UNIVERSIDADE DO ALGARVE

TRAWLING AND CREELING FOR NEPHROPS. IMPACTS ON BIODIVERSITY AND POPULATION STRUCTURE.

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THESIS

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Declaração de autoria do Trabalho

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

Acknowledgments

I dedicate this thesis to everyone that has always been there, my parents, to my brother, to all my years of work and study, to my dearest friends and to the randomness of life that brought me to where I stand today.

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There are a lot of others that deserved to be mentioned here, but the words are too few to spare and the space too precious so I will leave you with this,

Carpe Diem

Resumo

O lagostim (*Nephrops norvegicus*) é um crustáceo bentónico de águas profundas, com uma distribuição ampla que se estende desde a Islândia, as Ilhas Faroé e o noroeste da Noruega até a costa atlântica sul de Marrocos e ainda uma distribuição em bolsas dispersas no Mar Mediterrâneo. Os indivíduos adultos de *Nephrops norvegicus* podem ser encontrados nas zonas de plataforma continental e no talude entre os 90m e os 800m de profundidade em águas portuguesas. A distribuição nesta espécie pode ir desde fundos de vasa compacta ate fundos de vasa arenosa.

Ao longo dos anos esta espécie adquiriu alguma importância no sector das pescas devido ao seu crescente valor no mercado e é hoje em dia uma das principais espécies no arrasto de fundo de crustáceos na Europa. A atividade pesqueira resultante da exploração desta espécie tem demonstrado impactos ambientais negativos, com especial foco nos efeitos das redes de arrasto. Recentemente a pesca de Lagostim tem sido alvo de atenção por parte da Comunidade Europeia, com incentivos para a mudança de arte de captura da rede de arrasto para armadilhas, numa tentativa de redução das capturas acessórias.

Durante este estudo foi possível verificar que existem diferenças bastante demarcadas entre os dois tipos de artes utilizadas. Estas diferenças verificam-se nomeadamente a nível do valor comercial do lagostim e nas espécies afetadas por cada uma das artes.

Palavras-chave: *Nephrops norvegicus,* capturas acessórias, arrasto, armadilhas, gestão de recursos marinhos.

Abstract

The Norway Lobster (*Nephrops norvegicus*) is a deep- water burrowing decapod crustacean with a widespread distribution ranging from Iceland, the Faroe Island and northwestern Norway to the south Atlantic coast of Morocco with a patchy distribution on the Mediterranean Sea. In the Portuguese shelf and slope areas, adults are found on depths ranging from 90 to 800 m depth. The distribution of this species seems to be limited to high percentage of mud bottoms.

Along the years this species acquired some importance in the fisheries sector due to its market value. It is nowadays one of the main species in crustaceans' bottom trawling in Europe. The fishing activity for the exploitation of this species has shown some environmental impacts. In particular, trawl fisheries are known to directly impact the bottoms, and are associated with considerable amounts of bycatch and discards. Recently, the European community has turned the attention to creel fishery for Nephrops, encouraging the change from trawl to creel in this fishery in order to reduce the bycatch.

During this study it was possible to observe that there is a clear difference between both gears in what respects the commercial value of Nephrops caught as well as in terms of species affected by the gears.

Key words: *Nephrops norvegicus*, bycatch, trawl, creel, marine resources management

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1. Introduction

1.1. General concepts

Fisheries change the demographics of wild populations and the structure of ecosystems. These changes are dependent on the type of fishery, gear and affected area. Evidences to support these changes on the ecosystems are well documented and still undergoing study. One of the main issues is bycatch (Bell *et al.,* 2008; Bellido *et al.,* 2011; Catchpole *et al.,* 2006; Catchpole *et al.,* 2010; Davies *et al.,* 2009; Daw and Gray, 2005; Johnsen *et al.,* 2011; Kelleher *et al.,* 2005; Pita *et al.*, 2010; Wilcox *et al.*, 2009). Bycatch is present in all types of gears, global marine fisheries data showing that bycatch represents around 40% of the total marine catches worldwide (Davies *et al.*, 2009). Part of the bycatch is composed by species with commercial value, comprising up to 76% of the landed catch (Bojorquez, 1998), depending on the type of fishery and gear used (*métier).*

To fully understand the importance of the biomass waste produced in fisheries there is a need to have a definition of catch and bycatch. Bycatch is a term extensively used in many studies nowadays with different meanings. There are three accepted definitions of bycatch. One of the definitions currently accepted by the Fishery and Agriculture Organization of the United Nations (FAO) describes bycatch as "that proportion of the total organic material of animal origin in the catch, which is thrown away or dumped at sea, for whatever reason" (FAO Fisheries Report No. 547 FAO, 1996). This definition does not include plant material and post-harvest waste such as offal (Alverson *et al.,* 1994). Another definition refers to bycatch as the group of species discarded (Hall *et al.*, 2000) and a third definition (OECD 2001) includes in bycatch all the non-target fish retained and discarded. According to the Organization for Economic Co-operation and Development (OECD) bycatch is "total fishing mortality excluding that accounted directly by the retained catch of target species". This definition also includes fish that die as a result of interaction with the fishing gear, including mortality caused by "ghost fishing" (OECD 2001).

A more general definition of bycatch is currently used, and was adopted through this document, defining bycatch as the part of the catch that is constituted by the non-target-species. Taking these definitions into account, the quantity of biomass taken by the fishing gear may comprise the landed catch, including the target, accidental catches and non-target species that are marketable, and the discards, the catch fraction thrown back to the sea (Alverson *et al.*, 1994). The species included in each group may change category depending on a number of variables.

Bycatch can then be sold or discarded, depending on the circumstances. Discards are a main issue, and there is a high number of reasons for discarding. Most common reasons include regulatory measures (species protected, stock status, fishing quota attained, undersized individuals), and low market value (species with no value, damaged fish due to abrasion in the gear or handling onboard). Other factors, as the lack of space on board or vessel freezing capacity, among others, are also reasons for discarding. In such cases, only the most valuable species are retained, in a practice commonly known as *high grading* (Bellido *et al.*, 2011; Catchpole *et al.*, 2006; Catchpole *et al.*, 2010; Davies *et al.*, 2009; Daw and Gray 2005; Johnsen *et al.*, 2011). Discarded species may include protected or stock managed species and the lack of records on these catches may lead to failure on management policies (Catchpole *et al.*, 2006; Davies *et al.*, 2009; Daw *et al.*, 2005; Johnsen *et al.*, 2011).

A major issue related to the amount of by-catch and discards is gear selectivity. In the past, gear modifications were put in place to increase catch efficiency, but at present there is a concern to increase gear selectivity in order to avoid non-desirable, non-commercial and protected species (Aldrin *et al.*, 2012; Bellido *et al.*, 2011; Costa *et al.*, 2008; Johnsen *et al.*, 2011; Kronbak, 2009). This change in paradigm is related to the evolution of management policies, from single-species to ecosystem-based management (Bellido *et al.*, 2011; Hall *et al.*, 2000; Johnsen *et al.*, 2011; Simberloff, 1998). Although there are no conclusive studies about the ecosystem effects of a very selective fishing, the side effects of the exploitation of one species or a restricted group of species are considered preferred to the non-selective approach, due to the inexistence of market for the majority of bycatch species (Hall *et al.*, 2000). Another issue is market demand; while from an ecological point of view, the exploitation of species with lower trophic levels would lead to higher catch rates, market demand focus mostly on high trophic level species like tunas, sharks and other top predators that do not provide a sustainable fishery with high harvest rates (Hall *et al.*, 2000).

Bycatch can lead to conservation problems, when species caught include iconic species. These include mostly marine mammals, sharks, sea birds and some marine reptiles, and commercial species that cannot be caught due to regulatory measures (Simberloff, 1998). These aforementioned reasons can lead to public concerns on protection of marine life, with media circles focused on the unaccounted mortality caused by fisheries activities (Hall *et al.,* 2000).

Consequences of by-catch and discards go beyond the effects of mortality. The discarded bycatch will affect all the ecosystem by providing feeding opportunities to otherwise balanced communities with proper biomass intake and outtake. These disturbances are more evident on areas with intense fishing activity, affecting the constitution and demographics of the ecosystem, by indirectly benefiting scavenger communities and opportunistic species, (Catchpole *et al.,* 2008b).

Bycatch issues have been ignored in fisheries management to a high extent. Many reasons may account for this, as discards correspond to an “invisible” catch fraction. The declared catch on the port does not account for discards and hence only the data from landed catch are available (Wilcox *et al.,* 2009). This was less significant in the past, but with the increase in fishing effort resulting from the development of more efficient and less selective gears, the increase in bycatch became a problem for stock assessment mortality estimates, (Daw *et al.,* 2005). Gear improvement allowed for extending the fishing activity to previously ignored areas and the increased pressure on the target species lead to a decline in the abundance of these species (Johnsen *et al.,* 2011). The attempt to maintain the catch levels high also increased bycatch. However, the main management strategy is still based on single-species models, which do not take into account fisheries as a whole (Catchpole *et al.,* 2006).

Nowadays, one of the main factors for regulatory bycatch measures is the accidental catch of iconic groups as sea birds, mammals and sea turtles. The implementation of multispecies management policies can imply fishing closures whenever the bycatch of such species exceeds pre-determined amounts (Simberloff, 1998).

Global discards have declined in recent years (Davies *et al.,* 2009), nonetheless there are important exceptions. Deep-water fisheries in international waters are among these exceptions; stock declines and quota restrictions resulted in fishing effort increase and a consequent increase in discarded by-catch (Andrew *et al.*, 2007).

1.2. International and European Regulations for fisheries bycatch and discards

One of the most important international regulations affecting fisheries was the Third United Nations Convention on the Law of the Sea (UNCLOS) in 1982. This convention was held with the objective to create a common Law of the Sea for all the States involved, to "*promote the peaceful uses of the seas and oceans, the equitable and efficient utilization of their resources, the conservation of their living resources, and the study, protection and preservation of the marine environment*"(UNCLOS 1982). UNCLOS introduced the concept of exclusive economic zone (EEZ), an area over which a state has legal rights over the seabed and its resources. The EEZ extends the jurisdiction of coastal states from the previous 12 nautical miles (territorial waters) to 200 nautical miles beyond the shore line; as a consequence, most of the natural exploitable resources fell under the management responsibility of a country. It was expected that resources previously in international waters, would be better protected and managed.

Some guidelines for the sustainability of fisheries activities were proposed by FAO, resulting in the unanimous approval by the UN Council of the Code of Conduct for Responsible Fisheries" (FAO, 1995). Despite being of voluntary compliance, its principles have been generically adopted in fisheries strategic plans.

Along the years, several other conventions were approved to protect marine organisms like seabirds, dolphins and whales. Although in force, they were not able to solve the bycatch problem, and in 2010 FAO issued the International Guidelines on Bycatch Management and reduction of Discards (FAO, 2010). This guideline had the objective to assist in the implementation of an ecosystem approach to fisheries management.

1.3. The Common Fisheries Policy

In Europe, the Common Fisheries Policy (CFP) was created to manage the European Union stocks, through the establishment and further enforcement of a number of management measures. A central measure is the total allowable catch (TAC) (Johnsen *et al.*, 2011), setting up a limit for the total amount of fish which can be landed from a particular species and area. Other measures are of a more technical nature such as gear regulations, closed seasons and minimum landing sizes for individual species. Another cornerstone of the CFP lies in controlling the capacity of the fleets by limiting the number of licenses for some fisheries and/or the number at days at sea (Daw *et al.*, 2005).

The International Council for Exploration of the Sea (ICES) produces a research report on a yearly basis which is then discussed by the Advisory Committee (ACOM). ACOM is responsible for defining the current status and providing scientific advice for the different stocks. This report is discussed within the several committees on the EU, among them the Scientific, Technical and Economic Committee on Fisheries (STECF) and the European Parliament Fisheries Committee (Johnsen *et al.*, 2011). These committees are responsible for issuing a number of proposals on management issues which are then sent to the EU Council of Ministers for analysis and approval.

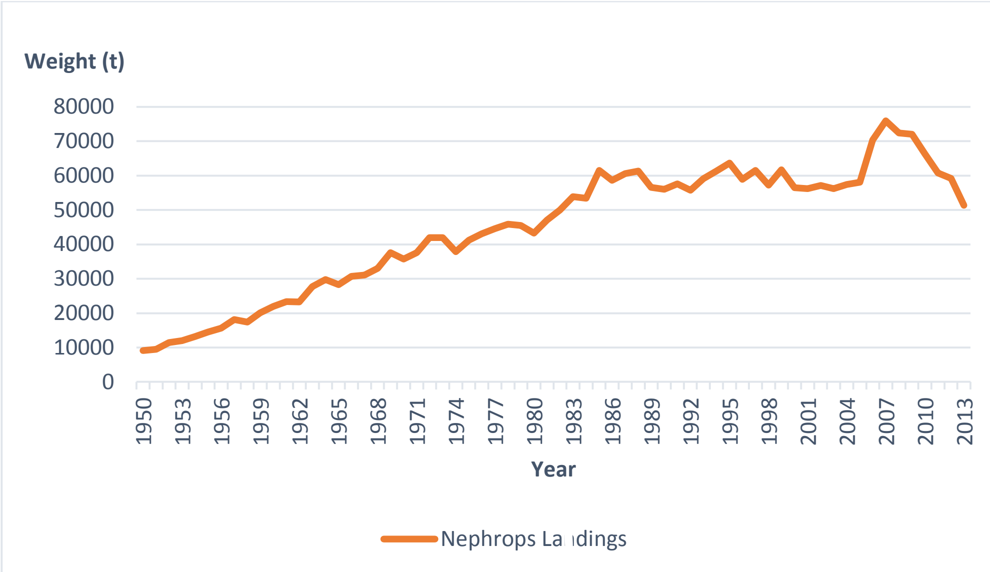
This approach to management can be understood as a top-down approach and it is widely regarded as having failed to successfully accomplish sustainable fisheries management in Europe (Johnsen *et al.*, 2011). The responsibility can be attributed to different parties. Technical and structural measures are rarely fully adopted at the policy stage and their enforcement is sometimes delayed due to economic or social interests prevailing over ecological sustainability (Johnsen *et al.*, 2011). Political devaluation of fisheries science also comes into play due to the inherent uncertainty of fisheries models and the resulting advice. The over-simplification of the scientific advice leads to disregard by politicians and the general public (Johnsen *et al.*, 2011). This whole scenario contributes to an encouragement to the scientific community to focus on other questions, reducing the quality and quantity of management-related research. Ultimately some blame can also be attributed to the scientific community, since fishers are more likely to be skeptical of scientific advice in which they have little or no involvement (Pita *et al.*, 2010).

