every analysed dimension although at different rates. Considering I_C, Portuguese fisheries sustainability increased along the considered time frame (r_C = 0.028, $p<0.05$, R^2= 0.897), from 0.394, in 1994, to 0.634, in 2004 (Figure 6.5a). The lowest sustainability value occurred in 1995 (0.335) and the highest in 2004. The TL method revealed that the overall Portuguese fisheries sustainability increased between 1995 and 1998, with the black fraction becoming smaller (Figure 6.5b). Sustainability decreased in 1999 and in the next years an increasing trend was evident with the increase of the white fraction.

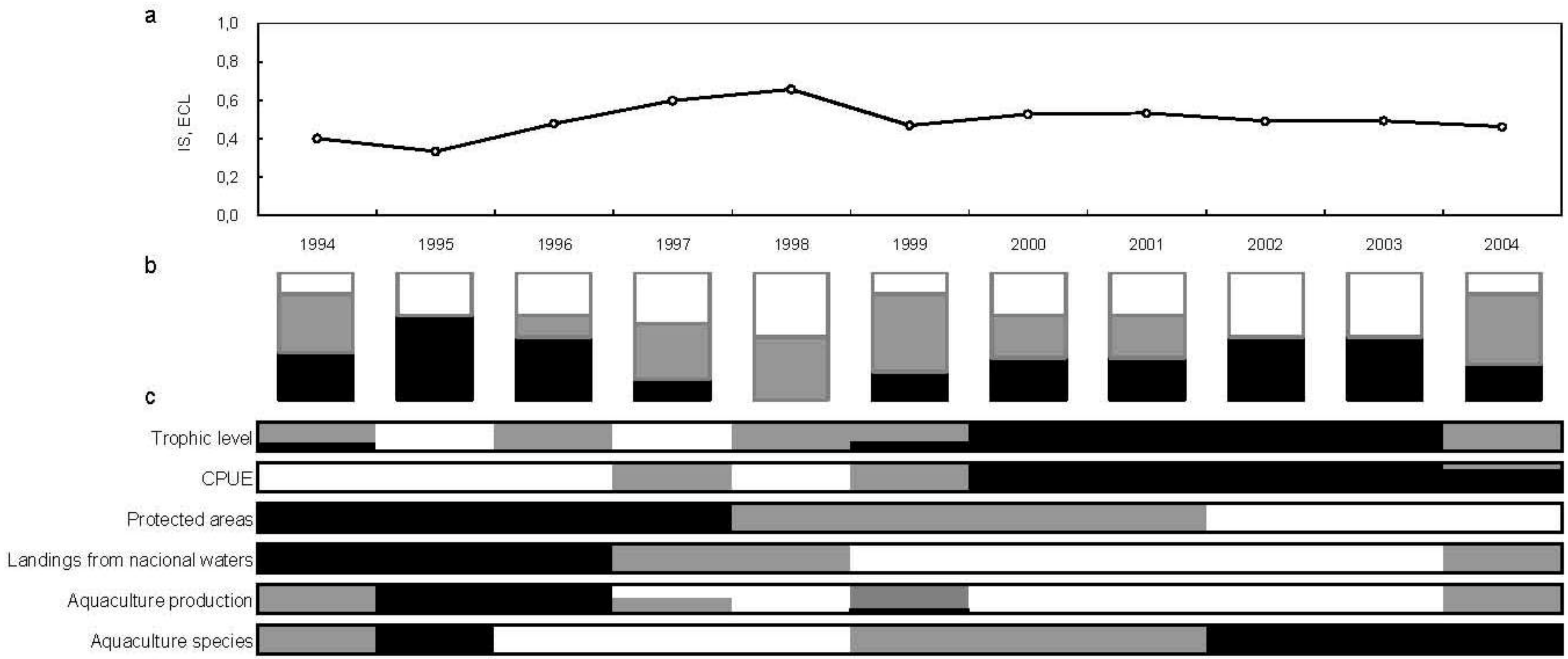


Figure 6.1. Ecological dimension: a) variation of sustainability ecological sub-index, b) traffic light results for integration of indicators and c) traffic light conversion of ecological indicators (black – dangerous values; grey – uncertainty; white – safe values).

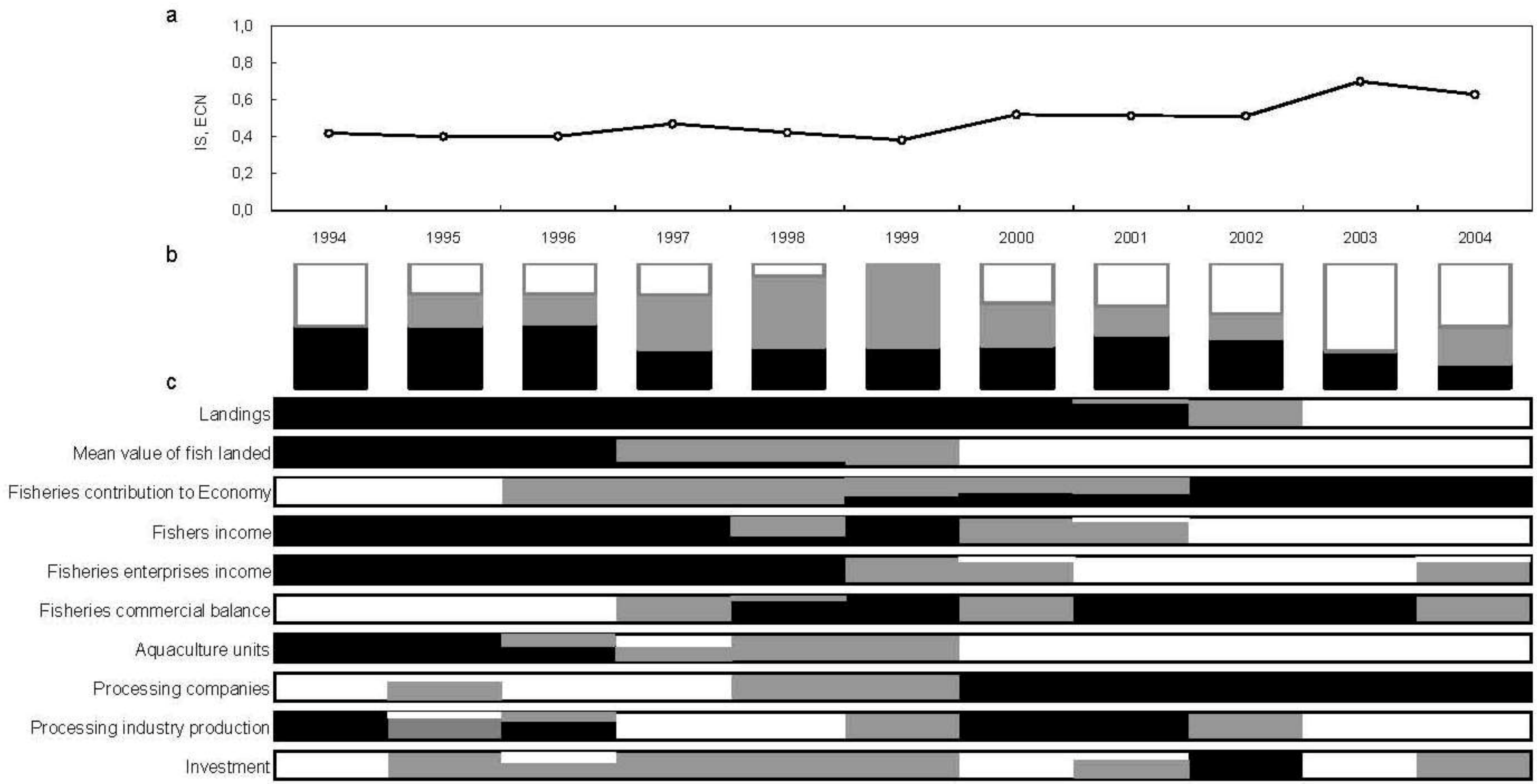


Figure 6.2. Economic dimension: a) variation of sustainability economic sub-index, b) traffic light results for integration of indicators and c) traffic light conversion of economic indicators (black – dangerous values; grey – uncertainty; white – safe values).

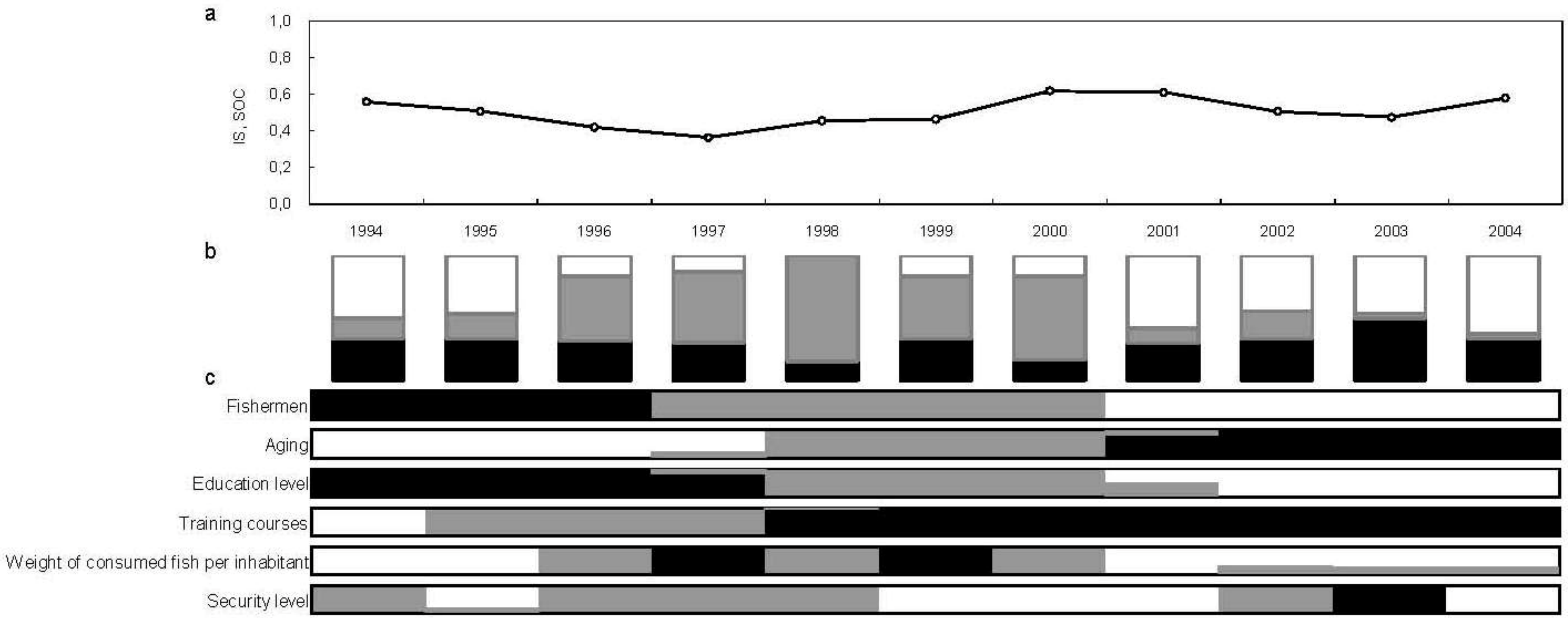


Figure 6.3. Social dimension: a) variation of sustainability social sub-index, b) traffic light results for integration of indicators and c) traffic light conversion of social indicators (black – dangerous values; grey – uncertainty; white – safe values).

a

b

c

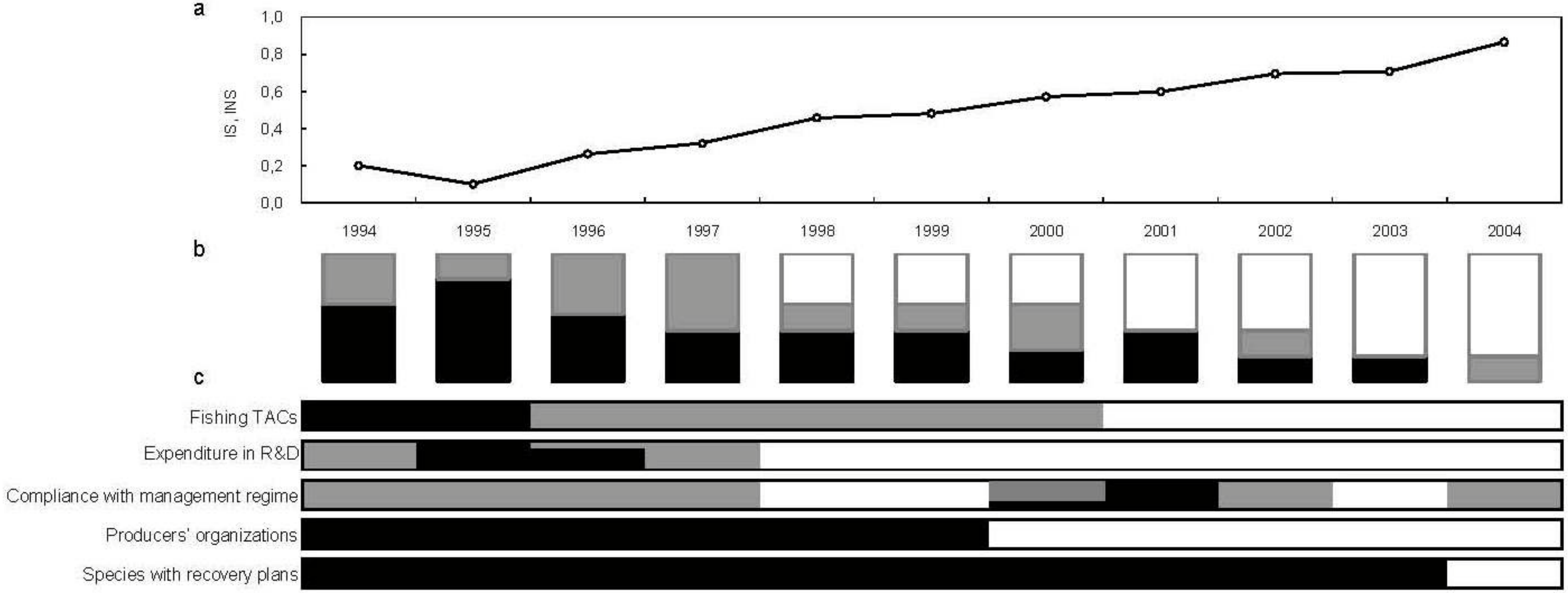


Figure 6.4. Institutional dimension: a) variation of sustainability institutional sub-index, b) traffic light results for integration of indicators and c) traffic light conversion of institutional indicators (black – dangerous values; grey – uncertainty; white – safe values).

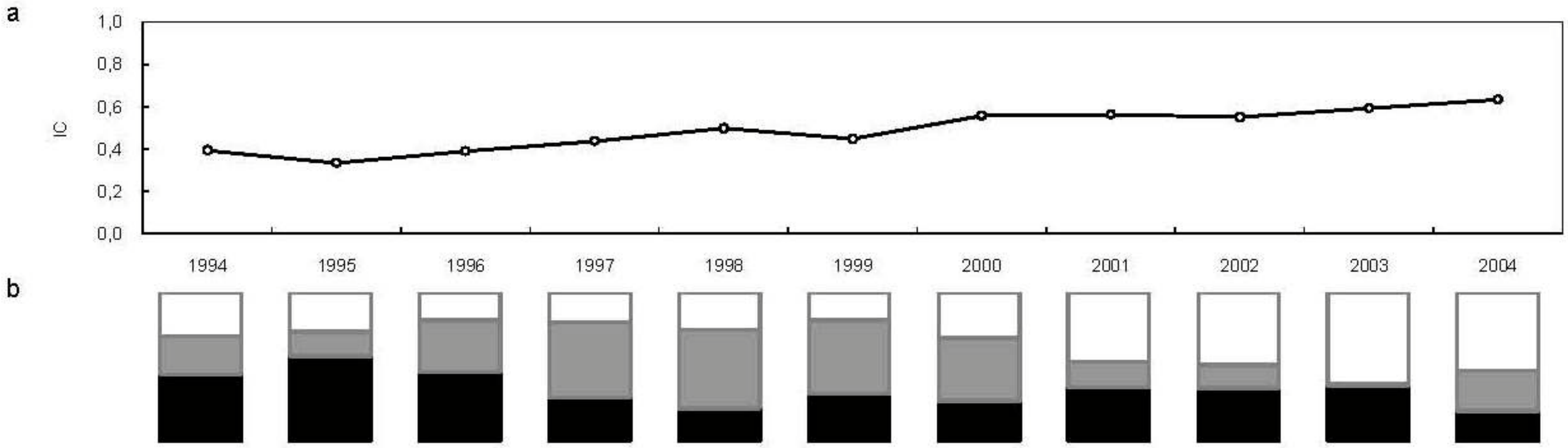


Figure 6.5. a) Variation of composite sustainable development index and b) overall traffic light result (black – dangerous values; grey – uncertainty; white – safe values).

Discussion

Modern governance requires broader and more active participation of development actors in decision-making, increased transparency and a systematic appraisal of management performance. This has led to a requirement for sustainability indicator frameworks for monitoring as well as for support the decision-making (Garcia and Staples, 2000a).

Even though great scientific effort has been dedicated to the sustainable development and management of fisheries, few studies are available regarding sustainability indicators, so previous work done in other sectors can be very useful to support fisheries science (Garcia and Staples, 2000b), as succeed in the present study . The index used in the present study, which was created to evaluate the performance of a company with time (Krajnc and Glavič, 2005), demonstrated its utility in tracking sustainability development of the fisheries sector through time. On the other hand, the TL method is a type of precautionary management framework suitable for use in fishery assessment in data-poor situations as in the case of the Portuguese fisheries.

Both methods incorporated a broad spectrum of information and presented a simplified and quantified expression of a composition of several indicators, integrating different evaluation fields and reflecting the trade-offs between them. In addition to providing a rapid assessment of the sustainability trends, they can be used to decide where management, or research resources, should be focused and analyse the consequent results of changes. Even though further development is called for in aggregation methodologies, the two methods used showed a high potential for application in sustainability assessment and can be used in a complementary way. Whereas the index methodology provides simple results, presenting information of a complex system through only a few numbers (Malkina-Pykh, 2002), TL method provides further detail: two similar values of index could be performed by two really different situations revealed by TL method.

However, controversy still remains concerning adequate techniques for the definition of colour boundaries and the choice of an aggregation method in TL method (RAP, 2001). In the absence of external data that allows the conversion of colour boundaries into formal reference points, these were set based on a simple conceptual model in which a deviation in a particular direction can be viewed as a warning signal, if on the undesirable side, or as a positive signal, if towards sustainability (Halliday *et al.*, 2001). Setting boundaries at the 33rd and 66th percentiles has been favoured in cases where the range of data is restricted (Halliday *et al.*, 2001), as in the present study. To avoid the loss of information that may occur through the integration of indicators, the Fuzzy TL method was used. Even though only three traffic lights were used, the changes are more continuous and provide a better representation of the condition of the system. In addition it also contains a representation of uncertainty: if the indicators are a mixture of colours, integration will show it and reveal that there is a conflict between the different indicators (RAP, 2001).

Not all indicators are equally significant. However, weighting indicators remains a controversial topic and in several cases it adds little to the accuracy of the overall result. At the initial stages of constructing TL decision systems, as in the current case, effort will be most useful if it is focused on the inclusion or exclusion of indicators rather than on the application of weightings (Halliday *et al.*, 2001).

The availability of data limited the selection of indicators to be applied. Even though some other indicators would most probably provide valuable information, data was not available and particularly long time series. Despite this limitation, the set of indicators used seems to describe well what is happening with the Portuguese fisheries sector. Good indicators schemes have failed to be successfully applied in other countries, since data did not exist for most of the indicators (Dahl, 2000). It is generally accepted as more convenient choosing an indicator that is theoretically less satisfactory but has a greater chance of reliable data collection and use (Dahl, 2000).

In this work, for any given year, sustainability levels revealed the development of the fisheries sector in comparison with the other analysed years. The sustainability of Portuguese fisheries increased in the analysed period in all dimensions. However, in ecological and social dimensions sustainability's performance progressed at a low rate and showed many oscillations. Both attained its maximum values in the middle of the analysed period and after that showed decreasing trends, which suggests that these two dimensions may not be in a truly sustainable pathway.

The decreasing trends presented by landings from Portuguese waters, by their mean trophic level and by CPUE compromise the ecological dimension of Portuguese fisheries sustainability and emphasize the need for measures. Whereas the first resulted mainly from the management measures undertaken after the joining to the EU in 1986, the other two decreases suggested that resources sustainability is at risk. The number of species with total allowable catches (TAC) has increased over the years, and for species with problematic exploitation situations, as hake, *Merluccius merluccius*, and Norway lobster, *Nephrops norvegicus*, recovery plans have also been implemented. The fisheries sector sustainability in the next years will be very dependent on the adjustment between fishery effort and the potential of the exploited resources.

Despite the increasing in marine protected areas in Portuguese EEZ, they still represent a minimal part of it (about 0.01%) and moreover some of these areas are not actively managed. Even though conflicts frequently occur between fisheries and protected areas, they provide benefits for fisheries, local economies and the marine environment. So, should be given further attention to this issue in the near future.

Given the high number of restrictions related to captures, it is important to improve the aquaculture sub-sector, through the increase and diversification of production, in order to build up the capacity of national auto-supply. Portugal has the highest values of fish consumption per capita of the EU and despite both imports and exports showed an increasing trend, Portuguese commercial balance for fisheries products has an increasing deficit. The increase in aquaculture units and their production between 1994 and 2004, despite the reduction in the number of species cultured, indicates that the tendency is in the right direction. But at the same time the number of processing companies decreased and its production oscillated. This sub-sector should also needs further development, since it has the potential to generate new employments, with positive effects in fisheries communities and it can use aquaculture products, contributing to the improvement of the aquaculture sub-sector.

Although landings showed a decreasing trend, its gross value increased as did the mean value of the landed fish. Moreover, both fishers earnings and fisheries enterprises profitability increased. However, enterprises' management and structure still presents some problems which results in low levels of profitability. Given the restrictions related to capture, development should be made directed to the reduction of harvesting costs and the enhancement of products quality in order to raise their landed value and, thus, sector profitability.

The number of fishers decreased more than 30% in the analysed period, while fishers' average age increased. This reflects the reduction of fleet size and the lack of interest of younger generations, mainly due to the low income, work instability and the safety and working conditions aboard vessels. Despite the improvement of the conditions onboard, there was not a significant decrease in the number of accidents. On the other hand, the percentage of fishers with the mandatory education level has increased in the last years, although they still have a relatively low education level. Many fishers have take part in training courses, but their number suffered a large decrease in the analysed period, also due to the reduced attractiveness of the sector.

Despite Portuguese fisheries Gross Value Added increased in the last years, the importance of the fishery activity in national economy has decreased. If we consider the high number of activities directly connected with the fisheries sector, the apparently low importance of the sector increased. This must be considered and should lead to greater efforts for more efficient management.

The value of the subsidies allocated to the sector, despite being highly variable over the years, provides not only an indication of the poor economic performance of the fisheries sector but also of the political difficulties in attaining effective fisheries management (FAO, 1999). The expenditure in Research and Development has been increasing year after year, which is very important since effective sustainable development requires information and research capacity (Garcia and Staples, 2000b).

Even though Portugal has given special attention to fisheries vigilance, results indicates that the regulations are often ignored facing other factors, probably economic ones. The lack of participation in decision making predisposes fishers to ignore rules designed to maintain a sustainable fishery. Nevertheless, the existence of producers organizations, which have increased in number in the last years, allows fishers to participate and have an effective role in the decision-making processes.

Achieving fisheries sustainability is complicated by a variety of interdependencies and trade-offs between economic, social, and ecological variables. The two methods used in a complementary way and the selected indicators seems to be a feasible and easily implemented framework to control Portuguese fisheries sector dynamic, adjust management policy and foster sustainable development. This framework allows results to be described simply which combined with the visual impact of TL, promotes their understanding. Although it does not precisely determine the sustainability of each indicator, which is impossible without true reference points, it can be used to understand sustainable trends in a given time period and which aspects need more attention and more urgent measures. Fishery management operates without necessarily having a specific target in view, but rather a domain to avoid, although defining a range of desirable conditions will be important (Caddy, 2002). Moreover it can be used to evaluate the potential impact of alternative policies on the status of fisheries sector. This framework may be developed in the future by including other indicators, identifying the respective reference points (target and/or limit reference points) and weighting indicators to reflect priorities according to the opinion of decision-makers.

Acknowledgements

This study was co-funded by the European Union through the FEDER - Fisheries Programme (MARE), as well as by Fundação para a Ciência e a Tecnologia (FCT) through the grant attributed to F. Baeta (Grant SFRH/BD/19223/2004).

References

Alder, J., Lugten, G., Kay, R., Feriss, B., 2001. Compliance with international fisheries instruments. In: Pitcher T.J., Sumaila U.R. and Pauly D. (ed.) Fisheries impacts on North Atlantic ecosystems, Evaluations and policy exploitation. Fisheries Centre Research Reports 9, 55-80.

Baeta, F., Pinheiro, A., Corte-Real, M., Costa, J.L., Almeida, P.R., Cabral, H., Costa, M.J., 2005. Are the fisheries in the Tagus estuary sustainable? Fish. Res. 76, 243-251.

