Population dynamics and assessment of exploited deep water decapods off Balearic Islands (western Mediterranean): from single to multi-species approach

Beatriz Guijarro
Ph.D. Thesis

POPULATION DYNAMICS AND ASSESSMENT OF EXPLOITED DEEP WATER DECAPODS OFF BALEARIC ISLANDS (WESTERN MEDITERRANEAN): FROM SINGLE TO MULTI-SPECIES APPROACH

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POPULATION DYNAMICS AND ASSESSMENT OF EXPLOITED DEEP WATER DECAPODS OFF BALEARIC ISLANDS (WESTERN MEDITERRANEAN): FROM SINGLE TO MULTI-SPECIES APPROACH

Memòria presentada per Beatriz Guijarro González per optar al títol de doctora del Programa de Doctorat d'Ecologia Marina de la Universitat de les Illes Balears, sota la direcció del Dr. Enric Massutí Sureda i del Dr. Joan Moranta Mesquida, i la ponència del Dr. Rafael Bosch Zaragoza.

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“Entre l’arena i el mar
no hi ha aroma més fina
que el perfum de saladina
que a ta pell dus amarat”
(‘Entre l’arena i el mar’, Xaloc Música)

“A la mar se cria el peix
i a la figuera les figues
en els teus llavis besades
i a les meves mans carícies”
(Fandango ‘La Malaguenya’, Música Nostra)

“Amb sa xarxa hi pots agafar
peixos en molta quantitat:
alerta que si ve al cas
no ens quedem sense cap.
[...]
Dins ella hi pots trobar
crancs, eriçons i copinyes,
peixos d'espècies molt fines,
sirenes i cavalls de mar”
(‘La Mar’, Pla Forana)

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Aim of the thesis

Deep water decapod crustaceans form a considerable fraction of the megafaunal biomass in the upper and middle slope in the western Mediterranean. They are also a very important component of the catches of the commercial fishery, like it is the case in the bottom trawl fishery which operates off the Balearic Islands. In the Balearic Islands, the most important species in terms of biomass is *Aristeus antennatus*, followed by a mixed category of shrimps (including Pandalidae and Pasiphaeidae), *Parapenaeus longirostris, Geryon longipes* and *Nephrops norvegicus*. Economically, *A. antennatus* is also the most important species, followed by *N. norvegicus*, the mixed category and *P. longirostris*.

The knowledge on deep water decapod crustaceans is mostly centred on single species and generally dependent on their economic importance in the commercial fisheries. Thus, studies aimed at *A. antennatus* are abundant in many areas, including the Balearic Islands, while those related to other species such as *P. longirostris* and Pandalidae are scarcer and, in the case of the Balearic Islands, practically absent. The main objective of this thesis is to improve the knowledge of deep water decapod crustaceans off the Balearic Islands, by studying not only the main target commercial species, but also their communities, through a more ecosystemic approach.

Although some studies have already focussed on the population dynamics and biology of the main commercial species, they are analysed here from a more detailed approach, taking into account the different environmental regimes found at two nearby locations from the Balearic Islands. Thus, population dynamics, biology and condition of *P. longirostris*, Pandalidae and *A. antennatus* are analysed separately for both locations. For some species, the possible relation with environmental factors has been discussed in different studies, but joint analysis using both biological and environmental data are scarce. This approach, which is applied here to *P. longirostris*, five Pandalidae and *A. antennatus*, can be considered as an advance of previous studies in the area.

The above mentioned ecosystemic approach involves studying not only the commercial species, but the entire epi-benthic community and has been applied here to characterise the species assemblages in the slope trawl fishing grounds. The assessment of the impact of fishing in each of these assemblages has been performed using several ecological indicators, which provide wide and complementary information, and which are summarized here using the Traffic Light method. This approach, firstly proposed for being used in data poor situations but useful to all kinds of stocks, appears to be more precautionary than traditional stock assessment methods. Both ecological indicators and the Traffic Light method are also used to assess the state of the main target species of the identified assemblages, *N. norvegicus* and *A. antennatus*, which have been previously assessed using more traditional stock assessment models, such as virtual population analysis.

Finally, the potential effects of new management measures to improve the selectivity and to reduce the fishing impact are analysed. This analysis is performed by comparing catch composition, commercial yields, retention efficiency, discards and size selectivity parameters using two different mesh shapes, the 40 mm diamond mesh codend in force until 2010 and the 40 mm square mesh codend, in force since then.

Structure of the thesis

This thesis is a collection of scientific papers, preceded by an Introduction (**Chapter 1**), in which the characteristics of the study area, the description of the bottom trawl fishery operating in the deep water fishing grounds off the Balearic Islands, as well as a short explanation of geographic distribution and population structure of the main decapod crustaceans landed are presented.

Chapter 2 describes all the data sources used to develop the subsequent chapters.

The population dynamics of the main deep water decapods crustaceans off the Balearic Islands, taking into account the influence of the environmental conditions, are analysed in Chapters 3, 4 and 5. The species were selected according to their biomass landed by the bottom trawl fleet and presented in this thesis according to their bathymetric distribution, from shallow to deep waters: *Parapenaeus longirostris* (**Chapter 3**), Pandalidae (**Chapter 4**) and *Aristeus antennatus* (**Chapter 5**). Each of these chapters can be read separately, because they have their own Summary and Keywords, an Introduction, as well as Material and Methods, Results and Discussion.

The species assemblages in the deep water trawl fishing grounds as well as the assessment of the impact of fishing on these assemblages are analysed in **Chapter 6**, by means of ecological indicators, both at species and at community level.

The potential effect of recently introduced new management measures to improve the selectivity and to reduce the impact of the fishery on the ecosystem in the deep water trawl fishing grounds is analysed in **Chapter 7**.

Finally, **Chapter 8** summarizes the main Conclusions.

Summary

In the western Mediterranean, deep water decapod crustaceans form a considerable fraction of the megafaunal biomass in the upper (US, 200-500 m) and middle slope (MS, 500-800 m), being also a very important component of the catches of the commercial fishery. In the Balearic Islands, they represent around 17% in weight and 50% in revenues of the bottom trawl fishery, which operates between 50 and 800 m depth. The most important species in terms of biomass is *Aristeus antennatus*, followed by a mixed category of shrimps (including Pandalidae and Pasiphaeidae), *Parapenaeus longirostris, Geryon longipes* and *Nephrops norvegicus*. Economically, *A. antennatus* is also the most important species, followed by *N. norvegicus*, the mixed category and *P. longirostris*.

The main objective of this thesis is to analyse the community and population dynamics of the deep water decapod crustaceans off the Balearic Islands. The partial objectives are: (i) to study the short spatial and temporal patterns of the main populations of two nearby locations with different environmental regimes; (ii) to explore relationships between the main species abundances and the environmental conditions; (iii) to characterise the species assemblages in the slope trawl fishing grounds; (iv) to estimate ecological indicators, both at species and at community level, to assess the impact of fishing in these communities, and (v) to analyse the effect of new management measures to improve the selectivity and to reduce the fishing impact.

Data have been obtained from different sampling strategies: (i) seasonal and annual scientific surveys (fishery-independent data), and (ii) directly from the fishing sector (fishery-dependent data). A third type of data was obtained from scientific selectivity pilot studies. During the scientific surveys and the pilot studies, abundance, biomass and length frequency distributions of all the species were collected. Biological information of *A. antennatus*, *P. longirostris* and Pandalidae were recorded during the scientific surveys, and during the seasonal surveys different environmental parameters were obtained. Fishery-dependent data came from daily sale bills and seasonal on board sampling monitoring of the bottom trawl fishery. In the pilot studies, information obtained was for landings and discards of two types of codends with different mesh shape (diamond and square) as well as revenues from landings.

Univariate and multivariate techniques have been used to analyse the data, including analysis of variance; cluster, redundancy and similarity percentage analysis; non-parametric correlations; multiple regressions and general additive models. Indicators of the state of the main species and the ecosystem were computed for fishery-independent data (annual surveys) and fishery-dependent data (daily sale bills) and summarised by means of the Traffic Lights methodology. Size selectivity for the two codends tested was modelled using the generalized logistic curve and length at first catch was also calculated.

The results show spatial and temporal differences for the species studied between the two locations analysed, in the Algerian (AsB) and Balearic (BsB) sub-basins. These differences are related to higher abundance of *P. longirostris* and *A. antennatus* in the BsB than in the AsB, while the opposite has been found for Pandalidae (except for one species). A better condition has been found for all the species in the BsB than in the AsB. The different environmental conditions between both locations (geomorphological structure, bottom characteristics, hydrographic factors and availability of potential trophic resources) can be on the basis on the differences found, with varied influence among species. In most cases, both reproductive period and condition show a marked seasonality, with spawning concentrated in summer, where the minimum values in the condition has been detected.

The results obtained from the analysis of indicators show different trends for the US and MS assemblages. The state of the US and of its main target species, *N. norvegicus*, seem to have improved for the last years, probably related to a fishing effort decrease. However, other factors than fishing effort may affect this species as its worst state is found in the less exploited area. For the MS and its target species, *A. antennatus*, no clear trends were found for both sources of data (fishery-independent and fishery-dependent). This can be explained by the different species included in each analysis as well as the different temporal sampling periods covered, as in some cases, such as *A. antennatus*, the high seasonal variability of its population dynamics is not reflected in the annual surveys (once a year).

When the two codends tested are compared, there is no difference in the catch composition or the yield between the two mesh shapes, although the percentage of total and commercial species discarded with a diamond mesh was higher than with a square mesh. At least in the short term, the escapement ratio and the economic loss with the diamond mesh were lower than with square mesh, but economic efficiency was no different between them. For all the main species compared, except one flatfish, size selectivity parameters were lower for the diamond than for the square mesh codend. Within the context of precautionary management, the introduction of the square mesh in the codend could be an appropriate and plausible measure to improve the state of the resources exploited by the deep water crustacean trawl fishery of the slope off the Balearic Islands and to reduce the impact of the fishery on the ecosystem.

The knowledge derived from the present thesis provide relevant information about how the species traits are mainly affected by water masses, sediment characteristic, trophic resources and fishing, since they influence the bathymetric distribution, abundances, biological parameters and condition of decapod crustaceans at a local scale. To understand how environmental characteristics and fishing impact interact to change the species distribution and the dynamics of the populations and communities is a key point for a better assessment of the resources and for a better application of the Ecosystem-Based Approach Management in the Mediterranean deep water ecosystems.

Resum

Al Mediterrani occidental, els crustacis decàpodes de profunditat formen una considerable fracció en la biomassa de la megafauna del talús superior (US, 200-500 m) i el talús mitjà (MS, 500-800 m), essent a més una part important de les captures de la pesca comercial. A les Illes Balears, representen aproximadament un 17% en pes i un 50% dels guanys de la pesqueria d'arrossegament de profunditat, que opera entre 50 i 800 m de fondària. L'espècie més important en biomassa és *Aristeus antennatus*, seguida d'una categoria de gambes mesclades (que inclou Pandalidae i Pasiphaeidae), *Parapenaeus longirostris*, *Geryon longipes* y *Nephrops norvegicus*. Des d'un punt de vista econòmic, *A. antennatus* és també l'espècie més important, seguida de *N. norvegicus*, la categoria de mescla i *P. longirostris*.

L'objectiu principal d'aquesta tesi és analitzar la comunitat i la dinàmica poblacional dels crustacis decàpodes de profunditat de les Illes Balears. Els objectius parcials són: (i) estudiar els patrons espacials i temporals a petita escala de les principals poblacions de dues zones properes, amb diferents règims ambientals; (ii) explorar les relacions entre l'abundància de les principals espècies i les condicions ambientals; (iii) caracteritzar les associacions d'espècies en els caladors d'arrossegament del talús; (iv) estimar indicadors ecològics, tant a nivell d'espècies com a nivell de comunitat, per avaluar l'impacte de la pesca en aquestes comunitats i (v) analitzar l'efecte de noves mesures de gestió per millorar la selectivitat i reduir l'impacte de la pesca.

Les dades s'han obtingut a partir de diferents estratègies de mostreig: (i) campanyes científiques estacionals i anuals (dades independents de la pesqueria) i (ii) directament del sector pesquer (dades dependents de la pesqueria). Un tercer tipus de dades s'han obtingut mitjançant estudis pilot de selectivitat. Durant les campanyes científiques i els estudis pilot, es va recollir informació de l'abundància, biomassa i distribució de la freqüència de talles de totes les espècies. Durant les campanyes científiques, es recollí informació biològica d'*A. antennatus*, *P. longirostris* i Pandalidae i durant les campanyes estacionals s'obtingueren diferents paràmetres ambientals. Les dades independents de la pesqueria foren fulles de venda diàries i mostratges estacionals a bordo de la flota d'arrossegament. En els estudis pilot, es recollí informació pels desembarcaments i els rebutjos, amb els dos tipus de cops de

diferent geometria de malla (ròmbica i quadrada), així com els guanys dels desembarcaments.

S'han utilitzat diferents tècniques univariants i multivariants, incloent l'anàlisi de variància; anàlisi cluster, de redundància i el percentatge de similitud; correlacions no paramètriques; regressions múltiples i models additius generalitzats. Se calcularen els indicadors d'estat de les principals espècies i de l'ecosistema per les dades independents de la pesqueria (campanyes anuals) i les dades dependents de la pesqueria (fulles de venda diàries) i es resumiren utilitzant la metodologia dels semàfors. La selectivitat dels dos cops utilitzats es modelà utilitzant la corba logística generalitzada i es calculà la talla de primera captura.

Els resultats mostren diferències espacials i temporals per les espècies estudiades entre les dues zones analitzades, a la sub-conca algerina (AsB) i la balear (BsB). Aquestes diferències són una major abundància de *P. longirostris* i *A. antennatus* a la BsB que a la AsB, mentre que per Pandalidae (excepte per una espècie) s'ha trobat el contrari. Totes les espècies presenten millor condició en la BsB que en la AsB. Les diferents condicions ambientals en ambdues zones (estructura geomorfològica, característiques del fons, factors hidrogràfics i disponibilitat de potencials recursos tròfics) poden ser la base de les diferències trobades, amb distinta influència segons les espècies. A la majoria dels casos, tant el període reproductiu com la condició mostren una marcada variabilitat, amb la fresa concentrada en estiu, quan la condició presenta els valors més baixos.

L'anàlisi d'indicadors mostra diferents tendències per a les associacions del US i MS. L'estat del US i de la seva principal espècie objectiu, *N. norvegicus*, pareix haver millorat durant els darrers anys, probablement degut amb una disminució de l'esforç pesquer. No obstant, a més de l'esforç pesquer altres factors podrien influir en aquesta espècie, ja que el pitjor estat es troba a la zona menys explotada. Pel MS i la seva espècie objectiu, *A. antennatus*, no s'ha detectat una tendència clara en les dues fonts de dades (dades independents i dependents de la pesqueria). Això se pot explicar per les diferents espècies incloses en cada anàlisi, així com la diferent cobertura temporal dels mostratges, ja que en alguns casos, com per *A. antennatus*, la gran variabilitat estacional de la seva dinàmica poblacional no es reflecteix en les campanyes anuals (que es duen a terme una vegada a l'any).

Quan se comparen els dos cops testats, no s'han trobat diferències en la composició de la captura o en els rendiments entre les dues geometries de malles, malgrat el percentatge total d'espècies rebutjades i d'espècies comercials rebutjades amb malla ròmbica fou major que amb malla quadrada. La proporció d'escapament i la pèrdua econòmica amb la malla ròmbica fou millor que amb malla quadrada, almenys a curt termini, però l'eficiència econòmica no fou diferent entre malles. Per totes les espècies comparades, excepte un peix pla, els paràmetres de selectivitat foren menors amb el cop de malla ròmbica que amb el de malla quadrada. En el context de gestió basada en el principi de precaució, la introducció de la malla quadrada en el cop pot ser una mesura apropiada i plausible per millorar l'estat dels recursos explotats per la pesqueria de crustacis de profunditat del talús de les Illes Balears i per reduir l'impacte de la pesca a l'ecosistema.

Els coneixements derivats d'aquesta tesi proporcionen informació relevant sobre com les característiques de les espècies estan principalment afectades per les masses d'aigua, les característiques dels sediments, els recursos tròfics i la pesca, ja que influeixen en la distribució batimètrica, abundància, paràmetres biològics i condició dels crustacis decàpodes a escala local. Entendre com les característiques ambientals i l'impacte de la pesca interactuen per modificar la distribució de les espècies i la dinàmica poblacional de les poblacions i comunitats és un punt clau per una millor avaluació dels recursos i per una millor aplicació de l'aproximació ecosistèmica a la gestió dels ecosistemes marins de profunditat del Mediterrani.

Resumen

En el Mediterráneo occidental, los crustáceos decápodos de profundidad forman una considerable fracción en la biomasa de la megafauna en el talud superior (US, 200-500 m) y el talud medio (MS, 500-800 m), siendo además una parte importante de las capturas de la pesca comercial. En las Islas Baleares, representan aproximadamente un 17% en peso y un 50% de las ganancias de la pesquería de arrastre de profundidad, que opera entre 50 y 800 m de profundidad. La especie más importante en términos de biomasa es *Aristeus antennatus*, seguida de una categoría de gambas mezcladas (que incluye Pandalidae y Pasiphaeida), *Parapenaeus longirostris*, *Geryon longipes* y *Nephrops norvegicus*. Económicamente, *A. antennatus* es también la especie más importante, seguida de *N. norvegicus*, la categoría de mezcla y *P. longirostris*.

El objetivo principal de esta tesis es analizar la comunidad y la dinámica poblacional de los crustáceos decápodos de profundidad de las Islas Baleares. Los objetivos parciales son: (i) estudiar los patrones espaciales y temporales a pequeña escala de las principales poblaciones de dos zonas cercanas, con diferentes regímenes ambientales; (ii) explorar las relaciones entre la abundancia de las principales especies y las condiciones ambientales; (iii) caracterizar las asociaciones de especies en los caladeros de arrastre del talud; (iv) estimar indicadores ecológicos, tanto a nivel de especies como a nivel de comunidad, para evaluar el impacto de la pesca en estas comunidades y (v) analizar el efecto de nuevas medidas de gestión para mejorar la selectividad y reducir el impacto de la pesca.

Los datos se han obtenido a partir de diferentes estrategias de muestreo: (i) campañas científicas estacionales y anuales (datos independientes de la pesquería) y (ii) directamente del sector pesquero (datos dependientes de la pesquería). Un tercer tipo de datos se han obtenido a partir de estudios pilotos de selectividad. Durante las campañas científicas y los estudios piloto, se recogió información de la abundancia, biomasa y distribución de la frecuencia de tallas de todas las especies. Durante las campañas científicas, se recogió información biológica de *A. antennatus*, *P. longirostris* y Pandalidae y, durante las campañas estacionales se obtuvieron diferentes parámetros ambientales. Los datos dependientes de la pesquería fueron hojas de venta diarias y muestreos estacionales a bordo de la flota de arrastre. En los estudios piloto, se recogió

información para los desembarcos y los descartes, con dos tipos de copos de diferente geometría de malla (rómbica y cuadrada), así como ganancias de los desembarcos.

Se han utilizados distintas técnicas univariantes y multivariantes, incluyendo el análisis de variancia; análisis cluster, de redundancia y del porcentaje de similitud; correlaciones no paramétricas; regresiones múltiples y modelos aditivos generalizados. Se calcularon los indicadores del estado de las principales especies y del ecosistema para los datos independientes de la pesquería (campañas anuales) y los datos dependientes de la pesquería (hojas de venta diarias) y se resumieron utilizando la metodología de los semáforos. La selectividad de los dos copos utilizados se modeló utilizando la curva logística generaliza y se calculó la talla de primera captura.

Los resultados muestran diferencias espaciales y temporales para las especies estudiadas entre las dos zonas analizadas, en la sub-cuenca argelina (AsB) y la balear (BsB). Estas diferencias son una mayor abundancia de *P. longirostris* y *A. antennatus* en la BsB que en la AsB, mientras que para Pandalidae (excepto para una especie) se ha encontrado lo contrario. Todas las especies presentaron mejor condición en la BsB que en la AsB. Las diferentes condiciones ambientales en ambas zonas (estructura geomorfológica, características del fondo, factores hidrográficos y disponibilidad de potenciales recursos tróficos) pueden estar en la base de las diferencias encontradas, con distinta influencia según las especies. En la mayoría de los casos, tanto el período reproductivo como la condición muestran una marcada estacionalidad, con el desove concentrado en verano, cuando la condición presenta los valores más bajos.

El análisis de indicadores muestra diferentes tendencias para las asociaciones del US y MS. El estado del US y de su principal especie objetivo, *N. norvegicus*, parece haber mejorado durante los últimos años, probablemente relacionado con una disminución del esfuerzo pesquero. Sin embargo, además del esfuerzo pesquero otros factores podrían influir a esta especie ya que el peor estado se encuentra en la zona menos explotada. Para el MS y su especie objetivo, *A. antennatus* no se ha detectado una tendencia clara en las dos fuentes de datos (datos independientes y dependientes de la pesquería). Esto podría explicarse por las diferentes especies incluidas en cada análisis, así como la diferente cobertura temporal de los muestreos, ya que en algunos casos, como para *A. antennatus*, la gran variabilidad estacional de su dinámica poblacional no se refleja en las campañas anuales (que se realizan una vez al año).

Cuando se comparan los dos copos probados, no se han encontrado diferencias en la composición de la captura o en los rendimientos entre las dos geometrías de mallas, aunque el porcentaje total de especies descartadas y de especies comerciales descartadas con malla rómbica fue mayor que con malla cuadrada. La proporción de escape y la pérdida económica con la malla rómbica fue mejor que con malla cuadrada, al menos a corto plazo, pero la eficiencia económica no fue diferente entre mallas. Para todas las especies comparadas, excepto un pez plano, los parámetros de selectividad fueron menores con el copo de malla rómbica que con el de malla cuadrada. En el contexto de gestión basada en el principio de precaución, la introducción de la malla cuadrada en el copo puede ser una medida apropiada y plausible para mejorar el estado de los recursos explotados por la pesquería de crustáceos de profundidad del talud de las Islas Baleares y para reducir el impacto de la pesca en el ecosistema.

Los conocimientos derivados de esta tesis proporcionan información relevante sobre cómo las características de las especies están principalmente afectadas por las masas de agua, las características de los sedimentos, los recursos tróficos y la pesca, ya que influyen en la distribución batimétrica, abundancia, parámetros biológicos y condición de los crustáceos decápodos a escala local. Entender cómo las características ambientales y el impacto de la pesca interactúan para modificar la distribución de las especies y la dinámica poblacional de las poblaciones y comunidades es un punto clave para una mejor evaluación de los recursos y para una mejor aplicación de la aproximación ecosistémica en la gestión de los ecosistemas marinos de profundidad del Mediterráneo.

CHAPTER 1.

INTRODUCTION

1.1. Introduction

Mediterranean fisheries are highly diverse, as they are composed by atomised fleets, a huge number of landing points spread over more than 40000 km of coasts and multispecies catches, with the absence of large monospecific stocks in comparison to those which inhabit some wide areas of the open oceans (Farrugio *et al.*, 1993; Lleonart and Maynou, 2003). Although they only represent a small proportion of the world production (<2%; Figure 1.1), the mean prices of landings (which are mainly sold fresh) are well above the average prices of world markets. Among them, demersal resources constitute a complex fishery as it is composed of a great number of species (over 100) of fish, crustaceans and molluscs, exploited by many different gears, but being the trawl the main one, both in terms of catch and fleet power (Caddy, 1993; Lleonart and Maynou, 2003).

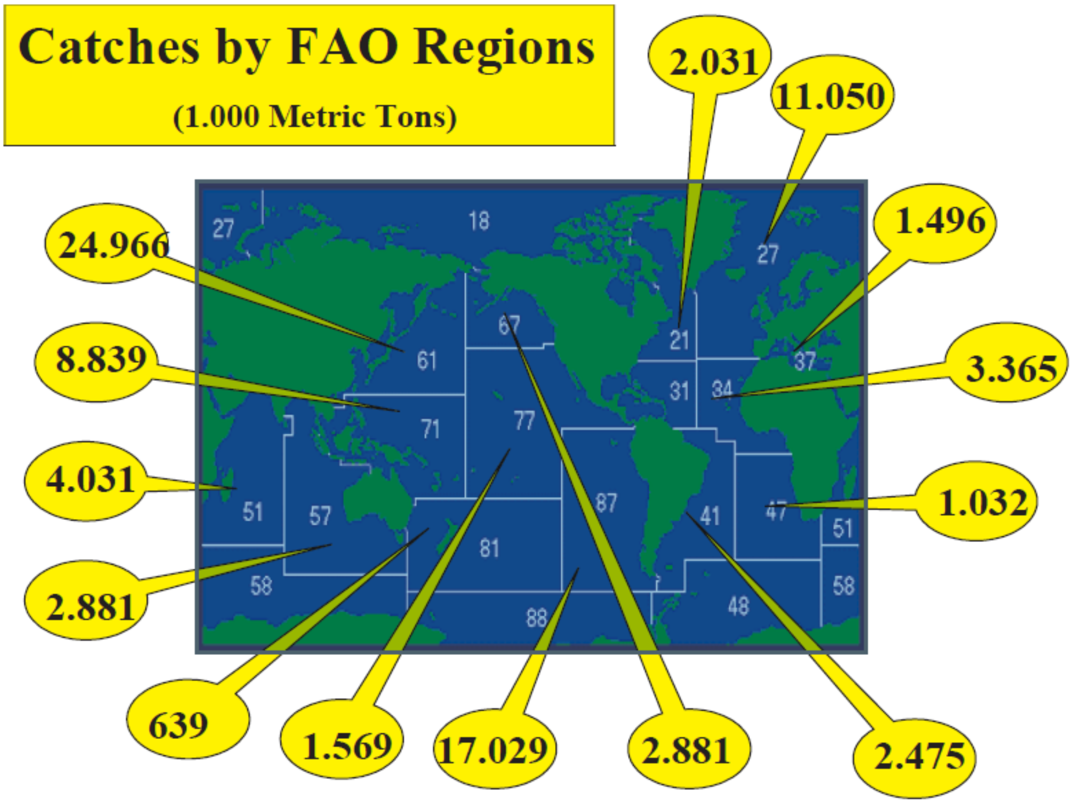


Figure 1.1. The world marine fisheries production by FAO fishery regions in 2005 (Source: FAO 2007. Fishtat Plus 2.32. Fisheries and Aquaculture Information and Statistics Service; Food and Agriculture Department).

The management of the Mediterranean fisheries is based on effort control. No total allowable catches (TACs) are implemented (except for some species, such as bluefin tuna and swordfish), nor are other types of adaptive management. Other technical measure, such as minimum landing sizes and minimum mesh sizes, are also implemented but not always enforced. Most of the rules concerning the management of demersal fisheries have been developed for trawling, not only because it is the main gear contributing to demersal catches, but also because it presents low selectivity in comparison with the most important artisanal gears (nets, longlines and traps). According to Spanish regulations (*Real Decreto* Nº1440/1999 of 10 September 1999 and *Orden* APA/79/2006 of 19 January 2006) trawling is carried out in fishing grounds deeper than 50 m and shallower than 1000 m, and the activity is limited to a maximum of 5 days per week and 12 hours per day. Trawling is forbidden on *Posidonia oceanica* (and other marine phanerogams) beds, coralline and maërl bottoms, which are considered protected habitats. The fishing vessels must have a length between 12 and 24 m and a maximum power not greater than 500 horse power. The gear used is a typical otter trawl. The minimum stretched mesh size in the codend allowed for all Spanish Mediterranean waters was 40 mm until 1st July 2010, when the bottom trawl net was replaced by a square meshed net of 40 mm at the codend or, at the duly justified request of the ship owner, by a diamond meshed net of 50 mm. After 1st February 2012, the diamond meshed net of 50 mm can only be used if its acknowledged size selectivity is equivalent to or higher than that of square meshed nets of 40 mm at the codend (Council Regulation, EC Nº1967/2006 of 21 December 2006 and Regulation EU No 1343/2011 of the European Parliament and of the Council of 13 December 2011).

Fishing exploitation in general and trawling in particular has a number of effects, not only because it directly reduces the abundance of commercial stocks, but also because it indirectly affects the by-catch species, by increasing their mortality, and the ecosystem, by disturbing marine habitats. The direct effects of towed gears such as bottom trawling include the scraping, scouring and resuspension of substratum, causing physical impacts on benthic organism an on the seabed (Jennings and Kaiser, 1998; Goñi, 1998). Fishing exploitation directly reduces the abundance, biomass and size of both target and by-catch species but it also has many indirect implications at community level (e.g. Dayton *et al.*, 1995; Haedrich and Barnes, 1997; Goñi, 1998; Philippart, 1998; Kaiser *et al.*, 1999; Gislason *et al.*, 2000; Kaiser and De Groot, 2000), as it removes potential preys of other species or predators that would otherwise control prey populations, it changes the density of some species which may affect competitive interactions and it provides to scavenging species with food. Some of these effects come from the already mentioned low selectivity of trawling gears, which is particularly relevant in fisheries mainly sustained by the youngest age groups, as it is the case of Mediterranean trawl fisheries (Caddy, 1993; Lleonart, 1999). This, together with the large percentage of catches that comes from species of low or null commercial values (Carbonell *et al.*, 1998; Moranta *et al.*, 2000; Sánchez *et al.*, 2004) and/or undersized individuals of target species (Oliver, 1991), provokes a useless high mortality as a significant part of the catch is discarded.

Although the effects of fishing on marine communities and ecosystems have been well known for long (Jennings and Kaiser, 1998), the scientific basis for the management of fisheries was founded in the study of exploited fish populations, using the target species of the commercial fleet as a primary unit and hence being the monospecific approaches the rule in assessment. In recent decades, there has been a progressive change from the traditional approach of fishery assessment and management, which considers populations as independent and auto-sustainable, to an ecosystemic approach, which considers the ecosystem as an assessment and management unit and takes into account the complexity of the ecosystems, their natural variations and the factors that control these changes, as well as the habitat and other components of the ecosystem and their interactions (Browman and Stergiou, 2004). Such an integrated multispecies approach to management measure is particularly essential in the multispecies Mediterranean fishery context, where the large number of species caught makes calculations for a single species of limited value for management (Caddy, 1990, 1993).

1.2. The study area

The Balearic Islands (western Mediterranean, Figure 1.2) are sited in the Balearic Promontory, a structural elevation 348 km in length, 105 km wide and from 1000 to 2000 m high with respect to the surrounding basins. It is 95 nautical miles away from the Iberian Peninsula, separated by depths of between 800 and 2000 m. The Balearic Promontory delimits the Balearic sub-basin (BsB, in the north) from the Algerian sub-basin (AsB, in the south). The shelf in the Balearic archipelago is narrow and steep on the northern side and wider with a gentler slope in the south. In the southeast of Mallorca there are numerous small canyons. The biggest canyon in the Balearic Islands is situated in the south of Menorca (Figure 1.2; Acosta *et al.*, 2004). There is not much terrigenous-muddy sediment due to the absence of river discharges. Sandy-muddy and detrital sediments occur at the shelf-slope break, whereas muddy bottoms of biogenic origin dominate the deeper areas (Acosta *et al.*, 2002).

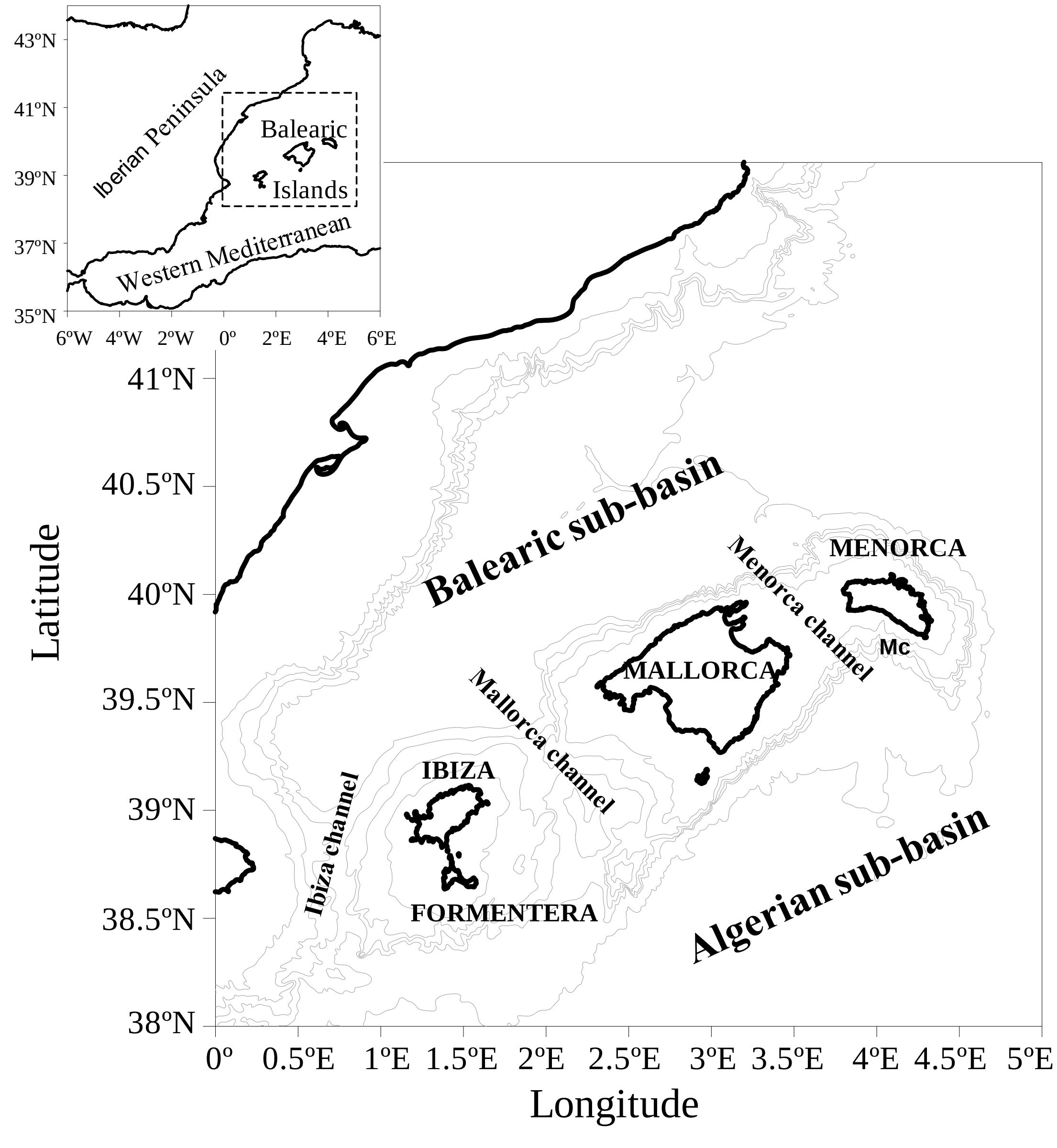


Figure 1.2. Map of the study area, showing the 200, 600, 800, 1000 and 2000 m isobaths. Mc: Menorca canyon.

The hydrographic conditions of the Balearic Islands have been extensively studied and the Balearic channels have been shown to control the regional circulation around the Balearic Islands (Pinot *et al.*, 2002). The regional circulation in the area is dominated by the Northern Current (NC) which carries down Atlantic waters (AW) from the Gulf of Lions along the continental slope of the Iberian Peninsula into the BsB (Font *et al.,* 1988). This current bifurcates when reaching the Ibiza Channel; one significant part crosses the channel transporting waters from the Mediterranean into the AsB, while other part cyclonically returns to the northeast forming the Balearic Current (BC) along the northern coasts of the Balearic Islands. This latter current is also increased by flows of AW passing northwards through both channels (Figure 1.3.a).

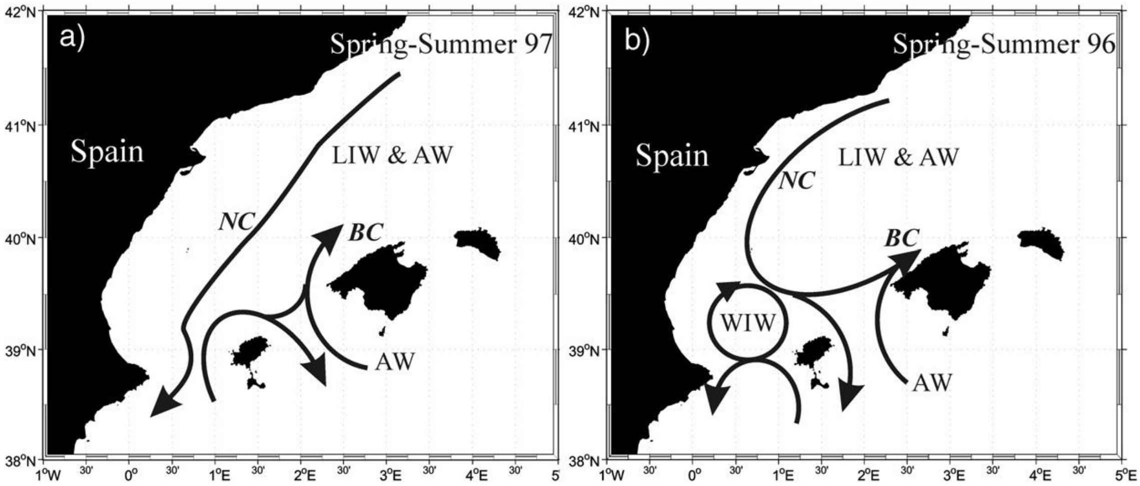


Figure 1.3. Averaged regional ocean circulation in the western Mediterranean corresponding to late spring–summer after a relatively mild winter, May 1997 (a) and after a relatively cold winter, May 1996 (b). Major currents in the region, the Northern Current (NC) and the Balearic Current (BC) are indicated. From Monserrat *et al.* (2008). AW: Atlantic Water; WIW: Western Mediterranean Intermediate Water; LIW: Levantine Intermediate Water.

This smooth general pattern is the one expected for late spring–summer after a previous relatively mild winter in the western Mediterranean, but fluctuates considerably in mesoscale, seasonal and interannual time scales, changing dramatically after a cold winter (García Lafuente *et al.*, 1995; Pinot *et al.*, 2002). The NC may be blocked when reaching the Ibiza Channel and then recirculates cyclonically joining the BC without significant transport of waters through the Ibiza Channel (Figure 1.3.b). This blocking has been related to the recurrent existence of anticyclonic channel size eddies trapped at the coastal edge of the NC in the Gulf of Valencia (Castellón *et al.*, 1990; Pinot *et al.*, 1995; Pinot and Ganachaud, 1999) and more precisely to the presence of significant amount of subsurface waters of Mediterranean origin, characterized by low temperatures (less than 13 °C) forming the anticyclonic gyres (Pinot *et al.*, 2002). This cold and relatively fresh waters, known as Western Mediterranean Intermediate Waters (WIW; Table 1.1) are generated during winter in the Gulf of Lions by deep convection when sea–air heat flux losses are high enough (Mertens and Schott, 1998; Pinot *et al.*, 2002). The Gulf of Lions, where deep convection usually takes place, is subject in winter to cold and dry winds from north and northwest, usually occurring in strong bursts and contributing to increase both sensible and latent heat flux losses from the ocean to the atmosphere. When this forcing is strong enough, during winter, weakly stratified underwaters, including salty Levantine Intermediate Waters (LIW, Table 1.1), may become exposed to the surface buoyancy flux and deep convection can occur to intermediate or full ocean depths (Millot, 1987; Schott *et al.*, 1996; Mertens and Schott, 1998). Then, these dense waters spread into the western basin, mainly as a boundary current along the continental slope (Send *et al.*, 1996).

Table 1.1. Characteristic values of potential temperature (θ; ºC) and salinity (S; psu) of the different water types and local values at the Balearic Islands (López-Jurado *et al.*, 2008). AW: Atlantic Water; WIW: Western Mediterranean Intermediate Water; LIW: Levantine Intermediate Water; WMDW: Western Mediterranean Deep Water.

Water mass	Values at origin	Local values
AW	$15.0 < \theta < 18.0$	$15.0 < \theta < 28.0$
	$36.15 < S < 36.50$	$36.50 < S < 37.50$
WIW	$12.5 < \theta < 13.0$	$12.5 < \theta < 13.0$
	$37.90 < S < 38.30$	$37.90 < S < 38.30$
LIW	$14.0 < \theta < 15.0$	$13.0 < \theta < 13.4$
	$38.70 < S < 38.80$	$38.45 < S < 38.60$
WMDW	$12.7 < \theta < 12.9$	$12.7 < \theta < 12.9$
	$38.40 < S < 38.48$	$38.40 < S < 38.48$

When the WIW, normally located between 100 and 300 m, are present in the Balearic Channels, they usually deflect downwards the more saline LIW which normally occupies these levels when WIW are absent. This fact is clearly seen both in temperature and salinity cross sections when comparing the situation after a mild winter with that observed after a colder one (Figure 1.4). The observed interannual variability of the regional circulation around the Balearic Islands is strongly related to the properties and the amount of WIW reaching the channels in late spring (Millot, 1999; Pinot *et al.*, 2002). This interannual variability modifies in turn the hydrographical properties of the waters surrounding the islands.

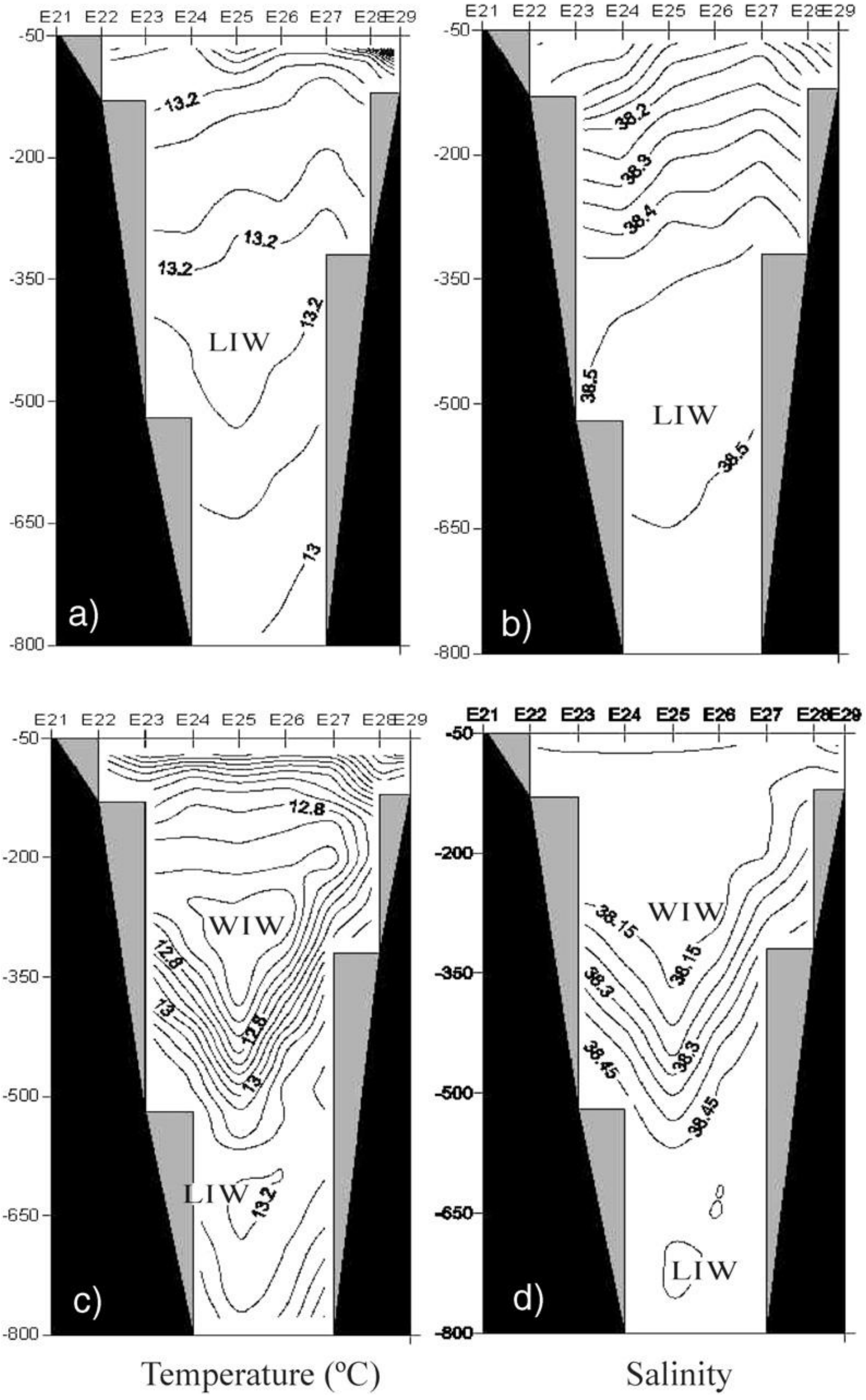


Figure 1.4. Vertical cross sections of potential temperature (°C) and salinity along the Ibiza channel after a relatively mild winter, May 1997 (a, b) and after a relatively cold winter, May 1996 (c, d). From Monserrat *et al.* (2008), after López-Jurado *et al.* (2001).

The Balearic channels have also been described as important passages for the exchange between the cooler, more saline waters of the BsB and the warmer, fresher waters of the AsB (Pinot *et al.*, 2002). These marked differences between the north and south are reflected in the structure of the water column. Western Mediterranean Deep Waters (WMDW, Table 1.1) appear deeper in the south, which implies that the LIW layer is wider as well as warmer and more saline. Both temperature and salinity show more variability in the north than in the south, where the water column variations seem to be much smoother, as the south is less affected by the above mentioned processes (López-Jurado *et al.*, 2008).

Within the general oligotrophic environment of the Mediterranean (Figure 1.5), the waters around the Balearic archipelago, where there is no supply of nutrients from land runoff, show more pronounced oligotrophy than the adjacent waters off the Iberian coast and the Gulf of Lions (Estrada, 1996; Bosc *et al.*, 2004). Frontal meso-scale events between Mediterranean waters and waters of Atlantic origin (Pinot *et al.*, 1995) and input of cold northern water into the channels (Fernández de Puelles *et al.*, 2004) act as external fertilisation mechanisms that enhance productivity off the Balearic Islands. Trophic web structures show differences between the BsB and AsB, as the trophic webs are supported more by plankton biomass than by benthos in the AsB, while suprabenthos plays a more important role in the BsB (Maynou and Cartes, 2000; Cartes *et al.*, 2001, 2008a).

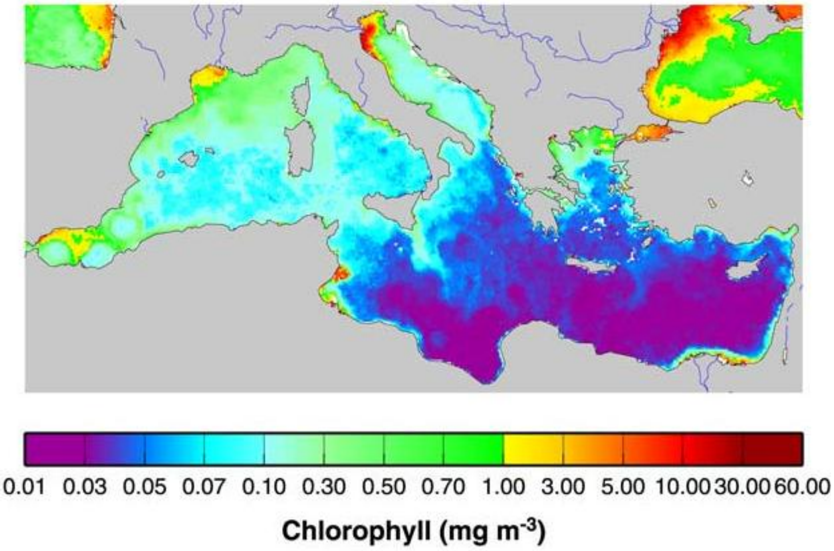


Figure 1.5. Monthly map (May 1999) of the chlorophyll concentrations. From Bosc *et al.* (2004).

1.3. The bottom trawl fishery off the Balearic Islands

Although it is not clear when the trawl fishery started in the Balearic Islands, the most probably date is during the last quarter of the 18th Century (Darder and Oliver, 2007). The exploitation of fishing grounds between 100 and 300 m depth started in 1939, due to the first signals of depletion of shallower grounds (Massutí, 1959, 1973). Deeper fishing grounds located between 300 and 800 m depth, which were formerly unknown or impracticable, started to be exploited in 1948, coinciding with its charting by the *Instituto Español de Oceanografía* (IEO) (Massutí, 1959, 1963; Massutí and Oliver, 1975).

The total number of trawlers operating off the Balearic Islands has decreased from the seventies but the mean horsepower has increased steadily since the beginning. The trawlers operating in Mallorca reached its maximum in 1977 (70) and started declining since then, until the current number (32) in 2010 (Figure 1.6). However, the real mean horsepower (which has been estimated to be 2.4 times higher than the nominal horsepower) by year has been increasing between 1965 and 2010 (Figure 1.6).

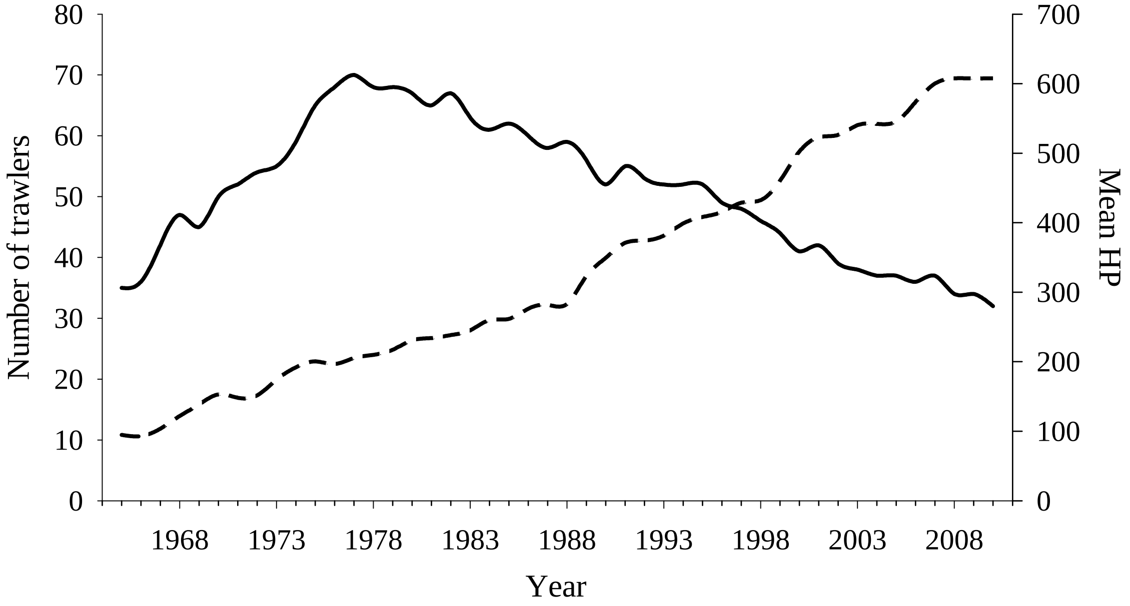


Figure 1.6. Number of trawlers (continuous line) and real mean horsepower (HP) per trawler (discontinuous line) by year for the bottom trawl fleet of Mallorca. From Quetglas *et al.* (2009).

In the Balearic Islands, bottom trawlers operate along a wide bathymetric range, from the shallow shelf (deeper than 50 m depth) to the middle slope (down to 800 m). They are multispecific and apply different fishing tactics (FT) even during the same fishing trip, depending on the season, weather conditions, and commercial factors (e.g., landing price, day of the week or boat order in the auction).

Up to four individual fishing tactics can be distinguished, being the most important species and depth range exploited the following (Moranta *et al.*, 2008a; Palmer *et al.*, 2009):

- Shallow shelf (SS; 40-80 m): targeting *Spicara smaris*, *Mullus surmuletus*, *Octopus vulgaris* and catching other species such as *Trachurus mediterraneus*, *Scyliorhinus canicula*, *Loligo vulgaris*, and a mixed fish category called “morralla”, composed by *Trachinus draco*, *Serranus cabrilla*, *Chelidonichthys lastoviza*, *Pagellus* spp., *Scorpaena notata*, *Scorpaena scrofa*, among others;

- Deep shelf (DS; 125-235 m): targeting *Merluccius merluccius* and catching other species such as *Trachurus trachurus*, *Illex coindetti*, *Raja* spp., *S. canicula*, and a mixed fish category also called “morralla” but with a different composition from the SS “morralla”: *Chelidonichthys cuculus*, *T. draco*, *Trigla lyra*, *S. cabrilla*, *Trisopterus minutus*, *Helicolenus dactylopterus*, among others.

- Upper slope (US; 350-600 m): targeting *Nephrops norvegicus* but with an important by-catch of *Micromesistius poutassou*, *M. merluccius*, *I. coindetti*, *Parapenaeus longirostris*, *Lepidorhombus boscii*, *Lophius piscatorius*, *H. dactylopterus* and *Phycis blennoides*.

- Middle slope (MS; 600-750 m): the only target species is *Aristeus antennatus*, which is taken along with a by-catch that includes *Galeus melastomus*, *Geryon longipes*, *M. merluccius*, *M. poutassou* and *P. blennoides*.

Although catches in the daily sale bills for each boat reflect a highly diverse mixture of species, these catches taken on such different fishing grounds can be identified from daily sale bills, because these fishing grounds have distinctive bottoms that are characterized by different assemblages of demersal species (Massutí and Reñones, 2005; Moranta *et al.*, 2008a). Thus, the analysis of discriminant analysis and artificial neural networks can allow us to estimate which FTs have been applied in each fishing trip (see Chapter 2). For a simpler interpretation, for those fishing trips in which two different FTs were performed, values on biomass and economic value were equally distributed for each FT and each fishing trip was computed as half day for each FT.

The most important fishing tactics in terms of total biomass landed by the bottom trawl fleet from Mallorca are those developed in the shelf, which represent up to 57% (40% SS and 17% DS, Figure 1.7), in front of the slope tactics, which represent 43% (19% US, 24% MS). In terms of fishing effort, the most important fishing tactic is the MS, which represents nearly half of the fishing trips (49%), followed by SS (26%), US (14%) and DS (11%). The same proportions are obtained when considering the economic value of the biomass landed.

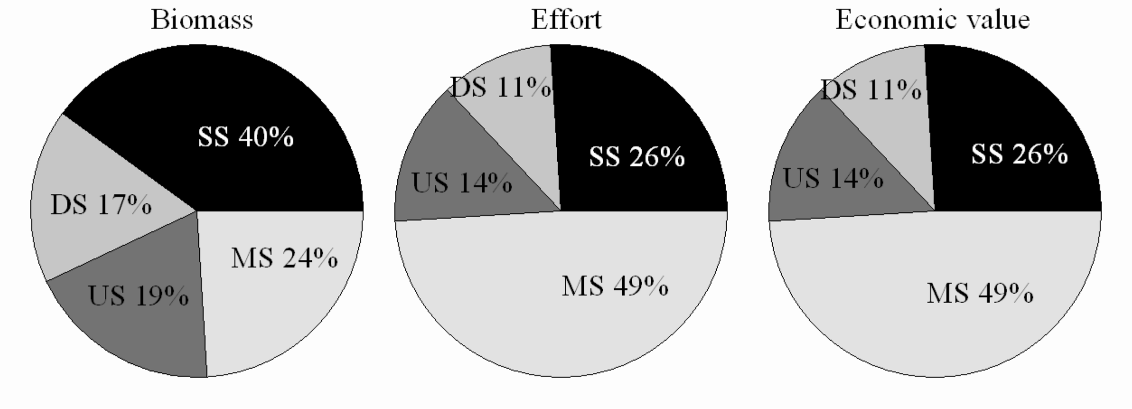


Figure 1.7. Percentage of landed biomass, fishing effort (number of trips) and economic value for each of the fishing tactics performed by the bottom trawl fleet from Mallorca, between 2000 and 2009. SS: shallow shelf; DS: deep shelf; US: upper slope; MS: middle slope.

The performance of effort targeting each fishing tactic varies among the different ports of Mallorca (Figure 1.8). For those ports whose fleet operates in the fishing grounds sited in the south and west of Mallorca (Andratx, Palma and Sóller) and one in the north (Pollença), the most important fishing tactic in terms of fishing effort is the MS (54-73%), while the rest of fishing tactics represent between 5-20%. For those ports whose fleet operates in the fishing grounds sited in the east and northeast of Mallorca (Portocolom and Cala Rajada), the most important fishing tactic is the SS, which represents around half of the fishing days (49-54%) but being the MS also very important (30-40%). There are two ports whose characteristics do not fit which any of these previous two groups: Alcúdia (north of Mallorca), in which MS is very important but followed by DS (30%) and Santanyí (southeast of Mallorca) in which most of the fishing days correspond to fishing tactics from the shelf (SS 82% and DS 15%).

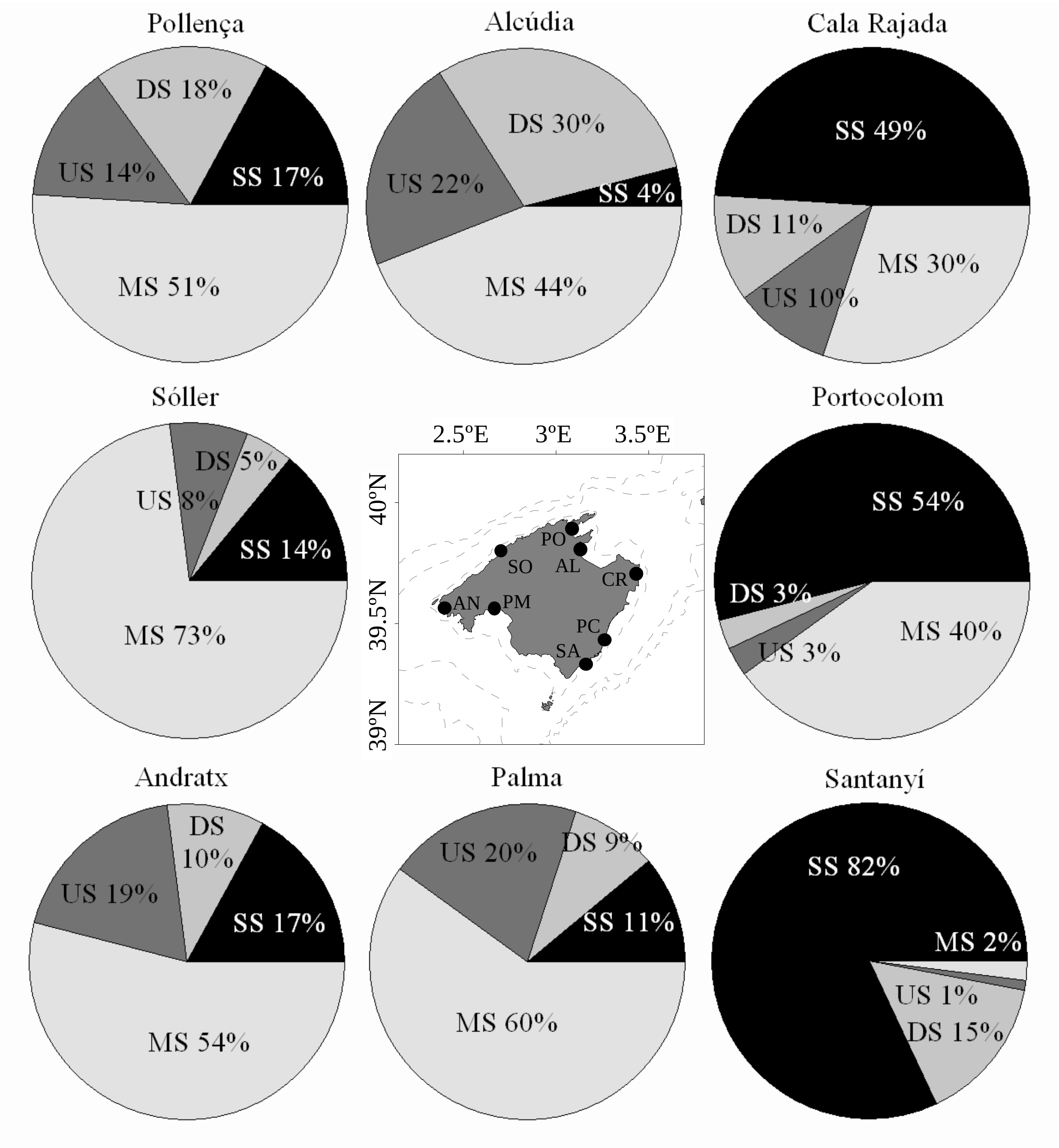


Figure 1.8. Percentage of fishing effort (number of trips) by fishing tactic for the bottom trawl fleet from Mallorca, for each port, between 2000 and 2009. SS: shallow shelf; DS: deep shelf; US: upper slope; MS: middle slope. The map shows the spatial distribution of the ports, showing the 200 and 800 m depth isobaths. PO: Pollença; AL: Alcúdia; CR: Cala Rajada; PC: Portocolom; SA: Santanyí; PM: Palma; AN: Andratx; SO: Sóller.

When computing the total number of fishing days by fishing tactic and year, there is a clear decreasing trend for all the fishing tactics, except in the case of DS, in which it remains more or less stable (Figure 1.9). This trend can be related to the above mentioned decrease of the number of trawlers during last 10 years. By month, there is a clear increase during summer months in the MS, with only a small decrease in SS and DS during this season, while for US remain practically constant during all year.

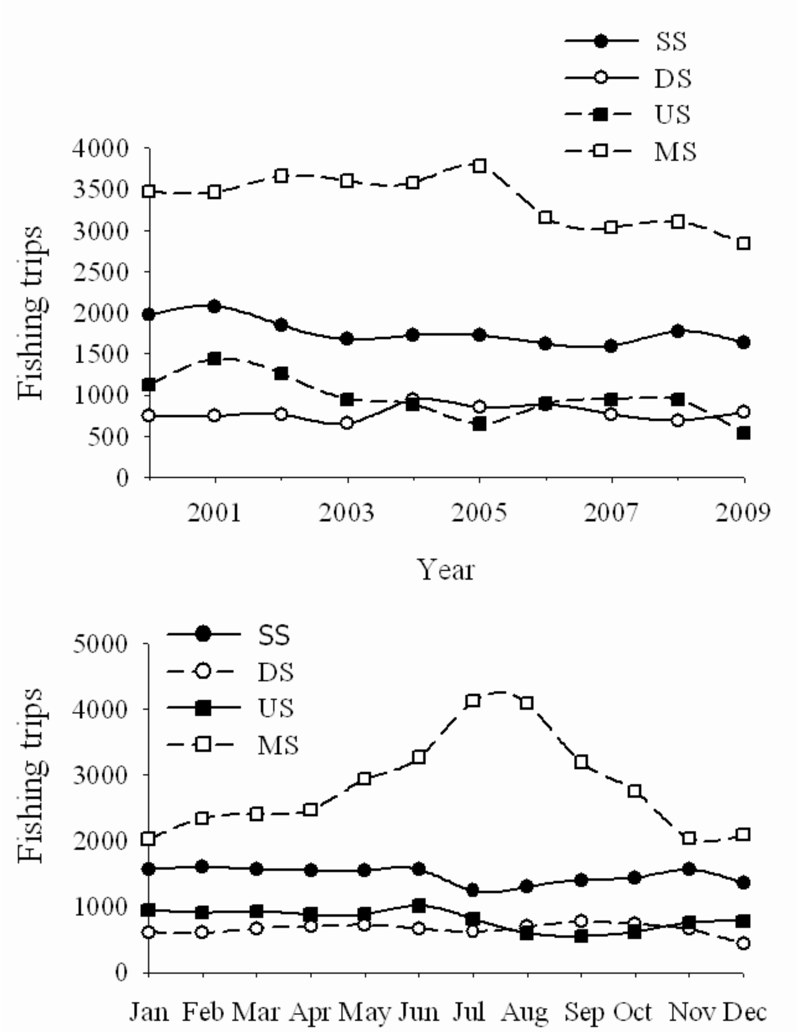


Figure 1.9. Total number of fishing trips by year (up) and month (down) for each of the fishing tactics performed by the bottom trawl fleet from Mallorca, between 2000 and 2009. SS: shallow shelf; DS: deep shelf; US: upper slope; MS: middle slope.