Conservation objectives have been clearly incorporated in the CFP since 2002 (EC, 2002). After a period of intense exploitation some stocks collapsed and the need for management was enforced. Currently there is an increasing effort to create gears that allow, not only an efficient catch, but also reduce the bycatch. In the case of Nephrops stocks, the classification as "bellow biologically safe limits" has only been declared for the Iberian and Mediterranean stocks (ICES 2004). Management measures to recover Nephrops Iberian stock were adopted by reduction of the total allowable catch (TAC) (Harley *et al.*, 2001; Abella and Rigini 1998). Technical measures related to gear selectivity have been adopted by a number of European countries (ICES 2004), but not in Portugal.

1.4. *Nephrops norvegicus* - fishery

The Norway lobster is a highly valuable resource, with an average price of 13.01€/Kg in Portugal (first sale). It is an important source of revenue for the trawl fleet in general, and for the crustacean trawl fishery in particular, and therefore its management needs to consider not only the biological component but the social and economic dimensions of this fishery as well (Ungfors *et al.*, 2013).

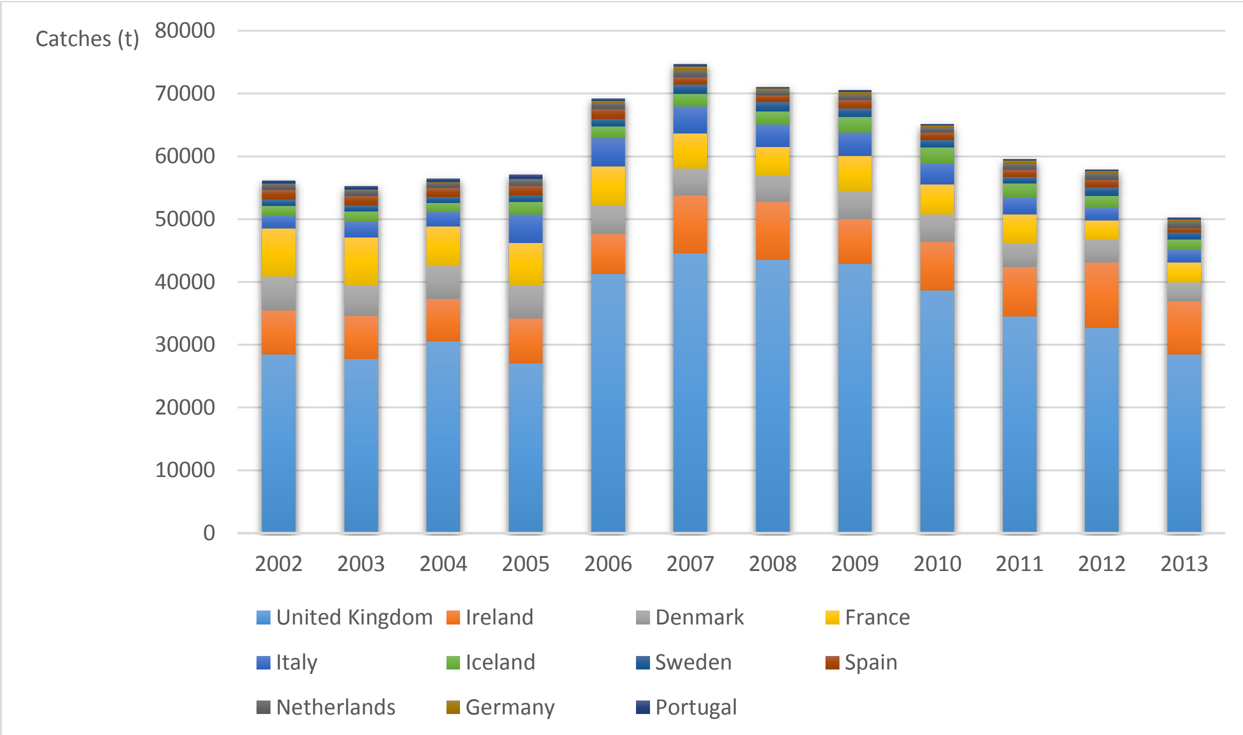
The landings of Nephrops increased from 1950 until the mid of the 1980´s, stabilizing since then at an average of 60,000t per year (Ungfors *et al.*, 2013) (Figure 1.1). Coastal waters of the Iberian Peninsula and the Mediterranean Sea show a decrease in landings even with increase in effort, thus new management practices must be adopted (Abelló *et al.*, 2002). In northern countries, like Sweden, new policies were introduced to make this fishery sustainable and there is a gradual shift of the effort from trawling gear to creels (Ziegler *et al.*, 2008).



Data source: FAO landings data.

Figure 1.1- European landings of *Nephrops norvegicus*.

The main producer is the United Kingdom responsible for 28.5 thousand tones (56.8% of the total world catch) (Figure 1.2) in 2013, followed by Ireland with 8.4 thousand tones (16.8%). Denmark and France catch around 3 thousand tones (6.0% and 6.2% respectively) and the remaining countries involved in the fishery (with decreasing importance are Italy, Iceland, Sweden, Spain, Netherlands, Germany and Portugal.



Data source: FAO landings data.

Figure 1.2- Total annual landings of Nephrops per country.

Gears used

The main gear used to catch Nephrops is the bottom otter trawl. Trawling gear has been developed along the years with different mesh types, cod ends and designs to increase their efficacy in catching the target species (Catchpole *et al.*, 2008a). Trawl selectivity changes according to the net section, the fore panels having large meshes so small organisms can escape, while the cod-end has a small mesh size to retain the target species. When trawling, the longer the haul, the less selective the cod-end will be due to biomass accumulation in this trawl section. (Kaykac *et al.*, 2009).

Management measures for Nephrops include annual total allowable catches (TACs), minimum landing size (MLS), closures in space and time, and specifically for trawlers, minimum codend mesh sizes (MMS) and maximum engine power. Regulations are not the same for all EU countries. In Portuguese waters, MMS in Nephrops trawls is 70 mm (Portaria

1557-A/2002, de 30 de Dezembro) and MLS is 20 mm (CL - carapace length). Both MMS and MLS should be based on maturation criteria that is, the MLS and the MMS length of 50% retention, should be equal or above the 50% maturation size of the female maturation ogive. This will mean that most individuals caught will have matured and reproduced at least once (Ungfors *et al*., 2013). However the MLS of 20 mm is well below the L50 maturation length of around 30mm, as indicated by Relini *et al*. (1998) for Algarve waters. It is also below the 50% retention in the legal mesh size of 70mm, around 25mm according to Fonseca *et al*. (2007). Despite the very low percentage of individuals with 20 mm CL in a trawl catch (Frandsen *et al.*, 2010; Fonseca *et al.*, 2007), there is still an important proportion retained with CL between 20 and 30 mm..

Trawls are among the less selective fishing gears and therefore the management of trawl fisheries must take into account all the bycatch, including commercially valuable and discarded species. Landings of commercial by-catch are usually recorded and therefore management can be achieved for these species (Catchpole *et al.*, 2008a; Doyen *et al.*, 2012). During the last decades, new trawl designs were developed in order to decrease trawl bycatch. These are commonly known by Bycatch Reduction Devices (BRD) and they contribute to exclude trawl by-catch either by sorting out unwanted species (physically or mechanically) or promoting escapement based on differences in behavior between crustaceans and fish species (Kronbak *et al*, 2009; Johnsen *et al.*, 2011). Northern countries such as Sweden started to use BRDs such as species-selective grids in order to reduce the bycatch. A similar device was developed for the Portuguese Nephrops trawl fishery by Fonseca *et al.* (2005), consisting of a grid sorting system, with a grid allowing the passage of Nephrops and rose shrimp to the trawl codend, while directing by-catch species to an upper trawl opening through which they escape from the trawl. However, these options are still not applied on southern European countries like Portugal (Johnsen *et al.*, 2011).

Creels are a passive gear deployed on the sea bottom and then hauled after a period of time. Presently, they account for a small portion of Nephrops catch, but before the development of industrial trawling fleets most crustacean species, including the Norway lobster, were caught in creels. Recently, this gear is being increasingly used due to the efforts to reduce bycatch

(Ziegler *et al.,* 2008). Creels are usually baited, in which case it is called a trap. The trap uses a simple catch mechanism: the target species gets into the trap usually by passing through a netting funnel (entrance), having its smaller opening turned into the inside of the trap, making it easy for the target species to get in but difficult to get out. This gear is highly selective, being characterized by very small amounts of bycatch (Ziegler *et al.,* 2008).

In Portugal, the minimum mesh size for traps is defined according to the percentage of target species caught per haul (*Portaria nº280/2002 de 15 de Março*: 8-24mm, 30-50mm and >50 mm with a minimum percentage of target species of 90%, 80% and 100% respectively).

Baited traps have increased efficiency due to the attractiveness of the bait. This is even more important on the sea bottom where the food-web is based on scavenging. In crustacean creeling, the most common and cheaper fish species are used for bait, such as mackerel (*Scomber scombrus*) and sardine (*Sardina pilchardus*) (Ziegler *et al.,* 2008). The fish are used whole in a similar condition to that used for human consumption, a situation that raises ethical concerns. Previous attempts to use loins or rotten fish failed due to the lack of acceptance of the final product by the consumer caused by smell and flavor of the crustacean meat that retained the bait smell and flavor. Artificial baits are being developed that can avoid the degradation of the final product and solve the problem of the use of fish on baited traps (Ziegler *et al.,* 2008).

Several studies have shown that traps are efficient in economic and environmental terms in Sweden (Ziegler *et al.,* 2008), Iceland (Ungfors *et al.,* 2013) and Portugal (Leocádio *et al.,* 2012). With the recent European policy of no discards (landing obligation), starting in 2015 with pelagic fisheries and extending to demersal fisheries in 2016, all quota species, as defined by catch limits in the TAC and quota Regulation, must be recorded, landed and counted for the quota, including any by-catch of pelagic quota species when caught in demersal operations (Defra, 2015).Therefore, the use of creels for these fisheries seems more and more profitable due to the dramatic reduction on the bycatch and the reduced fuel requirements when compared with trawl fisheries (Catchpole *et al*., 2010; Leocádio *et al*., 2012; Ungfors *et al.,* 2013), making traps a sustainable gear from a biological, as well as economic, point of view.

1.5. *Nephrops norvegicus* - biology

Reproductive cycle

The reproductive cycle in Nephrops changes according to latitude (Sardà, 1998). The incubation period can vary from 6 months, in the Mediterranean, to 10 months in Iceland, the most northern populations having biennial spawns (Tuck *et al.*, 1997; Tuck *et al.*, 2000). The eggs are extruded during summer and the larvae hatch in the end of winter or early spring, after which the female populations undergo a process of moulting followed by matting. Egg spawning in the Portuguese coast takes place in August and September. The ovigerous period lasts about 28 weeks and hatching takes place from January to April (Chapman and Rice, 1971; Sardà 1998).

The larval phase includes three *zoeal* stages with temperature-dependent duration, ranging from 15 days (at 17ºC) to 45 days (at 8ºC) (Figueiredo *et al.*, 1983). Nephrops *zoeae* are referred to occur between the ocean surface and 50 meters depth (Figueiredo *et al.*, 1983). The larvae describe a diurnal vertical migration (DVM behavior pattern) which will affect the dispersal distance (Figueiredo *et al.*, 1983). Environmental factors have a very decisive role during the *zoeae* development. Events such as offshore winds, that promote a stronger oceanic drift and abnormal seasonal temperatures, result in shifts from the optimal range levels for the development of Nephrops *Zoeae,* inducing years of poor recruitment that afterwards reflect on lower adult biomass (Figueiredo *et al.*, 1983).

Given that the adults are mainly sedentary, the larval phase has a very important role in the genetic connectivity between populations. Using DVM and with the influence of currents, populations export and import larvae from adjacent populations maintaining the genetic pool (Stamatis *et al.*, 2004). This species shows some genetic divergence at a regional scale, however genetic differentiation at the distributional range of the species doesn't seem to be significant to allow for the assumption of genetic isolation of populations (Stamatis *et al.*, 2004).

The size of first maturation (smallest size at which 50% of the females display functional reproductive capacity, with ripe ovaries and spermatophores) also changes according to latitude. Studies by Figueiredo *et al. (*1983), point out that the age of first maturity corresponds to the second and third year of life and is independent from size. However, data in Relini *et al*. (1998), using female Norway lobsters from the Algarve, indicate a 50% maturation length at around 30 mm. According to Queirós *et al.* (2013), some individuals with physiological readiness to reproduce may not be able to do so either due to small body size or underdevelopment of the body parts responsible for the mating process, a situation that should be taken into consideration when defining "maturity". Moreover, the use of primary sexual characters for the evaluation of the size of first maturation, may lead to underestimation of the size of the onset of maturity (SOM) (Queirós *et al.*, 2013). In Tuck *et al.* (2000), SOM values for females are between 21-34 mm carapace length and 29-46 mm for males.