Caddy, J.F., 1998. A short review of precautionary reference points and some proposals for their use in data-poor situations. FAO Fisheries Technical Paper 379, FAO, Rome.

Caddy, J.F., 1999. Deciding on precautionary management measures for a stock based on a suite of Limit Reference Points (LRPs) as a basis for a multi-LRP harvest law. NAFO Scientific Council Studies 32, 55-68.

Caddy, J.F., 2002. Viewpoint: limit reference points, traffic lights, and holistic approaches to fisheries management with minimal stock assessment input. Fish. Res. 56, 133-137.

Caddy, J.F., Wade, E., Surette, T., Hebert, M., Moriyasu, M., 2005. Using an empirical traffic light procedure for monitoring and forecasting in the Gulf of St. Lawrence fishery for the snow crab, *Chionoecetes opilio*. Fish. Res. 76, 123-145.

Chuenpagdee, R., Alder, J., 2001. Sustainability ranking of North Atlantic fisheries. In Pitcher, T., Sumaila, U.R. and Pauly D. (ed.). Fisheries impacts on North Atlantic ecosystems, Evaluations and policy exploitation. Fisheries Centre Research Reports Vol. 9, 49-54.

Commission of the European Communities, 2002. Communication from the Commission on the Reform of the Common Fisheries Policy: Road Map. CEC, Luxembourg.

Dahl, A.L., 2000. Using indicators to measure sustainability: recent methodological and conceptual frameworks. Ocean Coast. Manage. 51, 427-433.

DGPA, 2006. National Strategic Plan for Fisheries 2007-2013. Portuguese Fisheries and Aquaculture Bureau.

DJSI, 2003. DJSI-Dow Jones Sustainability Indexes. Dow Jones Sustainability World Indexes Guide, Version 5.0. Available at: http://www.sustainability-index.com.

FAO, 1995. Code of Conduct for Responsible Fisheries. FAO, Rome.

FAO, 1999. Indicators for sustainable development of marine capture fisheries. FAO Technical Guidelines for Responsible Fisheries 8. FAO, Rome.

Garcia S.M., Staples D., 2000a. Sustainability Indicators in Marine Capture Fisheries: introduction to the special issue. Ocean Coast. Manage. 51, 381-384.

Garcia S.M., Staples D., 2000b. Sustainability reference systems and indicators for responsible marine capture fisheries: a review of concepts and elements for a set of guidelines. Ocean Coast. Manage. 51, 385-426.

Garcia S.M., Cochrane K., Van Santen G., Christy F., 1999. Towards sustainable fisheries: a strategy for FAO and the World Bank. Ocean Coast. Manage. 42, 369-398.

Halliday R.G., Fanning L.P., Mohn R.K., 2001. Use of the traffic light method in fishery management planning. Canadian Science Advisory Secretariat Research Document 2001/108.

Krajnc D., Glavič P., 2005. A model for integrated assessment of sustainable development. Resour. Conserv. Recy. 43,189-208.

Liu, W.H., Ou C.H., 2007. A Comparative Analysis of Sustainable Fishery Development Indicator Systems in Australia and Canada. Sustain. Dev. 15, 28-40.

Liu W.H., Ou C.H., Ting K.H., 2005. Sustainable coastal fishery development indicator system: a case of Gungliau, Taiwan. Mar. Policy 29, 199-210.

Malkina-Pykh I.G., 2002. Integrated assessment models and response function models: pros and cons for sustainable development indices design. Ecol. Indic. 2, 93-108.

OECD, 2002. OECD – Organization for Economic Co-operation and Development. An Update of the OECD Composite Leading Indicators. Short-term Economic Statistics Division, Statistics Directorate/OECD. Available at: http://www.oecd.org.

Pitcher T.J., 1999. Rapfish, a rapid appraisal technique for fisheries and its application to the code of conduct for responsible fisheries. FAO Fisheries Circular 947. FAO, Rome.

Pitcher T.J., Preikshot D., 2001. RAPFISH: a rapid appraisal technique to evaluate the sustainability status of fisheries. Fish. Res. 49, 255-270.

RAP, 2001. Proceedings of the Fisheries Management Studies Working Group, 8-11 January, Bedford Institute of Oceanography, Dartmouth, Nova Scotia. DFO Canadian Science Advisory Secretariat Proceedings Series 2001/08.

Statistics Finland, 2003. Statistics Finland. Index of Environmental Friendliness. Available at: http://www.stat.fi/tk/yr/ye22_en.html.

WCED, 1987. Our Common Future. World Conference on Environment and Development. Oxford: Oxford University Press.

WEF, 2002. WEF – World Economic Forum. An Initiative of the Global Leaders of Tomorrow Environment Task Force. Annual Meeting 2002. Pilot Environmental Performance Index. Available at: http://sedac.ciesin.columbia.edu/es/esi/ESI2002_21MAR02a.pdf

CHAPTER 7

Are the fisheries in the Tagus estuary sustainable?

Authors

Filipa Baeta[a], Ana Pinheiro[a], Madalena Corte-Real[a], José Lino Costa[a], Pedro Raposo de Almeida[a], Henrique Cabral[a,b], Maria José Costa[a,b]

Authors' affiliation

[a]Instituto de Oceanografia, Faculdade de Ciências da Universidade de Lisboa, Campo Grande, 1749-016 Lisboa, Portugal

[b]Departamento de Biologia Animal, Faculdade de Ciências da Universidade de Lisboa, Campo Grande, 1749-016 Lisboa, Portugal

Published

Fisheries Research (2005) 76, 243-251.

Are the fisheries in the Tagus estuary sustainable?

Abstract: The comparative sustainability of seven Tagus estuary fisheries - beam-trawl, boat dredge, nets for glass eel, gill nets, eel basket, squid jig and octopus traps – is analysed using RAPFISH. This technique relies upon ordination of scored attributes, grouped in fields that cover ecological, economic, social, technological and ethical sustainability, performed using multi-dimensional scaling. Fisheries were analysed within each discipline and using all the attributes for an interdisciplinary approach. Leverage analysis is used to determine how much each attribute influences the ordination. Concerning the cross-discipline ordination, the studied fisheries lay around the mid-range of sustainability. The most sustainable fishery is octopus traps (57%) followed by squid jig (56%) that has the same results except for technological dimension. Eel basket and gill nets show the next best sustainability scores (55% and 53%, respectively). Glass eel fishery presents a poor sustainability (46%), laying close boat dredge and beam trawl, the fisheries with lower sustainability (44% and 43%, respectively). The leverage analysis shows that the ordinations are truly multivariate and that the results are not dominate by any attribute. More studies should be conducted on Tagus estuary fisheries in order to get more information about resources, fishermen and the activity, which will contribute to improve sustainability.

Keywords: fisheries, sustainability, RAPFISH, Tagus estuary.

Introduction

The Tagus estuary, located in the western Portuguese coast, is the largest in Portugal and one of the largest European estuaries, with an area of 325 km^2. This estuary is enclosed in the metropolitan area of Lisbon, the most populated zone of Portugal, and it has long been subjected to industrial development, urbanization and port and fishing activities.

This estuary is characterized by high species diversity and acts as a nursery area for several fish species (Costa and Bruxelas, 1989; Costa and Cabral, 1999), namely species with commercial value like the seabass *Dicentrarchus labrax* (Linnaeus, 1758) and the soles *Solea solea* (Linnaeus, 1758) and *Solea senegalensis* (Kaup, 1858).

In the past, fishermen from other parts of the country came to the Tagus attracted by the fish abundance. They constituted dispersed communities dedicated to particular species and using different fishing techniques. In the last quarter of the 19 century the most important fisheries were those dedicated to allis shad *Alosa alosa* (Linnaeus, 1758), sea lamprey *Petromyzon marinus* (Linnaeus, 1758) and meagre *Argyrosomus regius* (Asso, 1801)

(Baldaque da Silva, 1891).

The industrialization, which began in the mid 1950s, the intense agriculture, especially in the upper part of estuary, and the sewage from the growing population discharged into the estuary increased the pollution in this area causing a decrease in fish abundance and the disappearance of some species (Cabral *et al.*, 2001; Costa and Cabral, 1999).

In 1976, the Tagus Estuary Nature Reserve was created and some restrictive measures concerning the fisheries were implemented. Regulation forbidding or limiting the use of some fishing traditional techniques was created in 1990.

Nowadays, fishing communities are small and dispersed in the various councils that surround the estuary. Despite the low number of licensed people (ca. 500) engaged in these local fisheries, they represent an important employment niche and can be quite profitable. Fishermen maintain the same traditional techniques, even illegal ones. Most of the fisheries are seasonal so the same vessel uses different gears throughout the year.

Beam trawl fishing is illegal in all Portuguese estuaries, except for the Tagus estuary where it is quite common in the uppermost areas. Traditionally, this fishery catches mainly brown-shrimp *Crangon crangon* (Linnaeus, 1758), but due to its decreasing commercial value, fishes like the soles have became the main target species. Eel basket and nets for glass eel, the last strictly illegal, are also very common in the uppermost estuarine areas. Boat dredge, targeting bivalves like the clam *Ruditapes decussatus* (Linnaeus, 1758), squid jig and octopus traps are all common in the lower areas. Gill nets are widely used along the estuary and the target species are the meagre and the seabass.

Although several isolated scientific studies have been carried out in the Tagus estuary, few have focused on the Tagus fisheries. Cabral *et al.* (2002) studied the discards of beam trawl fishery in the nursery areas of this estuary, which represents ca. 90% of the captures, and Gamito and Cabral (2003) analysed some factors influencing the mortality of discards from the same fishery.

Until recently it was difficult to assess the sustainability of fisheries, especially when it required the integration of the information on the ecology, as well as social and economical aspects (Alder *et al.*, 2000). RAPFISH is a new multi-disciplinary rapid appraisal technique for evaluating the comparative sustainability of fisheries based on a large number of easy-to-score attributes grouped in a number of evaluation fields (Alder *et al.*, 2000; Pitcher, 1999; Pitcher and Preikshot, 2001). This technique is still under development but it has already been used in the sustainability assessment of a broad range of fisheries like North Atlantic fisheries (Alder *et al.*, 2000), African lake fisheries (Preikshot *et al.*, 1998) and different fleets off the coast of Northwest Africa (Pitcher and Preikshot, 1998).

This rapid assessment technique can give robust results, even with minimal information in any evaluation field (Preikshot *et al.*, 1998) as in the Tagus estuary fisheries. The present study aims to assess and compare the sustainability of the most important Tagus estuary fisheries, using the RAPFISH technique.

Material and Methods

The sustainability of seven Tagus estuary fisheries – beam trawl, gill nets, eel basket, nets for glass eel, boat dredge, squid jig and octopus traps – is evaluated using RAPFISH.

In RAPFISH analyses, sets of attributes, grouped into five dimensions critical for the long-term viability of fisheries, i.e. ecological, economic, social, technological and ethical, are scored on a ranked scale. Most of the indicators of sustainability discussed in the literature (FAO, 1999) are represented in the list of attributes of RAPFISH technique (Pitcher and Preikshot, 2001). Table 7.1 lists the attributes and respective scores for the referred five dimensions used in this analysis.

Each attribute was scored according to the information collected in field samplings (between 1998 and 2000), direct observation, interviews to fishermen and stakeholders (scientists and port authorities), official information from public institutions and peer-reviewed and 'grey' literature.

Using SPSS and Statistica softwares, a squared Euclidean distance matrix with attribute scores, normalised using Z-scores, is employed in a multi-dimensional scaling (MDS). To provide the ordination with fixed reference points, status is assessed relatively to the best and worst possible fisheries that may be constructed from the set of attributes of each dimension. Additional fixed reference points, expressing two halfway scores that have the maximum mutual difference, are included in the ordination to ensure that new evaluations do not flip vertically to their mirror image (Pitcher, 1999).

The first axis is rotated so that it is horizontal with the "good" (90°) and "bad" fisheries (270°) and then it is rescaled to percent with 0% as bad and 100% as good, so that fisheries are given a score along this axis.

The position of a fishery on the "good" and "bad" sustainability axis and its position relative to other fisheries help us assessing the relative sustainability of a set of fisheries. The position on the vertical y-axis represents changes in fisheries status that are not related to sustainability; this axis may be thought of as differences among fisheries achieved by obtaining the same sustainability rating from different combinations of attribute scores.

Fisheries were analysed first within each dimension and then using all the attributes for an interdisciplinary approach.

Attribute leveraging analysis shows the effect of removal of one attribute at a time on the ordination of the fisheries. For each attribute of a dimension, the sum of squares of the x-scores' differences is compared to that obtained with the full set of attributes. This provides a standard error (S.E.) expressing the leverage of each attribute on sustainability scores. The higher the value the greater the influence of the attribute on the fisheries ordination.

Scores in the different dimensions are combined in a "polygonal kite diagram" to facilitate comparison between fisheries. This diagram unites the RAPFISH scores plotted along the axes of a regular polygon (here a pentagon). Each axis represents one RAPFISH dimension and each line a fishery, with the outer rim representing best possible scores.

Table 7.1. List of the attributes used in RAPFISH analysis, showing the 'good' and 'bad' scores and definitions.

Attributes	Good	Bad	Notes
Ecological analysis			
Exploitation status	0	4	Under- (0); fully- (1); heavily- (2); over-exploited (3); almost completely collapsed (4).
Recruitment variability	0	3	COV: low <20% (0); medium 20-60% (1); high 60-100% (2); very high >100% (3).
Change in trophic level	0	2	Is trophic level of the catches in the ecosystem decreasing? No (0); somewhat, slowly (1); rapidly (2).
Migratory range	0	2	Number of jurisdictions encountered during life history (includes international waters): 1-2 (0); 3-4 (1); >4 (2).
Range collapse	0	3	Is there evidence of geographic range reduction? No (0); a little (1); a lot, fast (2); very great, rapid (3).
Size of fish caught	0	2	Has average fish size landed changed in past 5 years? No (0); yes, a gradual change (1); yes, a rapid change (2).
Catch before maturity	0	2	Percentage caught before size/age of maturity: none (0); some (>30%) (1); lots (>60%) (2).
Discarded bycatch	0	2	Percentage of target catch: low 0-10% (0%); medium 10-40% (1); high >40% (2).
Species caught	0	2	Includes species caught as by-catch (retained and discarded): low 1-10 (0); medium 10-100 (1); high >100 (2).
Primary production	4	0	g C/m2/year: low 0-50 (0); medium 50-100 (1); medium high 100-140 (2); high 140-220 (3); very high >220 (4).
Economic Analysis			
Profitability	0	4	Highly profitable (0); marginally profitable (1); break even (2); losing money (3); big losses (4).
Fisheries in GDP	2	0	Importance of fisheries sector in the economy: low (0); medium (1); high (2).
Average wage	4	0	Do fishermen make more or less than the average person? Much less (0); less (1); the same (2); more (3); much more (4).
Limited entry	4	0	Includes informal limitations: open access (0); almost none (1); very little (2); some (3); lots (4).
Marketable right	2	0	Marketable right/quota/share? None (0); some (1); mix (2); full ITQ, CTQ or other property rights (2).
Other income	0	3	In this fishery, fishing is mainly: casual (0); part-time (1); seasonal (2); full-time (3).
Sector employment	0	2	Employment in formal sector of this fishery: <10% (0); 10-20% (1); >20% (2).
Ownership	0	2	Profit from fishery mainly to: locals (0); mixed (1); foreigners (2).
Market	0	2	Market is principally: local/national (0); national/regional (1); international (2).
Subsidy	0	4	Are subsidies (including hidden) provided to support the fishery? No (0); somewhat (1); large subsidies (2); heavily reliant (3); almost completely reliant on subsidies (4).
Social Analysis			
Socialization of fishing	2	0	Fishermen work as: individuals (0); families (1); community groups (2).
New entrants into the fishery	0	3	Growth over past ten years: <10% (0); 10-20% (1); 20-30% (2); >30% (3).
Fishing sector	0	2	Households in fishing in the community: few, <10% (0); some, 10-30% (1); many, >30% (2).
Environmental knowledge	2	0	Level of knowledge about the fishery resource and its ecosystem and environment: none (0); some (1); lots (2).
Education level	2	0	Education level compared to population average: below (0); at (1); above (2).
Conflict status	0	2	Level of conflict with other sectors: none (0); some (1); lots (2).
Fisher influence	2	0	Strength of direct fishermen influence on actual fishery regulations: almost none (0); some (1); lots (2).
Fishing income	2	0	Fishing income as percentage of total family income: < 50% (0); 50-80% (1); >80% (2).
Kin participation	4	0	Do kin sell and/or process fish? None (0); very few relatives (1-2 people) (1); a few relatives (2); some relatives (3); many kin (4).

Table 7.1. Continuation.

Attributes	Good	Bad	Notes
Technological Analysis			
Trip length	0	4	Average days at sea per fishing trip: 1 or less (0); 2-4 (1); 5-8 (2); 8-10 (3); > 10 (4).
Landing sites	0	3	Landing sites are: dispersed (0); somewhat centralized (1); heavily centralized (2); distant water fleet with little, or no local landings (3).
Pre-sale processing	2	0	Processing before sale: none (0); some (1); lots (2).
Onboard handling	3	0	None (0); some (e.g. Salting, boiling) (1); sophisticated (e.g. Flash freezing, champagne ice) (2); live thanks (3).
Gear	0	1	Gear is: passive (0); active (1).
Selective gear	2	0	Device(s) and/or handling of gear to increase selectivity: few (0); some (1); lots (2).
FADS	0	1	Fish attraction devices: not used (0); bait is used (0.5); used (1).
Vessel size	0	4	Average length of vessels: <5 m (0); 5-10 m (1); 10-15 m (2); 15-20 m (3); >20 m (4).
Catching power	0	4	Have fishermen altered gear and vessel to increase catching power over past 5 years? No (0); very little (1); little (2); somewhat (3); a lot, rapid increase (4).
Gear side effects	0	3	Does gear have undesirable side effects (e.g. Cyanide, dynamite, trawl): no (0); some (1); a lot (2); fishing dominated by destructive fishing practices (3).
Ethical analysis			
Adjacency and reliance	3	0	Geographical proximity & historical connection: not adjacent/no reliance (0); no adjacent/some reliance (1); adjacent/some reliance (2); adjacent/strong reliance (3).
Alternatives	2	0	Alternatives to the fishery within community: none (0); some (1); lots (2).
Equity in entry to fishery	2	0	Entry based on traditional/historical access/harvests: not considered (0); considered (1); traditional indigenous fishery (2).
Just management	4	0	Inclusion of fishermen in management: none (0); consultations (1); co-management - government leading (2); co-management - community leading (3); co-management with all parts equal (4).
Mitigation of habitat destruction	4	0	Attempts to mitigate damage to fish habitat: much damage (0); some damage (1); no damage or mitigation (2); some mitigation (3); much mitigation (4).
Mitigation of ecosystem depletion	4	0	Attempts to mitigate fisheries-induced ecosystem change: much damage (0); some damage (1); no damage or mitigation (2); some mitigation (3); much mitigation (4).
Illegal fishing	0	2	Illegal catching/poaching/transsshipments: none (0); some (1); lots (2).
Discards and wastes	0	2	Discards and waste of fish: none (0); some (1); lots (2).
Influence in ethical formation	4	0	Structures which could influence values: strong negative (0); some negative (1); neutral (2); some positive (3); strong positive (4).

Results

The RAPFISH ordinations for the studied Tagus fisheries are represented in Figure 7.1. The higher sustainability scores are found in the ecological analysis. In this dimension, the observed scores lay between 57% for the beam trawl and 80% for both octopus traps and squid jig. In the economic ordination, all fisheries had the same sustainability score (45%), with the exception of the nets for glass eel, which had a score of 30%. A similar result was obtained for the social ordination, in which all the fisheries had a score of 51% on the sustainability axis, since all fisheries have the same score in each attribute. Scores in the technological dimension were between 47% and 74%. The higher scores were observed for eel basket and octopus traps, while the lower ones were obtained by beam trawl and boat dredge. The lower sustainability scores were observed for the ethical ordination. In this dimension the lowest score was obtained by boat dredge (7%) and the highest by squid jig and octopus traps (32%). Considering the combined analysis, all the seven fisheries laid around the mid-range of sustainability. The highest score was observed for octopus traps (57%), followed by squid jig (56%), eel basket (55%) and gill nets (53%). The lower scores were observed for beam trawl (43%), boat dredge (44%) and nets for glass eel (46%).

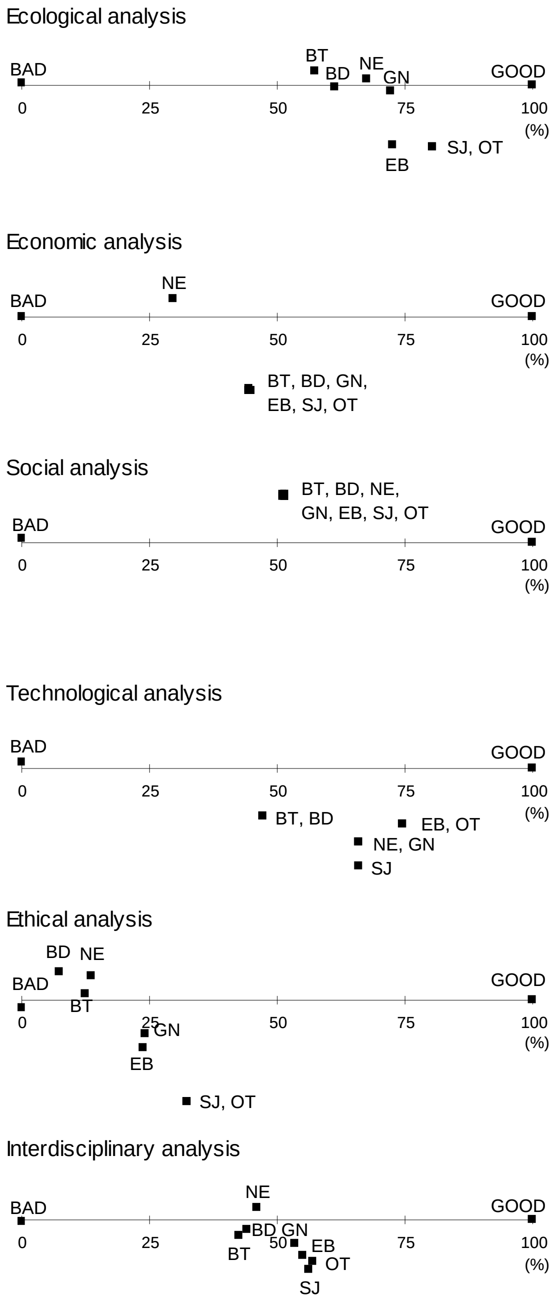


Figure 7.1. RAPFISH ordinations of the Tagus estuary fisheries in each dimension and in an interdisciplinary analysis. The horizontal axis represents sustainability scores between 0% and 100%, the ‘bad’ and ‘good’ fisheries locations, and the vertical axis represents differences among fisheries not related to sustainability. Fisheries represented by: BT, beam trawl; BD, boat dredge; NE, nets for glass eel; GN, gill nets; EB, eel basket; SJ, squid jig; OT, octopus traps.

Figure 7.2 illustrates the leverage analysis carried out for the attributes used in the definition of each dimension. Concerning the ecological analysis (Figure 7.2a), the attribute that seemed to have the greater influence on the ordination position of fisheries was ‘species caught’ (S.E. about 7.1%). The leverage of the other attributes ranged between 4.4% and 6.1%. In the economic dimension, the leverage analysis showed a great homogeneity between the influences of each attribute, with leverage ranging between 5.3% and 6.0%, except for ‘sector employment’ that had a leverage value of 4.5% (Figure 7.2b). Considering social dimension, the attribute that seemed to have higher influence was ‘educational level’ (S.E. about 6.3%), followed by the other attributes in a gradual decrease of influence until the lower score of 4.3% (Figure 7.2c). The higher values of leverage of attributes on RAPFISH scores were observed in technological ordination (Figure 7.2d). ‘Onboard handling’ attribute had a leverage value of 9.4%, followed by ‘pre-sale processing’ (S.E. of 8.5%). All the other attributes have lower leverage values between 5.1% and 6.5%. ‘Illegal fishing’ was the attribute that seemed to have higher influence (S.E. of 6.7%) in ethical ordination (Figure 7.2e). The leverage values of the other attributes decreased gradually until the lowest score of 4.5%.

The ‘kite diagram’ resulting from the combination of RAPFISH analysis is presented in Figure 7.3. It reveals that differences between the fisheries sustainability are related with the ecological, ethical and technological dimensions, while social scores are similar and economic ones differ only for glass eel fishery. This diagram also shows that octopus traps fishery is the most sustainable and that the squid jig fishery has similar results, except for technological dimension in which it achieves a lower score. The beam trawl and boat dredge are the worst fisheries in all dimensions with the exception of the economic one.