1.4. The deep water crustacean fishery

The knowledge and exploitation of deep water fishing grounds resulted in the apparition of new commercial species, especially crustaceans which acquired the highest economic interest. Later, the increase in the knowledge of new fishing grounds and the improvement and modernization of the fishing boats resulted in an extraordinary increase of crustacean catches. Under the denomination “shrimp”, several species were included: the red shrimp *A. antennatus*, the giant red shrimp *Aristaeomorpha foliacea*, the deep water rose shrimp *P. longirostris* and the genus *Plesionika* (Oliver Massutí, 1953). The catch curve of these shrimps (Figure 1.10) went up enormously during the first years, and reached two maximum values in 1958 and

1990 (300-350 t), with important oscillations between them. After this second maximum, landings have shown a slight decreasing trend.

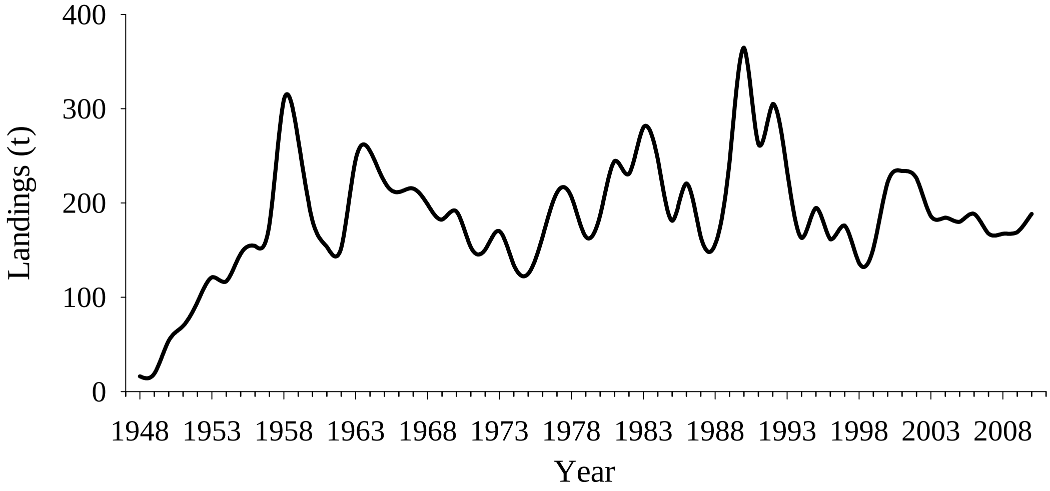


Figure 1.10. Landings of shrimps (*A. antennatus*, *A. foliacea*, *P. longirostris* and *Plesionika* spp.) from the bottom trawl fleet from Mallorca (Balearic Islands).

The first deep water fishing grounds exploited (i.e., fishing grounds from the slope, found deeper than 200 m, and thus corresponding to the US and MS fishing tactics) were those sited in the south of Mallorca, going the exploitation northern until reaching the fishing grounds of Menorca (Figure 1.11; Oliver, 1983). Nowadays, the only impracticable grounds in the slope are sited in the southeast of Mallorca and northeast of Menorca (Figure 1.12).

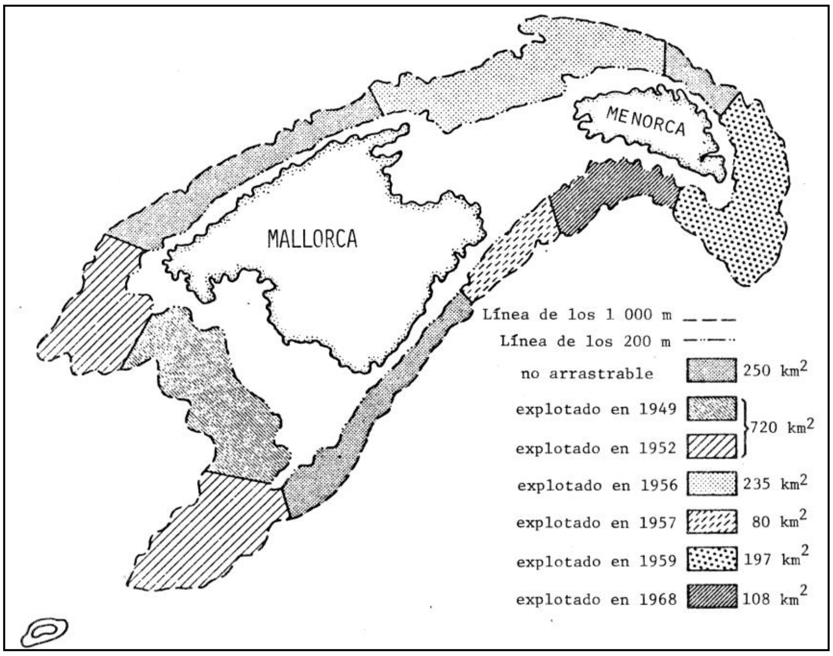


Figure 1.11. Evolution of the deep water fishing grounds exploited by the bottom trawl fleets from Mallorca and Menorca. From Massutí (1971) and Oliver (1983).

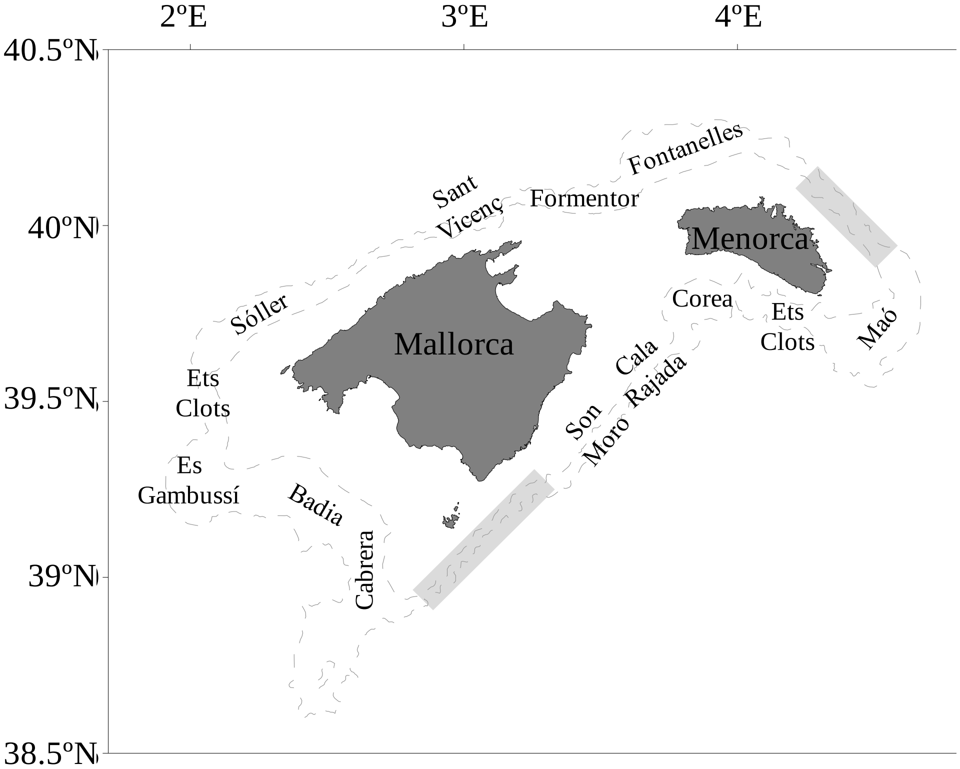


Figure 1.12. Demersal fishing grounds currently exploited by the bottom trawl fleet of Mallorca and Menorca. Grey areas indicate impracticable fishing grounds. The 200 and 800 m depth isobaths are shown.

There is no local fleet exploiting the deep water fishing grounds in Ibiza and Formentera, but fishing vessels coming from the mainland and landing their catches there have been reported from the sixties (Oliver, 1983). Around 50 vessels from the mainland were operating in these fishing grounds in 1993 (Figure 1.13), targeting the red shrimp *A. antennatus* and landing their catches in the ports of Alicante, Santa Pola and Villajoyosa, among others (García-Rodríguez and Esteban, 1999). The total annual landings for the historic series of *A. antennatus* landed in these ports were between 50 and 150 t, with a minimum in 1982 (~50 t) and a maximum in 1990-1992 (~150 t). Monthly landings showed large fluctuations between 15 and 55 kg/day per boat. The level of exploitation was slightly towards overexploitation, showing females an exploitation rate greater than males (García-Rodríguez and Esteban, 1999). This fishery is under a fishing plan (*Orden* APA/1728/2005 of 3rd of June) and nowadays the maximum number of vessels allowed to fish simultaneously in the area cannot exceed 40 trawlers, being the authorised vessels approved weekly. For these vessels, fishing is forbidden shallower than 150 m, catches are limited to certain species and fishing effort is restricted to 5 days per week and 13 hours at sea by day.

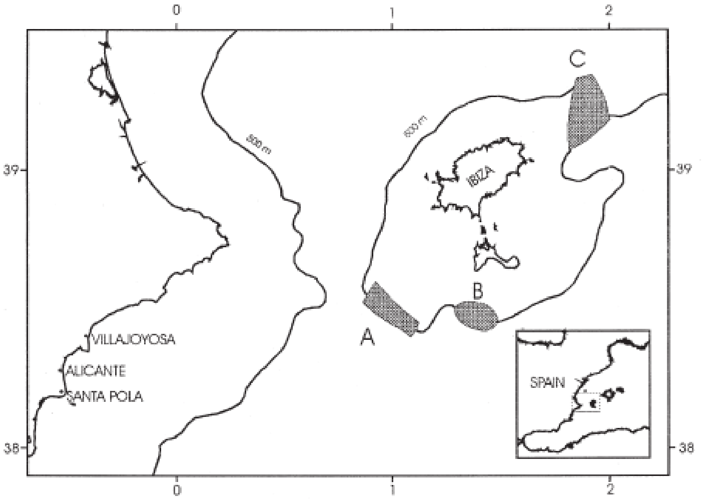


Figure 1.13. Location of the main fishing grounds exploited by vessels from the mainland (A: El Loco; B: El Clock; C: Tagomago). From García-Rodríguez and Esteban (1999).

The number of trawlers which operate in the deep water fishing of Mallorca has showed important variations during its history. In 1953, only 5 trawlers were operating these fishing grounds (Oliver Massutí, 1953), but this number increased up to 35 in 1965 (Quetglas *et al.*, 2009). Taking into account 2010 data, from the 32 bottom trawlers operating in Mallorca, we can consider that 5 (16%) of them operate almost exclusively in the deep water fishing grounds (number of trips performed in these grounds higher than 85%) and 4 (12.5%) rarely operate in these fishing grounds (number of trips performed in these grounds lower than 15%) (Figure 1.14). From the remaining 23 (72%), 11 operate more than 60% of their trips on these fishing grounds, 8 (25%) operate between 40 and 60% and 4 (12.5%) operate less than 40% in deep water fishing grounds.

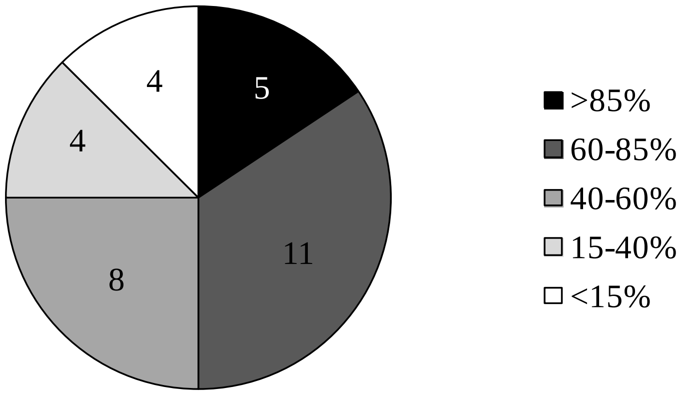


Figure 1.14. Number of boats from the bottom trawl fleet from Mallorca classified by the percentage of days (trips) operating in the deep water fishing grounds in 2010.

Although most of the deep water crustacean landed in the Balearic Islands come from the bottom trawl fleet, the use of traps for the caught of the caridean shrimp *Plesionika edwardsii* is an artisanal fishery currently developed in the deep water fishing grounds off Alicante, Columbretes Islands and Balearic Islands (García-Rodríguez *et al.*, 2000). The fishery started after experimental trials with traps carried out in practically inaccessible areas to the bottom trawl fleet, in the southeast of Mallorca (Massutí, 1967). This fishery operates between 350 and 500 m depth and the annual landings of *P. edwardsii* vary between 60 and 100 t per year (González *et al.*, 1992). Results from experimental surveys carried out along the Spanish coast showed that the largest yields were obtained in the fishing grounds off the Balearic Islands (García-Rodríguez *et al.*, 2000).

1.5. Deep water crustaceans

Deep water crustaceans represent 16% of the total biomass landed by the bottom trawl fleet off the Balearic Islands, which increases to 53% in terms of economical importance (mean data 2000-2009, Figure 1.15). The most important crustacean species is the deep water red shrimp *A. antennatus* (Risso, 1816), which represents 46% of the total weight of crustaceans landed and 72% in terms of economical importance. In terms of biomass landed, the second most important commercial category is a mixed category called *gambussí* formed by Pandalidae and Pasiphaeidae (25%), followed by the deep water rose shrimp *Parapenaeus longirostris* (Lucas, 1846), the deep sea crab *Geryon longipes* A. Milne-Edwards, 1882 (8%) and the Norway lobster *Nephrops norvegicus* (Linnaeus, 1758) (6%). Other species which represent less than 5% in weight each are the striped soldier shrimp *Plesionika edwardsii* (Brandt, 1851), the box crab *Paromola cuvieri* (Risso, 1816) and the giant red shrimp *Aristaeomorpha foliacea*. In terms of economical importance, the second most important species is *N. norvegicus* (9%), the mixed category Pandalidae-Pasiphaeidae (8%) and *P. longirostris* (6%), while the rest of species represent less than 5% each.

The case of the giant red shrimp *A. foliacea* is particularly worth-mentioning. This species was the most important crustacean caught by the deep water bottom trawl fleet shortly after this fishery started being exploited, representing up to 40% of crustaceans caught, followed by *A. antennatus* (Oliver Massutí, 1953). In fact, both species are mentioned as the two most important species for this fishery in early works

(Massutí, 1959), with *A. antennatus* dominant in experimental trawls carried out in the south of Menorca and *A. foliacea* dominant in the south of Mallorca (Massutí and Oliver, 1975). However, its importance decreased drastically, as it was already noted when comparing data from 1953 and 1964 (Massutí, 1971). This author noticed a substitution of *A. foliacea* by *A. antennatus* as the predominant crustacean in their characteristic depths, mentioning the same pattern for 1970. In fact, Massutí (1975) only mentions *A. antennatus* as deep water shrimp when analysing data between 1970 and 1974, not even mentioning the presence of *A. foliacea*.

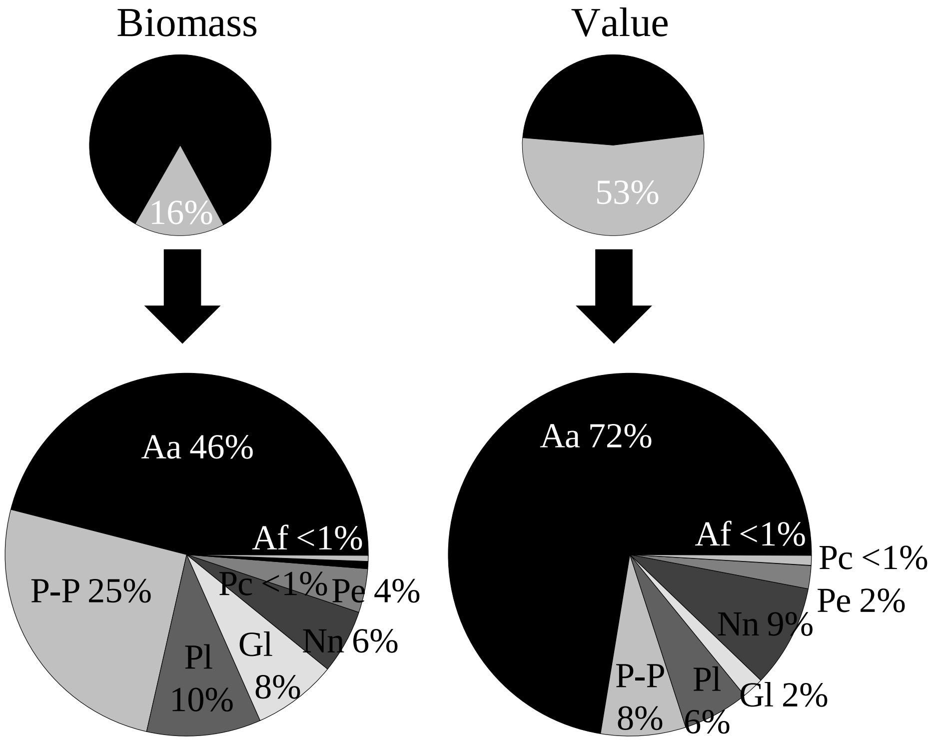


Figure 1.15. Percentage of deep water crustaceans in relation to total landings caught by the bottom trawl fleet of Mallorca (up) by biomass and values and percentage by species (down). Mean values for 2000-2009. Aa: *Aristeus antennatus*; P-P: Pandalidae and Pasiphaeidae; Pl: *Parapenaeus longirostris*; Gl: *Geryon longipes*; Nn: *Nephrops norvegicus*; Pe: *Plesionika edwardsii*; Pc: *Paromola cuvieri*; Af: *Aristaeomorpha foliacea*.

Historical data landings of this species were mixed with *A. antennatus*, among other species, and thus it is not possible to establish the exact pattern of this decrease, but a comparison of information obtained from on board observations can be done for different periods (Figure 1.16). Thus, the proportion of *A. foliacea* in relation to both red shrimps (*A. foliacea* and *A. antennatus*) has drastically decreased from the fifties, when it represented near 80% of them, until nowadays, when it represents around 7%, with intermediate values in the seventies, with near 50% of each species. This drop in

A. foliacea catches has also been detected off the nearby Catalan coast, when the species has become locally extinct. Significant temperature and salinity increases in the water masses where the species inhabited, related to the Nile damming in 1964, have been related to the extinction of the species in the area, and independent of climatic events or fishing effort increases (Cartes *et al.*, 2011). Landings of *A. foliacea* in Mallorca showed important oscillations between 1994 and 2010 (Figure 1.17), but never reached values higher than 2.5 tons by year.

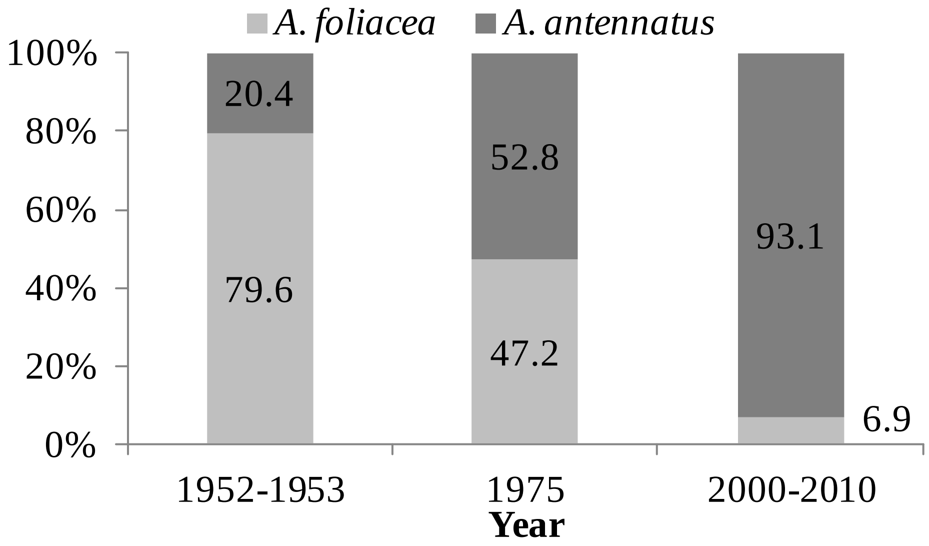


Figure 1.16. Proportion of *A. foliacea* and *A. antennatus* for three different periods: 1952-1953 (Oliver Massutí, 1953), 1975 (Oliver, 1983) and 2000-2010 (own data) in the south of Mallorca. For the first period, data are mean values from 5 commercial hauls on board F/V "Maroto". For the second, data are mean values from 6 experimental hauls carried out on board R/V "El Pescador". And for the last, data are mean values from 117 commercial hauls on board different fishing vessels operating from the port of Palma (11 hauls by year as a mean).

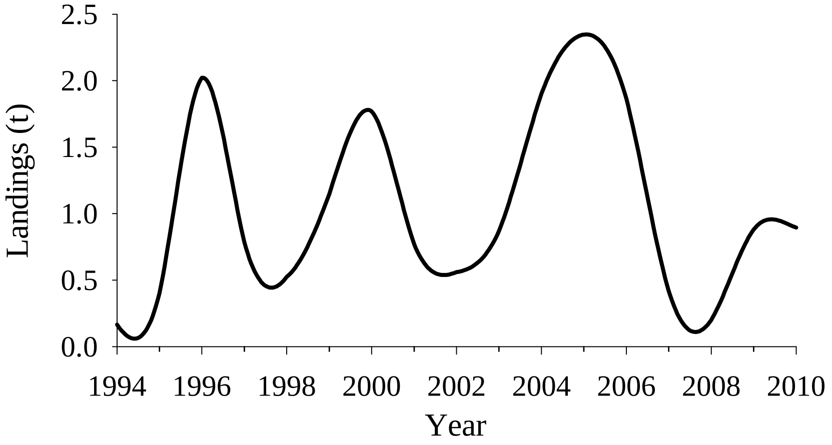


Figure 1.17. Landings of the giant red shrimp (*A.foliacea)* from the bottom trawl fleet from Mallorca (Balearic Islands).

1.5.1. *Aristeus antennatus*

The importance of the deep water red shrimp *A. antennatus* in the deep water fisheries of the Balearic Islands is reflected in the large number of studies related to this species, which have been carried out in the area since the sixties (Carbonell Quetglas, 2005 and references cited therein). Its annual catch in Mallorca between 1994 and 2010 has been oscillating between 100 and 150 t (Figure 1.18), showing a maximum of more than 200 t at the beginning of the series. Geographically, the most important fishing grounds around the Balearic Islands are those sited in the south and southeast of Menorca, and those sited in the western and southwestern of Mallorca (Figure 1.19).

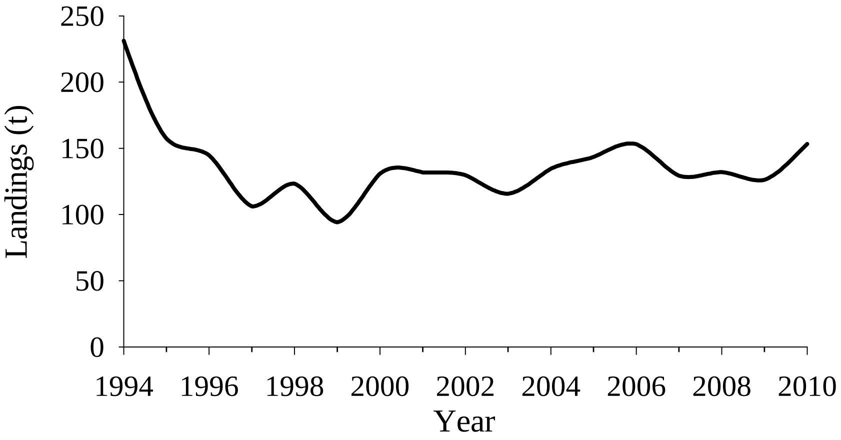


Figure 1.18. Landings of the deep water red shrimp (*A. antennatus)* from the bottom trawl fleet from Mallorca (Balearic Islands).

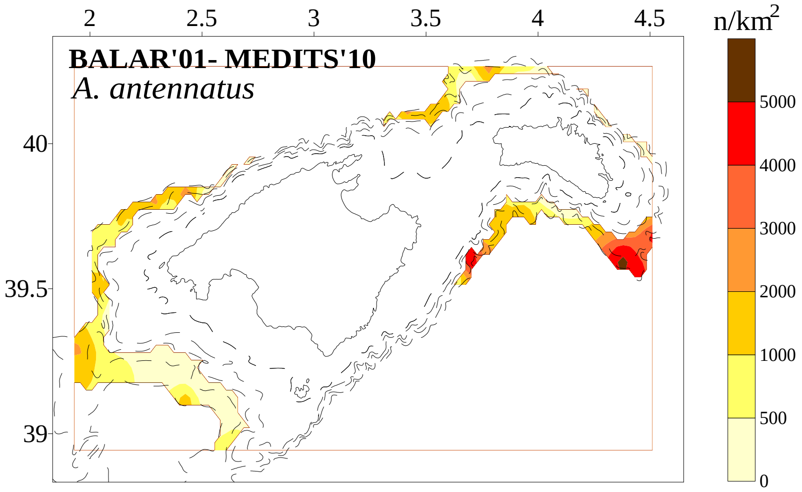


Figure 1.19. Geographical distribution of the deep water red shrimp *A. antennatus* on the fishing ground off the Balearic Islands obtained from the annual bottom trawl surveys between 2001 and 2010 (see Chapter 2). The 100, 200, 400, 600 and 800 m isobaths are shown.

Annual bottom trawl surveys, carried out since 2001 around the Balearic Islands (see Chapter 2), have shown the highest values at the beginning of the series, with maximum values in 2002, and lower values since 2005, with minima in 2005 and 2007 (Figure 1.20). Carapace length of the individuals caught is 10-65 mm, with a predominance of individuals between 20 and 45 mm (Figure 1.21).

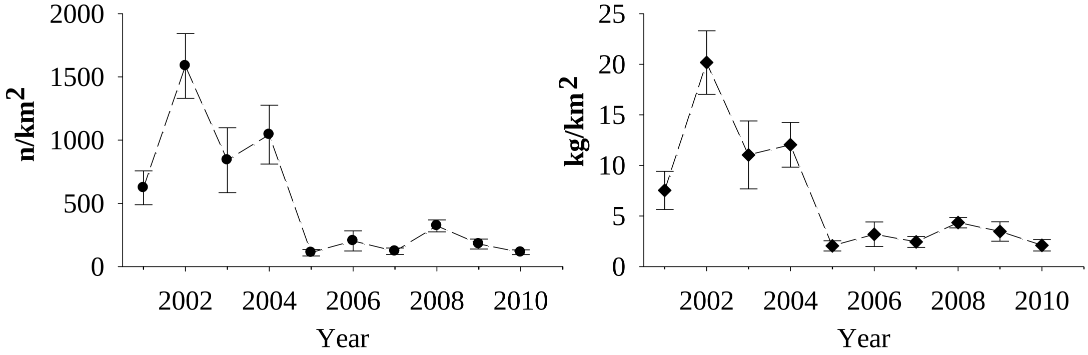


Figure 1.20. Abundance and biomass indices (error lines are standard errors) of the deep water red shrimp *A. antennatus* obtained from annual bottom trawl surveys between 2001 and 2010 (see Chapter 2).

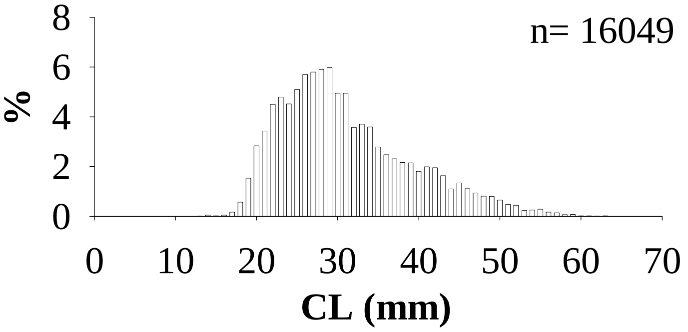


Figure 1.21. Mean length frequency distribution (CL: carapace length, in mm; percentage) of the deep water red shrimp *A. antennatus* obtained from annual bottom trawl surveys between 2001 and 2010 (see Chapter 2). Total number of individuals measured is also included.

The assessment of *A. antennatus* by non-equilibrium production models allowed the calculation of the maximum sustainable yield (Y_{MSY}) (Carbonell and Azevedo, 2003). Catches were 30% below the Y_{MSY} calculated from the Schaefer model (210 t), which suggested that the species was slightly underexploited. The comparison between estimated current biomass and virgin biomass, calculated using different models, showed the former is less than 20% of the latter, suggested that the stock is inside security levels and not in an overexploitation situation (Carbonell Quetglas, 2005). However, more recent assessments by virtual population analysis has shown that the stock is in overfishing status (GFCM, 2011).

1.5.2. Pandalidae and Pasiphaeidae

Landings of the mixed category *gambussí*, mainly composed by Pandalidae and Pasiphaeidae, have shown a slightly decreasing trend between 1994 and 2010, oscillating around 40 t at the beginning of the series and around 30 t after a maximum of 50 t in 2002. The minimum value (26 t) has been reached in 2010 (Figure 1.22).

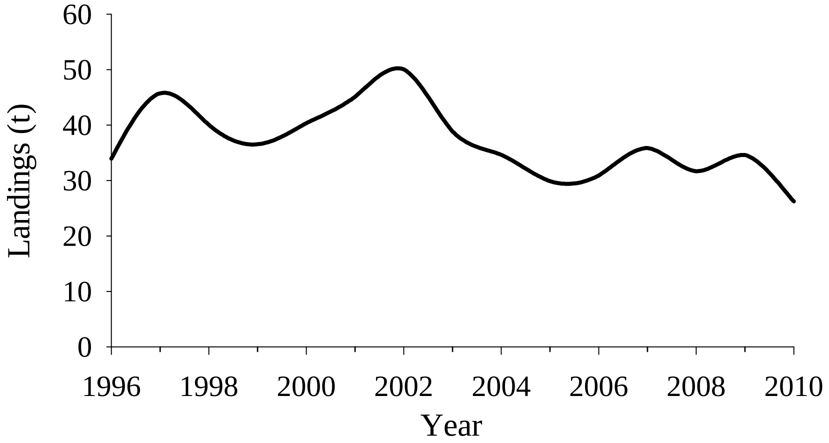


Figure 1.22. Landings of the mixed category *gambussí* mainly composed by Pandalidae and Pasiphaeidae. from the bottom trawl fleet from Mallorca (Balearic Islands).

Mean catches per unit of effort of this category (as kg/60') obtained from the seasonal fleet monitoring by on board sampling (see Chapter 2) shows that the main species in this category is the golden shrimp *Plesionika martia*, which represent up to 70% of the biomass, followed by the pink glass shrimp *Pasiphaea multidentata*, representing 19% (Figure 1.23). The rest of the species that can be found in this category show biomasses lower than 5%.

Figure 1.23. Catch composition, by species, of the commercial category *gambussí* obtained from on board sampling on the commercial bottom trawl fleet from Mallorca.

P. martia is mainly distributed in the fishing grounds in the west and southwest of Mallorca and in the southeast of Menorca (Figure 1.24). *P. muntidentata* is mainly distributed in the fishing grounds sited northwestern Mallorca (Figure 1.25).

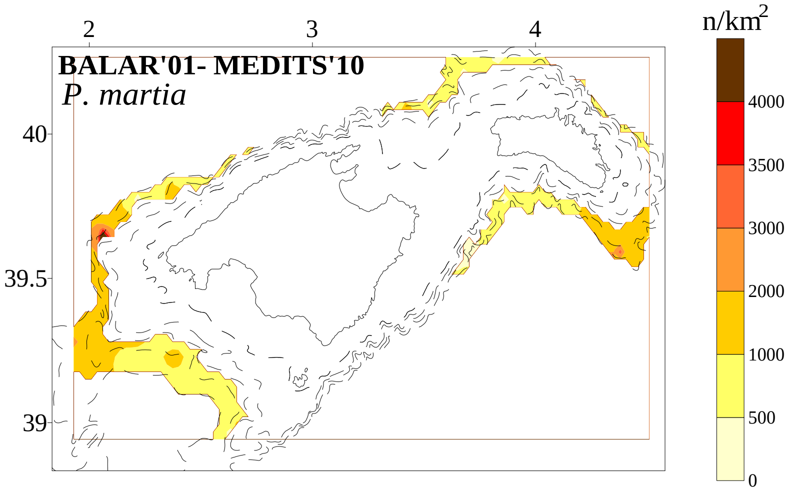


Figure 1.24. Geographical distribution of the golden shrimp *P. martia* on the fishing ground off the Balearic Islands obtained from annual bottom trawl surveys between 2001 and 2010 (see Chapter 2). The 100, 200, 400, 600 and 800 m isobaths are shown.

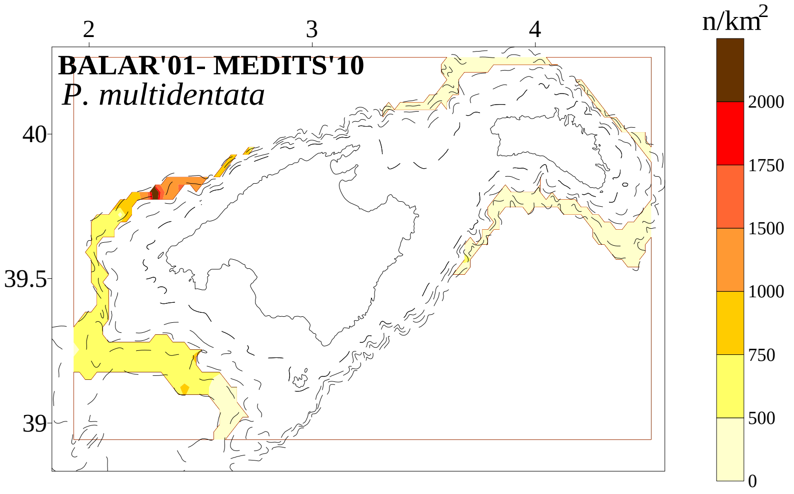


Figure 1.25. Geographical distribution of the pink glass shrimp *P. multidentata* on the fishing ground off the Balearic Islands obtained from annual bottom trawl surveys between 2001 and 2010 (see Chapter 2). The 100, 200, 400, 600 and 800 m isobaths are shown.

Annual bottom trawl surveys, carried out between 2001 and 2010 around the Balearic Islands (see Chapter 2), have shown the highest values of abundance and biomass of *P. martia* at the beginning of the series, with maximum values in 2001 and 2002, and lower values since 2003, with a relative maximum in 2007 (Figure 1.26). Also in the case of *P. multidentata*, the highest values are found at the beginning of the series, with a maximum in 2002, and lower values since then (Figure 1.27). For *P.*

martia, length range of the individuals caught is 7-35 mm, with a predominance of individuals between 17 and 24 mm (Figure 1.28). Neither of the species belonging to this commercial category has ever been assessed.

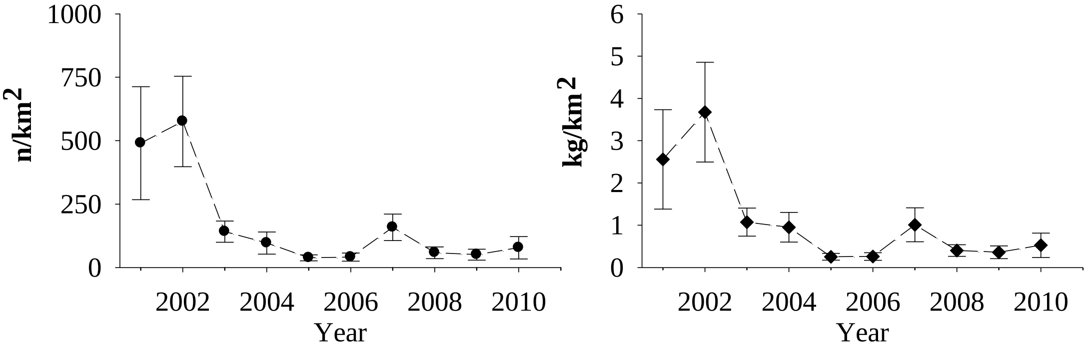


Figure 1.26. Abundance and biomass indices (error lines are standard errors) of the golden shrimp *P. martia* obtained from annual bottom trawl surveys between 2001 and 2010 (see Chapter 2).

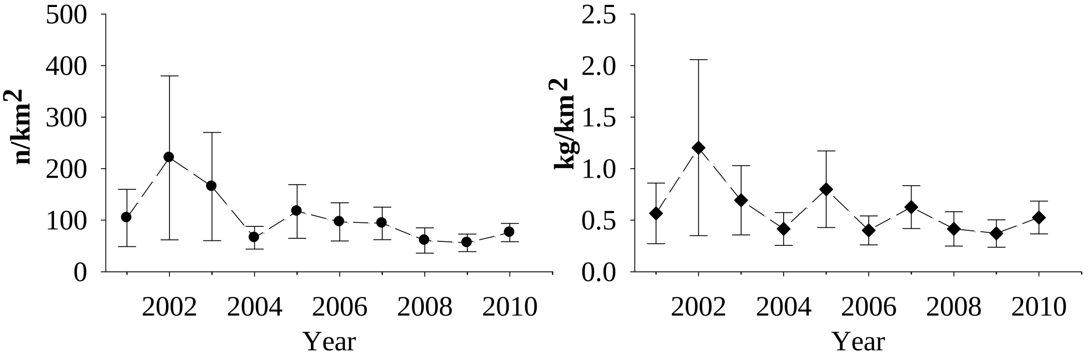


Figure 1.27. Abundance and biomass indices (error lines are standard errors) of the pink glass shrimp *P. multidentata* obtained from annual bottom trawl surveys between 2001 and 2010 (see Chapter 2).

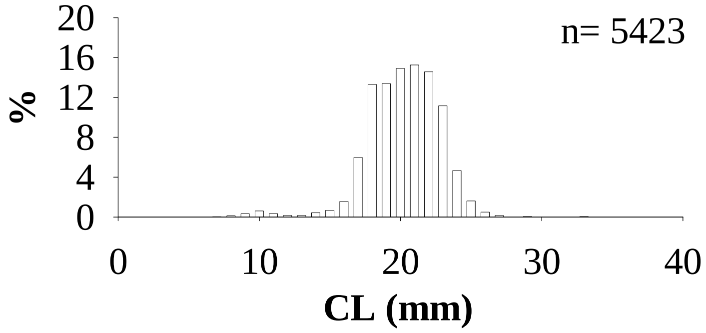


Figure 1.28. Mean length frequency distribution (carapace length, in mm; percentage) of the golden shrimp *P. martia* obtained from annual bottom trawl surveys between 2001 and 2010 (see Chapter 2). CL: carapace length. Total number of individuals measured is also included.

1.5.3. *Parapenaeus longirostris*

Landings of the deep water rose shrimp *P. longirostris* have shown great variations between 1994 and 2010. The first years of the data series showed minimum values of less than 1 t, while in 2001 it reached a maximum of 50 t. Since then, landings went down until reaching a new minimum of less than 1 t in 2006-2007, although since then landings have been increasing until reaching 7 t in 2010 (Figure 1.29). Geographically, the most important fishing grounds around the Balearic Islands are those sited in the south and northwestern of Mallorca (Figure 1.30).

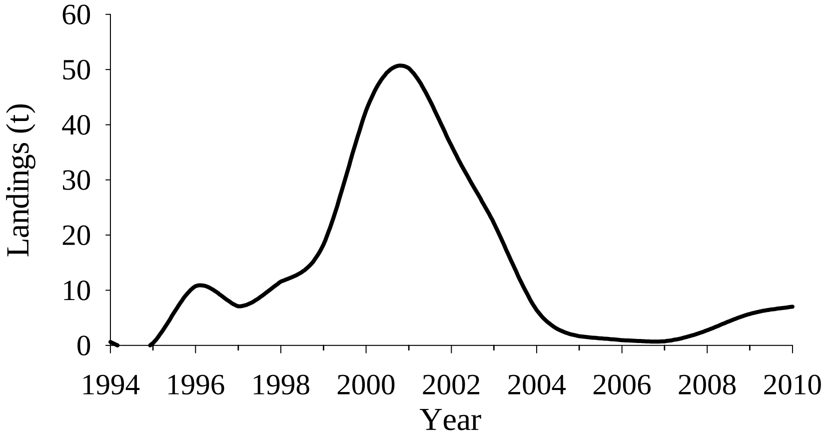


Figure 1.29. Landings of the deep water rose shrimp (*P. longirostris*) from the bottom trawl fleet from Mallorca (Balearic Islands).

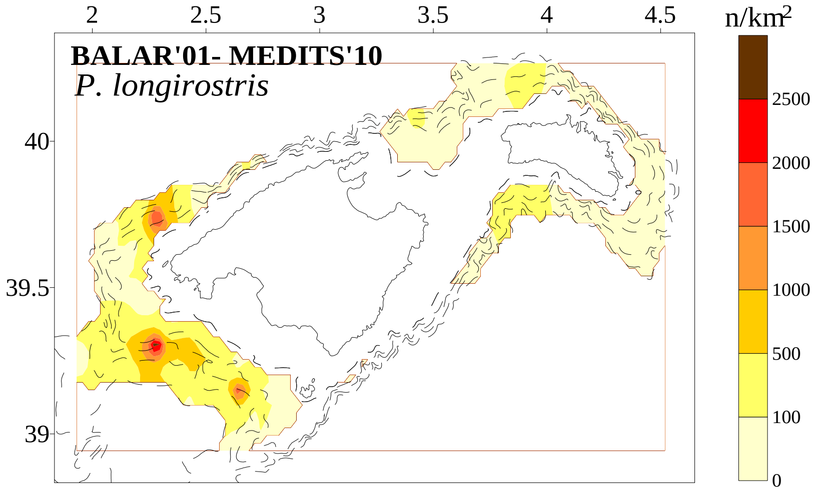


Figure 1.30. Geographical distribution of the deep water rose shrimp *P. longirostris* on the fishing ground off the Balearic Islands obtained from annual bottom trawl surveys between 2001 and 2010 (see Chapter 2). The 100, 200, 400, 600 and 800 m isobaths are shown.

Annual bottom trawl surveys, carried out between 2001 and 2010 around the Balearic Islands (see Chapter 2), have shown higher abundance and biomass indices in 2001 and 2002, with a sharp drop in the indices since then (Figure 1.31). Length range of the individuals caught was 10-47 mm, with a predominance of individuals between 20 and 35 mm (Figure 1.32).

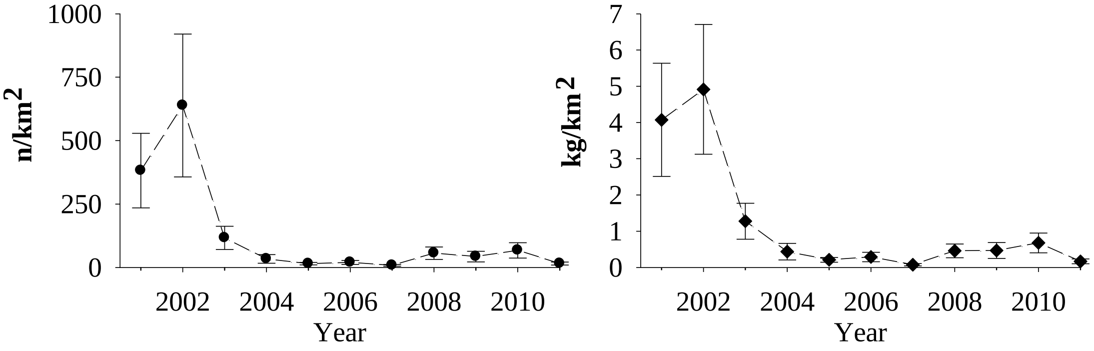


Figure 1.31. Abundance and biomass indices (error lines are standard errors) of the deep water rose shrimp *P. longirostris* obtained from annual bottom trawl surveys between 2001 and 2010 (see Chapter 2).

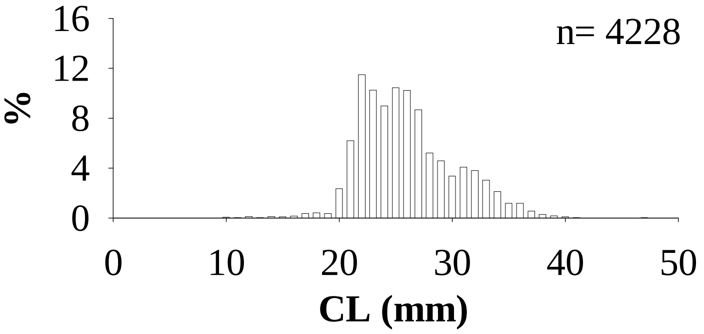


Figure 1.32. Mean length frequency distribution (carapace length, in mm; percentage) of the deep water rose shrimp *P. longirostris* obtained from annual bottom trawl surveys between 2001 and 2010 (see Chapter 2). CL: carapace length. Total number of individuals measured is also included.

The assessment of this species by virtual population analysis using length frequency distributions, landings and catches per unit of effort (2000-2009), as well as information from bottom trawl surveys as a tuning fleet (2001-2009) has shown a clear decreasing trend in the spawning stock abundance, total biomass and recruitment, although it seems that during the last two assessed years there is a certain recovering. The stock is considered overexploited, but the trends shown in the residuals for some of the ages and the underestimation of fishing mortality in the retrospective analysis reflects that the assessment is not very strong and there is some uncertainty (GFCM, 2010).

1.5.4. *Geryon longipes*

Landings of the deep sea crab *G. longipes* have shown oscillations between 1982 and 2010. Landings during the first years of the data series oscillated around 10-15 t, reaching maximum values near 30 t in 1995-1997 (Figure 1.33). Since then, values decreased again to 10-15 t and started increasing from 2007, until reaching again near 30 t. Geographically, the most important fishing grounds around the Balearic Islands for this species are those sited in the south off Mallorca as well as in the southwestern (Figure 1.34).

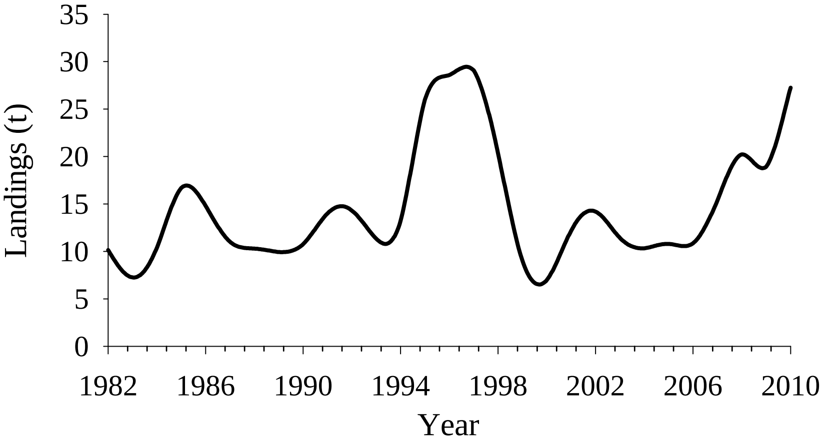


Figure 1.33. Landings of the deep sea crab (*G. longipes*) from the bottom trawl fleet from Mallorca (Balearic Islands).

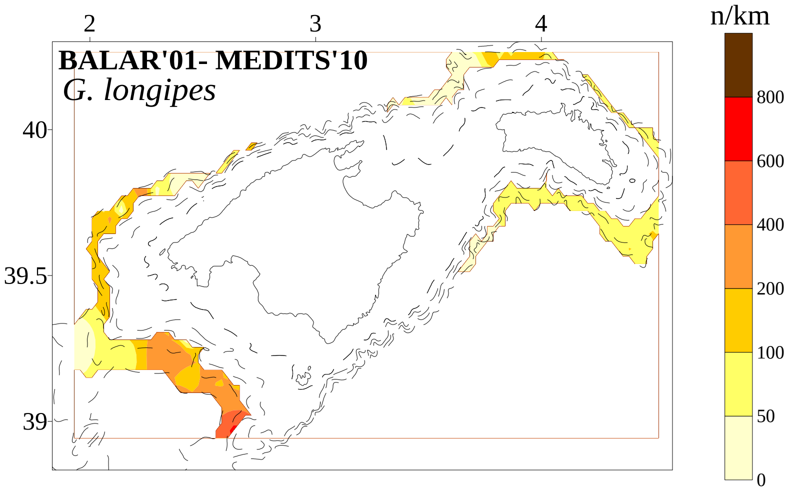


Figure 1.34. Geographical distribution of the deep sea crab *G. longipes* on the fishing ground off the Balearic Islands obtained from annual bottom trawl surveys between 2001 and 2010 (see Chapter 2). The 100, 200, 400, 600 and 800 m isobaths are shown.

Annual bottom trawl surveys, carried out between 2001 and 2010 around the Balearic Islands (see Chapter 2), have shown an increasing trend both in the abundance and biomass indices in the most recent years, as values from 2007 to 2010 practically duplicate those from the beginning of the data series, between 2001 and 2006 (Figure 1.35).

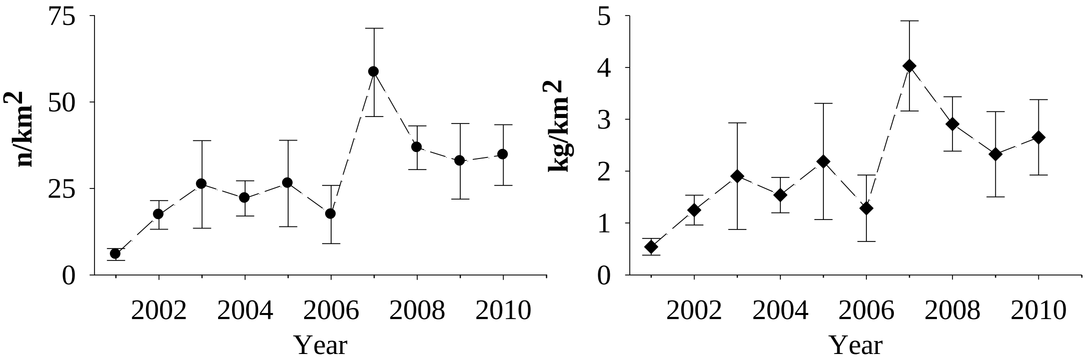


Figure 1.35. Abundance and biomass indices (error lines are standard errors) of the deep sea crab *G. longipes* obtained from annual bottom trawl surveys between 2001 and 2010 (see Chapter 2).

Length range of the individuals caught during the bottom trawl surveys was 14-69 mm, with a predominance of individuals between 35 and 60 mm (Figure 1.36). This species has never been assessed.

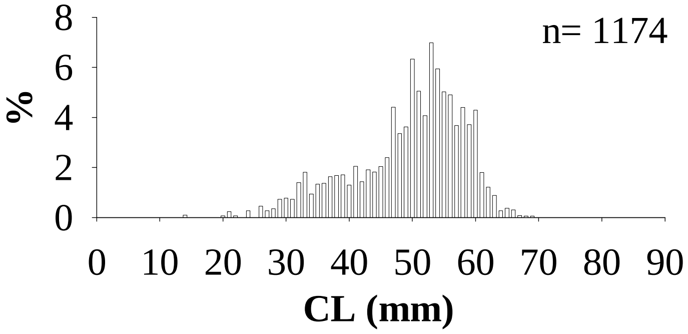


Figure 1.36. Mean length frequency distribution (carapace length, in mm; percentage) of the deep sea crab *G. longipes* obtained from annual bottom trawl surveys between 2001 and 2010 (see Chapter 2). CL: carapace length. Total number of individuals measured is also included.

1.5.5. *Nephrops norvegicus*

Landings of the Norway lobster *N. norvegicus* have shown important oscillations during the available data series, with maximum values higher than 20 t in 1996 and 2008, and an absolute minimum in 1999-2001, in which landings were less than 10 t (Figure 1.37). Geographically, the most important fishing grounds around the Balearic Islands are those sited in the northwestern of Menorca, although there are also important fishing grounds in the south of Mallorca and Menorca (Figure 1.38). This resource presents a marked seasonality, with higher values in winter and spring (Merella *et al.*, 1998).

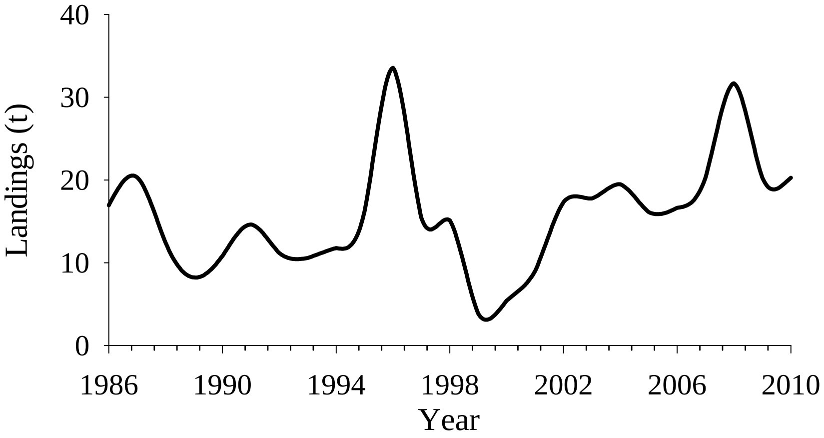


Figure 1.37. Landings of the Norway lobster (*N. norvegicus*) from the bottom trawl fleet from Mallorca (Balearic Islands).

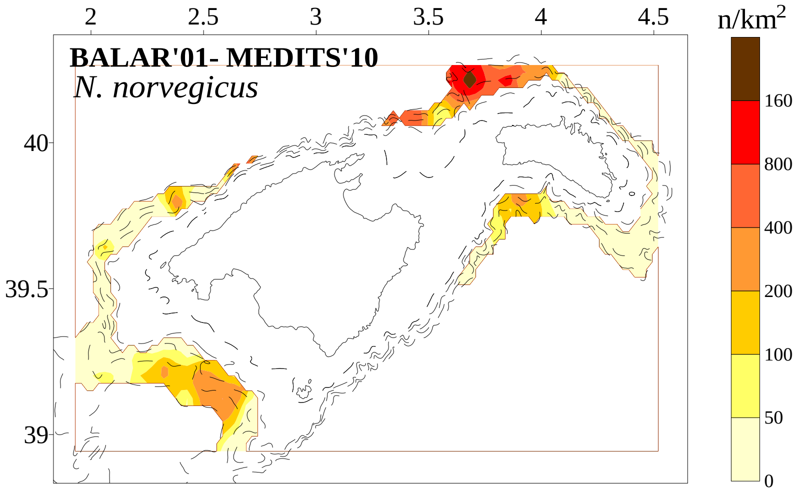


Figure 1.38. Geographical distribution of the Norway lobster *N. norvegicus* on the fishing ground off the Balearic Islands obtained from annual bottom trawl surveys between 2001 and 2010 (see Chapter 2). The 100, 200, 400, 600 and 800 m isobaths are shown.

Annual bottom trawl surveys, carried out between 2001 and 2010 around the Balearic Islands (see Chapter 2), have shown higher abundance and biomass indices in 2002 and 2007-2008 (Figure 1.39). Length range of the individuals caught was 6-69 mm, with a predominance of individuals between 30 and 45 mm (Figure 1.40).

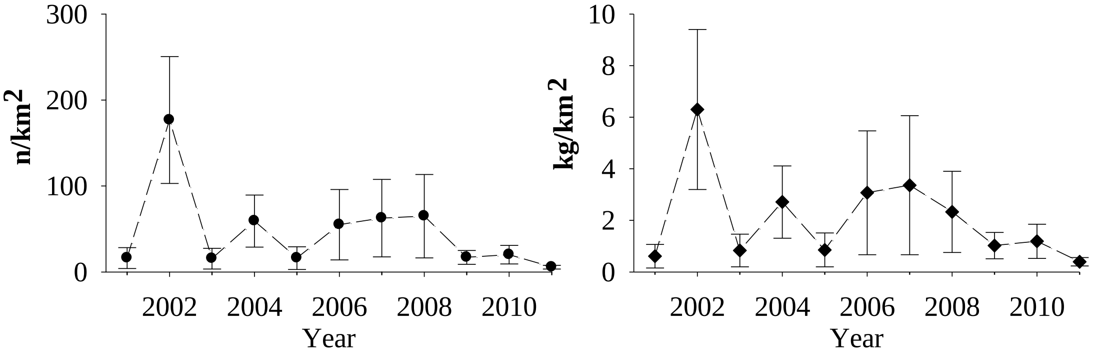


Figure 1.39. Abundance and biomass indices (error lines are standard errors) of the Norway lobster (*N. norvegicus*) obtained from annual bottom trawl surveys between 2001 and 2010 (see Chapter 2).

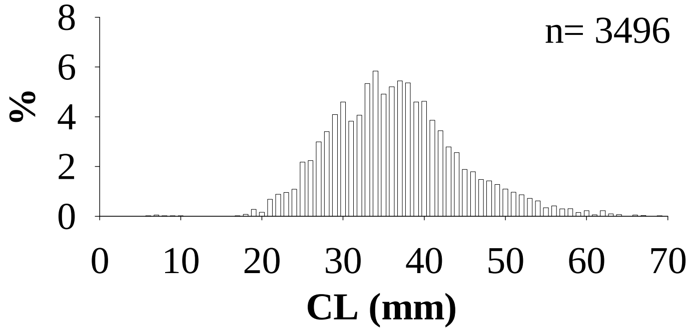


Figure 1.40. Mean length frequency distribution (carapace length, in mm; percentage) of the Norway lobster (*N. norvegicus*) obtained from annual bottom trawl surveys between 2001 and 2010 (see Chapter 2). CL: carapace length. Total number of individuals measured is also included.

The assessment of this species was carried out by means of virtual population analysis and yield per recruit on a mean pseudo-cohort using length frequency distributions and landings (2002-2009). The results showed moderate fishing mortality and intermediate abundance, and the status of the stock was assigned as overexploited (GFCM, 2010).

CHAPTER 2.

SAMPLING STRATEGIES

2.1. Introduction

Different sampling strategies have been used for the analysis of deep water decapods off the Balearic Islands. There are both data obtained during scientific surveys and so independent from the commercial sector (fishery-independent data) and data obtained directly from or in collaboration with the fishing sector (fishery-dependent data). A third type of data was obtained from scientific selectivity pilot studies carried out under commercial conditions.

Fishery-independent data are very useful not only because they avoid factors such as fisheries behaviour, which could bias estimates on commercial data, but also because they can provide information from the entire epibenthic community, constituting an appropriate tool for an ecosystem-based fisheries management, and for different environmental features which cannot be obtained from commercial sampling. These high quality data also constitute a useful tool in demersal fishery assessments, because such data can be incorporated into population dynamic models or be used in the construction of survey-based indicators. The main shortcoming of fishery-independent data is that scientific surveys are usually restricted to a certain period of the year or to a limited period of time, representing in most cases snapshots of particular spatio-temporal situations. Fishery-dependent data can cover these lacks as, when information of daily sale bills is available, the information of the entire fleet can be followed all the year round with a finer time scale, even daily. This information, complemented with an on board sampling programme, allows a fine monitoring of the commercial fleet and complements information obtained from fishery-independent data. Finally, scientific pilot studies, leaded by or in collaboration with the fishing sector, can provide different kinds of information, often representing an important and useful technology transfer to the fishing sector or even providing new information that can be applied to a better management of marine resources.

2.2. Fishery-independent data

2.2.1. Seasonal experimental surveys

Six surveys, with simultaneous bottom trawl and oceanographic sampling, were carried out between August 2003 and June 2004, at two different locations off Mallorca (Balearic Islands, western Mediterranean; Figure 2.1). These areas are traditional fishing grounds of the bottom trawl fleet, Cabrera (CA) in the south (Algerian sub-basin, AsB) and Sóller (SO) in the north west (Balearic sub-basin, BsB), separated by a distance of ca. 60 nm (Table 2.1).

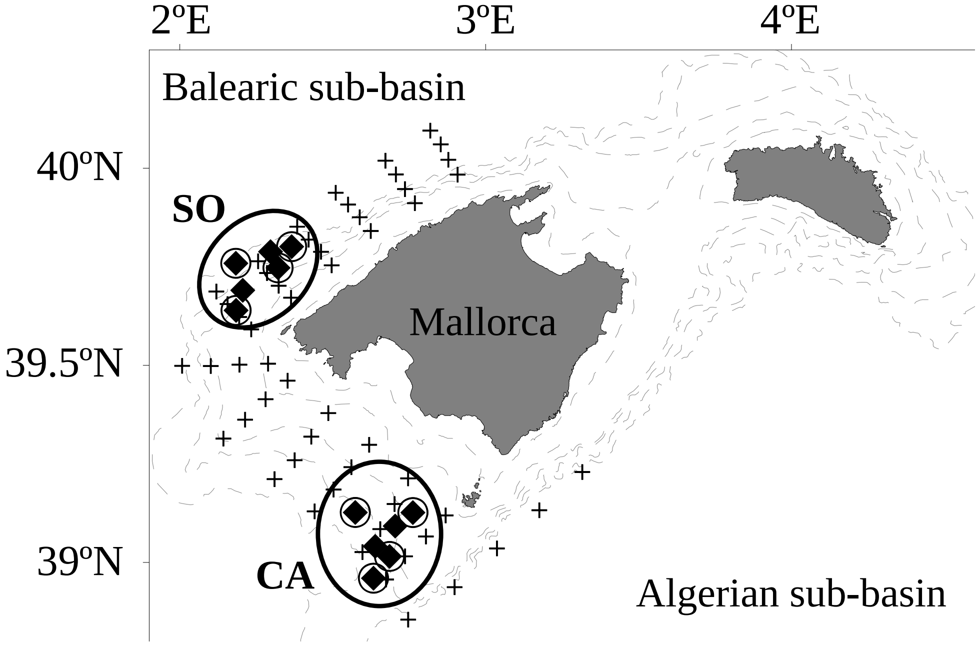


Figure 2.1. Map showing the situation of the traditional fishing grounds where the seasonal experimental surveys were carried out, Cabrera (CA) and Sóller (SO), as well as the sampling stations for the different types of sampling: bottom trawl (black diamonds), hydrographic (crosses) and zooplankton, suprabenthos and sediment stations (circles). The 50, 100, 200, 500 and 800 m isobaths are also shown.

Table 2.1. Seasons and dates of the seasonal experimental surveys.

Survey	Season	Bottom trawl survey	Oceanographic survey
IDEA0803	Summer	4th-9th August 2003	3rd-7th August 2003
IDEA0903	Autumn	25th Sept. – 04th Oct. 2003	25th Sept. – 1st Oct. 2003
IDEA1103	Autumn	14th-22nd November 2003	13th-21st November 2003
IDEA0204	Winter	6th-14th February 2004	14th-20th February 2004
IDEA0404	Spring	2nd-22nd April 2004	7th-13th April 2004
IDEA0604	Spring	18th-25th June 2004	23rd-28th June 2004

These surveys were carried out in the framework of the IDEA project (**I**nfluence of oceanographic structure and dynamics on **DE**mersal populations in the waters of the B**A**learic Islands; www.ba.ieo.es/idea). This project proposed to study the influence of abiotic and biotic factors on the ecosystems and demersal resources, as well as the population dynamics of two species subjected to exploitation on the shelf and slope of the western Mediterranean: the hake (*Merluccius merluccius*) and the red shrimp (*Aristeus antennatus*). The study was developed off Mallorca (Balearic Islands), which can be considered as an isolated demersal ecosystem, showing large oceanographic spatio-temporal variability (see Chapter 1). This project was an attempt of a multidisciplinary approach towards understanding the dynamics of the exploited deep water demersal ecosystems in the Balearic Islands.