Growth and moult

The moulting process is highly variable in length increment and moult frequency. These change according to the conditions of the environment and from individual to individual. The moult increment increases in absolute value with age, but is represents a higher percentage of the pre-moult size in younger individuals. The moult is more frequent in younger individuals and upon reaching sexual maturity males can moult as much as twice a year until they reach three, four years (Farmer 1973), while females will only moult once a year after maturation (Sardà 1995). The combination of more frequent molts and higher percent increase at moult in young individuals represents faster growth rates and an attenuation of growth rates with time can be observed in crustaceans as in other marine species such as fish. For this reason, Nephrops growth can be represented by the von Bertalanffy growth curve. ´

Age-length relationships do not show a clear pattern. Variability in growth, differences onset by the reproductive cycle and the absence of calcified structures that allow for exact ageing of individuals may account for the lack of such a pattern (Aydin and Aydin, 2011; Ayza *et al.*, 2011).

Behaviour

As a burrowing decapod, Nephrops spends most of its time hidden, coming out mainly during dawn and dusk in shallow waters (Hammond and Naylor, 1977). In areas where their distribution extends deeper than 150 m, the peak of activity slowly converges to a single peak that occurs at noon (Chapman and Howard, 1979; Rice and Chapman, 1971; Ungfors *et al.*, 2013). During their emergence from the burrows these individuals scavenge the seafloor. Studies show Nephrops exhibits some degree of fidelity to the burrow with occasional change of location associated with the creation of a new burrow (Chapman and Howard, 1979), consistent with short scavenging ranges. Their emergence rhythm is also conditioned by other factors such as seasonal variations, bottom type, individual size and water turbidity (Chapman and Howard, 1979).

1.6. Assessment and management of *Nephrops norvegicus*

In the North Atlantic, Norway, Iceland and the Faroe Islands manage their Nephrops fisheries independently while in Europe these fisheries are managed under the Common Fisheries Policy (CFP) (Johnsen *et al.*, 2011; Ungfors *et al.*, 2013). The current management policy is a top-down approach with input measures including minimum mesh sizes, closed seasons, closed areas. maximum number of days at sea and output measures such as total allowable catch quotas (TAC), minimum landing size (MLS) and catch composition (Ungfors *et al.*, 2013).

In Europe, the body responsible for the analysis of the scientific advice of the stock assessment and management from the International Council for the exploration of the Sea (ICES), is the Scientific, Technical and Economic Committee for Fisheries (STECF). This committee provides an overview of the ICES advice together with an evaluation and recommendation to the European Commission. *Nephrops norvegicus* is managed according to FUs, corresponding to stocks. Therefore an FU is defined as a subpopulation of individuals restricted to an area where they share similar life parameters as growth, fecundity, recruitment, mortality and, for management purposes, the same fishing mortality. Currently there are 8 FUs for Nephrops in the Mediterranean and 34 FUs in the North Atlantic from which 29 are in EU waters (Ungfors *et al.*, 2013).

Stock Assessment

There are multiple options for assessing stocks. For Nephrops, the most commonly used are surplus production models (SPM), length based cohort analysis (LCA) and in recent years, abundance information from underwater video cameras (UWTV).

SPMs are based on a series of catch (in weight) and effort. From these, the ratio catch per unit effort (CPUE) is related to effort and the model predicts the maximum equilibrium yield (MSY and the corresponding fishing effort (F_{max}).It is assumed that CPUE is proportional to stock abundance (Cadima, 2003). Fishing effort usually corresponds to the number of fishing operations, or fishing time. This can be number of traps set per day, number of hauls, time trawled or total soaking time (Harley *et al.*, 2001). SPMs are easy to apply but they may be deceiving because the ability of CPUE to indicate stock abundance is very limited. Marine species display assemblage behavior that changes according to the season, and fishers with the capacity to predict this behavior attain high CPUE. Environmental causes can change these concentrations and, if fishers continue to fish on those areas, the CPUE will be low causing underestimation of the true stock abundance (Harley *et al.*, 2001). Recent studies point out that the use of CPUE as the exclusive method for management, may lead to the collapse of a stock. Biological systems take time to answer to disturbances, hence a stock may be collapsing while CPUE values stay high, only dropping when the stock gets below the target reference points (Harley *et al.*, 2001).

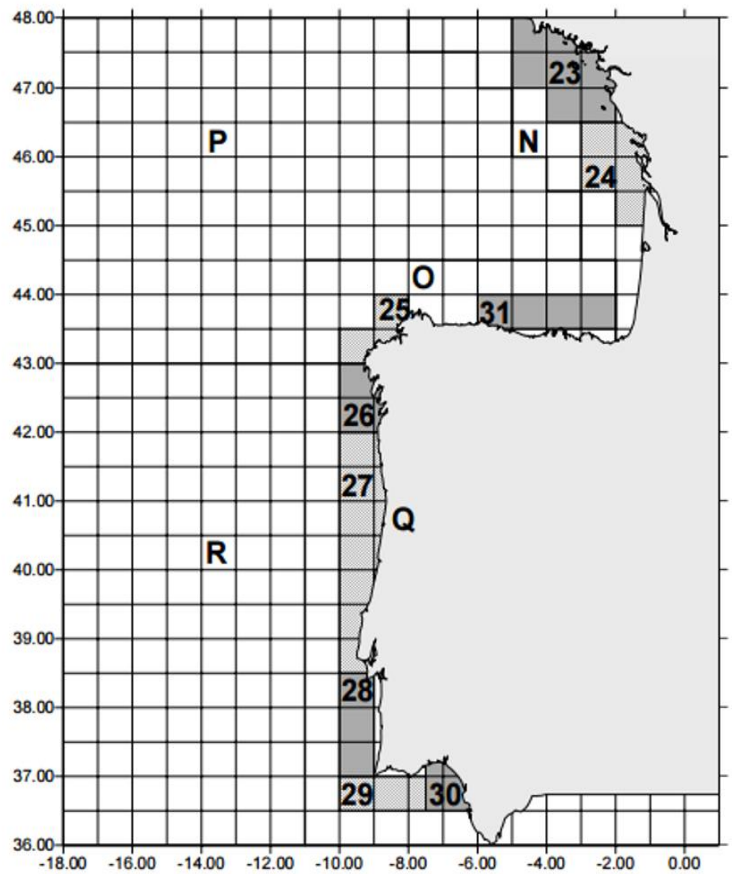
LCA is based on catch data (Hilborn and Walters, 1992). The inputs for the model are catch data from commercial fisheries, fishing mortality rates derived from catch data and an estimated value of natural mortality. This method computes the number of individuals in the stock and its survivors, predicting the stock composition in the following year by using additional information on recruitment and fecundity. However, it also requires growth information, in the form a function, usually the von Bertallanfy growth curve, which relates length and age, a relationship difficult to obtain in crustaceans (Aguzzi and Sardà, 2012).

The difficulty in obtaining age data is common to all crustaceans and results from the absence of permanent calcified parts, where growth rings can be formed. Traditional methods used in fish, where growth marks can be observed in otoliths or scales, do not have correspondence in crustacean. The correlation between length and age is therefore difficult, and growth curves are usually obtained with statistical techniques based on modal identification in length frequencies. Von Bertalanffy parameters can therefore be obtained and used in assessment models to convert length into age. Length data conversion is flawed due to the growth plasticity in Nephrops and may lead to bias (Ungfors *et al.*, 2013). Nevertheless, this method is considered to be the standard for Nephrops stock assessment, largely due to the absence of a better one. The method is as good as the base data used and therefore, it is highly dependent on the reliability of the fishers to report the catch (Aguzzi and Sardà, 2012).

Image based technologies made possible new procedures for Nehrops assessment. The use of cameras on trawls to assess Nephrops density was developed as an alternative to other conventional methods (Fonseca *et al.,* 2008; Lau *et al.,* 2012). With the creation of a proper algorithm that can analyze video and images, this method seems to offer a faster and easier way to assess Nephrops density, although problems have been reported with this technique (Fonseca *et al.,* 2008). Some limitations of this method has to do with the fact it counts burrows, not individual Nephrops. The second problem is that, while processing the image and identifying galleries, it is difficult to distinguish between primary entrances and secondary openings, and the counting of galleries or identification of gallery systems is difficult (Fonseca *et al.*, 2008).

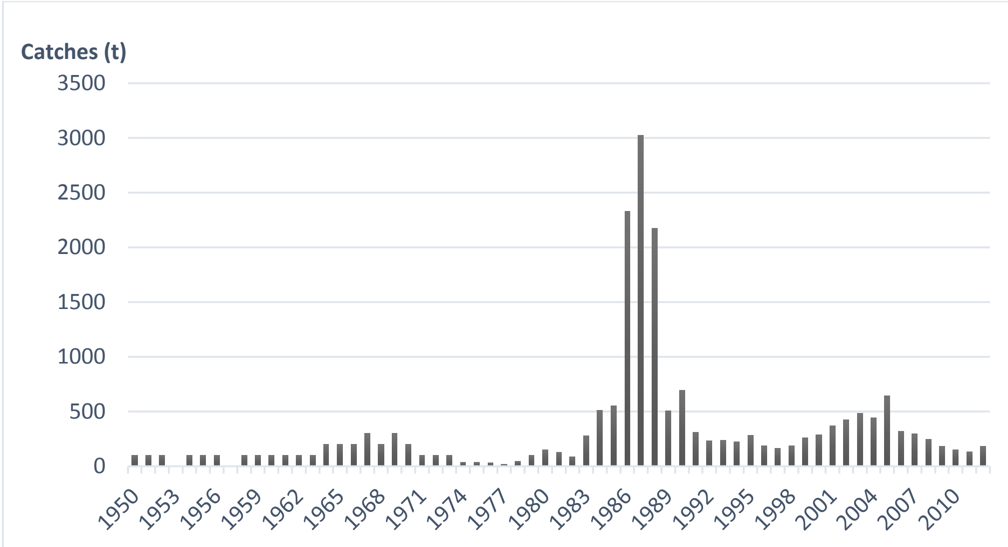
Management of Nephrops norvegicus

Portuguese waters include 3 functional units: FU 27, 28 and 29 (Figure 1.3) which belong to ICES area IXa. Records for Nephrops fisheries in Portugal are available in the FAO database since 1950. Landings reached a peak at 3025 t in 1987 and progressively declined until 1995. In 2012 the total landings were of 182 t (FAO landings 2012) (Figure 1.4).



Source of image: ICES, 2015

Figure 1.3-Nephrops functional units and management areas in subareas VIII, IX and X.



Source of data: FAO landings, 2012.

Figure 1.4- Total annual catches of Nephrops in Portugal from 1950 to 2012.

In Portugal, Nephrops started to be caught as bycatch of hake fisheries (Costa *et al.*, 2008) and thus the assessment in early years was mainly based on a rough estimate from the bycatch. As it started to attain economic importance, there was an allocation of part of the fleet to target Norway lobster (Castro *et al.*, 1998; González *et al.*, 2011; Ungfors *et al.*, 2013). Recent catch reports show a declining trend, which has been recorded since 1987. This reduction in Nephrops catches caused the effort to be shifted to other crustacean species such as the rose shrimp (*Parapenaeus longirostris*). Later the CFP established that all stocks should be exploited at the maximum sustainable yield (MSY), but to put this directive into practice, the biological reference points must be known. The reference points of all the Iberian Nephrops stocks are currently unknown, the only current assumption is that the stocks were exploited above the MSY due to the low CPUE (ICES, 2012). The current management policy is the maintenance of TAC and MLS, but the stock response has not been evaluated. In Portugal, Nephrops is currently managed under the Recovery Plan for Nephrops and southern hake (*Regulamento CE Nº 2166/2005, de 20 de Dezembro*).

Objective of the study

This study was developed with two main goals. One was to understand how traps and trawl gears affect the population structure of Nephrops. The other was to compare the impacts of these gears on the benthic community, in particular on species that compose the bycatch.

2. Methodology

This study was based on Nephrops population from FU 28 (SW coast of Portugal). The objective was to compare the catches from two types of gear, traps and trawl, hence samples for both gears were simultaneously taken in the same geographic location. This area is known as Mar de Sesimbra by the local fishermen. The area adjacent to the coast is a marine protected area, the Parque Marinho Luiz Saldanha. This protected area covers 53km^2 starting at Figueirinha's beach and ending in the Foz's beach, north of Cape Espichel. The continental shelf is narrow and the base of the slope, at around 1000 meters depth, is 20 km distant from the coast. This is the area where Setúbal and Lisboa canyons meet, which is limited at the south by a group of underwater hills (Infante Dom Pedro, Infante Santo and Infante Dom Henrique).

The crustacean trawler was 18.8 m overall length (LOA) and 8 m wide, fiberglass hull, gross tonnage (GT) of 69 t and engine power of 221 kW. The trap vessel (a polyvalent vessel operating several fixed gears, among them creels) was 15 m LOA, 23 GT, wooden hull and an engine power of 119 kW.

The dates of the study were chosen in order to cover different seasons during the year. The samples were obtained from 15th to 17th July 2014 (summer), 9th to 12th December 2014 (winter) and 17th to 19th March 2015 (spring).