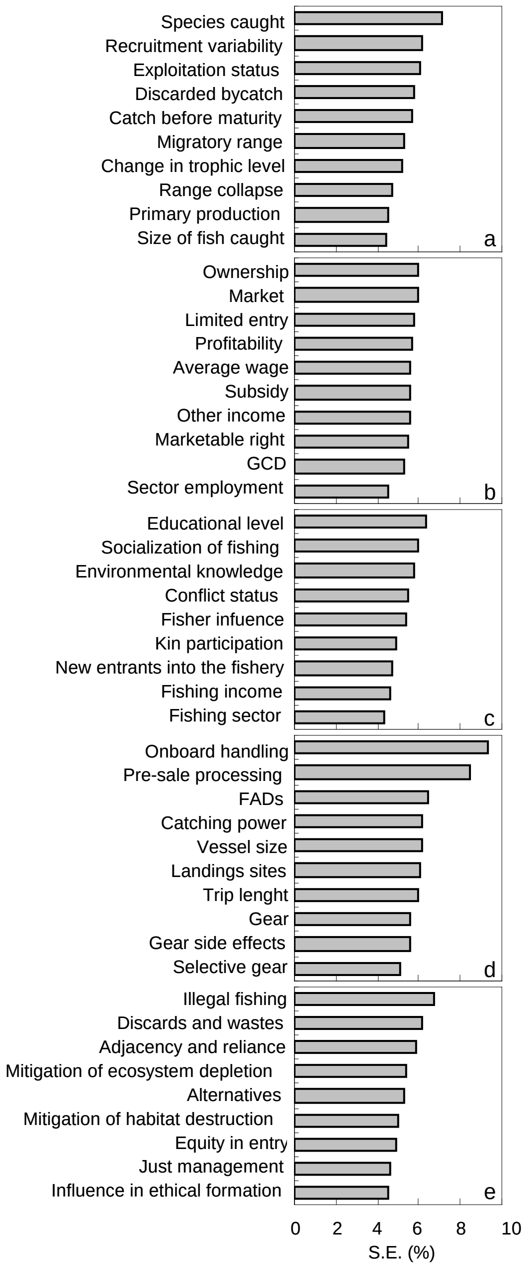


Figure 7.2. Attribute leverage analysis of the RAPFISH ordinations for Tagus estuary fisheries in a) ecological, b) economic, c) social, d) technological and e) ethical dimensions, based on the standard error in percent, S.E. (%).

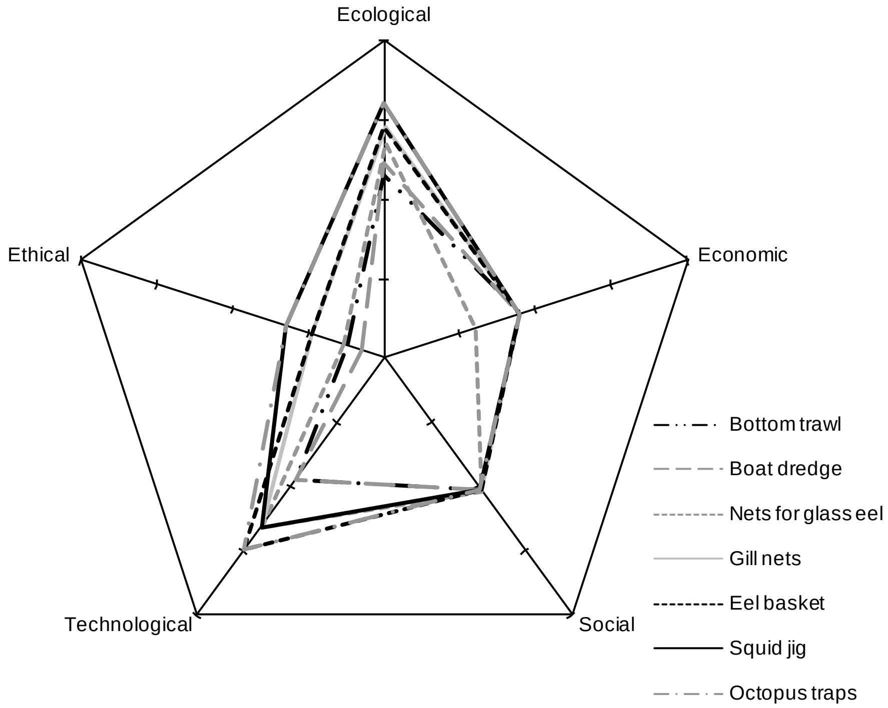


Figure 7.3. Kite diagram representing Tagus estuary fisheries sustainability scores in the five dimensions analysed.

Discussion

The results obtained are in agreement with what was expected and indicate that RAPFISH technique can give good results while comparing the status of fisheries.

In ecological ordination, the fisheries with higher sustainability scores (octopus traps, squid jig and eel basket) are those that capture a reduced number of species and have lower volumes of discards. Gill net fishery is as sustainable as eel basket, because even though the former captures more species, target species are not overexploited as happens with eel.

Glass eel fishery, beam trawl and boat dredge catch a high number of species, including a high percentage of individuals below size maturity and have elevated volumes of discards. As a result of moderate eel recruitment variability and homogeneity in fish size caught, glass eel fishery presents a sustainability score higher than beam trawl and boat dredge. Target species of beam trawl are characterized by a high variability in recruitment (Costa and Cabral, 1999), which, in addition to the other negative aspects already mentioned, makes this fishery the worst in ecological ordination. This fluctuating recruitment introduces uncertainty and risk in management and requires implementation of precautionary approaches; it also tends to complicate the discrimination of the relative importance of the impacts of fishing (Garcia *et al.*, 1999).

The glass eel fishery, an illegal activity, has the worst sustainability score in economical dimension. Although it is a highly profitable activity that involves much money in a subterranean economy, the market is international and the profit is mainly made by foreigners.

With the exception of glass eel fishery, the fisheries have the same scores in all economic attributes. The attributes that score towards sustainability are the low dependence of subsidies, the profitability of these fisheries and the fact that frequently fishermen earn wages above national wage. Provision of subsidies is the most important cause for economic waste and overfishing. It does not only indicate a poor economic performance of the fishery but also political difficulties in attaining effective fisheries management (FAO, 1999; Garcia *et al.*, 1999). In the absence of major market distortions, profitability is the most important economic criterion (FAO, 1999). Low or negative profitability usually indicates that fish stocks are exploited in a wasteful manner and fishing effort is excessive. An average wage above the national is an incentive for fishermen to support and obey management directives to ensure that their wages remain high or improve.

Even though Tagus fisheries are profitable and essential for subsistence of fisher families, their importance to the national economy is low. Increasing the importance of this sector to the wider community would grant it further support for effective management. The absence of marketable right and the fact that fisheries are full-time activities are also aspects that reduce the fisheries economic sustainability. The existence of other means to generate income, other than fishing, provides alternatives in case resources are threatened due to overexploitation.

In social terms, all the fisheries score equally in each attribute, showing the same sustainability score. This is because fisheries studied take place in a confined area – Tagus estuary – and are performed, if not by the same fishery community, by related ones. The central position of studied fisheries on the “sustainability” x-axis is justified by opposite trends of attributes, some towards sustainability and others against it.

Attributes that score towards the good end of the scale are the low number of households engaged in fisheries in the region, the decrease of the sector in the last years and the high percentage of fishing in the total family income. During the last years the quantity of licenses registered in the maritime delegations decreased, due to lack of interest from young people and subsidies that were given to the fishing cessation. Work in the fisheries sector, especially fishing, is often regarded as employment of last resort, because of the limited training and educational requirements. If the sector does not grow, then demand on resources and risk of unsustainable practices does not increase. However, this data must be seen with some precaution due to the great number of illegal fishermen, namely recreational ones that are in fact disguised and unregulated commercial fishermen. Among the negative aspects are the fact that fishermen are characterized by an education level below national average and the lack of kin participation in selling or processing fish.

In the technological dimension, the most sustainable fisheries – eel basket and octopus traps – are the most selective and the ones that use bait. The fisheries with lower sustainability – beam trawl and boat dredge – are those that use active gears and present gear side effects. Besides the physical impact upon the seabed, these bottom-fishing activities disturb the resident community to some degree (Kaiser *et al.*, 2002).

Small duration of fishing trips, reduced length of vessels and stability in catching power in the last years are characteristics that put the Tagus fisheries towards the good end of the scale. These features prevent overfishing and excessive fishing capacity. Practices that decrease the fisheries sustainability are the absence of onboard handling and processing before sale. Fish processing, associated with distribution and marketing, leads to a reduction of post-harvest losses and waste and an improvement of bycatch usage (FAO, 1995).

In ethical ordination, fisheries show reduced sustainability scores, which results from the fact that many attributes score towards the bad end of the scale.

Many illegal practices are made in the Tagus fisheries. Almost all fishermen capture and sell individuals before size of maturity. In the period when beam trawl fishery is forbidden many fishermen continue to use this gear. Nets for glass eel and boat dredge are forbidden in the estuary, but continue to be used. Costa and Cabral (1999) present lack of statutory control as the major problem of fishing activity in Tagus estuary.

Usually fishermen opinions are not considered in management decisions, which reduces the fisheries sustainability. New management strategies need to recognize the importance of cultural heritage, the related traditional rights, as well as the need for partnerships with stakeholders and decentralization of management powers (Garcia *et al.*, 1999).

Another aspect that has a negative effect on Tagus fisheries sustainability is the lack of attempts to mitigate damages to the ecosystem resulting from these activities. Fisheries with more sustainability (squid jig and octopus traps) are those that induced less significant damage on ecosystem and produced lower volumes of discards.

The organic material resultant from discards may cause changes in the structure and diversity of marine communities, favouring the proliferation of scavenger and decomposer species (Alverson *et al.*, 1994; Cabral *et al.*, 2002; Goñi, 1998). Measures to reduce discards are extremely important and should be promoted, especially economically viable ways of using the bycatch.

The cross-discipline analysis has produced no surprises. The sustainability scores obtained by the seven fisheries are in tune with what we would expect given the results of the five single disciplinary ordinations, which can be concluded with the analysis of 'kite diagram'.

Leverage analysis shows that the ordinations are genuinely multivariate, with all the attributes contributing more or less equally to the final result, as Pitcher and Preikshot (2001) observed in all cases they examined. As stated by Alder *et al.* (2000), we can say that RAPFISH estimates are stable and not dominated by one particular attribute. However, in technological ordination something curious happens: the two attributes with higher S.E. score equally for all the fisheries. This could be explained by the fact that their scores are the only ones in the bad extreme of the attributes scale, presenting zero values that when normalised using Z-scores will not change. Care should be taken, as the difference between these attributes' S.E. and the rest might not be overly representative. Therefore, leverage analysis results should be evaluated bearing in mind that the scale and the scores could be influencing the ordinations more than expected and concealing fisheries differences.

The resulting analysis is only indicative of relative sustainability of the fisheries, although its information is useful to determine where intervention is more necessary. In this study RAPFISH technique was performed with the attributes used in previous studies. It is important that the same sets of attributes, scoring definitions, anchor fisheries, and reference fisheries be used for all RAPFISH analyses, so that results can be compared (Kavanagh and Pitcher, 2004) allowing us to follow changes in status (Pitcher and Preikshot, 2001). However, in the future this technique could be adapted to the Portuguese reality, particularly with the elimination of some attributes and the addition of others, to improve assessment.

More studies should be conducted on Tagus fisheries in order to get a better knowledge about them and, consequently, a better management and higher sustainability. Furthermore, it is important to keep in mind that the sustainability of Tagus fisheries is also associated with responsible practices regarding land uses and management on an ecosystem perspective.

Acknowledgements

We are most grateful to Tony J. Pitcher for his help with RAPFISH technique. This research has been funded by the project ‘Effects of river flow changes on the fish communities of the Douro, Tejo and Guadiana estuaries and adjoining coastal areas. Ecological and socio-economic predictions’ (PDCTM/MAR/15263/1999) financially supported by the Fundação para a Ciência e a Tecnologia.

References

Alder, J., Pitcher, T.J., Preikshot, D., Kaschner, K., Ferriss, B., 2000. How good is good?: A rapid appraisal technique for evaluation of the sustainability status of fisheries of the north Atlantic. In: Pauly, D. and Pitcher, T.J. (Ed.), Methods for evaluating the impacts of fisheries on north Atlantic Ecosystems. Fisheries Centre Research Reports, Vol. 8, No. 2, pp. 136-182.

Alverson D.L., Freeberg M.H., Murawski S.A., Pope J.G., 1994. A global assessment of fisheries by-catch and discards. FAO Fisheries Technical Paper No. 339. FAO, Rome.

Baldaque da Silva, A.A.., 1891. Estado actual das pescas em Portugal. Imprensa Nacional, Lisboa.

Cabral, H.N., Costa, M.J., Salgado, J.P., 2001. Does the Tagus estuary fish communities reflect environmental changes?. Climate Res. 18, 119-126.

Cabral H.N., Teixeira C.M., Gamito R., Costa M.J., 2002. Importance of discards of a beam trawl fishery as input of organic matter into nursery areas within the Tagus estuary. Hydrobiologia 475/476, 449-455.

Costa, M.J., Bruxelas, A., 1989. The structure of fish communities on the Tagus Estuary, Portugal, and its role as a nursery for commercial fish species. Sci. Mar. 53, 561-566.

Costa, M.J., Cabral, H.N., 1999. Changes in the Tagus nursery function for commercial fish species: perspectives for management. Aquat. Ecol. 33, 287-292.

FAO, 1995. Code of Conduct for Responsible Fisheries. FAO, Rome.

FAO, 1999. Indicators for sustainable development of marine capture fisheries. FAO, Rome.

Gamito, R., Cabral H., 2003. Mortality of brown-shrimp discards from the beam trawl fishery in the Tagus estuary, Portugal. Fish. Res. 63, 423-427.

Garcia, S.M., Cochrane, K., Santen, G.V., Christy, F., 1999. Towards sustainable fisheries: a strategy for FAO and the World Bank. Ocean Coast. Manage. 42, 369-398.

Goñi, R., 1998. Ecosystem effects of marine fisheries: an overview. Ocean Coast. Manage. 40, 37-68.

Kaiser, M.J., Collie, J.S., Hall, S.J., Jennings, S., Poiner, I.R., 2002. Modification of marine habitats by trawling activities: prognosis and solutions. Fish Fish. 3, 114-136.

Kavanagh, P., Pitcher, T.J., 2004. Implementing Microsoft Excel software for RAPFISH: a technique for the rapid appraisal of fisheries status. Fisheries Centre Research Reports, Vol. 12, No. 2.

Pitcher, T.J., 1999. Rapfish, a rapid appraisal technique for fisheries, and its application to the code of conduct for responsible fisheries. FAO Fisheries Circular No. 947. FAO, Rome.

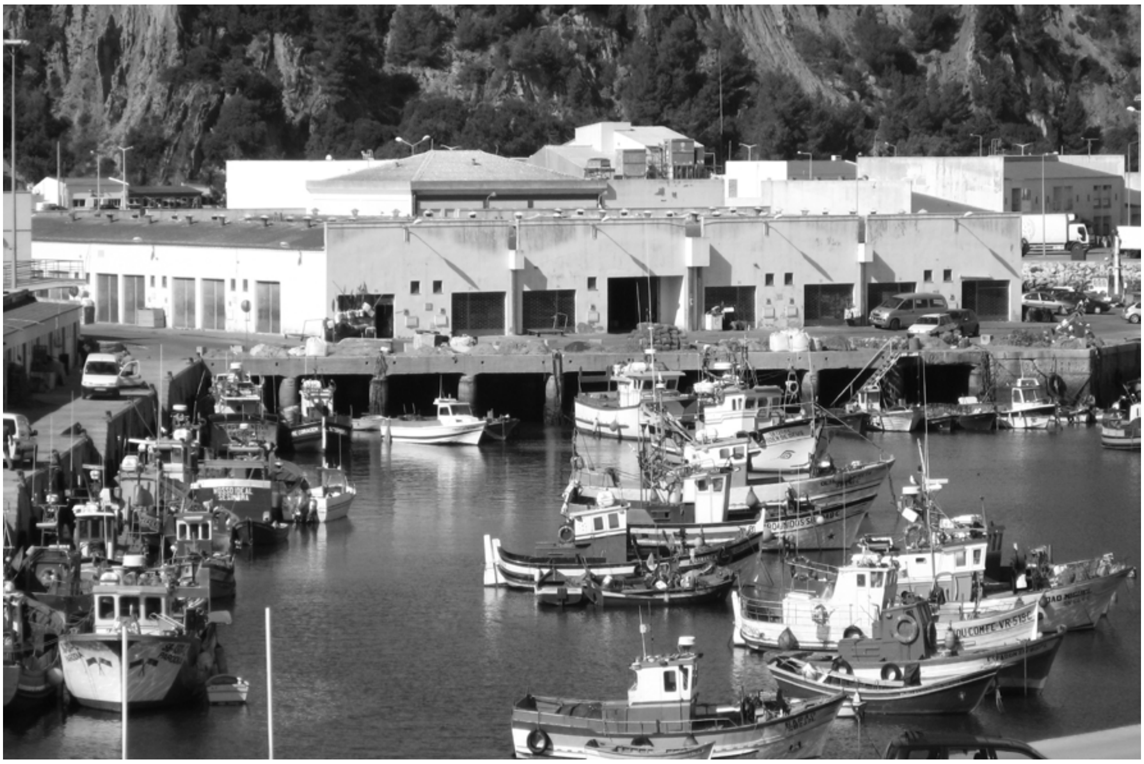
Pitcher, T.J., Preikshot, D., 1998. Rapid appraisal of the status of West African distant water fleet fisheries relative to home fleets using Rapfish technique. In: Bonfil, R., Munro, G., Sumaila, U.R., Valtysson, H., Wright, M., Pitcher, T., Preikshot, D., Haggan, N., Pauly, D. (Eds.), Distant Water Fleets: an Ecological, Economic and Social Assessment. Fisheries Centre Research Reports, Vol. 6, No. 6, pp. 90-93.

Pitcher, T.J., Preikshot, D., 2001. RAPFISH: a rapid appraisal technique to evaluate the sustainability status of fisheries. Fish. Res. 49, 255-270.

Preikshot, D., Nsiku, E., Pitcher, T., Pauly, D., 1998. An interdisciplinary evaluation of the status and health of African lake fisheries using a rapid appraisal technique. J. Fish Biol. 53 (Suppl. A), 381-393.

Part IV

Management of Portuguese fisheries



CHAPTER 8

Are we using the appropriate management measures to achieve the biological sustainability of fisheries? The case of Portuguese fisheries

Authors

Filipa Baeta[a], Maria José Costa[a,b], Henrique Cabral[a,b]

Authors' affiliation

[a]Instituto de Oceanografia, Faculdade de Ciências da Universidade de Lisboa, Campo Grande, 1749-016 Lisboa, Portugal

[b]Departamento de Biologia Animal, Faculdade de Ciências da Universidade de Lisboa, Campo Grande, 1749-016 Lisboa, Portugal

Submitted

Marine Policy

Are we using the appropriate management measures to achieve the biological sustainability of fisheries? The case of Portuguese fisheries

Abstract: Awareness of the poor state of world fisheries conduced to efforts to improve management in the hope of moving towards sustainability. However, the extent to which measures have been implemented and achieved results are not always the expected. In this study, the biological effects of measures that manage Portuguese fisheries since adoption of Common Fisheries Policy in 1986 was analysed. In general, management measures have not achieved the desired effects. Considering output measures, total allowable catches have not limited the catch in most cases, individual fishing quotas was implemented for sardine and hake, but were only effective for the first, and vessel catch limits, which exist only for sardine, were met due to the immediate economic benefits. Input measures (licences, individual effort quotas and gear and vessel restrictions) limited fishing effort, but was not possible to recognize their individual direct consequences. The effect of size selectivity measures was also difficult to assess individually, although it can be noted that they protect juveniles but also promote discards. Fishing closures seemed to have positive effects for sardine and nephrops, but not for hake. Results highlighted the urgent need for a new fisheries management system in Europe that guarantees long-term conservation of marine resources.

Keywords: management, fisheries, biological effects, Common Fisheries Policy, Portugal.

Introduction

In 2007 the United Nations Food and Agriculture Organization (FAO), which monitors the state of world fisheries, has estimated that 52% of the monitored stock groups were fully exploited, 19% overexploited, 8% depleted and 1% recovering (FAO, 2009) and therefore need urgent conservation and management measures. Fishing areas with the highest proportions (71−80%) of fully exploited stocks are the Northeast Atlantic, Western Indian Ocean and Northwest Pacific (FAO, 2009). The causes of the collapse of exploited marine populations have been subject of wide debate, confronting hypothesis that focus the problem on a excessive fishing effort which brings about overexploitation, against those that argue that fluctuations in population dynamics are attributable to natural environmental changes (Freire and Garcia-Allut, 2000).

During the last decades of the 20th century, governments and intergovernmental organisations have introduced various measures aimed at improving the sustainability of fisheries resources use. International conventions, multi-lateral agreements and new codes of conduct have created the framework for a new world order for fisheries, in which coastal states will increasingly depend on the resources occurring in their own waters (Moniz *et al.*, 2000). Nevertheless, the translation of scientific knowledge into practical policies is often slow and incomplete, as many other political, social and economic factors come into play (Daw and Gray, 2005). Fishery management is currently a challenging exercise. Fishery managers are under increasing pressure to find more effective solutions to the biological, economic and social problems of the fisheries they manage. The complexity and urgency of this task has created a market for quick and technical solutions to management problems, leading to the use of wholesale solutions to specialized problems (Degnbol *et al.*, 2006).

Fishing is a traditional and culturally important activity in Portugal. Portuguese waters are in the subtropical/temperate transition zone of the Eastern Atlantic. Also Portuguese and Galician coasts (International Council for the Exploration of the Sea, ICES, Divisions IXa and VIIIc, respectively) are upwelling areas with high productivity (ICES, 2008). These characteristics determine considerable species diversity and the abundance of small pelagic fish, such as sardine (*Sardina pilchardus*), which usually represents the larger fraction of the total landings. As a result of their high biodiversity, there are several distinct fleets using different fishing gear types targeting a wide diversity of commercially important species.

Portuguese fisheries have three major fleet segments: the purse seine fleet, the trawl fleet, which comprises vessels catching demersal fish and vessels targeting crustaceans; and the multigear fleet, mainly artisanal and the largest segment, which uses a high variety of fishing gears (gill and trammel nets, hooks and longline, traps and pots) and targets a large number of species. The pelagic purse seine fishery activity is directed, essentially, to the capture of sardine. Other small pelagic species, such as horse mackerel (*Trachurus trachurus*), chub mackerel (*Scomber japonicus*) and Atlantic mackerel (*Scomber scombrus*) are also caught, but have a much lower importance (INE, 2009). The crustaceans trawl fishery fleet operates with deep-water otter trawls and targets nephrops (*Nephrops norvegicus*), rose shrimp (*Parapenaeus longirostris*) and red shrimp (*Aristeus antennatus*), off the southwest and south coast of Portugal (Campos *et al.*, 2007). The remaining trawl vessels operate with semi-pelagic otter trawls throughout the Portuguese coast, targeting different fish species as horse mackerel, hake (*Merluccius merluccius*), anglerfishes (*Lophius* spp.), and in a small proportion also cephalopods as octopus (*Octopus vulgaris*) and squids (Campos *et al.*, 2007; Fonseca *et al.*, 2008). Horse mackerel is the most important species in the landings, followed by blue whiting (*Micromesistius poutassou*) and chub mackerel. In the multigear segment the fishing strategies, target species, types of fishing operations, and seasonal variation of fishing tactics are very complex and variable. During the same fishing trip a variety of different fishing gears can be used, and the species composition of the landing is the outcome of different gears and fishing operations. This segment includes very diverse fisheries such as the octopus traps fishery, the black scabbardfish (*Aphanopus carbo*) deepwater longline fishery, the swordfish (*Xiphia*s *gladius*) longline fishery or the trammel net fisheries for soles (*Solea* spp.), hake (*Merluccius merluccius*) or anglerfishes.

From Portugal's political point of view, the most important change in fisheries occurred with the adhesion to European Union (EU), in 1986, and the consequently adoption of EU's Common Fisheries Policy (CFP). In the last decades Portuguese landings, fishing fleet and number of fishermen have declined. The present Portuguese management system includes the establishment of annual total allowable catch (TAC) and quotas for some species and fishing areas, the application of technical conservation measures (minimum landing sizes, minimum mesh sizes, allowable percentages for by-catch species and target species, area closures and bans on the use of specific gear) and other restrictions to limit the fishing effort as prior administrative authorisation for the acquisition or construction of new fishing vessels and for the use of fishing gear, and annual fishing licences.

Policies worldwide, and also in EU, have put a marked emphasis in sustainability, but management have been performed using several instruments and measures which efficacy is mainly unknown. The objective of this work is to analyse the biological effects of the fisheries management measures adopted since Portuguese adhesion to the EU, determining which measures are effective for the conservation of marine fisheries. Furthermore, it aims to assess how well the various management measures have performed and to identify fishery-management issues.

Material and Methods

The biological consequences of applied fisheries management measures were analyzed for the important species in Portuguese landings and those subject to management measures for which there is an assessment of the state of the stock, i.e. sardine, horse mackerel, hake, nephrops, anglerfish, Atlantic mackerel, blue whiting and megrims (*Lepidorhombus* spp.). The evidence concerning biological consequences describes changes in abundance and composition of fish stocks, with the main biological consequence being the extent to which the target resource stock is protected from overexploitation.

This study was focused on the period between 1986 and 2007. Landings and respective TAC for the species stock and for ICES subareas that include Portuguese waters were analyzed simultaneously with indicators of the state of a resource: total biomass (B) or spawning stock biomass (SSB), i.e. a measure of the amount (or biomass) of adult fish in a stock, recruitment (R) and fishing mortality (F), i.e. a measure of the fishing pressure on a fish stock. The evolution of these indicators of the state of the stock was analyzed considering the implementation of management measures. The analyzed stocks are managed by the EU, autonomously or jointly with other partners, and ICES gives management advice. The main management objective for these stocks is to ensure that SSB remains above a threshold at which R may be impaired, and that F remains below a threshold level that would drive the stock below the biomass threshold (ICES, 2008).