M. merluccius and *A. antennatus*

2.2.1.a. Seasonal experimental bottom trawl surveys

Bottom trawl surveys were carried out on board the commercial bottom trawler F/V “Moralti Nou” (length 22 m; 59 gtr; nominal engine power: 365 hp). In each survey, 6 stations were sampled in each area (CA and SO), at around 150, 250, 350, 550, 650 and 750 m depth (Figure 2.1; Table 2.2), during daytime, using a commercial *huelvano* type trawl (Figure 2.2), with a 20 mm diamond mesh codend.

F/V “Moralti Nou”

Each haul was tracked using GPS and the opening of the net was monitored using a SCANMAR system. Horizontal and vertical net openings were, on average, 25 m and 1.8-2.1 m respectively. The towing speed varied between 2.4 and 3 knots and the trawling time varied between 45 and 60 minutes. A CTD SBE-37 was placed on the float-line of the net to record pressure, water temperature and conductivity, with a frequency of 10 seconds, both when the net was being lowered and raised along the water column and during the tow above the bottom.

CTD SBE-37 on the float-line of the net

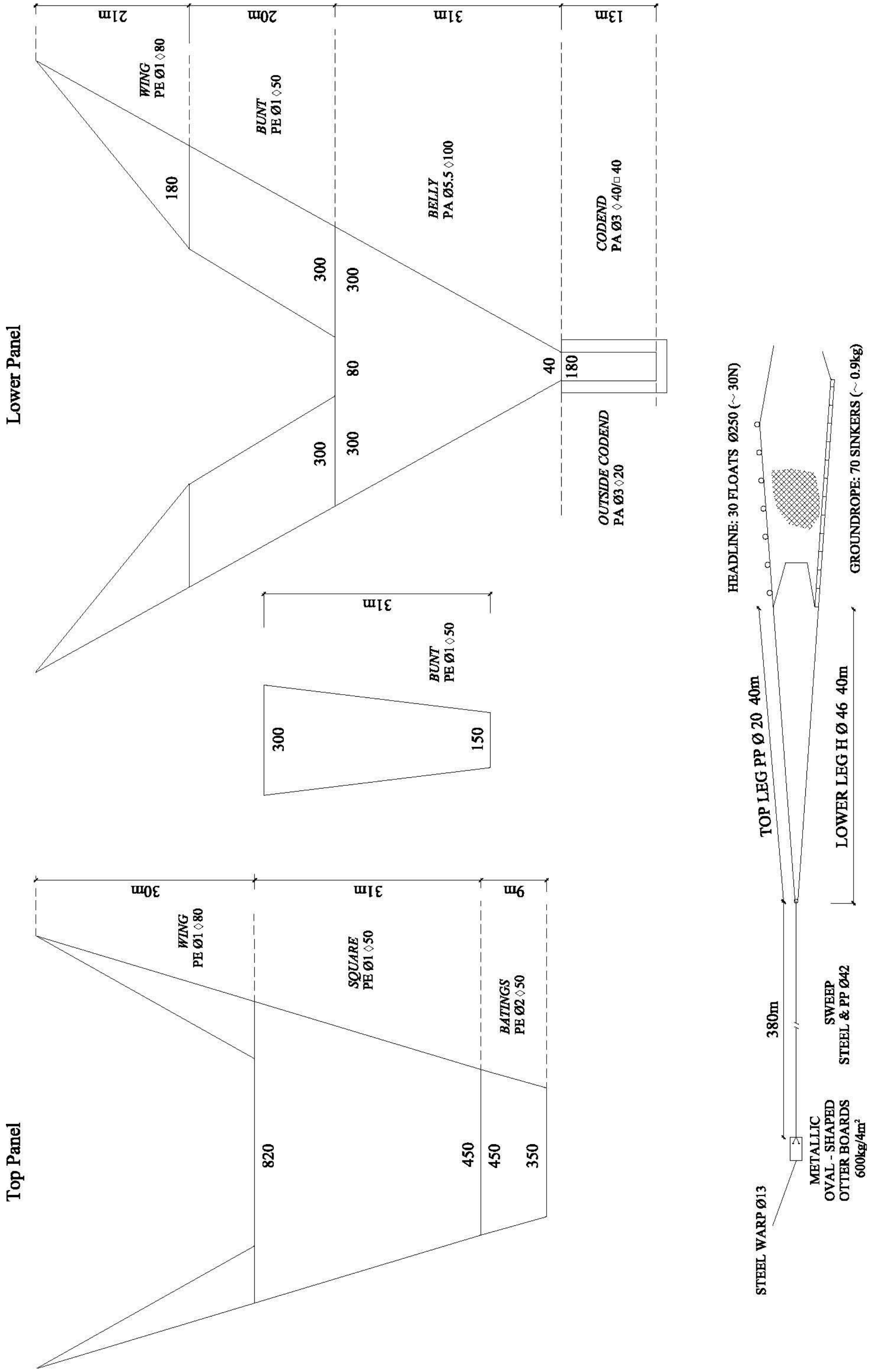


Figure 2.2. Schematic diagram of the commercial *huelvano*-type trawl gear used (PE: polyethylene; PA: polyamide; PP: polypropylene; H: hemp; ◊: diamond mesh; □: square mesh; Ø: diameter).

Table 2.2. Positions of the sampling stations for the commercial *huelvano*-type trawl during each seasonal experimental bottom trawl survey in both study areas.

Depth (m)	Cabrera (AsB)		Sóller (BsB)	
	Latitude	Longitude	Latitude	Longitude
150	39º06.97’N	002º44.54’E	39º39.75’N	002º12.46’E
250	39º04.24’N	002º42.10’E	39º42.42’N	002º13.68’E
350	39º59.97’N	002º41.43’E	39º45.40’N	002º20.20’E
550	39º07.68’N	002º34.39’E	39º48.36’N	002º23.11’E
650	39º04.58’N	002º36.19’E	39º48.05’N	002º20.46’E
750	38º56.68’N	002º37.77’E	39º46.44’N	002º13.07’E

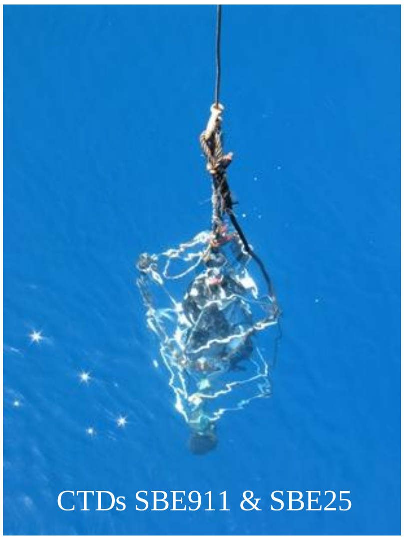

Sampling on board F/V “Moralti Nou”

The estimated swept area of each haul was used to standardise the catch (abundance and biomass) to 1 km^2. Total number and weight of all species caught were taken on board. The size of the most important species of fishes (total length), crustaceans (carapace length) and cephalopods (mantle length) was also recorded, and individuals from some species of fish and crustaceans were stored frozen for posterior biological sampling in the laboratory.

2.2.1.b. Seasonal experimental oceanographic surveys


R/V “Francisco de Paula Navarro”

Oceanographic surveys were carried out on board R/V “Francisco de Paula Navarro” (length 30 m; 178 gtr; nominal engine power: 759 hp), obtaining hydrographic data, samples of sediments, zooplankton in the water column and suprabenthos.



CTDs SBE911 & SBE25

Hydrographic data was obtained in a network of 57 stations (Figure 2.1), distributed in transects perpendicular to the coast and including the sampling stations prospected with the bottom trawl, with the CTDs SBE911 and SBE25 (24 Hz and 8 Hz, respectively). During the surveys, water samples were taken with bottles and later in the laboratory their salinity was determined using a Guildline model 8400A salinometer, allowing the CTDs being calibrated. The precision of these measurements was 0.01°C for temperature and 0.008 for salinity.

Macer-GIROQ sledge

A total of 46 samples with Macer-GIROQ sledges and with WP2 plankton nets were performed, at 150, 350, 650 and 750 m in both locations (Figure 2.1, Table 2.3), except for two stations which could not be sampled due to bad weather conditions, for obtaining data of suprabenthos and zooplankton. Distance between stations ranged from 3 to 10 nm, within each area. The sledge used had two superimposed nets with mouths sampling suprabenthos between 10-40 and 50-90 cm above the bottom. Only the lower net, where the largest amount of fauna was found, was processed. Meso-macrozooplankton in the water column was sampled using a non-closing WP2 net, with a mouth area of 1 m^2, in horizontal-oblique hauls performed from a few metres above the sea bottom (closest estimated distance to the bottom between 13-90 m by means of an inclinometer) to the sea surface. Both WP2 and sledges were equipped with 500 µm mesh size nets and were trawled to a similar speed (1.5 knots). The duration of sledge hauls over the bottom was 10 minutes and the duration of WP2 was 10 minutes close to the bottom (horizontal haul) and varied between 3-15 minutes during the recovery of the

WP2 plankton net

net throughout the entire water column. Standard 2030 flowmeters were attached to the mouth of nets to measure the amount of filtered water. All samples were collected during daytime. All taxa were counted and weighed (wet weight after eliminating water with blotting water) and data was standardised (abundance: individuals/100 m^2; wet weight: g/100 m^2) for each sample.

Table 2.3. Positions of the sampling stations for sledge, plankton net and grab carried out during each seasonal experimental oceanographic survey in both study areas.

Depth (m)	Cabrera (AsB)		Sóller (BsB)	
	Latitude	Longitude	Latitude	Longitude
150	39º06.97'N	002º44.54'E	39º39.75'N	002º12.46'E
350	39º59.97'N	002º41.43'E	39º45.40'N	002º20.20'E
650	39º04.58'N	002º36.19'E	39º48.05'N	002º20.46'E
750	38º56.68'N	002º37.77'E	39º46.44'N	002º13.07'E

Sediment for granulometric and organic analyses were collected using a Shipeck grab at each station (Figure 2.1, Table 2.3). Sediments were stored on board at -20ºC for later laboratory analyses, which comprised mineralogical composition and grain size, and organic matter analysis. The granulometric analysis was carried out using two different techniques: by dry sieving and using a Coulter LS particle size analyser (Tucker, 1988). The fraction (%) of gravel (2-64 mm), sand (0.0625-2 mm), silt (2-62.5 μm) and clay (0.06-2 μm) was estimated (Blott and Pye, 2001) at each station. The grain size distribution of each sample was summarised by logarithmically transforming its median into Φ values ($\Phi = -\log_2 d$, where d is the grain diameter in mm), as well as its sorting coefficient IGSD (Inclusive Graphic Standard Deviation) (Gray, 1981; Blott and Pye, 2001):

$$\sigma = \frac{\phi_{84} - \phi_{16}}{4} + \frac{\phi_{95} - \phi_5}{6.6}$$

The mineralogical composition was analysed by means of X-ray diffraction, which was performed on a Siemens D-5000 device (Tucker, 1988; Gingele and Leipe, 1997). The organic matter content was obtained as difference between dry weight (DW: 80ºC during 24 h until reaching constant weight) and ash weight (500ºC in a furnace during two hours) were obtained.

2.2.2. Annual experimental bottom trawl surveys

Annual experimental bottom trawl surveys were carried out between 2001 and 2010, during late spring and early summer (Table 2.4) on board R/V “Francisco de Paula Navarro” (2001-2006) and R/V “Cornide de Saavedra” (2007-2008; length: 67 m; 1113.13 gtr; nominal engine power: 1500 + 750 hp), following the international MEDITS bottom trawl survey program protocol (Bertrand *et al.*, 2002a).

Table 2.4. Dates of the annual experimental surveys carried out off Mallorca and Menorca.

Survey	Bottom trawl surveys
BALAR0401	1st-19th April 2001
BALAR0502	1st-25th May 2002
BALAR0603	15th June – 12th July 2003
BALAR0404	20th April – 18th May 2004
BALAR0605	16th June – 5th July 2005
BALAR 0506	25th May – 22nd June 2006
MEDITS_ES05_07	16th- 27th June 2007
MEDITS_ES05_08	7th-18th June 2008
MEDITS_ES05_09	10th-21st June 2009
MEDITS_ES05_10	13th-24th June 2010

The MEDITS programme (International bottom trawl surveys in the Mediterranean) started in 1994 with 4 countries (French, Greece, Italy and Spain). The main objective was obtaining standardised basic information on benthic and demersal species, both distribution and demographic structure, by systematic bottom trawl surveys. The standardised common protocol included the survey design, sampling gear, information collected, data management as well as data analysis. As this surveys did not covered the Balearic Islands, from 2001 this area was covered by a series of surveys around Mallorca and Menorca (BALAR, Massutí and Reñones, 2005), following the MEDITS protocol. In 2007, the Balearic Islands were incorporated to the MEDITS programme. Nowadays, the MEDITS programme includes 11 countries: Spain, Morocco, French, Italy, Malta, Slovenia, Croatia, Albania, Montenegro, Greece and Cyprus (Figure 2.3).

The surveys were performed in the traditional fishing grounds of the trawl fleet around Mallorca and Menorca (Figure 2.4), between 38 and 755 m depth. Sampling was carried out during daytime using a bottom trawl gear designed for experimental fishing with scientific purpose (GOC 73; Dremière *et al.*, 1999; Fiorentini *et al.*, 1999; Bertrand *et al.*, 2002b), with a codend of 20 mm. Number of stations per survey varied between 41 and 69, with a towing speed of around 3 knots and a trawling time between 20 and 60 minutes, depending on the depth. Each haul was tracked using GPS and the opening of the net was monitored using a SCANMAR system. Horizontal and vertical net openings were estimated, on average, 16 m and 2.7-3.2 m, respectively. These data were used to calculate the exact swept area and to standardise the catch (abundance and biomass) to 1 km^2. Total number and weight of all species caught were taken on board. The size of all the species of fishes and the most important species of crustaceans and cephalopods was also recorded and biological sampling of the most important species of fish, crustaceans and cephalopods was carried out.

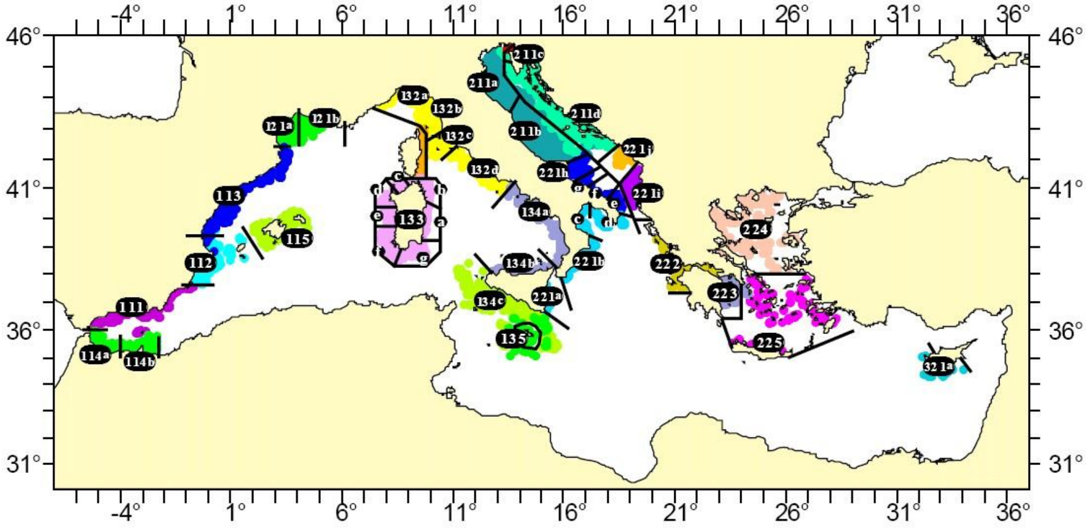


Figure 2.3. Map showing the coverage of the MEDITS surveys around the Mediterranean Sea. Numbers indicate MEDITS strata. From www.sibm.it/MEDITS 2011/principaleprogramme.html.

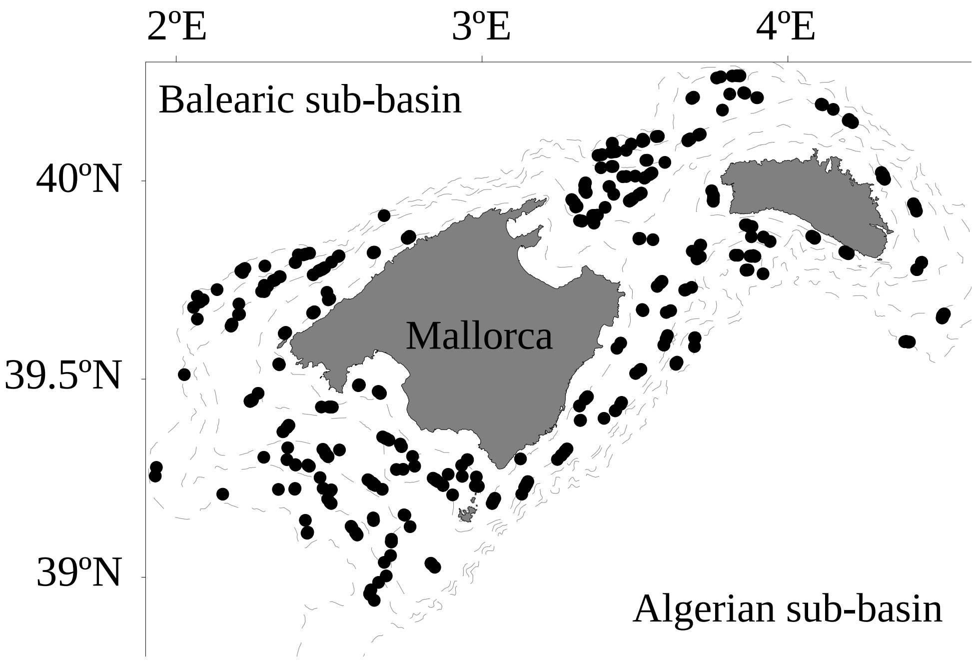


Figure 2.4. Sampling stations for the annual experimental surveys (2001-2008). The 50, 100, 200, 500 and 800 m isobaths are also shown.

Taking into account both environmental and fishing effort variability (Table 2.5), four different areas were considered in some of the analysis of data obtained during these surveys (Figure 2.5).

Table 2.5. Summary of the environmental and fishery characteristics of each of the areas analysed, based on previous studies (Pinot *et al*., 1995, 2002; Acosta *et al*., 2002, 2004;López-Jurado *et al*., 2008; Monserrat *et al*., 2008; Serrano *et al*., 2008) For fishing effort, low: <500 days/year; medium: 500–1000 days/year; high: >1000 days/year.

Area	North	West	South	East
Sub-basin	Balearic	Balearic	Algerian	Algerian
Hydrology	Balearic front. Cooler and more saline waters	Balearic front. Cooler and more saline waters	Warmer and fresher waters	Warmer and fresher waters
Bottom	Steep	Steep	Gentle, small canyons, submarine mountain	Steep, one big submarine canyon
Fishing effort	Low	Medium-High	Medium-High	Low

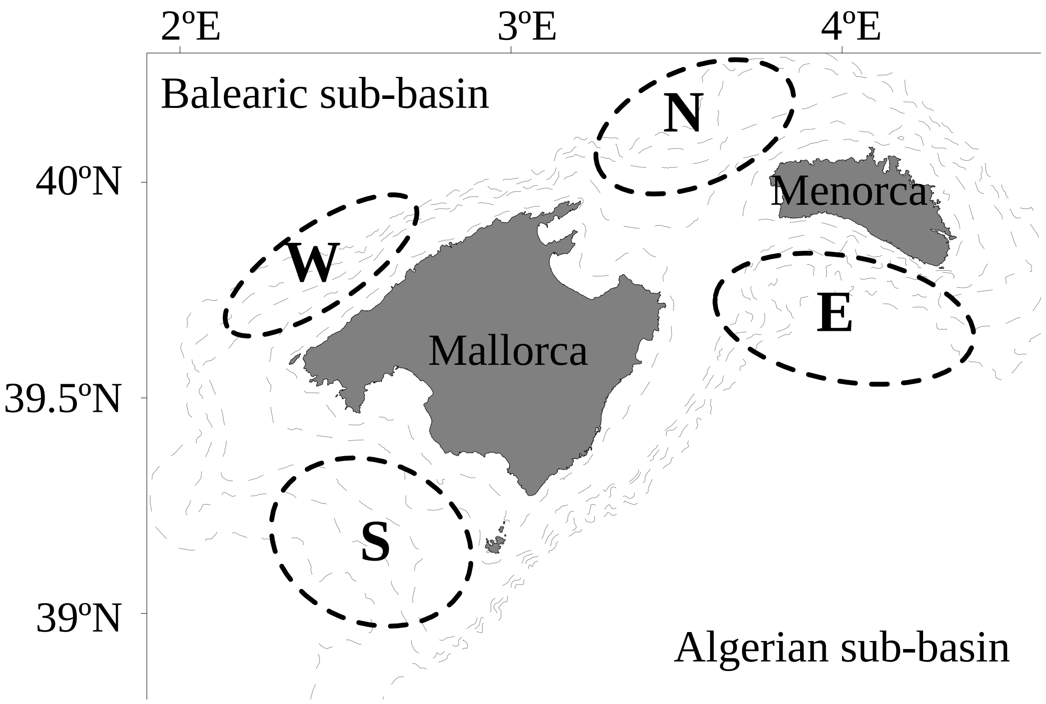


Figure 2.5. Map showing the areas considered for the analysis of data obtained during the experimental bottom trawl surveys, and the 50, 100, 200, 500 and 800 isobaths.

2.3. Fishery-dependent data

2.3.1. Daily sale bills


Landings of the commercial fleet in the port of Palma (Mallorca)

Landings of commercial species caught by the bottom trawl fleet which operates off Mallorca were compiled. This information consisted in the biomass landed by species or commercial categories, by boat and fishing trip, between 2000 and 2010. This trawl fleet carries out a single trip per day and frequently apply different fishing tactics (FT) during the same fishing trip (see Chapter 1). Each of the available daily sale bills was assigned to one or more fishing tactics using both discriminant analysis (DA) and artificial neural networks (ANN) (Palmer *et al.*, 2009). As the trawl fleet carries out a single trip per day, the sale bills were used to calculate standardised catch per unit of effort (CPUE, as kg/boat per day), for the period 2000-2008, by species or by FT using this methodology.

2.3.2. Seasonal fleet monitoring

From September 2003 to October 2004, the commercial fleet which operates in the fishing grounds of CA and SO was monitored by on board sampling. A total of 53 hauls (Figure 2.6) were monitored in 51 one day fishing trips on 6 different trawlers (Table 2.6), at depths between 108 and 726 m. Each haul was tracked using a GPS. The towing speed varied between 2.5 and 3 knots and the trawling time varied between 1.8 and 7.5 hours. These data were used to calculate the effective trawling time and to standardise the catch (abundance and biomass) to 60 minutes. Total number and weight of all species caught were taken, considering separately the fraction discarded from the fraction to be commercialized. The size of the most important species of fishes, crustaceans and cephalopods was also recorded. These sampling was carried out in the framework of the IDEA project (see point 1.1).

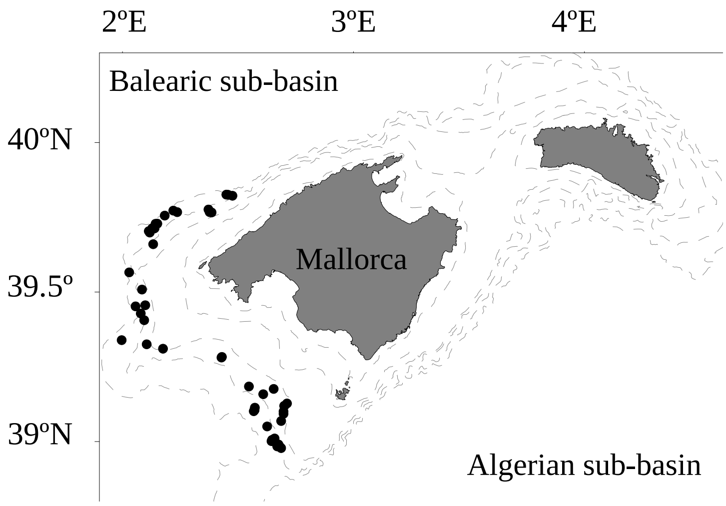


Figure 2.6. Map showing sampling stations for the bottom trawl fleet monitoring. The 50, 100, 200, 500 and 800 m isobaths are also shown.

Vessel	Length (m)	Gross tonnage	Nominal engine power (hp)
Antonia Munar Segundo	21.5	62.25	120
Es Llevant	20.8	53.95	165
Josep de Paraguay	19.6	49.83	195
Marruza	19.9	62.70	150
Moralti Nou	22.0	58.83	365
Villa de Sóller Segundo	23.0	66.08	365

2.4. Selectivity pilot surveys

Two selectivity pilot surveys were carried out on the main fishing grounds of the south of Mallorca (Figure 2.7) during autumn 2002 (September 23rd – October 22nd) and spring 2003 (May 13th – June 6th). These surveys belonged to two experimental pilot projects carried out under the proposal of an ownership firm (Albertí Morey, S.A.) and funded by the Secretary of Fisheries (Ministry of Agriculture, Fisheries and Food), in order to assess the potential profitability of new and innovative fishing techniques or gears in a regular basis for fishing resources.

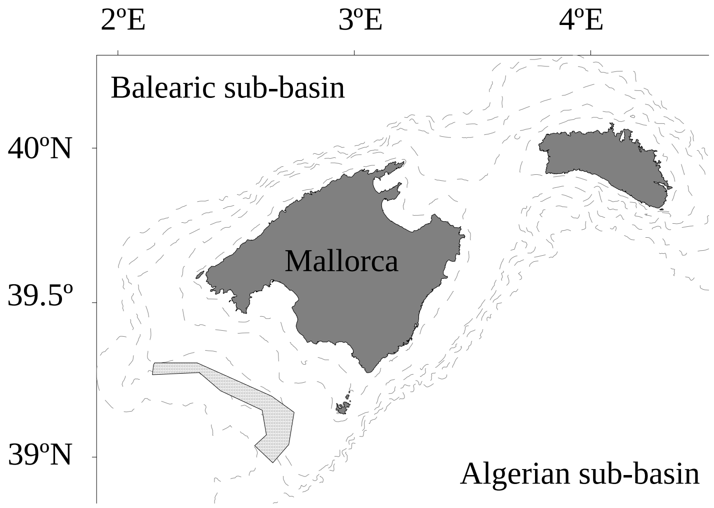


Figure 2.7. Map showing the fishing grounds sampled for the selectivity pilot surveys. The 50, 100, 200, 500 and 800 m isobaths are also shown.

The surveys were carried out on board the commercial bottom trawler F/V "Moralti Nou", using a conventional *huelvano* type trawl (Figure 2.2). Two codends of 40 mm nominal mesh size but different mesh shapes were used, a "traditional" diamond and an "experimental" square mesh shaped codend. The codend was covered with a net of 20-mm diamond mesh, attached directly to the funnel end of the net. In order to maintain a good flow of water and to avoid masking the codend meshes, the cover was 1.5 m wider and longer than the two codends. This method has been considered appropriate where catches are not very large (Wileman *et al.*, 1996), and it has been used in most of the trawl selectivity studies in the Mediterranean.

40 mm “traditional” diamond mesh codend with 20 mm diamond mesh cover

40 mm “experimental” square mesh codend with 20 mm diamond-mesh cover

Sorting and sampling on board F/V “Moralti Nou”

In all, 38 hauls were carried out in the upper and middle slope during daylight (18 in autumn and 20 in spring) between 251 and 737 m (Table 2.7), following commercial fishing procedures, but trying to make the same number of trawls with each shape of mesh and at similar depths. Each codend was used on the same gear and changed weekly. After each haul, catches in the codend and the cover were sorted by taxonomic and commercial (landings and discards) categories, counted and weighed separately. Total and carapace length of fish and crustaceans, respectively, were measured.

Table 2.7. Main characteristics of the commercial hauls (Ha) from the selectivity pilot surveys analysed by mesh shape (MS, DI: diamond; SQ: square). Initial latitude (I. Lat) and longitude (I. Lon), mean depth (De), course (Co), speed (Sp) and duration (Du) of each haul is also indicated.

Ha	Date	MS	I. Lat (N)	I. Lon (E)	De (m)	Co	Sp (kn)	Du (min)
1	24/09/02	DI	39º09.94’	002º38.57’	417	307º	2.7	262
2	25/09/02	DI	39º07.50’	002º45.22’	251	208º	2.7	262
3	26/09/02	DI	39º03.00’	002º38.24’	694	165º	2.5	285
4	27/09/02	DI	39º03.00’	002º38.25’	644	168º	2.5	280
5	30/09/02	SQ	39º09.27’	002º39.11’	410	303º	2.5	180
6	01/10/02	SQ	39º07.20’	002º38.83’	430	305º	2.7	285
7	02/10/02	SQ	39º02.60’	002º38.65’	696	176º	2.4	196
8	03/10/02	SQ	39º09.97’	002º35.30’	427	306º	2.7	275
9	04/10/02	SQ	39º09.87’	002º38.79’	431	304º	2.7	310
10	07/10/02	DI	39º09.32’	002º38.55’	431	291º	2.7	293
11	08/10/02	DI	39º08.97’	002º38.65’	450	305º	2.6	293
12	09/10/02	DI	39º03.85’	002º39.52’	463	314º	2.6	277
13	14/10/02	DI	39º02.69’	002º38.43’	710	177º	2.5	285
14	15/10/02	DI	39º02.61’	002º38.72’	707	185º	2.5	279
15	16/10/02	SQ	39º02.54’	002º38.07’	726	180º	2.4	260
16	17/10/02	SQ	39º02.44’	002º38.25’	717	182º	2.5	260
17	18/10/02	SQ	39º02.50’	002º38.09’	716	178	2.5	185
18	21/10/02	SQ	39º07.29’	002º38.83’	433	312º	2.7	285
19	12/05/03	DI	39º06.50’	002º40.45’	423	312º	2.6	289
20	13/05/03	DI	39º07.48’	002º42.67’	283	185º	2.5	255
21	14/05/03	DI	39º17.32’	002º09.91’	399	98º	2.6	265
22	15/05/03	DI	39º01.52’	002º38.29’	737	180º	2.5	309
23	16/05/03	DI	39º02.76’	002º36.76’	702	179º	2.5	303
24	19/05/03	SQ	39º03.04’	002º39.12’	475	314º	2.5	267
25	20/05/03	SQ	39º04.16’	002º39.09’	473	340º	2.6	255
26	21/05/03	SQ	39º03.56’	002º39.82’	465	318º	2.5	267
27	22/05/03	SQ	39º02.80’	002º38.28’	717	177º	2.5	301
28	23/05/03	SQ	39º02.85’	002º38.14’	726	178º	2.5	303
29	26/05/03	DI	39º02.90’	002º39.55’	467	298º	2.7	270
30	27/05/03	DI	39º02.25’	002º40.38’	471	331º	2.7	265
31	28/05/03	DI	39º04.87’	002º40.56’	463	315º	2.6	284
32	29/05/03	DI	39º14.80’	002º25.40’	687	181º	2.4	296
33	30/05/03	DI	39º02.70’	002º38.34’	721	176º	2.5	313
34	02/06/03	SQ	39º04.11’	002º40.56’	477	308º	2.5	180
35	03/06/03	SQ	39º06.34’	002º38.25’	483	314º	2.5	270
36	04/06/03	SQ	39º04.10’	002º40.15’	469	314º	2.5	267
37	05/06/03	SQ	39º03.00’	002º38.24’	715	177º	2.5	311
38	06/06/03	SQ	39º03.00’	002º38.24’	719	178º	2.4	310

Table 2.8. reflects the sampling strategies used in each chapter. However, a summary of the concrete data used in each case can be found in the correspondent chapter.

Table 2.8. Summary of data used in each of the chapter of the present thesis.

Chapter	Fishery-independent		Fishery-dependent		Pilot survey
	Seasonal	Annual	Daily bills	Fleet monitoring	
3. *P. longirostris*	X	X	X	X	
4. Pandalidae	X	X	X	X	
5. *A. antennatus*	X	X	X	X	X
6. Assessment		X	X		
7. Selectivity					X

CHAPTER 3.

PARAPENAEUS LONGIROSTRIS

Adapted from “Short spatio-temporal variations in the population dynamics and biology of the deep-water rose shrimp *Parapenaeus longirostris* (Decapoda: Crustacea) in the western Mediterranean”. Beatriz Guijarro, Enric Massutí, Joan Moranta and Joan E. Cartes. (2009). *Scientia Marina* 73(1): 183-197.

Abstract

The deep water rose shrimp *Parapenaeus longirostris* is a demersal decapod crustacean that is commercially exploited by the bottom trawl fleet. The aim of this chapter was to study the short spatial and temporal patterns of *P. longirostris* in two locations sited in the Algerian sub-basin (AsB, Cabrera: CA) and in the Balearic sub-basin (BsB, Sóller: SO) that have different environmental regimes and determine the relationship between these patterns and the environmental conditions. Information was obtained from seasonal surveys. The abundance, biomass, length, weight, sex and maturity stage of *P. longirostris* caught were recorded. Environmental parameters were obtained from seasonal surveys and included data on hydrography, trophic resources and sediment characteristics. Information about the bottom trawl fleet was obtained through fleet monitoring and daily landings data were obtained from sales records. Additionally, data from annual surveys was also obtained. Temporal differences were detected both annually, with a decreasing trend over the last years in species abundance, and seasonally, in the biological indexes analysed. Bathymetric differences were also found in abundance, mean length, sex ratio and condition of females. There were clear differences between the two locations studied, with higher abundance, condition and mean length and a lower length at first maturity for females in the northwestern location (SO, BsB) than in the southern location (CA, AsB). The bottom sediment and characteristics of the water masses, as well as the availability of potential trophic resources also seem to be important factors affecting the abundance of the deep water rose shrimp and could determine the differences found between the locations studies. Thus, the higher productivity found at this location, with higher density of preferred prey for the studied species together with adequate seafloor topography, sediment composition and hydrographical characteristics could be on the basis of these differences.

Keywords: *Parapenaeus longirostris*, spatio-temporal variations, reproduction, fishery, hydrography, bottom characteristics, prey availability.

3.1. Introduction

The deep water rose shrimp, *Parapenaeus longirostris* (Lucas, 1846), is a demersal decapod crustacean with a wide geographic distribution, which covers the entire Mediterranean and eastern Atlantic, from the north of the Iberian Peninsula to the south of Angola (Sobrino *et al.*, 2005). It is broadly distributed both in the Mediterranean and Atlantic between 20 m and 750 m (Tom *et al.*, 1988), while its maximum abundance has been observed between 100 and 400 m depth (Lembo *et al.*, 1999). Although it presents a clear size increment with depth (Froglia, 1982), some authors suggest that adults move during the spawning period to shallower waters, where the occurrence of larvae has been detected (Dos Santos, 1998). It is a species of commercial interest for the trawl fishery throughout its distribution range (Ribeiro-Cascalho and Arrobas, 1987; Levi *et al.*, 1995).

In the Mediterranean, the most abundant information on deep water rose shrimp comes from the eastern and central basins, where the species is more abundant than in the western basin (Abelló *et al.*, 2002a). Thus, in the eastern and central Mediterranean, there is information available on its distribution (e.g. Bombace, 1975; Lembo *et al.*, 2000), biology (e.g. Mori *et al.*, 2000; Bayhan *et al.*, 2005), diet (Kapiris, 2004), fishery (Sbrana *et al.*, 2006), including stock assessment (Levi *et al.*, 1995; Lembo *et al.*, 1999), and trawl selectivity (Ragonese and Bianchini, 2006; Deval *et al.*, 2006b). In the western Mediterranean, the available studies have only focused on its distribution (Abelló *et al.*, 2002a), diet (Cartes, 1995), energy content (Company and Sardà, 1998) and morphology (Sardà *et al.*, 2005) on the Iberian coast, and on its distribution (Nouar and Maurin, 2001) on the Algerian coast The role the environment plays in the abundance of deep water rose shrimp has not been studied in depth, although the possible relation between the species and some environmental factors has been discussed. Its abundance has been suggested to be related to bottom characteristics (Ribeiro-Cascalho and Arrobas, 1987; Tom *et al.*, 1988; Nouar and Maurin, 2001), benthic communities such as octocorallians (Nouar and Maurin, 2001) or crinoid beds (Colloca *et al.*, 2004) and the presence of certain water masses (Bombace, 1975). Prey availability is also an important factor that conditions the distribution of decapod crustaceans in deep water Mediterranean environments in which food is considered a limiting factor (Cartes, 1993; Cartes and Carrassón, 2004). In this area, the deep water rose shrimp has a diet based on infauna and suprabenthos (Cartes, 1995). Apart from this, the role of other factors has not been tested and not even a joint analysis of the deep water rose shrimp's abundance and the environmental variables has been previously performed.

The objectives of this chapter were: (i) to study the population dynamics, biology and condition of the deep water rose shrimp off the Balearic Islands; (ii) to compare these parameters in two locations with different environmental conditions and similar fishing exploitation rates, sited in the south and northwest areas off Mallorca; and (iii) to explore the relationships between the species and some environmental parameters (hydrography, sediment characteristics and potential trophic resources).

3.2. Materials and methods

3.2.1. Data source

All deep water rose shrimps caught during the seasonal bottom trawl surveys (see Chapter 2) were counted, weighed and measured (carapace length: mm CL) for both sexes separately. Standardised abundance (n/km^2) and biomass (g/km^2) were calculated according to survey and location (CA: Cabrera in the Algerian sub-basin, AsB, and SO: Sóller, in the Balearic sub-basin, BsB) for the total population as well as for small and large individuals. These size classes correspond to individuals up to and over 25 mm CL, which is approximately juveniles and adults respectively. Length frequency distributions per haul were calculated for the whole population from the 11484 specimens caught. For those hauls with more than 15 individuals, a mean length was calculated. Sex ratio, as a percentage of females, was calculated for each haul and also according to length.

For the biological sampling, all the individuals (for hauls with <50 individuals) or a sub-sample of at least 50 individuals (for hauls with >50 individuals) were collected and analysed at the laboratory. A total of 919 specimens were measured, weighed and sexed. Maturity was determined by macroscopic observation of the gonads. Four stages were used for females (I: immature/spent/post-spawned ovaries; II: developing ovaries; III: advanced ovaries; IV: ripe ovaries; Mori *et al.*, 2000) and two for males (I: immature; II mature). For females, gonad weight was also taken and two biological indexes were estimated for each female sampled: (i) gonadosomatic index

(GSI), as the percentage of gonad weight over total weight, and (ii) relative condition index (Kn; Le Cren, 1951), as observed weight over expected weight, estimated from a length-weight relationship, considering all data. The percentage of each maturity stage was estimated for each survey and location. The percentage of mature specimens (stages III-IV) according to size was also calculated, and the length at first maturity was modelled using only data from those months when the reproductive activity of the stock was at its maximum. Kn was also calculated for males.

Daily sale bills from 2001-2007 were also used (see Chapter 2). Monthly and annual standardised catch per unit effort (CPUE) for the trawl fleet operating off Mallorca were computed, using the presence of the species as criterion for selecting the days used. Catches, length frequency distributions and sex ratio from the seasonal fleet monitoring (see Chapter 2) were also computed.

Additionally, abundance, biomass, sex ratio and length frequency in deep water rose shrimp catches from the annual surveys (see Chapter 2) for the period 2001-2007 was also used, obtaining a mean length for those hauls with more than 15 individuals.

Environmental data was obtained during the seasonal oceanographic surveys (see Chapter 2). Several groups collected by the suprabenthic sledge, both from the infauna (Polychaeta, Bivalvia) and suprabenthos (Amphipoda Gammaridea), were considered to be potential trophic resources for deepwater rose shrimp, which was deduced from previous papers on diet (Cartes, 1995; Kapiris, 2004). The data for polychaetes and bivalves have only a comparative value within our sampling (between locations and seasons), and not in terms of absolute values.

3.2.2. Data analysis

One-way analysis of variance (ANOVA) was used to test seasonal differences for the standardised abundance and biomass from the seasonal bottom trawl surveys and mean length and sex ratio from the seasonal bottom trawl surveys and the seasonal fleet monitoring, after testing for normality of data and homogeneity of variances. When no differences were detected, a two-way ANOVA was used, considering location and depth as factors. When seasonal differences were expected for the biological indexes GSI and Kn, a one-way ANOVA was used to reject spatial differences, and a two-way ANOVA, considering season and depth as factors, was used after testing for normality of data and homogeneity of variances. A chi-squared test was applied to evaluate the predominance of each sex in relation to size class and depth.

Cluster analysis was used to analyse length frequency distributions, grouped into 5 mm intervals, from the seasonal bottom trawl surveys and the seasonal fleet monitoring. Similarity percentage analysis was also applied to estimate the dissimilarity between these groups and the contribution of the main size classes to this similarity.

The parameters of the size-weight relationship and the Von Bertalanffy growth function (VBGF) were determined for sex, location and for sexes and locations combined. These were calculated using a relationship in the form of: $W = a\ CL^{b}$, where W was the total weight in grams, CL the carapace length in millimetres and a and b the parameters to be estimated, with b as the allometric coefficient. The VBGF parameters were estimated from the analysis of length frequency distributions, grouped into 2 mm size classes, with the LFDA 5.0 software (Kirkwood *et al.*, 2001), following the equation: $CL_t = CL_\infty\ (1\text{-}e^{-k(t-t0)})$; where CL_∞ was the theoretical maximum length, CL_t the length at age t, k the growth coefficient and t_0 the age at which the size is 0. The Growth Performance Index (Φ'; Munro and Pauly, 1983) was also calculated for each sex, location and their combinations.

Redundancy Analysis (RDA) was used to detect possible variations in the environmental variables between surveys and locations. The RDA was used because it links the species composition (response) matrix directly with the environmental (explanatory) matrix. The environmental matrix was composed of one continuous variable (depth) and three categorical variables (location, stratum and survey).

Joint analysis of density values (abundance and biomass) and environmental parameters was performed by multiple regressions, considering the total population and both size classes (juveniles and adults) separately. The environmental variables used were mean, minimum and maximum temperature and salinity above the bottom, percentage of organic matter, sands, silts and clays from the sediments and the total prey biomass.

3.3. Results

The three datasets (seasonal surveys, seasonal fleet monitoring and annual bottom trawl surveys), with maximum abundance values between 300 and 450 m depth (polynomial curve fitted to abundances from annual bottom trawl surveys, $R^2 = 0.6$) showed that the bathymetric distribution of the deep water rose shrimp in the Balearic Islands ranges between 130 and 650 m depth. Both CPUE from the commercial fleet (Figure 3.1a) and abundances from the annual bottom trawl surveys (Figure 3.1b) showed maximum values in 2001-2002, with a clear decreasing trend since then. When seasonality was considered (Figure 3.1.c) the highest values for the commercial CPUE were detected during spring and minimum values during autumn. The abundance and biomass of juveniles, adults and the total population did not show significant seasonal differences in the seasonal surveys (Table 3.1). Therefore, a second ANOVA was performed with location and depth as factors. Depth and the interaction depth-location were significant ($p<0.05$) for juveniles, adults and the total population (both in n/km^2 and g/km^2), while location was only significant for adults (n/km^2). The post-hoc tests suggested that the highest values are found in SO at 350 m depth for juveniles, adults and the total population, while CA

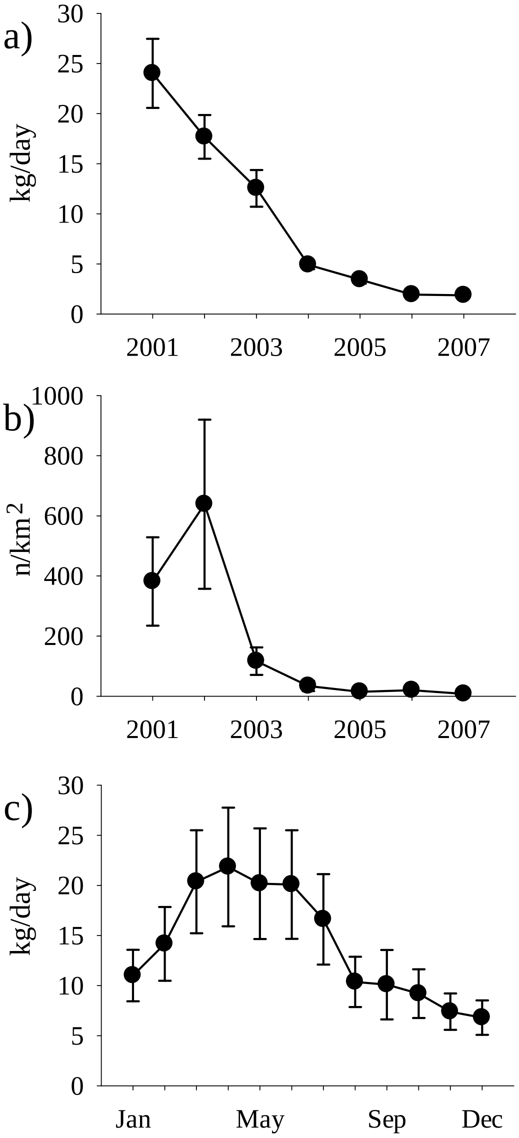


Figure 3.1. Catch per unit effort (CPUE) of *Parapenaeus longirostris* off the Balearic Islands: a) annual CPUE from the daily sale bills (kg/boat per day); b) CPUE from annual bottom trawl surveys (n/km^2); c) seasonal CPUE from the daily sale bills (kg/boat·per day). Error lines are standard errors.

showed different bathymetric trends, with the highest values for juveniles at 250 m and for adults at 550 m (Figure 3.2).

Table 3.1. Summary of the results of the analysis of variance (ANOVA) and post hoc Tuckey's Honest Significant Difference (HSD) test for all the indexes analysed, showing the significance of the factors: survey (S), depth (D), location (L) and their interactions (DxL: depth-location; SxL: season-location). CA: Cabrera; SO: Sóller; ns: not significant. D1: <350 m; D2: 350-450 m; D3: >450 m.

Seasonal surveys							
		One-way ANOVA	Two-way ANOVA				
		S		L	D	LxD	HSD
Abundance	Juveniles	ns		ns	<0.001	<0.001	250=350>550
	Adults	ns		<0.05	<0.001	<0.001	350>250=550; SO>CA
	Total	ns		ns	<0.001	<0.001	250=350>550
Biomass	Juveniles	ns		ns	<0.001	<0.001	250=350>550
	Adults	ns		ns	<0.001	<0.001	350>250=550
	Total	ns		ns	<0.001	<0.001	250=350>550
Mean length		ns		<0.001	<0.001	ns	550>350>250; SO>CA
Sex ratio		ns		ns	<0.05	ns	250>350
		L		S	D	SxD	HSD
GSI	Females	ns		<0.01	<0.001	ns	350>250
Kn	Females	<0.001	CA	<0.01	<0.01	<0.05	250>350>550
		(SO>CA)	SO	<0.001	ns	<0.05	
	Males	<0.001	CA	ns	ns	ns	
		(SO>CA)	SO	ns	ns	ns	
Seasonal fleet monitoring							
		One-way ANOVA	Two-way ANOVA				
		S		L	D	LxD	HSD
Mean length		ns		<0.001	<0.05	ns	D3>D2>D1; SO>CA
Sex ratio		ns		ns	<0.01	ns	D1=D2>D3

Cluster results from the length frequency analysis, when the whole population was considered, showed three different groups (Figure 3.3) for both the seasonal surveys and fleet monitoring. In both cases, the first group was composed by the shallower hauls from CA, formed by small individuals; the second one was formed by medium depths from CA and shallower to medium from SO; the third one was composed of larger individuals, with deeper hauls from CA and intermediate from SO. These differences between the two locations in the bathymetric distribution of the different length classes were also reflected in the size frequency distributions when depth and area were considered as factors, with a higher proportion of large individuals between 250 and 450 m depth at SO (Figure 3.3). The analysis of the mean length, according to location and depth, confirmed these significant differences between locations, for two datasets (seasonal surveys and fleet monitoring, Table 3.1), with higher values at SO. A general trend of increasing size with depth was detected, which was consistent in both locations (Table 3.1; lineal fit for the annual surveys, R^2= 0.8).

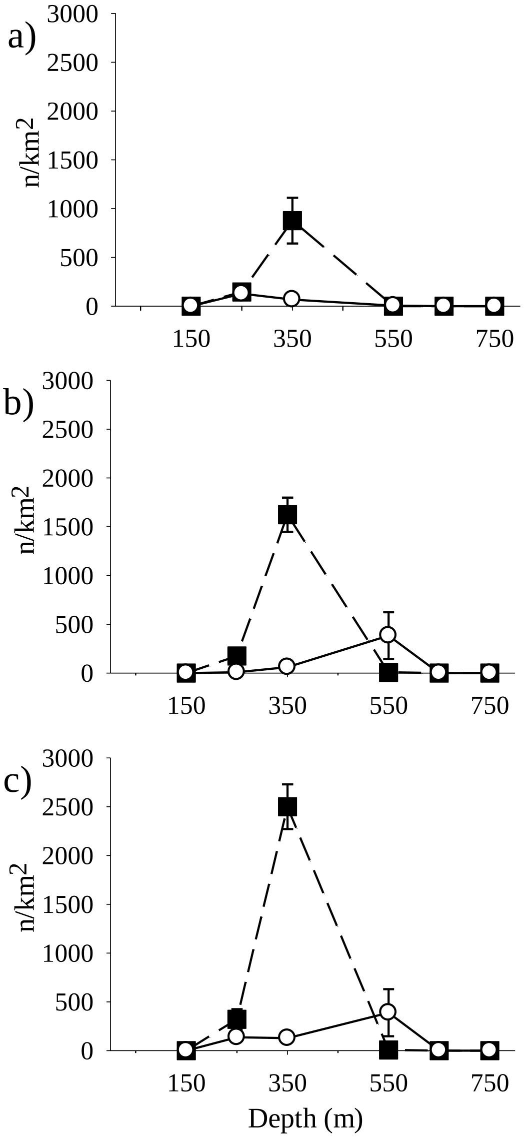


Figure 3.2. *Parapenaeus longirostris* abundance (n/km^2) estimated in relation to depth, for juveniles, adults and total population, from the seasonal surveys at each location studied (Cabrera: white circles and solid lines; Sóller: black squares and dashed line). Error lines are standard errors.

The results obtained for the length-weight relationships for females, males and total population are shown in Table 3.2. In all cases, values for the allometric coefficients were lower than 3. These values were similar for females and males; however, non-significant differences were found between SO and CA, and slightly higher values in SO compared to CA. The VBGF parameters showed high k values, especially for males. L_∞ was always higher for females (Table 3.2).

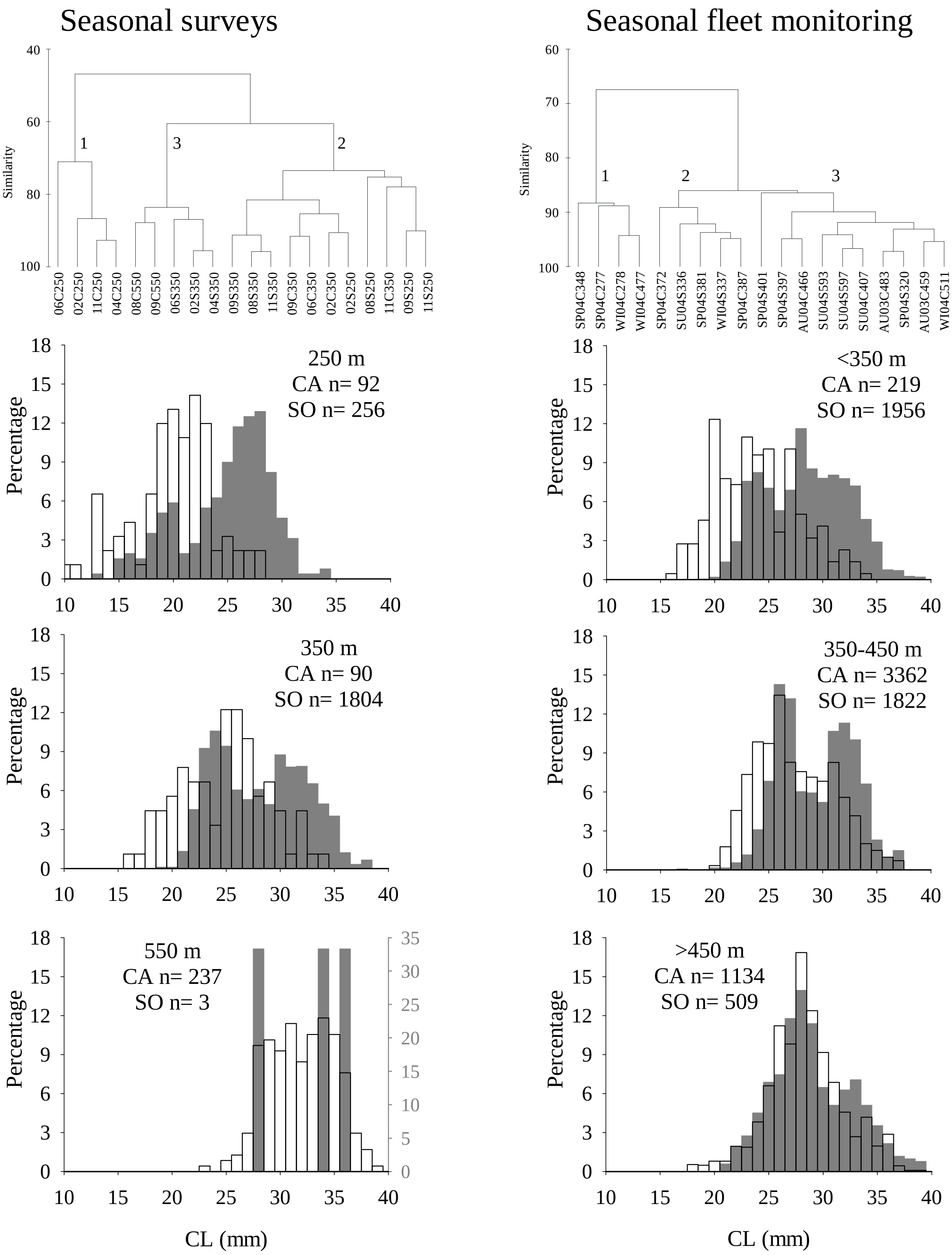


Figure 3.3. *Parapenaeus longirostris* length frequency distributions, according to depth and location (CA: white bars; SO: grey bars) from the seasonal surveys and the seasonal fleet monitoring, and results of the cluster analysis. Sample labels indicate survey/season (08: August 2003; 09: September 2003; 11: November 2003; 02: February 2004; 04: April 2004; 06: June 2004; AU03: autumn 2003; WI04: winter 2004; SP04: spring 2004; SU04: summer 2004; AU04: autumn 2004), location (C: Cabrera; S: Sóller) and mean depth (m); n: number of specimens measured.

Table 3.2. Relative (length-weight relationship: W= a CL^b) and absolute growth (CL_∞: theoretical maximum length, in mm; k: growth coefficient, in $years^{-1}$; t_0: age at which the size is 0; Φ': Growth Performance Index), according to sex and for the total population of *Parapenaeus longirostris*, for each location (CA: Cabrera; SO: Sóller) and for the two areas together (CA-SO).

Relative growth Seasonal surveys												
	Females				Males				Females+Males			
	a	b	r^2	n	a	b	r^2	n	a	b	r^2	n
CA	0.0027	2.4880	0.9838	159	0.0029	2.4688	0.9133	69	0.0027	2.4854	0.9838	228
SO	0.0027	2.5066	0.9563	434	0.0025	2.5160	0.9133	145	0.0022	2.5587	0.9673	579
CA-SO	0.0022	2.5626	0.9808	593	0.0024	2.5335	0.9776	214	0.0022	2.5682	0.9825	807

Absolute growth Seasonal surveys															
	Females					Males					Females+Males				
	CL_∞	k	t_0	score	Φ'	CL_∞	k	t_0	score	Φ'	CL_∞	k	t_0	score	Φ'
CA	41.0	0.65	-0.16	0.295	6.996	33.5	0.97	-0.10	0.486	6.993	40.9	0.69	-0.07	0.309	7.051
SO	45.0	0.66	-0.24	0.379	7.198	30.1	0.99	-0.79	0.706	6.799	40.0	0.85	-0.60	0.456	7.215
CA-SO	44.0	0.67	-0.21	0.445	7.168	31.3	1.00	-0.49	0.646	6.887	40.0	0.84	-0.49	0.447	7.203

Absolute growth Seasonal fleet monitoring															
	Females					Males					Females+Males				
	CL_∞	k	t_0	score	Φ'	CL_∞	k	t_0	score	Φ'	CL_∞	k	t_0	score	Φ'
CA	44.0	0.73	-0.92	0.326	7.254	30.9	0.99	-0.01	0.536	6.851	40.0	0.73	-0.99	0.348	7.063
SO	41.0	0.85	-0.27	0.433	7.265	31.5	0.90	-0.60	0.569	6.795	40.0	0.69	-0.23	0.315	7.007
CA-SO	44.0	0.85	-0.27	0.433	7.406	30.0	0.80	-0.10	0.701	6.579	40.0	0.89	-0.60	0.210	7.261

The overall sex ratio for the species was 73% females. There were no significant differences in the sex ratio in relation to survey, season or location, either for the seasonal surveys or the seasonal fleet monitoring (Table 3.1). However, there was a significant decreasing trend in the percentage of females with depth (Table 3.1; lineal fit for the annual surveys, $R^2= 0.5$). Females were always more abundant than males in the seasonal surveys data; however, males were more abundant than females in the deepest hauls of seasonal fleet monitoring. Sex ratio according to length showed an increment in the percentage of females in relation to length, i.e. males were more abundant in the smallest size classes and females predominated at sizes >28-30 mm CL.

Length at first maturity for females was estimated at 29.5, 27.0 and 28.5 mm CL for CA, SO and the combination of both locations, respectively. All males sampled were mature, so length at first maturity could not be calculated. Although maturing females were found all year round (maturity stages III and IV), two peaks were detected, one in November and a larger one in August and June (Figure 3.4a). There were no spatial differences in the GSI for females, but it showed significant differences between surveys, with the highest values in August (Figure 3.4b; Table 3.1). Significant differences were also obtained for this index in relation to depth, with the highest values at 350 m depth (Table 3.1). There was also an increasing trend with the maturity stage (Figure 3.4b). However, Kn showed significant differences between the two locations (Figure 3.4c; Table 3.1), with higher values in SO than in CA for both sexes. For females, differences in Kn were also found per survey, with two peaks, one in November and the other in June, and a decreasing trend with depth. Kn values also increased according to maturity stage in CA, and remained practically constant in SO (Figure 3.4c).

The summary values and statistics of the physical environmental parameters analysed are presented in Table 3.3. Significant differences were obtained in relation to depth (p=0.0001), and this variable accounted for the highest proportion of the explained variance (93.6%). Temperature values and the percentages of gravels and sands were higher at shallower depths, while the rest of the variables increased with depth (Figure 3.5). Significant differences were also detected between locations, but with a low proportion of the explained variance (3.7%). The differences were mainly due to the sediment granulometry, as gravel was predominant at SO at shallow depths. These differences in the sediment characteristics between locations were also clear when the percentage of silt and clays in relation to depth was considered (Figure 3.6a), with lower values in SO than CA in shallower waters and the opposite occurring between 300 m and 700 m depth. The dynamics of the main prey biomass at the 350 m station, which coincided with the maximum abundance of the deep water rose shrimp, showed higher values off SO (Figure 3.6b), which were marginally significant (t-test, p= 0.06) with maximum values in August and June. Minimal values were found in September and November.

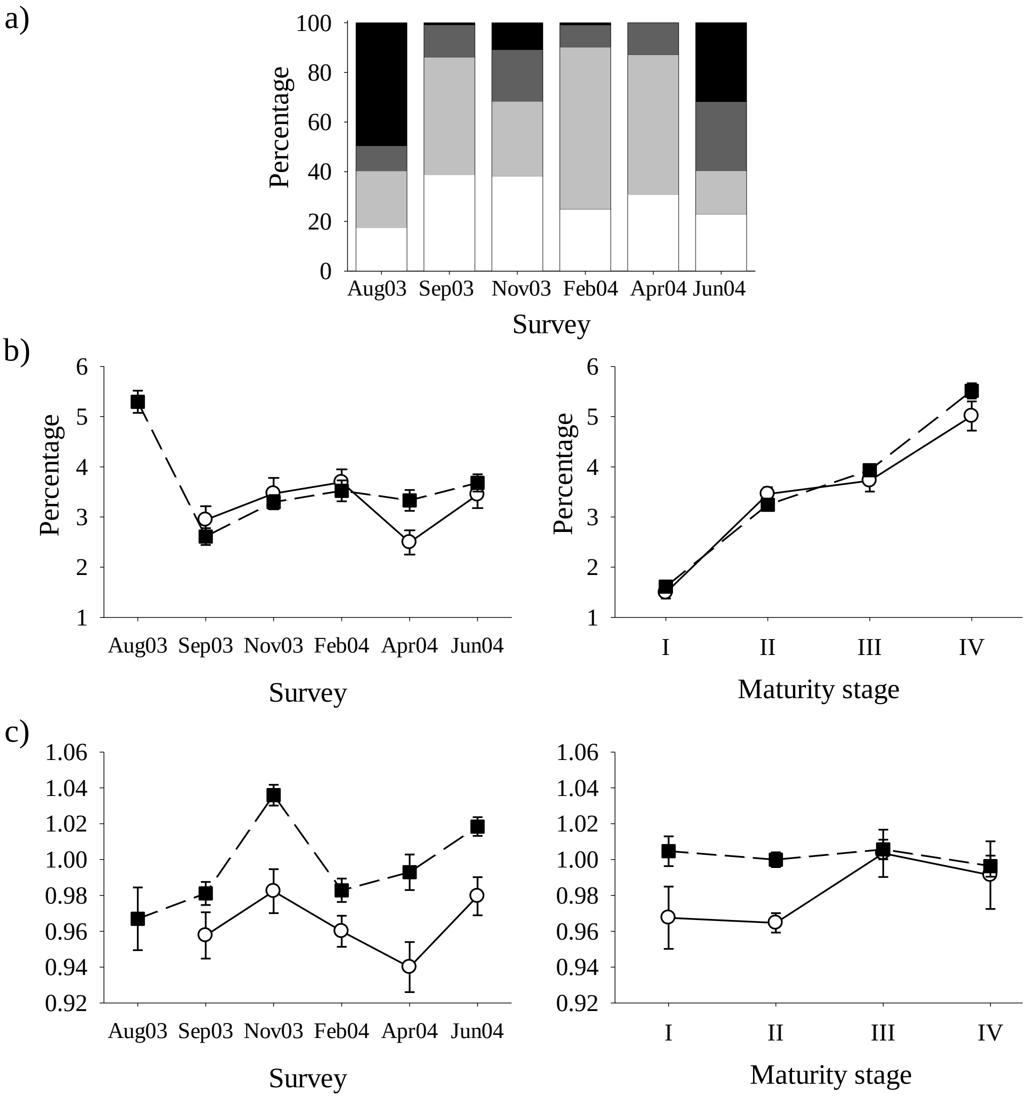


Figure 3.4. Percentage of each maturity stage (a; I: white; II: light grey; III: dark grey; IV: black; mature specimens correspond to stages III and IV), gonadosomatic index (b, GSI) and condition index (c, Kn) according to survey and location, and maturity stage and location, for females of *Parapenaeus longirostris* in the seasonal surveys. Cabrera: white circles and solid lines; Sóller: black squares and dashed lines. Error lines are standard errors.