The study was undertaken during regular fishing trips and had two conditioning factors: (1) not interfering or slowing down the fishing operations, (2) only one person dedicated to data collection in each vessel was available. Difficulties were of a different nature in each vessel. On board the trawler, the working conditions were good but the amounts of catch and bycatch to process were overwhelming in most hauls. On board the trap vessel, the working conditions were very harsh (open deck and very little space to work). The sampling procedures, for the catch and bycatch composition and Nephrops biological sampling, were adapted to those conditions to obtain sufficient data in the most efficient way.

2.1 Trawl samples

A standard commercial trawl net was used in the sampling, with a diamond mesh codend 70 mm mesh size. The GPS coordinates and time were registered at the start and the end of each haul. A total of 17 tows were conducted during this study, 8 during the summer, 3 during the winter, and 6 during the spring. The duration of the hauls was approximately 6 hours.

The length composition of the target species, Nephrops, was obtained for each tow, from a random sample (2 to 4 kg) taken before sorting Nephrops by size. The standard measurement for Nephrops was used, the carapace length (CL), the distance from the posterior border of the eye socket to the center of the posterior border of the cephalothorax (Figure *2.1*), measured to the lowest mm using calipers. During this process, the sex and the ovigerous conditions of the females were also registered.

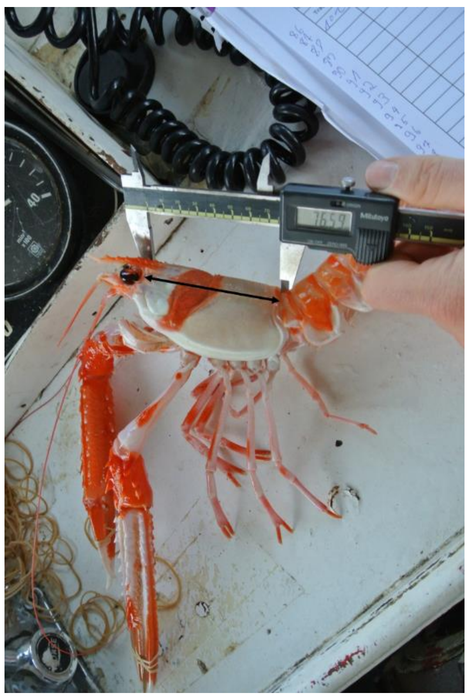


Figure 2.1-Photo showing the standard length for Nephrops.

The catch was sorted out by the crew and Nephrops, as well as commercial bycatch, were separated by species and weighted. The unwanted bycatch was stored in boxes before it was discarded at sea, the number of boxes was counted and one of the boxes was chosen to be sampled. This box was weighted, and all the species identified (presence/absence). The total weight of the discarded bycatch was estimated using, as extrapolation factor, the number of boxes.

2.2 Creel samples

Traps were set on the ocean floor, at the edge of the trawling grounds, for 5 days (soaking time).

The traps had a welded steel structure with dimensions 50x20x25 cm and were covered with 5 mm plastic net mesh (Figure 2.2). They included a funnel shape entrance and a bait cylinder pocket accessible from the outside. The entrance funnel had an inner opening of 15 cm and an outer opening of 25 cm, allowing the species to enter easily, but making the escape difficult. The bait cylinder with filled with sated bait. The most common species used were the largehead hairtail (*Trichiurus lepturus)* and Atlantic horse mackerel (*Trachurus trachurus)*, both chosen due to their low commercial value. Fish from previous fishing operations (from other trawling vessels from the same company) and of no value, were also used.

Figure 2.2- Photo of one of the traps used during this study.

The trap line followed the typical basic design of this gear, with a main line sitting on the bottom to which the traps are connected through a short cable. The main line is attached at each end to a vertical line with weights on the bottom and floaters and signaling flags at the surface (Figure 2.3). Individual traps have a secondary point of attachment to the main line, in order to increase the chance of recovery in case they get caught on the bottom. Each trap line consisted of 100 to 200 traps.

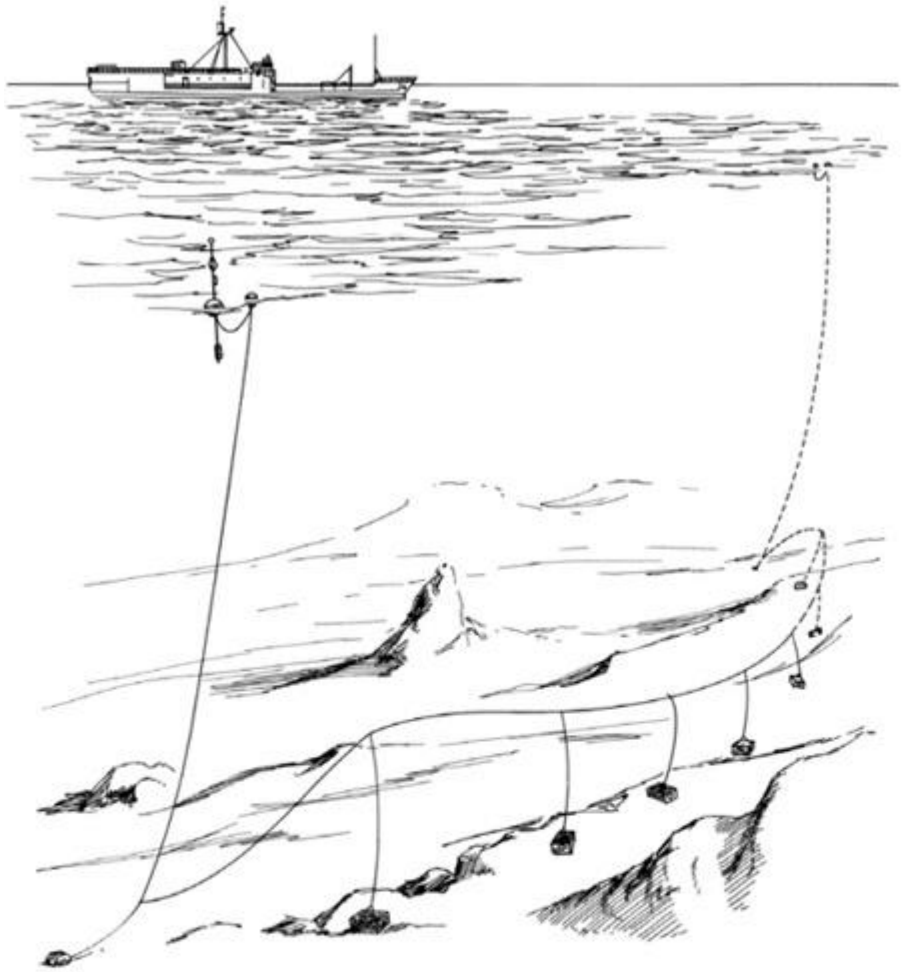


Figure source: Arana, 2014

Figure 2.3- Illustration of a trap line.

During haul up all species caught were identified and counted. All the Nephrops were measured and sexed. Since no scale was available on board, the weight of the Nephrops catch was obtained by adding the individual weights estimated by using a length-weight relationship, applied to each sex, based on a sample previously obtained for the same area:

$$w = aL^b$$

Where w is the weight in grams and L the length in mm. The parameters for females were a=0.0091, b=2.3286 and for males a=0.00043 and b=3.1101.

All species other than Nephrops, in this gear, were either discarded at sea or kept for future use as bait. This means that the fraction "retained bycatch" does not exist for this gear.

2.3 Biodiversity indexes

The level of information obtained for each species and fraction of the catch was the following:

- Target species, Nephrops: biological sampling (length distribution, sex ratio) and total weight per haul;
- Retained bycatch (only for trawling): species list and total weight by species and haul;
- Discarded bycatch: species list per haul (both gears) and total numbers by species (only traps).

In this situation, the only comparable information for all species and catch fractions was presence/absence (P/A).

Biodiversity indexes for presence/absence data were reviewed (Wilson and Shmida; 1984; Colwell and Coddington, 1994; Koleff *et al.*, 2003). Three indexes were applied (separately for each gear), two of them based on the frequencies or rare species (Whittaker, 1960 *in* Wilson and Shmida, 1984 and Lande, 1996 *in* Koleff *et al.*, 2003) and one based on the total number of species present (index modified from Chao, 1984 *in* Colwell and Coddington, 1994):

equation 1) Whittaker 1960

$$\beta_1 = \frac{S}{\tilde{\alpha}} - 1$$

equation 2) Lande 1996

$$\beta_2 = S - \tilde{\alpha}$$

equation 3) Modified Chao 1984

$$\beta_3 = S_{obs} + \left[\frac{L(2n-3)}{n} - \frac{M(n-2)^2}{n(n-1)}\right]$$

where S is the total number of species recorded (all seasons), $\tilde{\alpha}$ is the average number of species per season, S_{obs} is the number of species per season, L is the number of species that occur only once per season, M is the number of species that occurred in exactly two samples in a season and n is the number of samples per season.

Whittaker's and Lande's indexes are based on the total number of species present in all seasons and the average number of species present in each season. In eq. 1, since $S > \tilde{\alpha}$, and assuming $\tilde{\alpha} > 1$, β_1 will tend to have values close to zero at points of high diversity (where the ratio $S/\tilde{\alpha}$ will be only slightly above 1) and high values at points of low biodiversity where $S \gg \tilde{\alpha}$ and the ratio $S/\tilde{\alpha} >> 1$ (Koleff *et al.,* 2003). The range of possible values for β_1 is] 0, S-1 [.

The same variables are used in a more direct way in eq. 2, where β_2 varies inversely with biodiversity (Koleff *et al.,* 2003). The range of values for β_2 is] 0, S [.

Equation. 3 presents a different type of index, Chao's modified index, which is sensitive to the presence of rare species, expressed by the variables L and M. This index values rare species and when presented with samples with no rare species (L=M=0), $\beta_3 = S_{obs}$ (Koleff *et al.,* 2003). The quantity between brackets in eq. 3 is affected by L and M as well as the sample size n that defines the multipliers for L and M. The multiplier for M, equal to $(n-1)^2/(n^2-n)$, is always smaller than the multiplier for L. The quantity between brackets tends to be positive, with higher values associated to high frequencies of rare species. In theory, β_3 can fall below S_{obs} if M is considerably higher than L (Koleff *et al.,* 2003).

3. Results

3.1. Trawl samples

The location and time for each one of the 17 hauls are presented in (Figure 3.1).

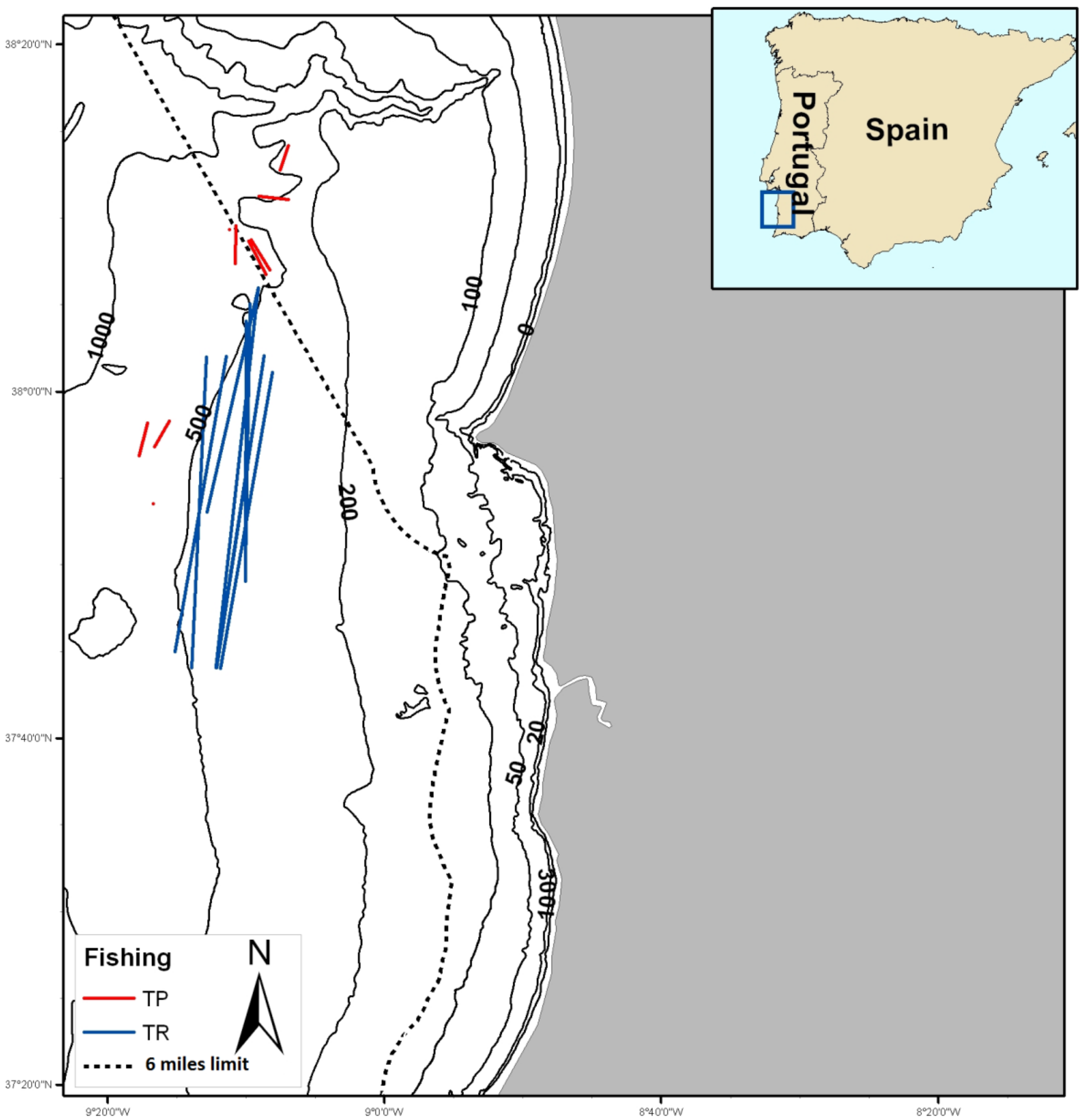


Figure 3.1- Sampled area. (TP-trap lines, TR-hauls)

Table 3.1 presents the sample size for Nephrons as well as the catch fractions (target species, bycatch discarded and bycatch retained) in the different hauls and Table 3.2 the percentages of each catch fraction in each haul. A total of 1027 Nephrons were sampled, 470 in the summer, 145 in the winter and 412 in the spring. Nephrons represented around 4% of the total catch in weight and 22% of the bycatch had commercial value and was retained. Most of the catch was systematically discarded. The percentage of discarded bycatch varied between a minimum of 57% in Summer and a maximum of 92% in Spring averaging around 75% in total.