Statistics and data series were collected from national and International institutions, namely Statistics Portugal (INE), the Fisheries and Aquaculture Bureau (DGPA) and ICES.

Fishery management measures can be divided into output controls, input controls, and technical measures (Sutinen, 1999). Output controls limit the catch of the fleet and/or the catch of individual fishing units per trip and/or period of time. These measures include TAC, which sets a maximum on the total catch allowed in the fishery for specific species, area, and time period; individual fishing quotas (IFQ), which restrict the catch of individual fishing units; and vessel catch limits, which restrict the amount a fishing unit can catch per trip or short period. Input controls limit the inputs used to produce catch. These measures include limited licenses, which restrict the number of fishing units; individual effort quotas, which restrict the amount of gear in the water or amount of time gear spends in the water; and gear and vessel restrictions, which restrict the size and other dimensions of each fishing unit. Technical measures include size and sex selectivity measures, which restrict the size and sex of fish that can be landed, and time and area closures, which limit the time and place where fishing units can operate.

In addition to management measures, systems characteristics may also influence fisheries. An important example of exogenous influences is a change in environmental conditions that can have major impacts on fisheries. Other examples include technological progress and market and trade developments. These and other exogenous influences can obscure the influence of management measures on fishery outcomes. Where possible, these and other explanations of the reported outcomes were investigated.

Results

Sardine

Sardine is the most landed species in Portugal, representing 38.4% of total landings in 2009, and is mainly caught by purse seine (INE, 2009). Purse seine fleet activity is regulated by national legislation since 1997: there is a management plan that establishes a maximum of 180 fishing days per year, a weekend ban, IFQ per year set by producer organizations, which in some cases distributed this quota in daily catch limits by vessel, and time and area closures (Table 8.1). Also there are some gear restrictions since 1987 concerning mesh size, net dimensions and operating distance to the coast. Sardine stock of the ICES divisions VIIIc and IXa have no management objectives neither TAC, except for 11 cm minimum landing size (MLS) since 1986. Stock is managed by Portugal and Spain collectively.

Over time landings at the ICES divisions VIIIc and IXa have decreased, as well as Portuguese landings (Figure 8.1a). Since 1986 SSB of this stock has varied notably and in the last decade an increasing trend was observed (Figure 8.1a). R also showed oscillations with isolated peaks in a few years and attained its lowest level in 2006 (Figure 8.1.b). In 2008 SSB was around the long-term average despite having decreased in the past two years probably due to recent successive low recruitments. F has also changed along the time, but since 1998 it has decreased and is now at a low level (Figure 8.1c).

Table 8.1. Management measures applied to species (✓) with reference to the date of application and some details to explain them (TAC – total allowable catch; IFQ – individual fishing quotas; MLS – minimum landing size). The asterisk (*) means that the management measure was not applied to the species but the species may be affected by it.

	Species	Sardine	Horse mackerel		Hake		Nephrops	Anglerfish		Atlantic mackerel		Blue whiting	Megrim
	Main gear	Purse seine	Purse seine	Trawl	Multigear	Trawl	Trawl	Multigear	Trawl	Purse seine	Trawl	Trawl	Trawl
Output measures	TAC		✓1986		✓1986		✓1986	✓1986		✓1986		✓1986	✓1986
	IFQ	✓1997			✓ 2007								
	Vessel catch limits	✓1997											
Input measures	Licences	✓	✓		✓		✓	✓		✓		✓	✓
	Individual effort quotas	✓1997 180 d y^{-1}	✓1997 180 d y^{-1}		✓2000 # nets			✓2000 # nets		✓1997 180 d y^{-1}			
	Gear and vessel limitations	✓	✓		✓		✓	✓		✓		✓	✓
Technical measures	Size selectivity	✓1986 MLS ✓mesh size	✓1986 MLS ✓mesh size		✓1986 MLS ✓mesh size		✓1986 MLS ✓mesh size	✓mesh size		✓1986 MLS ✓mesh size		✓mesh size	✓1986 MLS ✓mesh size
	Time and area closures	✓1997	*	*	✓1994	✓1994	✓2004	*	*	*	*	*	*
Recovery plan					✓2006		✓2006						

The effects of the reported fisheries regulations introduced in 1997 in the stock were not evident in the presented indicators but may have contributed to the decline in landings and in F in recent years. Although this could not be analysed due to data unavailability, time and area closures imposed to protect this stock may have contributed to the SSB improvement or, at least, prevented further deterioration of the state of the stock. Also, SSB is dependent on R and this, in turn, is very dependent on environmental conditions (Santos *et al.*, 2001), making it unmanageable.

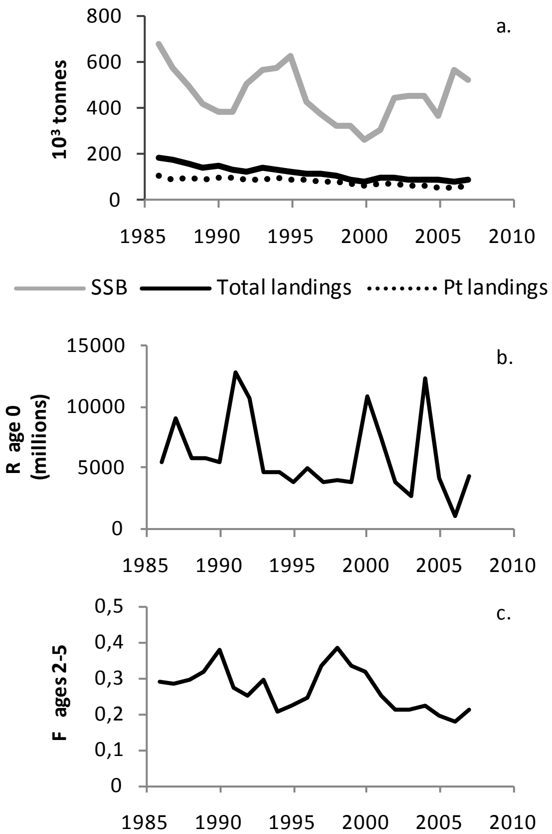


Figure 8.1. Sardine in ICES subareas VIIIc and IXa: a) Portuguese landings (Pt landings), total landings and spawning stock biomass (SSB), b) recruitment (R) and c) fishing mortality (F).

Horse mackerel

Horse mackerel was the fourth most landed species (5.4% of total landings) and the fifth in economic value in 2008 (INE, 2009). It is caught in Iberian waters mainly by Portuguese and Spanish bottom trawlers and purse seine fleet. Therefore its catch is regulated not only by measures that focus on the species (15 cm as MLS and TAC since 1987) but also by measures that regulate the purse seine fishery, detailed above for sardine, and measures that regulate trawl (Table 8.1). Gear restrictions relative to mesh size, minimum percentages of capture of target species and minimum distance to the coast that is allowed to operate with trawl were established in 1987. In 1994 temporal and spatial restrictions were also established to the trawl fleet in order enhance reproduction and growth of certain species, in particular hake: since that time it is not allowed to operate with trawl, during part of the year in certain coastal areas.

The Northeast Atlantic stock of mackerel is divided into three stocks - Northern, Western and Southern, the last covering ICES divisions VIIIc and IXa. Landings of the horse mackerel southern stock decreased over the years but in the last decade have remained relatively stable, and were always much lower than TAC. SSB showed a marked decrease since 1999, but has been increasing since 2003, reaching higher values in last years compared to in the beginning of the studied period (Figure 8.2a). R changed markedly with two important peaks in 1996 and 2004 (Figure 8.2b). This recent strong R is likely responsible for the increase in SSB. F of southern horse mackerel has been stable between 0.3 and 0.4 since 1999 (Figure 8.2c). It had a high peak in 1998, caused by the shortage of sardine in Spanish area, which made fishermen target horse mackerel (ICES, 2008).

The effects of fisheries regulations in this species stock are uncertain. Landings are well below TAC values, therefore this measure carries no effects on the stock. The effort quotas applied to seine fishery and the time and area closures related to trawl fleet may have had positive effects on the conservation of this species. However, the rise and fall of SSB was probably caused by complex interactions of different factors, both human and natural. It is very likely that changes in R due to upwelling events may have played an important role (Santos *et al.*, 2001).

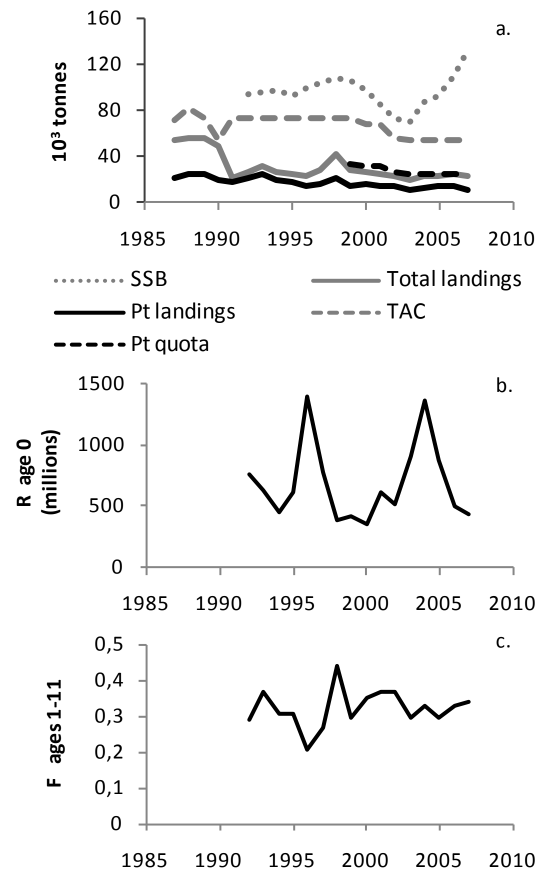


Figure 8.2. Horse Mackerel in ICES subareas VIIIc and IXa: a) Portuguese landings (Pt landings) and respective quota (Pt quota), total landings and TAC (for ICES areas VIIIc, IX and X and EC waters of CECAF 34.1.1), spawning stock biomass (SSB), b) recruitment in (R) and c) fishing mortality (F).

Hake

Although hake landings weight is small, this species a high commercial value in Portugal. It is mainly caught by the multigear fleet (gillnets and hooks), with trawl also having a significant contribution. Its catch is regulated by measures that focus on the species, 27 cm of MLS and TAC since 1987, and vessel catch limits since 2007, as well as by measures that regulate the operation with the different fishing gears (Table 8.1). In addition to measures already referred for trawl, for gillnets there are restrictions since 1987 on the distance between nets and distance to the coast, and on the residence time in the water. Restrictions on the number of nets, mesh size and concerning a minimum percentage of catch of target species are also applied since 2000. To protect hake, the use of nets was forbidden in certain areas in 1994

A single stock of hake is considered in ICES divisions VIIIc and IXa. Portuguese landings of this stock have decreased along the years, but total landings increased since 2005 due to Spanish landings (Figure 8.3a). TAC has been exceeded several times since 1995 and the same succeed with Portuguese quota between 2002 and 2007 (Figure 8.3a). SSB showed exactly the same trend as total landings (Figure 8.3a): it increased recently due to the increasing in R in recent years (Figure 8.3b). F increased along the years, reaching a maximum in 1995 and 2007 despite strong interannual variability (Figure 8.3c).

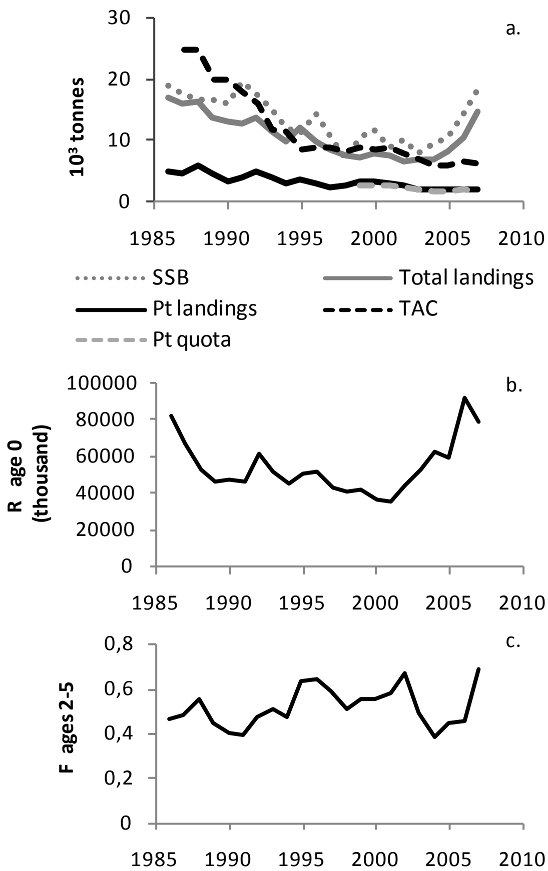


Figure 8.3. Hake in ICES subareas VIIIc and IXa: a) Portuguese landings (Pt landings) and respective quota (Pt quota), total landings and TAC (for ICES areas VIIIc, IX and X and EC waters of CECAF 34.1.1), spawning stock biomass (SSB), b) recruitment in (R) and c) fishing mortality (F).

This stock was classified as having reduced reproductive capacity and being harvested unsustainably (ICES, 2008). In 2006 a recovery plan was introduced to recover the stock to a spawning-stock biomass above 35 000 tonnes and to reduce fishing mortality to 0.27 by 2015. The main elements in the plan are a 10% annual reduction in F and a 15% constraint on TAC change between years.

TAC has been ineffective in regulating the fishery in recent years as landings highly exceed it. Also, the implementation of the recovery plan has not been effective: even though SSB increased (less than desired), F has also increased. Although there are no available data that allow confirming it, time and area closures imposed to trawl and gill and trammel nets to protect this stock may have contributed to the increase in R. Vessel catch limits, imposed in 2007, were exceeded, however, interpretations on its effectiveness are still premature.

Nephrops

Nephrops has a low importance in weight of Portuguese landings, but it achieves high sale values making it an important fisheries resource. It is mainly caught by the trawl fleet operating in the Portuguese southwest and southern coast. In ICES division IXa nephrops stock is divided in five Functional Units (FU 26-30), with the Portuguese fleet operating only in two of them, Southwestern Portugal (FU 28) and Southern Portugal (FU 29). These FU were managed at Community level, through the setting of TAC annually and the imposition of a MLS (7 cm) since 1987, and at national level by measures that regulate the operation of trawl fleet (Table 8.1). In order to reduce F in IXa division a seasonal ban was introduced in FU 28 since 2004. Recently, in 2006, the recognition of the critical state of over-exploitation of this stock, which is clearly outside safe biological limits, led to the application of exceptional management measures and a recovery plan has been established for this stock. This recovery plan has been in force since 2006 and aims to rebuild the stock within 10 years, with a reduction of 10% in F relative to the previous year and the TAC set accordingly.

Both total and Portuguese landings decreased since 1986 (Figure 8.4a). The same trend is presented by TAC (established to the entire IXa division), which has suffered a high reduction since 1999 and has been overshot by landings since 2003 (Figure 8.4a). Males SSB and R decreased until 1995 and have shown an increasing trend after that (Figure 8.4.b and c). Concerning females, both SSB and R remained fairly stable, increasing in the last years (Figure 8.4.b and c). F is higher for males than for females, as between September to February when carry the eggs the females are hidden in galleries (Moura and Cardador, 2005). For both sexes F showed a decline in the mid 1990s and subsequently increased slightly. In the last three years F has decreased for both sexes (Figure 8.4d).

TAC has been unsuccessful for this stock fishery in recent years as landings have exceeded its value annually. TAC is set for the 5 FU, which could conduce to disproportionate catches among FU. Time and area closures imposed to trawl to protect this stock may have contributed to the decrease in F and increase in SSB and R, but no evaluation of this closure has been conducted. Since 2006 there has been a reduction of fishing effort in response to the recovery plan, which can be related to the reduction in F.

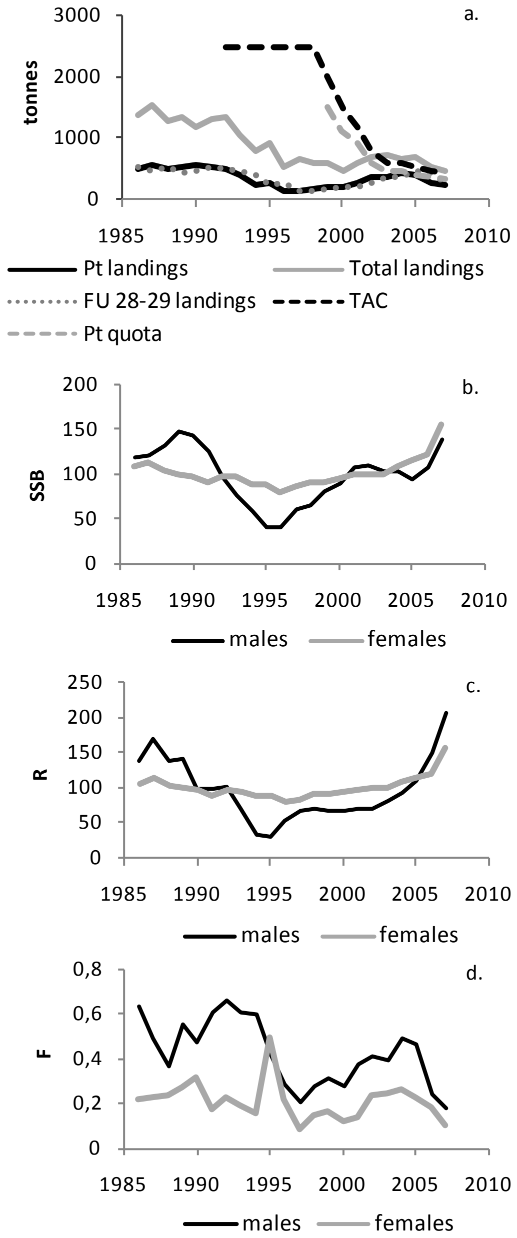


Figure 8.4. Nephrops in ICES subarea IXa: a) Portuguese landings (Pt landings) and respective quota (Pt quota), landings from functional units 28 and 29 (FU 28-29 landings), total landings and TAC (for ICES areas VIIIc, IX and X and EC waters of CECAF 34.1.1), b) spawning stock biomass (SSB), c) recruitment (R) and d) fishing mortality (F) of both sexes. SSB and R were relative to long term average.

Anglerfish

Anglerfish (*Lophius piscatorius* and *Lophius budegassa*) has low importance in landings total weight but it reaches high selling values. The two species are not usually landed separately and they are recorded together in port´s statistics. It is caught mainly by multigear fleet operating with gill nets and its capture is regulated by TAC since 1986 and, indirectly, by the measures that regulate the fishing gear operation (Table 8.1). There is no MLS for anglerfish but an EU Council Regulation fixed a minimum landing weight of 500 g for anglerfish, which was only applied in Spain since 2000.

Total landings have decreased considerably over time and despite some increase in the last few years they remain relatively low compared to the historical level (Figure 8.5a). Since the late 1990s TAC was reduced drastically and since 2003 has been exceeded by landings (Figure 8.5a). Portuguese landings increased in the 1980s and then showed a decreasing trend, but still exceeded Portuguese quota in the last years (Figure 8.5a). *L. budegassa* landings were always higher and more variable than ones from *L. piscatorius* (Figure 8.5a). B of both species has been well below the level associated with harvesting at maximum sustainable yield (Bmsy, the biomass necessary to produce maximum sustainable yield) since the late 1980s (Figure 8.5b). F has been well above fishing at maximum sustainable yield (Fmsy) for both stocks since the 1980s (Figure 8.5c).

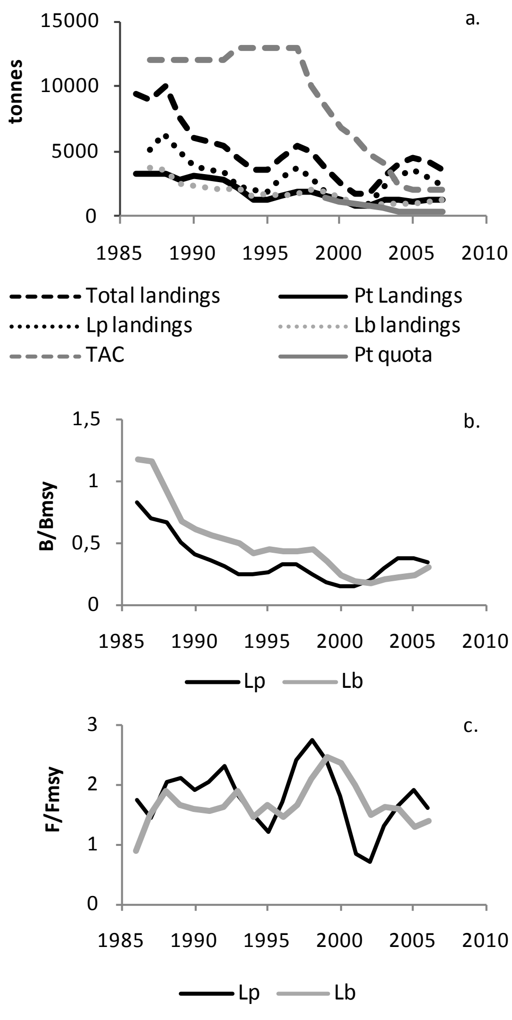


Figure 8.5. Anglerfish in ICES subareas VIIIc and IXa: a) Portuguese landings (Pt landings) and of each species (Lp - *Lophius piscatorius*; Lb - *Lophius budegassa*), Portuguese quota (Pt quota), total landings and TAC (for ICES areas VIIIc, IX and X and EC waters of CECAF 34.1.1), b) total biomass (B) in relation to the biomass necessary to produce maximum sustainable yield (Bmsy) and c) fishing mortality (F) in relation to fishing at maximum sustainable yield (Fmsy).

Management measures have not been effective in the management of these species. More restrictive TAC were introduced in association with the reduction in catches; however, its value has been exceeded consecutively. Despite this, a minimum landing weight has not yet been implemented in Portugal. The recovery plan for southern hake is expected to have a positive effect on the anglerfish stock, as they are caught in the same fisheries.

Atlantic mackerel

Atlantic mackerel was the ninth most landed species in Portugal in 2008 (1.4% of total landings). This species is mainly caught by seine fleet, with a small contribution of the multigear fleet. Its capture is regulated by EU measures that focus on the species (20 cm of MLS and TAC since 1987) and by national measures that regulate the operation of fishing gears (Table 8.1).

The term “Northeast Atlantic Mackerel” defines the Atlantic mackerel present in the area extending from ICES Division IXa in the South to Division IIa in the North, including the North Sea and Division IIIa. The spawning areas of mackerel are widely spread, and only the stock in the North Sea is clearly identified as a separate spawning component. Since it is impossible to allocate catches to the different stocks, they are at present considered as a single stock: the Northeast Atlantic mackerel stock. However, in order to be able to keep track of the development of the SSB in the different spawning areas, this stock is divided into three spawning components: Western, North Sea and Southern. Norway, EU and the Faroe Islands as coastal states agreed in 1999 about the total catch for 2000 and subsequent years.

Total landings of Northeast Atlantic mackerel stock were variable between 1986 and nowadays, attaining its lowest value in 2006 (Figure 8.6a). However, they almost always exceeded total TAC for this stock. Considering the TAC for ICES divisions VIIIc and IXa, which includes Portuguese quota, its values were variable but showed an increasing trend in the last years (Figure 8.6b). Moreover landings exceeded them in some years, especially since 2001. Portugal landings remained stable and never exceed TAC (Figure 8.6b). SSB of the combined stock decreased until the end of the 1990s but since 2003 showed an increasing trend and currently attain values similar to those in the beginning of the studied period (Figure 8.6a). R showed many oscillations along time, with a notorious peak in 2003 (Figure 8.6c), whereas F increased until 2003 and then decreased simultaneously with the increase in SSB (Figure 8.6d).

ICES classifies the stock as being harvested at increased risk (ICES, 2008). There are measures advised by ICES to protect the North Sea spawning component aimed at setting the conditions for a recovery of this component. In Portugal, the effects of fisheries regulations in the stock are uncertain but may have contributed to the decline in landings and in F in the last years, namely the restrictions imposed to seine fleet. About 50% of the variability in the Atlantic mackerel recruitment may be explained by means of environmental variables (Borja *et al.*, 2002), so R, from which SSB is dependent, is very difficult to manage.