Table 3.3. Summary values of the hydrographic variables (T and S) and sediment characteristics (OM, Φ, σ and percentage of gravel, sand, silt and clay), obtained in each survey at the two locations studied (CA: Cabrera; SO: Sóller), and the results of the redundancy analysis (RDA). The full RDA model contains all the variables included in the model: Depth (D), Location (L), Survey (S) and the interaction Location-Survey (LxS). The explained variance (EV) for the full model and each variable after extracting the effect of the co-variables is also indicated. Note that the sum of the variance explained for each variable is greater than 100% due to the shared variance. T: temperature; S: salinity; OM: organic matter; Φ: median; σ: inclusive graphic standard deviation.

		T (ºC)	S (psu)	OM (%)	Φ	σ	Gravel (%)	Sand (%)	Silt (%)	Clay (%)
CA	Aug'03	13.11±0.05	38.42±0.10	4.98±1.71	4.83±1.65	2.32±0.31	1.77	40.78	49.22	8.23
	Sep'03	13.13±0.05	38.43±0.09	4.70±2.13	4.35±1.83	2.16±0.35	3.52	41.47	47.47	7.54
	Nov'03	13.14±0.05	38.44±0.09	4.19±2.13	4.81±1.83	2.45±0.35	2.53	38.12	50.24	9.12
	Feb'04	13.19±0.14	38.43±0.12	4.13±1.43	4.98±2.51	2.04±0.36	2.03	34.43	52.30	11.25
	Apr'04	13.16±0.09	38.44±0.10	5.75±1.93	4.94±2.65	1.99±0.36	2.53	39.16	49.28	9.04
	Jun'04	13.11±0.06	38.45±0.10	5.97±1.97	4.37±2.36	2.11±0.36	2.38	44.58	45.56	7.49
SO	Aug'03	13.07±0.08	38.39±0.13	5.35±2.51	4.62±3.24	1.84±0.33	13.03	22.43	54.78	9.76
	Sep'03	13.14±0.10	38.42±0.11	5.51±1.90	4.12±2.43	2.23±0.27	8.18	38.97	46.62	6.23
	Nov'03	13.12±0.13	38.43±0.09	4.08±2.42	3.89±2.87	2.12±0.27	14.94	30.89	47.26	6.91
	Feb'04	13.15±0.18	38.40±0.12	4.25±2.42	4.88±3.10	2.12±0.29	9.58	23.85	55.95	10.63
	Apr'04	13.07±0.14	38.41±0.11	5.95±1.34	4.40±2.60	2.17±0.29	8.18	32.45	51.36	8.02
	Jun'04	13.09±0.08	38.46±0.09	6.91±2.02	4.47±2.94	1.97±0.31	10.85	26.30	54.24	8.61
RDA results		Effect	Covariance	Trace	EV	F-ratio	P			
		Full model		0.78		10.50	0.0001			
		D	L,S	0.73	93.59	127.10	0.0001			
		L	D,S	0.03	3.72	5.12	0.007			
		S	D,L	0.01	1.79	0.50	0.90			
		LxS	D,L,S	0.01	1.54	0.37	0.96			

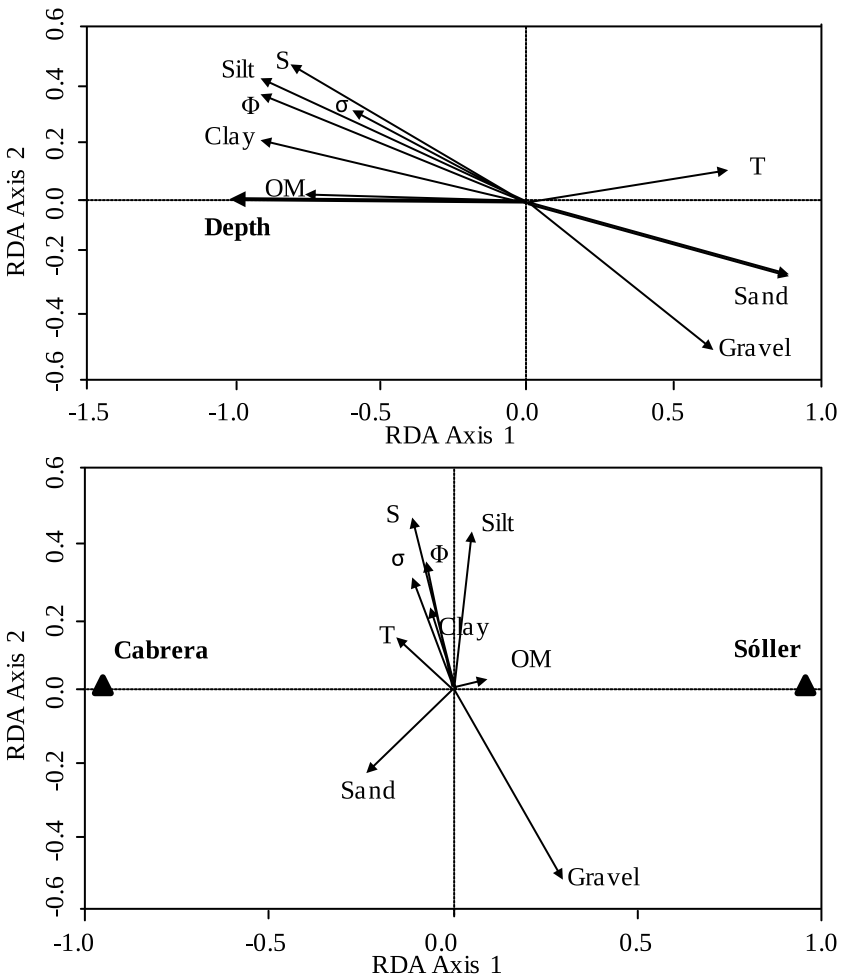


Figure 3.5. Results of the Redundancy Analysis (RDA) for the environmental variables matrix (T: temperature; S: salinity; OM: organic matter; Φ: median; σ: inclusive graphic standard deviation; sediment composition, as a percentage of granule, sand, silt and clay). In the top model, the variable location (Cabrera and Sóller) has been considered as covariable, while in the bottom model the covariable is depth.

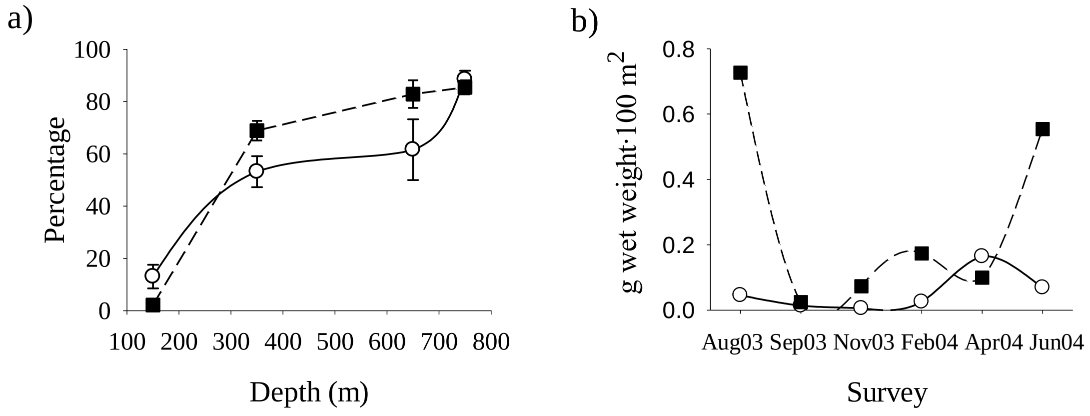


Figure 3.6. Percentage of silts and clays in sediments according to depth (a) and potential trophic resources for *Parapenaeus longirostris* in relation to season (b), at each location (Cabrera: white circles and solid lines; Sóller: black squares and dashed lines). Error lines are standard errors.

The results of the multiple linear regression showed that the environmental factors analysed influenced the juveniles more than the adults of deep water rose shrimp (Table 3.4). The most important factors were the bottom sediment characteristics and mean water salinity near the bottom, together with the abundance of potential preys. Juveniles were positively correlated to the percentage of silts, sands and clays and to the abundance of prey, while they were negatively correlated to the mean salinity near the bottom. These variables represented up to 91% of the variance explained. For adults, the significance of the models only explained 16% of variance, and was negatively correlated to the mean temperature near the bottom. The total population was negatively correlated to mean salinity and temperature and positively correlated to the prey, which explained 38% and 15% of variance for the abundance and biomass respectively.

Table 3.4. Summary results of the multiple linear regression of the standardised abundance (n/km^2) and biomass (g/km^2) of juveniles, adults and total population of *Parapenaeus longirostris* from the seasonal surveys, showing the response of the abundance and biomass to significant environmental variables. Variance explained in each model in brackets.

		Variable	Coefficient	p
Juveniles	n/km^2 (0.91)	Silt	5.300	0.003
		Mean salinity	-1.478	0.006
		Sand	6.852	0.004
		Clay	1.721	0.033
		Preys	0.400	0.130
		Organic matter	-0.411	0.078
	g/km^2 (0.87)	Silt	4.949	0.009
		Mean salinity	-1.586	0.011
		Sand	6.644	0.012
		Clay	1.807	0.056
		Preys	0.477	0.140
		Organic matter	-0.333	0.207
Adults	n/km^2 (0.16)	Mean temperature	-0.395	0.204
	g/km^2 (0.16)	Mean temperature	-0.383	0.219
Total	n/km^2 (0.38)	Mean salinity	-0.6801	0.043
		Preys	0.360	0.245
	g/km^2 (0.15)	Mean temperature	-0.384	0.218

3.4. Discussion

The population dynamics of the deep water rose shrimp in the Balearic Islands shows significant temporal differences both annually, concerning its abundance, and seasonally, concerning the biological and condition indexes analysed. Bathymetric differences were also detected in the abundance and in some biological parameters, such as the mean length and sex ratio, as well as in the condition of females. Spatial differences were also found between the two locations studied in the Algerian sub-basin (AsB, CA) and in the Balearic sub-basin (BsB, SO); adults were more abundant in the northwestern location (SO, BsB), where the condition index of both sexes and mean length were higher, while the length at first maturity for females showed the opposite trend, as it showed small values in this location. The bottom sediment and characteristics of the water masses, as well as the availability of potential trophic resources also seem to be important factors affecting the abundance of the deep water rose shrimp and could determine the differences found between the locations studied. Previous studies have suggested that the characteristics of water masses and substrate are factors that influence this species (Bombace, 1975; Ribeiro-Cascalho and Arrobas, 1987; Tom *et al.*, 1988; Nouar and Maurin, 2001).

The nearly complete absence of deep water rose shrimp on the Balearic shelf can be explained by the sediment characteristics at the bottom, as the lack of terrigenous muddy bottoms that originate from river run-off, means that this species is not distributed in as shallow depths as in other areas (20 m minimum depth; Sobrino *et al.*, 2005); 135 m was the minimum depth at which the shrimp was found in our study area. Similar results were obtained by Abad *et al.* (2007) in the Alboran Sea (southwestern Mediterranean), where rose shrimp was captured by the bottom trawl fleet between 150 and 350 m depth. However, this is not a general rule for the Mediterranean, as standardised MEDITS surveys reported the presence of this species from 50 m depth (Abelló *et al.*, 2002a). According to these authors, it is in these shallow waters that juveniles and larvae are usually found, while larger individuals are distributed in deeper waters, which is also reflected in our study by the increase in the mean length with depth. On a local scale, the high hydrographical variability between locations and differences in the geomorphology and sediments marked the variations found in the deep water rose shrimp between CA (AsB) and SO (BsB), southern and northwestern

Mallorca respectively. The slope in the BsB is steeper than in the AsB, where it is necessary to reach deeper bottoms in order to find the same sediment composition as in the BsB. This area is influenced more by the slope fronts, which transport the Western Mediterranean Intermediate Water (WIW) from the Gulf of Lions, one of the most productive areas in the Mediterranean owing to a number of oceanographic features, including a wide shelf, presence of submarine canons, river runoff, strong vertical mixing in winter and occasional coastal upwellings (Champalbert, 1996; Estrada, 1996; Bosc *et al.*, 2004; Canals *et al.*, 2006). These water masses, with low temperature (<13ºC) and salinity values, are mainly detected during late spring and summer in the Balearic Islands (López-Jurado *et al.*, 2001; Monserrat *et al.*, 2008; Fig. 3.7). Their presence increases he primary production in the area (Estrada, 1996), with the consequent enrichment of the trophic chain (Fernández de Puelles *et al.*, 2004). Cartes *et al.* (2008a) reported higher abundance of suprabenthos and zooplankton in the BsB than in the AsB, mainly in late spring and early summer when the WIW arrives to the Islands. Our results suggest that infauna and suprabenthos have a similar response to its dynamics at 350 m depth, with maximum biomass biomass in spring-summer. The highest CPUE values from the commercial trawl fleet for deep water rose shrimp were also obtained in spring. Therefore, the presence of muddy and more or less sandy sediments at depths with the highest productivity, which is refected in high availability of potential prey, marks the highest abundances for both juveniles and adults of the deep water rose shrimp in the northwestern location. However, in the southern, less productive location, juveniles and adults show different depths of maximum abundance (250 and 550 m, respectively) and a deeper distribution in order to find appropriate sediment characteristics, which are also probably favoured by the gentler slope at this location.

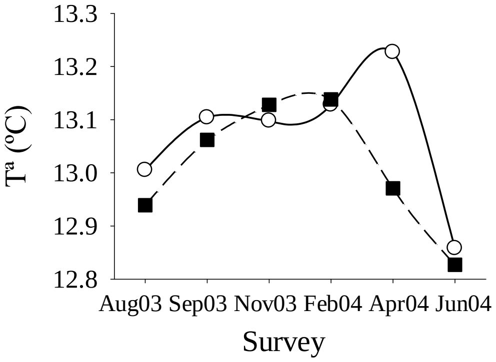


Figure 3.7. Minimum temperature in the water column, estimated from CTD SBE-911+ casts according to survey and location (Cabrera: white circles and solid lines; Sóller: black squares and dashed line), which indicates the presence of Western Intermediate Waters.

Both females and males were in a better condition in SO, the more productive location studied. Better condition in some fishes, modelled by lipid reserves, has been related to high productivity areas (Lloret *et al.*, 2002, 2005). This better condition is reflected not only in the condition index, but also in the allometric growth parameter. In the case of females, although seasonal differences in condition related to reproduction were detected, the higher values in SO were found all year round and for all the maturity stages. Other studies in the area showed a better condition in SO than in CA for the pandalids *Plesionika heterocarpus* and *Plesionika martia* (Chapter 4), for the red shrimp *A. antennatus* (Chapter 5) and for European hake *Merluccius merluccius* (L.) recruits (Hidalgo *et al.*, 2008), which confirms that the northwestern location is a more highly productive area than the southern location. The better condition of deep water rose shrimp in SO could be the reason for the smaller length at first maturity found for females there, as energetic condition has a positive effect on the probability of maturing (Baulier *et al.*, 2006). The values of length at first maturity estimated in our study are higher than those previously reported both in the Mediterranean (Levi *et al.*, 1995; Mori *et al.*, 2000; Ben Meriem *et al.*, 2001) and Atlantic (Ribeiro-Cascalho and Arrobas, 1987; Sobrino and García, 1994, 2007), and are similar to those reported by Spedicato *et al.* (1996), in the central Mediterranean. However, comparisons of the length at first maturity must be viewed with caution, as these values may be greatly influenced by sample size and composition (Mori *et al.*, 2000), especially if there is an absence of smaller lengths in the samples (Ben Meriem *et al.*, 2001). The differences between locations observed in our study cannot be attributed to any of these factors, because both areas show similar length frequency distributions, even with smaller specimens in CA than in SO.

The absence of a seasonal pattern in the abundance of juveniles reflects the continuous spawning found for this species in our study. Although high abundance of juveniles has been found for a certain season in some studies (for instance, during autumn in the central Mediterranean, Lembo *et al.*, 1999), continuous spawning is common both in the Mediterranean (Nouar, 1985; Tom *et al.*, 1988; Spedicato *et al.*, 1996; Mori *et al.*, 2000; Ben Meriem *et al.*, 2001; Bayhan *et al.*, 2005) and the Atlantic (Ribeiro-Cascalho and Arrobas, 1987; Sobrino and García, 1994; Dos Santos, 1998), with peaks of reproductive activity varying between areas without a clear trend. Our peaks of maximum spawning are reflected differentially in the biological indexes. Hence, maximum GSI values were detected in summer, while maximum Kn values were found in late spring and especially in autumn. This suggests that the spring-summer spawning period (especially summer) is more important than the autumn one, as the values of GSI are higher and the shrimp's condition is at its minimum in summer. As *P. longirostris* is iterouparous, the resource availability (higher in summer) may favour higher fecundity (GSI) in summer. According to Bayhan *et al.* (2005), the negative relationship between GSI and Kn is more pronounced during the period of most intense spawning. This lack of homogeneity in the seasonal behaviour of both parameters could be explained by the fact that larger mature females mainly spawn in spring and summer, whereas smaller adult females spawn in autumn (Sobrino and García, 2007), and the number of oocytes in the ovary increases significantly with length (Mori *et al.*, 2000). Thus, a higher number of oocytes in the mature ovaries of large females during summer is reflected in the highest GSI values, which also correspond to low Kn values. However, during the autumn spawning Kn presents high values, but the GSI is not as high as in summer.

The length-weight relationships suggest a negative allometry both for females and males, which has also been found in other studies both in the Mediterranean (Levi *et al.*, 1995) and the Atlantic (Ribeiro-Cascalho and Arrobas, 1987; Sobrino and García, 1994). Our results for the absolute growth agree with previous studies (see Sobrino *et al.*, 2005), which characterised the deep water rose shrimp as a fast growth species, with a life span of 2 to 3 years. Males grow faster than females and reach lower maximum lengths. Recent estimations of growth parameters, performed by quantification of the age pigment lipofuscin in the brains of this species (Vila, 2005), reported similar values to those found with more classical methods, which confirms the fast growth of deep water rose shrimp.

The highest CPUE values found for the species during spring in our study area agree with the season of maximum values observed by the commercial trawl fleet in the central Mediterranean (Sbrana *et al.*, 2006). Moreover, the decreasing trend found in the CPUE over the last years, which was confirmed by the annual surveys, has also been found in other areas in the western and central Mediterranean, such as the Iberian coast (GFCM, 2006) and the northern Tyrrhenian Sea (Sbrana *et al.*, 2006). This trend, however, differs from that found in the eastern Mediterranean (e.g. Sea of Marmara, Deval *et al.*, 2006a). The large fluctuations observed in Italian waters may be due not only to environmental conditions that greatly affect this short life span and fast growing species, but also to the different exploitation rates over the years (Sbrana *et al.*, 2006).

In the Balearic Islands, where the trawl fishing effort has not significantly changed over the last years (Chapter 1), the environmental conditions should be considered as the main factor affecting this species. The influence of environmental conditions (sediment, water masses and availability of prey), observed in our study in a short spatio-temporal range, should also be taken into account when long term trends are analysed. The importance of large scale factors on the population dynamics of deep water crustaceans has already been suggested (Relini and Orsi Relini, 1987; Carbonell *et al.*, 1999; Anderson, 2000; Lloret *et al.*, 2001; Wieland, 2004; Koeller *et al.*, 2007; Maynou, 2008). In our study area two oceanographic scenarios, associated with macro and meso-scale climate regimes, could influence the population dynamics of European hake and red shrimp (Massutí *et al.*, 2008). Although the annual data series available for the deep water rose shrimp is too short to analyse this matter further, it should be analysed in the future in order to obtain a wider view of the influence the environment has on this species.

The occurrence of adequate environmental characteristics, such as appropriate seafloor topography, sediment composition, hydrographical characteristics and prey availability seem to mark the short spatial and temporal differences found in the abundance, bathymetric distribution, biology and condition of the deep water rose shrimp in the Balearic Islands. This reflects the importance of the northwestern location as a high productivity area in the Archipelago, with trophic conditions acting as a link between geo-physical and biological changes.

CHAPTER 4.

PANDALIDAE

Adapted from “Small-scale differences in the distribution and population dynamics of pandalid shrimps in the western Mediterranean in relation to environmental factors”. Beatriz Guijarro, Emanuela Fanelli, Joan Moranta, Joan E. Cartes and Enric Massutí. (2012). *Fisheries Research* 119-120: 33-47.

Abstract

Pandalidae is one of the most diverse families of marine shrimps. The aim of this chapter was to study the short spatial and temporal patterns of pandalid shrimps in two locations sited in the Algerian sub-basin (AsB, Cabrera: CA) and in the Balearic sub-basin (BsB, Sóller: SO) that have different environmental regimes and determine the relationship between these patterns and the environmental conditions. Information was obtained from seasonal and annual surveys. The abundance and biomass of all the pandalid shrimps caught as well as the length, weight, sex and maturity stage of the most abundant species were recorded. Environmental parameters were obtained from seasonal surveys and included data on hydrography, trophic resources and sediment characteristics. Information about the bottom trawl fleet was obtained through fleet monitoring and daily landings data were obtained from sales records. Pandalid shrimps showed clear spatial differences in their population dynamics between the AsB and the BsB, which could be related to the different environmental conditions of the two sub-basins. The relative importance of pandalid shrimps of the genus *Plesionika* in the slope crustacean communities was higher in the AsB. The abundances of *Plesionika martia*, *Plesionika acanthonotus*, *Plesionika giglioli* and *Plesionika antigai* were higher in the AsB, and only *Plesionika heterocarpus*, the most benthic species among those analysed, was more abundant in the BsB, where trophic webs are supported largely by suprabenthos rather than zooplankton biomass. Water masses also play an important role in their distribution, but their influence depends on the specific bathymetric distribution. The mean length of *P. heterocarpus* was higher in the BsB, and that of *P. martia* was higher in the AsB. The condition index was higher in the BsB than in the AsB for both *P. heterocarpus* and *P. martia*. This could be because the BsB is influenced to a greater extent by slope fronts that increase the primary production in the area, and thus enrich the trophic chain. The condition index also showed seasonal differences, related to the reproductive cycle and to the availability of potential food resources.

Keywords: Pandalidae, spatio-temporal variations, trophic webs, reproduction, hydrography, condition, prey availability.

4.1. Introduction

Decapod crustaceans are a dominant or subdominant faunal component in subtemperate to subtropical assemblages, such as in the Mediterranean Sea. This is probably because they are more competitive in oligotrophic environments as in the Mediterranean sea, unlike in the nearby Atlantic Ocean where fish always dominate, and they are a key taxon linking the lower and higher trophic levels (Cartes and Sardà, 1992). Decapod crustaceans represent a very important fraction of demersal communities (Moranta *et al.*, 2008b), both on the continental shelf and especially on the slope. Among them, Pandalidae constitutes one of the most diverse families of marine shrimp. Pandalid shrimps have a broad distribution in both the Northern and Southern Hemispheres, and a wide bathymetric distribution, from the shelf to bathyal depths. It is one of the most commercially important prawn families, is abundant within decapod crustacean assemblages (Abelló *et al.*, 1988; Cartes and Sardà, 1993) and has an important ecological function due to its trophic role (Cartes *et al.*, 2002; Fanelli and Cartes, 2008).

Most studies on spatial variations of pandalid shrimps focus mainly on the vertical zonation, or bathymetric gradient (e.g. Carbonell and Abelló, 1998; Scigliano *et al.*, 2007), because it is considered the main factor behind faunistic changes. Although there are fewer studies on the horizontal zonation, there are works that analyse the spatial distribution at a regional level and that relate the differences between decapod communities to geomorphological and oceanographic characteristics (Abelló *et al.*, 1988, 2002b) or to different surface production regimes and food web organisations (Maynou and Cartes, 2000). Other environmental factors that affect the distribution of pandalid shrimp are the presence of detached intermediate nepheloid layers (i.e., layers of water above the ocean floor that contain significant amounts of suspended sediment) and light intensity. It has been suggested that detached intermediate nepheloid layers are potential deep water nursery habitats because a higher occurrence of juveniles and females has been detected in these areas (Puig *et al.*, 2001). Light intensity also affects the catchability of pandalid shrimp, as they show migratory and rhythmic movements in relation to the day–night cycle (Cartes *et al.*, 1993; Aguzzi *et al.*, 2007).

Nine species of pandalid shrimp have been found in the Mediterranean: *Chlorotocus crassicornis*, *Pandalina profunda*, *Plesionika acanthonotus*, *Plesionika* *antigai*, *Plesionika edwardsii*, *Plesionika giglioli*, *Plesionika heterocarpus*, *Plesionika martia* and *Plesionika narval* (Carbonell and Abelló, 1998; Vafidis *et al.*, 2005). Although they have a wide bathymetric range, their specific distribution is restricted to certain depth ranges, following a general pattern of species substitution and increasing size with depth (e.g. Carbonell and Abelló, 1998; Maynou and Cartes, 2000; Vafidis *et al.*, 2005). Pandalidae can be included in a trophic guild that mainly exploits benthopelagic resources, preying on euphausiids and mesopelagic decapods, although some species exploit other compartments (Labropoulou and Kostikas, 1999; Cartes *et al.*, 2002; Fanelli and Cartes, 2004). Pandalid shrimps are caught as by-catch by the bottom trawl fishery and sold with other species (Chilari *et al.*, 2005; Vafidis *et al.*, 2005) or discarded (Machias *et al.*, 2004). Some species (*P. edwardsii* and *P. narval*) are also caught with traps and can be of considerable commercial value (García-Rodríguez *et al.*, 2000; Colloca, 2002).

Although there is much information on some pandalid shrimp species in the Mediterranean (see Vafidis *et al.*, 2005 for a review), there is little information on this group in the Balearic Islands. The only available studies are related to potential fisheries with traps (Massutí, 1967), the biology of *P. edwardsii* (García-Rodríguez *et al.*, 2000) and the feeding habits and trophic levels of *P. heterocarpus* and *P. martia* (Fanelli and Cartes, 2008). As in other areas, pandalid shrimps are caught as a by-catch by the trawl fleet and marketed as a mixture (*gambussí*) composed of species of the genera *Plesionika* and *Pasiphaea* (Chapter 1). These genera represent a relatively small catch in the slope fishery (Vafidis *et al.*, 2005).

The main objective of this study was to analyse the relations among several environmental conditions (hydrography, trophic resources and sediment characteristics) and their impacts on the short scale spatial (two nearby locations) and temporal (seasonal and annual) patterns of pandalid shrimps off the Balearic Islands. This main objective was divided into three further aims: (i) to study the population dynamics (abundance, biomass, bathymetric distribution and size composition), biology (sex ratio and maturity) and condition of the shrimps; (ii) to compare these at two locations with different environmental conditions; and (iii) to explore the relationship between the abundance and biomass of pandalid shrimps and certain environmental variables.

4.2. Materials and methods

4.2.1. Data source

Information related to the abundance, biomass and length frequency distribution of all the pandalid shrimps caught during the seasonal bottom trawl surveys (see Chapter 2) was obtained, as well as biological information – individual carapace length and weight, sex and maturity stages for females according to Company and Sardà (1997) and Fanelli and Cartes (2008) – of the most abundant species. Standardised abundance (n/km^2) and biomass (g/km^2) were calculated according to survey and locations.

The information obtained from the fishery consisted in the biomass landed for the mixed category *gambussí*, from the daily sale bills from 2000 to 2007 and its species composition, from the on board monitoring during the seasonal fleet monitoring (see Chapter 2). These data were available separately for the fleet, which operates in both locations: Cabrera (CA, AsB, S area) an Sóller (SO, BsB, W area)

The abundance and biomass of each species were determined from the annual surveys between 2001 and 2007 (see Chapter 2)

Environmental data was obtained during the seasonal oceanographic surveys (see Chapter 2), including hydrographic parameters (water temperature and salinity), density of potential trophic resources and sediment characteristics.

4.2.2. Data analysis

Standardised catch per unit effort (CPUE, as kg/day per boat) of *gambussí* was obtained by month and location from the daily sales records considering only those fishing trips made at depths where this category is potentially caught (middle slope, see Chapter 2 for further information on fleet segmentation). This information was obtained for two ports in Mallorca, Palma and Sóller, whose fleets operate in CA and SO, respectively. Between these two areas, there is an annual fleet displacement from CA towards SO between May and September (Moranta *et al.*, 2008b), and therefore the daily sales records from these months were assigned to SO.

The specific composition of the mixed category *gambussí* was estimated separately for CA and SO from the on board monitoring as the percentage of total weight. Combining this with the standardised CPUE, a new standardised CPUE was computed considering only pandalid shrimps. Data were log-transformed to obtain data normality and homogeneous variances, and an analysis of variance (ANOVA) was carried out with season, year and location as factors.

Seasonal data were analysed considering the two locations (CA and SO), while for the annual data we considered four areas (W, N, S and E). Two separate three-way ANOVA were performed, one for the seasonal surveys (with depth, location and season as factors) and one for the annual surveys (with depth, location and year as factors). To avoid an excessive number of zeros in the matrices only the abundances (n/km^2) and biomasses (g/km^2) of the species with an occurrence percentage larger than 10% were used. As before, data were log-transformed to obtain data normality and homogeneous variances. The bathymetric distribution of the five most abundant pandalid shrimps was calculated quantitatively using the centre of gravity (COG; Daget, 1976) and habitat width (HW; Pielou, 1969) analyses separately for the annual and seasonal surveys. The COG model was used to calculate the centre of the species distribution and locate it precisely by means of a descriptor (in this case, depth). The HW model provides a measure of heterogeneity of the species distribution. The two values were determined as follows: $COG = (x_1 + 2x_2 + 3x_3 + \ldots + nx_n)/\Sigma(x_i)$, where x_i represents the calculated mean abundance values of species x present in stratum i (before the analysis the sampled depth was divided into strata of 100 m), and $HW = e^{H'}$, where e is the exponential function and H' is the Shannon–Wiener function ($H' = -\Sigma_i(p_i \ln(p_i))$), where p_i is the relative abundance of the species in each stratum i. These models are very useful for analysing spatial and temporal variations in the bathymetric distribution of the species and have been applied in previous studies of demersal communities (e.g. Stefanescu *et al.*, 1992; Moranta *et al.*, 1998; Labropoulou and Papaconstantinou, 2000; Labropoulou *et al.*, 2008).

General Additive Models (GAM; Hastie and Tibshirani, 1990) were used to assess relationships between the density of the most abundant species and environmental variables obtained from the seasonal surveys. This statistical tool can be used to analyse the density dependent and density independent effects on population dynamics (e.g. Ciannelli *et al.*, 2004). We used the classic general model. GAM were carried out with the R package, using variations of GAM formulations as implemented in the mgcv library (Wood, 2004). A Gaussian distribution was used with log-transformed data. The model selection criterion was based on minimising the generalised cross validation (GCV). The lowest GCV indicates the best compromise between model complexities (e.g. number of parameters) and observed data. The continuous environmental variables included in the model were the mean temperature and salinity above the bottom, abundance of the suprabenthos and zooplankton (as potential trophic resources) and the percentage of mud (fraction of silts and clays in the sediment composition). Location and season were included as factors. Both the non-linear and linear components for each variable were penalised. As few individuals of the other species were caught, further analyses were only carried out for *P. heterocarpus* and *P. martia*, except in the case of the sex ratio, which was analysed for *P. heterocarpus*, *P. giglioli*, *P. martia* and *P. acantonothus*. Length frequency distributions obtained from the seasonal surveys were determined in relation to location and season. Geographical and seasonal differences in mean length (carapace length in mm), sex ratio (as the percentage of females) and percentage of ovigerous females were tested with an analysis of variance (two-way ANOVA) for these two species. When these factors were not found to be significant, another ANOVA was used to test bathymetric differences. Length at first maturity was calculated considering only the period of maximum reproductive activity for females by fitting a logistic curve using the least-squares method. The relative condition index (Kn; Le Cren, 1951) was calculated by sex for the two species as the observed weight over the expected weight, estimated from a length–weight relationship calculated considering all the biological data available. Seasonal and geographical differences were also tested using two-way ANOVA.

4.3. Results

Eight pandalid shrimp species were found during the annual and seasonal bottom trawl surveys carried out around the Balearic Islands (Table 4.1): *C. crassicornis*, *P. acanthonotus, P. antigai*, *P. edwardsii*, *P. giglioli*, *P. heterocarpus*, *P. martia* and *P. narval*. They were distributed in a wide bathymetric range, from around 200 m to more than 700 m depth at the deepest stations sampled. The most important species, both in terms of abundance and biomass, were *P. heterocarpus* and *P. martia*, while *C. crassicornis* and *P. narval* could be considered as occasional species. The other four species (*P. acanthonotus*, *P. antigai*, *P. edwardsii* and *P. giglioli*) had intermediate values.

Table 4.1. Number of hauls in which each species was caught (N), number of individuals caught (n), range of bathymetric distribution (BR, in m), percentage of occurrence (% O), of abundance (% A) and of biomass (% B) of the pandalid shrimp found in the Balearic Islands, from the seasonal and annual bottom trawl surveys. Bathymetric range sampled during each survey is shown in brackets.

Seasonal bottom trawl surveys (138-752 m)						
Species	N	n	BR	% O	% A	% B
C. crassicornis	-	-	-	-	-	-
P. acanthonotus	37	2909	181-752	51.39	19.41	11.30
P. antigai	14	711	252-661	19.44	4.29	1.40
P. edwardsii	3	934	251-356	4.17	5.31	7.56
P. giglioli	21	1197	337-735	30.56	8.25	5.03
P. heterocarpus	18	3705	248-663	25.00	24.57	15.57
P. martia	35	5457	581-752	48.61	36.43	57.41
P. narval	1	294	255-255	1.39	1.73	1.71

Annual bottom trawl surveys (38-755 m)						
Species	N	n	BR	% O	% A	% B
C. crassicornis	5	4	328-442	1.26	0.03	0.02
P. acanthonotus	54	1075	358-755	13.57	3.14	2.13
P. antigai	46	2386	327-668	11.56	8.11	4.00
P. edwardsii	17	4215	269-664	5.03	11.34	21.88
P. giglioli	67	3405	316-738	16.83	10.52	6.68
P. heterocarpus	48	18307	253-744	12.06	51.56	39.80
P. martia	79	3858	367-755	19.10	15.23	25.48
P. narval	10	25	327-629	2.51	0.07	0.02

Clear differences were found in the composition of *gambussí* between the two locations studied (Figure 4.1a): Pandalidae (represented mainly by *P. martia*) made up more than 90% of the biomass in the southern location (CA, AsB) but less than 50% in the northwestern location (SO, BsB). In this last location, Pasiphaeidae (represented mainly by *Pasiphaea multidentata*) made the largest contribution to the total biomass (around 50%). The presence of other families (Aristeidae, Penaeidae, Sergestidae, Oplophoridae, Processidae and Solenoceridae) was quite low in both locations. Total annual commercial landings for the period 2000–2007 of the mixed category of *gambussí* shrimps in the Balearic Islands varied between 30 and 50 t per year. No seasonal differences were detected in the pandalid CPUEs (ANOVA, p> 0.05), but annual and spatial differences were found (two-way ANOVA; year p< 0.001; location p< 0.001; year x location p< 0.01). Mean annual CPUEs in CA (6–11 kg/day per boat) were higher than in SO (2–4 kg/day per boat, Figure 4.1b). Although the annual trend was more marked in CA than in SO, in both cases a maximum value was recorded around 2002, followed by a decreasing trend until 2006 when CPUE values seemed to recover.

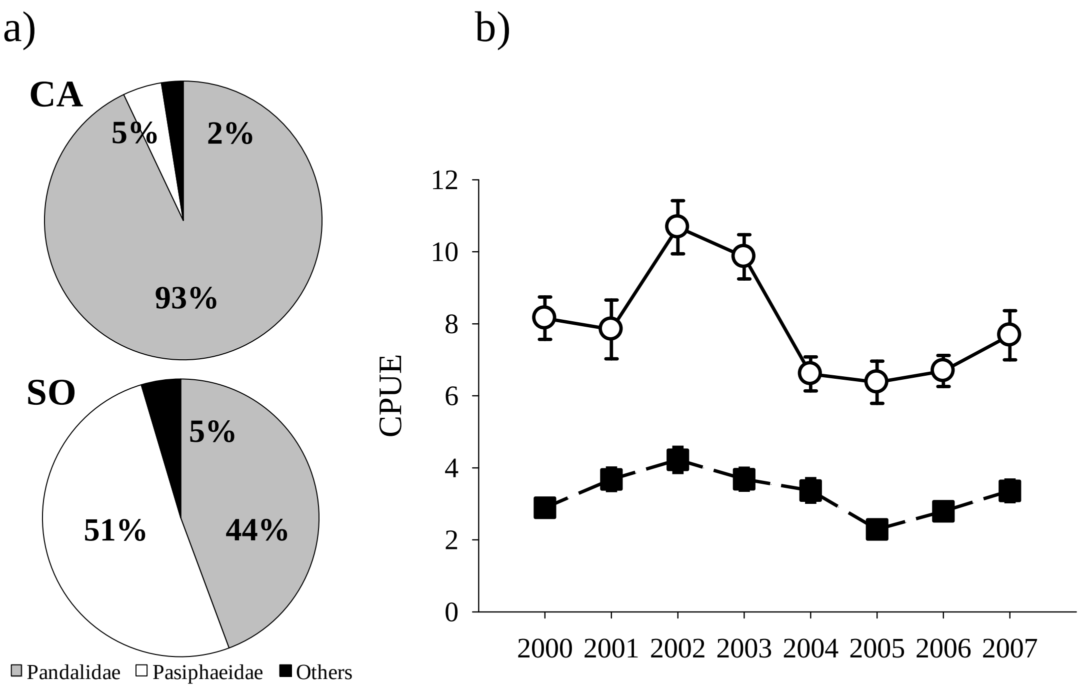


Figure 4.1. (a) Catch composition (as a percentage of total weight) of the commercial category *gambussí* and (b) catch per unit effort (CPUE, in kg/day per boat) of pandalid shrimps from two ports of Mallorca, whose fleets operate in the southern (CA: Cabrera; white circles and solid line) and northwestern (SO: Sóller; black squares and dashed lines) fishing grounds of the island. Error bars are standard errors.

Bathymetric differences in the abundance and biomass of all the species analysed were found in the seasonal and annual surveys: *P. antigai*, *P. giglioli* and *P. heterocarpus* had a shallower bathymetric distribution, and *P. martia* and *P. acanthonotus* had a deeper distribution. Geographical differences were also significant, and the density of all the species was generally higher in the AsB (S, including CA, and E), except for *P. heterocarpus*, which was more abundant in the BsB (W, including SO). No seasonal variability was detected for any of the species and annual variability was only detected for the deepest species (*P. martia* and *P. acanthonotus*). *P. martia* was more abundant during the years 2001, 2002 and 2007 (Figure 4.2; Table 4.2). The highest CPUE values for the commercial fleet for the mixed category *gambussí* were reached in 2002 and 2003 (Figure 4.1.b).

The significant interactions between location and depth indicate that the bathymetric distribution of the species varied between locations. The COG analysis provided a graphical interpretation of these variations in the bathymetric patterns of the different species (Figure 4.3). *P. antigai* showed a similar COG in the two locations and the four areas. However, both *P. heterocarpus* and *P. giglioli* had a shallower distribution in the BsB. Although no spatial differences were found with the COG between CA and SO for *P. martia* in the seasonal surveys, the species had a shallower distribution in the BsB (W and N) than in the AsB (E and S) in the annual surveys. Different results were obtained with the two datasets for *P. acanthonotus*: in the seasonal surveys it showed a shallower distribution in the AsB (CA), while in the annual surveys it showed a shallower distribution in the BsB (W).

The environmental variables influenced the abundance and biomass of the various pandalid shrimps differently during the seasonal surveys (Table 4.3; Figure 4.4). Season was a significant factor for *P. giglioli*, *P. martia* and marginally for *P. acanthonotus* (p= 0.072). Location was also significant for three of the species, both for abundance and biomass, with higher values in CA than in SO for *P. acanthonotus* and *P. antigai*, while the opposite was found for *P. heterocarpus*. Temperature was only significant for *P. heterocarpus*, and showed a non-linear increasing trend. Salinity affected the abundance and biomass, and showed a non-linear increasing trend for all the species except *P. antigai*, for which a non-linear decreasing trend was observed. The presence of prey resources also influenced the shrimp species differently: the abundance of suprabenthos influenced the density of *P. giglioli* and *P. heterocarpus,* while the abundance of zooplankton was significant for *P. giglioli* and *P. martia*. The percentage of mud on the bottom, as a proxy of sediment characteristics, was only significant for *P. heterocarpus*.

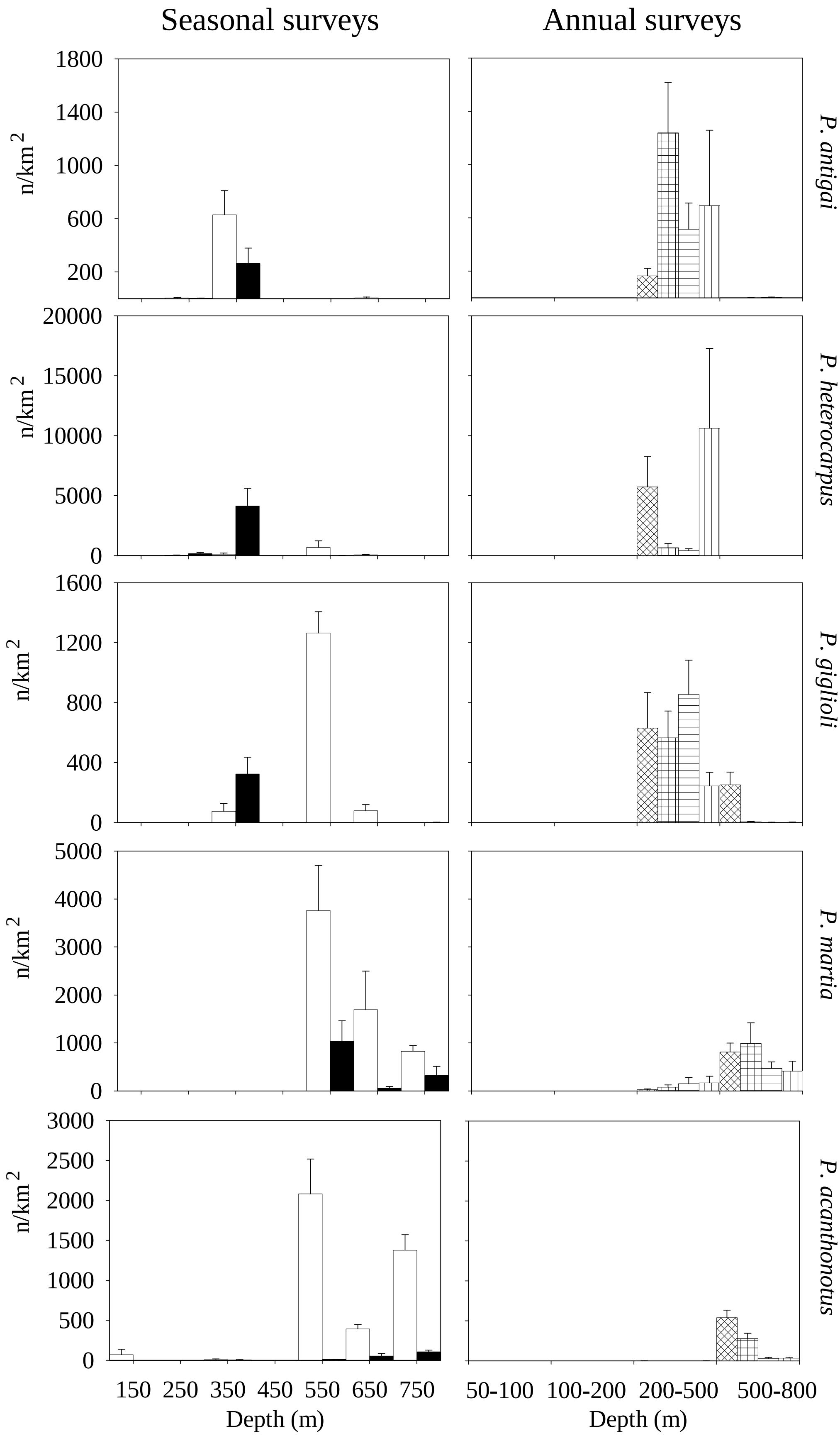


Figure 4.2. Abundance (n/km^2) in relation to depth for the five most abundant pandalid shrimps from the seasonal and annual bottom trawl surveys at each location (CA: Cabrera; SO: Sóller) and area (S, E, N, W) studied in the Balearic Islands. Error bars are standard errors.

Table 4.2. Summary of the results of the analysis of variance (ANOVA) for the seasonal and annual surveys for pandalid shrimp abundance and biomass, showing the significance of the factors: season (S), depth (D), location (L), year (Y) and the interaction depth x location (DxL). ns: not significant.

Seasonal surveys						
		P. antigai	*P. heterocarpus*	*P. giglioli*	*P. martia*	*P. acacanthonotus*
Abundance	S	ns	ns	ns	ns	ns
	D	<0.001	<0.001	<0.001	<0.001	<0.001
	L	ns	ns	<0.001	<0.001	<0.001
	DxL	ns	<0.001	<0.001	<0.001	<0.001
Biomass	S	ns	ns	ns	ns	ns
	D	<0.001	<0.001	<0.001	<0.001	<0.001
	L	ns	ns	<0.001	<0.001	<0.001
	DxL	ns	<0.001	<0.001	<0.001	<0.001
Seasonal fleet monitoring						
		P. antigai	*P. heterocarpus*	*P. giglioli*	*P. martia*	*P. acacanthonotus*
Abundance	S	ns	ns	ns	<0.001	<0.01
	D	<0.001	<0.001	<0.001	<0.001	<0.001
	L	<0.001	<0.001	<0.001	ns	<0.001
	DxL	<0.001	<0.001	<0.001	<0.05	<0.001
Biomass	S	ns	ns	ns	<0.001	<0.01
	D	<0.001	<0.001	<0.001	<0.001	<0.001
	L	<0.001	<0.001	<0.001	ns	<0.001
	DxL	<0.001	<0.001	<0.001	<0.05	<0.001

The length frequency distributions of *P. heterocarpus* did not show differences between locations and/or seasons, except in April 2004, when small individuals were found in CA, and February and June 2004, when no individuals were caught in CA (Figure 4.5). The length frequency distributions of *P. martia* were also very similar in both locations and throughout the year, although some small individuals were detected in November 2003. The mean length of the two species showed a significant increasing trend with depth (Table 4.4), but it also showed significant spatial differences. For the same depth, the mean length of *P. heterocarpus* was larger in SO than in CA, while the opposite trend was found for *P. martia*. No seasonal differences were found.

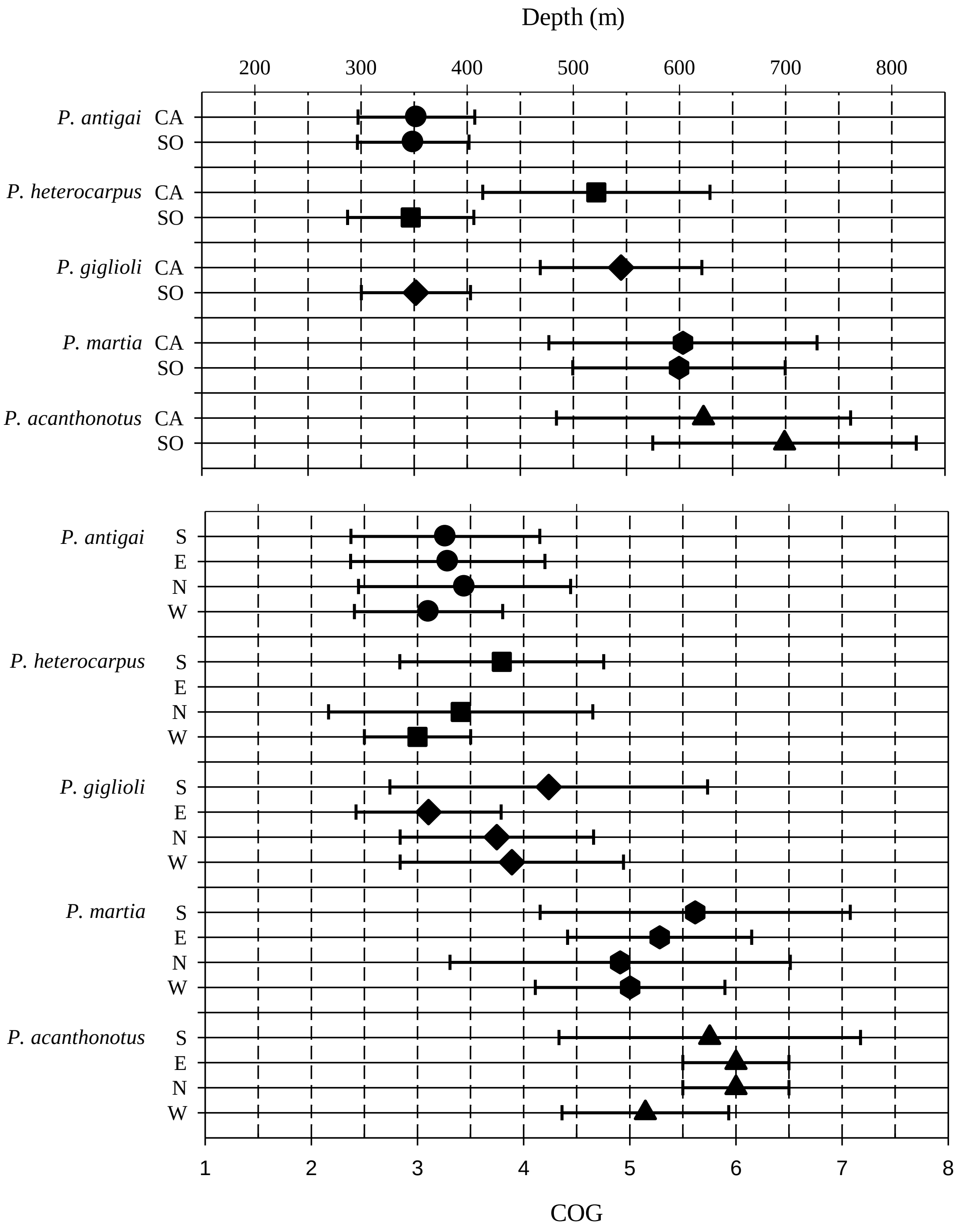


Figure 4.3. Bathymetric distribution of the five most abundant pandalid shrimps in the Balearic Islands by location (CA: Cabrera; SO: Sóller) and area (S, E, N, W), for the seasonal (up) and annual (down) bottom trawl surveys. Symbols represent the centre of gravity (COG) and error lines represent the habitat width (HW).

Table 4.3. Results of generalised additive models (GAM) applied to the five most abundant pandalid shrimps in the Balearic Islands from the seasonal surveys for the dependent variable (abundance in n/km^2 and biomass in g/km^2). Temp.: temperature; Suprab.: suprabenthos abundance; Zoo: zooplankton abundance; Mud: percentage of silt and clay; DE: deviance explained; ns: not significant.

Abundance					
Species	*P. antigai*	*P. heterocarpus*	*P. giglioli*	*P. martia*	*P. acanthonotus*
Season	ns	ns	<0.05	<0.05	<0.1
Location	<0.05	<0.01	ns	-	<0.01
Temp.	-	<0.001	ns	-	-
Salinity	<0.001	<0.1	<0.05	<0.001	<0.001
Suprab.	ns	<0.1	<0.05	-	-
Zoopl.	-	-	<0.05	<0.1	-
Mud	-	<0.05	-	-	-
GCV	2.4896	3.3685	2.7361	1.2499	1.6401
R^2	0.732	0.858	0.692	0.896	0.843
DE (%)	78.9	93.5	83.9	91.4	87.6
Biomass					
Species	*P. antigai*	*P. heterocarpus*	*P. giglioli*	*P. martia*	*P. acanthonotus*
Season	ns	ns	-	<0.1	<0.1
Location	<0.05	<0.05	-	ns	<0.01
Temp.	-	<0.001	ns	-	-
Salinity	<0.001	<0.1	<0.1	<0.001	<0.001
Suprab.	-	<0.1	<0.05	-	-
Zoopl.	-	-	-	ns	-
Mud	-	<0.05	ns	-	-
GCV	2.9948	4.7513	3.9817	1.3045	2.2486
R^2	0.694	0.854	0.577	0.942	0.835
DE (%)	74.4	93.5	71.9	95.7	87

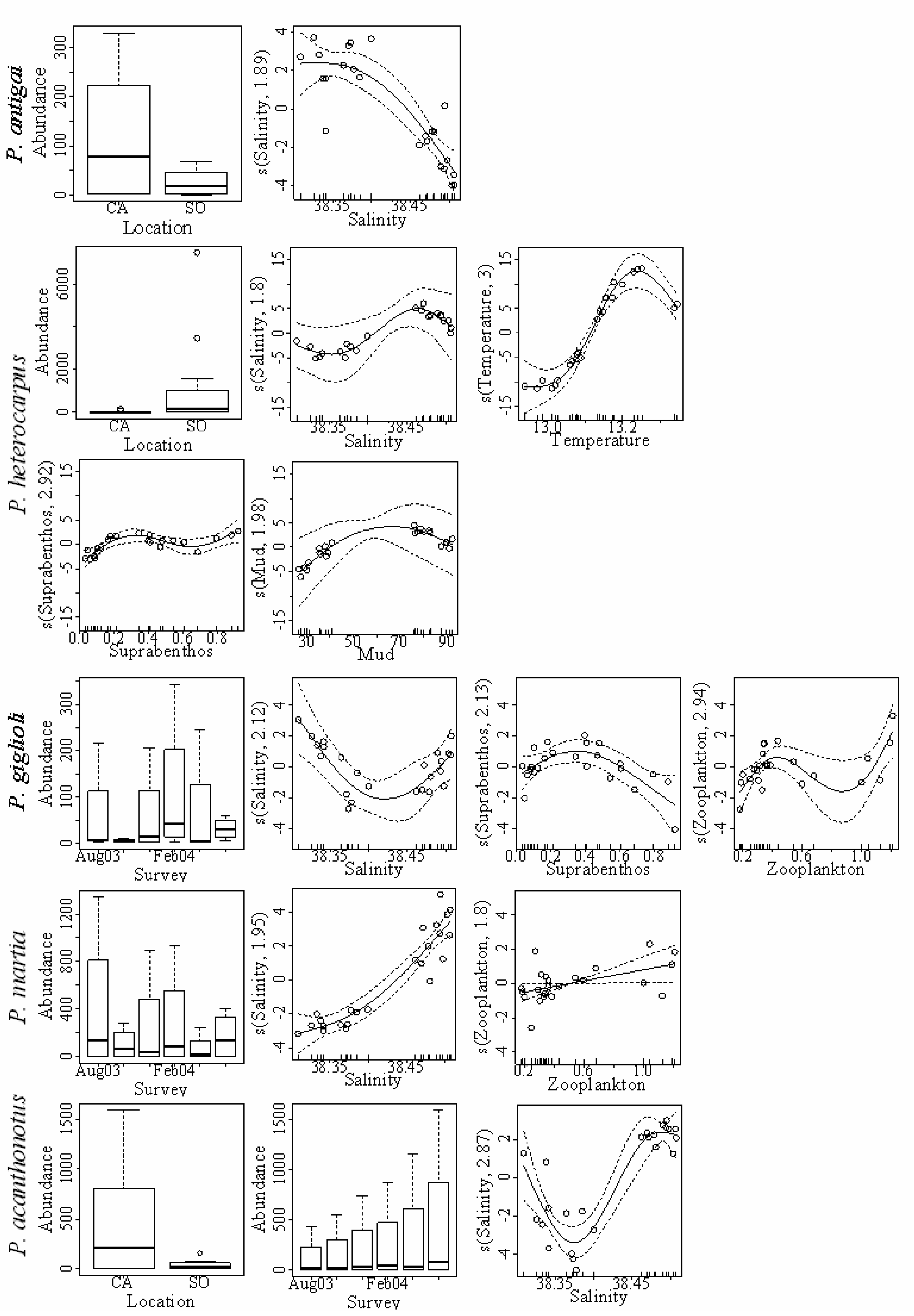


Figure 4.4. Plots of the best significant generalised additive models (GAM) applied to the five most abundant pandalid shrimps in the Balearic Islands. The effects of the significant environmental variables on the abundance (n/km^2) of these shrimps are shown for the seasonal surveys. CA: Cabrera; SO: Sóller. Standard error areas are also shown.

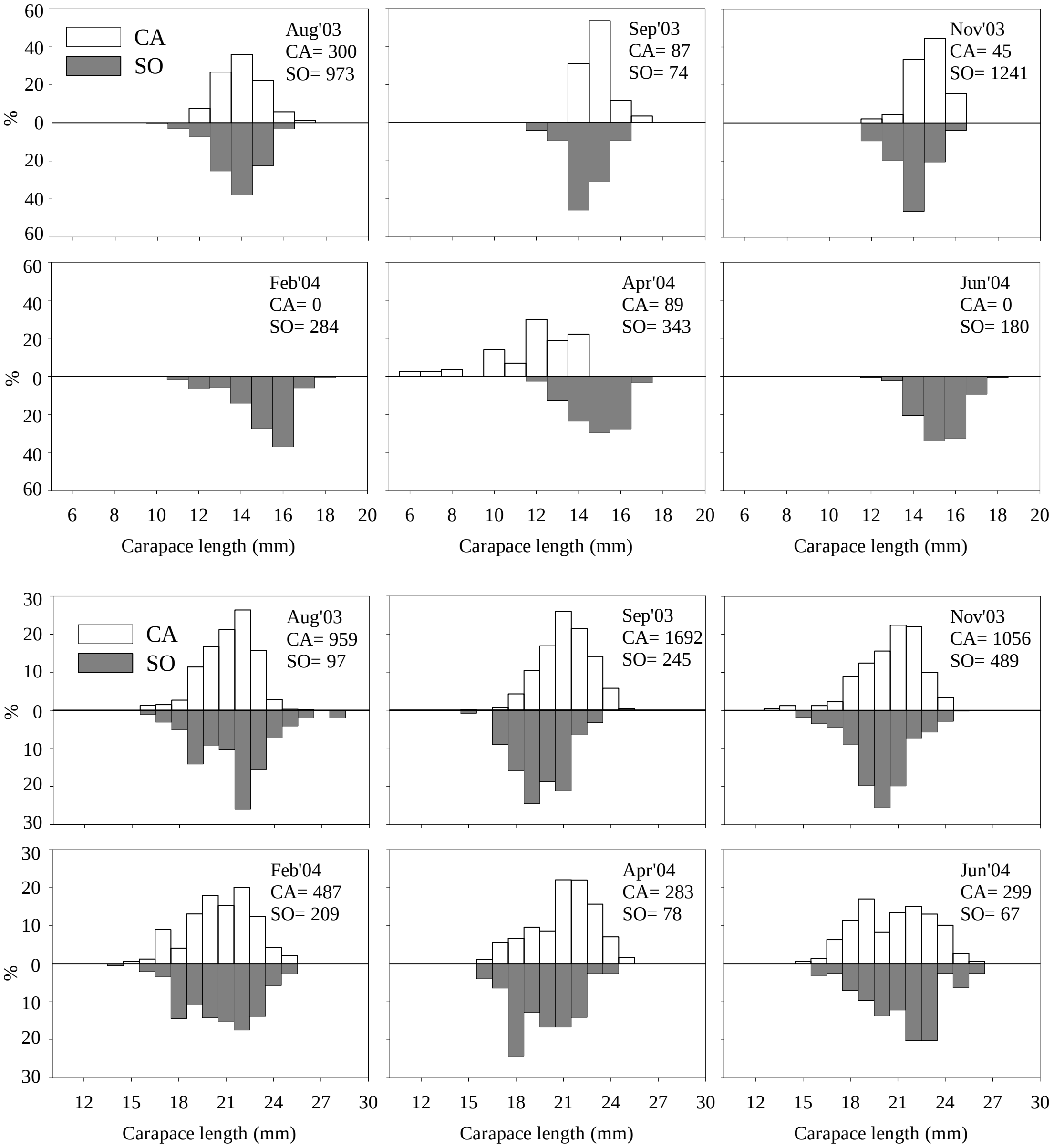


Figure 4.5. Length frequency distributions of *P. heterocarpus* (up) and *P. martia* (down) for the seasonal surveys by location (CA: Cabrera; SO: Sóller) and season. Numbers indicate individuals measured.

The sex ratio of *P. acanthonotus* and *P. heterocarpus* did not show any significant differences for any of the factors analysed, with mean values of 68% and 74% females, respectively. The sex ratio did not show significant differences between locations and seasons for either *P. giglioli* or *P. martia*; however, one-way ANOVA showed bathymetric differences in the percentage of females, which had higher values in the deepest samples in both cases, increasing from 54% to 75% females in the first case ($p < 0.05$) and from 56% to 73% females in the second case ($p < 0.01$).

Table 4.4. Mean length (carapace length; mm) for *P. heterocarpus* and *P. martia*, by location (CA: Cabrera; SO: Sóller) and depth from the seasonal surveys, and results from the post hoc test. Two-way ANOVA results are also shown. *: p< 0.05; **: p< 0.01; *** p< 0.001.

P. heterocarpus			*P. martia*		
Depth (m) *	Location *		Depth (m) ***	Location ***	
	CA	SO		CA	SO
250	9.1	13.0	250	-	-
350	12.7	14.6	350	-	-
550	14.4	-	550	20.3	19.8
650	14.5	-	650	21.1	19.1
750	-	-	750	22.4	21.7
Post Hoc Test	CA<SO; 250= 350< 550< 650		Post Hoc Test	CA>SO; 550= 650< 750	

The percentage of ovigerous females of *P. heterocarpus* was higher than 80% in all the seasons, without seasonal or geographical differences. Small individuals were very scarce, so it was not possible to calculate length at first maturity. However, *P. martia* showed a clear spawning peak during late spring–summer (April–September, Figure 4.6). The maturity curve was very similar for the two locations with a similar length at first maturity: 18.0 and 17.7 mm CL for CA and SO, respectively.

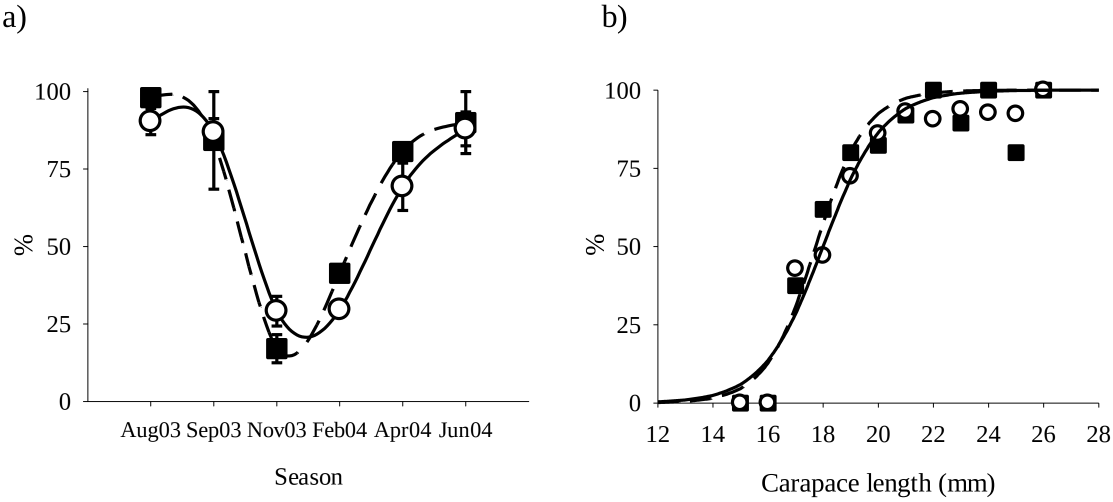


Figure 4.6. Percentage of ovigerous *P. martia* females by season and location (a), and by size class (b), for each location for the seasonal bottom trawl surveys. Maturity curves by location, considering only the main spawning period (April–September), are also shown. CA: Cabrera (white circles and solid line); SO: Sóller (black squares and dashed lines). Error bars are standard errors.