Table 3.3 and Table 3.4 include the species composing the bycatch discarded and the bycatch retained respectively. The most important retained species are the anglerfish and the hake, followed by the dogfish and the gurnards. All retained species were also discarded, including Nephrops. There were multiple reasons for discarding. The most important one was lack of market value; this was the case for lantern shark, slimehead, pipefish, grenadier, lantern fishes, and hermit crabs, carrying crab, swimmer crab, whelks, sea urchins and sea cucumbers. For other species, such as conger, rockfish, megrim, anglerfish, greater forkbeard, rays, dogfish, rose shrimp, red shrimp, brown crab, Norway lobster and squid only the small sizes are discarded. The curled octopus and the blue whiting, with catches quite uniform in terms of the size of individuals, are retained when the caught amounts are low, and discarded otherwise. For hake, the main reason for discarding is quota limitations.

Table 3.1- Trawl – general information on the different catch fractions for the different hauls.

Season	Haul ID	Duration (hours)	Nephrops (1) Sample size (Numbers)	Nephrops (1) Sample weight (kg)	Nephrops Total weight (kg)	Discarded bycatch (3) Total weight (kg)	Retained bycatch Total weight (kg)	(4) Total catch
Summer	TR 01	6.9	44	2.75	20	315	173	508
	TR 02	5.2	47	3.66	18	345	185	548
	TR 03	5.1	94	6.47	29	300	201	530
	TR 04	7.0	49	2.76	23	360	118	501
	TR 05	5.2	56	2.80	33	450	145	628
	TR 06	5.5	65	3.83	24	390	58	472
	TR 07	7.5	50	1.89	36	375	123	534
	TR 08	4.9	65	4.19	26	360	64	450
Total summer		47.3	470	28.35	209	2895	1067	4171
Winter	TR 09	7.0	75	4.94	38	675	176	889
	TR 10	5.5	38	2.48	41	720	178	939
	TR 11	5.3	32	2.30	36	795	173	1004
Total Winter		17.8	145	9.72	115	2190	527	2832
Spring	TR 12	5.7	36	2.20	19	480	159	658
	TR 13	3.6	65	3.85	32	840	282	1154
	TR 14	7.6	144	10.19	18	660	222	900
	TR 15	6.0	46	2.70	23	345	36	404
	TR 16	8.2	54	2.54	10	465	30	505
	TR 17	4.0	67	4.10	15	540	89	644
Total Spring		35.1	412	25.58	117	3330	818	4265
Total		100.2	1027	63.65	441	8415	2412	11268

(1) Sample weight estimated with the application of a weight-length relationship; (2) Corresponds to 1 box of discarded bycatch; (3) Extrapolated based on number of boxes; (4) Total catch = Nephrops weight + retained bycatch + discarded bycatch.

Table 3.2- Trawl – information on the proportion of the different catch components.

Season	Haul ID	Nephrops (%)	Discarded bycatch (%)	Retained bycatch (%)
Summer	TR 01	3.9	62.0	34.1
	TR 02	3.3	63.0	33.8
	TR 03	5.5	56.6	37.9
	TR 04	4.6	71.9	23.6
	TR 05	5.3	71.7	23.1
	TR 06	5.1	82.6	12.3
	TR 07	6.7	70.2	23.0
	TR 08	5.8	80.0	14.2
Total summer		5.0	69.4	25.6
Winter	TR 09	4.3	75.9	19.8
	TR 10	4.4	76.7	19.0
	TR 11	3.6	79.2	17.2
Total Winter		4.1	77.3	18.6
Spring	TR 12	2.9	72.9	24.2
	TR 13	2.8	72.8	24.4
	TR 14	2.0	73.3	24.7
	TR 15	5.7	85.4	8.9
	TR 16	2.0	92.1	5.9
	TR 17	2.3	83.9	13.8
Total Spring		2.7	78.1	19.2
Total		3.9	74.7	21.4

Table 3.3- Trawl - species composition of the discarded bycatch (1-presence/0-absence) for the different hauls.

	Species		Summer								Winter			Spring					
Family	Scientific name	Common name	TR 01	TR 02	TR 03	TR 04	TR 05	TR 06	TR 07	TR 08	TR 09	TR 10	TR 11	TR 12	TR 13	TR 14	TR 15	TR 16	TR 17
	Fish																		
Congridae	*Conger conger*	European conger	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Squalidae	*Etmopterus sp.*	Lantern shark	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Scorpaenidae	*Helicolenus dactylopterus*	Rockfish	1	1	0	1	1	1	1	1	1	0	1	1	1	0	1	1	1
Trachichthydae	*Hoplostethus sp.*	Slimehead	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Scophtalmidae	*Lepidorhombus whiffiagonis*	Megrim	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Lophiidae	*Lophius sp.*	Anglerfish	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Macroramphosidae	*Macroramphosus scolopax*	Longspine snipefish	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Macrouridae	*Malacocephalus sp.*	Grenadier	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Merlucciidae	*Merluccius merluccius*	European hake	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Gadidae	*Micromesistius poutassou*	Blue whiting	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Myctophidae	*Myctophidae.*	Lantern fishes	1	0	1	1	1	0	1	1	0	1	1	1	1	1	1	0	1
Gadidae	*Phycis blennoides*	Greater forkbeard	1	1	1	1	0	0	0	0	1	0	1	1	0	1	1	1	1
Rajidae	*Rajidae*	Rays	1	0	0	1	0	0	0	0	1	1	1	1	1	0	0	1	1
Scyliorhinidae	*Scyliorhinus canicula*	Small-spotted dogfish	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Triglidae	*Triglidae*	Gurnards	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Crustaceans																		
Aristeidae	*Aristeus antennatus*	Red shrimp	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Cancridae	*Cancer pagurus*	Brown crab	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Nephropidae	*Nephrops norvegicus*	Norway lobster	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Paguroidea	*Paguroidea*	Hermit crabs	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Penaeidae	*Parapenaeus longirostris*	Deep-water rose shrimp	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Homolidae	*Paromola cuvieri*	Carrying crab	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Portunidae	*Polybius henslowii*	Swimmer crab	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Molluscs																		
Buccinidae	*Buccinidae*	Whelks	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Octopodidae	*Eledone cirrosa*	Curled octopus	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Loliginidae	*Loligo vulgaris*	European squid	1	0	0	0	1	1	0	0	1	1	0	1	1	1	1	1	1
	Equinoderms																		
Echinoidea	*Echinoidea*	Sea urchins	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Holothurioidea	*Holothurioidea*	Sea cucumbers	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Table 3.4- Trawl - species composition (total catch in kg) of the retained bycatch for the different hauls.

Species			Summer								Winter			Spring						Total
Family	Scientific name	Common name	TR 01	TR 02	TR 03	TR 04	TR 05	TR 06	TR 07	TR 08	TR 09	TR 10	TR 11	TR 12	TR 13	TR 14	TR 15	TR 16	TR 17	
	Fish																			
Congridae	*Conger conger*	European conger	5	8	0	0	9	0	4	4	5	12	8	5	5	0	0	0	7	72
Scorpaenidae	*Helicolenus dactylopterus*	Rockfish	4	2	0	10	2	8	4	3	9	0	3	3	2	10	0	2	3	65
Lophiidae	*Lophius sp.*	Anglerfish	25	32	50	43	41	26	44	35	29	32	41	43	65	80	20	5	32	643
Merlucciidae	*Merluccius merluccius*	European hake	28	32	27	15	8	10	12	7	30	42	24	26	43	26	7	7	23	367
Gadidae	*Micromesistius poutassou*	Blue whiting	25	50	20	0	0	0	0	0	25	25	30	25	48	20	0	0	0	268
Gadidae	*Phycis blennoides*	Greater forkbeard	6	4	3	1	0	0	0	0	3	0	5	5	3	0	0	0	0	30
Rajidae	*Rajidae*	Rays	1	0	0	2	0	0	0	0	4	6	7	0	0	0	0	2	0	22
Scyliorhinidae	*Scyliorhinus canicula*	Small-spotted dogfish	32	10	45	5	30	0	28	3	15	18	28	19	45	32	0	7	10	327
Triglidae	*Triglidae*	Gurnards	15	6	25	8	29	7	24	5	11	5	8	2	29	3	2	0	0	179
	Crustaceans																			
Penaeidae	*Parapenaeus longirostris*	Rose shrimp	1[(1)]	1[(1)]	1[(1)]	1[(1)]	1[(1)]	1[(1)]	1[(1)]	1[(1)]	1[(1)]	1[(1)]	1[(1)]	1[(1)]	1[(1)]	1[(1)]	1[(1)]	1[(1)]	1[(1)]	
	Molluscs																			
Octopodidae	*Eledone cirrosa*	Curled octopus	31	40	30	33	25	6	6	6	44	37	18	30	41	50	6	6	13	422

(1) The rose shrimp was not weighted. Residual quantities (less than 1 kg) were caught in all hauls.

3.2. Creel samples

Data from the trap fishery are presented in Table 3.5 and Table 3.6. A total of 5 trap sets were carried out during the Summer and 6 during the Winter. The weather conditions did not allow sampling in the spring. The number of traps per line was conditioned by the seafloor pattern; in rocky areas the number of traps will be just enough to cover the mud floor available among the rocks. Several lines of traps were deployed during each trip. During this study a total of 1777 traps were deployed and sampled, 787 during summer and 990 during the winter.

Table 3.5- Traps– general information on the catch fractions for the different hauls.

Season	Line ID	Soaking time (days)	Number of traps	Nephrops		Discarded bycatch species (numbers of species)
				Total number	Total weight (kg)	
Summer	TP 1	5	200	34	3.63	5
	TP 2	5	140	69	6.99	5
	TP 3	5	163	86	9.60	3
	TP 4	5	143	22	2.45	6
	TP 5	5	141	65	7.60	4
Total Summer			787	276	29.19	
Winter	TP 6	7	150	93	13.21	0
	TP 7	7	150	85	12.45	0
	TP 8	7	150	43	6.31	3
	TP 9	3	180	125	16.30	4
	TP 10	3	180	13	12.79	4
	TP 11	3	180	82	12.23	4
Total Winter			990	531	73.20	
Total			1777	87	12.21	

Table 3.6- Species composition of discarded bycatch (numbers) for the traps.

Species			Summer					Spring						
Family	Scientifc name	Common name	TP 01	TP 02	TP 03	TP 04	TP 05	TP 06	TP 07	TP 08	TP 09	TP 10	TP 11	TOTAL
	Fish													
Congridae	*Conger conger*	European conger	0	0	0	1	0	0	0	0	0	0	0	1
Scorpaenidae	*Helicolenus dactylopterus*	Rockfish	0	0	0	1	0	0	0	0	1	1	1	4
Melucciidae	*Merluccius merluccius*	European hake	0	0	0	0	0	0	0	0	2	2	2	6
	Crustaceans													
Aristeidae	*Aristeus antennatus*	Red shrimp	1	1	0	0	0	0	0	0	0	0	0	2
Cancridae	*Cancer pagurus*	Brown crab	3	0	0	3	1	0	0	1	0	0	0	8
Paguroidea	*Paguroidea*	Hermit crab	0	1	1	0	0	0	0	0	0	0	0	2
Homolidae	*Paromola cuvieri*	Carrying crab	1	0	0	0	0	0	0	0	0	0	0	1
Portunidae	*Polybius henslowii*	Swimmer crab	1	2	1	2	1	0	0	3	0	0	71	81
	Molluscs													
Buccinidae	*Buccinidae*	Whelks	2	1	8	6	15	0	0	2	2	2	2	46
Octopodidae	*Eledone cirrosa*	Curled octopus	0	1	0	1	0	0	0	0	0	0	0	2
	Equinoderms													
Echinoideia	*Echinoideia*	Sea urchins	0	0	0	0	0	0	0	0	0	1	1	2
Holothuroidea	*Holothuroidea*	Sea cucumbers	0	0	0	0	1	0	0	0	0	0	0	1

A total of 12 different bycatch species were captured, including 3 species of fish belonging to 3 families, 5 species of crustaceans (5 families), 2 species of Molluscs (2 families), 2 species of Echinoderms (2 families). All the species in the traps were also captured with the trawl. In the Summer a total of 10 bycatch species were captured, while in Winter only 6 were. Most species were captured during Summer, in particular the crabs. The only exception was the swimming crab, the most abundant species in the catches that was almost entirely captured during the Winter.

3.3. Bycatch analysis

A summary of all species caught in both gears and their fate in terms of retention or discarding at sea is presented in Table 3.7. Figure 3.2 summarizes the total number of species caught in each trap line and haul.

Table 3.7- Total catch by species with identification of presence/absence and discarded bycatch or retained bycatch.