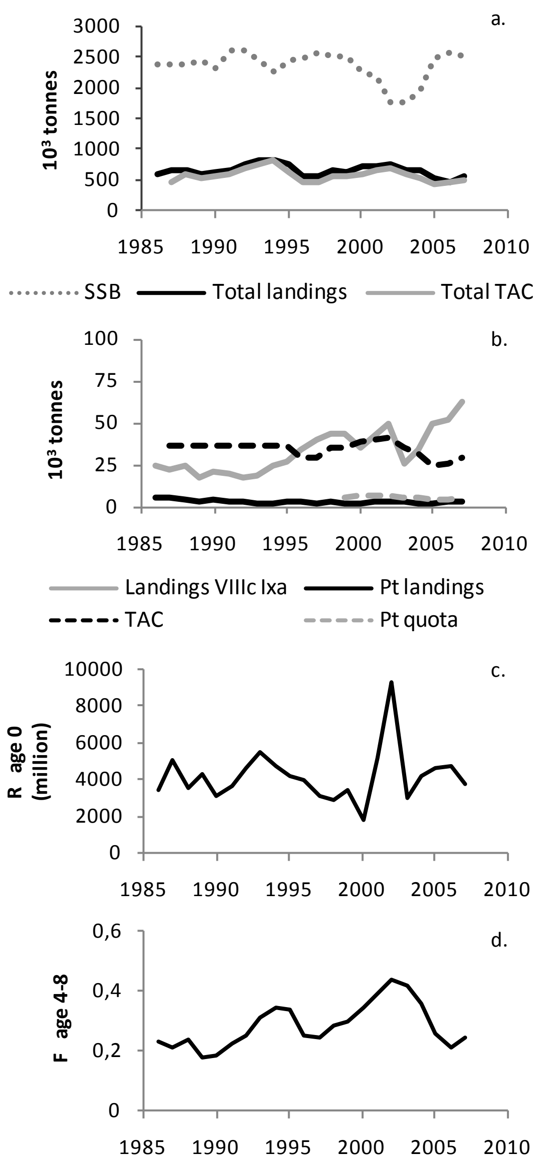


Figure 8.6. Northeast Atlantic Mackerel stock, which covers the area extending from ICES Division IXa in the South to Division IIa in the North, including the North Sea and Division IIIa: a) total landings, respective total TAC and spawning stock biomass (SSB), b) Portuguese landings (Pt landings) and respective quota (Pt quota), landings for ICES areas VIIIc and IXa and TAC (for ICES areas VIIIc, IX and X and EC waters of CECAF 34.1.1), c) recruitment (R) and d) fishing mortality (F).

Blue whiting

Blue whiting fishery is currently the largest in the Northeast Atlantic (Bjørndal, 2009). In Portugal, this species is the seventh most landed species (2.5% of total landings), however, it has a reduced commercial value. It is mainly caught by trawl and is regulated by TAC since 1987 and by measures that regulate the operation of fishing fleets (Table 8.1). This species is managed considering a combined stock that covers ICES divisions I to IX, XII and XIV and is classified as having full reproductive capacity but being harvested at increased risk (ICES, 2008). In 2006, the coastal states (EU, Norway, Iceland and Faroe Islands) agreed on a management plan for the multi-annual management of this stock, which aimed at preventing that the TAC exceeded 2 million tonnes in 2006 and at a systematic lowering of the TAC in next years. Due to the lack of international agreement for many years on how to divide this total quota among the nations, there was no agreed catch limit before 2006, which led to catches and TAC well above the ICES advice (ICES, 2008) and to unsustainability of blue whiting fishery. In 2008, the coastal states agreed to implement a long-term management plan from 2011 onwards with a significant reduction in fishing mortality.

Total stock landings increased since the end of 1990s, whereas Portuguese landings remained relatively stable and never exceeded the quota (Figure 8.7a and b). SSB increased since 1997 attaining a historical peak in 2003, but has decreased sharply since then (Figure 8.7a). R increased considerably since 1995, but in the last years it is in the very low end of the historical time series (Figure 8.7c). After a decrease in the early 1990´s, F increased since 1995 (Figure 8.7d).

The results obtained with the management plan are not notable and it is not easy to assess the results of national measures considering a stock that occupies such a large area. The large landings over the last decade were supported by high recruitments. Most recent years with low R, combined with a high F, have resulted in a continuing decline in SSB. F for blue whiting stock resultant from Portuguese fleet could be changed by restrictions imposed to demersal mixed fisheries to recover the southern hake and nephrops stocks.

Megrim

Two species of megrim are managed together as a whole stock, megrim (*Lepidorhombus whiffiagonis*) and four-spot megrim (*Lepidorhombus boscii*), and grouped in landings statistics. The two species combined have a reduced importance in Portuguese landings and a reduced commercial interest. They are caught as bycatch by the trawl fleet and in small quantities by multigear fleet. This stock is managed by measures that focus on the species (20 cm of MLS and TAC since 1987) and by measures that rule the operation of trawl fleet (Table 8.1).

Total landings decreased slightly between 1986 and nowadays, whereas TAC decreased sharply in the early 1990s and since 2000, remaining stable in the last years (Figure 8.8a). TAC was never exceeded by total landings. In Portugal, megrim landings have a reduced importance (Figure 8.8a). SSB of both species has decreased since the late 1980s. For *L. whiffiagonis*, SSB has been stable close to the historic low. For *L. boscii*, SSB shows an upwards trend after reaching a historical minimum in 2001 (Figure 8.8a). For *L. boscii*, R appears rather variable, without displaying any clear pattern over time, while for *L. whiffiagonis* recent R has been at low levels (Figure 8.8b). F has declined for both species in parallel with the landings (Figure 8.8c). At recent levels of F, SSB has been stable for *L. whiffiagonis* and showed some signs of increase for *L. boscii*.

The effects of fisheries regulations in the stock are uncertain. These species are essentially caught in mixed fisheries and management measures applied to other species may have implications in their stock.

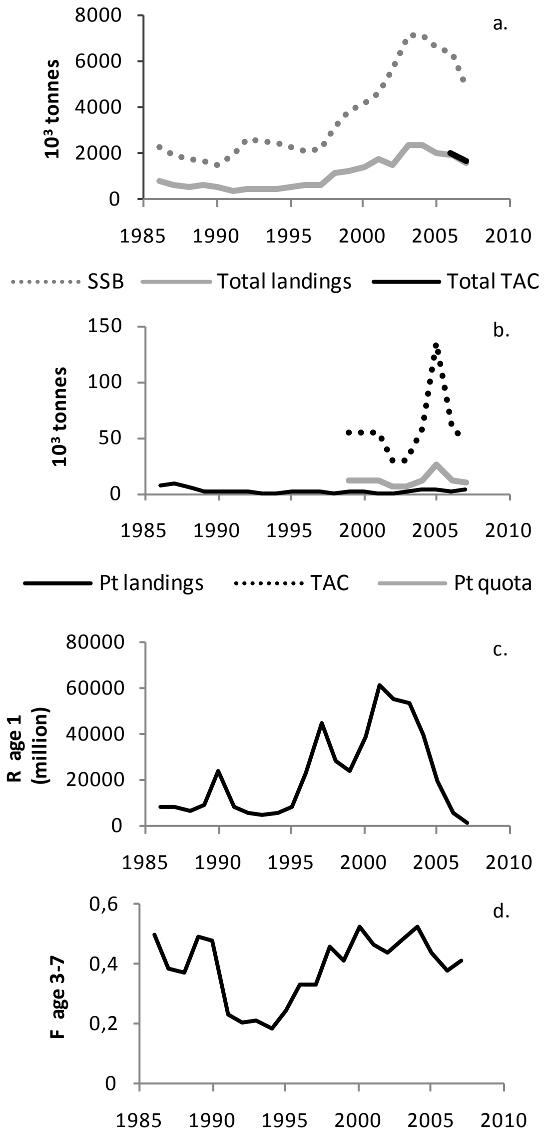


Figure 8.7. Blue whiting combined stock that covers ICES divisions I to IX, XII and XIV: a) total landings, respective total TAC and spawning stock biomass (SSB), b) Portuguese landings (Pt landings), Portuguese quota (Pt quota) and TAC (for ICES areas VIIIc, IX and X and EC waters of CECAF 34.1.1), c) recruitment (R) and d) fishing mortality (F).

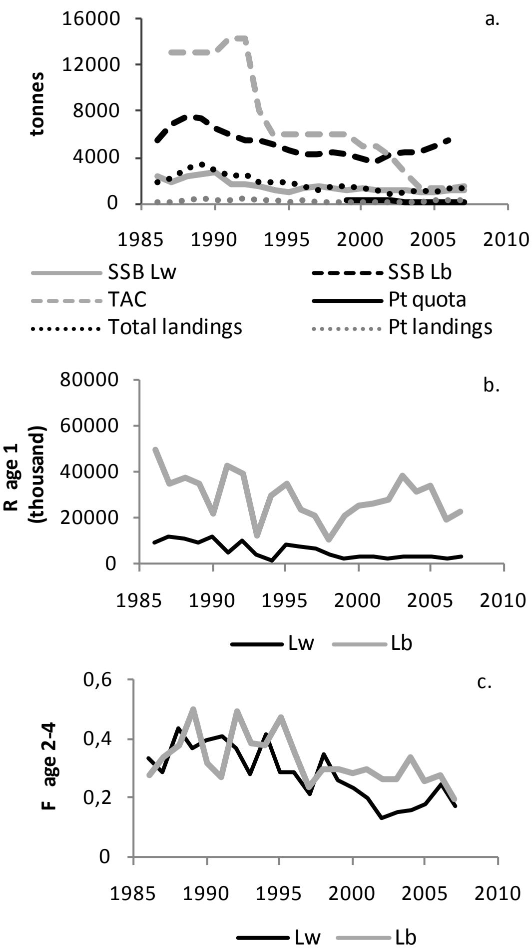


Figure 8.8. Megrim in ICES subareas VIIIc and IXa: a) Portuguese landings (Pt landings) and considering each species (Lw - *Lepidorhombus whiffiagonis*; Lb - *Lepidorhombus boscii*), Portuguese quota (Pt quota), total landings and TAC (for ICES areas VIIIc, IX and X and EC waters of CECAF 34.1.1), and spawning stock biomass (SSB), b) recruitment (R) and c) fishing mortality (F) of each species.

Discussion

The present work evaluated the biological consequences of management on species though the success of a management system can be defined in terms of its biological, economic, social, and political objectives. In a biological perspective, failure has been taken as the decline, or even collapse, of the fish stock as a direct consequence of the management regime, while from the socio-economic point of view, failure is reflected in poor economic performance of the fishery (Morgan, 1997). Clearly, economic and social objectives cannot be met while a stock is in such a depleted state that the long-term sustainability of the fishery is threatened, but equally, biological objectives are unlikely to be met without consideration of economic and social objectives (Beddington *et al.*, 2007). However, it is well known that, in general, the multiple objectives of fisheries management cannot be simultaneously optimised (Pope, 1997).

Most management measures are expected to provide some degree of conservation benefit maintaining or rebuilding resource stocks to desired levels. Considering Portuguese fisheries the effects of management measures can only be assessed with high degree of certainty to some measures, as TAC and IFQ, since it is easy to see if landings exceed its values. Other measures, as time and area closures, allow for some speculation, while for the remaining only very general conclusions may be draw about their possible influence on the final result of a package of measures. Assessing the utility of particular management tool usually cannot be done in isolation because effects off one tool are dependent on how other tools are being used (Holland, 2003).

In general, and despite those limitations, the package of management measures applied to the species studied have not achieved the desired effects. Few improvements occurred in the state of stocks associated with its implementation. Considering output measures, TAC has not limited catch: from seven case studies in which it is applied it has been exceeded in four (hake, nephrops, anglerfish and Atlantic mackerel). IFQ was implemented for sardine and hake, but seems to work only in the first case. Vessel catch limits were respected since with these measure fishermen obtain immediate economic benefits. Individual direct effects of input measures – licences, individual effort quotas and gear and vessel restrictions – could not be recognized, however as they limit fishing effort their effects is likely been positive. The same succeed with size selectivity measures, although it can be noted that despite protecting juveniles, they also promote discards. Fishing closures seem to have positive effects in the case of sardine and nephrops, but not in the case of hake.

The causes for this failure may arise from the development of management measures or from their functioning. In the development phase advice from scientists, based on observations of the status of stocks, is not always implemented, with serious ultimate consequences for the sustainability of the resource. A clear example is that of TAC definition: even when the scientific basis or TAC is well established, TAC have been subjected to manipulation in a political context (Morgan, 1997) and often set at levels above the desirable. Also problematic is the measures functioning, e.g. TAC is often exceeded, the amount of gear used is often much higher than the allowed, gear and vessel limitations are not always met, sometimes time and area closures are not respected. Results could be different if the management measures were totally met.

To ensure that biological objectives are met, it is essential that regulations are enforceable, and this has often proved to be difficult (Beddington *et al.*, 2007), particularly in multispecies fisheries (Suuronen and Sardà, 2007). Most fishermen have an opportunistic approach to non-compliance and will consider non-compliance behaviour in situations where there is a large economic gain to be obtained (Sutinen *et al.*, 1990). The effects of management measures cannot be quantified, and the measures appropriately evaluated, if the legislation is not properly enforced.

The complexity of most fisheries can be another reason for their poor performance of management measures. Fisheries harvesting multiple species, as most Portuguese fisheries, are expected to be more difficult and costly to manage than single-species fisheries (Sutinen and Soboil, 2003). In multi-species fisheries no single management measure or combination of measures can achieve the optimal fishing mortality for all species: almost any change will favour one species at the expense of another (Sutinen, 1999).

The TAC system is highly inefficient: it is constantly exceeded, and therefore has no apparent effect on the state of the stocks. When the quota for one species has been reached, fishing will still continue targeting other species stock. Species for which the quota has been reached will therefore still be caught and either discarded or landed illegally. Catch seems to be more affected by the condition of the stocks in nature rather than the TAC, as could be seen in hake and anglerfishes cases, whose catches have increased in the last years as the biomass increased. To ensure that TAC effectively restricts fisheries catches some measures should be taken.

Units of the stock to which the TAC are implemented are not always the more adequate. TAC for nephrops in ICES divisions VIIIc and IXa is set for five combined fishery units and a disproportionate amount could be taken from one or the other of the units, which could result in a unsustainable fishing mortality on one of them. There is growing evidence that there may be several components in the Northeast Atlantic blue whiting stock, but the results are not yet conclusive (ICES, 2008) but, if it is true, exploitation must be properly distributed among them to avoid local depletion. Cases in which distinct species are managed through the same TAC should also be considered carefully, since they can also result in a disproportionate catch of one species. Although it would be better that the TAC corresponds to only one species, in these cases the joint status of the several species should be considered when developing management measures.

TAC may be an incentive for fishermen to expand the fishing activity in order to utilize the catch possibilities in an accelerated way before resources is taken by other producers (Sutinen, 1999). TAC conduces to competition between producers and to shorter fishing seasons in situations that fishing is closed when the year’s cumulative catch has reached the TAC. However, it is thought that if the TAC is correctly specified and enforced, this measure should contribute to maintain a stock level well above that of bionomic equilibrium. If, however, the TAC is not respected by fishermen and not adequately enforced by authorities, widespread illegal fishing can occur (Beddington *et al.*, 2007).

In addition to be more easily controllable, IFQ allow the control of the number of participants in a species fishery, reducing the competition between them and counteracting some of the negative effects of TAC. On the other hand, fishermen tend to retain the larger and more valuable fish in order to maximize the economic benefits from their IFQ, which lead to discards. Moreover, IFQ have been effective in limiting catch at, or below, the TAC level determined by management authorities (Sutinen and Sobiol, 2001). Considering the present case studies only sardine and hake stocks management has IFQ. In the case of sardine this measure was introduced in 1997 and effects are difficult to assess given the strong influence of environmental factors in this stock. This measure was introduced in hake stock management only in 2007 and until now failed to achieve the desired objectives, since the landings continue to exceed the TAC.

Vessel catch limits exist only for sardine caught by purse seine fleet. Producers organizations define an informal maximum daily catch for individual fishing boats with the objective of managing the total quota as a function of local market-price fluctuations. This measure is accomplished by fishermen but its biological effects are very difficult to assess, since they are implemented to achieve economic goals.

Input measures are usually more easily enforceable than output measures. Input measures limit the number of vessels and their fishing effort, however, their effects are not clearly visible in the state of the stock, so it is not possible to evaluate their effectiveness. It can only be stated that they have a positive effect on stocks, since without it stocks would likely be in a worse condition. All vessels must be licensed for the use of fishing gear and to fish; few licences are designed specifically to species, as succeeds with swordfish. However, licence limitation is not sufficient to reduce capacity. It requires other mechanisms to control capacity since increases in capacity can take another forms besides the number of vessels, as the increase in vessel's horsepower, length, and/or tonnage, changes in gear, as the adoption of technological innovations, and changes in fishing periods or areas (Ward *et al.*, 2004). Also the size and other dimensions of each fishing unit are limited, e.g. most gears are limited in size or number considering the vessel size. However, in general, fishers avoid the regulations by substituting other factor inputs or new types of gear for the inputs that have been restricted (Ward *et al.*, 2004).

Technical measures, as size and sex selectivity and time and area closures, constrain the relationship between input and output measures (Sutinen, 1999). Size selectivity is mainly related with MLS and nets mesh and hooks size. In European fisheries MLS are defined for most commercial species to prevent the catch of undersized fish (Catchpole *et al.*, 2005), controlling F by age group (Tzanatos *et al.*, 2008). MLS seems to be one of the management instruments easiest to enforce, however, it is difficult to control especially in the case of small-scale fisheries (Tzanatos *et al.*, 2008). MLS was applied to Portuguese fisheries with adhesion to the EU and it is not possible to analyze the outcome of their application. There is only weak evidence that with this measure the average size of fish landed increases and that discards increase with its implementation (Sutinen and Sobiol, 2001). The regulation of fishing gear structure, mainly minimum net mesh sizes, has historically been the primary measure used to reduce the capture of juvenile commercial fish. Despite easy to control, mesh size selectivity is a difficult management tool to employ in mixed fisheries, as Portuguese fisheries, which simultaneously target several species with different growth and maturity parameters (Catchpole *et al.*, 2005).

Fishing closures have a potential beneficial effect on conservation, depending on assumptions about the spatial concentration of juveniles, diffusion rates and concentration of effort (Holland, 2003). The expected fishery benefits resulting from the establishment fishery closures most often include increases of SSB, biomass, body size and reproductive output of exploited species. Several studies have been done worldwide, mostly in tropical waters, but also in some temperate waters to demonstrate these benefits (Gell and Roberts, 2002; Sutinen and Sobiol, 2001). Few studies demonstrated the potential to replenish exploited fish stocks through the dispersal of larval or adult fish from the closed areas into regions where fishing is allowed (Sutinen and Sobiol, 2001). However, the results are not always positive. The effects of a closure established in 1989 to protect plaice have been disappointing, since juvenile plaice mortality has increased and the plaice spawning stock biomass has declined to below safe biological limits (Horwood *et al.*, 1998) due to a decline in the growth rate of young plaice as a function of their high density, a decrease in food supply and the increase in investment and activity of the vessels permitted in the closed area (Rijnsdorp, 1999). This failure demonstrates the necessity of a comprehensive understanding of the biology of protected species and the effects of fleet displacement (Catchpole *et al.*, 2005).

In Portugal fishery seasonal closures exists since 1994 for the protection of juvenile hake. R has been increasing since 2002 but it is unclear what the role of closure in that increase. Since 1997 both Portuguese and Spanish closed areas are enforced at either specified periods of the year or on a permanent basis to protect sardine, but as the stock of sardine is very dependent on environmental conditions it is very difficult to draw conclusions about its effectiveness. In 2004 trawl closures were created to protect nephrops. No evaluation of these closures has been conducted (ICES, 2008) but these measures may have contributed to a reduction in F and increase in SSB and R. Thus, the effect of closures in assuring resource conservation is not clear, but it is considered that resources might be in a worse state of preservation without them, as stated in OECD (1997).

A recovery plan for southern hake and Iberian nephrops stocks has been in force since the end of January 2006. However, recovery plans for hake have not been effectively implemented, since F has been increasing. Considering nephrops, F has been decreasing, while SSB and R have been increasing, which may already be resulting from the recovery plan. It is premature to discuss about its success given that they are quite recent. Nonetheless, it is known that successful recovery plans are more difficult for long-lived groundfish, as hake, than for small pelagic fish and commercial invertebrates, as nephrops (Caddy and Agnew, 2004).

Not all of the responsibility for ineffective conservation policies can be attributed to the politicians and fishers. Some of the reasons may be found in the nature of fisheries science, as its lack of certainty, its limited scope since it is generally confined to single species assessments and its distance from fishers (Daw and Gray, 2005).

The management of commercial fisheries clearly requires a good scientific understanding of the behaviour of the exploited stock or stocks (Beddington *et al.*, 2007). Nevertheless, in 1995 the FAO in its Code of Conduct for Responsible Fisheries proposed the principle of Caution, which argues that the lack of data or uncertainties should not be justification for non-implementation of the regulation of fisheries. It is difficult to analyse the level of exploitation to which the Portuguese coastal resources are subjected to and its state since the assessments carried out to date are either non-existent or highly fragmentary. Also data on landings are not totally reliable since the identification of species at fish auction is not always correct. Efforts should be made to discriminate landed species, namely species that are managed through the same TAC. Another failure in traditional management systems has been single-species assessments, when fisheries should to be managed in an ecosystem context. It is very important to account for multispecies interactions in fisheries analysis and management (Sutinen and Sobiol, 2001).

In addition, it is important to integrate fishers in the assessment and management process and develop management systems using their experience. Hilborn (2004) stated that failures of fisheries management were due to failures to recognize the importance of people and people management, rather than a failure of single-species management. Management of the sardine fishery has been given special attention by the government, researchers and OP and the results seem to be positive. With the 2002 reform of the CFP, Regional Advisory Councils (RAC) were created, made up of representatives of the fisheries sector and other groups affected by the CFP, while scientists are invited to participate in the meetings as experts. However, RAC have not been effective, since their recommendations and suggestions have been little considered.

There is presently an obvious divergence between the resources with stock status assessment and species that should be assessed in Portugal. EU requires that the state of stocks of certain species is monitored, some with minor significance in Portugal, as megrim, but there are many species that are very important in Portuguese fisheries which should be properly managed and are not, as black scabbardfish, octopus and chub mackerel. Black scabbardfish is the sixth most landed species and the third in economic value (INE, 2009). Stock is only regulated by TAC since 2003 and a specific licensing system. The status of the species is unknown, but indicators for the southern area, which is exploited by the Portuguese longliners, have been relatively stable during the past decade. However, black-scabbard fish has a long life span, slow growth and low reproductive potential, and, therefore, is particularly vulnerable to fishing (Moura *et al.*, 2006). If a precarious situation is achieved, the recovery of the stock is a very slow process. Octopus ranked third in landings and generates the highest revenue of all species taken in Portuguese fisheries (INE, 2009). The stock is only managed by a minimum landing weight (750 g) and, indirectly, by measures that regulate the operation of fishing fleets. In 1996 artisanal fisheries representatives considered that octopus resources might be in danger of overexploitation and requested that the species should be the object of protective measures (Pereira, 1999) but until nowadays the state of this species stock is not assessed. Chub mackerel is the second most landed species in Portugal, however, it has a reduced selling value. Its stock, of unknown state, is only managed by a MLS (20 cm) and, indirectly, by measures concerning the operation of fishing fleets.

There is no doubt that there is a major problem with the world's fisheries resources, and, despite serious attempts to improve management and to facilitate recovery of depleted stocks, the success has been limited (Beddington *et al.*, 2007). CFP is widely regarded as having failed to conserve the fisheries resources of the EU. Many of the important commercial stocks (e.g. North Sea cod) have suffered serious declines and are threatened with collapse and management measures have proven ineffective. The reply from management bodies to this situation has been a gradual reduction in TAC accompanied by more restrictive technical measures and local closures (Caddy and Agnew, 2004) or to ignore the problems (Raakjær, 2003). Essentially, management actions undertaken have tended to remain within the established management framework. The perception that a completely new situation has to be faced requiring much more serious and coordinated efforts by scientists, managers and stakeholders, is only now dawning (Caddy and Agnew, 2004).

Considering Portuguese fisheries it is not easy to conclude on the biological effects of the applied management measures on stocks. This is not an easy task that is still aggravated by the poor enforcement of legislation and noncompliance by fishermen. In general the goals have not been achieved and some measures seem to work better than others. It is obvious that there is an urgent need for a new fisheries management system in Europe that guarantees long-term conservation of natural marine resources. There have been successes in fisheries management and the tools for appropriate management exist (Beddington *et al.*, 2007).

Acknowledgements

This study was co-funded by the European Union through the FEDER - Fisheries Programme (MARE), as well as by Fundação para a Ciência e a Tecnologia (FCT) through the grant attributed to F. Baeta (Grant SFRH/BD/19223/2004).

References

Beddington, J.R., Agnew, D.J., Clark, C.W., 2007. Current Problems in the Management of Marine Fisheries. Science 316, 1713-1716.

Bjørndal, T., 2009. Overview, roles, and performance of the North East Atlantic fisheries commission (NEAFC). Mar. Policy 33, 685-697.

Borja, A., Uriarte, A., Egaña, J., 2002. Environmental factors and recruitment of mackerel, Scomber scombrus L. 1758, along the north-east Atlantic coasts of Europe. Fish. Oceanogr. 11, 116-127.

Caddy, J.F., Agnew, D.J., 2004. An overview of recent global experience with recovery plans for depleted marine resources and suggested guidelines for recovery planning. Rev. Fish Biol. Fisher. 14, 43-112.

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

Catchpole, T.L., Frid, C.L.J., Gray, T.S., 2005. Discards in North Sea fisheries: causes, consequences and solutions. Mar. Policy 29, 421-430.

Daw, T., Gray, T., 2005. Fisheries science and sustainability in international policy: a study of failure in the European Union's Common Fisheries Policy. Mar. Policy 29, 189-197.