The relative condition index showed significant differences for location and season for *P. heterocarpus* and *P. martia* (Figure 4.7). In all cases, Kn values were higher in SO than in CA ($p < 0.001$ for females and $p < 0.05$ for males of *P. heterocarpus*; $p < 0.001$ for females and $p < 0.01$ for males of *P. martia*). Minimum Kn values were found in late spring–summer (June 2004 and August 2003) for females ($p < 0.001$) and males ($p < 0.05$) of *P. heterocarpus*. For *P. martia*, minimum values also occurred in summer (August 2003) for both sexes ($p < 0.001$ for females and $p < 0.001$ for males), with two maximums for females (September 2003 and June 2004) and one for males (September 2003).

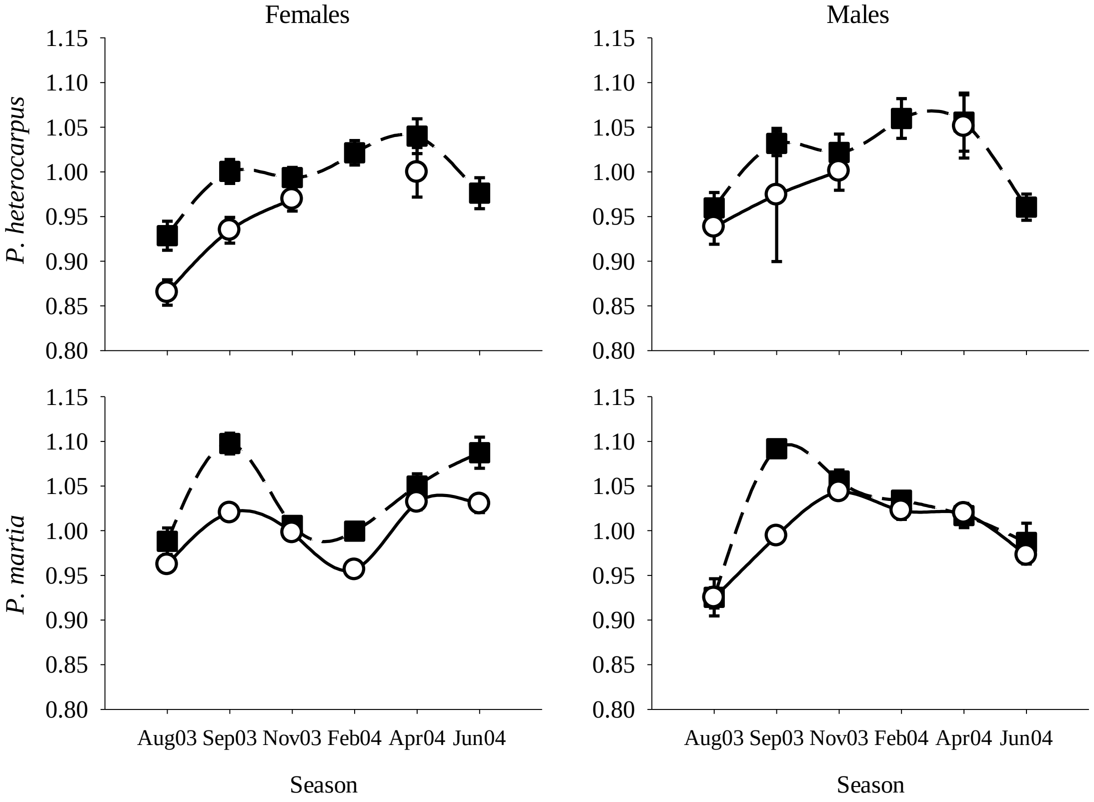


Figure 4.7. Relative condition index for females and males by survey and location of *P. heterocarpus* and *P. martia* for the seasonal bottom trawl surveys. CA: Cabrera (white circles and solid line); SO: Sóller (black squares and dashed line). Error bars are standard errors.

4.4. Discussion

Clear short spatial scale differences were found in the population dynamics of the pandalid shrimps distributed off the Balearic Islands. These differences could be related to the different environmental conditions found in the two sub-basins in which the sampling locations were situated: the Algerian sub-basin (AsB) in the south (CA, S, E) and the Balearic sub-basin (BsB) in the north (SO, W, N). These two environments have different geomorphical structures, sediment characteristics, hydrographic factors and trophic web structures.

Pandalid shrimps in the Balearic Islands show wide bathymetric distributions that overlap between species; however, their species-specific abundances are restricted to certain depth ranges and they show bathymetric patterns similar to those of populations studied off the Iberian coast (e.g. Abelló *et al.*, 1988; Carbonell and Abelló, 1998; Puig *et al.*, 2001) and eastern Mediterranean (Vafidis *et al.*, 2005; Scigliano *et al.*, 2007). Nevertheless, we found clear spatial differences in the depth of maximum abundance for *P. heterocarpus*, *P. giglioli* and *P. acanthonothus*, although some differences were found between the two datasets analysed probably due to the different sampling periods. Spatial differences between adjacent locations have been described on the Iberian Mediterranean coast and have also been related to local environmental variables such as short scale topographic specificities, bottom characteristics and local differences in oligotrophy (Carbonell *et al.*, 2003). Other factors, such as light intensity cycles, also influence the catchability of some pandalid shrimps (Cartes *et al.*, 1993), which could explain the near absence of *C. crassicornis* in the present study, as sampling took place during the day. *C. crassicornis* probably hides in the sediment during the day and emerges and disperses at night, when its densities increase markedly (Aguzzi *et al.*, 2007).

Short scale spatial differences in the abundance and biomass of pandalid shrimps in the Balearic Islands were clearly detected with different data sources. From the information obtained by observers on board commercial trawlers, the relative importance of pandalid shrimps in the crustacean communities of the slope was found to be higher in the AsB than in the BsB, where Pasiphaeidae predominate. Daily sales records also showed significantly higher pandalid CPUE values in the AsB than in the BsB. In the analysis by species, both the seasonal and annual surveys showed that all Pandalidae, except *P. heterocarpus*, were clearly more abundant in the AsB than in the BsB. Mesopelagic species, such as *Pasiphaea sivado*, predominate in the upper-slope community of the Catalan Sea in the BsB (Cartes *et al.*, 1994). Differences in trophic web structures have been found between the Catalan Sea (BsB) and the southwest of the Balearic Islands (AsB). Cartes *et al.* (2001, 2008a) detected higher suprabenthic biomass in the BsB than in the AsB, where trophic webs are supported by plankton biomass rather than benthos. In our study, the analysis of the relative contributions of the decapod crustacean feeding guilds in the two areas showed that the non-migratory macroplankton feeders (such as Pandalidae of the genus *Plesionika*) dominated in the AsB, and the benthos was less important in the trophic web of this area. However, in the BsB there was a higher contribution of the feeding guilds that are closely related to bottom resources, i.e., epibenthos, infaunal and deposit feeders (Maynou and Cartes, 2000). When feeding guilds were compared at a more local scale between data obtained from the seasonal surveys in the present study and data from another two nearby areas also situated in the AsB (CA) and the BsB (SO), the results showed a similar trend (Table 4.5). This was especially clear on the middle slope, where bottom related resources were nearly 80% in the BsB, while non-migratory macroplankton feeders represented around 50% in the AsB. Differences detected in the annual surveys also agreed with the CPUEs obtained, as high values were recorded in 2002 as well as in more recent years. Although the information that is currently available cannot explain these annual oscillations, recent studies have shown that the transport of particulate organic matter associated with cascading, a climate induced phenomenon, affects the population of another deep water species, the red shrimp *Aristeus antennatus*, and explains the oscillations found in its landings on the nearby Catalan coast (Company *et al.*, 2008).

Although Pandalidae constitute a relatively homogeneous trophic guild that mainly exploits pelagic resources, such as euphasiids and mesopelagic decapods, some species show certain differences, like *P. heterocarpus*, which also consumes infauna (Labropoulou and Kostikas, 1999; Cartes *et al.*, 2002; Fanelli and Cartes, 2004), and *P. martia*, *P. heterocarpus* and *P. giglioli*, which have been reported to scavenge in some areas, at least as a secondary activity (Fanelli and Cartes, 2004). In our study, *P. martia* was clearly related to the zooplankton abundance, while *P. acanthonotus* and *P. antigai* were not related to any potential prey. This suggests that *P. acanthonotus* and *P. antigai* are not linked to their main food resources, at least during the day time when the sampling was carried out. Marked diel patterns of catchability have been previously detected on the bottom in association with light intensity cycles for some pandalid shrimps, such as *P. martia* (Cartes *et al.*, 1993; Aguzzi *et al.*, 2007). The relations found between the abundance of *P. heterocarpus* and the abundance of the suprabenthos and the sediment characteristics of the bottom confirmed that this species is the most benthic pandalid shrimp among those analysed. The stomach content analysis carried out for *P. heterocarpus* during the seasonal surveys suggests that benthic prey make a large contribution to its diet; however, in the BsB, mesopelagic resources were more abundant than in other areas (Fanelli and Cartes, 2008), which is in accordance with the above mentioned differences in the trophic webs of the two sub-basins. *P. giglioli* was the only species related to both suprabenthos and zooplankton. Although this species follows the general trophic pattern of other pandalid shrimp in the Alboran Sea (SW Mediterranean), as mesopelagic species are its most important prey, scavenging has been found to be a secondary activity in its feeding habits (Fanelli and Cartes, 2004), and some benthic prey are also frequently ingested in the Sardinian channel (Mura, 1995). Our results suggest that in our study area *P. giglioli* exploits not only pelagic prey but also other resources that are closely related to the bottom.

Table 4.5. Abundance (Abund.; n/km^2) and relative contribution (%) of decapod crustacean feeding guilds by location (CA: Cabrera, SO: Sóller) from the seasonal surveys, obtained from abundance indexes.

Shelf break/Upper slope (150-350 m)	CA		SO	
	Abund.	%	Abund.	%
Small detritivorous feeders	-	-	-	-
Epibenthos feeders	320.7	15.5	105.9	1.0
Infaunal feeders	360.3	17.4	1311.7	11.9
Non-migratory macroplankton feeders	1082.5	52.3	3786.1	34.2
Migratory macroplankton feeders	-	-	2906.4	26.3
Large detritus-scavengers	305.1	14.7	2944.6	26.6
Middle slope (550-750 m)	CA		SO	
	Abund.	%	Abund.	%
Small detritivorous feeders	8.2	0.1	-	-
Epibenthos feeders	129.3	1.5	89.6	1.1
Infaunal feeders	3426.5	40.5	6079.7	76.9
Non-migratory macroplankton feeders	4076.1	48.1	531.8	6.7
Migratory macroplankton feeders	614.3	7.3	1169.8	14.8
Large detritus-scavengers	216.2	2.6	32.6	0.4

Both *P. heterocarpus* and *P. giglioli*, the two species with feeding behaviour that is most related to the bottom, showed different bathymetric trends in the two sub-basins: they were found in shallower waters (around 350 m depth) in the BsB (SO for the seasonal surveys, N and W for the annual surveys) than in the AsB (CA for the seasonal surveys, S for the annual surveys). Furthermore, as mentioned above, the abundance of *P. heterocarpus* showed larger mean values in the BsB than in the AsB at the same depth. Differences in bathymetric trends were also found in the same study area for the deep water rose shrimp *Parapenaeus longirostris*, whose diet in this area is based on infauna and suprabenthos (Cartes, 1995). Its maximum abundance was also at 350 m depth in the BsB, while it was found in deeper waters in the AsB (Chapter 3). In addition, the slope in the BsB is steeper than in the AsB, and it is necessary to reach deeper bottoms in the AsB to find the same sediment composition as in the BsB. Therefore, the important role that seafloor topography and sediment composition play in the bathymetric distribution of *P. heterocarpus* and *P. giglioli* suggest that both species are closely related to the bottom, like *P. longirostris*.

The characteristics of the water masses also seem to play an important role in the abundance of all the Pandalidae analysed, as salinity was significant in all the generalised additive models performed, although in different ways. This has also been found for other crustaceans, such as *P. longirostris* and *A. antennatus* (Ghidalia and Bourgois, 1961; Bombace, 1975; Relini and Orsi Relini, 1987; Tom *et al.*, 1988; Demestre and Martin, 1993; Chapters 3 and 5). The wide bathymetric distribution of pandalid shrimps indicates that, depending on the species, they can be influenced by different water masses, like Western Mediterranean Intermediate Waters (WIW), Levantine Intermediate Waters (LIW, characterised by a maximum temperature and salinity) and Western Mediterranean Deep Waters (WMDW). The shallowest species, *P. antigai*, showed a clear decreasing abundance with increasing salinity, which seems to relate this species to WIW, characterised by low salinity and temperature values. However, the deepest species, *P. martia* and *P. acanthonotus*, showed a clear increasing trend with increasing salinity, which is probably related to the warmer and more saline LIW as well as the WMDW, which is also characterised by high salinity. For the two species found in intermediate waters, *P. heterocarpus* and *P. giglioli*, the relationship to salinity was more complex. These species also showed marked differences in their centre of gravities between areas, which could be related to differences in the water column, as the LIW layer is wider in the AsB (López-Jurado *et al.*, 2008). This could explain why the deepest maximum range was found for the two species in this area. The interaction between the frontal system and the benthic environment was also related to the presence of small individuals of some pandalid species at the depths where these systems are found (Company and Sardà, 1997). Fanelli and Cartes (2008) found that the LIW determines the seasonal bathymetric pattern of *P. heterocarpus*.

Although there were some differences between locations in the mean length by depth for *P. heterocarpus* and *P. martia*, length trends were in agreement with what has been found for pandalid shrimps in other areas, with smaller individuals inhabiting shallower waters (Carbonell and Abelló, 1998; Scigliano *et al.*, 2007; Vafidis *et al.*, 2008). This intraspecific size segregation by depth has been related to resource partitioning as an adaptation that allows coexistence (Cartes *et al.*, 1993). However, some spatial differences have also been found for other species, such as *C. crassicornis*, which showed this pattern in the eastern (Scigliano *et al.*, 2007) but not the western Mediterranean (Carbonell and Abelló, 1998). Pandalidae adapt their life histories and spatial distributions to the surrounding environmental features, such as intermediate nepheloid layers (INL) that detach from the seabed. The presence of INL has been associated with a higher juvenile abundance, as the juveniles can take advantage of the benefits these layers offer (Puig *et al.*, 2001). In the Catalan Sea, the only species which did not exhibit any significant trends in population structure in relation to depth was *P. acanthonotus*, whose depth distribution did not intersect with the INL detachments either.

Our results showed that females were predominant for both *P. heterocarpus* and *P. martia*, and the proportion of females increased with depth, like in other areas. However, this does not seem to be a general trend in pandalid shrimps, as various studies have detected different trends in the sex distribution by depth (Company and Sardà, 1997; Campisi *et al.*, 1998; Carbonell and Abelló, 1998; Maiorano *et al.*, 2002; Chilari *et al.*, 2005). For instance, some studies have found a similar abundance for males and females (García-Rodríguez *et al.*, 2000), or that the number of males increases with depth (Colloca, 2002), or no pattern (Vafidis *et al.*, 2008). These sex ratio and size by depth distributions are considered to be associated with reproductive behaviour in the sense that pandalid shrimp would have a preferential area for recruitment (Company and Sardà, 1997). However, large scale geographical differences in the bathymetric distribution (e.g. first appearance of bathyal decapods) have been related to differences in oligotrophy in the Mediterranean Sea, and thus to the surface primary production (Maynou and Cartes, 2000). We obtained higher length at first maturity values for *P. martia* in the present work (17.7–18.0 mm CL) than those determined in other studies carried out in the central Mediterranean (15.5 mm CL: Maiorano *et al.*, 2002) and also on the Spanish Mediterranean coast (15.58 mm CL: Carbonell *et al.*, 2003). These differences could be due to the low abundance of individuals smaller than 15 mm CL collected in our samples, probably because the juveniles of this species are distributed in areas that were not sampled in the present surveys or due to differences in the mesh codend size used in the surveys. There is little information on recruitment of pandalid shrimps, but it seems that juveniles tend to aggregate in the same depth ranges in which higher percentages of females are present (Puig *et al.*, 2001). In our study, juveniles were only found for *P. heterocarpu*s in April in the AsB, which is also the month with the highest percentage of juveniles in the Catalan Sea (Puig *et al.*, 2001). Recruitment seems to occur in different seasons depending on the area, although spring has been suggested to be the main season for settlement of new recruits in the Catalan Sea (Company and Sardà, 1997), while for *P. martia* in the Ionian Sea recruitment occurs in summer (Maiorano *et al.*, 2002) and for *P. edwardsii* in the south Tyrrhenian Sea it takes place in January (Colloca, 2002).

The better condition found for both *P. heterocarpus* and *P. martia* in the BsB is in agreement with other studies in the area on decapod crustaceans, such as the deep water rose shrimp *P. longirostris* (Chapter 3) and the red shrimp *A. antennatu*s (Chapter 5), as well as some fish, like the European hake *Merluccius merluccius* (Hidalgo *et al.*, 2008). Better condition in some fish, modelled according to lipid reserves, has been related to high productivity areas (Lloret *et al.*, 2002, 2005). Higher abundances of suprabenthos and zooplankton in BsB compared to AsB were mainly detected in late spring-early summer (Cartes *et al.*, 2008a) when WIW reach the islands and reinforce the Balearic Current (Monserrat *et al.*, 2008; López-Jurado *et al.*, 2008). These waters, characterised by low temperature (<13 ◦C) and salinity values, come from the Gulf of Lions, one of the most productive areas in the Mediterranean (Champalbert, 1996; Bosc *et al.*, 2004; Canals *et al.*, 2006). Their presence increases the primary production in the area (Estrada, 1996) and enriches the trophic chain (Fernández de Puelles *et al.*, 2004).

Apart from spatial differences, the condition index also showed seasonal differences for both *P. heterocarpus* and *P. martia* that could be related to the reproductive period, at least in the second case. The reproductive cycle has been found to affect the biochemistry and condition of decapods (Rosa and Nunes, 2003; Bayhan *et al.*, 2005; Carbonell *et al.*, 2008; Chapter 5), although a general trend of life history adaptation with depth has been described not only for pandalid shrimps (Company and Sardà, 1997) but also for decapod crustaceans in general (Company *et al.*, 2003). An increase in seasonality in reproductive periods was observed from the shallowest (*P. heterocarpus*, in our case, with a high percentage of mature females all year round) to the deepest species (*P. martia*, with a maximum number of mature females in spring–summer). This is probably due to a decrease in the available energy, which means that year round reproductive activity is not possible for the middle slope dwelling species. The relation between the condition index and the reproductive cycle was clear for *P. martia*, whose minimum condition index value was found in August, when the percentage of ovigerous females was at its maximum. This species showed strong temporal changes in diet composition and it seemed to prefer prey with high caloric content in spring–summer, just before the peak of mature females (Fanelli and Cartes, 2008). Thus, the higher energetic requirements of *P. martia* for reproduction in summer seem to be met by an increase in the caloric content of its diet, similarly to *A. antennatus*, which also showed an increase in food consumption and a high condition in pre-spawning females in the same study area (Cartes *et al.*, 2008a; Chapter 5). Changes in the condition index for *P. heterocarpus* could not be related to the reproductive cycle as they did not show any seasonal pattern; however, the condition index showed seasonal variations, with minimum values in summer and an increasing trend from then on. These differences could be related to changes in the feeding and diet of *P. heterocarpus*, which, although less evident than in *P. martia,* showed two diet groups: one in summer–autumn and one in winter–spring (Fanelli and Cartes, 2008). These authors found that larger seasonal fluctuations occurred in pelagic prey compared to benthic prey, since changes in the diet of *P. heterocarpus*, which also preys on benthic organisms, were less evident than in the strictly bentho-pelagic feeder *P. martia*. Similar patterns of higher variability in feeding intensity among zooplankton feeders have been found in bathyal fish (Madurell and Cartes, 2005).

In conclusion, the geographical distribution of the pandalid shrimps in the Balearic Islands is strongly related to the environmental variables, especially to trophic shifts in their diets that are probably linked to changes in prey availability and thus to hydrographical and geomorphologic characteristics. This implies that important differences can be found between nearby areas if their environmental conditions differ, which should be taken into account in the sampling designs of future studies in order to detect the short scale variability. Seasonal differences in the condition index were mainly related to the reproductive cycle and food availability. Although the biological parameters were very similar in the two locations studied, the condition index showed marked differences between the two sites in accordance with some studies on other decapod crustaceans. This confirms the clear differences found between the two adjacent locations.

CHAPTER 5.

ARISTEUS ANTENNATUS

Adapted from “Population dynamics of the red shrimp *Aristeus antennatus* in the Balearic Islands (western Mediterranean): Short spatio-temporal differences and influence of environmental factors”. Beatriz Guijarro, Enric Massutí, Joan Moranta and Paz Díaz. (2008). *Journal of Marine Systems* 71: 385-402.

Abstract

The red shrimp *Aristeus antennatus* is one of the target species of the bottom trawl fishery of the Balearic Islands. The aim of this chapter was to study the short spatial and temporal patterns of *A. antennatus* in two locations sited in the Algerian sub-basin (AsB, Cabrera: CA) and in the Balearic sub-basin (BsB, Sóller: SO) that have different environmental regimes and determine the relationship between these patterns and the environmental conditions. Information was obtained from seasonal surveys. The abundance, biomass, length, weight, sex and maturity stage of *A. antennatus* caught were recorded. Environmental parameters were obtained from seasonal surveys and included data on hydrography, trophic resources and sediment characteristics. Information about the bottom trawl fleet was obtained through fleet monitoring and daily landings data were obtained from sales records. Additionally, data from annual surveys, selectivity pilot studies and surveys carried out off Algeria was also obtained. Short spatial and temporal differences have been detected between both locations. The population at CA was more demographically homogeneous, while that at SO showed important variations, like high abundance of juveniles recruiting to fishing grounds in autumn–winter and high abundance of large females during summer. Several differences have also been found in the biology of the species between locations, such as males were more abundant in SO than in CA. Also, the reproductive period started sooner in SO than in CA, and the condition of pre-spawning females was better in SO. The percentage of total lipids in the hepatopancreas was minimal during the spawning period, showing their importance as a reserve of energy for the ovary ripening. Water masses could play an important role in these differences, the characteristics of water masses being more stable in CA than in SO. Red shrimp adult females seemed to be more correlated with the warmer and more saline Levantine Intermediate Waters, while juveniles (males and females) and adult males were more correlated with the colder Western Mediterranean Deep Waters, detected only in SO during autumn–winter. Two different hypothesis of mobility patterns for the species are discussed in relation to these observed differences.

Keywords: *Aristeus antennatus*, spatio-temporal variations, reproduction, fishery, hydrography, fishing grounds, condition.

5.1. Introduction

The red shrimp, *Aristeus antennatus* (Risso, 1816), is a decapods crustacean distributed throughout the Mediterranean and the eastern Atlantic, from Portugal to Cabo Verde Islands (Arrobas and Ribeiro-Cascalho, 1987). It is found in the muddy bottoms of the slope, between 400 and at least 3300 m (Sarda *et al.*, 2004) and carries out important bathymetric migrations (Relini *et al.*, 2000). This species is one of the most valuable deep water resources in the western and central basins of the Mediterranean, remaining practically unexploited in the east (Papaconstantinou and Kapiris, 2001). Notwithstanding its wide bathymetric distribution, it is mainly exploited between 500 and 800 m depth, being the target species of the well developed bottom trawl fisheries on the upper slope of the western basin (Sardà *et al.*, 2003a).

There have been many studies on the biology, ecology and fishery of this species in the western Mediterranean, especially off the northeastern Iberian coast. As examples, it can be cited those related to diet (Cartes, 1994), reproduction (Demestre and Fortuño, 1992; Sardà *et al.*, 2003b), growth (Company and Sardà, 2000), spatiotemporal dynamics (Tobar and Sardà, 1992; Demestre and Martin, 1993; Sardà *et al.*, 1994, 1997; Tudela *et al.*, 2003; Maynou, 2008) and exploitation (Demestre and Lleonart, 1993; Sardà and Maynou, 1998). Some of these studies have shown spatial and seasonal mobility patterns, both at a local (Sardà *et al.*, 1994, 1997) and meso-scale (Tudela *et al.*, 2003), being discussed in relation to environmental factors and the biological cycle of the species.

The annual catches of red shrimp in the Balearic Islands are estimated to be around 100–200 t (Chapter 1). In Mallorca, around 80% of red shrimp catches come from fishing grounds sited south and northwest of the island, and there is a seasonal displacement of the local fishing fleet targeting red shrimp. During the summer months, the whole fleet concentrates on the fishing grounds sited to the northwest of Mallorca. Studies on the red shrimp conducted in the Balearic Islands, which have been focused on general biology and fishery (Carbonell *et al.*, 1999, 2006; García-Rodríguez and Esteban, 1999; Carbonell and Azevedo, 2003), have not considered the spatio-temporal complexity observed on the population dynamics of this species, which suggests some relation with the environmental variability observed in the area. Thus, the aim of this work is to study short spatial and temporal patterns in the population dynamics of red shrimp off the Balearic Islands, in relation to some abiotic and biotic factors. As a first step, a descriptive analysis of the abundance, population dynamics and biology was carried out separately for both locations, southern and northwestern Mallorca. This was followed by a joint analysis, as advance on the above mentioned papers, between the abundance of this resource and the distinct compartments of the ecosystem sampled (hydrographic and substrate characteristics and trophic resources).

5.2. Material and methods

5.2.1. Data source

Data were collected during the seasonal bottom trawl surveys and the on board fleet monitoring (see Chapter 2). For each haul from both data sources, red shrimp caught were weighed, counted and measured (carapace length: mm CL) for both sexes separately. For the seasonal surveys, at least 50 individuals of each haul were collected and analysed at the laboratory. Each specimen was measured, weighed and sexed. Maturity was determined by macroscopic observation (Demestre and Fortuño, 1992), adopting seven gonadal stages for females (I: undeveloped, II: undeveloped/resting, III: developing, IV: maturation, V: advanced maturation, VI spawning, VII: post-spawning) and two for males (I: undeveloped, II: developed). Gonads and hepatopancreas were also weighed. For females, total lipids of the hepatopancreas (as percentage of dry weight) were determined by the gravimetric Soxhlet extraction method (Manirakiza *et al.*, 2001).

For the seasonal surveys, standardised abundance (n/km^2) and biomass (g/km^2) were calculated for each haul, by sex, for juveniles and mature individuals, using maturity curves from the biological sampling carried out in each survey and location. For the fleet monitoring, no biological sampling was carried out, so the three commercial categories sorted on board were used (small <32 mm, medium 32–50 mm and large >50 mm). In this case, abundance and biomass were standardised to 60 minutes tows. Length frequency distributions by haul, both for the seasonal surveys and fleet monitoring, were calculated separately for females and males.

For the seasonal surveys and fleet monitoring, sex ratio was calculated as a percentage of males. The following biological indexes were estimated for each single individual sampled: (i) gonadosomatic index (GSI), as a percentage of gonad weight over total weight; (ii) hepatosomatic index (HSI) as a percentage of hepatopancreas weight over total weight and (iii) relative condition index (Kn; Le Cren, 1951), as observed weight over expected weight, estimated from a length–weight relationship, by sex, considering all data.

Percentage of each maturity stage was estimated by sex, survey and location. For females, the percentages of mature individuals (stages III–VII) and presence of spermatophore by size were also calculated. Length at first maturity was also obtained by sex and location, using only data from those months with the maximum reproductive activity of the stock for females (August and June) and for the whole year in males. For females, the maximum reproductive potential, as the intersection of the gonadic maturity curve and the mating complementary curve (i.e. absence of spermatophore) from the period with the maximum reproductive activity of the stock, was also considered.

From September 2003 to September 2004, the commercial fleet targeting red shrimp which operates in these locations was also monitored by log-books, where the skippers registered basic data from each of the hauls (e.g. situation, mean depth and fishing ground). Daily landings for the period 2000–2005 were also used (see Chapter 2), reducing the three commercial categories available to two, grouping medium and large categories together.

Environmental data was obtained during the seasonal oceanographic surveys (see Chapter 2). Mean, minimum and maximum water temperature and salinity above the bottom were calculated for each trawl. As red shrimp have a highly diversified diet (Cartes, 1994), total zooplankton and total suprabenthos were considered as potential trophic resources for the species, as well as two groups considered as important in the diet of this species, Isopoda from the sledge and Natantia from the Bongo net and from the sledge.

Additionally, abundance, biomass, and length frequency of red shrimp catches from the annual bottom trawl surveys for the period 2002-2005 and from the selectivity pilot surveys (see Chapter 2) were also used, as well as the same data obtained from the Algerian coast during 2004 in bottom trawl surveys carried out following the same protocol of the annual surveys and from the pilot selectivity pilot surveys.

5.2.2. Data analysis

Fishing strategies of six vessels operating in both locations (CA and SO; fleet mobility estimated from log-books) were detected from multivariate analysis of daily sale bills (e.g. García-Rodríguez, 2003; Alemany and Alvárez, 2003). Standardised catch per unit of effort (CPUE, kg/day) for the small and medium+large red shrimp commercial categories was estimated. Thus, a monthly CPUE was calculated by location, considering a synthetic study year averaging the six year data.

Cluster analysis was used to analyse length frequency distributions, grouped in 10 mm intervals to simplify interpretation, obtained from the seasonal surveys and fleet monitoring. Similarity percentage analysis was also used to estimate the dissimilarity between groups obtained and the contribution of main size classes to each. Short spatio-temporal differences in standardised abundance and biomass, as well as biological parameters, were analysed using a two-way analysis of variance (ANOVA), after testing for normality of data and homogeneity of variances. Survey or season, location and depth were considered as factors.

Length-weight parameters were calculated, by sex and location, applying a potential relationship. Von Bertalanffy growth parameters were also estimated, by sex and location, from the analysis of length frequency distributions, grouped in 2 mm size classes after a three running average. The already mentioned length-frequency distributions obtained from other surveys in our study area were also analysed, as additional data, to validate the growth parameters estimations.

The relationship between standardised abundance and biomass from the seasonal surveys and environmental variables was tested by non-parametric correlations (Spearman R). This analysis was performed on both juveniles and adults, by sex. It was also applied to data obtained during the annual surveys, the selectivity pilot studies and additional data obtained from other surveys carried out off the Algerian coast. In the first case, as there were available biological data, it was performed on both juveniles and adults, by sex, while in the second case these data were not available, so two size categories were used, corresponding to the two size categories previously used for analysing CPUEs from daily sale bills (<32 mm, small and ≥32 mm, medium+large). The environmental variables used were mean, minimum and maximum temperature and salinity, percentage of organic matter, sands and mud in the sediments, abundance of total suprabenthos and zooplankton, Isopoda and Natantia in the Bongo and in the sledge.

5.3. Results

For the seasonal surveys, juveniles and adults showed different trends (Figure 5.1). The abundance and biomass of juveniles, both males and females, were greater in SO than in CA (Table 5.1), and showed significant differences between surveys, with the highest values during November in SO. Adults showed different trends by sex. For females, higher values were found during February and April in CA and during August and September in SO. The latter was especially clear in biomass, which indicated the presence of large adult females. Males, again more abundant in SO than in CA, showed peaks during November in SO and during April in CA.

Similar results were obtained for the commercial fleet (Figure 5.2), abundance and biomass of small individuals being higher in SO than in CA (Table 5.1) with a clear peak of males during winter in SO. Although no significant differences were found between seasons for females, they showed maximum values in SO during autumn and winter. For medium females, abundance and biomass were higher in CA than in SO during the whole year, except during summer, while maximum values for medium males were found again during winter in SO. Large individuals (only females) showed the highest values, both for abundance and biomass, in SO during summer. CPUEs from the synthetic year showed similar trends (Figure 5.2): the small category showed higher values in SO than in CA, with maximums during winter (especially January–March) and the medium+large category showed maximums in SO during summer, while they were higher in CA during the rest of the year.

Length frequency distributions of catches also showed differences between locations and surveys or seasons (Figure 5.3), which were clearly reflected in the cluster results, both for surveys (CS, Figure 5.4a) and fleet (CF, Figure 5.4b). Thus, for females, cluster analysis identified four groups. A unique cluster (CS1, CF2) grouped all samples from CA, while samples from SO formed three different clusters: (i) CS2/CF3 mostly composed of spring (April–June) samples, in which small specimens between 20 and 39 mm predominated; (ii) CS3/CF4 mostly composed of autumn (November) samples, with the highest abundance of these small individuals; (iii) CS4/CF1 composed of samples taken during summer (August–September), characterised by small (20–29 mm) and large (50–59 mm) specimens.

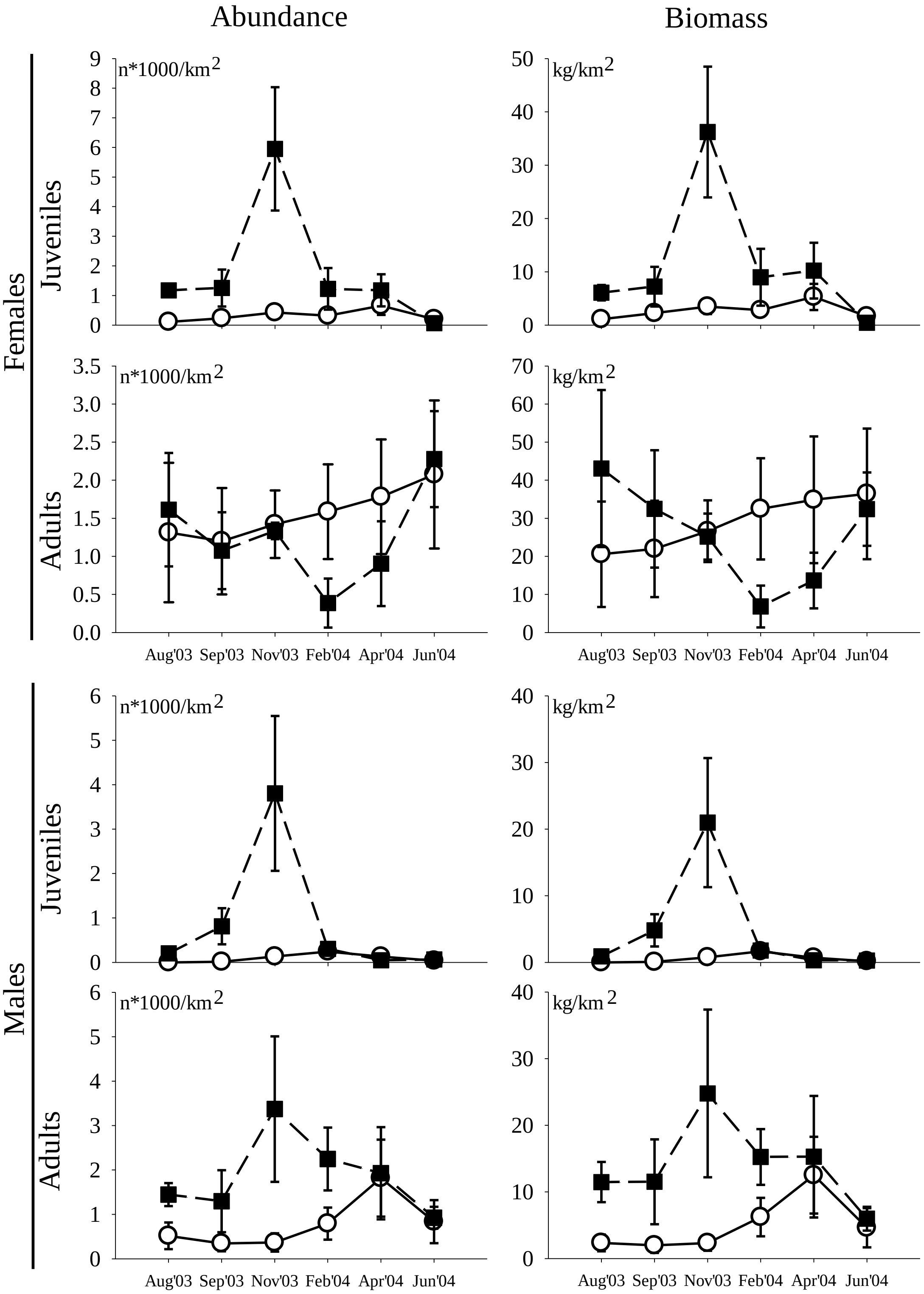


Figure 5.1. Mean abundance and biomass for juveniles and adults, by sex, obtained from the seasonal surveys. Error bars are standard errors. White circles and solid line: Cabrera; black squares and dashed line: Sóller.

Table 5.1. Summary of the results of the analysis of variance (ANOVA) and post hoc Tuckey's Honest Significant Difference (HSD) test, for all the indexes analysed, showing the significance of the factors survey or season (S), location (L) and their interaction (SxL). D: Depth; I: August 2003; II: September 2003; III: November 2003; IV: February 2004; V: April 2004; VI: June 2004. 1: autumn 2003; 2: winter 2004; 3: spring 2004; 4: summer 2004. CA: Cabrera; SO: Sóller.

Seasonal bottom trawl surveys						
Index	Size class	Sex	S	L	S x L	HSD
Abundance	Juveniles	F	<0.05	<0.01	ns	SO>CA
		M	<0.01	<0.001	<0.01	SO>CA
	Adults	F	ns	ns	ns	
		M	ns	<0.05	ns	SO>CA
Biomass	Juveniles	F	<0.05	<0.05	ns	SO>CA
		M	<0.001	<0.001	<0.001	SO>CA
	Adults	F	ns	ns	ns	
		M	ns	<0.05	ns	SO>CA
Sex ratio			ns	<0.05	ns	SO>CA
% matures		F	<0.001	ns	<0.001	I=VI>II=III=IV=V
		M	<0.001	<0.05	<0.001	III<I=II=IV=V=VI; CA>SO
% spermatophore		F	<0.001	ns	<0.001	
GSI		F	<0.001	ns	<0.001	
		M	<0.001	<0.001	<0.05	SO>CA
Kn		F	<0.001	<0.05	<0.05	SO>CA
		M	<0.001	ns	<0.001	
HSI		F	<0.001	<0.05	<0.001	CA>SO
% lipids		F	<0.001	ns	<0.001	
			D	L	D x L	HSD
Sex ratio			<0.001	<0.001	<0.05	550<650=750; SO>CA
Seasonal fleet monitoring						
Index	Size class	Sex	S	L	S x L	HSD
Abundance	Small	F	ns	<0.05	ns	SO>CA
		M	<0.05	<0.05	ns	SO>CA
	Medium	F	ns	<0.001	<0.05	CA>SO
		M	ns	<0.05	ns	SO>CA
	Large	F	ns	<0.05	<0.001	SO>CA; SO-4>rest
Biomass	Small	F	ns	ns	ns	
		M	<0.05	<0.05	ns	SO>CA
	Medium	F	ns	<0.001	<0.05	CA>SO
		M	ns	<0.05	ns	SO>CA
	Large	F	<0.05	<0.05	<0.001	4>1=2=3; SO>CA; SO-4>rest
Sex ratio			<0.05	<0.05	ns	1=4<2=3; SO>CA

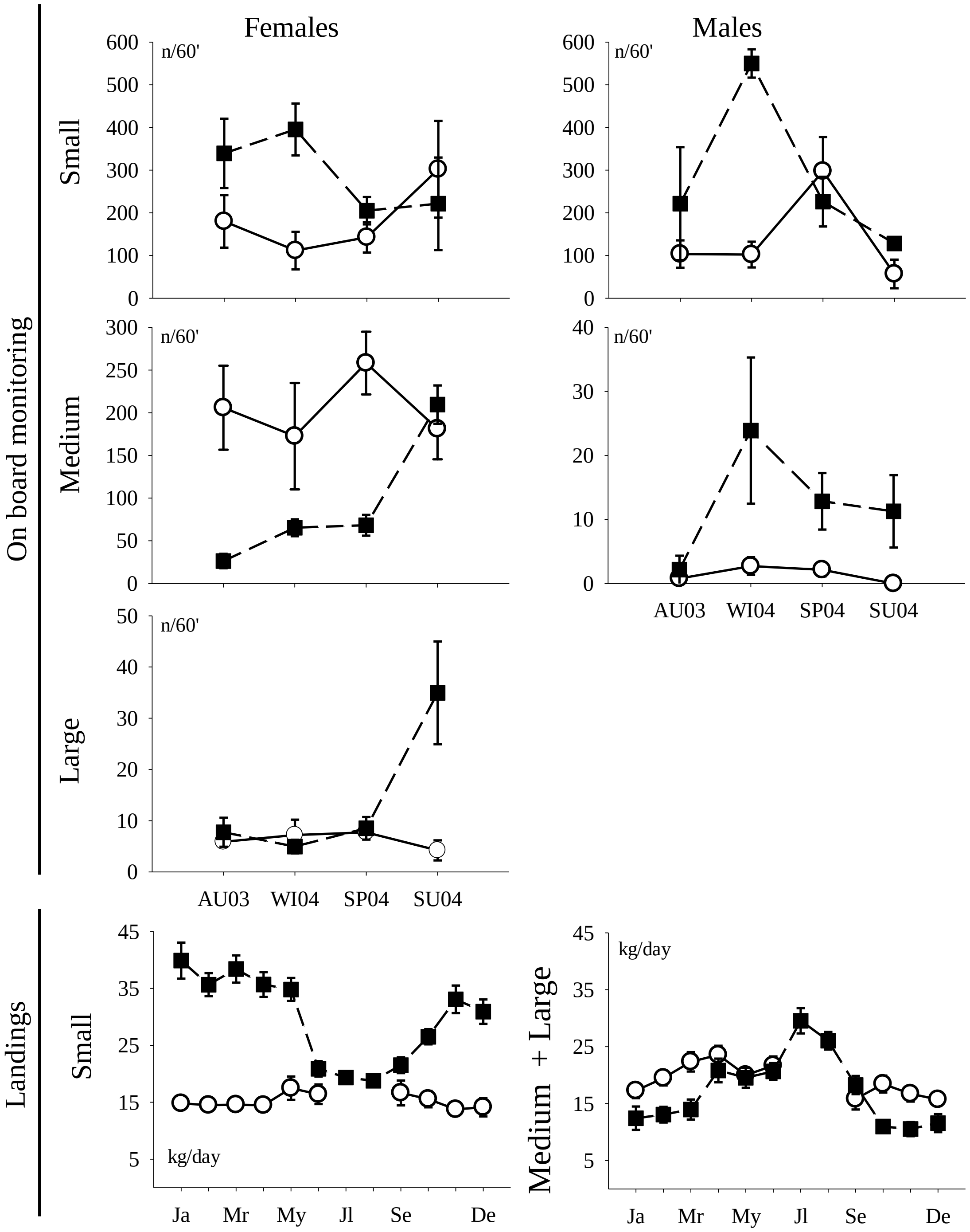


Figure 5.2. Mean abundance for the three commercial categories, by sex, obtained from the on board monitoring and mean standardised CPUEs from the landings of three trawlers operating in each of the locations studied, during a synthetic year (2000–2005). AU03: autumn 2003; WI04: winter 2004; SP04: spring 2004; SU04: summer 2004. Error bars are standard errors. White circles and solid line: Cabrera; black squares and dashed line: Sóller.

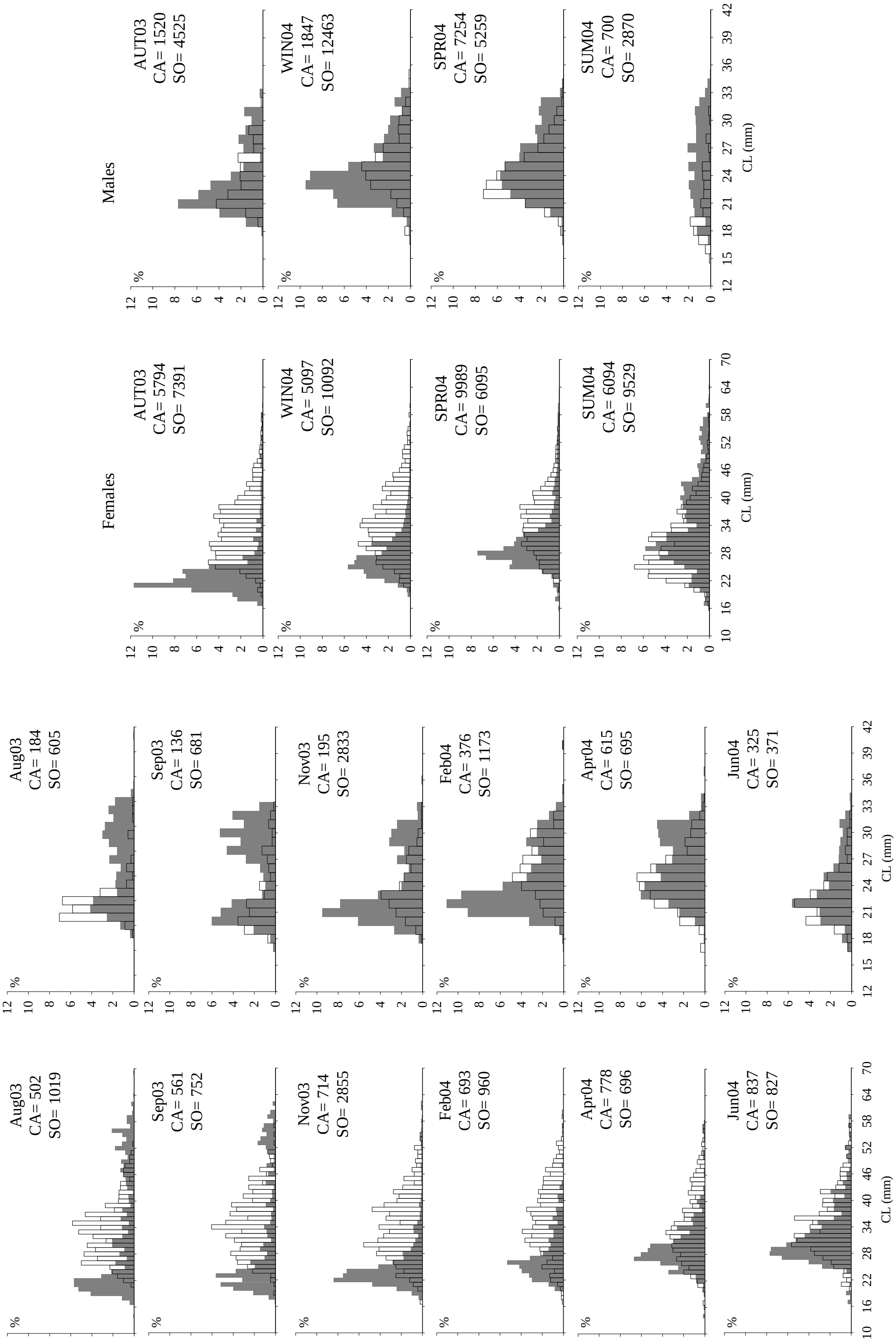
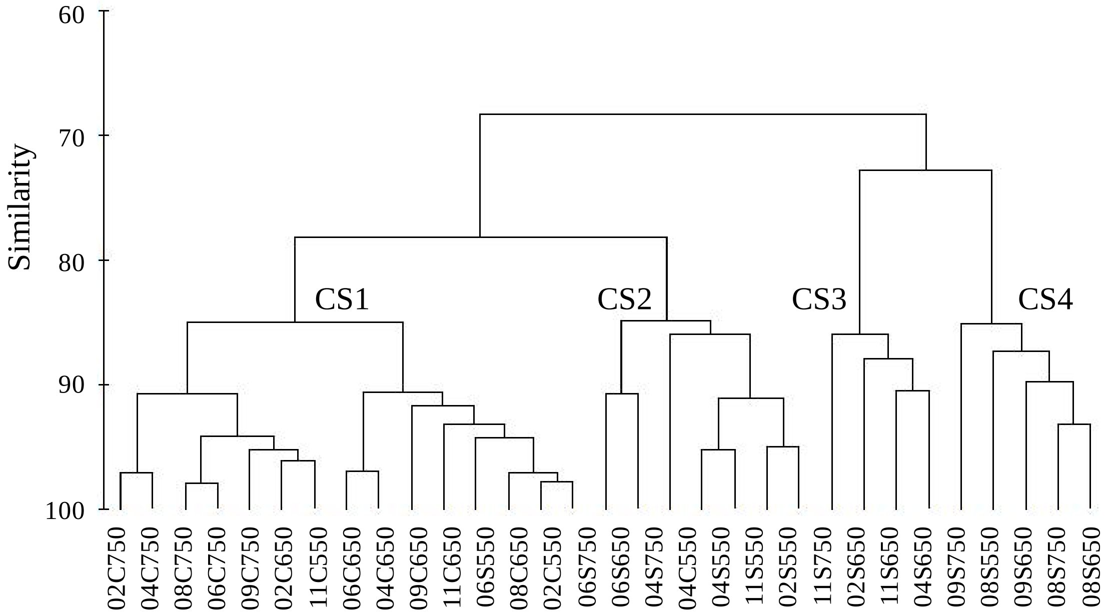


Figure 5.3. Length frequency distributions from the seasonal surveys (down) and fleet monitoring (up), as percentage of total population, by sex and survey or season, for Cabrera (CA, white) and Sóller (SO, grey). Total numbers by location are also shown in the figure.

a) Seasonal surveys



b) Fleet monitoring

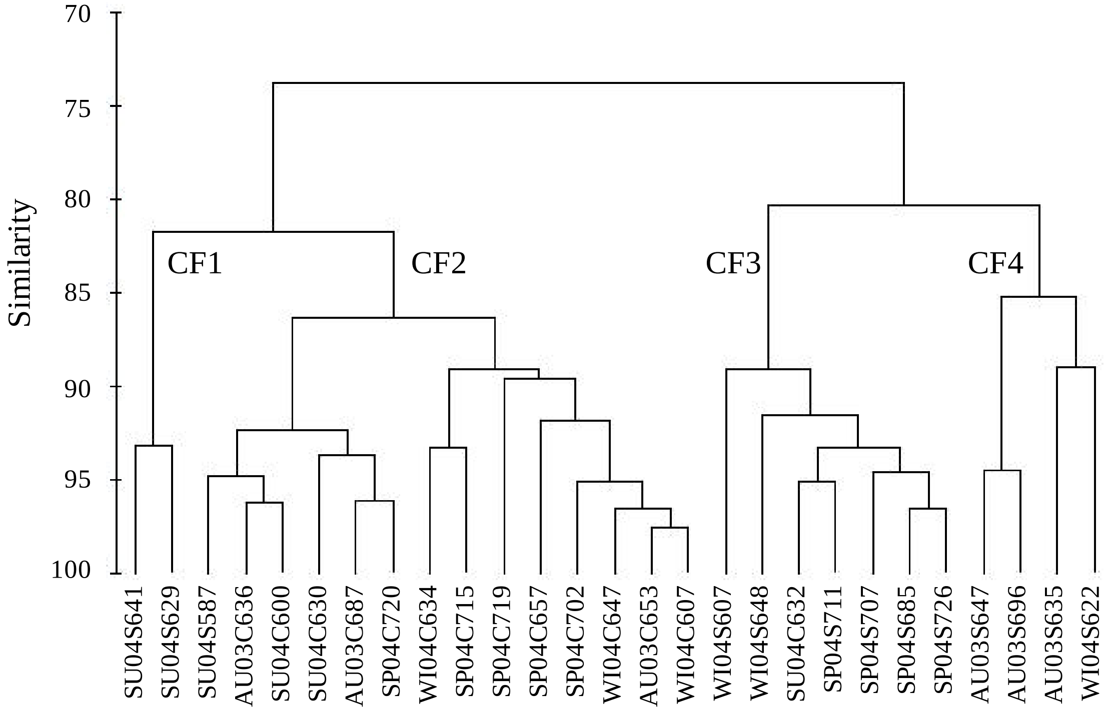


Figure 5.4. Cluster results for females, for the seasonal surveys (CS) and fleet monitoring (CF). C: Cabrera, S: Sóller. 08: August 2003; 09: September 2003; 11: November 2003; 02: February 2004; 04: April 2004; 06: June 2004. AU03: autumn 2003; WI04: winter 2004; SP04: spring 2004; SU04: summer 2004. Depth in m. Similar results were obtained for males and total population.

Sex ratio showed the same tendency both in the seasonal surveys and fleet monitoring (Figure 5.5). The proportion of males was significantly higher in SO than in CA (Table 5.1). For the fleet monitoring, seasonal differences were also detected, with the highest values of sex ratio during winter in SO. Seasonal surveys also showed maximum values during February in SO, but the differences were not significant. However, a second ANOVA, considering location and depth as factors, showed location, depth and their interaction as significant. Sex ratio increased with depth, especially in SO, where the proportion of males was equal to females at 650 m and even higher at 750 m (chi-square, P<0.05). In CA, females were more abundant than males for the whole bathymetric range.

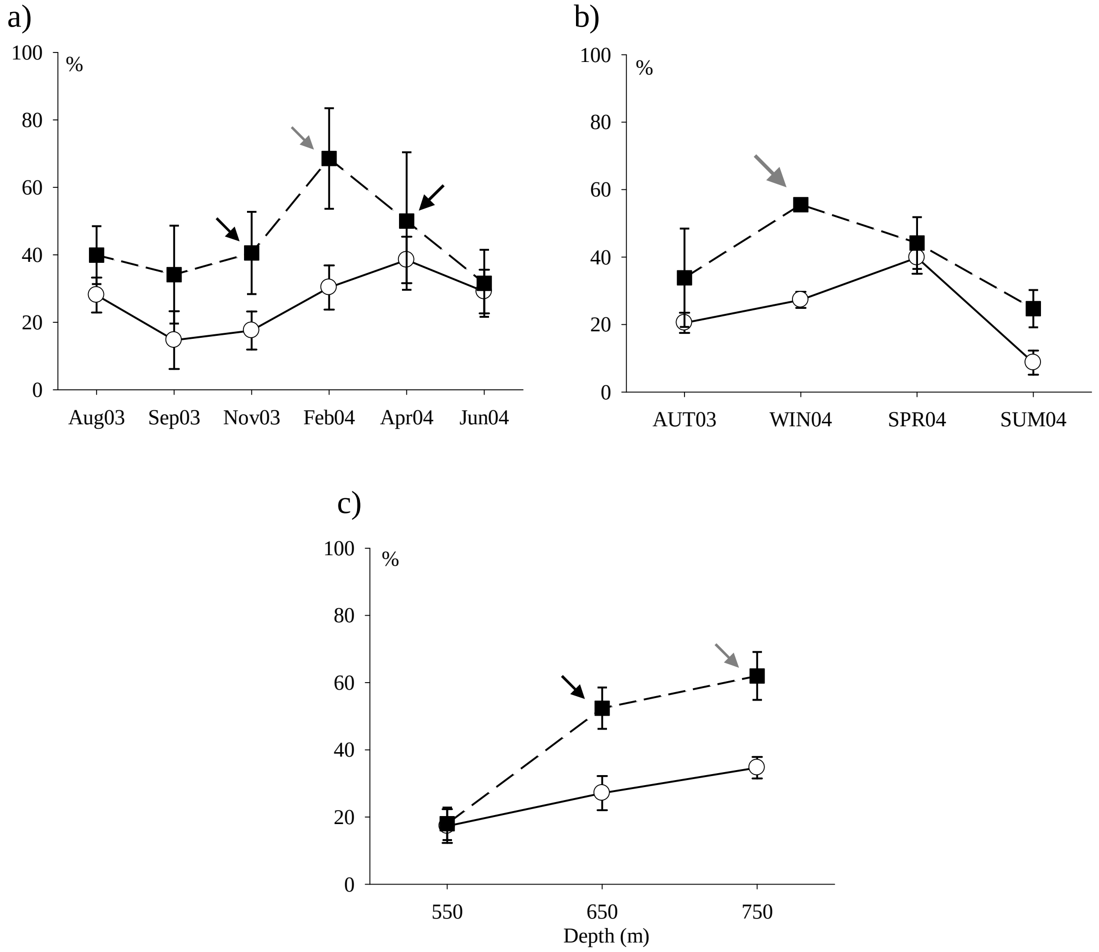


Figure 5.5. Sex ratio (as males in relation to total population) obtained from the seasonal surveys by survey and location (a), for the fleet monitoring by season and location (b) and for the seasonal surveys by location and depth (c). White circles and solid line: Cabrera; black squares and dashed line: Sóller. Black arrows indicate equal proportion of males and females; grey arrow indicates higher proportion of males than females. Error bars are standard errors.

For both locations, females with maturing gonads were mostly found in June and August, although in SO a small proportion of individuals showed initial stages of maturity even in April (Figure 5.6a). During June in SO, more than 50% of the females were at advanced stages of maturation (V, VI), while in CA this proportion was not found until August. Some post-spawning females (stage VII) appeared in SO from August, but they did not appear until September in CA. The percentage of mature females showed differences by location and the interaction location-survey (Table 5.1). In June, it was higher in SO than in CA, while during August it was higher in CA than in SO (Figure 5.6b). Females with spermatophores were found throughout the year, with significant differences by survey and the interaction location-survey (Table 5.1). In June, the proportion of mated females was higher in SO than in CA, while during August–September it was higher in CA than in SO (Figure 5.6.c). Mature males were found during all surveys (Figure 5.6d), showing significant differences by the three factors (Table 5.1). During February–April, the percentage of mature males was higher in SO than in CA, while the opposite was found for the rest of the year.

Length at first maturity for males was lower than for females (Table 5.2), showing slight differences between areas, with lower values in SO for females (CA: 26.5 mm CL; SO: 23.5 mm CL) and higher for males (CA: 17.8 mm CL; SO: 20.2 mm CL). Maximum reproductive potential for females also showed similar values at both locations, but in SO the length at which 50% of females had spermatophores were higher than length at first maturity, while the opposite was found in CA.

Both for females and males, survey and the interaction location-survey were significant for gonadosomatic index (GSI), relative condition index (Kn), hepatosomatic index (HSI) and the percentage of total lipids in the hepatopancreas (Table 5.1). By contrast, the location was only significant for Kn and HSI for females and GSI for males. For females, GSI was higher in SO than in CA during June, while it was higher in CA than in SO during August. For males, GSI was higher in SO than in CA, with minimum values in November–February for both locations (Figure 5.7). Relative condition index (Kn) for females was higher in SO than in CA, showing in both locations maximum values during February–April, and a decreasing trend during June–September. For males, Kn showed minimum values in CA during August and in SO during September (Figure 5.7). The hepatosomatic index (HSI) for females was higher in SO than in CA during April–June, and higher in CA than in SO during the rest of the year (Figure 5.7). In both locations, minimum values were found during August–

September, with an increasing trend from November to June. The percentage of total lipids showed a similar trend to the HSI among surveys (Figure 5.7).

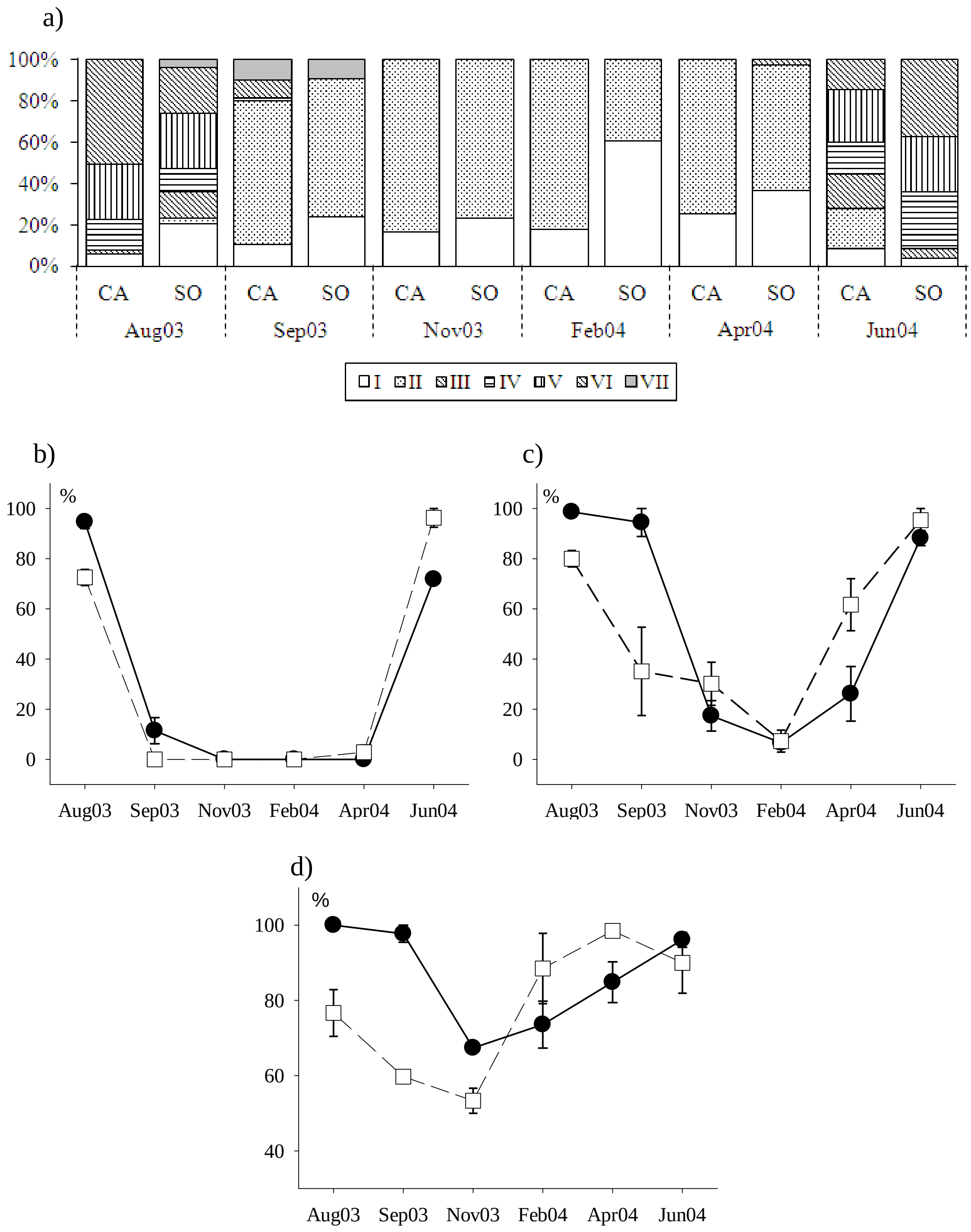


Figure 5.6. Percentage of each maturity stage for females (a), percentage of mature females (b), percentage of females with spermatophore (c) and percentage of mature males (d), by survey and location. White circles and solid line: Cabrera; black squares and dashed line: Sóller. Error bars are standard errors.

Table 5.2. Length at first maturity(L_{50} mat), in mm CL, for females, males, and sexes combined, length at which 50% of females have a spermatophore (L_{50} spe.) and maximum reproductive potential (MRP) for females, for the both locations and locations combined.

	Location	Females	Males	Females + Males
L_{50} mat	CA	26.5	17.8	17.8
	SO	23.5	20.2	20.6
	CA+SO	24.6	19.2	19.8
L_{50} spe.	CA	25.6		
	SO	28.8		
	CA+SO	27.0		
MRP	CA	25.9		
	SO	24.4		
	CA+SO	25.4		

The results obtained for the size-weight relationships are shown in Table 5.3. The allometric coefficient was slightly higher in SO (2.49) than in CA (2.45) for females, while the opposite for males (CA: 2.48; SO: 2.35). Similar results were found for the von Bertalanffy growth parameters in both areas (Table 5.4), with values of L_∞ around 60 mm for females and 46 mm for males, and k around 0.48 year^{-1} for females and 0.53 year^{-1} for males.

For the 14 environmental variables analysed, only temperature and salinity were significantly correlated to abundance and biomass (Table 5.5). Bottom temperature was inversely correlated to the abundance and biomass of juveniles and adult males while, for juvenile females, there was a negative relationship with salinity. Salinity was positively correlated to abundance of mature females. For the additional surveys analysed, carried out off Mallorca-Menorca and off Algeria, a positive correlation was also observed between the abundance and biomass of females with both salinity and temperature (Table 5.6).