Species				Trawls		Traps	
Family	Scientific Name	Common name (EN)	Common name (PT)	Discarded (Y/N)	Retained (Y/N)	Discarded (Y/N)	Retained (Y/N)
	Fish						
Congridae	*Conger conger*	Conger eel	Safio	Yes	Yes	No	Yes
Squalidae	*Etmopterus sp.*	Lantern shark	Lixinha da fundura	Yes	No	-	-
Scorpaenidae	*Helicolenus dactylopterus*	Offshore rockfish	Cantarilho	Yes	Yes	No	Yes
Trachichthydae	*Hoplostethus sp.*	Slimehead	Peixe olho-de-vidro	Yes	No	-	-
Scophtalmidae	*Lepidorhombus whiffiagonis*	Megrim	Areeiro	Yes	Yes	-	-
Lophiidae	*Lophius sp.*	Monk fish	Tamboril	Yes	Yes	-	-
Macroramphosidae	*Macroramphosus scolopax*	Longspine snipefish	Trombeteiro	Yes	No	-	-
Macrouridae	*Malacocephalus sp.*	Rattail	Peixe-Rato	Yes	No	-	-
Merlucciidae	*Merluccius merluccius*	Hake	Pescada	Yes	Yes	No	Yes
Gadidae	*Micromesistius poutassou*	Blue whiting	Verdinho	Yes	Yes	-	-
Myctophidae	*Myctophidae.*	Lantern fishes	Escolarinho	Yes	No	-	-
Gadidae	*Phycis blennoides*	Greater forkbeard	Abrótea	Yes	Yes	-	-
Rajidae	*Rajidae*	Ray	Raias	Yes	Yes	-	-
Scyliorhinidae	*Scyliorhinus canicula*	Small-spotted catshark	Pata-Roxa	Yes	Yes	-	-
Triglidae	*Triglidae*	Gurnard or Sea robin	Cabras	Yes	Yes	-	-
	Crustaceans						
Aristeidae	*Aristeus antennatus*	Red shrimp	Camarão	Yes	No	Yes	No
Cancridae	*Cancer pagurus*	Brown crab	Sapateira	Yes	No	Yes	No
Nephropidae	*Nephrops norvegicus*	Norway lobster	Lagostim	Yes	Yes	No	Yes
Paguroidea	*Paguroidea*	Hermit crab	Caranguejo Ermita	Yes	No	Yes	No
Penaeidae	*Parapenaeus longirostris*	Deep-water rose shrimp	Gamba	No	Yes	-	-
Homolidae	*Paromola cuvieri*	Carrying crab	Caranguejola	Yes	No	Yes	No
Portunidae	*Polybius henslowii*	Swimmer crab	Caranguejo	Yes	No	Yes	No
	Molluscs						
Buccinidae	*Buccinidae*	Whelks	Búzios	Yes	No	Yes	No
Octopodidae	*Eledone cirrosa*	Curled octopus	Polvo Cabeçudo	Yes	Yes	No	Yes
Loliginidae	*Loligo vulgaris*	Squid	Lula	Yes	Yes	-	-
	Echinoderms						
Echinoidea	*Echinoideia*	Sea urchin	Ouriço-do-mar	Yes	No	Yes	No
Holothurioidea	*Holothuroidea*	Sea cucumber	Pepino do Mar	Yes	No	Yes	No

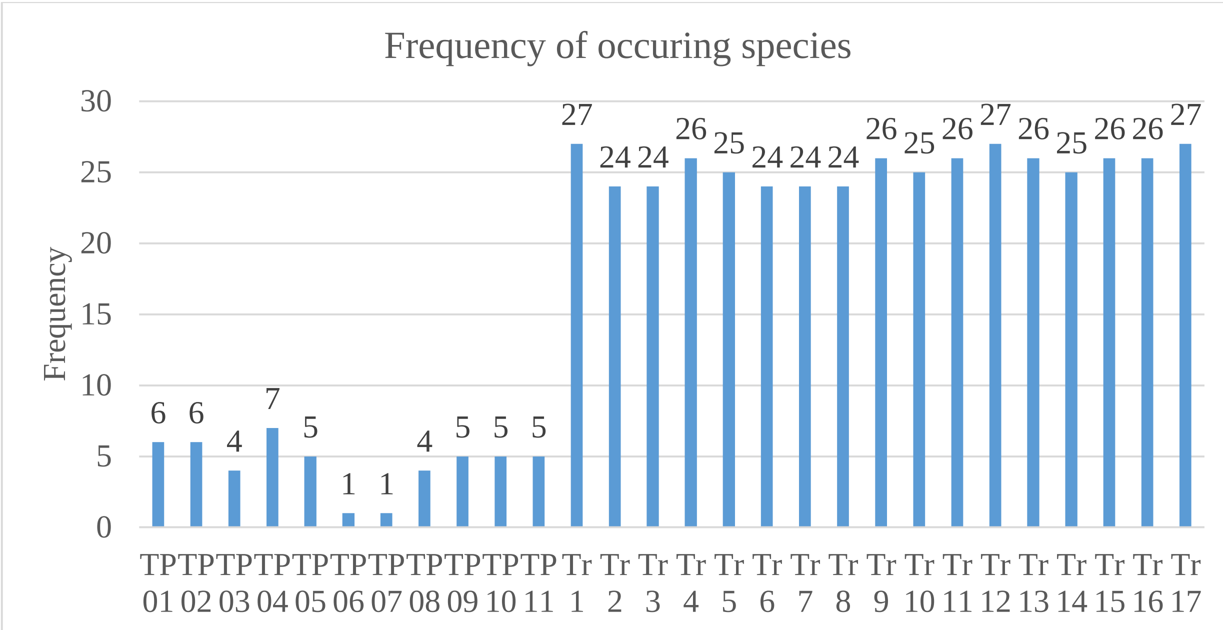


Figure 3.2- Number of species present in each sample. TP represents trap samples and TR represent trawl samples.

The impact of the trawl fishery on benthic biodiversity is clearly higher when compared to the traps. The difference is mainly associated with the active and passive nature of trawl and traps. While the trawling sweeps the grounds and catches all species not able to run away (both benthic and benthopelagic), the traps stay on the bottom and catch only benthic species that are attracted to the bait and do not exit the traps, mostly invertebrate scavengers.

The usage given to the bycatch of the traps is more consistent, only Nephrops is kept for commercial purposes. Although the bycatch species from the traps were only counted, while in the trawler they were weighted, the disproportion of the importance of the bycatch fraction in the two gears unequivocally indicates the much higher impact on bottom biodiversity of trawling (Figure 3.3).

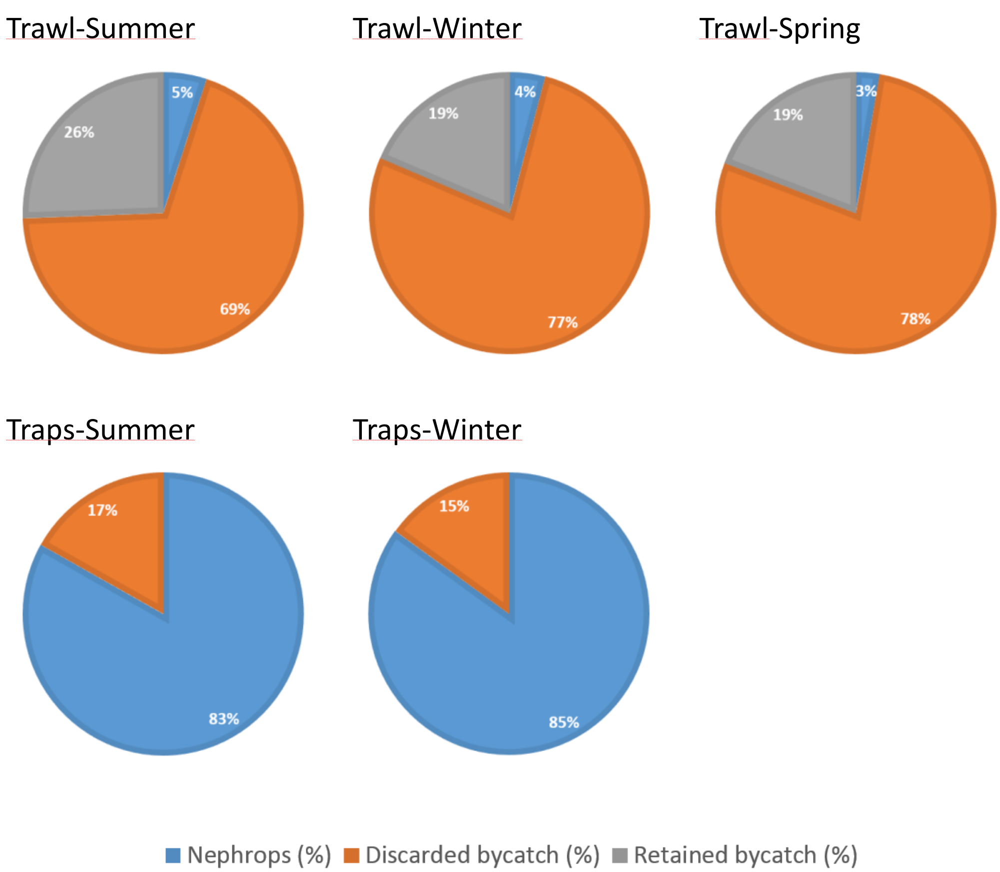


Figure 3.3-Proportion of the several constituents of the catch.

The biodiversity indexes (Table 3.8) as expected, were notoriously different between traps and trawls. β_1 and β_2 indexes are inversely related with the number of rare species while β_3 represents the number of species present and varies in opposite direction of the other indexes. These indexes are derived from beta diversity indexes and time was our continuous variable.

Table 3.8- Biodiversity presence-absence indexes values.

Gear	Season	β_1	β_2	β_3
Trawl	Summer	0.091	2.25	26.36
Trawl	Winter	0.052	1.33	26.33
Trawl	Spring	0.032	0.83	27.00
Traps	Summer	1.143	6.40	15.25
Traps	Winter	2.429	8.50	7.43

For the trawling little differences were found among seasons for all the indexes. This means that the composition of the catch, for the period of the study, had little changed. The variation in the seasonal values for these indexes is mainly due to the presence of three species, *P. blenoides*, *L. vulgaris* and skates. The differences between seasons are more pronounced for the traps, but since the species count is based on rare occurrences of most species, the index variation may be biased.

3.4. Population structure

The length distribution parameters for Nephrops caught with both gears are presented in Table 3.9.

Table 3.9- Summary of length distribution parameters for Nephrops.

	CL (mm)			
	Minimum	Maximum	Mean	Standard deviation
Trawl	**30**	**75**	**43.7**	**8.6**
Males	31	75	44.2	8.8
Females	30	59	41.9	7.7
Berried females	31	53	41.3	5.6
Traps	**15**	**76**	**56.9**	**6.8**
Males	15	76	56.8	6.8
Females	56	60	58.8	1.6
Berried females	56	59	58.3	1.5

The percentage of males, females and ovigerous females are presented in Table 3.10. Berried females were present in the winter samples (49 individuals) and summer (only one individual). The proportion of females is higher in the trawl, the trap samples were constituted almost entirely by males.

Table 3.10- Percentage of individuals of each sex in each gear (F=females, Fe=females bearing eggs, M=males); a) trawl and b) traps.

a)

Trawl	Spring	Summer	Winter
F	21%	18%	6%
Fe	0%	0%	31%
M	79%	82%	63%
Total (n)	412	470	145

b)

Traps	Summer	Winter
F	0%	1%
Fe	0%	1%
M	100%	98%
Total (n)	270	530

Length frequency distributions, for each gear and season, are presented in Figure 3.4. An analysis of the length distributions clearly indicates that trawlers catch a fraction of smaller individuas from both sexes that are not present in the traps.