Degnbol, P.,Gislason, H., Hanna, S., Jentoft, S., Nielsen, J.R., Sverdrup-Jensen, S., Wilson, D.C., 2006. Painting the floor with a hammer: Technical fixes in fisheries management. Mar. Policy 30, 534–543.

FAO, 1995. Code of Conduct for Responsible Fisheries. FAO, Rome.

FAO, 2009. The State of World Fisheries and Aquaculture 2008. FAO Fisheries Department, FAO, Rome.

Fonseca, T., Campos, A., Afonso-Dias. M., Fonseca, P., Pereira, J., 2008. Trawling for cephalopods off the Portuguese coast—Fleet dynamics and landings composition. Fish. Res. 92, 180-188.

Freire, J., Garcia-Allut, A., 2000. Socioeconomic and biological causes of management failures in European artisanal fisheries: the case of Galicia (NW Spain). Mar. Policy 24, 375-384.

Gell, F.R., Roberts, C.M., 2002. The Fishery Effects of Marine Reserves and Fishery Closures. WWF-US. (http://www.worldwildlife.org/what/wherewework/coastaleastafrica/WWFBinaryitem2821.pdf)

Hilborn R., 2004. Ecosystem-based fisheries management: the carrot or the stick? Mar. Ecol. Prog. Ser. 274, 275–278.

Holland, D.S., 2003. Integrating spatial management measures into traditional fishery management systems: the case of the Georges Bank multispecies groundfish fishery. ICES J. Mar. Sci. 60, 915-929.

Horwood, J.W., Nichols, J.H., Milligan, S., 1998. Evaluations of closed areas for fish stock conservation. J. Appl. Ecol. 35, 893-903.

ICES. 2008. Report of the ICES Advisory Committee, 2008. ICES Advice, 2008. Books 1 - 10. 1842 pp.

INE, 2009. Estatísticas da Pesca 2008. Instituto Nacional de Estatistica, Portugal, 98 pp.

Moniz, A., Kovács, I., Vicente, D., Ramos, A.R., 2000. Fisheries Development and Fisheries Dependent Communities in Portugal: Socio-Economic Change and Strategic Planning. Munich Personal RePEc Archive (http://mpra.ub.uni-muenchen.de/7154/).

Morgan, G.R., 1997. Individual Quota Management in Fisheries - Methodologies for Determining Catch Quotas and Initial Quota Allocation. FAO Fisheries Technical Paper T371.

Moura, O., Cardador, F., 2005. Pescada, lagostim, carapau e sardinha da costa continental portuguesa: situação e propostas de gestão para 2005. IPIMAR divulgação 30, IPIMAR.

Moura, O., Cardador, F., Figueiredo, I., 2006. Pescada, lagostim, peixe-espada preto: situações e medidas de gestão para 2006. IPIMAR divulgação 33, IPIMAR.

OECD, 1997. Towards Sustainable Fisheries: Economic Aspects of the Management of Living Marine Resources. OECD, Paris.

Pereira, J.M.F., 1999. Control of the Portuguese artisanal octopus fishery. Nolan, C.P. (ed.) Proceedings of the International Conference on Integrated Fisheries Monitoring. Sydney, Australia, 1-5 February 1999. FAO, Rome.

(http://www.fao.org/docrep/x3900e/x3900e09.htm)

Pope, J.G., 1997. Integrating and presenting scientific fisheries management advice for complex fisheries subject to multiple objectives. In: Montero CC, editor. Multiple objectives and fisheries management: strategies for the future, Vilamoura International Meeting on Fisheries, Portugal, 3–4 November 1997.

Raakjær N.J., 2003. An analytical framework for studying: compliance and legitimacy in fisheries management. Mar. Policy 27, 425-432.

Rijnsdorp, A., 1999. The North Sea's “Plaice box” as a marine protected area. ACP-EU Fisheries Research Report Number 5, RIVO, Netherlands.

Santos, A.M.P., Borges, M.F., Groom, S., 2001. Sardine and horse mackerel recruitment and upwelling off Portugal. ICES J. Mar. Sci. 58, 589–596.

Suuronen, P., Sardà, F., 2007. The role of technical measures in European fisheries management and how to make them work better. ICES J. Mar.Sci. 64, 751-756.

Sutinen, J.G., 1999. What works well and why: evidence from fishery management experiences in OECD countries. ICES J. Mar. Sci. 56, 1051-1058.

Sutinen, J.G., Rieser, A., Gauvin, J.R., 1990. Measuring and explaining noncompliance in federally managed fisheries. Ocean Dev. Int. Law 21, 335-372.

Sutinen, J.G., Soboil, M., 2001. The performance of fisheries management systems and the ecosystem challenge. Reykjavik Conference on Responsible Fisheries in the Marine Ecosystem, Reykjavik, Iceland, 1-4 October 2001.

Sutinen, J.G., Soboil, M., 2003. The performance of fisheries management systems and the ecosystem challenge. in Sinclair, M., Valdimarsson (eds) Responsible fisheries in the marine ecosystem. FAO and CABI Publishing.

Tzanatos, E., Somarakis, S., Tserpes, G., Koutsikopoulos, C., 2008. Catch length analysis, relation to minimum landing sizes and management implications from a Mediterranean small-scale fishery (Patraikos Gulf, Greece). Fish. Res. 93, 125-134.

Ward, J.M., Kirkley, J.E., Metzner, R., Pascoe, S., 2004. Measuring and assessing capacity in fisheries. 1. Basic concepts and management options. FAO Fisheries Technical Paper. No.433/1. FAO, Rome.

CHAPTER 9

MPA as management tools for small scale fisheries: the case study of Arrábida Marine Protected Area (Portugal)

Authors
Marisa Batista[a], Filipa Baeta[a], Maria José Costa[a,b], Henrique Cabral[a,b]

Authors' affiliation
[a]Instituto de Oceanografia, Faculdade de Ciências da Universidade de Lisboa, Campo Grande, 1749-016 Lisboa, Portugal
[b]Departamento de Biologia Animal, Faculdade de Ciências da Universidade de Lisboa, Campo Grande, 1749-016 Lisboa, Portugal

Submitted
Ocean and Coastal Management

MPA as management tools for small scale fisheries: the case study of Arrábida Marine Protected Area (Portugal)

Abstract: Marine protected areas (MPA) have been widely suggested as a tool for both fisheries management and conservation goals. These multiple objectives are hard to achieve simultaneously, since conservation objectives often have a negative influence in the social and economical contexts. MPA success namely for fisheries management, entails the implementation of restrictive measures that in a short-time frame may have negative effects on local fishermen communities. It is extremely important to evaluate their performance and effectiveness aiming at a quasi-optimal management, minimizing the impacts on the social domain. In this study, a simple and easy-to-use methodology for assessing MPA effectiveness as a small-scale fisheries management tool was developed, based in a set of indicators grouped in four dimensions (ecological, economic, social and management). This methodology can be applied even with few scientific data available and considering stakeholders' knowledge. Arrábida MPA (Portugal) was used as a case study and it was found that with MPA implementation socioeconomic aspects were impaired, while the other two dimensions showed an improvement trend. Thus, the overall score was the same before and after MPA implementation, with a median scale score. Results of this method application can give important indications about the state of a MPA and evaluates if the initial goals are being achieved through the implemented measures. The method is of easy communication and can be a useful tool for decision making and fisheries management processes.

Keywords: Marine Protected Areas, Ecosystem based fisheries management, small-scale fisheries, MPA effectiveness, multi-dimension indicators, Portugal.

Introduction

Fisheries management has been traditionally based in single-species approaches (ICES, 1998), which uses sets of constrains to define "outside safe biological limits" (Cury *et al.*, 2005). However, the "quasi" failure of these approaches is widely recognized (Garcia and De Leiya-Moreno, 2003). The global trend in marine stocks is towards an increase of overexploited, depleted and recovering stocks and a decrease of the under and moderately exploited stocks (FAO, 2009). This demonstrates that, although many management measures were introduced to improve the sustainability of resources' use, most of the stocks are requiring effective and precautionary management.

In addition, the application of single-species assessment and management methods is rather inefficient when applied to multispecies fisheries, namely the artisanal fisheries, which usually have a high spatio-temporal variation associated with a diversity of gears and target species (Tzanatos *et al.*, 2005; Vinther *et al.*, 2004). For example, when total allowable catches (TAC) is applied to a species that is captured jointly with other species, without or with higher established TAC, captures of the first species can exceed the imposed limit as a bycatch. The application of such limits can minimize landings of overfished stocks, but cannot avoid their mortality. Since artisanal small-scale fisheries have high representativeness in world fisheries (FAO, 2003a; McGoodwin, 1990), it is urgent to adapt management procedures towards their sustainability worldwide.

Several authors have emphasized that a shift in paradigm away from single-species management is required (e.g. Christensen *et al.*, 1996; Froese *et al.*, 2008: Vinther *et al.*, 2004). It is widely accepted that fisheries must be managed regarding the entire ecosystem in which they are included, and should take into account all ecosystem components (e.g. habitats, food webs, target and non target species) (Frid *et al.*, 2005; Jennings and Kaiser, 1998; Murawski, 2000). However, to implement an ecosystem-based fisheries management (EBFM), a strong effort to achieve and integrate scientific results is necessary (in a wide context, i.e. including economy, sociology, ecology, management, climatology, geography, amongst other fields of science) and management expertise.

In the context of EBFM, Marine Protected Areas (MPA) has been often referred as an appropriate tool for a multiplicity of fisheries management problems related to conservation of exploited stocks, preservation of biodiversity, enhancement of fisheries yields and other societal goals (Constanza *et al.*, 1998; Dugan and Davis, 2004; Murawski, 2007; Roberts *et al.*, 2001). MPA can achieve conservation goals whereas stock and fishery-wide approaches have proven to be inefficient (Field *et al.*, 2006) and also provide non conservation goals, such as increases in fisheries productivity by insurance against stock collapse, increases in densities and average sizes of individuals, development of marine science knowledge and protection of cultural diversity (Gerber *et al.*, 2003; Halpern, 2003).

Even though MPA have been used worldwide as a tool for the conservation of marine resources and interweaving fisheries management (Bohnsack, 1993; Ray, 1999), they are not perfect. The economical, social, political and institutional elements in which they are inserted at community, regional, national and international levels, all have influence on MPA objectives (Kelleher, 1999) and, in most cases, the traditional multiplicity of objectives inherent to MPA design is hard to integrate. A MPA, in particular, can be a biological accomplishment, resulting in the abundance of fish, diversity and habitat improvement, and a social failure, lacking participation in MPA management, share of economic benefits and conflict resolution mechanisms (Christie *et al.*, 2003). In this situation, the biological gains will probably disappear unless social issues are addressed (Pollnac and Crawford, 2000), which proves that finding ways to avoid socioeconomic problems that occur from the implementation of a MPA, whose benefits only become clear after a certain time, should be a top MPA objective.

MPA design, implementation and management should be dynamic processes, with stakeholders, namely fishermen, researchers, managers and marine policy collaborating and discussing several approaches to managing marine resources (Christie and White, 1997; Pomeroy, 1995). Incorporating local knowledge into the decision making process and creating community-based resource management systems can have multiple benefits, such as greater levels of accordance with limitations implemented and lower levels of conflicts between stakeholders (Berkes *et al.*, 2000; Russ and Alcala, 1999; Scholz *et al.*, 2004;).

In addition, the evaluation of MPA management performance is of high importance, determining if the implemented measures and methodologies are working well and if MPA objectives are being properly achieved (Alder *et al.*, 2002). However, the success of evaluation processes is also dependent from the initial establishment of explicit and well articulated objectives. Monitoring plans are important in all the processes, allowing the collection of important and helpful data to management and evaluation processes (Allison *et al.*, 1998; Claudet and Pelletier, 2004). Nevertheless, few work has been done on these issues and are usually based in long monitoring series and large research projects (e.g. Alder *et al.*, 2002; Himes, 2007; Ojeda-Martínez *et al.*, 2007; Ojeda-Martínez *et al.*, 2009; Pomeroy *et al.*, 2004; Pomeroy *et al.*, 2005a). Most of these studies were focused in the use of indicators, which are increasingly used as management tools to address environmental issues, allowing the assessment of development and management performance. They are appropriate tools to communicate and make accessible important information of a scientific or technological nature to non-technological user groups (Garcia and Staples, 2000).

Due to the increasing importance of MPA as fisheries management tools, the magnitude and vulnerability of small-scale fisheries and the difficulty of many countries in implementing and developing long and coherent management and monitoring programs to assess the effectiveness of MPA for small-scale fisheries, the present paper aims to develop a practical methodology to assess MPA performance, if it is achieving the initial objectives and the development trends, namely in what concerns multispecies small-scale fisheries. This methodology was based in a set of indicators, grouped in ecological, social, economical and management fields. Arrábida MPA (Portugal) was used as a case study to demonstrate the method application.

Material and Methods

Indicators selection and classification

A literature review provided the selection of a wide set of indicators, grouped into four critical dimensions for the long-term viability of a MPA, i.e. ecological, economic, social, and management. An initial evaluation of the set of possible indicators was done, which lead to the selection and in some cases to the modification of previously compiled indicators. Indicators drawn from the literature review were selected based in two criteria: (1) their relevance to a specific characteristic of small-scale fisheries, considering the four dimensions pointed out above, and (2) their capacity to be adapted in a situation of poor monitoring plans, diffuse and discontinued scientific data.

After selection of the final set of indicators for each dimension (Tables 9.1 to 9.4), an original scale of five scores (where 1 was always considered the worse score and 5 the best) was designed for the classification of indicators, with each score adapted individually for each indicator. The classification methodology can be used to evaluate and compare the performance of MPA in different time frames.

The indicators selection and the classification scale were firstly completed by the authors and then revised by a multi-disciplinary group of consultants with recognized expertise in ecology, sociology, economics and resource management. Their corrections and suggestions were discussed with the authors and included in a final revision of the process previously described.

Some of the ecological indicators are calculated regarding the scores obtained for various species, e.g. “Exploitation status of target species”, “Catch per unit of effort”, “Migratory range”, “Recruitment variability”, “Catch before maturity” and “Size of fish caught” considering target species of small scale fisheries occurring in the MPA. The indicator “Exploitation status of non-target species” only considers the most important non-target species captured.

Thus, the final score of each indicator obtained from the scoring of various species is calculated as a median score. The same measure is utilized to aggregate all the individual indicators scores into the final score of each of the four dimensions considered (ecological, social, economic and management) and ultimately to determine a general score (based on all indicators). The median was chosen over the mean values, because it is more robust in the presence of outlier values and it might be seen as a better indication of a central tendency.

Finally, polygonal kite diagrams can be performed in order to allow a practical view of the results, facilitating their interpretation. In these diagrams, each axis represents one dimension and each line a certain period analyzed (e.g. periods before and after MPA implementation), with the outer rim representing the best possible scores.

Table 9.1. Management goals, description and scale of scores for each ecological indicator of the set established for the assessment of MPA effectiveness as a tool for fisheries management.

Indicator dimension	Management goals	How can MPA help?	Indicator		Description	Scores scale
Ecological	Recovery of overexploited resources	Reduce/banishing fishing on overexploited species	Ecl 1	Exploitation status of target species	Considering the exploitation of all living resources within the protected area, at what level are most targeted resources exploited	1- Almost completely collapsed/ Depleted 2- Over fished 3- Fully fished 4- Moderately exploited 5- Under exploited
			Ecl 2	Exploitation status of non-target species	Considering the exploitation of all living resources within the protected area, at what level are non-targeted resources exploited	
	Preserve stocks of commercially exploited species	Increasing fish abundance within and around the protected area	Ecl 3	Catch per unit of effort (CPUE)	For exploited resources has catch per unit of effort (CPUE) been declining in past years	1- Very small 2- Small 3- Medium 4- High 5- Very high
			Ecl 4	Migratory range	How many living resources migrate outside of the MPA either in the short-term (daily feeding etc.) or long term (part of their life cycle)?	
		Decreasing the level of juveniles in captures	Ecl 5	Recruitment variability	Overall, has recruitment variability of most living resources been low or consistent (within the normal range of variability)?	1- Very low (relatively to last years) 2- Lower (relatively to last years) 3- The same (relatively to last years) 4- Higher (relatively to last years) 5- Very high (relatively to last years)
			Ecl 6	Catch before maturity	For most exploited resources, what is their level of exploitation before they are mature?	1- Very high (>90%) 2- High (60 to 90%) 3- Median (30% to 60%) 4- Small (10% to 30%) 5- Almost null (<10%)
		Increasing fish mean size	Ecl 7	Size of fish caught	What is the average size of fish landed?	1- Almost all are small individuals (>90%) 2- More than a half are small individuals (55% to 90%) 3- Near a half are small individuals (45% to 55%) 4- Less than a half are small individuals (10 to 45%) 5- Less than 10% are small individuals
	Equilibrate species interactions/ increase in trophic level	Equilibrating/ increasing trophic level	Ecl 8	Change in trophic level	For those living resources that are exploited, what is the trophic level?	1- Very high (relatively to last years) 2- High (relatively to last years) 3- Medium (relatively to last years) 4- Small (relatively to last years) 5- Very small (relatively to last years)

Table 9.1. Continuation.

Indicator dimension	Management goals	How can MPA help?		Indicator	Description	Scores scale
Ecological	Reduction of discards	Avoiding or minimizing bycatch	Ecl 9	Discarded bycatch	Considering the principal métiers occurring in MPA, what is the average discard rate?	1- Very high rate (>90%) 2- More than a half (55% to 90%) 3- Near a half (45% to 55%) 4- Less than a half (10 to 45%) 5- Less than 10%
	Preservation of biodiversity	Decreasing human pressures on the marine species and promoting MPA connection (MPA networks); Maintaining or even increasing species diversity	Ecl 10	Diversity of Species caught	Considering the principal métiers occurring in MPA, has the number of species caught changed in the last years?	1- Very low 2- Lower 3- Near the same 4- Higher 5- Very high
			Ecl 11	Habitat diversity	Has the habitat diversity declined from the original suite of habitats?	1- Very high decline 2- Considerable decline 3- Maintenance 4- Some increase 5- High increase
	Prevent the habitat degradation	Avoiding or minimizing human impacts on the marine environment	Ecl 12	Mitigation of habitat destruction	Are habitats in MPA being impacted (are they being damaged?) or are they being restored/ rehabilitated? Are there plans in place to mitigate damages?	1- Big damage 2- Some damage 3- No damage or mitigation 4- Some mitigation 5- Much mitigation
			Ecl 13	Habitat impacts	Level of habitat destruction or alteration when the operations are established or in processing-exploitation	1- Strong impacts or de impacts are widespread or chronic 2- Considerable impacts 3- Some impacts 4- Few impacts or impacts are confined to less than 10% of the MPA spatial area 5- No impacts

Table 9.2. Management goals, description and scale of scores for each economical indicator of the set established for the assessment of MPA effectiveness as a tool for fisheries management.

Indicator dimension	Management goals	How can MPA help?		Indicator	Description	Scores scale
Economic	Increase or maintain the incoming of fishing	Increasing or even maintaining local fisheries profitability	Ecn 1	Profitability	Are fishermen making money with their activity in MPA?	1- Big losses 2- Money loss 3- Break even 4- Marginally profitable 5- Highly profitable
		Providing decent wages to fishermen; Ensuring that their wages remain high or improve	Ecn 2	Average wage	Do fishermen working in the MPA make more or less than the average person in their local community?	1- Much more 2- More 3- The same 4- Less 5- Much less
			Ecn 3	Other incomes	Are other opportunities or alternatives for income generation outside of the MPA available for local fishermen?	1- No opportunities 2- Very few opportunities 3- Few opportunities 4- Some opportunities 5- Many opportunities
			Ecn 4	Subsidies	Are any forms of compensation available to fishermen for loss of resources in MPA?	1- Almost completely reliant on subsidies 2- Heavily reliant 3- Large subsidies 4- Somewhat 5- No

Table 9.3. Management goals, description and scale of scores for each social indicator of the set established for the assessment of MPA effectiveness as a tool for fisheries management.

Indicator dimension	Management goals	How can MPA help?		Indicator	Description	Scores scale
Social	Minimize fishermen disagreement with management measures and assure that they are not very affected by those measures	Reducing level of conflicts between fishers	Soc 1	Level of conflict between users	Are MPA users peaceful using the MPA or are being conflicts between them?	1- Very high level of conflicts 2- Considerable level of conflicts 3- Some conflicts 4- Rare conflicts 5- No conflicts
		Determining access to resources based on historical or traditional user; minimizing fishers conflicts;	Soc 2	Entry/ Limited entry	Including informal limitations, access to commercially exploited MPA resources is limited?	1- Significant limitations 2- Open access 3- Almost no limitations 4- Few limitations 5- Some limitations
			Soc 3	Acess rights	Are access rights (for resources or access to MPA) transferable, i.e. can be sold for profit or loss?	1- No transferable rights 2- Few are transferable 3- Some are transferable 4- Many are transferable 5- All are fully transferable
		Developing some of the fisheries, less harmful to marine resources	Soc 4	New entrants into the fishery	Are fisheries in MPA capacity to employ new people, give new fishing licenses or the opposite?	1- Many exits from the fishery 2- Some exits 3- No entrances or exits from the fishery 4- Some new entrants 5- Many new entrants
		Increasing fishermen environmental knowledge	Soc 5	Environmental knowledge	Do fishermen know the environmental importance of MPA?	1- Ignorance 2- Low knowledge 3- Some knowledge 4- Considerable knowledge 5- Full knowledge

Table 9.4. Management goals, description and scale of scores for each management indicator of the set established for the assessment of MPA effectiveness as a tool for fisheries management.

Indicator dimension	Management goals	How can MPA help?		Indicator	Description	Scores scale
Management	Adequate enforcement, implementation, monitoring and acceptance of management measures	Consulting MPA users along the management process	Man 1	MPA management	Are fishermen included in the management process?	1- Exclusion 2- Inefficient consultation 3- Occasional/ rare consultation 4- Regular consultation 5- Co-management
		Adequating enforcement level	Man 2	Enforcement	Is the enforcement adequate in MPA?	1- Completely inefficient 2- Limited efficiency 3- Some efficiency 4- Considerable adequate 5- Completely adequate
			Man 3	Ilegal fishing	Is illegal fishing practices frequent in MPA?	1- Very frequent (Generalized) 2- Frequent 3- Rare 4- Very rare (occasionally) 5- Inexistent
		Doing an adequate implementation, monitoring and control of the implemented measures	Man 4	Implementation	Are all the components of the management plan implemented?	1- No implementation 2- Almost no components implemented 3- Some components implemented 4- Almost all components implemented 5- Fully implemented
			Man 5	Monitoring, Control	How extensive is Monitoring and control (MC) within the MPA to either monitor compliance with the MPA plan or compliance with resources management plans within the MPA?	1- No effective MC undertaken 2- Sporadic MC with limited effectiveness 3- Sporadic MC with effectiveness 4- There are MC activities but not extensive 5- Extensive MC activities conducted
		Improving the scientific research on MPA	Man 6	Research	To what degree does research undertaken in the MPA contribute directly to the MPA?	1- No contribution 2- Limited contribution 3- Some contribution 4- Considerable contribution 5- Total contribution
		Obtaining acceptance and awareness of MPA users	Man 7	Awareness	What is the level of awareness and understanding of management measures by fishermen in the MPA?	1- No awareness 2- Low level of awareness 3- Medium level of awareness 4- High level of awareness 5- Total awareness

Application of the methodology to the Arrábida MPA (Portugal)

Arrábida MPA was created in 1998 although management measures were only published seven years later (Figure 9.1). Its' objectives have a wide scope, concerning both conservation and fisheries management objectives: preserve biodiversity and recover overexploited resources; recover habitats; promote scientific research; encourage environmental awareness and education; support progressive adaptation of the general rules of effluent emission; promote natural tourism considering sustainable development by promoting economic-cultural regional activities, such as traditional longline fishery.