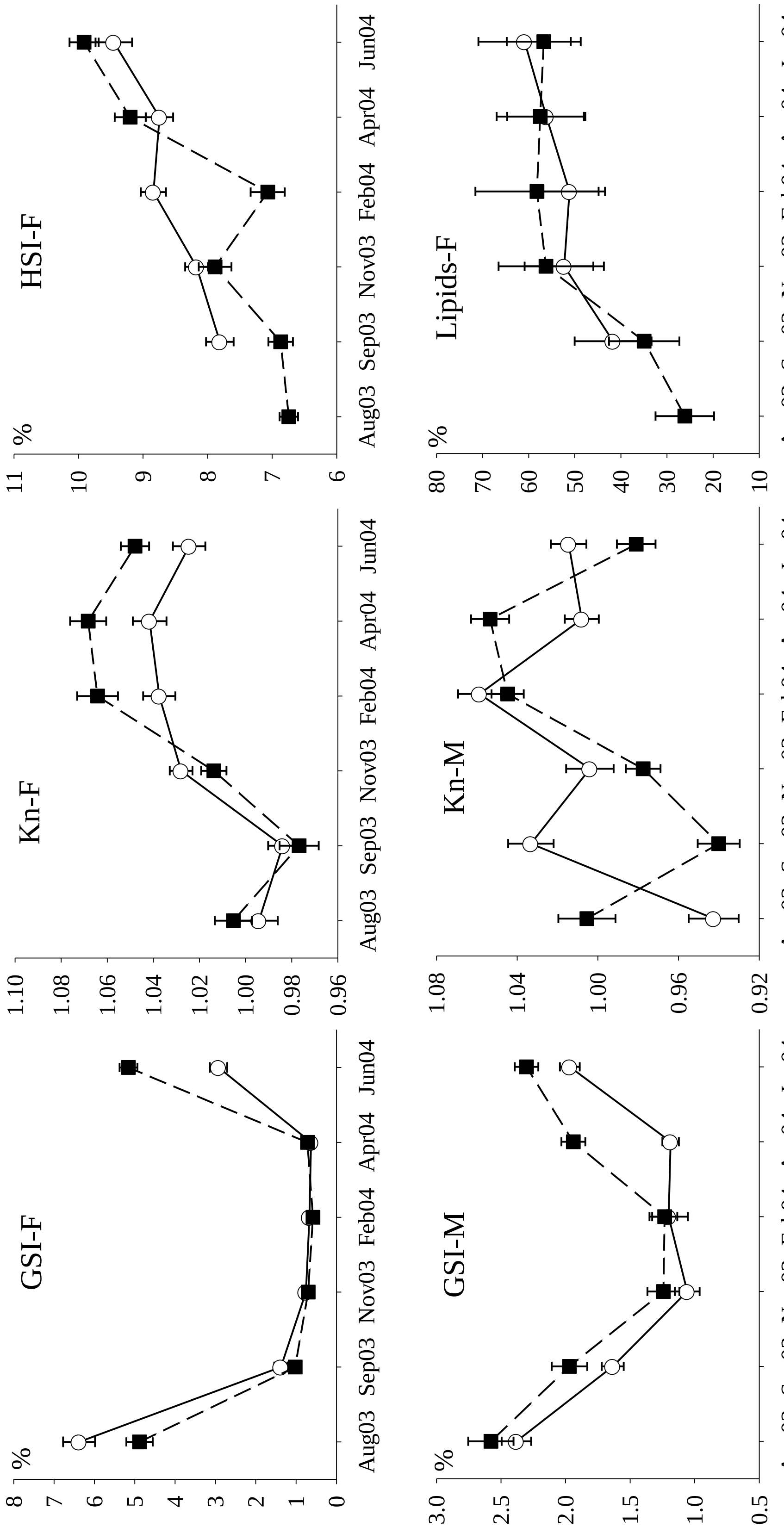


Figure 5.7. Gonadosomatic index for females (GSI-F) and males (GSI-M); relative condition index for females (Kn-F) and males (Kn-M), hepatosomatic index for females (HSI-F) and percentage of total lipids for females (Lipids-F), by survey and location. White circles and solid line: Cabrera; black squares and dashed line: Sóller. Error bars are standard errors.

Table 5.3. Weight-length relationship (a: slope; b: allometric coefficient) by survey and for all surveys, for females, males and sexes combined, for each location and localities combined. CA: Cabrera; SO: Sóller.

		Females			Males			Females + Males		
		a	b	r^2	a	b	r^2	a	b	r^2
CA	Aug’03	0.0026	2.4550	0.987	0.0020	2.5167	0.957	0.0018	2.5601	0.992
	Sep’03	0.0025	2.4658	0.992	0.0028	2.4303	0.978	0.0029	2.4218	0.995
	Nov’03	0.0027	2.4553	0.993	0.0024	2.4733	0.971	0.0023	2.4937	0.995
	Feb’04	0.0027	2.4557	0.992	0.0043	2.3133	0.959	0.0028	2.4403	0.993
	Apr’04	0.0030	2.4214	0.988	0.0017	2.5774	0.976	0.0023	2.4913	0.990
	Jun’04	0.0024	2.4782	0.991	0.0036	2.3516	0.973	0.0024	2.4822	0.994
	All surveys	0.0026	2.4554	0.990	0.0021	2.5146	0.967	0.0024	2.4849	0.992
SO	Aug’03	0.0026	2.4545	0.993	0.0049	2.2535	0.983	0.0027	2.4466	0.994
	Sep’03	0.0029	2.4158	0.993	0.0041	2.2901	0.981	0.0025	2.4504	0.993
	Nov’03	0.0024	2.4843	0.996	0.0037	2.3314	0.984	0.0022	2.4998	0.995
	Feb’04	0.0014	2.6595	0.990	0.0039	2.3414	0.974	0.0017	2.5993	0.987
	Apr’04	0.0020	2.5431	0.994	0.0037	2.3585	0.966	0.0022	2.5230	0.992
	Jun’04	0.0018	2.5631	0.994	0.0031	2.3873	0.975	0.0018	2.5717	0.993
	All surveys	0.0024	2.4893	0.992	0.0036	2.3537	0.970	0.0014	2.6570	0.980
CA+SO	Aug’03	0.0025	2.4665	0.992	0.0031	2.3808	0.971	0.0023	2.4848	0.993
	Sep’03	0.0028	2.4277	0.993	0.0044	2.2821	0.974	0.0027	2.4351	0.993
	Nov’03	0.0025	2.4733	0.995	0.0033	2.3682	0.979	0.0023	2.4978	0.995
	Feb’04	0.0020	2.5401	0.991	0.0040	2.3322	0.969	0.0023	2.5063	0.990
	Apr’04	0.0025	2.4764	0.990	0.0021	2.5306	0.971	0.0023	2.5048	0.991
	Jun’04	0.0020	2.5338	0.992	0.0020	2.5338	0.992	0.0020	2.5360	0.993
	All surveys	0.0025	2.4690	0.991	0.0030	2.4031	0.969	0.0023	2.4891	0.992

Table 5.4. Growth parameters obtained from the seasonal surveys, fleet monitoring, annual surveys and selectivity pilot studies (na: not enough data available). CA: Cabrera; SO: Sóller.

		Location	L_∞	k	t^{-1}	Score	φ'
Females	Seasonal surveys	CA	55.9	0.63	-0.29	0.38	3.29
		SO	63.7	0.48	-0.16	0.43	3.29
	Fleet monitoring	CA	63.0	0.43	-0.10	0.39	3.23
		SO	58.1	0.37	-0.49	0.56	3.09
	Annual surveys	CA	65.0	0.39	-0.59	0.65	3.22
		SO	56.5	0.48	-0.27	0.68	3.18
	Pilot surveys	CA	55.3	0.58	-0.25	0.86	3.25
Males	Seasonal surveys	CA	48.0	0.52	-0.40	0.25	3.08
		SO	44.8	0.51	-0.34	0.65	3.01
	Fleet monitoring	CA	46.0	0.52	-0.09	0.82	3.04
		SO	45.0	0.52	-0.38	0.27	3.03
	Annual surveys	CA	na	na	na	na	na
		SO	na	na	na	na	na
	Pilot surveys	CA	48.5	0.60	-0.44	0.41	3.15

5.4. Discussion

In the western Mediterranean, red shrimps are distributed over a wide depth range, showing clear bathymetric differences in its population structure (Sardà *et al.*, 1994, 2004a). At depths shallower than 1000 m, the population is mostly composed of adults, with females dominant and showing clear spatio-temporal variations in its population dynamics. Below 1000 m depth, the population is more stable, mostly composed of juveniles and dominated by males. In this sense, red shrimp is comparable to other decapod crustaceans, both shallow and deep water species, which show important spatial and seasonal sex and size segregation (e.g. Company and Sardà, 1997; García and Le Reste, 1997).

Our results have shown short spatial and temporal differences in the population dynamics of red shrimp distributed along the fishing grounds off the Balearic Islands. These differences can be related to the different environmental conditions found in the two sub-basins in which the two sampling locations are placed, the Algerian sub-basin in the south (AsB, CA) and the Balearic sub-basin in the north (BsB, SO). These different environments involve not only the geomorphical structure of the bottom but also the hydrographic factors, although some authors have suggested that temperature, which in the western Mediterranean is constant at around 13±0.5 °C below 200 m, cannot be a determinant factor to explain the spatio-temporal dynamics observed in red shrimp, considering population structure and behaviour of this species as independent of this parameter (Sardà *et al.*, 2003b).

Table 5.6. Spearman correlation between abundance and biomass and environmental parameters for the seasonal surveys (*: $p < 0.05$; **: $p < 0.01$; ***: $p < 0.001$). Mean T: mean temperature; Min T: minimum temperature; Max T: maximum temperature; Mean S: mean salinity; Min S: minimum salinity; Max S: maximum salinity; % OM: percentage of organic matter; % Sa.: percentage of sands; % Mu.: percentage of mud; Suprab.: total suprabenthos; Zoopl.: total zooplankton; Isop: Isopoda; Nat. B.: Natantia from the Bongo net; Nat. Sle.: Natantia from the sledge.

	Juveniles				Adults			
	Females		Males		Females		Males	
	n/km^2	g/km^2	n/km^2	g/km^2	n/km^2	g/km^2	n/km^2	g/km^2
Mean T	ns	-0.61*	ns	ns	ns	ns	-0.82**	-0.73**
Min T	ns	-0.58*	ns	ns	ns	ns	-0.80**	-0.71**
Max T	-0.68*	-0.73*	ns	ns	ns	ns	-0.80**	-0.76**
Mean S	-0.61*	-0.66*	ns	ns	0.70**	ns	ns	ns
Min S	-0.61*	-0.66*	ns	ns	0.70**	ns	ns	ns
Max S	-0.65*	-0.68*	ns	ns	0.84***	ns	ns	ns
% OM	ns	ns	ns	ns	ns	ns	ns	ns
% Sa.	ns	ns	ns	ns	ns	ns	ns	ns
% Mu.	ns	ns	ns	ns	ns	ns	ns	ns
Suprab.	ns	ns	ns	ns	ns	ns	ns	ns
Zoopl.	ns	ns	ns	ns	ns	ns	ns	ns
Isop.	ns	ns	ns	ns	ns	ns	ns	ns
Nat. B.	ns	ns	ns	ns	ns	ns	ns	ns
Nat. Sle.	ns	ns	ns	ns	ns	ns	ns	ns

Higher abundance of juveniles in SO could be related to the location of these fishing grounds, in the channel between Mallorca and the Iberian coast, with depths of up to 2300 m. The gentle slope of these fishing grounds could enhance the impingement of small individuals, which predominate in the population at depths exceeding 1000 m in the BsB (Sardà *et al.*, 1994, 2003a). The fishing grounds of CA are located in the Mallorca channel, not deeper than 1000 m and connected to the greatest depths of the AsB (2500 m) by an abrupt scarp, incised by numerous small canyons (Acosta *et al.*, 2002).

Table 5.7. Spearman correlation between abundance and biomass and temperature and salinity obtained from the annual surveys and surveys carried out off Algeria (*: $p< 0.05$; **: $p< 0.01$; ***: $p< 0.001$).

		Juveniles				Adults			
Annual surveys		Females		Males		Females		Males	
		n/km^2	g/km^2	n/km^2	g/km^2	n/km^2	g/km^2	n/km^2	g/km^2
	Mean T	ns	ns	ns	ns	0.93***	0.93***	ns	ns
	Min T	ns	ns	ns	ns	0.95***	0.95***	ns	ns
	Max T	ns	ns	ns	ns	0.95***	0.95***	ns	ns
	Mean S	ns	ns	ns	ns	0.86***	0.86***	ns	ns
	Min S	ns	ns	ns	ns	0.86***	0.86***	ns	ns
	Max S	ns	ns	ns	ns	0.83*	0.83*	ns	ns
Algerian surveys		<32 mm				≥32 mm			
		Females		Males		Females		Males	
		n/km^2	g/km^2	n/km^2	g/km^2	n/km^2	g/km^2	n/km^2	g/km^2
	Mean T	ns	ns	ns	ns	0.94**	0.86*	ns	ns
	Min T	ns	ns	ns	ns	0.94**	0.86*	ns	ns
	Max T	ns	ns	ns	ns	0.94**	0.86*	ns	ns
	Mean S	ns	ns	ns	ns	ns	ns	ns	-0.83*
	Min S	ns	ns	ns	ns	ns	ns	ns	ns
	Max S	ns	ns	ns	ns	0.83*	ns	-0.86*	-0.94*

The negative correlations found between temperature and juveniles and adult males could indicate possible links with the water masses, although these correlations cannot be taken as a cause effect relationship. Western Mediterranean Deep Waters (WMDW), characterised by low values of temperature, has only been observed on the fishing grounds of SO during autumn-winter (Figure 5.8). This is the period when the maximum recruitment of juveniles to fishing grounds and the maximum presence of adult males have been observed in SO which also coincides with the period of highest abundance of juveniles off the nearest Iberian coast (Sardà *et al.*, 1994; Tudela *et al.*, 2003). WMDW has not been found on the fishing grounds of CA, where very low abundances of juveniles have been observed. Similarly, the abundance of adult females could be influenced by the presence of Levantine Intermediate Waters (LIW), which is characterised by high salinity. Their maximum abundance has been found during summer in SO, whose fishing grounds are more influenced by the LIW from early spring to early autumn (Figure 5.8), coinciding with the reproductive period for the species in the area. The same reproductive period has been observed off the nearest Iberian coast, where large mature females are also mainly found during summer on the upper slope (Sardà *et al.*, 1994, 1997). No large aggregations of mature females have been detected in CA, where medium and large females are more abundant than in SO from late autumn to winter, coinciding with the period when the influence of the LIW in its fishing grounds is higher than in SO.

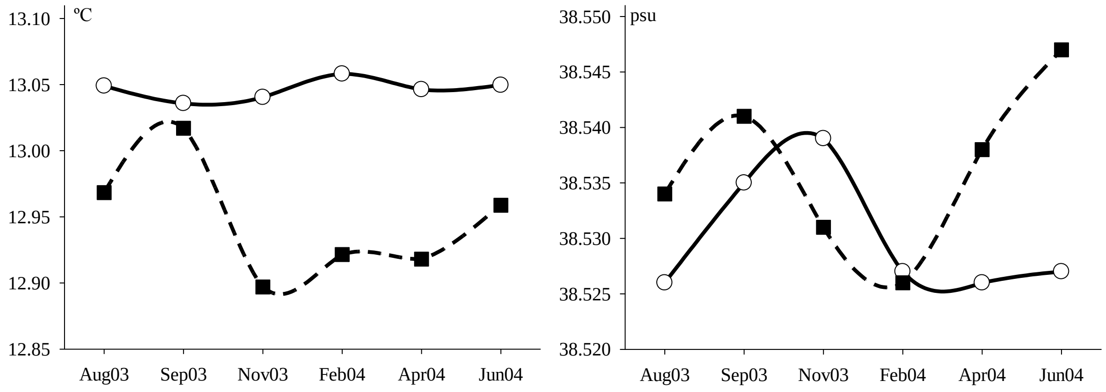


Figure 5. 8. Hydrographic data obtained during the oceanographic surveys with a CTD SBE-911+ in the water column (López-Jurado *et al.*, 2008): minimum temperature detected (a), indicating the presence of Western Mediterranean Deep Water and maximum salinity detected (b), indicating the presence of Levantine IntermediateWaters, by survey and location. White circles and solid line: Cabrera; black squares and dashed line: Sóller.

This important role played by water masses in the distribution of red shrimp has been previously suggested (Relini and Orsi Relini, 1987), relating their abundance and distribution mainly to Deep Water (Ghidalia and Bourgois, 1961; Bombace, 1975; Demestre and Martin, 1993), which seems to influence juveniles and male adults. Both this and the relationship found between LIW and adult females would explain the depth dependent size distribution found for this species, with fishing grounds mainly occupied by adult females and smaller sized individuals, mainly males, occupying deeper waters (Sardà *et al.*, 2003a).

Although no significant relationships have been found between the population dynamics of red shrimp and its potential trophic resources and sediment, food availability seems to be the principal limiting factor in the deep water food webs (Gage and Tyler, 1990). This has been one of the main factors proposed to explain spatial and seasonal mobility patterns of this species in the northwestern Mediterranean. According to Cartes (1998), the greater availability of food for decapods between late spring and early autumn would explain the maximum values on the open slope, both in their abundance and catches of commercial species such as red shrimp. Its higher abundance in the canyons during autumn and winter has been explained by the higher productivity of these areas, the regular influx of organic matter, and enhanced food resources due to the autumn plankton bloom (Sardà *et al.*, 1994; Sardà *et al.*, 1997; Tudela *et al.*, 2003). Peaks of biomass for suprabenthos in summer and both in summer and winter for zooplankton have been detected in the study area (Cartes *et al.*, 2008a). These seasons coincide with the most important biological events of the red shrimp population (reproduction and recruitment to fishing grounds). Pending further research on this topic, our results suggest that red shrimp and its main food resources are uncoupled, at least during daytime, when the sampling was carried out. The migrations along the bottom to shallower areas of the slope at night suggested for this species (Cartes *et al.*, 1993) could be on the basis of this uncoupling. The absence of any relationship between abundance and sediment characteristics can be explained by the feeding behaviour of red shrimp, which is as a passive scavenger (Cartes, 1994). In contrast, other decapod crustaceans more closely related to the bottom (*Nephrops norvegicus*, *Parapenaeus longirostris* and *Plesionika heterocarpus*) have been related to sediment characteristics (Maynou and Sardà, 1997; Chapters 3 and 4).

Some differences have also been found in the biological parameters of red shrimp between both locations, most of them related to the reproductive biology. In both locations, the percentage of males increases with depth, as has been widely described in the western Mediterranean, suggesting a mechanism to minimise the intra-specific competition (Sardà *et al.*, 1997; Sardà *et al.*, 2003a). However, the percentage of males is higher in SO than in CA and even higher than those previously reported in the fishing grounds both off the northeastern Iberian coast (Sardà *et al.*, 2003b) and off the Balearic Islands, where males represent around 30% of the population and only in

March is the sex ratio 1:1 (Carbonell *et al.*, 1999). From the seasonal surveys in SO, our results showed predominance of females from late spring to early autumn, but of males during winter and a sex ratio of 1:1 in late autumn and early spring. These differences could be due to the distinct sampling methods applied in both studies. The present study has used a homogeneous sampling along the whole bathymetric range exploited, while Carbonell *et al.* (1999) analysed samples from commercial catches, probably biased by the fact that commercial hauls target big red shrimps and also by the selectivity of the commercial nets. These authors reported minimum sizes of 15 mm CL, while our results showed values of 10 mm.

The reproductive period observed (during late spring and summer) coincides with that reported by other studies in the western Mediterranean (Sardà and Demestre, 1987; García-Rodríguez and Esteban, 1999; Carbonell *et al.*, 1999), but starts sooner in SO (early spring) than in CA (late spring). The condition of females (hepatosomatic index and Kn) is better in the former location during the pre-spawning period and the maximum reproductive potential of the species is also higher in SO. The percentage of total lipids in the hepatopancreas did not show differences between locations. Our results differ from those previously reported for red shrimp in Atlantic waters (Rosa and Nunes, 2003). According to these authors, energy requirements of the developing ovary seem to be more dependent on the ingestion of dietary lipids than on hepatopancreas reserves. Our results show that both values of the percentage of lipids in the hepatopancreas and the hepatosomatic index (HSI) are minimal during the advanced spawning period (summer), before gradually recovering until late spring, when the maturation process starts. This suggests that lipids of the hepatopancreas might play an important role as a source of energy for ovary ripening. This could also be supported by the coincidence of both minimum and maximum values of percentage of lipids in the hepatopancreas with minimum and maximum values of caloric content in the diet of red shrimp, especially for medium and large females (Cartes *et al.*, 2008a). The better condition of red shrimp in SO could be the reason for the smaller length at first maturity found for females there, as energetic condition has a positive effect on the probability of maturing (Baulier *et al.*, 2006). The better condition found in this area is in agreement with other studies on decapods crustaceans, such as P. longirostris (Chapter 3) and both *P. heterocarpus* and *Plesionika martia* (Chapter 4), as well as some fish, like the European hake *Merluccius merluccius* (Hidalgo *et al.*, 2008). Better condition in some fish, modelled according to lipid reserves, has been related to high productivity areas (Lloret *et al.*, 2002, 2005).

On the whole, the open upper slope fishing grounds off northwestern Mallorca, sited in the Balearic sub-basin, may operate as an area where big females aggregate from late spring to summer for undergoing gonadal ripening, fertilization and spawning. It explains the displacements of the trawl fleet northwards during summer, targeting this high market value catch. Males, which have been observed mature all year round, were also abundant in the area during winter and early spring, when mating could take place from the physical contact between sexes. After mating, red shrimp females carry the spermatophores for some months in the thelycum, thus storing sperm that can be used later to fertilise eggs in the absence of males (Demestre and Fortuño, 1992). During late autumn and winter, small individuals concentrate on the same grounds. It follows the same well known pattern observed off the northeastern Iberian coast (Sardà *et al.*, 1994, 1997), also found in the BsB, whose deep waters might sustain an unexploited population. A fraction of this population migrates up to the upper slope on both margins, showing similar temporal patterns in its dynamics and maintaining the red shrimp fisheries of the continental and insular slope at depths down to 800-1000 m depth (Demestre and Martin, 1993; Demestre and Lleonart, 1993; Carbonell *et al.*, 1999). The only difference is the high levels of juveniles and small individuals found on the slope fishing grounds off northwestern Mallorca, in spite of the absence of submarine canyons in this area (Acosta *et al.*, 2002). These values are higher than those reported in the canyons on the continental slope, considered as centres of juvenile concentration (Sardà and Cartes, 1997) and recruitment areas for the species (Sardà *et al.*, 1997; Tudela *et al.*, 2003), so this result still requires an explanation. In fact, the latter authors concluded that “there is still no hypothesis as to why females undergoing gonadal maturation would concentrate primarily on the middle and lower slope in spring and summer or why shrimps of smaller sizes concentrate in canyons heads”.

The southern Mallorca location did not show the same pattern, with a quite stable population throughout the year. Two hypotheses could explain the population dynamics for red shrimp in this area. Firstly, adults could migrate from this area to the northwestern Mallorca slope for spawning in late spring and summer and return in autumn. In fact, a dispersion of shoals after spawning and some migratory movements have been reported for the species (Sardà *et al.*, 1994; Relini *et al.*, 2004). Hence the northwestern area could act as the spawning and recruitment grounds for the whole slope around Mallorca, although some juveniles could migrate from the northwestern to the southern slope, which would explain the small peak of recruitment detected 2–4 months later in this area. However, the high increase of large females in the northwestern slope cannot be only explained by the migration from southern fishing grounds, as the decrease in this last area is not of the same range. Moreover, the movements described in the northeast Iberian coast are between fishing grounds separated by a maximum of 20 nm (Sardà *et al.*, 1997), whereas in the present study the distances between locations are up to 60 nm.

Another possibility is that the red shrimp population off southern Mallorca could be less related to the population dynamics of the species in the BsB. The fishing grounds off southern Mallorca (AsB) would not be influenced by the spawning and recruitment grounds detected in the northwestern slope, so other areas of the Algerian subbasin could determine the population dynamics of the species on these grounds. Although there is a lack of information on this sub-basin, in the 1980s, larger individuals were found during summer around the Emile Baudot seamount (M. Massutí, pers. comm.), located south of the studied fishing grounds. In that decade, a fraction of the trawl fleet remained in this area instead of carrying out the already explained northwards movements during summer. Nowadays, the exploitation of this seamount has been abandoned because of its large distance from any port of Mallorca, the present regulation limiting the fishing activity of trawl fleet to 12 hours per day and, more recently, the high fuel cost. Recruitment grounds affecting southern fishing grounds could be located in the vicinity of the canyons found on the slope of eastern Mallorca and southern Menorca (Acosta *et al.*, 2002). In fact, CPUE of the trawl fleet operating in these areas shows higher values than those found off southern Mallorca and of the same range as those found in the northwest (Figure 5.9), but the highest values are found in spring, reinforcing the possibility of different dynamics for the red shrimp population in the BsB and in the AsB.

Although seasonal patterns found in the population dynamics of red shrimp are similar to previous studies, the clear differences found between the two nearby locations illustrate the important role the environmental conditions play in the dynamics of this resource. Thus, the observed short spatio-temporal mobility patterns of red shrimp off Balearic Islands can affect catchability of certain fractions of the population. For this reason, these results should be taken into account for the assessment and management of this important resource. It is especially relevant for this species, which is generally believed to be fully exploited in the area, that these results are considered in the current discussions regarding the necessity to adopt management measures such as spatial closed fishing seasons for the improvement of the state of the resource (GFCM, 2005).

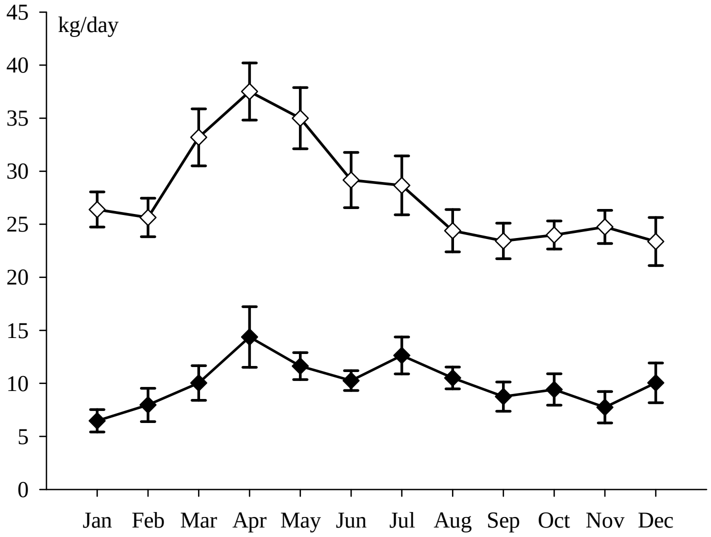


Figure 5.9. Mean standardised CPUEs from the landings of three trawlers of Cala Rajada and Portocolom harbours (see Figure 1.8), operating in the northeast of Mallorca, during a synthetic year (2000–2005), for the commercial categories, small (white diamonds) and large (black diamonds). Standardization was carried out following the procedures described in Chapter 2. Error bars are standard errors.

CHAPTER 6.

ASSESSMENT

Adapted from "Assessment of the deep water trawl fishery off the Balearic Islands (western Mediterranean): from single to multi-species approach". Beatriz Guijarro, George Tserpes, Joan Moranta and Enric Massutí. (2011). *Hydrobiologia* 670: 67-85.

Abstract

The bottom trawl fishery developed on the slope off Balearic Islands has been analysed from different sources of information: (i) data obtained during annual bottom trawl surveys developed annually since 2001; (ii) daily sale bills from the bottom trawl fleet, available since 2000. Considering both hydrographical and geomorphologic conditions, the study area was divided in four geographical sectors. Multivariate techniques were applied to identify assemblages and their main species, and to investigate the influence of environmental variables in the slope communities. Fishery-independent and fishery-dependent indicators were calculated, both at specific and community level, for the assemblages identified. In all cases, they were summarised using the Traffic Light approach. Three assemblages have been identified in the slope trawl fishing grounds off the Balearic Islands: (1) the almost unexploited shelf break, where teleosts predominate; (2) the upper slope, where teleosts still predominate but crustaceans are also very important (with *Nephrops norvegicus* as target species); (3) and the middle slope, where crustaceans predominate (with *Aristeus antennatus* as target species). Depth was the main factor affecting the species composition of the assemblages, although other factors such as area, year and effort level also affect. Indicators estimated from both sets of data suggested an improvement in the state of *N. norvegicus*, although the results suggest the influence of other factors than fishing impact in the state of this resource. For *A. antennatus*, marked differences have been found depending on the data source. In the upper slope, indicators suggested an improvement in the state of this assemblage, which can be related to a decreasing trend found in the fishing effort exerted in this depth range. Indicators from the middle slope showed differences for both sets of data. The characteristics of both data sources and of the species analysed are discussed as responsible of these differences.

Keywords: *Nephrops norvegicus*, *Aristeus antennatus*, assessment, community, ecosystem approach, indicators, Traffic Lights.

6.1. Introduction

Mediterranean bottom trawl fisheries are multispecies as they are targeting more than 100 demersal species of fishes, crustaceans and molluscs, with an important commercial value and abundance (Caddy, 1993; Lleonart and Maynou, 2003). In spite of that, monospecific approaches are usually the rule in assessments (e.g. Farrugio *et al.*, 1993; Lleonart and Maynou, 2003). In recent decades, there has been a progressive change from the traditional approach of fishery assessment to a new ecosystem approach (Browman and Stergiou, 2004; Pikitch *et al.*, 2004). This new approach is particularly important in the multispecies Mediterranean fishery, as the calculations for a single species are of limited value for management in this type of fisheries (Caddy, 1993).

Within the ecosystem-based approach, there is an increasing need for measuring the impact of fishing on ecosystems and, as a consequence, many indicators targeting various components of ecosystems have been developed and discussed (e.g. Trenkel and Rochet, 2003; Nicholson and Jennings, 2004). One of the ways of using indicators is examining whether the indicator is currently changing (Rochet and Trenkel, 2003). However, the complexity of exploited ecosystems forces to examine multiple indicators to accumulate evidence, raising the question of how to summarise them. One of the ways is the Traffic Light (TL) method. This approach was firstly proposed as a type of precautionary management framework suitable for use in fishery assessment in data-poor situations (Caddy, 1999, 2002), but it can be used to assess the status of all stocks whether rich or poor in data (Halliday *et al.*, 2001). The TL displays time series in such a way that helps to perceive likely transitions of indicators and relationships between variables visually (Caddy *et al.*, 2005). This methodology has been applied for single- and multi-species assessments both in the Atlantic and the Mediterranean (Caddy *et al.*, 2005; DFO, 2005; Ceriola *et al.*, 2007, 2008; Guijarro *et al.*, 2012) and appears to be more precautionary than traditional stock assessment methods (Koeller *et al.*, 2000).

Over the last times, the methods available to be used in stock assessment models have changed from those using only catch, catch-at-age and survey or CPUE data to methods that use every source of data available in a totally integrated framework (Hilborn, 2003). In this sense, TL provides a way of bringing a variety of monitoring results, results from traditional stock assessment models and methods, anecdotal observations and political/economic considerations into management decisions (Koeller *et al.*, 2000). One of the main shortcomings in Mediterranean fishery assessments, which is related to their diversity and complexity, is the lack of suitable data because in spite of the existence of fairly reliable historical data series of landings, data on effort are almost absent (Lleonart and Maynou, 2003). In this sense, bottom trawl surveys are very useful, not only because they avoid factors such as fisheries behaviour which could bias estimates on commercial data, but also because they can provide information from the entire epibenthic community. In this sense, fishery-independent data allow the study of single species (e.g. Abella *et al.*, 1999; Lombarte *et al.*, 2000; Tserpes and Peristeraki, 2002), taxonomic groups (Abelló *et al.*, 2002a; Massutí and Moranta, 2003) and faunal assemblages (Moranta *et al.*, 1998; Massutí and Reñones, 2005; Dimech *et al.*, 2008), constituting an appropriate tool for an ecosystem-based fisheries management.

In the Balearic Islands, assessments of some of the main species exploited by the bottom trawl fishery have been made based on population dynamics (Oliver, 1993; García-Rodríguez and Esteban, 1999; GFCM, 2011), production models (Carbonell and Azevedo, 2003; Quetglas *et al.*, 2009) and regression analysis (Alemany and Alvárez, 2003); all of them have considered the single species as the basic unit of the analysis. Multi-species studies have been performed considering fish and cephalopod assemblages separately (Massutí *et al.*, 1996b; Moranta *et al.*, 2000; Quetglas *et al.*, 2000), as well as the entire megafaunal demersal communities (Massutí and Reñones, 2005; Moranta *et al.*, 2008b; Ordines and Massutí, 2009).

The aim of this chapter is to assess the deep water trawl fishery resources off the Balearic Islands from single to multi-species approach. This chapter has three main objectives: (i) to identify and characterise the species assemblages in the deep water trawl fishing grounds off the Balearic Islands; (ii) to analyse the spatio-temporal trends in abundance and biomass from different taxonomic groups, including the influence of environmental conditions and (iii) to estimate ecological indicators (both at single- and multi-species level) to assess the impact of fishing on these communities.

6.2. Materials and methods

6.2.1. Data source

Two different sources of data were used. Firstly, fishery-independent data was obtained from the annual bottom trawl surveys carried out in the Balearic Islands between 2001 and 2008 (see Chapter 2). For an initial number of 452 stations sampled, 153 were considered for this study (15–20 stations by year), which correspond to those carried out in the slope (between 200 and 800 m depth). Four different areas were considered during this study (see Chapter 2). The number of stations analysed by area were 44, 35, 43 and 31 for the northern, western, southern and eastern areas, respectively. Information obtained was related to the total catch (biomass and abundance) by species, length frequency distributions of all fish and commercial crustaceans and cephalopods, and biological sampling (individual length, weight, sex and maturity) of the main commercial species. Secondly, fishery data was obtained from the landings of the bottom trawl fleet which operates in the island of Mallorca between 2000 and 2008 (see Chapter 2). This information consisted in the biomass landed by species or commercial categories. Each of the 60847 daily sale bills was assigned to one or more fishing tactics following the methodology described in Chapter 2 and only those trips carried out in the upper and middle slope (41729) were used.

6.2.2. Data analysis

Different multivariate techniques were used for the community analysis, in order to analyse biomass and abundance indices by station, obtained from the surveys, expressed in terms of weight (g) and number per km^2. Only species with a frequency of occurrence larger than 15% in all surveys were included in the analysis in order to reduce the variability in the species matrix due to the presence of a lot of zero values. As a first step, cluster analysis and multidimensional scaling were applied after square root transformation to identify assemblages. The Bray-Curtis similarity index was chosen as the similarity coefficient and Group Average was utilised as the clustering algorithm (Clarke and Warwick, 1994). Similarity Percentage Analysis (SIMPER) was applied to identify the species that mostly contribute to the differences among the detected station groups (Clarke, 1993). In addition, supervised machine learning approaches (Mitchel, 1997), and in particular the decision tree construction method as implemented by the C4.5 algorithm (Quinlan, 1993), were employed as an alternative method to identify the power of the examined species (attributes) in classifying the stations into the predefined depth classes. In order to assess the power of the predicted classification scheme, the analysis was firstly applied to the 2001–2005 data set (learning data), and the decision trees built were used to predict the classification of the 2006–2008 data (test data) into the assemblages previously detected.

Redundancy Analysis (RDA, ter Braak and Smilauer, 2002) was also applied to link the species composition matrix (biomass and biomass) directly with the environmental matrix. Environmental information available was depth, hydrography (temperature, salinity and flow velocity near the bottom) obtained from a model and phytoplankton pigment concentration (ppc, mg Chl a/m^3), obtained from Kempler (2009), as indicator of the availability of trophic resources at the lowest levels of the trophic chain (Cartes *et al.*, 2004). Data from different periods, simultaneously and before 1, 2, 3 and 4 months of the sampling, were considered. Fishing effort was also included in the model. Three levels of effort were considered: low (<500 days/year), medium (500–1000 days/year) and high (>1000 days/year). For each of the stations, an effort level was assigned taking into account the fishing tactic, the number of daily fishing trips and the nearest port. The variables included in the model were depth, area, year, effort, temperature, current velocity, simultaneous ppc and ppc 3 months before sampling. Generalized Additive Models (GAM; Hastie and Tibshirani, 1990) were used to relate abundance of different taxonomic groups with environmental variables. The taxonomic groups considered were elasmobranchs, teleosts, crustaceans, molluscs and others. The variables included in the model were the same than for the RDA.

Fishery-independent indicators were computed both at population and at community levels. At population level, indicators used were frequency of occurrence, abundance (n/km^2), biomass (g/km^2), centre of gravity (COG, Daget, 1976), size based indicators and condition index (Kn; Le Cren, 1951). Frequency of occurrence, abundance and biomass were computed both for total population and for recruits. The COG model allows calculating and locating with precision the centre of species distributions by means of a descriptor (in this case, depth). It is determined as follows: $COG = (x_1 + 2x_2 + 3x_3 + \ldots + nx_n)/\Sigma(x_i)$, where x_i represents the calculated mean abundance values of the species x present in the stratum i (before analysis the sampled depth was divided into strata of 100 m). Size based indicators calculated were mean

(ML) and mean maximum length (MML) and mean (MM) and mean maximum body mass (MMBM). MML and MMBM were computed averaging the maximum length/body mass of each species in each haul. The individual weight of each specimen was calculated from bibliographic length–weight relationships (Merella *et al.*, 1997; Quetglas *et al.*, 1998a,1998b; Company and Sardà, 2000; Papaconstantinou and Kapiris, 2003; Morey *et al.*, 2003; Mendes *et al.*, 2004) as well as own data obtained during these surveys and the seasonal bottom trawl surveys (Chapter 2). Kn was calculated as observed weight over expected weight, estimated from a length–weight relationship calculated considering all biological data available, by sex.

At the community level, assessment was performed using density, diversity and size based indicators. Density indicators were abundance (n/km^2), biomass (g/km^2) and percentage of non-commercial species (both in abundance and biomass). Diversity indicators were total number of species (S), species richness (Margalef, $d= (S-1)/\log(N)$, where N is the total number of individuals), Pielou's evenness ($J'= H'/\log(S)$), Shannon–Wiener index ($H'=-SUM(P_i*\log_2(P_i))$, where P_i is the proportion of each species in each sample) and ABC plots (K-dominance curves; Warwick, 1986; Clarke, 1990). For the latter, those species only reported in a single haul or in a single survey were removed. As the results of ABC plots depend on the species included in the analysis (Jouffre and Inejih, 2005), a second analysis was performed including only those species which have appeared in all surveys. Size based indicators were biomass, abundance and diversity spectra, and the above described MML, ML, MMBW and MBW.

Normalised biomass size spectra (Jennings *et al.*, 2002) were computed by dividing the biomass in a given body mass class interval by the width of that class interval (in antilog dimensions). The relationship between body mass (as $\log_2$ classes) and total normalised biomass ($\log_2$ transformed) was described using least squared linear regressions, considering only the body mass class in which the biomass starts to decline. Size spectra (Bianchi *et al.*, 2000) were constructed for each survey by plotting the natural logarithm of the total number of individuals caught by 5 cm length class against the natural logarithm of the middle of each length class. Diversity spectra (Gislason and Rice, 1998) were constructed by plotting the Shannon–Wiener index (calculated for each 5 cm length class) against the mid length of each length group. For these three metrics, the slope of the spectrum for each year or area was used as an indicator of changes in the exploitation rate (Bianchi *et al.*, 2000). The slope decreases when increases fishing mortality (Hall *et al.*, 2006), so it can be considered a good measure of fishing impacts (Gislason and Rice, 1998).

Fishery-dependent indicators were computed both at population and community level. At population level, density and economic indicators were computed. Density indicators were annual landings by boat (as kg/boat), landings per day for total fleet (as kg/day), landings per boat and day (LPUE, as kg/day per boat), both for total population and the small sized commercial category (as a proxy of recruits). Economic indicators (Ceriola et al., 2008) were revenue by boat (€/boat), revenue by day (as €/day), revenue by boat and day (RPUE, as €/day per boat) and average price (as €/kg). At community level, these same indicators were computed, but without taking into account size groups. Number of boats and number of days were also calculated.

The summary of these indicators, both fishery-dependent and independent indicators and both at population and community level, was performed using Traffic Lights (TL, Caddy, 1999, 2002; Koeller *et al.*, 2000). The TL is a system of red, yellow and green lights which categorise multiple indicators of the state of a fishery and ecosystem, considering red as bad, yellow as intermediate and green as good. A number of options are available for establishing boundaries for TL, like Limit Reference Points, a percentage of the average value or using the 33rd and 66th percentiles (Halliday *et al.*, 2001). This last option was used in this work, adapting the rules depending of the expected effect of increasing fishing pressure in each indicator. Although TL has been usually employed for evaluating temporal variation of indicators in assessment (DFO, 2005; Ceriola *et al.*, 2007, 2008; Guijarro *et al.*, 2012), in this work, both spatial and temporal trends were tested using this method. Thus, a mean value for each of the indicators has been computed by year or area and a different colour was assigned if this value was under the 33rd percentile (red, bad state), between the 33rd and 66th percentile (yellow, intermediate state) or over the 66th percentile (green, good state). For those indicators that we expect to increase with high fishing pressure (like effort indicators themselves or percentage of non-commercial species), the rules were the opposite. As a summary, a single TL was created for fishery-independent and fishery-dependent data, assigning the colour of the most abundant one for each year or area.

6.3. Results

Total catch during the 8 years of annual bottom trawl surveys in the fishing grounds of the slope off the Balearic Islands was 11391 kg and 725817 individuals, of a total of 363 species (or families when it was not possible to arrive at species level) corresponding to 108 teleosts, 19 elasmobranchs, 75 crustaceans, 46 molluscs, 27 echinoderms and 94 belonging to other groups.

Cluster and MDS results showed three different groups related to depth (Figure 6.1), corresponding to those hauls carried out between 200 and 299 m depth (SB, shelf break), 300 and 499 m depth (US, upper slope) and 500 and 800 m depth (MS, middle slope). The results of the SIMPER analysis (Table 6.1) showed high values of average dissimilarity between groups, larger than 90%, and confirmed the presence of these well-defined groups. The species that characterise the SB were mostly teleosts (like *Capros aper*, *Merluccius merluccius* and *Micromesistius poutassou*) and the elasmobranch *Scyliorhinus canicula*. The most important species in the US were also teleosts, crustaceans (from the genus *Plesionika*, *Parapenaeus longirostris* and *Nephrops norvegicus*), the elasmobranch *Galeus melastomus* and the cephalopod *Sepietta oweniana*. In the MS, crustaceans were predominant (like *Aristeus antennatus*), followed by teleosts and the elasmobranchs *G. melastomus* and *Etmopterus spinax*. Decision tree analysis confirmed these groups, as the supervised machine learning showed a very high level of classification (Table 6.2). Miss-classification was higher for the stations of the shallowest group in which the number of samples was the lowest.

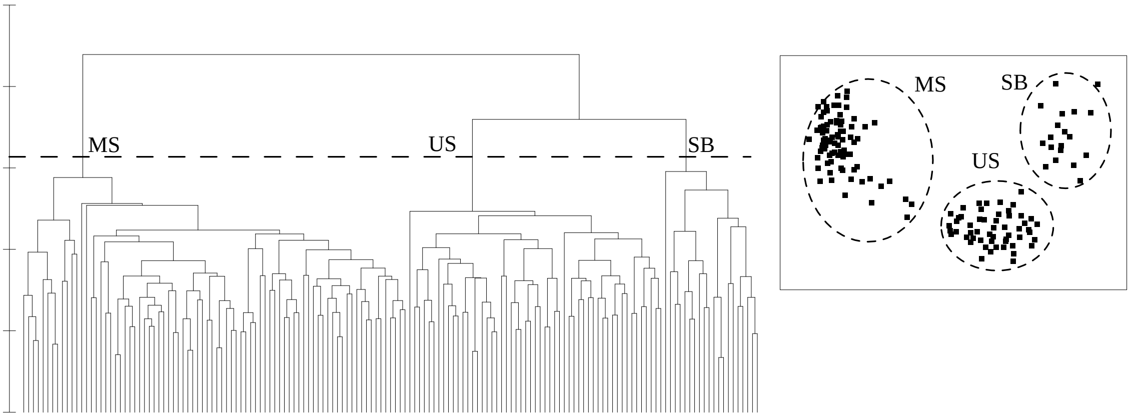


Figure 6. 1. Dendrogram and MDS ordination of samples made during the annual bottom trawl surveys, showing the three different assemblages obtained from the cluster analysis: shelf break (SB, 200–299 m), upper slope (US, 300–499 m) and middle slope (MS, 500–800 m).

Table 6.1. SIMPER results for each assemblage identified from the dendogram and for the species that contributed to at least 90% of the differences between these groups: mean abundance (Av. Ab.: n/km^2), average similarity (Av. Sim.), standard deviation (SD), percentage contribution to the similarity (Contrib%), percentage contribution to the similarity accumulated (Cum.%), average dissimilarity (Av. Diss.). Taxonomic group (Tax.) for each of the species is also shown (TE: teleosts; EL: elasmobranchs; CR: crustaceans; MO: molluscs).

Species	Tax.	Av. Ab.	Av. Sim.	Sim/SD	Contrib%	Cum.%
Shelf break; Av. Sim.= 27.21						
Scyliorhinus canicula	EL	3545.91	9.46	0.85	34.78	34.78
Capros aper	TE	18084.62	6.32	0.65	23.24	58.02
Merluccius merluccius	TE	1714.21	3.66	0.58	13.46	71.47
Micromesistius poutassou	TE	3982.98	2.55	0.36	9.39	80.86
Synchiropus phaeton	TE	1077.83	1.55	1.05	5.68	86.54
Helicolenus dactylopterus	TE	645.19	1.35	0.76	4.96	91.50
Upper slope; Av. Sim.= 33.37						
Gadiculus argenteus	TE	13609.48	14.21	1.09	42.59	42.59
Galeus melastomus	EL	2438.46	2.18	0.70	6.53	49.13
Caelorynchus caelorhynchus	TE	1961.63	2.06	0.88	6.16	55.29
Plesionika heterocarpus	CR	4543.87	1.97	0.45	5.91	61.19
Sepietta oweniana	MO	1319.66	1.65	0.81	4.94	66.13
Chlorophtalmus agassizi	TE	2406.85	1.59	0.64	4.76	70.90
Plesionika giglioli	CR	857.83	1.50	0.61	4.51	75.40
Helicolenus dactylopterus	TE	1048.90	1.26	1.02	3.77	79.17
Phycis blennoides	TE	545.00	1.19	0.89	3.57	82.75
Micromesistius poutassou	TE	1534.96	1.16	0.63	3.47	86.21
Plesionika antigai	CR	731.23	0.59	0.62	1.77	87.99
Parapenaeus longirostris	CR	966.57	0.58	0.45	1.75	89.74
Nephrops norvegicus	CR	553.20	0.52	0.37	1.57	91.31
Middle slope; Av. Sim.= 36.17						
Aristeus antennatus	CR	2687.68	12.16	1.05	33.63	33.63
Lampanictus crocodrilus	TE	1924.95	7.80	1.12	21.57	55.19
Plesionika martia	CR	811.75	2.78	0.81	7.68	62.87
Galeus melastomus	EL	704.30	2.20	0.77	6.08	68.95
Phycis blennoides	TE	348.62	2.12	0.94	5.87	74.82
Pasiphaea multidentata	CR	554.38	2.11	0.54	5.83	80.65
Nezumia aequalis	TE	273.38	1.67	1.03	4.61	85.26
Plesionika acantonothus	CR	220.29	0.87	0.62	2.41	87.67
Sergia robusta	MO	258.48	0.80	0.46	2.22	89.89
Geryon longipes	CR	130.28	0.74	0.52	2.05	91.93
Pairwise comparisons						Av. Diss.
Shelf break vs. Upper slope						89.73
Shelf break vs. Middle slope						99.03
Upper slope vs. Middle slope						94.39

Table 6.2. Estimated information gain for the 15 highest rates for the examined attributes (species) from the supervised machine learning approach and classification success by assemblage for the training and the test data sets.

Attribute (species)	Information gain
Sepietta oweniana	0.941
Aristeus antennatus	0.85
Gadiculus argenteus	0.829
Lampanictus crocodrilus	0.773
Synchiropus phaeton	0.753
Nezumia aequalis	0.751
Lepidorhombus boscii	0.722
Scyliorhinus canicula	0.692
Capros aper	0.691
Sergia robusta	0.644
Parapenaeus longirostris	0.639
Helicolenus dactylopterus	0.625
Chlorophtalmus agassizi	0.613
Trigla lyra	0.606
Geryon longipes	0.584

Class	Classification success	
	Training (%)	Test (%)
Shelf break	100%	63%
Upper slope	100%	100%
Middle slope	100%	96%

Full models from the RDA results were found significant ($p<0.01$) both for biomass and abundance (Table 6.3). Depth was the main factor affecting the species composition, while the rest of the significant variables explained low percentages of the variance. In any of the models, the variables related to primary production were found to be significant. Deviance explained from the GAM models applied to biomass of all the groups analysed varied between 25 and 79% (Table 6.4). In all cases, depth and year were significant factors. For total, elasmobranchs, teleosts, molluscs and others there was a non-linear decreasing trend with depth and crustaceans showed an increasing trend with depth (Figure 6.2). By years, both elasmobranchs and crustaceans showed the highest values for 2002, and molluscs in 2005, although any taxonomic group showed a clear inter-annual trend. Area was a significant factor for some of the taxonomic groups as biomass showed the highest values in the north for total and teleosts and in the south for crustaceans. Fishing effort was marginally significant for elasmobranchs and crustaceans, with different trends: the highest values of biomass for elasmobranchs were found with low or medium levels of fishing effort, but for crustaceans it was higher with medium and high levels.

Table 6.3. Results of the redundancy analysis for the density (abundance in n/km^2 and biomass in g/km^2) matrix of the species. The trace, the explained variance (EV), the F statistic and its significance (p value) for both the full model, which contains all the variables included in the model and for each individual variable after extracting the effect of the covariable is also indicated. D: depth, A: area, Y: year, E: effort, T: temperature, V: current velocity, PP: primary production. Only non-correlated variables were included in the model.

Depth * Area * Year * Effort * Temperature * Velocity * Primary Production						
	Effect	Cov	Trace	EV (%)	F ratio	p value
Abundance	Full model		0.595	59.5%	10.941	0.0020
	Depth	A, Y, E, T, V, PP	0.278	27.8%	92.097	0.0020
	Area	D, Y, E, T, V, PP	0.028	2.8%	3.075	0.0020
	Year	D, A, E, T, V, PP	0.033	3.3%	1.539	0.0160
	Effort	D, A, Y, T, V, PP	0.018	1.8%	2.965	0.0060
	Temperature	D, A, Y, E, V, PP	0.023	2.3%	7.661	0.0020
	Velocity	D, A, Y, E, T, PP	0.060	6.0%	19.850	0.0020
	Primary Production	D, A, Y, E, T, V	0.007	0.7%	0.778	0.7840
Biomass	Full model		0.576	57.6%	10.104	0.0020
	Depth	A, Y, E, T, V, PP	0.272	27.2%	85.863	0.0020
	Area	D, Y, E, T, V, PP	0.026	2.6%	2.708	0.0020
	Year	D, A, E, T, V, PP	0.027	2.7%	1.234	0.0800
	Effort	D, A, Y, T, V, PP	0.016	1.6%	2.546	0.0060
	Temperature	D, A, Y, E, V, PP	0.019	1.9%	6.157	0.0020
	Velocity	D, A, Y, E, T, PP	0.046	4.6%	14.679	0.0020
	Primary Production	D, A, Y, E, T, V	0.009	0.9%	0.967	0.5100

Table 6.4. Results of generalised additive models (GAM) applied to the different groups of species and all the species (Total), showing the dependent variable (abundance in n/km^2 and biomass in g/km^2), the explanatory variables (D: depth; A: area; Y: year; E: effort, T: temperature, PP: primary production), as well as the score, R-squared (R^2) and deviance explained (DE) values. The significance of each explanatory variable (***: p<0.001; **: p<0.01; *: p<0.05; +: p<0.1; ns: not significant or p≥0.1) is also indicated.

	D	A	Y	E	T	PP	Score	R^2	DE(%)
Abundance									
Total	***	***	***	ns	ns	ns	0.421	0.178	80
Elasmobranchs	***	ns	***	+	ns	ns	0.507	0.078	46.9
Teleosts	***	***	***	ns	ns	ns	0.336	-0.023	82.7
Crustaceans	***	+	***	+	ns	ns	0.269	0.047	52.1
Molluscs	***	ns	***	ns	ns	ns	0.732	0.133	63.1
Others	***	***	***	ns	ns	ns	1.598	0.103	59.8
Biomass									
Total	***	***	***	ns	ns	ns	0.429	0.191	71.5
Elasmobranchs	***	ns	***	+	ns	ns	0.894	0.143	25.5
Teleosts	***	***	**	ns	ns	ns	0.190	0.125	79.2
Crustaceans	***	+	***	+	ns	ns	0.251	0.126	32.9
Molluscs	***	*	***	ns	ns	ns	0.592	0.386	51.4
Others	***	***	***	ns	ns	ns	1.84	-0.58	42.2

Traffic Light method for *N. norvegicus* showed similar results among years and between areas with both set of data (Figure 6.3). The highest proportion of reds was found in the first years (except for 2002 for density indicators) and of greens in the last years. Condition of both males and females did not show this trend, with the lowest values during the last year. Spatially, the highest number of greens were found in the northern and southern locations (although the northern location showed reds in the length based indicators) and of reds in the eastern. In fact, in this location, length based indicators could not be computed due to the low number of individuals caught. On the contrary, TL for *A. antennatus* showed very different results with both set of data (Figure 6.4). Density indicators from surveys showed high numbers of reds during the last years (except for 2008). The opposite trend has been found for fleet based indicators, with the highest numbers of reds at the beginning of the series. Condition showed differences between both sexes, with the lowest values of the series for males in the last 2 years. Spatial TL showed some differences but depending on the group of indicators. For example, in the case of fishery-independent indicators, the east showed high number of greens for density indicators but reds for size-based and condition indicators. In the case of fishery-dependent indicators, the south showed high number of reds for density indicators but of greens for economic ones. On the contrary, the west showed the highest numbers of greens in all cases.

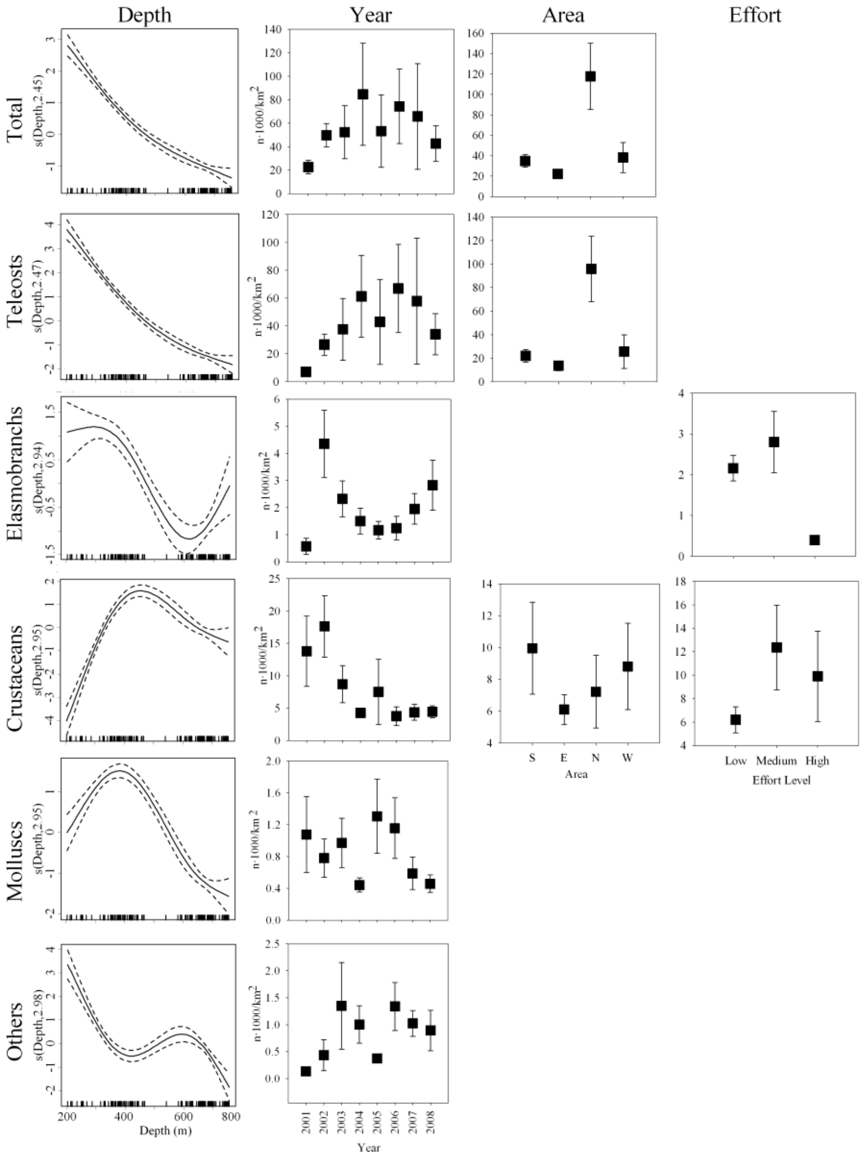


Figure 6.2. Plots of the best significant generalised additive modelling (GAM) applied to the abundances of each of the taxonomic groups (total, teleosts, elasmobranchs, crustaceans, molluscs and others) for depth, and mean abundance values (n/km^2) for the significant factors year, area (S: south, E: east, N: north, W: west) and effort level (low: <500 days/year; medium: 500–1000 days/year; high: >1000 days/year). Error lines are standard errors.

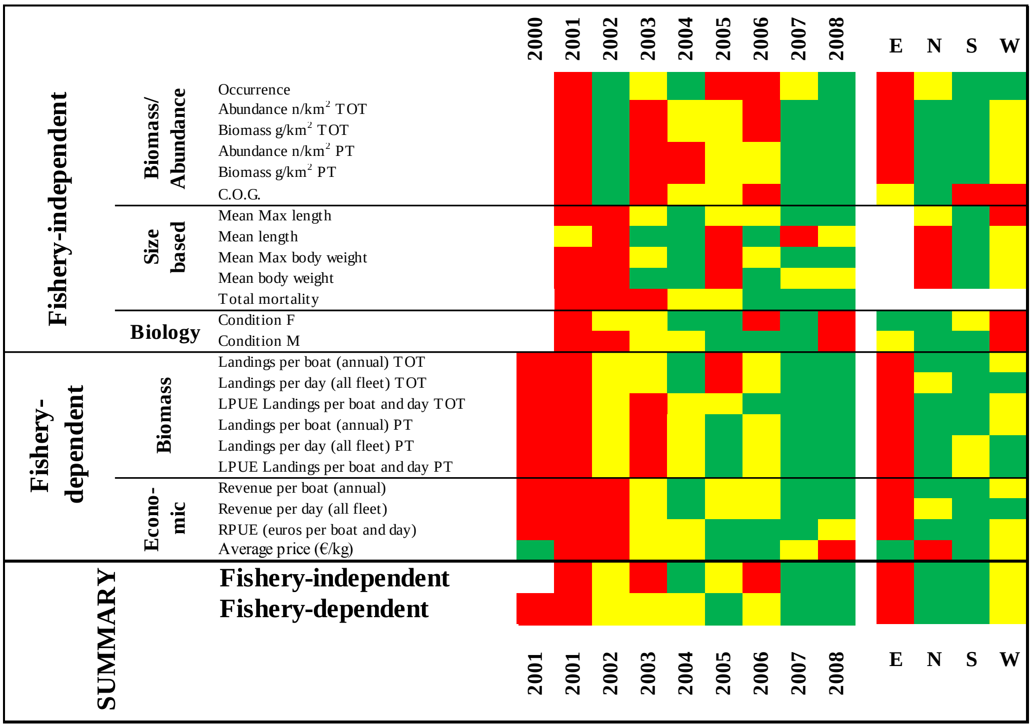


Figure 6.3. Traffic Lights displaying biological and economic indicators response for the Norway lobster *Nephrops norvegicus* in the Balearic Islands. Red: <33rd percentile; yellow: 33rd–66th percentiles; green: >66th percentile.