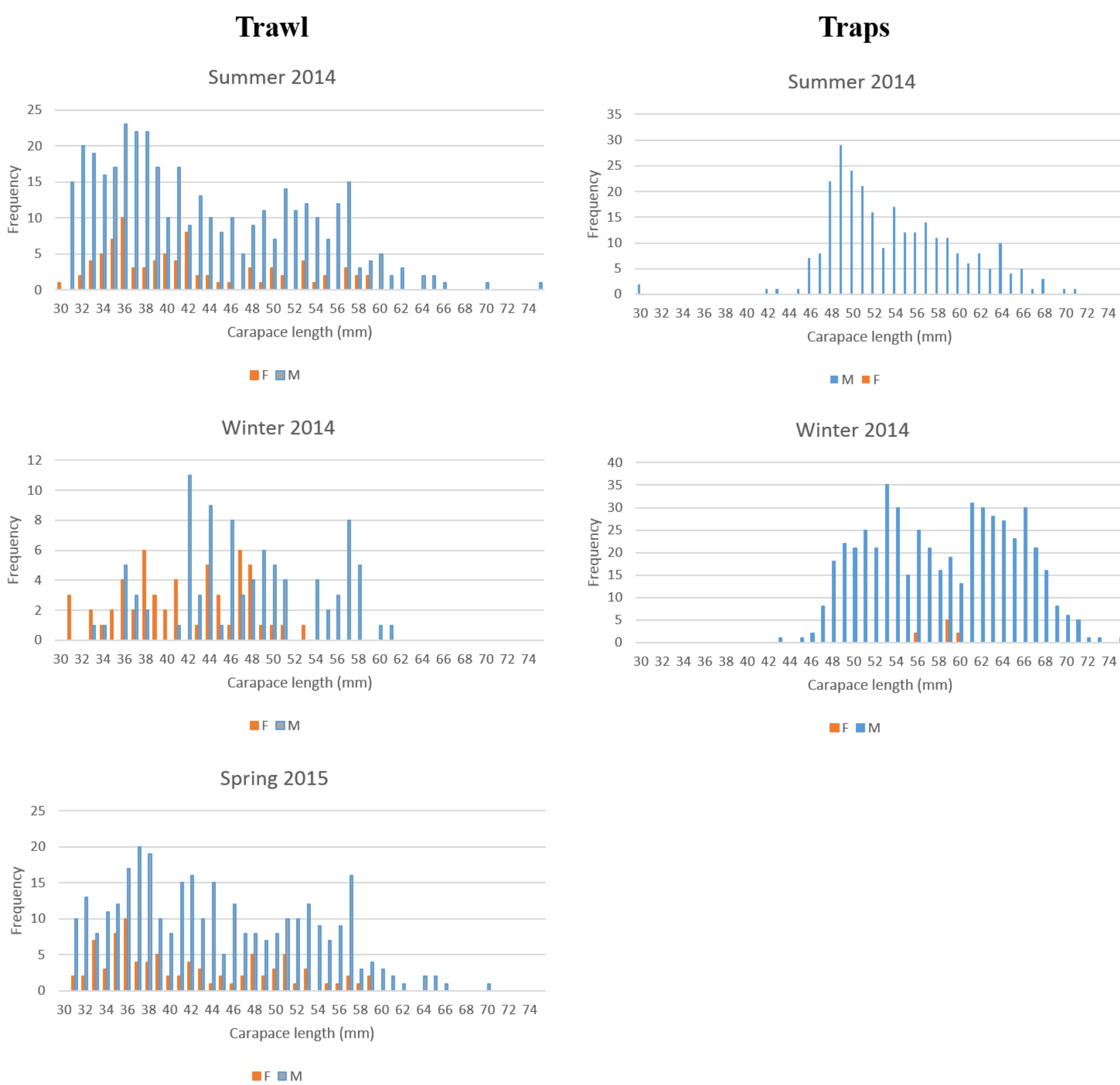


Figure 3.4- Nephrops length frequency distributions by gear and season.

4. Discussion

The purpose of this study was to compare the species diversity of the catch and the size structure of Nephrops between two gears targeting the same species (Nephrops) in the same area. The fishing operations of both gears were conducted in the same area and at the same time, in order to guarantee that the biotic community and Nephrops population are the same. Complete overlap of the areas was not possible, because the trawling activity is not compatible with the presence of fixed gears, but the bathymetry was similar and the fishing grounds contiguous (Figure 3.1). The coordination of the operations between the two skippers was guaranteed by using vessels from the same company.

Nephrops trawl activity and trap fisheries have been the focus of several studies, and several areas of Europe have different policies to allocate effort between traps and trawls. Creel fisheries for Nephrops are well established in Nordic regions such as Western Scotland and the Swedish Skagerrak. In the Faroe Islands a sustainable creel fishery developed where trawling was banned and in other European regions creels are being currently tested as an alternative to trawls as is the case of the North eastern part of the Adriatic Sea. In other areas, creeling operations are experimental (the central Adriatic sea, Morello *et al.* 2009) or at a reduced scale (Portuguese coast, Leocádio *et al*.2012).

With respect to faunistic diversity of catches and quantities of by catch, the higher values for the trawl are not a surprise. Similar results were attained in all studies where traps were compared to trawls. A total of 27 species belonging to 26 families were captured. All species were present in the trawl but only 13 on the traps. The number of species present in each haul was consistently higher than the corresponding number in each trap line, indicating much higher impact of trawling on bottom biodiversity. This impact is even higher when it is analyzed in terms of biomass or number of individuals, much higher in the trawl when compared to traps.

In several studies comparing trawl and trap fisheries similar conclusions were reached. Trawls have a higher impact in terms of biomass, both from the target species and the bycatch. The main issue with trawl fisheries is the high proportion of unwanted catch (species and biomass), usually more than half of the catch being discarded at sea. This is true for most trawl fisheries (Alverson *et al.*1994), especially those targeting crustaceans. Some countries have developed ways of using this bycatch, reducing the amount of discards. An example is the shrimp trawl fisheries in China where most bycatch is landed to produce fishmeal (Chiu *et al.*, 2013), a procedure replicated in South American countries. Some other countries have developed other ways to deal with the discard problem such as Canada and Northern countries that have enforced the use of by-catch reducing devices in trawls, for example grid sorting systems or square mesh windows, allowing the escapement of a significant fraction of the unwanted catch (Alverson *et al.*1994).

Trawl impacts are also generally high on the sea floor (Guijarro *et al.*,2011; Martín *et al.*, 2014). The trawl doors scrap the ocean floor during their activity, destroying any structures present in their path. The movement of the vessel will also cause pressure on the gear, responsible for abrasions in the catch and even the death of some individuals due to crushing (Guijarro *et al.*, 2011). Once inside the trawl net, escapement is possible but the injuries inflicted to the individuals during the process are of such an extent that most individuals will die; all these factors will affect the real mortality caused by this gear (Leocádio *et al.*, 2012). This is relevant for this study because it was noticed that the individuals of most species arrived at the deck either dead or with serious injuries. Mortality of the bycatch will be very high even for small fish and crustaceans that are discarded, leading to the question of whether the use of this type of gear can be justified and sustainable, having into account the small amount of catch retained for commercial purposes (Guijarro *et al.*, 2011).

The effects of the traps on the sea bottom are less important, but still not negligible. Some studies indicate that the deployment of this gear can lead to disturbances on the sea bottom (Leocádio *et al.*, 2012), but most criticisms come from the unseen bycatch of this gear (Hall *et al.*,2000). A hypothesis could be that the bycatch species present in the traps are rare events, but the long soaking time of the traps may lead the capture of species that are consumed by predators or scavengers and are never accounted as bycatch. It has been registered that some species of predators can freely enter the traps and feed on the catch. This behavior has been recorded in several trap fisheries, with species such as *Octopus magnificus*

(Groeneveld *et al.*, 2006), using the traps to get easy meals (Favaro *et al.*,2010; Raby *et al.*, 2014; Watanuki *et al.*,2000).

With the acknowledgement of the importance of managing fisheries at an ecosystem level and reducing discards, the renovation of stocks by safeguarding juveniles has been enforced, and traps fisheries have increased in the recent years. During this study it was possible to observe that the majority of the trawl catch had no commercial value, mainly due to the abundance of undersized individuals and unmarketable species. Another factor was the degree of damage observed in a high number of individuals.

Contrary to trawls, creels yielded little or no bycatch with individuals of commercially important species rarely caught. Most of the individuals caught belonged to the family *Buccinidae* and were discarded due to the lack of commercial value.

The higher impact of trawling has to do with the nature of the gears and with their fishing process because trawling relies on the engine power to drag the net throughout the ocean floor catching most of the individuals in the area swept while in the creel case, the catch will depend on the attraction power of the bait and access to the creel entrances (Morello *et al.*, 2009).

The size distributions of Nephrops caught by creels and bottom trawling were different. The trawl catch was composed of a wide size range (30 mm to 75 mm) but 50% of the individuals were below 43 mm carapace length whereas the trap catch was composed of large size individuals (42mm to 76mm) with the exception of a single individual with 15 mm. The selectivity for larger individuals, mostly males, is commonly recorded in creel fisheries and this is attributed to behavioral differences (Morello *et al.*, 2009). Selectivity for larger sizes can be double edge sword, on one side it guarantees that smaller individuals survive to reach reproductive size, on the other side it can lead to a decrease in the age of first maturity, an effect that has been widely reported on fish species (Cubillos *et al.*, 2014).

The condition and size of Nephrops changes their market value (Eriksson 2006; Milligan *et al.*, 2009; Leocádio *et al.*, 2012; Ridgway *et al.*, 2006). This is largely evidenced for the ex-vessel price (DGRM 2015). In 2014, the price per Kg of Nephrops caught with a trawler had a mean value of 13.47€/kg while the price per Kg of Nephrops caught with traps was

40.45€/kg. This gap in value is due not only to size differences but also because individuals caught with traps arrive on deck alive, are kept alive in tanks on board and are sold alive. Markets nowadays value fresh products due to their quality and therefore individuals sold alive provide an opportunity to value trap fisheries (Eriksson 2006;, Milligan *et al.,* 2009). Although the trawl caught roughly 3 times the amount of Nephrops, the ex-vessel value for the traps was 3 times higher, and total income from Nephrops was not much different between the two gears. However, when valuing both fisheries, trawling had the added income from the bycatch species. During this study, a total of 11 bycatch species were kept, of which, at least two of the most abundant, anglerfish and hake, reach high market prices.

5. Conclusion

With all considerations in mind, the sustainability of Nephrops fisheries should be improved and two kinds of actions are suggested. One aspect is the improvement of selectivity with gear modifications such as BRDs. Some of these devices were tested with good results in the Portuguese crustacean trawling fleet and the retention of important bycatch species, such as blue whiting *Micromesistius. poutassou*, can be significantly reduced (Fonseca *et al.*, 2005, 2007). These management measures can be important for the south coast, where traps do not seem to be, at this point, a viable option, due to, Nephrops smaller sizes in this area when compared to the southwest coast. A second line of action should be the exclusion of trawlers from certain areas, allowing the expansion of the creel fishery, at the moment restricted to areas inside the 6 miles limit or in a few other small areas of hard bottoms inaccessible to trawling. This approach would be important for the Southwest coast from Sesimbra to Cape St. Vincent. In this region, the exclusion of trawling between the 6 and 12 miles would not require negotiations at the EU and could be very positive, not only for the creel fisheries but for other fixed gears as well. The added income such a measure would bring with improve the economic sustainability of local polyvalent fleets. If such a management measurement is implemented, studies should be conducted in order to evaluate the effects of the gear change, on all aspects of fisheries sustainability namely, ecosystem recovery and socioeconomic aspects.

Other factors should be considered when comparing gears, for example fuel consumption, employment and social conditions. With respect to fuel, a previous study done on the same fleets showed that during one day of activity the trawler spent 9 times the amount of fuel when compared with the trap vessel (Leocádio *et al*., 2012). With respect to employment, the trap vessel can accommodate up to 6 crew member (usually 5 at a given time) and the trawler employs 7 crew members. The multiplication factor (jobs generated) maintaining the working conditions, are clearly better in the trawler. In the trap vessel all work is done on an open deck with much worst conditions for resting, having meals or taking care of personal hygiene. A conversion of the fleet needs to consider comfort and safety conditions for the vessels crews.

6. References

Abella, A., Righini, P., 1998. Biological reference points for the management of *Nephrops norvegicus* stocks in the northern Tyrrhenian Sea. Journal of Natural History 32, 1419-1430.

Abelló, P., Abella, Á., Adamidou, A., Jukic-Peladic, S., Maiorano, P., Spedicato, M.T., 2002. Geographical patterns in abundance and population structure of *Nephrops norvegicus* and *Parapenaeus longirostris* (Crustacea: Decapoda) along the European Mediterranean coasts. Scientia Marina 66, 125-141.

Aguzzi, J., Sardà, F., 2012. A review of burrow counting as an alternative to other typical methods of assessment of Norway lobster populations. Reviews in Fish Biology and Fisheries 22, 409-422.

Aldrin, M., Mortensen, B., Storvik, G., Nedreaas, K., Aglen, A., Aanes, S., 2012. Improving management decisions by predicting fish bycatch in the Barents Sea shrimp fishery. ICES Journal of Marine Science 69, 64-74.

Alverson, D.L.; Freeberg, M.H.; Pope, J.G.; Murawski, S.A. A global assessment of fisheries bycatch and discards. FAO Fisheries Technical Paper. No. 339. Rome, FAO. 1994. 233p.

Andrew J. Davies, J. Murray Roberts, Jason Hall-Spencer, 2007. Preserving deep-sea natural heritage: Emerging issues in offshore conservation and management, Biological Conservation, 138, 299-312.

Arana, P.M., 2014. Chilean jagged lobster, *Projasus bahamondei*, in the southeastern Pacific Ocean: current state of knowledge. Latin American journal of Aquatic Research 42, 1-17.

Aydin, I., Aydin, C., 2011. Length-Length and Length-Weight Relationships in *Nephrops norvegicus* from the Aegean Sea (Linnaeus, 1758). Mediterranean Marine Science 12, 121-128.

Ayza, O., Tuset, V.M., González, J.A., 2011. Estimation of size at onset of sexual maturity and growth parameters in Norway lobster (*Nephrops norvegicus*) off the Portuguese coast. Fisheries Research 108, 205-208.

Bell, M., Elson, J., Addison, J., Revill, A., Bevan, D., 2008. Trawl catch composition in relation to Norway lobster (*Nephrops norvegicus* L.) abundance on the Farn Deeps grounds, NE England. Fisheries Research 90, 128-137.

Bellido, J.M., Santos, M.B., Pennino, M.G., Valeiras, X., Pierce, G.J., 2011. Fishery discards and bycatch: solutions for an ecosystem approach to fisheries management? Hydrobiologia 670, 317-333.

References

Bojorquez, L.F., 1998 Bycatch utilization in Mexico. *In* Report and Proceedings of the FAO/DFID Expert Consultation on Bycatch Utilization in Tropical Fisheries. Beijing, 21-28 September 1998. Rome, FAO, 1998.

Cadima, E.L. 2003. Fish stock assessment manual. FAO Fisheries Technical Paper. No. 393. Rome, FAO. 2003. 161p.

Castro, M., Mytilineou, C., Gancho, P., 1998. Methodological considerations concerning the use of length frequency analysis for growth studies in the Norway lobster, *Nephrops norvegicus* (L.). Scientia Marina 62, 61-69.