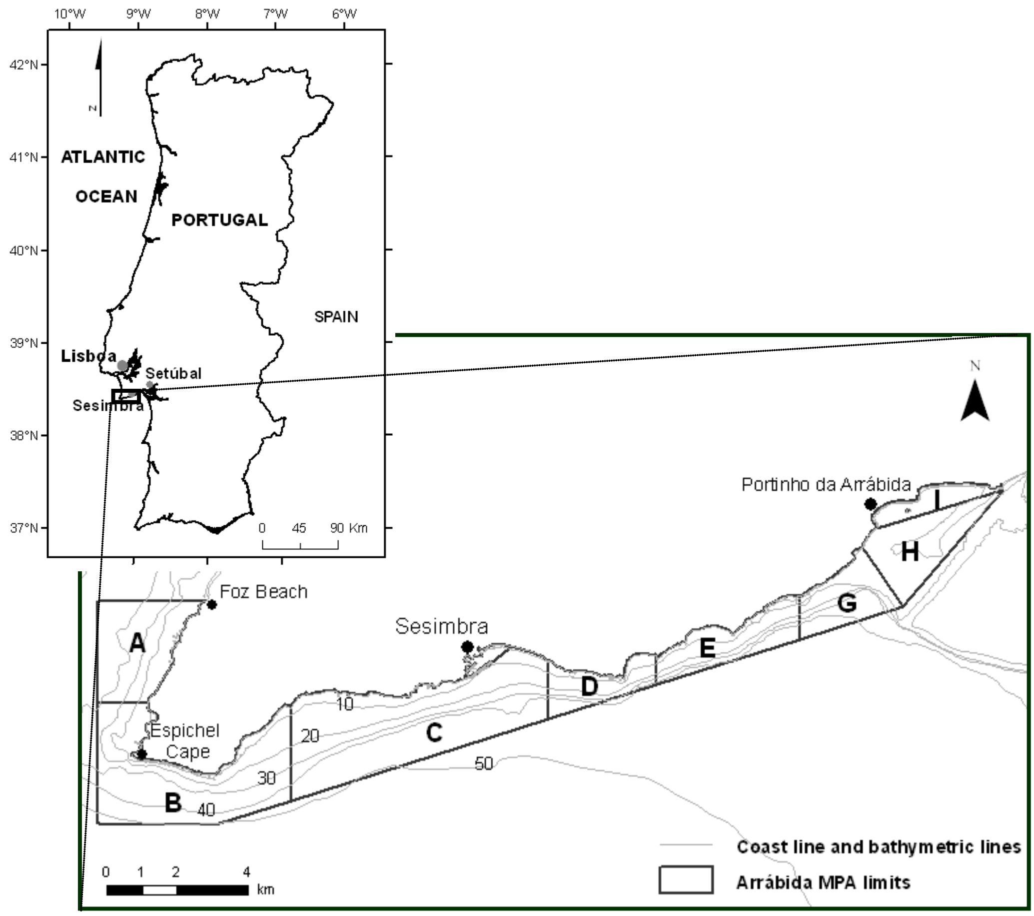


Figure 9.1. Location of Arrábida Marine Protected Area. A, C and H are areas of complementary protection; B, D, G e I are areas of partial protection and F is the area of total protection.

The Arrábida MPA management plan imposes restrictions to various activities, namely to local small-scale fisheries which has high socio-economical importance in the area. Dredging, trawling, discards, hand-collecting fishing and capture of any marine organism using scuba-diving gear are not allowed. Furthermore, only vessels with less than seven meters can have licenses to fish within the MPA, which, to be renewed annually, requires that fishermen effectuate landings in a minimum number of days in the previous year.

Arrábida MPA contemplates three protection typologies: complementary protection areas, where only the general restrictions mentioned above are applied; partial protection areas for which there are additional restrictions imposed to human activities, especially commercial fishing (purse seining, gill and trammel nets fishing are totally interdicted and trap and longline fishing are allowed only 200 meters offshore); and total protection area (no-take area) human presence is generally not allowed.

Arrábida MPA does not have a true monitoring plan neither a collection of multidisciplinary scientific data for the period before its implementation. The available data results from diverse research projects, dispersed in time and with objectives not directed to the MPA establishment or monitoring. Thus, biodiversity and habitats were almost the only information used in MPA planning and design.

Data for method application was collected from technical and non-technical reports, unpublished data and peer reviewed articles. Since data for some indicators was insufficient statistical data series from landings in the local fishing harbour, Sesimbra, were collected in the Portuguese Fisheries and Aquaculture Bureau (DGPA). Data resultant from research projects conducted between 2004 and 2008 in the area, that included fisheries observations on-board commercial vessels, working with the most utilized fishing gears in this region (nets, traps and longlines) were also used (e.g. for individuals' length and weight data). Interviews to local fishermen were performed in 2004 and in 2007, and included questions about vessels and gears characteristics, fishing effort, captures, economic and social topics and also opinions about fisheries and the environment in general. Also, a multidisciplinary group of specialists were consulted, including local researchers working in the MPA, in order to obtain the most realistic scores for the indicators with less scientific data available.

The indicators were calculated regarding two periods, the period before MPA implementation and the period after MPA implementation. In the latter period, for some indicators' scores a *statu quo* scenario was assumed based on current available data, considering predictable patterns in species biology, fishermen behaviour and existing political regulations.

A diagram for each indicator's dimension was performed and the values obtained for the two considered periods were represented. The median scores of each indicator's dimension and the general median score of all indicators were also represented in a polygonal kite diagram.

Results

Most ecological indicators suffered an improvement after the MPA implementation (Figure 9.2a). Indicators related to habitats, "habitat diversity" and "habitat impacts", and "catch before maturity", showed the greater improvement (more than one value in the scale). "Habitat diversity" and "habitat impacts" increased their performances due the expected recovery of seagrass beds and algal coverage resultants from the implementation of no-take and limited-used areas and the consequent decreased of human impact within MPA. "Mitigation of habitat impacts", a related indicator, also improved for the period after MPA implementation but to a lesser degree. The score increase of "Catch before maturity" is largely related with the marked decrease in captures of small individuals of *Octopus vulgaris* Cuvier, 1797, and *Sepia officinalis* Linnaeus, 1758, typically high in near shore longlines and hand jig fisheries (at less than 200 m from shore).

"Exploitation status of non-target species" increased for the period after MPA implementation, since most of non-target species maintained the same score for the both periods (between 3 and 5). *Necora puber* Linnaeus, 1767 and *Spondyliosoma cantharus* (Linnaeus, 1758) obtained better scores for the period after MPA (from 3 to 4). Amongst the most captured non-target species, *Boops boops* (Linnaeus, 1758), *Scomber japonicus* Houttuyn, 1782, and *Halobatrachus didactylus* Bloch and Schneider, 1801, obtained the maximum score.

"Migratory range" and "recruitment variability" scores had small increases after MPA implementation due to the fact that for some of the target species there were no registered increases. In "migratory range" only *O. vulgaris*, *Pagrus pagrus* (Linnaeus, 1758) and *Diplodus* spp., amongst the eight target species or groups of species, increased their scores from 2 to 3 with MPA implementation. In "recruitment variability", the referred species and S. *officinalis* improved their scores from 3 to 4, while the remaining species maintained the score of 3 both before and after MPA implementation.

"Exploitation status of target species", "catch per unit of effort", "size of fish landed", "change in trophic level" and "discarded bycatch" were the exceptions to the general improvement tendency observed above, maintaining the same values in both periods. Although these indicators, which are directly related with fisheries activities, scored relatively high values (3 or 4), the scores' maintenance between periods resulted from to the already low significance of the fishing gears prohibited in the MPA area and to the relocation of the limited fishing activities to MPA areas where they were still allowed.

"Discarded bycatch" showed some decreases for the period after MPA implementation, as a result of the prohibition of fishing near the coast, where many species without commercial value are usually caught (e.g. Labridae, Holothuroidea), particularly by nets and longlines. However, this decrease was not sufficient to raise the indicator score.

Considering the economic dimension (Figure 9.2b), "Average wage", "Other incomes" and "Subsides" maintained the same scores in both periods, while "Profitability" had a decrease after MPA. Moreover, a decrease in fisheries "profitability" is the expected tendency to the future of the Arrábida MPA. The losses in fishing area and the concentration of all vessels in a smaller area lead to the decrease of captures per vessel and spill-over effects are not expected to reverse this tendency.

The diagram representing social indicators showed an overall tendency to a decrease in scores after the implementation of the MPA (Figure 9.2c). Although two of the five indicators, "entry/ limited entry" and "environmental knowledge", had higher scores after the MPA implementation, it is important to highlight that three of the five social indicators achieved scores bellow the mean of the scale for the period after the MPA implementation. "Illegal fishing" suffered the greater improvement after the MPA implementation due to the improvement of restrictions.

In the fourth dimension considered, all management indicators showed an improvement in scores after the implementation of the MPA (Figure 9.2d), with "Monitoring, control" and "research" showing the highest score increases. "Monitoring control" and "Awareness" were classified with the worse level of our classification scale, however the first has raised four levels for the period after MPA. For this dimension, the great improvement in scores of some of the indicators is due to the reduced existence of management in this area before MPA implementation, which resulted in the attribution of low scores to most of the indicators for the period before MPA.

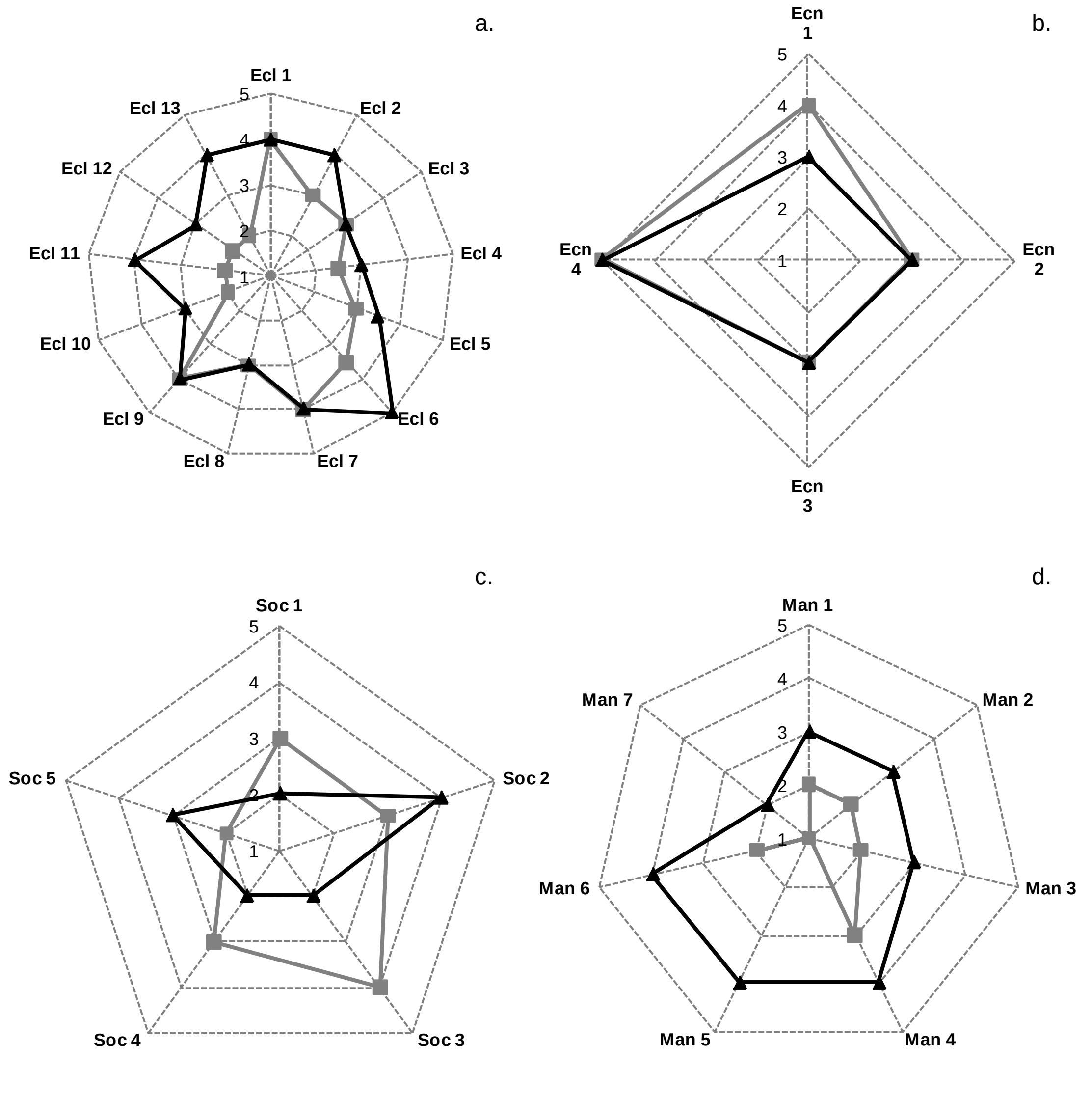


Figure 9.2. Polygonal kite diagrams representing the classification of ecological (a), economic (b), social (c) and management (d) indicators. Grey lines with squares represents the classification of each indicator before MPA establishment; black lines with triangles represent classification obtained after MPA implementation. Ecological: Ecl 1 - Exploitation status of target species, Ecl 2 - Exploitation status of non target species, Ecl 3 - CPUE, Ecl 4 - Migratory range, Ecl 5 - Recruitment variability, Ecl 6 - Catch before maturity, Ecl 7 - size of fish landed, Ecl 8 - Change in trophic level, Ecl 9 - Discarded bycatch, Ecl 10 - Diversity of species caught, Ecl 11 - Habitat diversity, Ecl 12 - Mitigation of habitat destruction, Ecl 13 - Habitat impacts; economic: Eco 1 - Profitability, Eco 2 - Avarage wage, Eco 3 - Other incomes, Eco 4 - subsidies; Social: Soc 1 - Level of conflicts between users, Soc 2 - entry/ Limited entry, Soc 3 - Acess rights, Soc 4 - new entrants into the fishery, Soc 5 - environmental Knowledge; Management: Man 1 - MPA management, Man2 - Enforcement, Man 3 - Illegal fishing, Man 4 - Implementation, Man 5 - Monitoring control, Man 6 - Research, Man 7 - Awareness.

Figure 9.3 showed that ecological and management dimensions revealed a tendency to improve with the MPA implementation, while economic and social dimensions experienced the opposite tendency. Social dimension appears to be the most impaired amongst all the considered. Although all the dimensions showed a positive or negative influence by the MPA implementation, the overall median score (considering all individual indicators) was constant both before and after MPA implementation and situated in the mean of the classification scale.

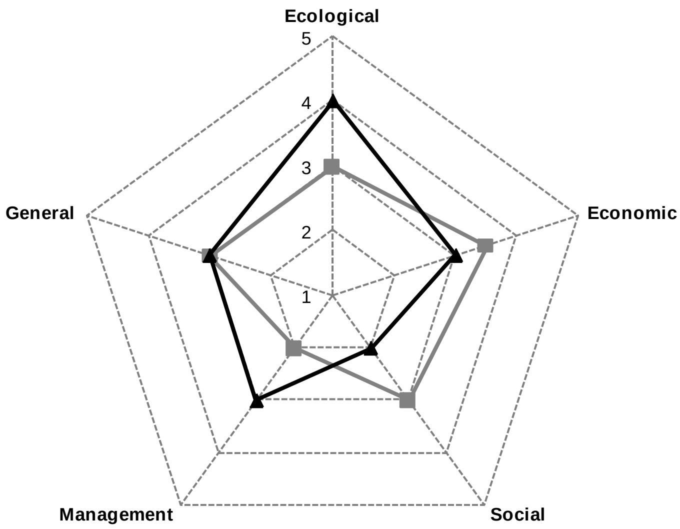


Figure 9.3. Polygonal kite diagram representing the median classification of four dimensions of indicators that were considered and the median classification of the MPA joining all the dimensions ("Overall").

Discussion

Most of the world fisheries are becoming unsustainable, but strong efforts to reverse this trend are being done, through the application of management measures to improve fisheries status (e.g. FAO, 2009). The traditional single-species fisheries management approaches should give place to an EBFM, and several international documents have presented guidelines to meet this goal (see Garcia and Cochrane, 2005 for a review). However, the goals of ecosystem approaches to fisheries are difficult to achieve given the need to balance diverse societal objectives, by taking into account the knowledge and uncertainties about biotic, abiotic, and human components of ecosystems and their interactions and applying an integrated approach to fisheries within ecologically meaningful boundaries (FAO, 2003b). Thus, effective implementation of management strategies based in ecosystem approaches will not be straightforward, and will need to face the challenge of meeting various objectives simultaneously: ecological, economic and social considerations are required to support ecosystem approaches, consistent with political aspirations for achieving sustainability.

Over the last decades the spatial extent of MPA increased at a growth rate of 5.2% per year (Wood *et al.*, 2007). MPA, as an EFBM tool, has usually a multiplicity of objectives regarding both conservation and fisheries management. This makes the effectiveness of the MPA a hotly debated topic, with some arguing that protected areas should form a core element of future fisheries management (Allison *et al.*, 1998) and others considering that MPA are simply one element of the fisheries management toolkit (Hilborn *et al.*, 2004). It has also been acknowledged that some conservation and fisheries management objectives are not achieved simply by implementing MPA (Fanshame *et al.*, 2003).

There is no consensus about what effects MPA can have in ecosystems and fisheries sustainability (Pelletier *et al.*, 2008). Fewer than 10% of MPA achieve their management goals and objectives (Pomeroy *et al.*, 2004; Wood *et al.*, 2007), and in many cases the effects resulting from protection are not duty disseminated, creating uneasiness in many stakeholders and users (Ojeda-Martinez *et al.*, 2009). However, it has also been recognized that some conservation and fisheries management objectives are not achieved simply by implementing MPA. Given this, there is a widely recognized necessity for marine and coastal managers to be more systematic in using MPA to create a set of best management practices. To meet this need, there is general consensus that evaluation of management effectiveness will improve MPA practice (Pomeroy *et al.*, 2004).

In this context, the methodology here developed can be seen as one more step towards a better assessment of ecosystems sustainable development. It is a practical semi-quantitative assessment method that can be applied even when data is scarcely available, providing a useful tool for managers assessment of the effectiveness of a MPA, namely in respect to fulfill the small-scale fisheries goals. The evaluation of management measures and the effectiveness of their application are extremely important because it allows the alteration of measures and monitoring in order to maximize ecological results and minimize the impact of measures in local human life. Therefore, the methodology developed allows decision-makers to obtain a set of indications/ tendencies and to identify the most fragile points within the process of achieving fisheries goals. Also it is characterized by the easiness of results communication among stakeholders, including them in the evaluation process and also providing a base for decision making.

Chosen indicators are simple and based on data usually available, but still allow an overview of the status of the several MPA dimensions. The complexity of indicators should depend on the resources available for management (Jennings, 2005). When few management resources are available, simple indicators may be desirable. It is generally accepted that it is preferable to choose an indicator that is theoretically less satisfactory but has a greater chance of reliable data collection and use (Dahl, 2000). Some of the published works on this topic exhaustibly listed indicators that can be useful in the assessment of MPA effectiveness (e.g. Alder *et al.*, 2002; Ojeda-Martinez *et al.*, 2009; Pomeroy *et al.*, 2005a) which can be a disadvantage in cases where the available data is limited for the classification of many of these indicators. The set of indicators defined in the present study is relatively short and ultimately, relies on stakeholders and researchers knowledge.

The method of indicators aggregation here described is also simpler than other methods previously developed (e.g. Alder *et al.*, 2002) and therefore more easily applicable by non-specialists. Furthermore, due its characteristics, this methodology can be applied generally to all kinds of MPA with fisheries objectives, making comparisons amongst a wide range of MPA possible.

Other component of this methodology is the consultation of multi-disciplinary experts and some stakeholders, in order to well select and classify indicators. The inclusion of stakeholders along the processes of design, implementation and management is a good way for understanding, since the beginning, where stakeholders' interests lie and suit management measures taking their knowledge and interests in account, leading to a climate of major acceptance and collaboration (e.g. Brown *et al.*, 2001; Christie and White, 2000; Himes, 2003, 2007). During the process of Arrábida MPA implementation, there was an inefficient consultation of stakeholders, i.e. they were not included in any part of the MPA process. Therefore, most of the local stakeholders, especially fishermen, have demonstrated their disagreement against management measures applied, defending that they are not economically sustainable neither favorable for biodiversity or resources recovery, but instead will harm fishermen and other MPA users. The combination of resource management and livelihood opportunities are important incentives for long term sustainability of a MPA (Pomeroy *et al.*, 2005b). However, response of fishermen to a policy depends on their attitudes, personalities, and livelihoods, hence it will vary both among groups and between individuals within any group (Gelcich *et al.*, 2004).

The assessment of Arrábida MPA effectiveness as a fishery management tool using the present methodology showed that measures implemented appear to improve the performance of ecological indicators, but simultaneously resulted in the decrease of human social and economic dimensions, which is very dangerous for the MPA sustainability. For example, the method predictions evidenced a much needed change in the direction of some of the management measures in order to avoid the predictable losses in small-scale fisheries profitability.In this situation illegal uses will remain, and in Arrábida MPA "illegal fishing" showed a tendency to increase after the MPA implementation, putting all the MPA goals at risk. Illegal activities in any managed area can be dangerous, since with time they can influence the performance of applied measures or modify the response of indicators utilized to evaluate MPA effectiveness. Thus, social and economical dimensions are those needing more attention from managers and government. It is evident that efforts to apply a collaborative process in the Arrábida MPA, in order to collect stakeholders concerns and suggestions should be done, aiming at a more consensual approach.

On the other side, results obtained for Arrábida MPA showed improvement in ecological dimension, namely concerning the habitat recovery goals and biodiversity preservation. The improvement in ecological indicators can signify also an improvement in commercial species, which may have positive effects at socio-economic level, although considerations about this topic are hard to do with the present available data.

The management dimension of Arrábida MPA predicts an increase in effectiveness of this fisheries dimension, which may be an important step towards attaining the MPA fisheries goals and an important support against illegalities. However, management of areas surrounding MPA is also of great importance since their un-management can dissolve the possible benefits from MPA implementation (Field *et al.*, 2006; Pelletier *et al.*, 2008; Sethi and Hilborn, 2008).

Given the improvement of some indicators and the worsening of others, the "Overall" score attributed to the Arrábida MPA was the same in both considered periods (score 3), which is not sign of complete failure but means that it is urgent to take measures in order to improve the general score. Social dimension of small-scale fisheries, fisheries characteristics and their real needs should be accompanied closely, in order to avoid the possibility of a MPA future failure.

Methods based in indicators, even those based in different indicators' dimensions, do not integrate the dimension of uncertainty, e.g. factors affecting global economy, diseases and epidemics (both in animals and humans), environmental disasters or climate changes. Thus, assumptions made for the period after the MPA implementation can differ from the predictions and alter the results. Furthermore, marine ecosystems complexity makes impossible to completely assess them. Thus, any assessment based in indicators or other techniques has to be carefully developed and their results interpreted as tendencies susceptible to change. This highlights also the importance of continuous monitoring and assessment, following by continuous efforts to apply and adequate the management options for a determined protected area.

The major advantage of the proposed method is that it can be applied to any MPA regarding fisheries goals, even with few data available, and also can be used as a system guide for MPA planners and managers. This method can represent an advance in avoidance of inefficient paper reserves, due to its easy applicability, easy communication and relatively low data requirements. The method is a way to do not the best but the possible assessment. However, in the future, when more detailed and precise data are available, this method will provide a more realistic approach. Depending on the situation, it is important to evaluate the need for adding more indicators and replace or enable others. However, the solutions for MPA effectiveness improvement may be in monitoring, despite this is an expensive solution that only give results over the long term.

Acknowledgements

The authors would like to thank all the scientists and stakeholders that actively collaborate in the process of identification and classification of the indicators. This study was co-funded by the European Union trough the FEDER - Fisheries Programme (MARE), as well as by Fundação para a Ciência e Tecnologia (FCT) trough the grant attributed to F. Baeta (Grant SFRH/ BD/ 19223/ 2004).

References

Alder, J., Zeller, D., Pitcher, T., Sumaila, R., 2002. A Method for Evaluating Marine Protected Area Management. Coast. Manage. 30, 121 - 131.

Allison, G.W., Lubchenco, J., Carr, M.H., 1998. Marine reserves are necessary but not sufficient for marine conservation. Ecol. Appl.8, S79-S92.

Berkes, F., Colding, J., Folke, C., 2000. Rediscovery of traditional ecological knowledge as adaptive management. Ecol. Appl. 10, 1251-62.

Bohnsack, J., 1993. Marine reserves: They enhance fisheries, reduce conflicts and protect resources. Oceanus Fall 36, 63-71.

Brown, K., Adger, W.N., Tompkins, E., Bacon, P., Shim, D., Young, K., 2001. Trade-off analysis for marine protected area management. Ecol. Econ. 37, 417-434.

Christie, P., White, A.T., 1997. Trends in development of coastal area management in tropical countries: from central to community orientation. Coast. Manage. 25, 155-81.

Christie, P., White, A.T., 2000. Tropical coastal management. Coast Manage. 28, 1-122.

Christie, P., McCay, B.J., Miller, M.L., Lowe, C., White, A.T., Stoffle, R., Fluharty, D.L., McManus, L.T., Chuenpagdee, R., Pomeroy, C., Suman, D.O., Blount, B.G., Huppert, D., Eisma, R.V., Oracion, E., Lowry, K. and Pollnac, R.B., 2003. Toward developing a complete understanding: A social science research agenda for marine protected areas. Fisheries 28, 22-26.

Christensen, V., 1996. Managing fisheries involving predator and prey species. Rev. Fish Biol. Fisher. 6, 417-442.

Claudet, J., Pelletier, D., 2004. Marine protected areas and artificial reefs: A review of the interactions between management and scientific studies. Aquat. Living Resour. 17, 129-138.

Constanza, R., Andrade, F., Antunes, P., van den Belt, M., Boesch, D., Boersma, D., Catarino, F., Hanna, S., Limburg, K., Low, B., Molitar, M., Pereira, J. G., Rayner, S., Santos, R., Wilson, J., Young, M., 1998. Principles for sustainable governance of the oceans. Science 281, 198-199.

Cury, P.M., Mullon, C., Garcia, S.M., Shannon, L.J., 2005. Viability theory for an ecosystem approach to fisheries. ICES J. Mar. Sci. 62, 577-584.

Dahl A.L., 2000. Using indicators to measure sustainability: recent methodological and conceptual frameworks. Ocean Coast. Manage. 51, 427-433.

Dugan, J. E., Davis, G. E., 1992. Applications of Marine Refugia to Coastal Fisheries Management. Can. J. Fish. Aquatic Sci. 50: 2029- 2042.