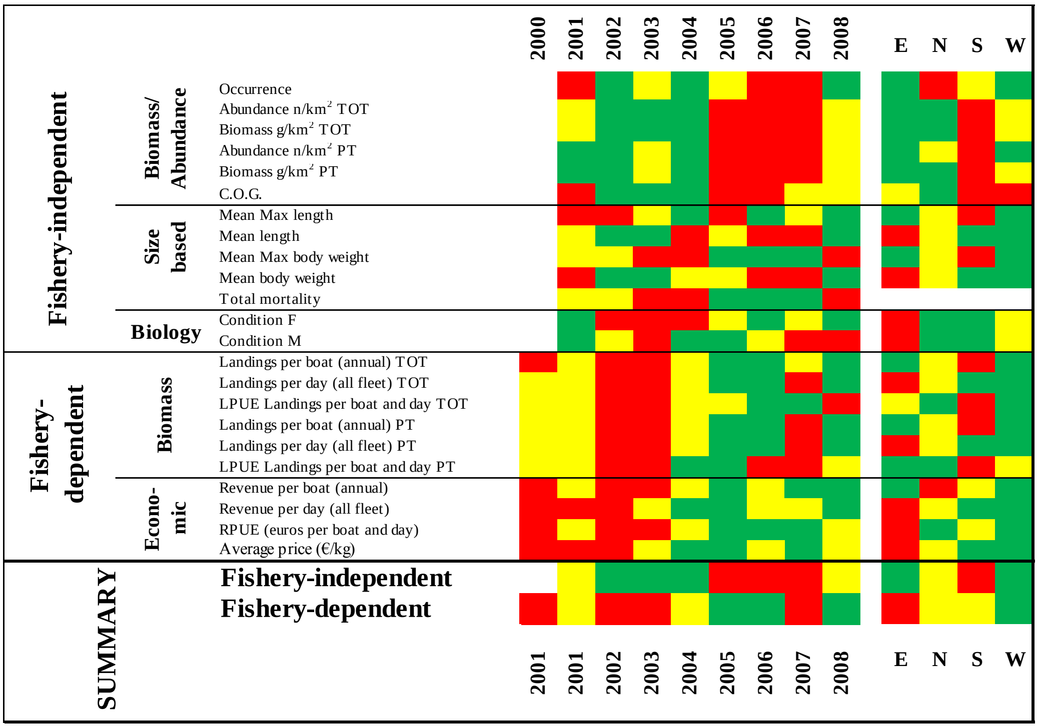
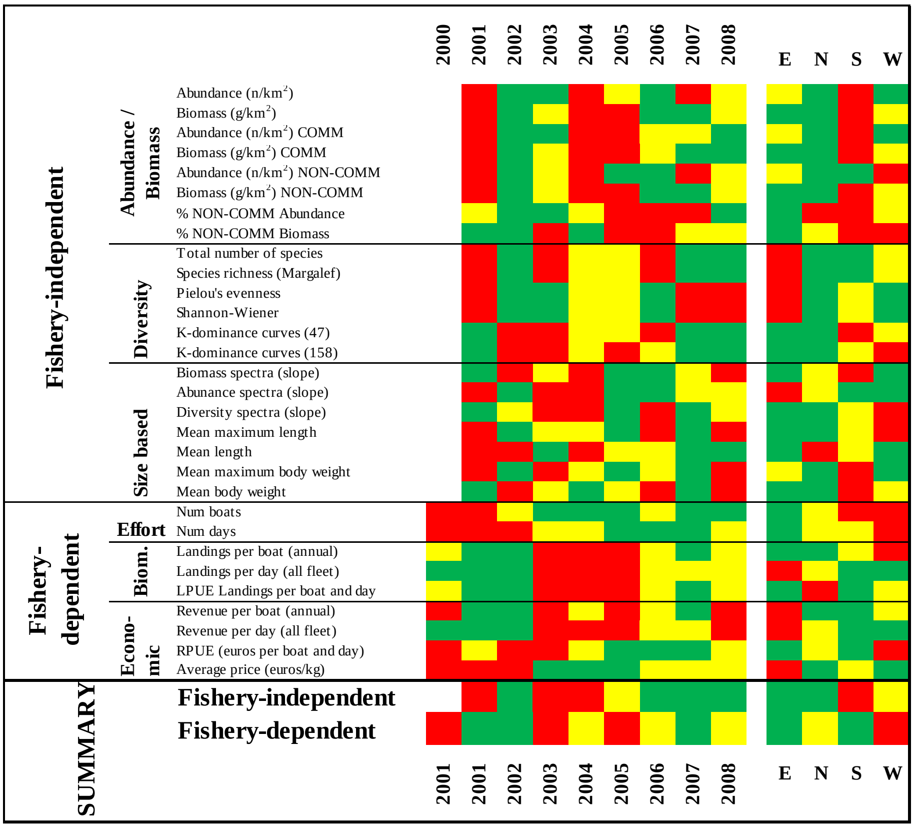


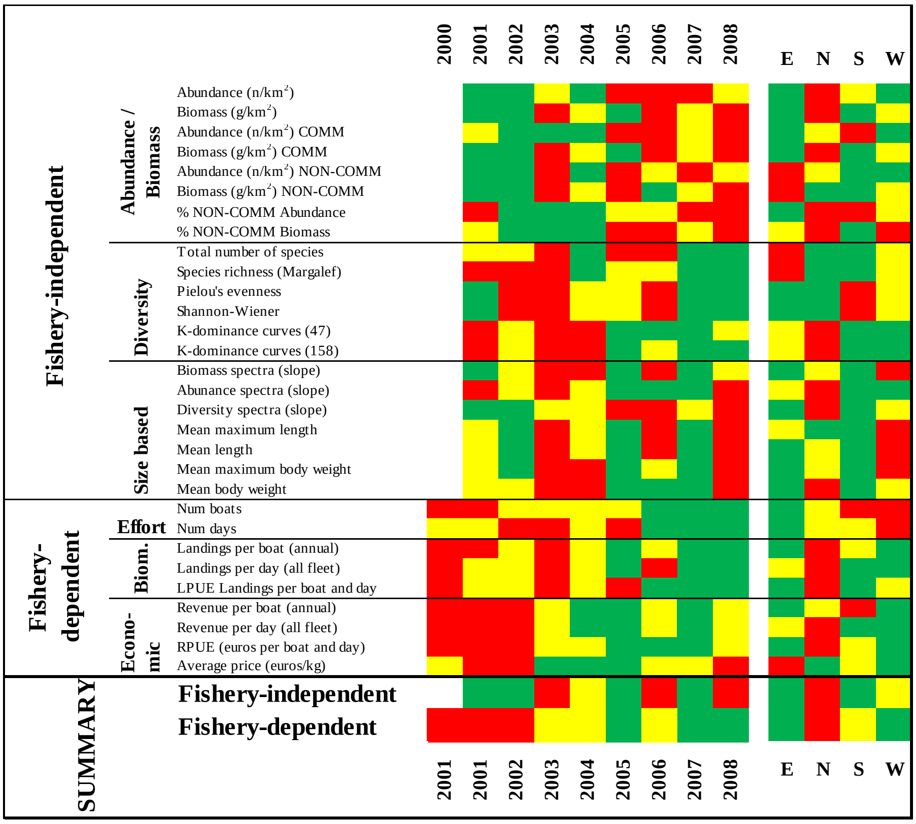
Figure 6.4. Traffic Lights displaying biological and economic indicators response for the red shrimp *Aristeus antennatus* in the Balearic Islands. Red: <33rd percentile; yellow: 33rd–66th percentiles; green: >66th percentile.

At community level, TL for US showed similar results with both sources of data (Figure 6.5). Although the summary in both cases was quite similar, without red values in the last 3 years, fishery-independent indicators showed reds, yellows and greens distributed heterogeneously along years. By contrast, number of reds was very low for the fishery-dependent indicators during the last 3 years. Spatially, fishery-independent indicators showed high number of reds in the south and of greens in the east and the north. For fishery-dependent indicators, number of reds was lower in the north and south. The west and south showed the highest levels of effort. TL for MS showed several differences between both sources of data, but depending on the type of indicators (Figure 6.6). Density indicators from fishery-independent data showed a temporal transition from high number of greens to high number of reds. The opposite trend was found for diversity indicators. Size based indicators did not show any clear temporal trend. In general, fishery-dependent indicators went from high number of reds to high number of greens. Spatially, results were similar between both sources of information, with the highest number of reds in the north and the lowest in the east.



			2000	2001	2002	2003	2004	2005	2006	2007	2008	E	N	S	W
Fishery-independent	**Abundance / Biomass**	Abundance (n/km^2)		🟥	🟩	🟩	🟥	🟨	🟩	🟥	🟨	🟨	🟩	🟥	🟩
		Biomass (g/km^2)		🟥	🟩	🟨	🟥	🟥	🟩	🟩	🟨	🟩	🟩	🟥	🟨
		Abundance (n/km^2) COMM		🟥	🟩	🟩	🟥	🟥	🟨	🟨	🟩	🟨	🟩	🟥	🟩
		Biomass (g/km^2) COMM		🟥	🟩	🟨	🟥	🟥	🟨	🟩	🟩	🟩	🟩	🟥	🟨
		Abundance (n/km^2) NON-COMM		🟥	🟩	🟨	🟥	🟩	🟩	🟥	🟨	🟨	🟩	🟩	🟥
		Biomass (g/km^2) NON-COMM		🟥	🟩	🟨	🟥	🟥	🟩	🟩	🟨	🟩	🟩	🟥	🟨
		% NON-COMM Abundance		🟨	🟩	🟩	🟨	🟥	🟥	🟥	🟩	🟩	🟥	🟥	🟨
		% NON-COMM Biomass		🟩	🟩	🟥	🟩	🟥	🟥	🟨	🟨	🟩	🟨	🟥	🟥
	Diversity	Total number of species		🟥	🟩	🟥	🟨	🟨	🟥	🟩	🟩	🟥	🟩	🟩	🟨
		Species richness (Margalef)		🟥	🟩	🟥	🟨	🟨	🟥	🟩	🟩	🟥	🟩	🟩	🟨
		Pielou's evenness		🟥	🟩	🟩	🟨	🟨	🟩	🟥	🟥	🟥	🟩	🟨	🟩
		Shannon-Wiener		🟥	🟩	🟩	🟨	🟨	🟩	🟥	🟥	🟥	🟩	🟨	🟩
		K-dominance curves (47)		🟩	🟥	🟥	🟨	🟨	🟥	🟩	🟩	🟩	🟩	🟥	🟨
		K-dominance curves (158)		🟩	🟥	🟥	🟨	🟥	🟨	🟩	🟩	🟩	🟩	🟨	🟥
	Size based	Biomass spectra (slope)		🟩	🟥	🟨	🟥	🟩	🟩	🟨	🟥	🟩	🟨	🟥	🟩
		Abunance spectra (slope)		🟥	🟩	🟥	🟥	🟩	🟩	🟨	🟨	🟥	🟨	🟩	🟩
		Diversity spectra (slope)		🟩	🟨	🟥	🟥	🟩	🟥	🟩	🟨	🟩	🟩	🟨	🟥
		Mean maximum length		🟥	🟩	🟨	🟨	🟩	🟥	🟩	🟥	🟩	🟩	🟨	🟥
		Mean length		🟥	🟥	🟩	🟥	🟨	🟨	🟩	🟩	🟩	🟥	🟨	🟩
		Mean maximum body weight		🟥	🟩	🟥	🟨	🟩	🟨	🟩	🟥	🟨	🟩	🟥	🟩
		Mean body weight		🟩	🟥	🟨	🟩	🟨	🟥	🟩	🟥	🟩	🟩	🟥	🟨
Fishery-dependent	**Effort**	Num boats	🟥	🟥	🟨	🟩	🟩	🟩	🟨	🟩	🟩	🟩	🟨	🟥	🟥
		Num days	🟥	🟥	🟥	🟨	🟨	🟩	🟩	🟩	🟨	🟩	🟨	🟨	🟥
	Biom.	Landings per boat (annual)	🟨	🟩	🟩	🟥	🟥	🟥	🟨	🟩	🟨	🟩	🟩	🟨	🟥
		Landings per day (all fleet)	🟩	🟩	🟩	🟥	🟥	🟥	🟨	🟨	🟨	🟥	🟨	🟩	🟩
		LPUE Landings per boat and day	🟨	🟩	🟩	🟥	🟥	🟥	🟨	🟩	🟨	🟩	🟥	🟩	🟨
	Econo-mic	Revenue per boat (annual)	🟥	🟩	🟩	🟥	🟨	🟥	🟨	🟩	🟥	🟥	🟩	🟩	🟨
		Revenue per day (all fleet)	🟩	🟩	🟩	🟥	🟥	🟥	🟨	🟨	🟥	🟥	🟨	🟩	🟩
		RPUE (euros per boat and day)	🟥	🟨	🟥	🟥	🟨	🟩	🟩	🟩	🟨	🟩	🟨	🟩	🟥
		Average price (euros/kg)	🟥	🟥	🟥	🟩	🟩	🟩	🟨	🟨	🟨	🟥	🟩	🟨	🟩
SUMMARY		**Fishery-independent**		🟥	🟩	🟥	🟥	🟨	🟩	🟩	🟩	🟩	🟩	🟥	🟨
		Fishery-dependent	🟥	🟩	🟩	🟥	🟨	🟥	🟨	🟩	🟨	🟩	🟨	🟩	🟥
			2001	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**E**	**N**	**S**	**W**

Figure 6.5. Traffic Lights displaying biological and economic indicators response for the upper slope assemblage in the Balearic Islands. Red: <33rd percentile; yellow: 33rd-66th percentiles; green >66th percentile, except for percentage of non-commercial species and effort variables (number of boats and number of days) in which opposite.



			2000	2001	2002	2003	2004	2005	2006	2007	2008	E	N	S	W
Fishery-independent	Abundance / Biomass	Abundance (n/km^2)		🟩	🟩	🟨	🟩	🟥	🟥	🟥	🟨	🟩	🟥	🟨	🟩
		Biomass (g/km^2)		🟩	🟩	🟥	🟨	🟩	🟥	🟨	🟥	🟩	🟥	🟩	🟨
		Abundance (n/km^2) COMM		🟨	🟩	🟩	🟩	🟥	🟥	🟨	🟥	🟩	🟨	🟥	🟩
		Biomass (g/km^2) COMM		🟩	🟩	🟥	🟨	🟩	🟥	🟨	🟥	🟩	🟥	🟩	🟨
		Abundance (n/km^2) NON-COMM		🟩	🟩	🟥	🟩	🟥	🟨	🟥	🟨	🟥	🟨	🟩	🟩
		Biomass (g/km^2) NON-COMM		🟩	🟩	🟥	🟨	🟥	🟩	🟨	🟥	🟥	🟩	🟩	🟨
		% NON-COMM Abundance		🟥	🟩	🟩	🟩	🟨	🟨	🟥	🟥	🟩	🟥	🟥	🟨
		% NON-COMM Biomass		🟨	🟩	🟩	🟩	🟥	🟥	🟨	🟥	🟨	🟥	🟩	🟥
	Diversity	Total number of species		🟨	🟨	🟥	🟩	🟥	🟥	🟩	🟩	🟥	🟩	🟩	🟨
		Species richness (Margalef)		🟥	🟥	🟥	🟩	🟨	🟨	🟩	🟩	🟥	🟩	🟩	🟨
		Pielou's evenness		🟩	🟥	🟥	🟨	🟨	🟥	🟩	🟩	🟩	🟩	🟥	🟨
		Shannon-Wiener		🟩	🟥	🟥	🟨	🟨	🟥	🟩	🟩	🟩	🟩	🟥	🟨
		K-dominance curves (47)		🟥	🟨	🟥	🟥	🟩	🟩	🟩	🟨	🟨	🟥	🟩	🟩
		K-dominance curves (158)		🟥	🟨	🟥	🟥	🟩	🟨	🟩	🟩	🟨	🟥	🟩	🟩
	Size based	Biomass spectra (slope)		🟩	🟨	🟥	🟥	🟩	🟥	🟩	🟨	🟩	🟨	🟩	🟥
		Abunance spectra (slope)		🟥	🟨	🟥	🟨	🟩	🟩	🟩	🟥	🟨	🟥	🟩	🟩
		Diversity spectra (slope)		🟩	🟩	🟨	🟨	🟥	🟥	🟨	🟥	🟩	🟥	🟩	🟨
		Mean maximum length		🟨	🟩	🟥	🟨	🟩	🟥	🟩	🟥	🟨	🟩	🟩	🟥
		Mean length		🟨	🟩	🟥	🟨	🟩	🟥	🟩	🟥	🟩	🟨	🟩	🟥
		Mean maximum body weight		🟨	🟩	🟥	🟥	🟩	🟨	🟩	🟥	🟩	🟨	🟩	🟥
		Mean body weight		🟨	🟨	🟥	🟥	🟩	🟩	🟩	🟥	🟩	🟥	🟩	🟨
Fishery-dependent	Effort	Num boats	🟥	🟥	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟨	🟥	🟥
		Num days	🟨	🟨	🟥	🟥	🟨	🟥	🟩	🟩	🟩	🟩	🟨	🟨	🟥
	Biom.	Landings per boat (annual)	🟥	🟥	🟨	🟥	🟨	🟩	🟨	🟩	🟩	🟩	🟥	🟨	🟩
		Landings per day (all fleet)	🟥	🟨	🟨	🟥	🟨	🟩	🟥	🟩	🟩	🟨	🟥	🟩	🟩
		LPUE Landings per boat and day	🟥	🟨	🟨	🟥	🟨	🟥	🟩	🟩	🟩	🟩	🟥	🟩	🟨
	Econo-mic	Revenue per boat (annual)	🟥	🟥	🟥	🟨	🟩	🟩	🟨	🟩	🟨	🟩	🟨	🟥	🟩
		Revenue per day (all fleet)	🟥	🟥	🟥	🟨	🟩	🟩	🟨	🟩	🟨	🟨	🟥	🟩	🟩
		RPUE (euros per boat and day)	🟥	🟥	🟥	🟨	🟨	🟩	🟩	🟩	🟨	🟩	🟥	🟨	🟩
		Average price (euros/kg)	🟨	🟥	🟥	🟩	🟩	🟩	🟨	🟨	🟥	🟥	🟩	🟨	🟩
SUMMARY		Fishery-independent		🟩	🟩	🟥	🟨	🟩	🟥	🟩	🟥	🟩	🟥	🟩	🟨
		Fishery-dependent	🟥	🟥	🟥	🟨	🟨	🟩	🟨	🟩	🟩	🟩	🟥	🟨	🟩
			2001	2001	2002	2003	2004	2005	2006	2007	2008	E	N	S	W

Figure 6.6. Traffic Lights displaying biological and economic indicators response for the middle slope assemblage in the Balearic Islands. Red: <33rd percentile; yellow: 33rd– 66th percentiles; green: >66th percentile, except for percentage of non-commercial species and effort variables (number of boats and number of days) in which opposite.

6.4. Discussion

Three different assemblages have been detected in the slope off the Balearic Islands, with the bathymetric gradient as the main factor conditioning them: the shelf break (200–299 m), the upper slope (300–499 m) and the middle slope (500–800 m). The shallowest assemblage corresponds to a bathymetric zone where the fleet usually does not operate. The other two assemblages can be comparable to the fishing tactics (FT) identified in the crustacean bottom trawl fishery in the Balearic Islands, targeting the Norway lobster *N. norvegicus* and the red shrimp *A. antennatus*, in the upper and middle slope, respectively (Chapter 7; Palmer *et al.*, 2009). These assemblages are in agreement with previous studies performed in the same area (Massutí and Reñones, 2005), where the existence of six species assemblages was described, three of them in the slope similarly to those found in this study.

Depth is generally considered as the main factor governing the faunal assemblages (see Carney, 2005 for a general review). In our study, depth was found to be significant for all the analysis performed. However, it is not a causative factor and other factors, such as temperature, high pressure and limited food availability have also been proposed as causal factors (Carney, 2005). Depth related trends in density were different depending on the taxonomic group analysed. Teleosts showed a clear decreasing trend, similarly than elasmobranchs and others and both crustaceans and molluscs showed an increasing trend until a maximum (Labropoulou and Papaconstantinou, 2000; Colloca *et al.*, 2003; Massutí and Reñones, 2005). The variance explained in the model by the rest of significant factors (year, area, effort and hydrographic characteristics) was quite low (less than 7%). In the case of year, the low variance explained seems to be more related to differences in temporal species specific abundances than to assemblage species composition. The high rate of classification success for the test data set in the supervised machine learning suggests the consistency of the observed species pattern throughout the examined years. Although there was not a clear trend by years, both elasmobranchs and crustaceans showed the highest values in 2002.

Geographical variations found can be related to the different hydrodynamic and geomorphologic conditions, which can vary between these closed geographical areas, similarly to what has been found in other studies (Abelló *et al.*, 2002b; Massutí *et al.*, 2004; Gaertner *et al.*, 2005). Spatial differences can also be related to differences in fishing exploitation (Gristina *et al.*, 2006; Moranta *et al.*, 2008b; Dimech *et al.*, 2008). Larger values of density were detected in the eastern and northern areas,where fishing effort was lower. However, effort was only marginally significant for two groups, elasmobranchs and crustaceans. Larger values of elasmobranch density were found with low and middle effort. This trend can be related to the biological characteristics of these species, which made them particularly vulnerable to fishing pressure (e.g. Aldebert, 1997; Bertrand *et al.*, 1998; Stevens *et al.*, 2000). The Balearic Islands have been reported as an area of higher diversity of demersal elasmobranchs in comparison to the adjacent waters off the Iberian Peninsula (Massutí and Moranta, 2003). The differences found at the short spatial scale analysed in this study remarked the especially vulnerability of this species to fishing pressure. Crustaceans showed higher values of biomass with middle and high effort levels. For *A. antennatus*, short scale temporal variability in catches has been related to the ability of fishermen to remove competitors at a differentially higher rate, leading to a higher catch of this species (Sardà and Maynou, 1998).

The use of TL for integrating different type of indicators in the assessment of the deep water fishery of the Balearic Islands has been revealed as a simple and useful tool for summarising large amount of both scientific and fishery data. By taking into consideration a wider range of factors than traditional assessment methods, the TL precautionary decision framework reduces the risk of missing important stock dynamics, environmental or ecosystem signals (Halliday *et al.*, 2001). Its simplicity is also a strong argument for using this method and it does not require that previously used analyses be abandoned as their outputs can be incorporated into this more general framework. The method has potential not only for single species assessment, but also as a decision framework in management at the ecosystem level. In fact, indicators are needed to support the implementation of an ecosystem approach to fisheries (Jennings, 2005) and the complexity of exploited ecosystems forces to examine multiple indicators and a need to summarise them (Rochet and Trenkel, 2003).

For *N. norvegicus*, there was a quite clear improvement in the state of the population. The state of exploitation of the stocks of *N. norvegicus* in the Mediterranean, appears to be from slightly growth overexploited to near the optimum level of exploitation depending on the area (Sardà *et al.*, 1998). However, in the Balearic Islands there has been an overall negative trend in the landings of this species between 1986 and 1995 (Merella *et al.*, 1998), although we should take into account that landings do not represent the state of the resources as well as CPUE does (Lleonart and Maynou, 2003). In fact, the fishing effort in the Balearic Islands has been gradually decreasing from 1994 to 2008 (Quetglas *et al.*, 2009; Chapter 2). Recent results using more traditional assessment methodology (i.e. virtual population and yield per recruit analysis), showed that the species seems to be moderately exploited (GFCM, 2010). When comparing the different areas, Norway lobster population from the northern and southern areas are those in the better state, which are the two areas where the species is mainly landed by the trawl fleet (Merella *et al.*, 1998). The worst estate was found in the eastern area, although this is the area with the lowest levels of effort. Thus, other factors than fishing pressure may influence this resource. Differences in population structure for this species have been related to exploitation levels (Abelló *et al.*, 2002a) and environmental conditions such as sediment characteristics, related to its burrower behaviour (Maynou and Sardà, 1997). In the study area, short spatial differences on other crustaceans have been related to sediment characteristics and trophic webs (Chapter 3). The relative contribution of decapod crustacean feeding guilds closely related to the bottom resources are higher in the Balearic sub-basin (BsB; e.g., Maynou and Cartes, 2000; Cartes *et al.*, 2008a) than in the Algerian sub-basin (AsB). This could explain the scarcity of this species in the eastern area, but not the presence and good state of *N. norvegicus* in the south, so probably the occurrence of both adequate sediment composition and prey availability seem to mark the short spatial differences found for this species.

For *A. antennatus*, differences between both sources of data can be explained by the high seasonal variability in the population dynamics of this resource. Large mature females aggregations in summer have been detected during the spawning period and a maximum recruitment of juveniles in the fishing grounds in the BsB have been detected during autumn–winter (Sardà *et al.*, 1994, 1997; Tudela *et al.*, 2003; Chapter 5). This seasonal dynamics of the species also determines the fleet behaviour. In fact, there is an annual displacement of the trawl fleet targeting red shrimp from the southern fishing grounds to the western ones during the spawning period, targeting the adult females aggregations (Chapter 5; Moranta *et al.*, 2008b). In our case, fishery-dependent data provides better information for this resource than fishery-independent data, as the first one covers all the year while the second has been obtained during a concrete period of the year. Our survey data were obtained during spring, without spawning aggregations or recruitment processes. In this sense, fishery-dependent indicators showed an improvement in the state of this stock during the last years. In fact, the assessment of this species using non-equilibrium production models in these areas suggested that red shrimp is slightly underexploited (Carbonell and Azevedo, 2003). It is important to remark that condition showed differences between both sexes, with the lowest values of the series for males in the last 2 years, similarly of what has been detected from commercial fleet data (Carbonell *et al.*, 2008). Geographically, the western area presented the best state of exploitation, although the fishing effort is high. This western areas has been pointed out as highly productive area (Chapter 3, 4 and 5). In this area, higher abundance of suprabenthos and zooplankton has been detected (Cartes *et al.*, 2008a), and also it is more influenced by the more productive waters coming from the

Gulf of Lions (Champalbert, 1996; Bosc *et al.*, 2004; Canals *et al.*, 2006), which increases the primary production in the area and thus enriches the trophic chain (Estrada, 1996; Fernández de Puelles *et al.*, 2004). These oceanographic conditions could favour *A. antennatus* more than *N. norvegicus* due to the differences on trophic webs already mentioned, as *A. antennatus* diet is based on mesopelagic preys (Cartes *et al.*, 2008b).

At community level, different results have been found in the two assemblages analysed with TL. In the case of the upper slope, similar results have been found using fishery-dependent and fishery-independent data. In this case, it seems to be an improvement of the state of this assemblage during last years. This can be probably due to the decreasing trend in effort found especially from 2003. Also the highest values of abundance for elasmobranchs and crustaceans detected by other methods in 2002 was reflected both from the fishery-dependent and fishery-independent data. The eastern location seemed to be in a better state, which was the area with the lowest levels of effort. On the contrary, the western area, with high levels of effort, showed the worst state for this assemblage.

In the case of the middle slope, where *A. antennatus* is the most important species in the assemblage (around 30% in abundance) and represents near 80% of landings (Moranta *et al.*, 2000), several differences have been found between both sources of information. Fishery-dependent annual indicators seem to show an improvement in the state of this assemblage, while it seems the contrary for the fishery-independent data, especially for density indicators and size based ones. When these indicators were computed geographically, these differences were not so important. The better state was found in the eastern location but the worst in the northern, although this area presents intermediate levels of effort, which suggest that not only fishing pressure is the responsible of the state of this assemblage. Differences between both sources of information can also be attributed to the different species included in each case. Fishery-dependent data only included information from the landed species and not from those discarded, while fishery-independent data covered the entire nekton-benthic community. In the former set of data, discards from *A. antennatus* can be considered nil (Carbonell *et al.*, 1999). These differences can also be attributed to the difference efficiency between the gears used during the scientific surveys and commercial gears which, in the case of commercial Italian trawl, have shown higher efficiency for benthic species when compared with the surveys and lower for some others released from the bottom as well as for the pelagic ones (Fiorentini *et al.*, 1999). Bottom trawl gears used in scientific surveys also showed a great variability of escapement values among species, which could affect the proportion rates of the species sampled during a standard survey as well as the size frequency distribution as for some species the escape rate was size dependant, like in the case of large size classes escaping effectively from the trawl, probably because their greater swimming endurance (Dremière *et al.*, 1999). Although this, for some species, the comparison from surveys and commercial fleet has given very acceptable results (Abella *et al.*, 1999).

Although both fishing exploitation and the environment affect the population dynamics of marine resources (Hughes *et al.*, 2003; Hsieh *et al.*, 2006; Cury *et al.*, 2008), their responses can be different depending on the species, taxonomic groups and their predominance in the communities. In this sense, although studies covering the entire epibenthic community are essential for implementing an ecosystem based fishery management, species based approaches are also necessary to understand single populations and to analyse how they contribute to the general trends of the entire community. However, analysis of indicators at single species level has provided a good response to know the status of the population, whereas the multispecies indicators have revealed some difficulties in interpretation (Ceriola *et al.*, 2008). In fact, ecosystem considerations do not substitute for what is already known from a single species approach (Link, 2002) and the ecosystem based approach can be implemented in systems with different levels of information and uncertainty (Pikitch *et al.*, 2004). Finally, it is important to take into account that although fishery-independent information provides high quality and useful data, we have to take the results carefully for those species with important seasonal variations in their catchability and population dynamics and for those communities where these species predominate.

CHAPTER 7.

SELECTIVITY

Adapted from “Selectivity of diamond- and square-mesh codends in the deepwater crustacean trawl fishery off the Balearic Islands (western Mediterranean)”. Beatriz Guijarro and Enric Massutí. (2006). ICES *Journal of Marine Science*. 63: 52-67.

Abstract

An analysis of 38 bottom trawl hauls at depths between 251 and 737 m off the Balearic Islands during autumn 2002 and spring 2003 was used to compare the species and size selectivity of 40 mm diamond and square mesh codends under commercial conditions. There was no difference in the catch composition or the yield that could be attributable to mesh shape, although the percentage of total and commercial species discarded with a diamond mesh was higher than with a square mesh. At least in the short term, the escapement ratio and the economic loss with the diamond mesh were lower than with square mesh, but economic efficiency was no different between them. For all the main species compared, except one flatfish, size selectivity parameters were lower for the diamond than for the square mesh codend. Selectivity values for the one flatfish species were similar. From the results it is concluded that, within the context of precautionary management, introduction of a 40 mm square mesh in the codend could be an appropriate and plausible measure to improve the state of the resources exploited by the deep water crustacean trawl fishery of the upper and middle slope off the Balearic Islands, and to reduce the impact of the fishery on the ecosystem.

Keywords: Balearic Islands, bottom trawl, codend selectivity, deep water, discards, diamond and square meshes.

7.1. Introduction

Knowledge of gear selectivity is crucial to good fisheries management. Its improvement contributes to minimizing the catch of juveniles by regulating the size at first capture, increasing the yield per recruit of targeted species, and reducing the discards and hence the impact of fishing on ecosystems (Armstrong *et al.*, 1990; MacLennan, 1992), some of the principles implicitly enshrined in the Code of Conduct for Responsible Fisheries (Garcia, 2000). The General Fisheries Commission for the Mediterranean (GFCM) stressed the incongruence between the minimum legal size for hake (*Merluccius merluccius*; 20 cm total length, TL) and Norway lobster (*Nephrops norvegicus*; 20 mm carapace length, CL), established by European legislation, and the estimated length of first capture (12 cm and 16 mm, respectively), given the legal minimum 40 mm diamond mesh in force at that moment for trawling in the Mediterranean (GFCM, 2000), and encouraged studies aimed at improving the selectivity of trawls, in trying to eliminate these contradictions and reducing discards (GFCM, 2001).

Size and shape of the mesh in the codend have been demonstrated as the main factors influencing the selectivity of trawl catches (e.g. Robertson and Stewart, 1988; Reeves *et al.*, 1992). Diamond shaped mesh in trawl nets stretches under tension during the haul and has a tendency to close when the codend fills, thus reducing its effective selectivity compared with square mesh, which remains open during a tow (Robertson and Stewart, 1988). For this reason, many studies on square mesh have been carried out (e.g. MacLennan, 1992; Campos *et al.*, 2002; He, 2007; Broadhurst *et al.*, 2010; Queirolo *et al.*, 2011).

Decapod crustaceans, specifically *N. norvegicus* and *Aristeus antennatus* (red shrimp), are the prime target of the deep water bottom trawl fishery carried out in the western Mediterranean (Sardà, 1998; GFCM, 2004). The fishery is well developed on the slope off the Balearic Islands (Merella *et al.*, 1998; García-Rodríguez and Esteban, 1999; Carbonell *et al.*, 1999). Stock assessments of these two and other target species of the Mediterranean demersal trawl fisheries (e.g. *M. merluccius*) suggest overfishing (Sardà, 1998; García-Rodríguez and Esteban, 1999; GFCM, 2010, 2011).

Catch composition of the deep water crustacean fisheries off the Balearic Islands revealed that discards, mainly fish (73%) and crustaceans (16%), represent on the whole

42% of the total catch (Moranta *et al.*, 2000). However, some differences are evident by depth, both in the percentage of discards and in the composition. In the depths at which *N. norvegicus* is targeted (upper slope, 300-500 m), discards represent 66% of the catch, while in the depths at which *A. antennatus* is mainly caught (middle slope, 500-800 m), discards represent 49%. In the middle slope, fish, mainly undersize commercial species, constitute ~90% of the catch and ~75% of the discards. In the middle slope, landings comprise both crustaceans (60%) and fish (40%), although fish (mostly unmarketable species) constitute 70% of the discards.

In the Mediterranean, studies on trawl selectivity using square mesh in the codend have been undertaken mainly in the eastern basin, and have focused on catch composition and discarding (Stergiou *et al.*, 1997b), as well as selectivity parameters of target species (e.g. Petrakis and Stergiou, 1997; Stergiou *et al.*, 1997a; Sala *et al.*, 2008; Lucchetti, 2008; Tosunoglu *et al.*, 2009; Kaykac *et al.*, 2009a; Tokac *et al.*, 2010; Aydin *et al.*, 2011). In the western basin, several studies have compared the effects of diamond mesh of different sizes in the codend (e.g. Sardà *et al.*, 1993, 2006; Ragonese *et al.*, 2001; Ragonese *et al.*, 2002) and some have assessed the influence of square mesh on target species (e.g. Mallol *et al.*, 2001; Sardà *et al.*, 2004b, 2006; Bahamon *et al.*, 2006).

The current study was initiated to compare, under commercial fishing conditions in the trawl fishery for crustaceans off the Balearic Islands, catch composition, commercial yields, retention efficiency, discards, and size selectivity parameters, using the 40 mm "traditional" diamond mesh codend in force until 2010, and an "experimental" square mesh codend of similar mesh size. This "experimental" codend was implemented in 2010 (Council Regulation (EC) No 1967/2006 of 21 December 2006), after the completion of this study. The main objective was to analyse the effect of the introduction of such a codend as a possible management measure to improve the state of the resources and to reduce the impact of the fishery on the ecosystem.

7.2. Materials and methods

7.2.1. Data source

Data was obtained from two selectivity pilot studies conducted in the main fishing grounds on the slope south of Mallorca, employing the covered codend method (see Chapter 2). After each haul, catches in the codend and the covernet were sorted by taxonomic and commercial (landings and discards) categories, counted and weighed separately. TL and CL of fish and crustaceans, respectively, were measured.

7.2.2. Data analysis

The PRIMER package was used to analyse the standardized biomass matrix of species by trawl (kg/60'retained in the codend). After square-root transformation, cluster analysis was applied to assess the different fishing strategies, choosing Bray-Curtis as the similarity index and UPGMA to link samples. Species recorded in fewer than 5% of the samples were omitted from the analysis. A similarity percentage analysis (SIMPER) was also applied to estimate the dissimilarity between groups and the contribution of main species to each.

Two-way analysis of variance (ANOVA) was applied to test differences between mesh shape and season in the commercial yields (kg/60' retained in the codend) of those species whose cumulative contribution, by SIMPER analysis, was higher than 90%. It was also used to analyse the total catch, the catch of commercial species, total discards, and the discards of commercial species retained in the codend. Data were transformed to $\sqrt{x}$ or log(x+1) as necessary and checked for normality, and Cochran's test was applied to test the homogeneity of variance. In some cases, transformation did not produce homogeneous variance, but ANOVA is considered a robust analysis when sample sizes are equal (Zar, 1996).

To assess economic performance in the short term of both mesh shapes, the escapement ratio (ER: proportion of the catch escaping, as kg/60', in relation to the total catch), the economic loss (EL: proportion of the value of fish and shellfish escaping, as €/60', in relation to the total value), and the economic efficiency (EE: €/kg of the retained catch in relation to the total weight caught) were estimated by depth range, season, and mesh shape. To test differences between mesh shape and season, two-way ANOVA was applied. To transform the proportional data (ER and EL) to a normal distribution, the procedure was:

$$X' = \left(\frac{180}{\pi}\right) * \arcsin\sqrt{\frac{X}{100}}$$

Homogeneity of the variance was tested with Cochran's test. Gear saturation for both mesh shapes was analysed by testing, through simple linear regression, the independence between the transformed ER and the retained catch.

For species in which ANOVA was applied and specimens were present in the covernet, length frequency distributions in the codend and the cover were calculated by haul, season, and mesh shape. Size selectivity was modelled using the generalized logistic curve

$$S_L = \frac{e^{(S_1+S_2*L)}}{1+e^{(S_1+S_2*L)}}$$

where S_L is the retained proportion of length class L, and S_1 and S_2 are the parameters to estimate. Such a manner of non-linear adjustment is one of the methods most recommended (Wileman *et al.*, 1996). The selection parameters L_{25}, L_{50}, and L_{75}, or lengths at which 25, 50, and 75%, respectively, of the specimens are retained in the codend, were calculated from:

$$L_{25} = \frac{-S_1 - \ln(3)}{S_2}\ ;\ L_{50} = \frac{-S_1}{S_2}\ ;\ L_{75} = \frac{-S_1 + \ln(3)}{S_2}\ .$$

Adjustment was done with the SYSTAT package, following a maximum likelihood procedure, and using the iteratively reweighted least squares method and r^2 as the index of adjustment.

This logistic model was applied haul by haul. A mean selectivity curve, taking into account between haul variability, was estimated using ECWeb (ConStat), a software that follows the methodology proposed by Fryer (1991). As in some hauls the number of retained and escaped fish was insufficient for estimating the selection curve, the logistic model was also applied on the basis of pooled data from all hauls.

7.3. Results

In total, the catch was 6029 kg with an economic value of 3685 € (Table 7.1). Teleosts were the most important group in terms of weight (55%) and second in economic value (32%); crustaceans were the most important group by value (64%) and the second by weight (28%). Elasmobranchs and cephalopods were less important, constituting 14% and 6% by weight, respectively, and 1-3% by economic value. Only two species appeared in all hauls (*M. merluccius* and *P. blennoides*), both constituting >5% of the total weight, but the most important species were *M. poutassou*, *Galeus melastomus*, *A. antennatus*, and *Parapenaeus longirostris*, which constituted 15%, 9%, 7%, and 8% by weight, respectively. The biggest contributions in terms of economic value were *A. antennatus* (32%), followed by *P. longirostris* (18%), and *M. merluccius* (10%). Although *N. norvegicus* comprised just 3% by weight, its importance in economic terms was great (9%).

In the similarity dendrogram (Figure 7.1), a first cluster separated trawls in 399-483 m (SL1) from those in 644-737 m (SL2), with two hauls (<300 m) not taken into account for further analysis. A second cluster separated trawls made during spring (SL1-S and SL2-S) from those made during autumn (SL1-A and SL2-A). There was no association attributable to differences in mesh shape. The results of SIMPER confirmed these clusterings of trawls (Table 7.2). The greatest dissimilarity was when depth intervals were compared, because they showed a different species composition: *M. merluccius*, *P. longirostris*, *M. poutassou*, *P. blennoides*, *N. norvegicus*, and *Lepidorhombus boscii* were the dominant species in SL1, whereas SL2 was dominated by *A. antennatus*, *G. melastomus*, *P. blennoides*, *Geryon longipes*, and *Plesionika martia*. Seasonal differences were less noticeable, a result attributable to distinct contributions by some of these species.

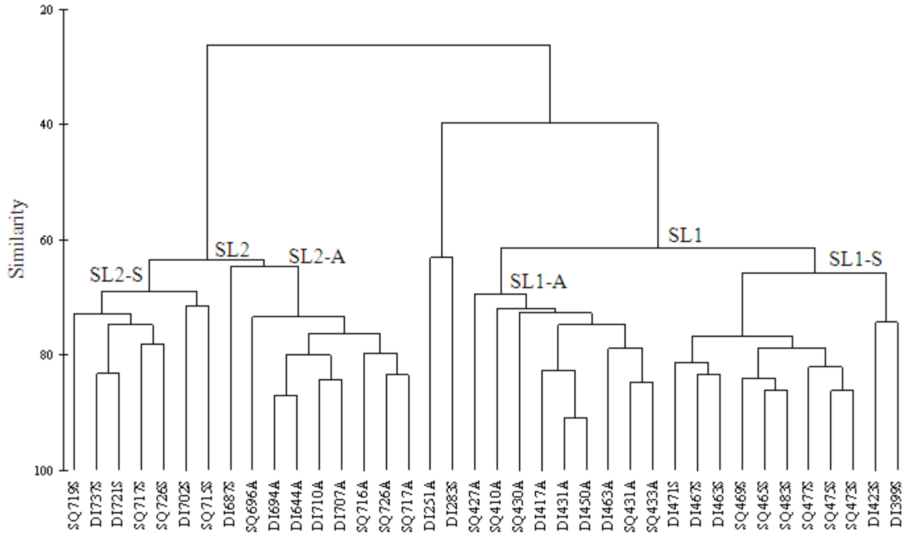


Figure 7.1. Dendrogram of trawls for the two selectivity surveys. Mesh shape (DI: diamond; SQ: square), mean depth (m), and season (A: autumn; S: spring) are shown for each trawl.

Table 7.1. Species and commercial categories caught during the two trawl selectivity surveys off Mallorca, during autumn 2002 and spring 2003, with their market code (high, H: >6 €/kg; medium, M: 3-6 €/kg; low, L: <3 €/kg; discards, D: non-commercial species), average price (€/kg), frequency of occurrence (F; %), proportion by weight (W; %), and economic value (V; %) by season and for both seasons combined. The absolute numbers of analysed trawls and total catch, by weight (W; kg) and economic value (V; €), are also shown.

Taxon	Market code	Price (€/kg)	Autumn			Spring			Both seasons		
			%F	%W	%V	%F	%W	%V	%F	%W	%V
Teleosts			100	51.0	32.9	100	53.4	31.5	100	52.4	32.1
Helicolenus dactylopterus	L	1.6	83	2.7	0.1	60	1.4	0.2	71	1.9	0.2
Merluccius merluccius	H	6.6	100	10.4	14.7	100	4.7	6.5	100	6.9	10.0
Micromesistius poutassou	M	3.2	94	6.7	2.8	80	20.9	14.1	87	15.3	9.3
Lepidorhombus spp.[1]	H	6.7	100	4.1	4.0	65	3.5	3.5	82	3.7	3.7
Lophius spp.[2]	H	6.5	89	6.5	6.6	80	3.7	2.9	84	4.8	4.5
Phycis blennoides	L	2.0	100	9.7	2.5	100	4.6	1.8	100	6.6	2.1
Mixed teleosts[3]	D,L,M,H	3.6	100	9.8	2.3	100	13.2	2.3	100	11.8	2.3
Mixed macrurids[4]	D	0.0	100	1.1	0.0	95	1.3	0.0	97	1.2	0.0
Elasmobranchs			100	16.4	0.8	100	12.2	0.4	100	13.8	0.6
Galeus melastomus	L	0.6	100	9.8	0.0	95	8.4	0.0	97	8.9	0.0
Mixed rays[5]	L	1.7	100	3.6	0.7	50	0.6	0.2	74	1.8	0.4
Mixed sharks[6]	L,M	1.7	100	3.1	0.1	90	3.2	0.2	95	3.2	0.2
Crustaceans			100	29.1	63.5	100	26.6	65.3	100	27.6	64.5
Aristaeomorpha foliacea	H	27.7	0	0.0	0.0	25	0.1	0.2	13	0.0	0.1
Aristeus antennatus	H	25.8	44	7.8	35.3	40	7.6	30.0	42	7.7	32.3
Geryon longipes	L	2.5	50	2.1	1.2	40	1.4	1.0	45	1.7	1.1
Nephrops norvegicus	H	25.5	72	4.2	8.2	75	2.8	10.0	74	3.4	9.2
Parapenaeus longirostris	H	11.9	56	6.9	12.7	60	9.4	21.4	58	8.4	17.7
Plesionika edwardsii	H	7.7	33	3.3	3.3	15	0.9	1.3	24	1.9	2.1
Plesionika martia	M	3.2	44	2.5	2.8	40	1.0	1.4	42	1.6	2.0
Mixed crustaceans[7]	D,L	0.6	100	2.3	0.0	100	3.4	0.0	100	3.0	0.0
Cephalopods			94	3.0	2.7	100	7.5	2.8	100	5.7	2.8
Loligo vulgaris	H	11.2	56	1.4	2.2	25	0.3	1.0	39	0.7	1.6
Mixed octopuses[8]	D,L	0.7	78	0.5	0.0	65	3.2	0.6	71	2.2	0.3
Mixed squid and cuttlefish[9]	D,L	1.6	100	1.0	0.5	100	4.0	1.2	100	2.8	0.9
Others[10]			55	0.6	0.0	60	0.4	0.0	79	0.5	0.0
Total			T	W	V		T	W	V		T
			18	2385	15603		20	3645	21263		38

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[1] *Lepidorhombus boscii* and *Lepidorhombus whiffiagonis*.

[2] *Lophius budegassa* and *Lophius piscatorius*.

[3] *Anthias anthias*, *Argentina sphyraena*, *Argyropelecus hemigymnus*, *Arnoglossus rueppelli*, *Bathysolea profundicola*, *Boops boops*, *Capros aper*, *Cetrolophus niger*, *Chauliodus sloani*, *Chelidonichthys cuculus*, *Chlorophthalmus agassizi*, *Citharus linguatula*, *Conger conger*, *Epigonus telescopus*, *Epigonus denticulatus*, *Gadiculus argenteus*, *Hoplostethus mediterraneus*, *Lampanyctus crocodilus*, *Lepidion lepidion*, *Lepidopus caudatus*, *Lepidotrigla cavillone*, *Molva dypterigia macrophtalma*, *Mora moro*, *Mullus surmuletus*, Myctophidae, *Nettastoma melanurum*, *Notacanthus bonapartei*, *Notolepis rissoi*, *Pagellus acarne*, *Pagellus bogaraveo*, *Peristedion cataphractum*, *Phycis phycis*, *Pontinus kuhlii*, *Scorpaena elongata*, *Scorpaena notata*, *Scorpaena scrofa*, *Serranus cabrilla*, *Serranus hepatus*, *Stomias boa*, *Symphurus nigrescens*, *Symphurus ligulatus*, *Synchiropus phaeton*, *Trachinus draco*, *Trachurus mediterraneus*, *Trachurus trachurus*, *Trigla lyra*, *Uranoscopus scaber*, and *Zeus faber*.

[4] *Caelorinchus caelorinchus*, *Hymenocephalus italicus*, and *Nezumia aequalis*.

[5] *Dipturus oxyrinchus*, *Leucoraja naevus*, *Raja clavata*, and *Raja polystigma*.

[6] *Dalatias licha*, *Etmopterus spinax*, *Scyliorhinus canicula*, and *Squalus acanthias*.

[7] *Macropipus tuberculatus*, *Munida* spp., *Palinurus mauritanicus*, *Paromola cuvieri*, *Pasiphaea sivado*, *Pasiphaea multidentata*, *Plesionika giglioli*, *Plesionika heterocarpus*, *Plesionika antigai*, *Polycheles typhlops*, and *Sergestes arcticus*.

[8] *Bathypolypus sponsalis*, *Eledone cirrhosa*, *Eledone moschata*, *Octopus salutii*, and *Scaergus unicirrhus*.

[9] *Histioteuthis bonnellii*, *Histioteuthis reversa*, *Illex coindetti*, *Sepia orbignyana*, *Sepietta oweniana*, and *Todarodes sagitattus*.

[10] Echinidae, *Gryphus vitreus*, Porifera, and Salpidae.

Table 7.2. SIMPER results for each trawl group identified from the dendrogram and for the species that contributed to at least 90% of the differences between these groups: mean yields ($\bar{Y}$ as kg/60’ retained in the codend); average similarity $\bar{S}_i$; s.d., standard deviation; percentage contribution to the similarity %$\bar{S}_i$; average dissimilarity $\bar{\delta}_i$.

Species	$\bar{Y}$	$\bar{S}_i$	$\bar{S}_i$ /s.d.	%$\bar{S}_i$	$\sum\bar{S}_i$ %
SL1-A; $\bar{S}_i$ = 62.50					
Merluccius merluccius	7.70	16.25	2.89	26.01	26.01
Parapenaeus longirostris	4.51	10.62	2.03	16.99	42.99
Phycis blennoides	3.24	8.49	3.59	13.58	56.57
Nephrops norvegicus	2.68	6.98	2.98	11.16	67.74
Lepidorhombus boscii	1.73	3.88	2.34	6.20	73.94
Micromesistius poutassou	1.83	3.52	1.73	5.63	79.57
Helicolenus dactylopterus	1.41	2.80	1.95	4.48	84.05
Lophius piscatorius	1.11	2.03	1.42	3.25	87.29
Loligo vulgaris	0.76	1.40	2.54	2.24	89.53
Lophius budegassa	0.56	1.13	1.41	1.82	91.35
SL1-S; $\bar{S}_i$ = 64.41					
Micromesistius poutassou	17.81	19.09	1.68	29.64	29.64
Parapenaeus longirostris	8.22	12.98	3.93	20.15	49.79
Merluccius merluccius	3.48	5.13	1.53	7.97	57.76
Lepidorhombus boscii	2.40	3.91	4.37	6.07	63.83
Phycis blennoides	2.49	3.81	3.19	5.91	69.74
Eledone cirrhosa	2.15	3.42	3.04	5.32	75.06
Nephrops norvegicus	2.35	3.36	1.75	5.22	80.28
Illex coindetii	1.41	2.37	2.88	3.68	83.96
Helicolenus dactylopterus	1.04	1.59	3.58	2.46	86.42
Galeus melastomus	0.84	1.07	1.89	1.66	88.09
Lophius piscatorius	1.12	1.05	1.37	1.63	89.72
Todarodes sagittatus	1.06	1.01	0.99	1.57	91.29
SL2-A; $\bar{S}_i$ = 65.89					
Aristeus antennatus	6.05	18.57	3.40	28.19	28.19
Galeus melastomus	7.67	15.10	2.17	22.91	51.10
Phycis blennoides	2.68	7.03	4.19	10.67	61.77
Micromesistius poutassou	2.53	5.77	1.76	8.76	70.53
Geryon longipes	1.74	5.32	2.92	8.08	78.61
Plesionika martia	2.44	4.93	1.32	7.48	86.09
Lophius piscatorius	2.60	4.09	0.83	6.21	92.30
SL2-S; $\bar{S}_i$ = 65.17					
Aristeus antennatus	7.58	28.59	2.89	43.88	43.88
Galeus melastomus	6.26	18.26	3.10	28.01	71.89
Geryon longipes	1.24	4.35	3.96	6.67	78.56
Phycis blennoides	1.51	3.14	4.75	4.81	83.37
Plesionika martia	0.82	2.42	5.73	3.71	87.09
Merluccius merluccius	0.51	1.67	2.21	2.56	89.65
Etmopterus spinax	0.61	1.37	1.46	2.10	91.75
Pairwise comparisons					$\bar{\delta}_i$
SL1-A vs. SL2-A					78.53
SL1-A vs. SL1-S					53.21
SL1-S vs. SL2-S					89.89
SL1-A vs. SL2-A					78.53

The comparison of yields of the main species and different catch categories revealed that most differences were seasonal (Table 7.3). Total catch, catch of commercial species, total discards, and yields of *A. antennatus*, *P. longirostris*, and *M.*

poutassou obtained in SL1 during spring were higher than in autumn, whereas yields of *P. martia* and *G. longipes* in SL2 and of *H. dactylopterus*, *M. merluccius*, and *P. blennoides* in SL1 during autumn were higher than in spring. The only differences related to mesh shape were observed in SL2, where total discards and the discards of commercial species were higher in the diamond mesh than in the square mesh. The interaction of both factors (season and mesh shape) was significant only for the catch of commercial species and for *H. dactylopterus* and *M. poutassou* in SL1.

Table 7.3. Yields (kg/60'retained in the codend, ±s.e.) for the main species, total catch, catch of commercial species (Catch comm.), total discards, and discards of commercial species (Discards comm.) within each trawl group identified from the dendrogram and two-way ANOVA, showing the significance (ns: not significant; *: p<0.05; **: p<0.01; ***: p<0.001) of the factors season (S), mesh shape (M), and their interaction (SxM).

	SL1				SL2			
	Autumn		Spring		Autumn		Spring	
	Diamond	Square	Diamond	Square	Diamond	Square	Diamond	Square
A. antennatus	-	-	-	-	5.4±1.0	6.7±0.7	8.4±0.5	8.0±0.9
G. longipes	-	-	-	-	1.4±0.2	2.1±0.2	0.9±0.1	1.3±0.1
N. norvegicus	2.4±0.5	2.9±0.4	1.8±0.6	2.8±0.1	–	–	–	–
P. longirostris	5.3±1.2	3.2±0.8	6.1±0.7	9.0±0.4	–	–	–	–
P. martia	–	–	–	–	3.1±0.4	2.3±0.8	0.5±0.1	0.7±0.1
G. melastomus	–	–	–	–	9.6±3.3	5.8±2.2	2.2±0.8	5.8±1.8
H. dactylopterus	2.2±0.3	0.7±0.1	0.5±0.1	1.0±0.1	–	–	–	–
L. boscii	1.9±0.4	1.6±0.4	1.6±0.3	2.0±0.3	–	–	–	–
L. piscatorius	0.9±0.2	1.2±0.5	1.6±0.8	0.7±0.3	–	–	–	–
M. merluccius	8.6±1.3	7.0±2.3	4.3±0.2	2.8±0.8	–	–	–	–
M. poutassou	2.4±0.6	1.2±0.4	9.8±3.5	24.1±5.3	–	–	–	–
P. blennoides	4.1±0.3	2.4±0.3	1.9±0.2	2.8±0.4	3.3±1.1	2.0±0.1	1.7±1.2	0.9±0.2
Total catch	34.2±3.5	29.0±4.5	43.4±4.5	59.3±6.5	30.4±5.3	26.2±5.0	19.1±0.5	24.8±4.0
Catch comm.	30.9±2.9	26.1±4.0	36.1±4.9	53.9±5.8	24.7±3.7	25.0±4.9	17.0±1.7	21.9±3.6
Total discards	2.3±0.8	1.9±0.7	4.7±1.5	3.4±0.6	6.1±1.9	1.8±0.8	5.7±0.7	4.7±0.8
Discards comm.	2.1±0.8	1.9±0.7	4.7±1.5	3.4±0.6	4.0±1.3	0.7±0.3	3.0±0.2	1.8±0.4

	SL1			SL2		
	S	M	SxM	S	M	SxM
A. antennatus	–	–	–	*	ns	ns
G. longipes	–	–	–	**	ns	ns
N. norvegicus	ns	ns	ns	–	–	–
P. longirostris	**	ns	ns	–	–	–
P. martia	–	–	–	***	ns	ns
G. melastomus	–	–	–	ns	ns	ns
H. dactylopterus	**	ns	***	–	–	–
L. boscii	ns	ns	ns	–	–	–
L. piscatorius	ns	ns	ns	–	–	–
M. merluccius	**	ns	ns	–	–	–
M. poutassou	***	ns	*	–	–	–
P. blennoides	*	ns	ns	ns	ns	ns
Total catch	**	ns	ns	ns	ns	ns
Catch comm.	**	ns	*	ns	ns	ns
Total discards	*	ns	ns	ns	*	ns
Discards comm.	ns	ns	ns	ns	**	ns

Catch composition by commercial and taxonomic categories (Figure 7.2) revealed that the percentage of catch discarded from the diamond mesh net (18-45%) was greater than from the square mesh net (6-18%). Such a reduction with the square mesh was also observed in the results for commercial species discarded (7-17% with the diamond mesh, 2-7% with the square mesh). Elasmobranchs and teleosts were the dominant commercial species discarded (31-91% and 6-33%, respectively), followed by crustaceans (7-43%) and cephalopods (≤2%).

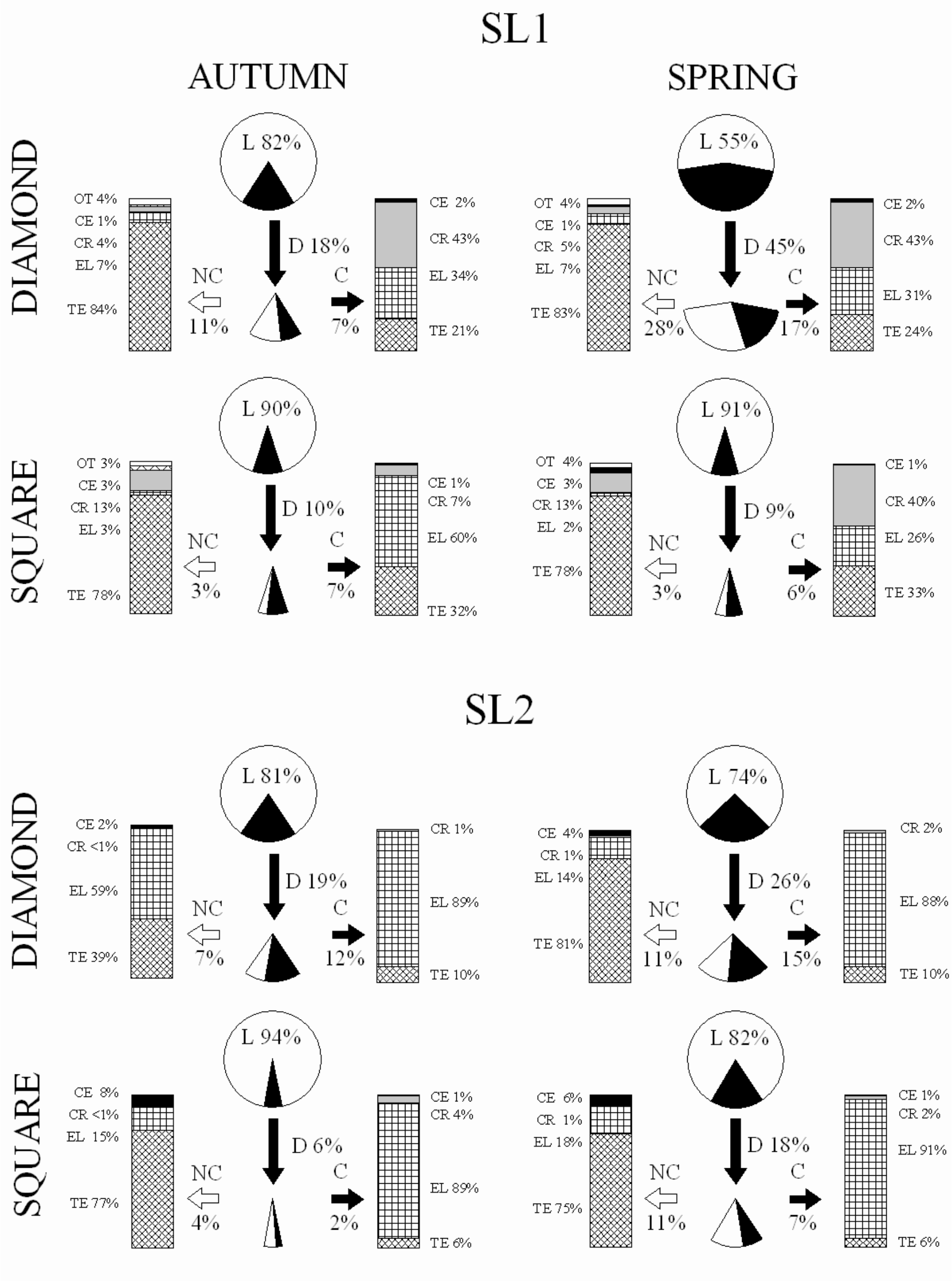

Figure 7.2. Catch composition for trawl groups SL1 and SL2 identified from the dendrogram, by season and mesh shape (L: landings; D: discards; C: commercial species; NC: non-commercial species; TE: teleosts; EL: elasmobranchs; CR: crustaceans; CE: cephalopods; OT: others).

A clear increase in the escapement ratio from diamond to square mesh was observed (Figure 7.3). This is reflected in the economic loss, which is significantly higher with the square than with the diamond mesh. By contrast, there were no differences in economic efficiency between mesh shapes, with season as the only significant factor. With both factors combined (mesh and season), there was no significant difference. No saturation was detected, because the relationships between the escapement ratio and the retained catch did not fit a linear regression: p= 0.322 for diamond mesh and p= 0.624 for square mesh (Figure 7.4).

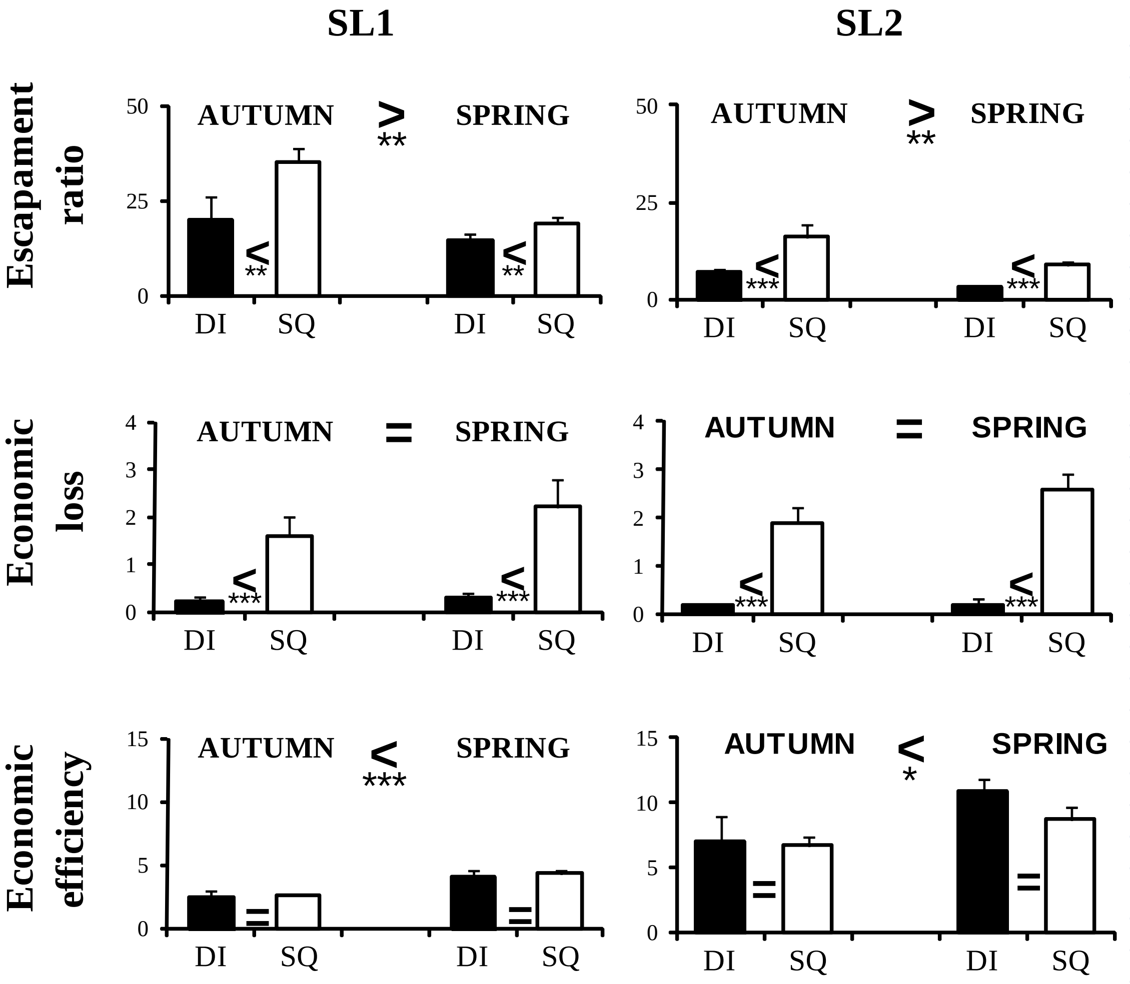

Figure 7.3. Average (±s.e.) escapement ratio, economic loss, and economic efficiency for trawl groups SL1 and SL2 identified from the dendrogram, by season and mesh shape. The results of two-way ANOVA, showing the significance (=: not significant; *: p<0.05; **: p<0.01; ***: p<0.001) of the factors season (autumn and spring) and mesh shape (D: diamond; SQ: square), are shown.

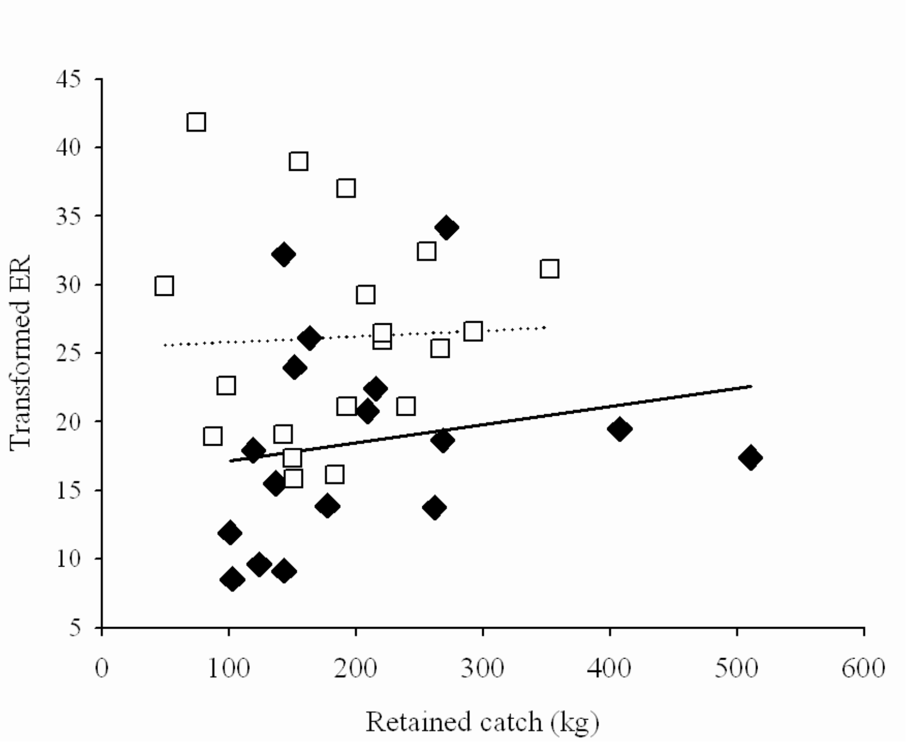

Figure 7.4. Transformed escapement ratio vs. retained catch in weight (kg) and regression lines for diamond (♦, thin line) and square (□, dotted line) mesh shape. Regression lines are not significant (p>0.05).