Catchpole, T., Frid, C., Gray, T., 2006. Resolving the discard problem - A case study of the English *Nephrop*s fishery. Marine Policy 30, 821-831.

Catchpole, T., Revill, A., 2008a. Gear technology in *Nephrops* trawl fisheries. Reviews in Fish Biology and Fisheries 18, 17-31.

Catchpole, T., van Keeken, O., Gray, T., Piet, G., 2008b. The discard problem .– A comparative analysis of two fisheries: The English Nephrops fishery and the Dutch beam trawl fishery. Ocean & Coastal Management 51, 772-778.

Catchpole, T.L., Gray, T.S., 2010. Reducing discards of fish at sea: a review of European pilot projects. Journal of Environmental Management 91, 717-723.

Chapman, C., Howard, F., 1979. Field observations on the emergence rhythm of the Norway lobster *Nephrops norvegicus*, using different methods. Marine Biology 51, 157-165.

Chapman, C., Rice, A., 1971. Some direct observations on the ecology and behaviour of the Norway lobster *Nephrops norvegicus*. Marine Biology 10, 321-329.

Chiu, A, Li, L, Guo, S, Bai, J, Fedor, C, & Naylor, RL 2013, Feed and fishmeal use in the production of carp and tilapia in China, Aquaculture414-415, 127-134.

Colwell, R.K. & Coddington, J.A., 1994. Estimating terrestrial biodiversity through extrapolation. Phil. Trans. Royal Soc. London B 345, 101-118.

Costa, M., Erzini, K., Cerveira Borges, T., 2008. Bycatch of crustacean and fish bottom trawl fisheries from southern Portugal (Algarve). Scientia Marina 72, 801-814.

Cubillos, L, Claramunt, G, & Castro, L 2014, Simulation of fishery-induced changes on the reproductive cycle of common sardine, *Strangomera bentincki*, off central southern Chile, Fisheries Research 160, 103-111.

Davies, R., Cripps, S., Nickson, A., Porter, G., 2009. Defining and estimating global marine fisheries bycatch. Marine Policy 33, 661-672.

References

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

DEFRA, 2015: Consultation on the Implementation of the Demersal Landing Obligation in England. 56p. Accessed 8 Dec 2015 https://www.gov.uk/government/consultations/common-fisheries-policy-implementation-of-the-demersal-landing-obligation-discard-ban-in-england

DGRM, 2015: Recursos da Pesca. Série Estatística volume 27 A-B Ano 2014. 180p.

Doyen, L., Thebaud, O., Béné, C., Martinet, V., Gourguet, S., Bertignac, M., Fifas, S., Blanchard, F., 2012. A stochastic viability approach to ecosystem-based fisheries management. Ecological Economics 75, 32-42.

ICES. 2012. Report of the Study Group on Nephrops Surveys (SGNEPS), 6–8 March 2012, Acona, Italy. ICES CM 2012/SSGESST:19. 36 pp.

EC, 2002. Council Regulation (EC) No 2371/2002 of 20 December 2002 on the conservation and sustainable exploitation of fisheries resources under the Common Fisheries Policy. Official Journal of the European Communities, 31.12.2002 , L 358/59.

Eriksson, S.P., 2006. Differences in the condition of Norway lobsters (*Nephrops norvegicus* (L.)) from trawled and creeled fishing areas. Marine Biology Research 2, 52-58.

FAO, 1995. Code of Conduct for Responsible Fisheries. Rome, FAO. 41 p.

FAO, 2010. Report of the Technical Consultation to Develop International Guidelines on Bycatch Management and Reduction of Discards. Rome, 6–10 December 2010. Rome, FAO Fisheries and Aquaculture Report. 41p.

Farmer, A., 1973. Age and growth in *Nephrops norvegicus* (Decapoda: Nephropidae). Marine Biology 23, 315-325.

Favaro, B, Rutherford, D, Duff, S, & Côté, I 2010, 'Bycatch of rockfish and other species in British Columbia spot prawn traps: Preliminary assessment using research traps. Fisheries Research, 102, 199-206.

Figueiredo, M.J., Margo, O., Franco, M., 1983. The fecundity of *Nephrops norvegicus* (L.) off the Portuguese West coast. Boletim do Instituto Nacional de Investigação das Pescas 9, 5-16.

Fonseca, P., Campos, A., Larsen, R., Borges, T., Erzini, K., 2005. Using a modified Nordmøre grid for by-catch reduction in the Portuguese crustacean-trawl fishery. Fisheries Research 71, 223–239.

Fonseca, P., Campos, A., Millar, R., 2007. Codend selection in the deep-water crustacean trawl fishery in Portuguese southern waters. Fisheries Research 85, 49–60.

Fonseca, P., Correia, P.L., Campos, A., Lau, P.Y., Henriques, V., 2008. Fishery independent estimation of benthic species density - a novel approach applied to Norway lobster *Nephrops norvegicus*. Mar. Ecol. Prog. Ser 369, 267-271.

Frandsen, R., Herrmann, B., Madsen, N., Krag, L.A., 2011. Development of a codend concept to improve size selectivity of Nephrops (*Nephrops norvegicus*) in a multi-species fishery. Fisheries Research 111, 116-126.

Frandsen, R.P., Herrmann, B., Madsen, N., 2010. A simulation-based attempt to quantify the morphological component of size selection of *Nephrops norvegicus* in trawl codends. Fisheries Research 101, 156-167.

Groeneveld, J.C., G. Maharaj, and C.D. Smith. 2006. Octopus magnificus predation and bycatch in the trap fishery for spiny lobsters *Palinurus gilchristi* off South Africa. Fisheries Research 79, 90-96.

Guijarro, B., Tserpes, G., Moranta, J., Massutí, E., 2011. Assessment of the deep water trawl fishery off the Balearic Islands (western Mediterranean): from single to multi-species approach. Hydrobiologia 670, 67-85.

Hall, M.A., Alverson, D.L., Metuzals, K.I., 2000. By-catch: problems and solutions. Marine Pollution Bulletin 41, 204-219.

Hammond, R., Naylor, E., 1977. Effects of dusk and dawn on locomotor activity rhythms in the Norway lobster *Nephrops norvegicus*. Marine Biology 39, 253-260.

Harley, S.J., Myers, R.A., Dunn, A., 2001. Is catch-per-unit-effort proportional to abundance? Canadian Journal of Fisheries and Aquatic Sciences 58, 1760-1772.

Hilborn, R, Walters, CJ. 1992. Quantitative Fisheries Stock Assessment: Choice, Dynamics and Uncertainty. Springer Science & Business Media, 570 p.

ICES. 2004. The Nephrops fisheries of the Northeast Atlantic and Mediterranean – A review and assessment of fishing gear design. ICES Cooperative Research Report, No. 270, 40p.

Johnsen, J.P., Eliasen, S., 2011. Solving complex fisheries management problems: What the EU can learn from the Nordic experiences of reduction of discards. Marine Policy 35, 130-139.

Kaykac, H., Özbilgin, H., Tokac, A., 2009. Effects of mesh configuration on the selectivity of demersal trawl codends for *Nephrops norvegicus* (Linnaeus, 1758) (Decapoda, Nephrophidae). Crustaceana 82, 1569-1578.

Kelleher, K., 2005.Discards in the world’s marine fisheries. An update. FAO Fisheries Technical Paper. No. 470. Rome, FAO. 131p.

References

Koleff, P., Gaston, K. J. and Lennon, J. J. 2003. Measuring beta diversity for presence–absence data. Journal of Animal Ecology, 72, 367–382.

Kronbak, L.G., Nielsen, J.R., Jørgensen, O.A., Vestergaard, N., 2009. Bio-economic evaluation of implementing trawl fishing gear with different selectivity. Journal of Environmental Management 90, 3665-3674.

Lau, P.Y., Correia, P.L., Fonseca, P., Campos, A., 2012. Estimating Norway lobster abundance from deep-water videos: an automatic approach. IET image processing 6, 22-30.

Lande R., 1996. Statistics and partitioning of species diversity and similarity among multiple communities, Oikos, 76: 5-13.

Leocádio, A.M., Whitmarsh, D., Castro, M., 2012. Comparing Trawl and Creel Fishing for Norway Lobster (Nephrops norvegicus): Biological and Economic Considerations. PLoS ONE 7(7): e39567. doi:10.1371/journal.pone.0039567.

Martín J., Puig P., Masqué P., Palanques A., Sánchez-Gómez A., 2014. Impact of Bottom Trawling on Deep-Sea Sediment Properties along the Flanks of a Submarine Canyon. PLoS ONE 9 (8): e104536. doi:10.1371/journal.pone.0104536.

Milligan, R., Albalat, A., Atkinson, R., Neil, D., 2009. The effects of trawling on the physical condition of the Norway lobster *Nephrops norvegicus* in relation to seasonal cycles in the Clyde Sea area. ICES Journal of Marine Science 66, 488-494.

Morello, Elisabetta B., Bruno Antolini, Maria Emilia Gramitto, R. James A. Atkinson, and Carlo Froglia. 2009. The fishery for *Nephrops norvegicus* (Linnaeus, 1758) in the central Adriatic Sea (Italy): Preliminary observations comparing bottom trawl and baited creels. Fisheries Research 95, 325-331.

OECD, 2001. Review of Fisheries in OECD Countries: Policies and Summary Statistics 2001, OECD Publishing, Paris, 350 p.

Johnsen, J., Eliasen, S., 2011. Solving complex fisheries management problems: what the EU can learn from the Nordic experiences of reduction of discards. Marine Policy 35, 130-139.

Pita, C., Pierce, G.J., Theodossiou, I., 2010. Stakeholders' participation in the fisheries management decision-making process: Fishers' perceptions of participation. Marine Policy 34, 1093-1102.

Queirós, A.M., Weetman, A., McLay, H.A., Dobby, H., 2013. Geographical variation in size at the onset of maturity of male and female Norway lobster *Nephrops norvegicus* (L., Homarida: Decapoda) in Scottish waters. Fisheries Research 139, 132-144.

Raby, Graham D, Jessica R Packer, Andy J Danylchuk, and Steven J Cooke. 2014. The understudied and underappreciated role of predation in the mortality of fish released from fishing gears. Fish & Fisheries 15, 489-505.

Relini, L., Zamboni, A., Fiorentino, F., Massi, D., 1998. Reproductive patterns in Norway lobster *Nephrops norvegicus* (L.), (Crustacea Decapoda Nephropidae) of different Mediterranean areas. Scientia Marina 62, 25-41.

Rice, A., Chapman, C., 1971. Observations on the burrows and burrowing behaviour of two mud-dwelling decapod crustaceans, *Nephrops norvegicus* and *Goneplax rhomboides*. Marine Biology 10, 330-342.

Ridgway, I., Taylor, A., Atkinson, R., Chang, E., Neil, D., 2006. Impact of capture method and trawl duration on the health status of the Norway lobster, *Nephrops norvegicus*. Journal of Experimental Marine Biology and Ecology 339, 135-147.

Sardà, F., 1995. A review (1967-1990) of some aspects of the life history of *Nephrops norvegicus*, ICES Marine Science Symposia 199, 78-88.

Sardà, F., 1998. *Nephrops norvegicus* (L.): Comparative biology and fishery in the Mediterranean Sea. Introduction, conclusions and recommendations. Scientia Marina 62, 5-15.

Simberloff, D., 1998. Flagships, umbrellas, and keystones: is single-species management passé in the landscape era? Biological Conservation 83, 247-257.

Stamatis, C., Triantafyllidis, A., Moutou, K., Mamuris, Z., 2004. Mitochondrial DNA variation in Northeast Atlantic and Mediterranean populations of Norway lobster, *Nephrops norvegicus*. Molecular Ecology 13, 1377-1390.

Tuck, I., Atkinson, R., Chapman, C., 2000. Population biology of the Norway lobster, *Nephrops norvegicus* (L.) in the Firth of Clyde, Scotland II: fecundity and size at onset of sexual maturity. ICES Journal of Marine Science 57, 1227-1239.

Tuck, I., Chapman, C., Atkinson, R., 1997. Population biology of the Norway lobster, *Nephrops norvegicus* (L.) in the Firth of Clyde, Scotland – I: Growth and density. ICES Journal of Marine Science 54, 125-135.

Ungfors, A., Bell, E., Johnson, M.L., Cowing, D., Dobson, N.C., Bublitz, R., Sandell, J., 2013. Nephrops Fisheries in European Waters. Advances in Marine Biology 64, 247-314.

United Nations, 1982. United Nations Convention on the Law of the Sea. Accessed 9 December 2015, http://www.un.org/depts/los/convention_agreements/texts/unclos/unclos_e.pdf.

Watanuki, N, Hirayama I., Kawamura G., 2000. Why do cuttlefish *Sepia esculenta* enter basket traps? Space occupation habit hypothesis. Fisheries Science 66, 190-197.

Whittaker, R. H. 1960. Vegetation of the Siskiyou Mountains, Oregon and California. Ecological. Monographs. 30: 279-338.

Wilcox, C., Donlan, C.J., 2009. Need for a clear and fair evaluation of biodiversity offsets for fisheries bycatch. Conservation Biology: 23, 770.

Wilson, M. V., and A. Shmida. 1984. Measuring Beta Diversity with Presence-absence Data. Journal of Ecology 72, 1055–1064.

Ziegler, F., Valentinsson, D., 2008. Environmental life cycle assessment of Norway lobster (Nephrops norvegicus) caught along the Swedish west coast by creels and conventional trawls—LCA methodology with case study. The International Journal of Life Cycle Assessment 13, 487-497.