Fanshame, S., Vanblaricom, G. R., Shelly, A. A., 2003. Restored top carnivores as detriments to the performance of marine protected areas intended for fishery sustainability: a case study with red abalones and sea otters. Conserv. Biol. 17, 273-283.

FAO, 2003a. Strategies for increasing the sustainable contribution of small-scale fisheries to food security and poverty alleviation. FAO, Rome. 1-14.

FAO, 2003b. Fisheries management. The ecosystem approach to fisheries. FAO technical guidelines for responsible fisheries 4 (suppl. 2). 112 pp.

FAO, 2009. The State of World Fisheries and Aquaculture 2008. FAO Fisheries Department, Rome, 176 pp.

Field, J.C., André, E.P., Methot, R.D., Thomson, C.J., 2006. Does MPA mean 'Major Problem for Assessments'? Considering the consequences of place-based management systems. Fish Fish. 7, 284-302.

Frid, C., Paramor, O., Scott, C., 2005. Ecosystem-based fisheries management: progress in the NE Atlantic. Mar. Policy 29, 461-469.

Froese, R., Stern-Pirlot, A., Winker, H., Gascuel, D., 2008. Size matters: How single-species management can contribute to ecosystem-based fisheries management. Fish. Res. 92, 231-241.

Garcia, S.M., Staples, D.J., 2000. Sustainability reference systems and indicators for responsible marine capture fisheries: a review of concepts and elements for a set of guidelines. Mar. Freshwater Res. 51, 385-426.

Garcia, S.M., Cochrane, K. L. (2005). Ecosystem approach to fisheries: a review of implementation guidelines. ICES J. Mar. Sci. 62, 311-318.

Garcia, S.M., De Leyda-Moreno, J.I., 2005. Evolution of the state of fish stocks in the North East Atlantic within a precautionary framework, 1970-2003: a synoptic evaluation. ICES J. Mar. Sci. 62, 1603-1608.

Gelcich, S., Gareth, E., Kaiser, M.J., 2004. Importance of Attitudinal Differences among Artisanal Fishers toward Co-Management and Conservation of Marine Resources. Conserv. Biol. 19, 865-875.

Gerber, L.R., Botsford, L.W., Hastings, A., 2003. Population models for marine reserve design: a retrospective and prospective synthesis. Ecol. Appl. 12, S47-S64.

Halpern, B.S., 2003. The impact of marine reserves: do reserves work and does reserve size matter? Ecol. Appl. 12, S117-S137.

Hilborne, R., Stokes, K., Maguire, J.J., Smith, T., Botsford, L.W., Mangel, M., Orensanz, J., Parma, A., Rice, J., Bell, J., Cochrane, K.L., Garcia, S., Hall, S.J., Kirkwood, G.P., Sainsbury, K., Stefansson, G., Walters, C., 2004. When can marine reserves improve fisheries management? Ocean Coast. Manage. 47, 197-205.

Himes, A.H., 2003. Small-scale Sicilian fisheries: Opinions of artisanal fishers and sociocultural effects in two MPA case studies. Coast. Manage. 31, 389-408.

Himes, A. H., 2007. Performance indicator importance in MPA management using a multi-criteria approach. Coast. Manage. 35, 601-618.

ICES, 1998. Report of the working group on ecosystem effects of fishing activities. ICES CM 1998/ACFM/ACME: 1 Ref. E. 263 pp.

Jennings, S, Kaiser, J.M., 1998. The effects of fishing on marine acosystem. Adv. Mar. Bio. 34, 201-352.

Jennings, S., 2005. Indicators to support an ecosystem approach to fisheries. Fish. Fish. 6, 212-232.

Kelleher, G., 1999. Guidelines for Marine Protected Areas, IUCN, Gland, Switzerland, and Cambridge, UK: xxiv +107pp.

Mangi, S.C., Roberts, C.M., Rodwell, L.D., 2007. Reef fisheries management in Kenya: preliminary approach using the driver-pressure-state-impacts-response (DPSIR) scheme of indicators. Ocean Coast. Manage. 50, 463-80.

McGoodwin, J.R., 1990. Crisis in the World's Fisheries: People, Problems and Policies. Stanford Univerisity Press, Stanford, California. 235 pp.

Murawski, S.A., 2000. Definition of overfishing from an ecosystem perspective. ICES J. Mar. Sci. 57, 649-658.

Murawski, S.A., 2007. Ten myths concerning ecosystem approaches to marine resource management. Mar. Policy 31, 681-690.

Ojeda-Martínez, C., Bayle-Sempere, J.T., Sánchez-Jerez, P., Forcada, A., Valle, C., 2007. Detecting conservation benefits in spatially protected fish populations with meta-analysis of long-term monitoring data. Mar. Biol. 151, 1153-1161.

Ojeda-Martínez, C., Casalduero, F.G., Bayle-Sempere, J.T., Cebrián, C.B., Valle, C., Sanchez-Lizaso, J.L., Forcada, A., Sanchez-Jerez, P., Martín-Sosa. P., Falcón, J.M., Salas, F., Graziano, M., Chemello, R., Stobart, B., Cartagena, P., Pérez-Ruzafa, A., Vandeperre, F., Rochel, E., Planes, S., Brito, A., 2009. A conceptual framework for the integral management of marine protected areas. Ocean Coast. Manage. 52, 89-101.

Pelletier, D., Claudet, J., Ferraris, J., Benedetti-Cecchi,L., Garcìa-Charton, A., 2008. Models and indicators for assessing conservation and fisheries-related effects of marine protected areas. Can. J. Fish. Aquatic. Sci. 65, 765-779.

Pollnac, R. B. and Crawford, B. R., 2000. Discovering Factors that Influence the Success of Community-Based Marine Protected Areas in the Visayas, Philippines. Coastal Management Report 2229 PCAMRD Book Series No. 33, Coastal Resources Center, University of Rhode Island, Narragansett, RI, USA, and Philippine Council for Aquatic and Marine Research and Development, Los Banos, Laguna, Philippines.

Pomeroy, R.S., 1995. Community-based and co-management institutions for sustainable coastal fisheries management in Southeast Asia. Ocean Coast. Manage. 27, 143-62.

Pomeroy, R.S., Parks, J., Watson, L.M., 2004. How is your MPA doing?. A guidebook of natural and social indicators for evaluating marine protected area management effectiveness. IUCN- The world conservation union, 217 pp.

Pomeroy, R., Watson, L.M., Parks, J.E., 2005a.How is your MPA doing? A methodology for evaluating the management effectiveness of marine protected areas. Ocean Coast. Manage. 48, 485-502.

Pomeroy, R.S., Oracion, E.G., Pollnac, R.B., Caballes, D.A., 2005b. Perceived economic factors influencing the sustainability of integrated coastal management projects in the Philippines. Ocean Coast. Manage. 48, 360-377.

Ray, G.C., 1999. Coastal-marine protected areas: agonies of choice. Aquatic Conserv. 9, 607-614.

Roberts, C.M., Bohnsack, J.A., Gell, F., Hawkins, J.P., Goodridge, R., 2001. Effects of marine reserves on adjacent fisheries. Science 294, 1920-1923.

Russ, G.R., Alcala, A.C., 1999. Management histories of Sumilon and Apo Marine Reserves, Philippines, and their influence on national marine resource policy. Coral Reefs 18, 307-19.

Scholz, A., Bonzon, K., Fujita, R., Benjamin, N., Woodling, N., Black, P., Steinback, C., 2004. Participatory socioeconomic analysis: drawing on fishermen's knowledge for marine protected area planning in California. Mar. Policy 28, 335-349

Sethi, S.A., Hilborn, R., 2008. Interactions between poaching and management policy effect marine reserves as conservation tools. Biol. Conserv. 141, 506 - 516.

Tzanatos, E., Dimitriou, E., Katselis, G., Georgiadis, M., Koutsikopoulos, C., 2005. Composition, temporal dynamics and regional characteristics of small-scale fisheries in Greece. Fish. Res. 73, 147-158.

Vinther, M., Reeves, S.A., Patterson, K.R., 2004. From single-species advice to mixed-species management: taking the next step. ICES J. Mar. Sci. 61, 1398-1409.

Wood L.J., Fish L., Laughren J., Pauly D., 2007. Assessing progress towards global marine protection targets: shortfalls in information and action. Fisheries centre working paper 2007-03. Vancouver, B.C., Canada: The University of British Columbia.

Part V

General discussion and final remarks

CHAPTER 10

General Discussion and Final Remarks

Impacts of Portuguese fisheries

Sustainability of Portuguese fisheries

Management of Portuguese Fisheries

Questions and directions for future research

General discussion and final remarks

Several aspects about Portuguese fisheries were addressed in the previous chapters, namely their impacts on the environment, sustainable development and management, and the specific objectives and conclusions were presented in each study. This chapter highlights the most important findings and the new approaches that came out from those studies, and discusses their implications. Finally, some questions left open will be underlined and a perspective for future research is presented.

Impacts of Portuguese fisheries

The sustainable development of fisheries requires the adoption of an ecosystem based fisheries management (EBFM). EBFM is a significant departure from traditional fisheries management, considering the impact that fishing has on all aspects of the marine ecosystem, and not only the target species (Pikitch *et al.*, 2004). Thus, it is important to be aware of the impacts that fisheries have on the environment, which is not always easy due to the scarcity of data.

The risk assessment method developed in chapter 2 was successful in identifying and quantifying environmental effects of seven Portuguese fisheries - crustacean trawl, fish trawl, pelagic purse seine, trammel nets for soles, octopus traps, swordfish longline and deepwater longline for black scabbardfish - and prioritizing issues and research needs, providing a decision tool which should lead to better management decisions. This method is relatively simple to apply and all issues can be assessed even with minimal data available. Overall, the ecological impact requiring more urgent attention is bycatch, which in some cases led to significant amounts of discards. The impact on protected species is more important on swordfish longline fishery, since bycatch from this fishery often includes high quantities of sharks and sea turtles. As it was expected, impacts on benthic habitats are higher in trawl fishing. Fisheries impact on trophic interactions could not be assessed given the lack of specific data for each fishery. Considering results obtained applicable mitigation and management measures could be identified to respond to the risks that fishing poses to the ecological sustainability of the marine ecosystem.

Considering that bycatch represents the ecological effects that generate the highest concern and the importance of a better fisheries management and conservation measures concerning elasmobranchs (Stevens *et al.*, 2000), the main objective of chapter 3 was to analyze elasmobranch catches and discards on a trammel net fishery in the Portuguese west coast. A total of 11 elasmobranch species (seven Rajiformes, two Torpediniformes and two Carchariniformes) were caught as bycatch in a trammel net fishery targeting soles and cuttlefish. Elasmobranchs accounted for 4% of the total fish catches and 15% of the total weight, similarly to results for a trammel net fishery in southern Portugal obtained by Coelho *et al.* (2005). However, whereas in the later study discards were low, accounting for only 5.4% of the elasmobranch catch in number, in the present study, discarding was important in terms of the number of species (seven out of 11) and number of individuals (24.8%) although not in weight (7.8%). This study also allowed obtaining management-relevant information on elasmobranch species characteristics, abundance and distribution. A marked seasonality was noticed, probably related to the migratory habits of these species and for the most abundant species depth range preferences were also outlined.

The impact of each of the fisheries studied on trophic interactions was not assessed in chapter 2 due to lack of appropriate and specific data of each fishery. However, it was possible to evaluate the impact of overall Portuguese fisheries in trophic webs (chapter 4). Mean trophic level (TLm) of mainland landings showed a decreasing trend since 1970. Based on Pauly *et al.* (1998) hypothesis that landings data can be used as ecosystem indicators, with changes in its TLm as a reflex of the changes in the ecosystem, the decreasing trend found in the mainland data may be interpreted as a decrease in abundance of high trophic level species relative to low trophic level ones in the ecosystem, i.e. changes occurred in the structure of marine food webs. However, the decrease observed in our data (0.05 per decade) was lower than that estimated by Pauly *et al.* (1998) for Northeast Atlantic (about 0.2 per decade) or on a global scale (0.1 per decade). Moreover, results for Azores and Madeira pointed to the higher sustainability of fisheries in these regions, with increasing TLm in the analyzed period. In addition, results obtained in chapter 4 revealed that the relative distribution of fish market prices in Portugal has changed over the past decades, with high trophic level species increasing in value comparatively to species with lower trophic levels: as species of higher TL become less abundant, their prices increased, and vice versa. Similar results were obtained by Pinnegar *et al.* (2002, 2006) for the Celtic Sea fish community.

Data on the quantity of lost static fishing gears or on how long such gears continue to fish is scarce (Pawson, 2003). Little is known about the effects of trammel nets ghost fishing in the Portuguese coast, with only two studies conducted in the southern coast (Erzini *et al.*, 1997; Santos *et al.*, 2003). Also this fisheries impact was not considered in chapter 2. Thus, in chapter 12 trammel nets' ghost fishing off the Portuguese central coast was analysed, comparing the structural evolution and changes in fishing capacity of lost trammel nets rocky and sandy bottoms. In both bottom types, nets' fishing area decreased to about 40% in the first month and then gradually in rocky bottoms or sharply in sandy bottoms. During the 285 days of the experiment 541 and 257 individuals were estimated to have been caught per 100 m of net in rocky and sandy bottoms, respectively, with catching efficiency decreasing in a negative exponential trend simultaneously with nets deterioration. Catching efficiency was estimated to decrease to below 1% after 10–11 months on rocky bottom and 8 months on sandy bottom. Authors who have set experimental nets in inshore waters reported similar trends of lost trammel nets evolution and lifetime (Erzini et al, 1997; Kaiser *et al.*, 1996).

Sustainability of Portuguese fisheries

Considering the importance of the fisheries sector in Portugal, the analysis of its sustainability is of the highest importance. Chapter 6 reported the overall increase in Portuguese fisheries sustainability in the last years. However, in ecological and social dimensions sustainability's performance progressed at a low rate and showed many oscillations, which may suggest that these two dimensions may not be in a truly sustainable pathway. The availability of data limited the selection of indicators to be applied, however, the set of indicators used seems to describe well what is happening with the Portuguese fisheries sector. Also the two indicator aggregation methods applied, which may be used complementarily, showed a high potential in tracking sustainability development of the fisheries sector through time.

The Tagus estuary is the largest in Portugal and one of the largest in Europe. Tagus fisheries represent an important employment niche that can be quite profitable, with fishermen maintaining traditional techniques, even if some are illegal. Thus, it was important to assess the sustainability of these small-scale fisheries (chapter 7). Results were indicative of the relative sustainability of the different fisheries, which is useful to determine where intervention is more necessary in order to improve sustainability of these fisheries with such social importance. The artisanal Tagus fisheries studied present mid-range sustainability. The most sustainable fishery is octopus traps (57%) followed by squid jig (56%). Eel basket and gill nets showed the next best sustainability scores (55% and 53%, respectively). Glass eel fishery presents a poor sustainability (46%), laying close boat dredge and beam trawl, the fisheries with lower sustainability (44% and 43%, respectively). RAPFISH technique was very useful in comparing the status of fisheries, integrating data on ecology, as well as social and economical aspects.

Management of Portuguese Fisheries

Management policies and strategies are essential to ensure sustainable exploitation of aquatic living resources. Thus, in chapter 8 the biological effects of the fisheries management measures adopted after Portuguese adhesion to the EU was analysed, verifying that in general they have not the desired effects. It is important to be aware that effects off one tool are dependent on how other tools are being used (Holland, 2003). Considering output measures, TAC generally did not limit catches, IFQ was implemented for two species, but only work in one case whereas vessel catch limits seemed to be respected due to the immediate economic benefits. Considering input measures (licences, individual effort quotas and gear and vessel restrictions), it was impossible to recognize their individual direct consequences. Nevertheless, they limited fishing effort and without them stocks would be probably in poorer condition. In addition, the effect of the size selectivity measures was impossible to discern, although it can be noted that they protect juveniles but also promote discards. Fishing closures seemed to have positive effects for sardine and nephrops, but not for hake.

MPA is a recent ecosystem management approach tool, increasingly applied with both conservation and fisheries management goals. The methodology developed in chapter 9 can be seen as a step in the assessment of effectiveness of MPA, namely concerning small scale-fisheries, and of MPA effects in ecosystems sustainability. It is a practical semi-quantitative assessment method that can be applied even with minimal data available and that allows to understand tendencies in MPA development and the identification of most fragile points within the process of achieving fisheries goals. Concerning the case study of the Arrábida MPA (Portugal), the global score achieved was the same before and after MPA establishment. Measures implemented appeared to improve the performance of ecological indicators, but resulted in the decrease of human social and economic qualities, which compromise the future of this MPA.

Questions and directions for future research

Achieving sustainable use of marine fisheries and ecosystems is not easy, but it can be enhanced by a better recognition of the scope and magnitude of the problems to be solved, to which this study presents a significant contribution.

The method developed in chapter 2, in addition to identifying issues requiring better information to ensure Portuguese fisheries sustainability, provide a method that can be the basis for future informed decision making and help in the transition to a fisheries management considering the ecosystem context. This method can be applied to the same fisheries in the future, when more detailed and precise data are available, which will ensure a more realistic evaluation, or to different fisheries. In addition, this model can be modified to assess other fisheries impacts on the environment or expanded to assess economic, social and/or cultural risks since ecology is only one of the components of the effective fisheries decision analysis framework required to a achieve a better fisheries management.

Concerning elasmobranch, its importance in the marine ecosystem and vulnerability to fishing are notable and thus, they should be subject to a careful management. Assessment of elasmobranchs bycatch and discards, in order to understand the magnitude of the impact of fisheries on these species, as well as further studies to better understand the biology and ecology of the species are needed and constitute important steps towards the development of a management measures to ensure the sustainability of these resources,

Further studies on the ecosystem's structure and functioning, and specially understanding of multispecies interactions, are still required to promote better management solutions to address and attempt to reverse in the long-term the decreasing trend found in TLm through ecosystem based approaches. Rebuilding of marine trophic web is needed, which must take place alongside the extraction of marine resources for human food.

The absolute and relative impacts of gear loss on fish stocks and on the marine environment remain poorly understood and information on the economic and social impacts is still lacking. Determining the amount of lost nets, in order to estimate the real effects of ghost fishing on stock levels, and clarifying changes in the ghost fishing function over time are perhaps the most urgent aspects to study. Also previous studies have been undertaken in conditions that are not entirely representative of the broad range of conditions encountered in fishing, hampering the perception of the real magnitude of the problem. Attempts should be made to perform future studies under the same conditions of fishing activity. Technical measures and legislation against ghost fishing should also be developed, especially at local scale.

Methods used to assess fisheries sustainable development can be applied to evaluate the potential impact of alternative policies on the status of fisheries sector. Also this framework may be developed in the future by including other indicators, identifying the respective reference points (target and/or limit reference points) and weighting indicators to reflect priorities according to the opinion of decision-makers. Additional studies should be conducted on Tagus estuary and its fisheries in order to get a better knowledge and, consequently, a better management and improve sustainability of these traditional fisheries.

Considering Portuguese fisheries management, it is obvious that there is an urgent need for a new fisheries management system in Europe that guarantees long-term conservation of natural marine resources. To achieve this goal, scientific understanding of the biology, ecology and behaviour of the exploited stock or stocks is required, as well as of exactly ecological effects of management measures on stocks. Also data is scarce for highly some important species in Portuguese fisheries, which are not and should be properly managed, as black scabbardfish, octopus and chub mackerel.

For some of management tools, such an MPA, towards a more integrate approach, it is essential to establish adequate monitoring plans in order to obtain data on its development and make the management a dynamic process. If more detailed and precise data are available, methodology developed in chapter 9 provides a more realistic approach of MPA effectiveness. Depending on the studied MPA peculiarities, it is important to evaluate the need for adding more indicators and replace or enable others in the developed framework.

References

Coelho, R., Erzini, K., Bentes, L., Correia, C., Lino, P.G., Monteiro, P., Ribeiro, J., Gonçalves, J.M.S., 2005. Semi-pelagic longline and trammel net elasmobranch catches in southern Portugal: catch composition, catch rates and discards. J. Northw. Atl. Fish. Sci. 35, 531-537.

Erzini, K., Monteiro, C.C., Ribeiro, J., Santos, M.N., Gaspar, M., Monteiro, P., Borges, T.C., 1997. An experimental study of gill net and trammel net 'ghost fishing' off the Algarve (southern Portugal). Mar. Ecol. Prog. Ser. 158, 257-265.

Holland, D.S., 2003. Integrating spatial management measures into traditional fishery management systems: the case of the Georges Bank multispecies groundfish fishery. ICES J. Mar. Sci. 60, 915-929.

Kaiser, M.J., Bullimore, B., Newman, P., Lock, K., Gilbert, S., 1996. Catches in “ghost fishing” set nets. Mar. Ecol. Prog. Ser. 145, 11-16.

Pauly, D., Christensen, V., Dalsgaard, J., Froese, R., Torres, F., 1998. Fishing down marine food webs. Science 279, 860-863.

Pawson, M.G., 2003. The catching capacity of lost static fishing gear: introduction (Editorial). Fish. Res. 64, 101-105.

Pikitch, E.K., Santora, C., Babcock, E.A., Bakun, A., Bonfil, R., Conover, D.O., Dayton, P., Doukakis, P., Fluharty, D., Heneman, B., Houde, E. D., Link, J., Livingston, P. A., Mangel, M., McAllister, M. K., Pope, J., Sainsbury, K. J., 2004. Ecosystem-Based Fishery Management. Science 305, 346-347.

Pinnegar, J. K., Hutton, T. P., Placenti, V., 2006. What relative seafood prices can tell us about the status of stocks. Fish Fish. 7, 219-226

Pinnegar, J.K., Jennings, S., O'Brien, C.M., Polunin, N.V.C., 2002. Long-term changes in the trophic level of the Celtic Sea fish community and fish market price distribution. J. Appl. Ecol. 39, 377-390.

Santos, M.N., Saldanha, H.J., Gaspar, M.B., Monteiro, C.C., 2003. Hake (*Merluccius merluccius* L., 1758) ghost fishing by gill nets off the Algarve (southern Portugal). Fish. Res. 64, 119-128.

Stevens, J.D., Bonfil, R., Dulvy, N.K., Walker, P.A., 2000. The effects of fishing on sharks, rays, and chimaeras (chondrichthyans), and the implications for marine ecosystems. ICES J. Mar. Sci. 57, 476-494.

Agradecimentos

Gostaria de agradecer a todos que contribuiram para esta tese, nomeadamente:

- À Professora Catedrática Maria José Costa pelo apoio incondicional na orientação desta tese e pela disponibilidade com que me recebeu na sua equipa de investigação;

- Ao Professor Henrique Cabral, que me deu a oportunidade de realizar este trabalho, pelo seu constante entusiasmo, pelas suas ideias e por ter apoiado também as minhas; foi para mim um grande previlégio trabalhar sob sua orientação e fazer parte do seu grupo;

- À Fundação para a Ciência e a Tecnologia pela bolsa de doutoramento que possibilitou a execução desta tese;

- A todos os co-autores dos artigos desta tese pela sua valiosa contribuição;

- À DGPA pela disponibilização de dados indispensáveis à realização de parte deste trabalho;

- Ao ICNB, à Capitania do Porto de Setúbal e à Delegação Marítima de Sesimbra por possibilitarem a realização dos trabalhos experimentais na área marinha do Parque Natural da Arrábida;

- A todos os pescadores que contribuiram para a realização deste trabalho;

- À equipa da Zoologia Marinha do Instituito de Oceanografia, especialmente à Rita, Marisa, Vanessa, Susana, Joana, Anabela, Tadeu, Patrick, Susanne, Sofia, Miguel, Miguel Ruano e Inês pela colaboração no trabalho de campo e de laboratório, pelo esforço e dedicação na leitura dos artigos até ao mais ínfimo detalhe, pelas valiosas sugestões, pelo apoio na execução desta tese, e sobretudo pela imensa amizade;

- À Marisa por ter acompanhado de perto todo este trabalho e ter estado sempre disponível para tudo, especialmente na fase final, tal como a Vanessa;

- À Rita, minha “parceira de corrida de tese”, por todo o apoio que me deu ao longo deste tempo e pela grande amizade;

- À minha familia e amigos pela amizade e apoio incondicionais, em particular ao meu tio João e ao meu avó Emiliano que fizeram as redes para nós “perdermos”;

- Aos meus pais, sem os quais nunca teria chegado onde cheguei, e ao meu irmão, que à sua maneira também me apoiou sempre;

- Ao Filipe por tudo… não existem palavras suficientes para exprimir como foi importante neste trabalho;

- Ao Jep e ao Parma por terem sido a minha companhia na fase de escrita.

A autora desta tese foi financiada com uma bolsa de doutoramento da Fundação para a Ciência e a Tecnologia (Referência SFRH/BD/19223/2004).

Os projectos onde se integram partes do presente trabalho foram co-financiados pela União Europeia através do FEDER - Programa MARE e pela Fundação para a Ciência e a Tecnologia.

FCT Fundação para a Ciência e a Tecnologia
MINISTÉRIO DA CIÊNCIA, TECNOLOGIA E ENSINO SUPERIOR Portugal

Ciência.Inovação 2010 Programa Operacional Ciência e Inovação 2010
MINISTÉRIO DA CIÊNCIA, TECNOLOGIA E ENSINO SUPERIOR

Governo da República Portuguesa

Fundo Europeu de Desenvolvimento Regional

O Mar nas suas Mãos Mare