For the main commercial species, the lengths of the retained and escaped individuals are shown in Figures 7.5 and 7.6 and summarized in Table 7.4. Their selectivity parameters, calculated by mesh shape, season, and both seasons combined, are shown in Tables 7.5 and 7.6. Selectivity curves are shown in Figures 7.7 and 7.8. For those species where it was possible to estimate size selectivity with both methods, values were similar. In all species, there was an increase in the length at first capture from diamond to square mesh, the only exception being for *L. boscii*, for which the length at first capture was similar for both mesh shapes.

7.4. Discussion

This chapter compares the selectivity of the “traditional” diamond and an “experimental” square mesh in the codend, under commercial conditions, in the deep water crustacean trawl fishery off the Balearic Islands. In contrast to other studies comparing both meshes in the Mediterranean (e.g. Petrakis and Stergiou, 1997; Stergiou *et al.*, 1997a; Stergiou *et al.*, 1997b), we took into account not only the size selectivity parameters for the main species but also the selectivity in relation to catch composition, commercial yield and discards. These are important aspects in fisheries management.

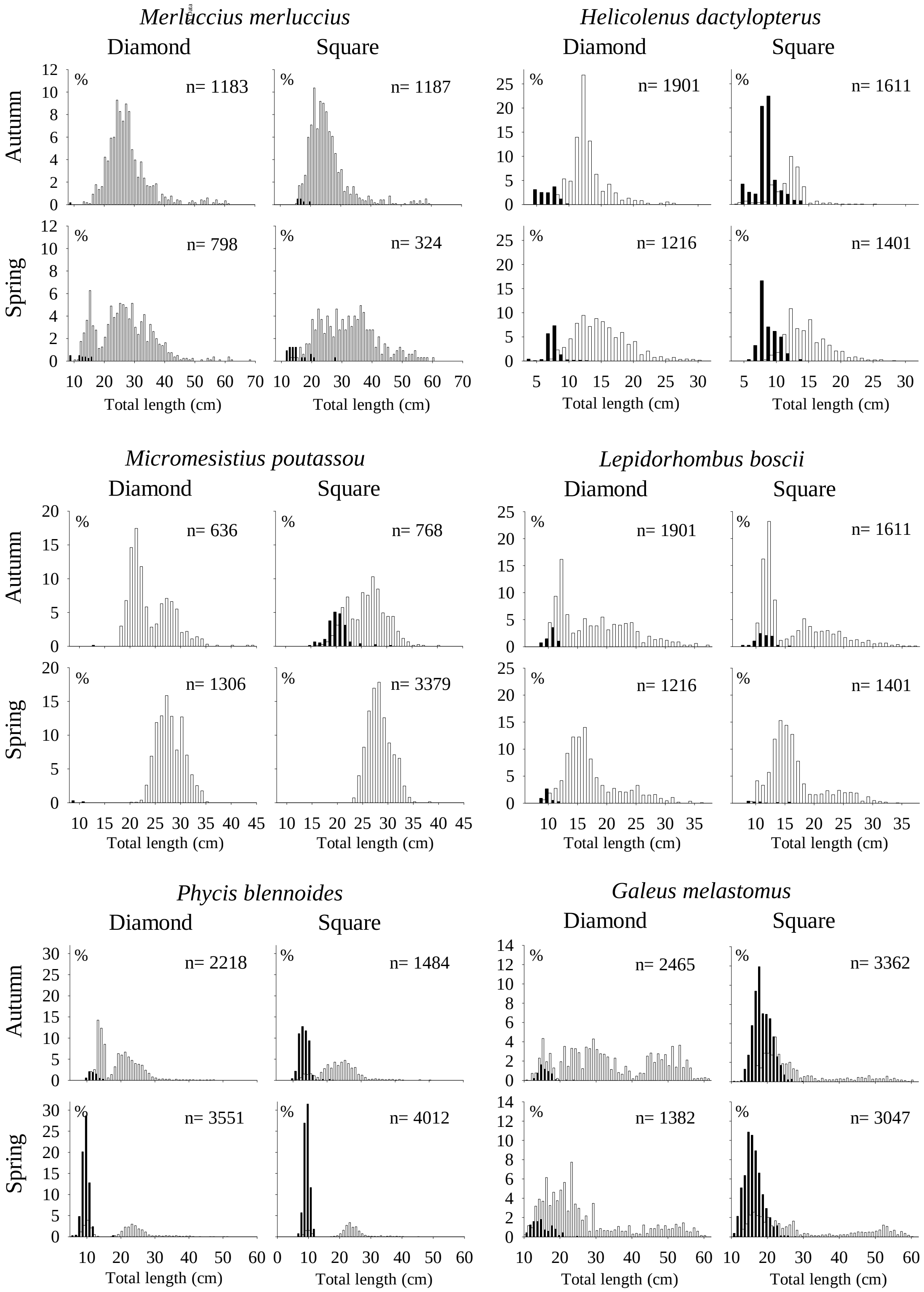

Figure 7.5. Length frequency distributions (in percentage) of the individuals retained in the codend (white bars) and escaped (black bars) from the main fish species caught with diamond and square meshes by season. The number of individuals measured (n) is also shown.

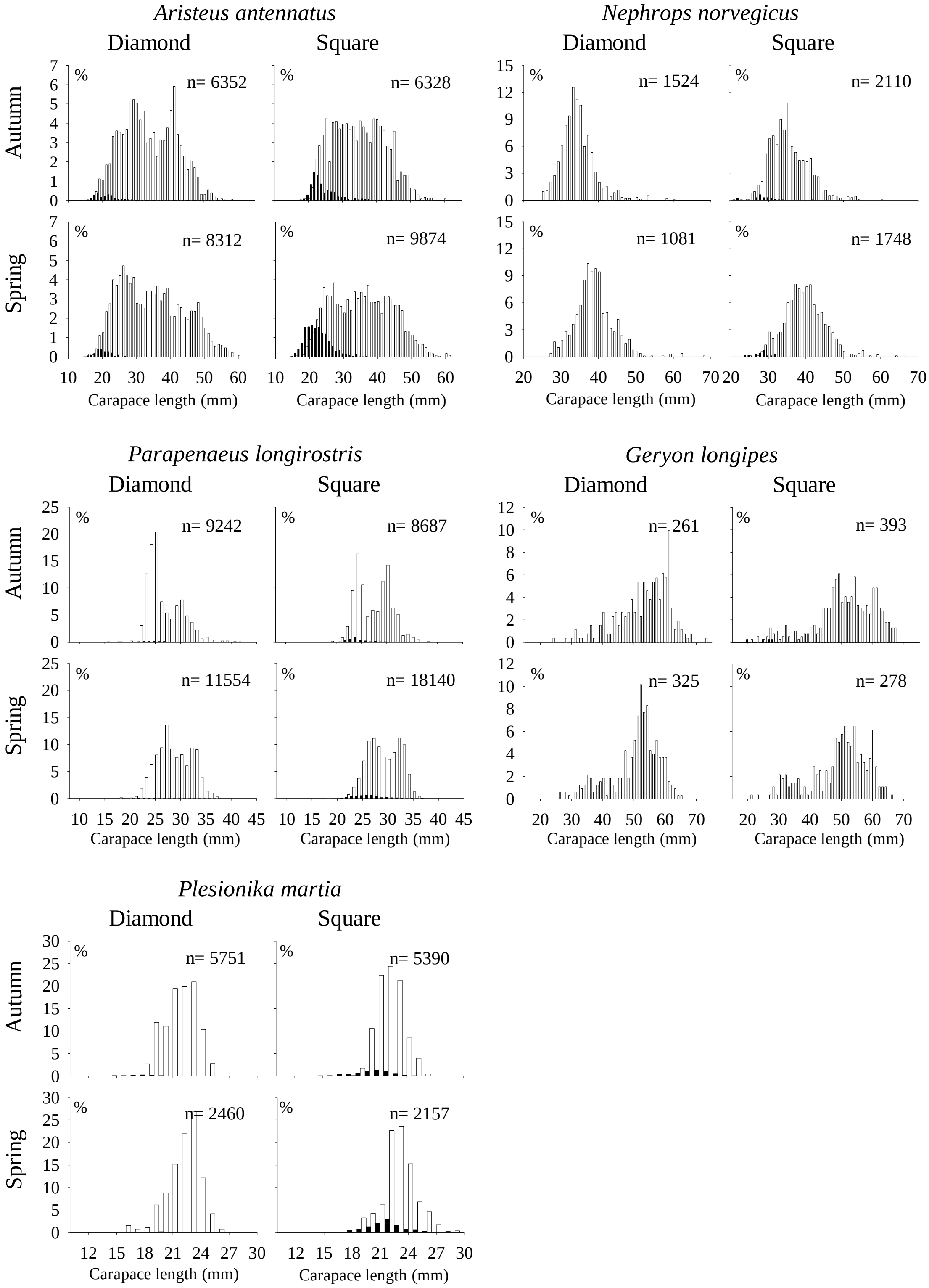

Figure 7.6. Length frequency distributions (in percentage) of the individuals retained in the codend (white bars) and escaped (black bars) from the main crustacean species caught with diamond and square meshes by season. The number of individuals measured (n) is also shown.

Table 7.4. Descriptive statistics (n: number of individuals; $\bar{x}$: average; s.d.: standard deviation) from the length frequency distribution (fish, total length in cm; crustaceans, carapace length in mm) for the main species caught with diamond (DI) and square (SQ) meshes (MS) by season (Seas.; AUT: autumn;. SPR: spring).

Species	Seas.	MS	Codend				Cover			
			n	$\bar{x}$ ±s.d.	Mode	Range	n	$\bar{x}$ ±s.d.	Mode	Range
M. merluccius	AUT	DI	1183	27.6±7.3	24	13-61	2	9.0±0.0	9	9-9
		SQ	1169	26.3±6.8	22	16-60	18	18.3±1.4	17;18	17-21
	SPR	DI	775	26.4±9.1	15	10-68	23	12.0±2.9	8;9;12	8-16
		SQ	303	32.0±9.4	36	13-60	21	15.6±3.9	13;14;15	12-28
M. poutassou	AUT	DI	635	23.7±4.2	21	18-44	1	13.0±0.0	13	13-13
		SQ	610	25.9±3.7	27	16-40	158	20.4±2.1	20	15-31
	SPR	DI	1300	27.7±2.6	27	20-35	6	9.7±1.0	9	9-11
		SQ	3379	28.1±2.4	28	23-38	0	–	–	–
P. blennoides	AUT	DI	2069	18.9±5.7	13	11-47	149	12.0±1.2	11	10-15
		SQ	752	23.2±5.7	25	11-60	732	13.4±1.4	13	10-22
	SPR	DI	1075	19.5±8.0	10	7-51	2476	9.8±1.1	10	6-18
		SQ	869	21.5±7.0	23	7-54	3143	9.7±0.9	10	7-12
H. dactylopterus	AUT	DI	1652	12.7±2.8	12	8-26	249	6.8±1.4	8	5-10
		SQ	589	11.7±2.5	12	4-25	1022	8.6±1.7	9	4-14
	SPR	DI	1022	14.9±4.2	12	7-30	194	7.6±1.3	8	3-13
		SQ	839	14.5±3.3	12	8-32	562	9.0±1.4	8	6-14
L. boscii	AUT	DI	624	17.6±6.2	12	10-37	50	10.3±1.5	11	6-12
		SQ	711	15.9±5.9	12	10-38	66	11.5±1.6	11	6-16
	SPR	DI	1077	17.2±4.8	16	9-36	49	10.0±0.8	10	9-12
		SQ	1575	16.3±4.5	14	9-34	20	11.3±2.5	9	9-16
G. melastomus	AUT	DI	2326	33.6±13.1	15	12-61	139	15.9±1.7	15	11-24
		SQ	1269	27.6±10.6	22	15-62	2093	18.9±2.6	18	10-30
	SPR	DI	1236	27.4±12.5	24	11-61	146	16.2±2.7	16	12-26
		SQ	1128	30.0±14.2	17	12-61	1919	17.4±2.6	16	11-31
A. antennatus	AUT	DI	6221	33.7±7.9	41	18-58	131	20.9±2.9	19	14-29
		SQ	5846	34.7±7.7	25;39	19-60	482	24.6±4.1	22	15-44
	SPR	DI	8143	34.5±9.4	26	16-60	169	20.5±2.4	19;20	15-29
		SQ	8482	36.3±8.8	28	17-62	1392	23.6±3.6	22	16-38
P. longirostris	AUT	DI	9157	26.4±3.2	25	16-39	84	23.0±3.2	23;24	12-27
		SQ	8465	27.1±3.3	24	19-38	222	24.2±1.8	24	21-30
	SPR	DI	11523	28.5±3.4	27	18-37	31	23.9±2.8	23	17-33
		SQ	17379	29.0±3.2	32	18-37	761	26.3±2.9	27	21-37
P. martia	AUT	DI	5686	21.6±1.7	23	18-25	65	18.2±2.2	18	13-23
		SQ	5089	22.1±1.6	22	17-30	301	20.5±1.9	21	14-26
	SPR	DI	2447	22.0±1.8	23	16-26	13	21.1±2.7	20	18-28
		SQ	1920	22.9±1.7	23	19-29	237	21.7±2.0	22	16-27
N. norvegicus	AUT	DI	1524	34.2±4.5	33	25-60	0	–	–	–
		SQ	2062	35.2±5.0	35	24-60	48	28.2±3.6	28	21-42
	SPR	DI	1081	38.6±5.1	37	27-68	0	–	–	–
		SQ	1710	39.4±5.4	37	25-66	38	28.3±2.2	29	24-32
G. longipes	AUT	DI	261	53.0±8.4	61	24-73	0	–	–	–
		SQ	389	51.0±9.5	49	21-67	4	25.0±3.6	20;25;27;28	20-28
	SPR	DI	325	50.3±7.8	52	26-65	0	–	–	–
		SQ	278	49.1±9.2	51;54	21-66	0	–	–	–

Table 7.5. Selectivity parameters (S_1 and S_2, selection curve parameters; L_{25}, L_{50}, and L_{75}, lengths at which 25%, 50%, and 75%, respectively, of the specimens are retained in the codend; R_{11}, R_{12}, and R_{22}, variance matrix of parameter estimates) by mesh shape, season (Se.; A: autumn; S: spring), and both seasons combined (T) for the main species, estimated by the method of Fryer (1991).

Species	Se.	Diamond								Square							
		S_1	S_2	L_{25}	L_{50}	L_{75}	R_{11}	R_{12}	R_{22}	S_1	S_2	L_{25}	L_{50}	L_{75}	R_{11}	R_{12}	R_{22}
M. poutassou	A	–	–	–	–	–	–	–	–	-17.990	0.894	18.9	20.1	21.4	18.650	-0.902	0.044
	S	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	T	–	–	–	–	–	–	–	–	-17.990	0.894	18.9	20.1	21.4	18.650	-0.902	0.044
P. blennoides	A	-12.050	1.005	10.9	12.0	13.1	27.170	-1.887	0.131	-10.430	0.704	13.3	14.8	16.4	5.994	-0.463	0.037
	S	-7.425	0.589	10.7	12.6	14.5	4.741	-0.341	0.025	-7.639	0.559	11.7	13.7	15.6	2.015	-0.142	0.010
	T	-8.987	0.735	10.7	12.2	13.7	4.623	-0.341	0.026	-7.881	0.548	12.4	14.4	16.4	1.188	-0.082	0.006
H. dactylopterus	A	-26.380	3.032	8.3	8.7	9.1	12.420	-1.388	0.160	-8.337	0.785	9.2	10.6	12.0	8.190	-0.719	0.064
	S	-12.090	1.325	8.3	9.1	10.0	1.463	-0.156	0.017	-14.93	1.357	10.2	11.0	11.8	1.387	-0.111	0.009
	T	-13.910	1.562	8.2	8.9	9.6	1.499	-0.177	0.021	-13.01	1.19	10.0	10.9	11.9	3.783	-0.325	0.028
L. boscii	A	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	S	-7.992	0.846	8.1	9.4	10.7	11.630	-1.105	0.105	–	–	–	–	–	–	–	–
	T	-8.951	0.903	8.7	9.9	11.1	6.310	-0.545	0.048	-14.69	1.443	9.4	10.2	10.9	78.980	-7.507	0.714
G. melastomus	A	–	–	–	–	–	–	–	–	-10.63	0.470	20.3	22.6	24.9	0.847	-0.020	0.001
	S	-3.779	0.283	9.5	13.4	17.3	1.285	-0.062	0.003	-7.792	0.358	18.7	21.8	24.8	0.493	-0.020	0.001
	T	-4.025	0.305	9.6	13.2	16.8	0.954	-0.045	0.002	-8.840	0.395	19.6	22.4	25.1	0.443	-0.015	0.001
A. antennatus	A	–	–	–	–	–	–	–	–	-19.480	0.897	20.5	21.7	23.0	93.140	-4.380	0.206
	S	–	–	–	–	–	–	–	–	-7.725	0.345	19.2	22.4	25.6	0.154	-0.006	0.001
	T	–	–	–	–	–	–	–	–	-12.130	0.550	20.1	22.1	24.1	13.780	-0.652	0.031
P. longirostris	A	–	–	–	–	–	–	–	–	-28.800	1.437	19.3	20.0	20.8	51.680	-2.715	0.142
	S	–	–	–	–	–	–	–	–	-13.980	0.658	19.6	21.2	22.9	7.958	-0.407	0.021
	T	-9.754	0.587	14.7	16.6	18.5	7.318	-0.310	0.013	-19.070	0.943	19.1	20.2	21.4	21.910	-1.116	0.057
P. martia	A	–	–	–	–	–	–	–	–	-9.111	0.551	14.5	16.5	18.5	0.802	-0.039	0.002
	S	-15.550	0.968	14.9	16.1	17.2	3.059	-0.166	0.009	-30.380	1.602	18.3	19.0	19.6	9.001	-0.485	0.027
	T	-15.550	0.968	14.9	16.1	17.2	3.059	-0.166	0.009	-18.51	1.000	17.4	18.5	19.6	18.870	-0.966	0.049
N. norvegicus	A	–	–	–	–	–	–	–	–	-22.110	0.852	24.7	26.0	27.2	10.910	-0.392	0.014
	S	–	–	–	–	–	–	–	–	-19.560	0.700	26.4	27.9	29.5	23.770	-0.801	0.027
	T	–	–	–	–	–	–	–	–	-17.330	0.651	24.9	26.6	28.3	7.872	-0.296	0.011

Table 7.6. Selectivity parameters (S_1 and S_2, selection curve parameters; L_{25}, L_{50}, and L_{75}, lengths at which 25%, 50%, and 75%, respectively, of the specimens are retained in the codend; 95% CI, 95% confidence interval of L_{50}; r^2, correlation coefficient) by mesh shape, season (Se.; A: autumn; S: spring), and both seasons combined (T) for the main species, estimated from pooled data.

Species	Se.	Diamond						Square					
		S_1	S_2	L_{25}	L_{50}	L_{75}	r^2	S_1	S_2	L_{25}	L_{50}	L_{75}	r^2
M. merluccius	A	–	–	–	–	–	–	-9.437	0.618	13.5	15.3 (14.8-15.7)	17.0	0.942
	S	-32.435	2.801	11.2	11.6 (11.4-11.8)	12.0	0.998	-14.262	0.928	14.2	15.4 (14.9-15.8)	16.5	1
	T	-33.344	2.878	11.2	11.6 (11.3-11.9)	12.0	0.998	-15.026	0.983	14.2	15.3 (14.9-15.6)	16.4	0.987
M. poutassou	A	–	–	–	–	–	–	-8.635	0.420	17.9	20.5 (18.6-22.5)	23.1	0.545
	S	–	–	–	–	–	–	–	–	–	–	–	–
	T	–	–	–	–	–	–	-9.682	0.478	17.9	20.2 (19.1-21.4)	22.5	0.757
P. blennoides	A	-23.688	2.039	11.1	11.6 (11.4-11.9)	12.2	0.967	-12.610	0.777	14.8	16.2 (15.8-16.6)	17.6	0.995
	S	-6.099	0.483	10.4	12.6 (11.9-13.4)	14.9	1	-11.209	0.816	12.4	13.7 (13.1-14.4)	15.5	1
	T	-6.409	0.533	10.0	12.0 (11.5-12.5)	14.1	0.978	-8.818	0.542	14.2	16.3 (15.6-16.9)	18.3	0.996
H. dactylopterus	A	-28.221	3.334	8.1	8.5 (8.4-8.5)	8.8	0.996	-14.113	1.303	10.0	10.8 (10.6-11.0)	11.7	1
	S	-14.075	1.591	8.1	8.8 (8.6-9.1)	9.5	1	-14.394	1.306	10.2	11.0 (10.9-11.1)	11.9	1
	T	-16.306	1.884	8.1	8.7 (8.4-8.9)	9.2	0.968	-6.789	0.612	9.3	11.1 (10.3-11.8)	12.9	0.988
L. boscii	A	-26.857	2.601	9.9	10.3 (8.9-11.8)	10.0	0.997	-431.810	43.291	9.9	9.9 (9.8-10.2)	10.0	0.994
	S	-13.551	1.328	9.4	10.2 (10.1-10.3)	11.0	1	-35.954	3.809	9.2	9.4 (9.4-9.5)	9.7	0.999
	T	-10.510	1.070	8.8	9.8 (9.7-10.0)	10.8	0.998	-29.246	3.064	9.2	9.5 (9.5-9.6)	9.9	0.998
G. melastomus	A	-59.472	4.675	12.5	12.7 (12.0-13.5)	12.9	0.976	-10.381	0.465	20.0	22.3 (21.9-22.7)	24.7	1
	S	-2.499	0.229	6.1	10.9 (9.7-12.1)	15.7	0.997	-6.810	0.312	18.3	21.8 (21.3-22.4)	25.4	1
	T	-2.854	0.248	7.1	11.5 (10.8-12.3)	15.9	0.931	-7.334	0.331	18.8	22.2 (21.7-22.6)	25.5	1
A. antennatus	A	-23.789	1.336	17.9	18.0 (17.9-18.0)	18.0	0.998	-12.291	0.579	19.4	21.3 (20.7-21.9)	23.2	0.968
	S	-16.987	1.017	15.6	16.7 (16.3-17.1)	17.8	0.986	-7.855	0.347	19.5	22.6 (22.1-23.1)	25.8	0.993
	T	-17.060	0.994	16.1	17.2 (16.7-17.6)	18.3	0.984	-9.180	0.416	19.4	22.1 (21.6-22.5)	24.7	0.991
P. longirostris	A	-15.460	0.883	16.3	17.5 (17.2-17.8)	18.7	0.993	-26.106	1.284	19.5	20.3 (20.2-20.4)	21.2	0.999
	S	–	–	–	–	–	–	-14.511	0.696	19.3	20.8 (20.6-21.1)	22.4	0.981
	T	-22.821	1.324	16.4	17.2 (17.1-17.4)	18.1	0.998	-21.566	1.046	19.6	20.6 (20.4-20.8)	21.7	0.998
P. martia	A	-331.150	19.479	16.9	17.0 (16.9-17.0)	17.1	0.999	-20.833	1.156	17.1	18.0 (17.1-18.9)	19.0	0.912
	S	–	–	–	–	–	–	-425.320	22.463	18.8	18.9 (18.9-19.0)	19.0	0.984
	T	-55.819	3.374	16.2	16.5 (16.2-17.0)	16.9	0.999	-20.303	1.118	17.2	18.2 (17.3-19.0)	19.2	0.93
N. norvegicus	A	–	–	–	–	–	–	-13.362	0.545	22.5	24.5 (24.2-24.8)	26.5	0.971
	S	–	–	–	–	–	–	-16.702	0.609	25.6	27.4 (26.9-28.0)	29.2	0.987
	T	–	–	–	–	–	–	-36.839	1.496	23.9	24.6 (24.3-25.3)	25.4	0.995
G. longipes	A	–	–	–	–	–	–	-26.850	1.070	24.1	25.1 (24.9-25.3)	26.1	1
	S	–	–	–	–	–	–	–	–	–	–	–	–
	T	–	–	–	–	–	–	-26.960	1.075	24.0	25.1 (24.6-25.5)	26.1	1

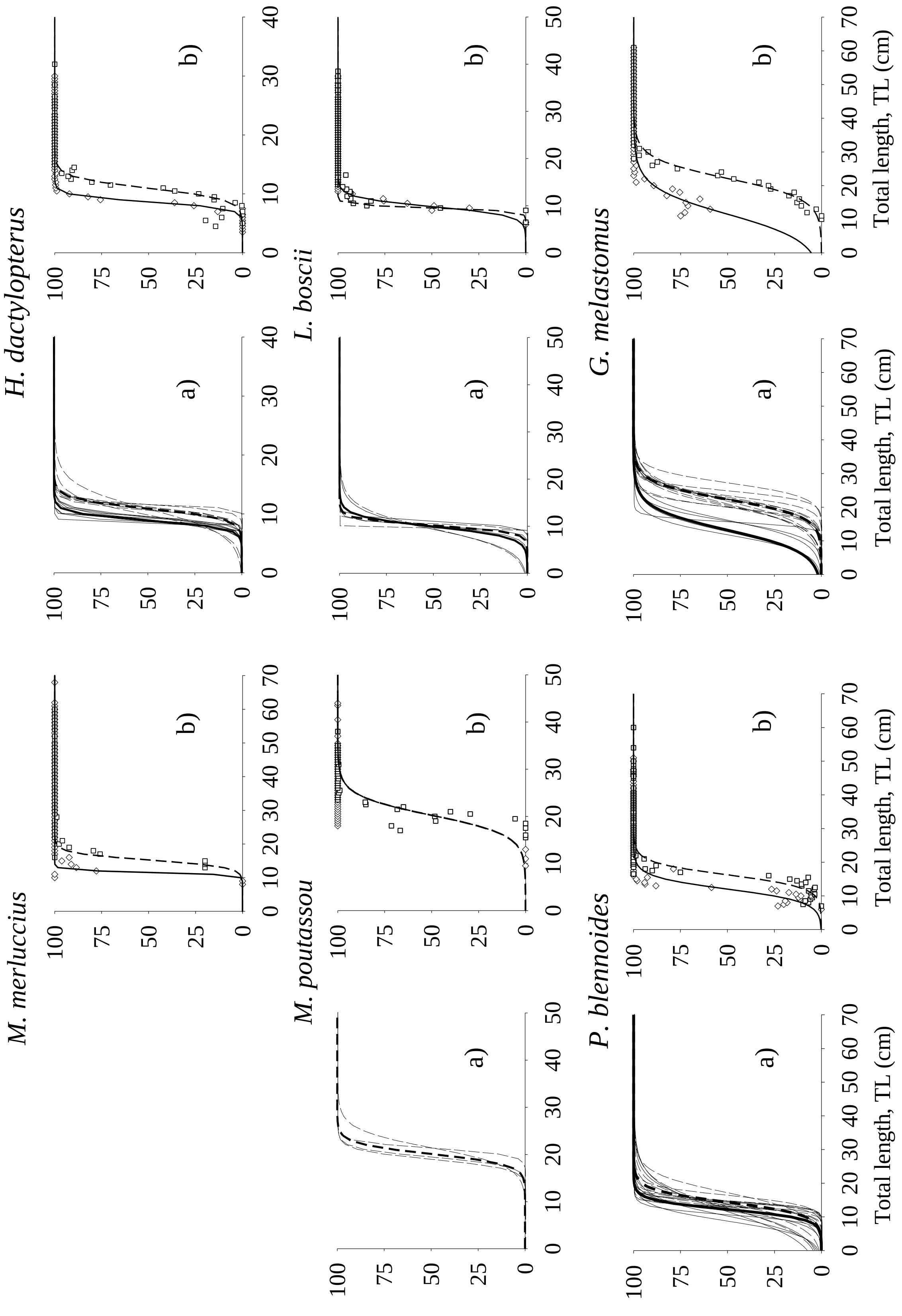

Figure 7.7. Selectivity curves (seasons combined) of the main fish species by mesh shape (solid line, diamond mesh; dashed line, square mesh) and method of analysis. Panels marked (a) are individual haul curves (thin lines) and the mean curve (thick line) calculated using the method of Fryer (1991); those marked (b) display the data (◊: diamond mesh; □: square mesh) and selection curves from pooled hauls.

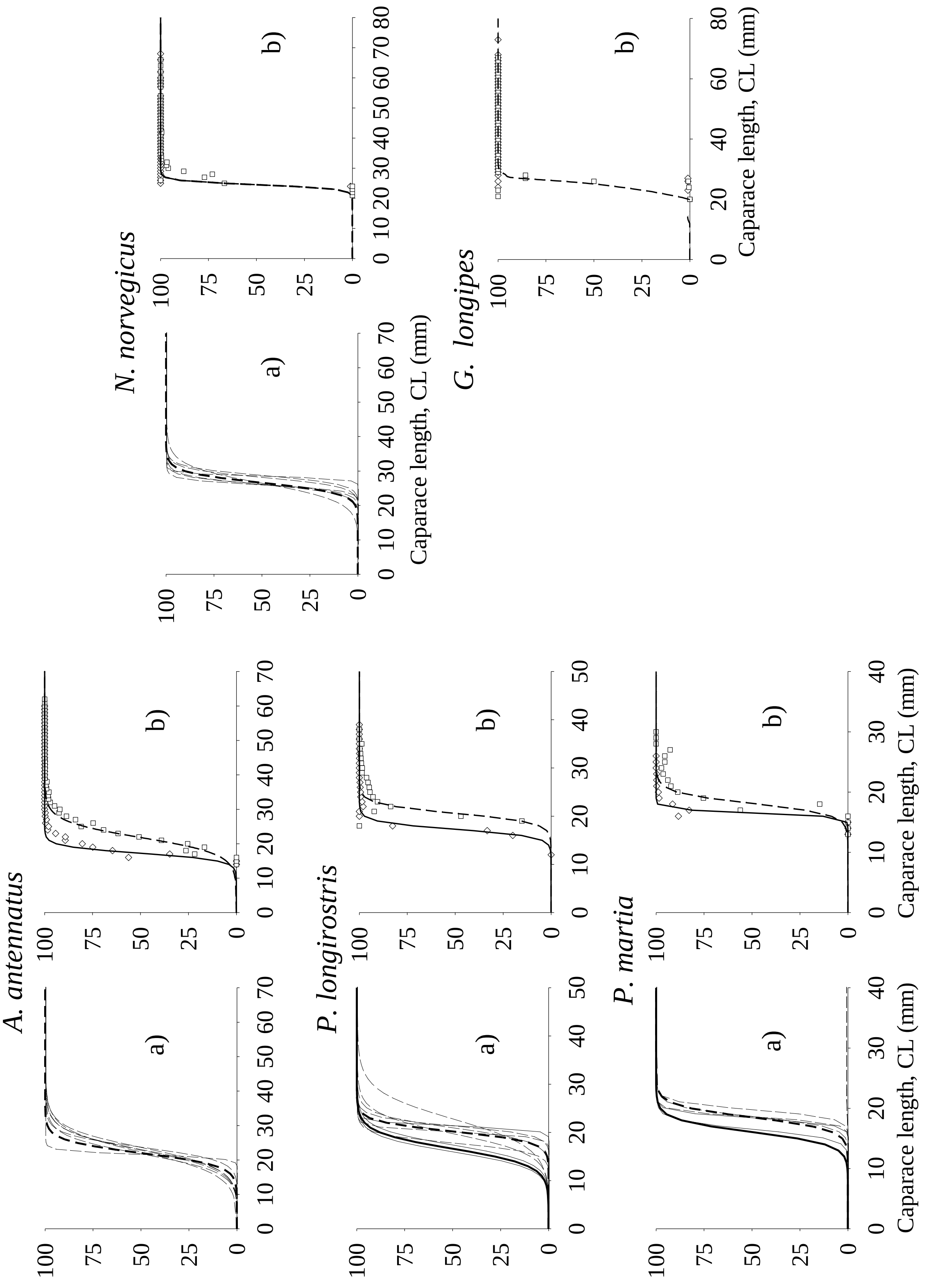

Figure 7.8. Selectivity curves (seasons combined) of the main crustacean species by mesh shape (solid line, diamond mesh; dashed line, square mesh), and method of analysis. Panels marked (a) are individual haul curves (thin lines) and the mean curve (thick line) calculated by the method of Fryer (1991); those marked (b) display the data (◊: diamond mesh; □: square mesh) and selection curves from pooled hauls.

No differences between mesh shapes were observed in the species composition of catches. By contrast, bathymetric differences in catch composition confirmed two fishing strategies, previously described for the trawl fishery of the study area targeting *N. norvegicus* between 350 and 600 m (Merella *et al.*, 1998) and *A. antennatus* deeper than this (Carbonell *et al.*, 1999). Besides these two crustaceans, other by-catch species were also caught. In the first fishing strategy, *M. merluccius* and *P. longirostris*, two species with high market value and yields greater than *N. norvegicus*, can be also considered target species. In the second strategy, *G. melastomus* is the only by-catch species with yields higher than *A. antennatus*, but this elasmobranch cannot be considered as a target species because of its low market value.

No differences between mesh shapes were observed by comparing commercial yields for the main species, although the comparison showed some seasonal differences for *P. longirostris*, *H. dactylopterus*, *M. merluccius*, *M. poutassou*, *P. blennoides*, *A. antennatus*, *G. longipes*, and *P. martia*, probably related to their time of recruitment, which in the western Mediterranean is clearly seasonal for some (Massutí *et al.*, 1996, 2001; Company and Sardà, 1997; Recasens *et al.*, 1998). However, total discards and discards of commercial species for hauls targeting on *A. antennatus* showed differences between the mesh shapes, in both cases discarding being higher with diamond than with square mesh. Such a reduction was also observed in the percentage of the discarded catch, both total and commercial species, using square mesh in each fishing strategy. For total discards, it varied between 8% and 36%, depending on depth interval and season. These two factors affect the abundance and size range of the exploited species in this fishery and they are on the basis of temporal variations observed in catches, landings, and discards (Moranta *et al.*, 2000). The reduction of 4-11% of commercial species discarded mainly affected the elasmobranchs *Scyliorhinus canicula* and *G. melastomus*, the teleosts *P. blennoides*, *H. dactylopterus*, and *L. boscii*, and crustaceans of the genus *Plesionika*. On the whole, such a reduction could benefit the environment by decreasing the impact of the fishery upon such a fragile ecosystem (Moranta *et al.*, 2000), one that is particularly important for elasmobranchs because fishing affects this group more than it does on most teleosts (Stevens *et al.*, 2000). The Balearic Islands has one of the most diverse and abundant elasmobranch populations in the western Mediterranean and, for this reason, harvesting strategies should be linked to conservation of species in the area (Massutí and Moranta, 2003).

According to Fryer (1991), the selectivity of a net can vary between hauls, so the estimation of selection curves from a model based on between haul variation provides more realistic parameters than consideration of pooled data over hauls. In the Mediterranean, the small catches mean that the number of fish and shellfish retained and that escape per haul are small too, precluding estimation of selectivity parameters that take into account between haul variability (Petrakis and Stergiou, 1997). In fact, such information has been scarce during many years and only recently several studies have used this methodology (e.g. Ragonese *et al.*, 2002; Ordines *et al.*, 2006; Sala *et al.*, 2006; Kaykac *et al.*, 2009b; Tokac *et al.*, 2010; Aydin and Tosunoglu, 2010; Aydin *et al.*, 2011). In our study, estimation of selection curves using this method was not possible for *M. merluccius* and *G. longipes*, and is more limited also for several other species with diamond mesh than with square mesh. In any case, previous and current results show similar values for selectivity parameters estimated from both methods.

Selectivity parameters were clearly lower for the diamond than for the square mesh as it has been found in other studies (e.g. Sala *et al.*, 2008; Lucchetti, 2008; Tosunoglu *et al.*, 2009; Kaykac *et al.*, 2009a; Tokac *et al.*, 2010). The only exception was *L. boscii*, whose values were similar. In the eastern Mediterranean, selectivity parameters for this species were higher for diamond than for square mesh (Petrakis and Stergiou, 1997). In general, square mesh is more selective than diamond mesh of similar size for roundfish (Robertson and Stewart, 1988), but the opposite pertains to flatfish (Millar and Walsh, 1992).

The estimated length at first capture (L_{50}) with 40 mm square mesh for *M. merluccius* is similar to that obtained for the same species in the Mediterranean (13-16 cm TL; Petrakis and Stergiou, 1997; Bahamon *et al.*, 2006; Lucchetti, 2008; Sala and Lucchetti, 2010; Aydin and Tosunoglu, 2010). Similarly, L_{50} with 40 mm square mesh for *P. blennoides* is similar to those obtained in other areas (14-16 cm TL; Bahamon *et al.*, 2006; Aydin and Tosunoglu, 2010). For *N. norvegicus*, the L_{50} with the square mesh in the current study is similar to those estimated by Stergiou *et al.* (1997a) for the eastern Mediterranean with the same size mesh (24 mm CL), but larger than the various values reported for diamond mesh: 18-23 mm with 40 mm mesh (Stergiou *et al.*, 1997a; Mytilineou *et al.*, 1998; Bahamon *et al.*, 2006; Sala and Lucchetti, 2010) and 15-21 mm with different mesh sizes (38, 42 and 48 mm; Sardà *et al.*, 1993; Mytilineou *et al.*, 1998;

Sala *et al.*, 2008). In any case, square mesh is clearly more efficient than diamond mesh when trawling for *N. norvegicus*.

Although nothing is known in the Mediterranean about the survival of deep water fish and shellfish after escapement from codends, survival rates for fish species in the continental shelf from the Aegean Sea have been estimated between 70 and 100% for 6 different species, being the survival rates equal for both shape meshes or even higher with square mesh than with diamond mesh (Metin *et al.*, 2004; Ozan Düzbastilar *et al.*, 2010a, 2010b). In the case of elasmobranchs and decapods, their tougher skin and rigid integument, respectively, should allow better survival.

The introduction of a 40 mm square mesh codend to the deep-water trawl fishery off the Balearic Islands would improve the exploitation pattern of the main target species, which currently show clear symptoms of overexploitation (Sardà, 1998; García-Rodríguez and Esteban, 1999; GFCM, 2010, 2011), by reducing the fishing pressure on small fish, generating improvements in the state of these resources and benefits in their yield per recruit. Although such a change in codend mesh would produce a small, but significant, increase in the escapement ratio (5-15%) and an economic loss (1.4-2.4%), the yields of main species, in terms of biomass, and the economic efficiency would be maintained. In part, this is because escaping individuals are small and of relatively low value. Marked long term benefits might be obtained by using the 40 mm square mesh codend for certain species such as *M. merluccius*, *Trisopterus minutus* or *P. blennoides* (Bahamon *et al.*, 2007). Further, even given small economic loss in the short term, there may be recovery in the medium and longer term, as demonstrated for the *P. longirostris* fishery off the Gulf of Cádiz (Sobrino *et al.*, 2000).

In addition, an increase in L_{50} with the use of a square mesh would remove some of the contradictions in management of the Mediterranean trawl fishery. For *N. norvegicus*, the estimated L_{50} with square mesh is greater than the minimum legal landing size (20 mm CL), which contrasts with the pessimistic perspective of Sardà (1998), who concluded that “fisheries regulations relating to mesh trawl selectivity for *Nephrops* are not efficient and should be abandoned”. For *P. longirostris* and *A. antennatus*, species without a minimum legal landing size, the L_{50} with square mesh is at the size at first maturity, estimated at 20-29 mm CL (Mori *et al.*, 2000; Ben Meriem *et al.*, 2001; Dereli and Erdem, 2011; Kasalica *et al.*, 2011; Chapter 3) and 16-29 mm

CL (García-Rodríguez and Esteban, 1999; Carbonell *et al.*, 1999; Chapter 5), respectively. Although effective, a square mesh will not allow such a target objective to be reached for *M. merluccius*, for which the legal landing size is 20 cm TL and the length at first maturity estimated to be 32-35 cm TL (Oliver, 1993; Recasens *et al.*, 2008). Reducing the catch of undersized marketable species, which only influences fishing mortality without yielding economic benefit, could help the fishery by minimizing the handling and sorting time of catches and improving the quality of landings.

Simulations on the potential ecosystem effects in the NW Mediterranean indicated that the improvement of trawl selectivity would have noticeable and complex direct effects both on target and non-target demersal species (Coll *et al.*, 2008). These effects would include the increase of biomass and catch of various commercial species and the decrease of invertebrates and juvenile and small sized fish species, due to higher predation mortalities and trophic cascades in the food web. A slight increase in the mean trophic level of the community and of the catch was also predicted, as well as of ecosystem biomass diversity. However, the introduction of the 40 mm square mesh codend would not be enough for the recovery of highly exploited or overexploited demersal species and a greater reduction of fishing effort would be necessary (Coll *et al.*, 2008).

In conclusion, within the context of precautionary management, the recently introduced 40 mm square mesh in trawl codends can be an appropriate and plausible measure to improve the state of the resources exploited by the deep water crustacean trawl fishery off the Balearic Islands, and concomitantly reduce the impact of the fishery on the ecosystem.

CHAPTER 8.

CONCLUSIONS

Conclusions

1. The deep water crustacean trawl fishery off the Balearic Islands (western Mediterranean), which operates in the slope between 300 and 800 m depth, represents 34% of the total biomass landed and 50% of the revenues obtained by the bottom trawl fishery in the last decade. The importance of decapod crustaceans in the slope communities of this area increases when increasing depth. They are uncommon in the scarcely exploited shelf break (200-300 m), where teleost fishes predominate; they represent the second most important group in the upper slope (300-500 m), after teleosts; and they predominate in the middle slope (500-800 m). In the upper slope, the most important crustaceans are *Plesionika* spp., *Parapenaeus longirostris* and *Nephrops norvegicus*, while in the middle slope the predominant crustacean is *Aristeus antennatus*.

2. For the first time in the Balearic Islands, the distribution, population dynamics and biological parameters of these species have been compared between the Balearic (BsB) and the Algerian (AsB) sub-basins, northern and southern the Archipelago respectively, with distinct environmental conditions. These different environments involve geomorphical structure, bottom characteristics, hydrographic factors and the availability of potential trophic resources, with a different influence among species.

3. The mean abundance of adults and juveniles of *P. longirostris* in shallower waters of the BsB (340 n/km^2 and 600 n/km^2) is, respectively, four and five times greater than in the AsB (67 n/km^2 and 150 n/km^2). This is explained by the concurrence in the BsB at the same depth (~350 m) of major presence of muddy-sandy sediments, and high productivity, reflected in high availability of potential preys, with respect to the AsB.

4. The abundance of species of the genus *Plesionika*, as well as their contribution to the communities, is higher in the AsB where trophic webs are mainly supported by zooplankton than in the BsB. The mean annual catch per unit effort (CPUE) is >6 and <4 kg/day per boat for the AsB and the BsB, respectively. Only the most benthic species *Plesionika heterocarpus* is more abundant in the BsB, where trophic webs are more supported by suprabenthos. Water masses also influence the bathymetric distribution of these species. The shallowest *Plesionika antigai*, whose centre of gravity (COG) is ~350

m, inhabits in Western Mediterranean Intermediate Waters. The deepest species *Plesionika martia* (COG ~600 m) and *Plesionika acanthonotus* (COG ~650 m) are distributed in Levantine Intermediate Waters and Western Mediterranean Deep Waters. The two species found in intermediate depths, *P. heterocarpus* and *Plesionika giglioli* show a deeper distribution in the AsB (COG 450-550 m in AsB and ~350 m in BsB), where the Levantine Intermediate Waters layer is wider.

5. The population dynamics of *A. antennatus* shows major fluctuations in the BsB, principally high abundance of juveniles recruiting to middle slope in autumn-winter (~6000 females/km^2 and ~4000 males/km^2) and high abundance of adult females during summer (~2300 females/km^2). The population in the AsB is demographically more homogeneous throughout the year, both for juveniles (~400 females/km^2 and ~100 males/km^2) and adult females (~1500 individuals/km^2). The maximum abundance of adult females is related to the presence of cores of Levantine Intermediate Waters in the middle slope, whose influence during early spring to early autumn in the BsB is higher than in the AsB. Juveniles are favoured by the presence in the middle slope of cores of Western Mediterranean Deep Waters.

6. Reproductive period shows a marked seasonality, with the spawning concentrated in summer for *P. longirostris*, *P. martia* and *A. antennatus*. For *P. heterocarpus*, the percentage of ovigerous females was >80% in all seasons. Seasonality is also reflected in the condition, with the lowest values during the spawning period. For *A. antennatus*, seasonal changes in the lipids content of the hepatopancreas are related to its reproductive cycle, with minimum values during the spawning period, which reflects the importance of lipids as source of energy for ovary ripening.

7. The slope of the more productive BsB can act as a fundamental habitat for most of the studied species, especially for spawning and recruitment events. This is based on the better condition found in the BsB for *A. antennatus* females during the pre-spawning period and both for males and females of *P. longirostris*, *P. heterocarpus* and *P. martia*. This better condition is also reflected on a lower length at first maturity for females in the BsB for *P. longirostris* (BsB: 28.5 mm carapace length CL; AsB: 29.5 mm CL), *P. martia* (BsB: 17.7 mm CL; AsB: 18.0 mm CL) and *A. antennatus* (BsB: 23.5 mm CL;

AsB: 26.5 mm CL). Furthermore, females of *P. longirostris* also show higher values of the von Bertalanffy growth rate (k) in the BsB (0.85) than in the AsB (0.73).

8. The Traffic Light approach for integrating different types of indicators has been revealed as a simple and useful tool for the assessment of the deep water fishery of the Balearic Islands, as it allows combining and summarising the large amount of indicators needed in the new and broader Ecosystem-Based Fisheries Management. These indicators, related both to species and communities, provide wide and complementary information as they combine the precision and high quality of the data obtained in the experimental surveys (fishery-independent data) with the daily year-round information obtained from the fishing sector (fishery-dependent data).

9. At community level, an improvement in the state of the upper slope assemblage is detected for last years, as a result of a fishing effort decrease. This is also reflected spatially, with the best state in the eastern area, coinciding with the lower levels of effort, and the opposite for the western. At specific level, *N. norvegicus* shows an improvement in its state during last years for the whole area which can also be related to this factor. No clear results have been obtained for *A. antennatus*, with marked differences between the assessment obtained from fishery-dependent and fishery-independent information. These differences between both sources of data can be explained by the high seasonal variability in the population dynamics of this resource, not covered by late-spring scientific surveys. Other factors than fishing exploitation can affect these resources, as the best state for *A. antennatus* is found in the highest exploited, but most productive western area (BsB).

10. Within the context of precautionary management, the recent introduction of the 40 mm square mesh in the codend is an appropriate and plausible technical measure to the deep water crustacean trawl fishery in the western Mediterranean, by improving the exploitation pattern of the main target species and by reducing the impact of the fishery on the ecosystem, with no change in its economic efficiency.

11. The slope of the Balearic Islands with clear differences at a short spatial scale in geomorphical structure, bottom characteristics, hydrographic factors, availability of potential trophic resources and fishing effort at a short spatial scale represents an

excellent scenario to study how fishing exploitation and environment affect deep marine ecosystems. The knowledge derived from the present thesis provide relevant information about how the species traits are mainly affected by water masses, sediment characteristic, trophic resources and fishing, since they influence the bathymetric distribution, abundances, biological parameters and condition of decapod crustaceans at a local scale. To understand how environmental characteristics and fishing impact interact to change the species distribution and the dynamics of the populations and communities is a key point for a better assessment of the resources and for a better application of the Ecosystem-Based Approach Management in the Mediterranean deep water ecosystems.

Conclusions

1. La pesqueria de crustacis d'arrossegament de fons de les Illes Balears (Mediterrani Occidental), que opera en el talús entre 300 i 800 m de profunditat, representa el 34% de la biomassa total desembarcada y el 50% dels guanys obtinguts per la pesqueria d'arrossegament de fons. La importància dels crustacis decàpodes a les comunitats del talús en aquesta àrea augmenta en augmentar la profunditat. Són escassos en el poc explotat marge de la plataforma (200-300 m), on predominen els peixos teleostis, representen el segon grup més important al talús superior (400-600 m), després dels teleostis, y predominen en el talús mitjà (500-800 m). Al talús superior, els crustacis més importants són *Plesionika* spp., *Parapenaeus longirostris* i *Nephrops norvegicus*, mentre que al talús mitjà el crustaci predominant és *Aristeus antennatus*.

2. Per primera vegada a les Illes Balears, s'ha comparat la distribució, dinàmica poblacional i els paràmetres biològics d'aquestes espècies, entre les subconques Balear (BsB) i Algerina (AsB), situades al nord i al sud de l'arxipèlag respectivament, que presenten diferents condicions ambientals. Aquests ambients diferents inclouen l'estructura geomorfològica, les característiques del fons, els factors hidrogràfics i la disponibilitat de potencials recursos tròfics, amb una influència diferent per les espècies.

3. L'abundància mitjana d'adults i juvenils de *P. longirostris* en aigües menys profundes en la BsB (340 n/km^2 and 600 n/km^2) és, respectivament, quatre i cinc vegades major que en la AsB (67 n/km^2 and 150 n/km^2). Això s'explica per la concurrència a una mateixa profunditat (~350 m) en la BsB de sediments fangosos-sorrencs y elevada productivitat, reflectida en una elevada disponibilitat de preses potencials, en comparació a la AsB.

4. La abundància de les espècies del gènere *Plesionika*, així com la seva contribució a les comunitats, es major a la AsB, on les xarxes tròfiques se suporten fonamentalment en zooplàncton, que a la BsB. La captura mitjana anual per unitat d'esforç (CPUE) és > 6 i <4 kg/dia per vaixell para la AsB i la BsB, respectivament. Només l'espècie més bentònica *Plesionika heterocarpus* és més abundant a la BsB, on les xarxes tròfiques se suporten més en suprabentos. Les masses d'aigua també influencien la distribució batimètrica d'aquestes espècies. L'espècie d'aigües menys profundes *Plesionika*

antigai, el centre de gravetat (COG) de la qual és ~350 m, habita en les Aigües Intermèdies del Mediterrani Occidental. Les espècies més profundes *Plesionika martia* (COG ~600 m) y *Plesionika acanthonotus* (COG ~650 m) es distribueixen en l'Aigua Llevantina Intermèdia i les Aigües Profundes del Mediterrani Occidental. Les dues espècies que es troben en profunditats intermèdies, *P. heterocarpus* i *Plesionika giglioli*, mostren una distribució batimètrica més profunda a la AsB (COG ~350 m i ~550 m en AsB i AsB, respectivament), on la capa d'Aigües Llevantines Intermèdies és més amplia.

5. La dinàmica poblacional d'*A. antennatus* mostra majors fluctuacions en la BsB, principalment una elevada abundància de juvenils reclutant al talús mitjà a la tardor-hivern (~6000 femelles/km^2 i ~4000 mascles/km^2) i una elevada abundància de femelles adultes durant l'estiu (~2300 femelles/km^2). La població a la AsB és demogràficament més homogènia durant tot l'any, tant per a juvenils (~400 femelles/km^2 i ~100 mascles/km^2) com per a femelles adultes (~1500 individus/km^2). L'abundància màxima de femelles adultes està relacionada amb nuclis de Aigües Llevantines Intermèdies al talús mitjà, la influència de les quals entre principis de primavera i principis de tardor a la BsB és major que a la AsB. Els juvenils es veuen afavorits per la presència al talús mitjà de nuclis d'Aigües Profundes del Mediterrani occidental.

6. El període reproductiu mostra una marcada estacionalitat, amb la posta concentrada a l'estiu per *P. longirostris*, *P. martia* i *A. antennatus*. Per *P. heterocarpus,* el percentatge de femelles ovígeres fou >80% a totes les estacions. L'estacionalitat també es reflecteix a la condició, amb els valors més petits durant el període de posta. Per *A. antennatus*, els canvis estacionals en el contingut de lípids a l'hepatopàncrees estan relacionats amb el cicle reproductiu, amb valors mínims durant l'època de posta, cosa que reflecteix la importància dels lípids com a font d'energia per la maduració de l'ovari.

7. El talús de la més productiva BsB pot actuar con un hàbitat fonamental per a la majoria d'espècies estudiades, especialment pels esdeveniments de posta i reclutament. Això es basa en la millor condició que s'ha trobat a la BsB per a femelles d'*A. antennatus* durant el període de pre-posta i per ambdós mascles i femelles de *P. longirostris, P. heterocarpus* i *P. martia*. Aquesta millor condició també es reflecteix en una talla de primera maduresa per a femelles menor a la BsB per *P. longirostris* (BsB:

longitud cefalotòrax LC 28.5 mm; AsB: 29.5 mm CL), *P. martia* (BsB: 17.7 mm CL; AsB: 18.0 mm CL) i *A. antennatus* (BsB: 23.5 mm CL; AsB: 26.5 mm CL). A més, les femelles de *P. longirostris* també presenten valors de la taxa de creixement de von Bertalanffy (k) més alts a la BsB (0.85) que a la AsB (0.73).

8. L'aproximació dels semàfors és una eina útil para l'avaluació ecosistèmica dels recursos marins, ja que permet combinar i resumir un elevat nombre d'indicadors. Aquest indicadors, tant per espècies com per ecosistemes, proporcionen informació àmplia i complementària, ja que combinen la precisió i gran qualitat de les campanyes experimentals (dades independents de la pesqueria) amb la informació de tot l'any del sector pesquer (dades dependents de la pesqueria).

9. A nivell de comunitat, s'ha detectat una millora en l'estat de l'associació del talús superior, com a resultat d'una disminució de l'esforç pesquer. Això també es reflecteix espacialment, amb un millor estat a l'àrea est, coincidint amb els nivells més baixos d'esforç, i el contrari a l'oest. A nivell específic, *N. norvegicus* mostra una millora en el seu estat durant els darrers any a tota l'àrea cosa que també es pot relacionar amb aquest factor. No s'han obtingut resultats clars per *A. antennatus*, amb marcades diferències entre l'avaluació obtinguda amb informació depenent i independent de la pesqueria. Aquestes diferències entre ambdós fonts de dades se poden explicar per la gran variabilitat estacional en la dinàmica poblacional d'aquest recur, que no queda coberta per las campanyes d'investigació de finals de primavera. Altres factors diferents a l'explotació pesquera poden afectar aquests recursos, ja que el millor estat per *A. antennatus* se troba en la zona oest (BsB) més explotada, però més productiva.

10. Dins el context del principi de precaució aplicat a la gestió, la recent introducció de la malla quadrada de 40 mm en el cop és una mesura tècnica apropiada i plausible para la pesqueria de profunditat de crustacis en el Mediterrani occidental, millorant el patró d'explotació de les principals espècies objectiu i reduint el impacte de la pesca a l'ecosistema, sense canvis en la seva eficiència econòmica.

11. El talús de les Illes Baleares, amb clares diferències en estructura geomorfològica, característiques del fons, factors hidrogràfics, disponibilitat de recursos tròfics i esforç pesquer a petita escala espacial, representa un escenari excel·lent per estudiar com

l’explotació pesquera i el medi ambient afecten els ecosistemes marins profunds. Els coneixements derivats d’aquesta tesi proporcionen informació rellevant sobre com les masses d’aigua, las característiques dels sediments, els recursos tròfics i la pesca afecten les característiques de les espècies, ja que influencien a la condició, distribució batimètrica i l’abundància dels crustacis decàpodes a escala local. Entendre la manera en què les característiques ambientals i l’impacte pesquer interactuen per canviar la distribució de les espècies i la dinàmica de les poblacions i comunitats és un punt clau per a una millor avaluació dels seus recursos i per a una millor aplicació d’una aproximació ecosistèmica a la gestió de les pesqueries d’aigües profundes del Mediterrani.

Conclusiones

1. La pesquería de crustáceos de profundidad de las Islas Baleares (Mediterráneo occidental), que opera en el talud entre 300 y 800 m de profundidad, representa el 34% de la biomasa total desembarcada y el 50% de las ganancias obtenidas por la pesquería de arrastre de fondo. La importancia de los crustáceos decápodos en las comunidades del talud en esta área aumenta al aumentar la profundidad. Son escasas en el apenas explotado margen de la plataforma (200-300 m), donde predominan los peces teleósteos, representan el segundo grupo más importante en el talud superior (400-600 m), después de los teleósteos, y predominan en el talud medio (500-800 m). En el talus superior, los crustáceos más importantes son *Plesionika* spp., *Parapenaeus longirostris* y *Nephrops norvegicus*, mientras que en el talud medio el crustáceo predominante es *Aristeus antennatus*.

2. Por primera vez en las Islas Baleares, se ha comparado la distribución, dinámica poblacional y los parámetros biológicos de estas especies, entre las sub-cuencas Balear (BsB) y Argelina (AsB), situadas al norte y al sur del archipiélago respectivamente, que presentan diferentes condiciones ambientales. Estos ambientes diferentes incluyen la estructura geomorfológica, las características del fondo, los factores hidrográficos y la disponibilidad de los potenciales recursos tróficos, con diferente influencia para las especies.

3. La abundancia media de adultos y juveniles de *P. longirostris* en aguas menos profundas en la BsB (340 n/km^2 y 600 n/km^2) es, respectivamente, cuatro y cinco veces mayor que en la AsB (67 n/km^2 y 150 n/km^2). Esto se explica por la concurrencia en una misma profundidad (~350 m) en la BsB de sedimentos fangosos-arenosos y elevada productividad, reflejada en una elevada disponibilidad de presas potenciales, en comparación con la AsB.

4. La abundancia de las especies del género *Plesionika*, así como su contribución a las comunidades, es mayor en la AsB, donde las redes tróficas se apoyan fundamentalmente en zooplancton, que en la BsB. La captura media anual por unidad de esfuerzo (CPUE) es >6 y <4 Kg/día por barco para la AsB y la BsB, respectivamente. Sólo la especie más bentónica *Plesionika heterocarpus* es más abundante en la BsB, donde las redes tróficas

se basan más en suprabentos. Las masas de agua también influyen en la distribución batimétrica de estas especies. La especies de aguas menos profundas *Plesionika antigai*, cuyo centro de gravedad (COG) es ~350 m, habita en el Agua Intermedia del Mediterráneo Occidental. Las especies más profundas *Plesionika martia* (COG ~600 m) y *Plesionika acanthonotus* (COG ~650 m) se distribuyen en el Agua Levantina Intermedia y el Agua Profundad del Mediterráneo Occidental. Las dos especies que se encuentran en profundidades intermedias, *P. heterocarpus* y *P. giglioli*, muestran una distribución batimétrica más profundad en la AsB (COG ~350 m y ~550 m en BsB y AsB, respectivamente), donde la capa de Agua Levantina Intermedia es más amplia.

5. La dinámica poblacional de *A. antennatus* muestra mayores fluctuaciones en la BsB, principalmente una elevada abundancia de juveniles reclutando en el talud medio en otoño-invierno (~6000 hembras/km^2 y ~4000 machos/km^2) y una elevada abundancia de hembras adultas durante verano (~2300 hembras/km^2). La población en la AsB es demográficamente más homogénea durante todo el año, tanto para juveniles (~400 hembras/km^2 y ~100 machos/km^2) como para hembras adultas (~1500 individuos/km^2). La abundancia máxima de hembras adultas está relacionada con núcleos de Aguas Levantinas Intermedias en el talud medio, cuya influencia entre principios de primavera y principios de otoño en la BsB es mayor que en la AsB. Los juveniles se ven favorecidos por la presencia en el talud medio de núcleos de Aguas Profundas del Mediterráneo Occidental.

6. El período reproductor muestra una marcada estacionalidad, con la puesta concentrada en verano para *P. longirostris*, *P. martia* y *A. antennatus*. Para *P. heterocarpus*, el porcentaje de hembras ovígeras fue >80% en todas las estaciones. La estacionalidad también se refleja en la condición, con los valores más pequeños durante el período de puesta. Para *A. antennatus*, los cambios estacionales en el contenido de lípidos en el hepatopáncreas están relacionados con el ciclo reproductor, con valores mínimos durante la época de puesta, lo que refleja la importancia de los lípidos como fuente de energía en la maduración del ovario.

7. El talud de la más productiva BsB puede actuar como un hábitat fundamental para la mayoría de las especies estudiadas, especialmente para los acontecimientos de puesta y reclutamiento. Esto se basa en la mejor condición que se ha encontrado en la BsB para

las hembras de *A. antennatus* durante el período de pre-puesta y para machos y hembras de *P. longirostris*, *P. heterocarpus* y *P. martia*. Esta mejor condición también se refleja en una talla de primera madurez para hembras menor en la BsB para *P. longirostris* (BsB: longitud cefalotórax CL 28.5 mm; AsB: 29.5 mm CL), *P. martia* (BsB: 17.7 mm CL; AsB: 18.0 mm CL) y *A. antennatus* (BsB: 23.5 mm CL; AsB: 26.5 mm CL). Además, las hembras de *P. longirostris* también presentan valores de la tasa de crecimiento de von Bertalanffy (k) más altos en la BsB (0.85) que en la AsB (0.73).

8. La aproximación de los semáforos es una herramienta útil para la evaluación ecosistémica de los recursos marinos, ya que permite combinar y resumir un elevado número de indicadores. Estos indicadores, tanto para especies como para ecosistemas, proporcionan información amplia y complementaria, ya que combinan la precisión y gran calidad de las campañas experimentales (datos independientes de la pesquería) con la información de todo el año del sector pesquero (datos dependientes de la pesquería).

9. A nivel de comunidad, se ha detectado una mejora en el estado de la asociación del talud superior, como resultado de una disminución del esfuerzo pesquero. Esto también se refleja espacialmente, con un mejor estado en el área este, coincidiendo con los niveles más bajos de esfuerzo, y lo contrario en el oeste. A nivel específico, *N. norvegicus* muestra una mejora en su estado durante los últimos años en toda el área, lo que también se puede relacionar con este factor. No se han obtenido resultados claros para *A. antennatus*, con marcadas diferencias entre la evaluación obtenida con información dependiente e independiente de la pesquería. Estas diferencias entre ambas fuentes de datos se pueden explicar por la gran variabilidad estacional en la dinámica poblacional de este recurso, que no queda cubierta con las campañas de investigación de finales de primavera. Otros factores diferentes a la explotación pesquera pueden afectar estos recursos, ya que el mejor estado para *A. antennatus* se encuentra en la zona oeste (BsB) más explotada, pero más productiva.

10. En el contexto del principio de precaución aplicado a la gestión, la reciente introducción de la malla cuadrada de 40 mm en el copo es una medida técnica apropiada y plausible para la pesquería de profundidad de crustáceos en el Mediterráneo occidental, mejorando el patrón de explotación de las principales especies objetivo y

reduciendo el impacto de la pesca en el ecosistema, sin cambios en su eficiencia económica.

11. El talud de las Islas Baleares, con claras diferencias en estructura geomorfológica, características del fondo, factores hidrográficos, disponibilidad de recursos tróficos y esfuerzo pesquero a pequeña escala espacial, representa un escenario excelente para estudiar cómo la explotación pesquera y el medio ambiente afectan a los ecosistemas marinos profundos. Los conocimientos derivados de esta tesis proporcionan información relevante sobre cómo las masas de agua, las características de los sedimentos, los recursos tróficos y la pesca afectan a las características de las especies, ya que influyen en la condición, distribución batimétrica y abundancia de los crustáceos decápodos a escala local. La manera en que las características ambientales y el impacto pesquero interactúan para cambiar la distribución de las especies y la dinámica de las poblaciones y comunidades es un punto clave para una mejor evaluación de sus recursos y para una mejor aplicación de una aproximación ecosistémica en la gestión de las pesquerías de aguas profundas del Mediterráneo.

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