



University of the Algarve

Faculty of Sciences and Technology

Centro de Ciências do Mar

Master in Marine Biology

The impact of the Arrábida Marine Park (Portugal) on the
decapod crustacean *Eualus cranchii* - A case study

by

Joana Reis

Thesis submitted for the partial fulfillment of the title of

Master of Science in Marine Biology

Supervisors:

Margarida Castro (CCMAR)

Cátia Bartilotti (IPMA)

Faro

2015

Declaração de autoria de trabalho:

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

Copyright

A universidade do Algarve tem o direito, perpétuo e sem limites geográficos, de arquivar e publicitar este trabalho através de exemplares impressos reproduzidos em papel ou de forma digital, ou por qualquer outro meio conhecido ou que venha inventado, de o divulgar através de repositórios científicos e de admitir a sua cópia e distribuição com objectivos educacionais ou de investigação, não comerciais, desde que seja dado crédito ao autor e editor.

Joana Reis (nº 49331)

“I am really dedicated to understand the planet on which we live and know that means I must go beneath the sea to see 72 percent of what is going on.”

Robert Ballard, Ocean Researcher

Abstract

Marine protected areas (MPAs) have been widely suggested as a tool for fisheries management, conservation goals and mitigation of other negative impacts of humans on the oceans. Within MPAs, sub-areas can be considered including Fully Protected Areas (FPA) and Partially Protected Areas (PPA), each one with different restrictions regarding anthropogenic activities. They can contribute to the increase of abundance and biodiversity of marine species and habitat improvement.

This study aims to observe the abundance of the decapod crustacean *Eualus cranchii* at two different depths (surface and bottom) within fully- and partially- protected areas of the Arrábida Marine Park on the west coast of Portugal, in order to understand the effect of a protected area on the abundance of this species. Samples were collected every two weeks, from April to September 2013 at a fixed location in the FPA and PPA using Standard Monitoring Units for Recruitment of Fish (SMURFs), a tool that measures recruitment and settlement patterns in a repeatable way, helping to determine fish larval sources and sinks.

A Three-Way ANOVA was performed to observe the existence of differences in abundance of *E. cranchii* as a function of protection type (FPA and PPA), depth (surface and bottom) and time (April, July and September). All level interactions were considered.

The results showed that all three main factors were significant. Higher abundances are associated with FPA with about 77 % of the total number of individuals of *E. cranchii* present. With respect to depth 88 % of the individuals were found on the bottom. The highest larval abundance was recorded in July, representing 77 % of the total individuals analyzed in this study. Additionally, there was a significant interaction of time with protection level indicating that there were different trends along time in each area.

Overall, MPAs can be viewed as a valuable tool to protect species abundance and diversity, yet they should not be considered as a final solution as other large-scale effects and subsequent community changes in coastal areas may also influence the abundance and distribution of marine species.

Key Words: MPA, Arrábida Marine Park, Decapod crustaceans, *Eualus cranchii*, SMURFs

Resumo

As áreas marinhas protegidas (AMP) têm sido fortemente sugeridas como ferramenta para gestão de pescas, conservação e atenuação de impactos negativos criados pelo Homem nos oceanos. Dentro delas, outras sub-áreas podem ser estabelecidas, as Áreas Totalmente Protegidas (ATP) e as Áreas Parcialmente Protegidas (APP), cada uma com diferentes restrições no que diz respeito a actividades antropogénicas. Estas áreas podem contribuir para o aumento de abundância e biodiversidade de espécies marinhas, e também melhorar os seus habitats.

Este estudo focou-se na observação da abundância e distribuição de espécies de crustáceos decápodes, dando especial atenção à espécie *Eualus cranchii*, por ter sido a mais abundante. Esta foi analisada em duas profundidades diferentes (superfície e fundo), em ambas as áreas, totalmente e parcialmente protegidas, no Parque Marinho da Arrábida, na costa Oeste de Portugal continental, com o intuito de compreender o efeito de uma área marinha protegida na abundância desta espécie. A amostragem foi feita bi-semanalmente de Abril a Setembro de 2013, num ponto fixo da ATP e APP do parque marinho, com *Standard Monitoring Units for Recruitment of Fish* (SMURFs), um método que mede os padrões de recrutamento de forma repetida e auxilia na determinação de fontes larvares de peixes.

O teste de análise de variância foi usado para observar a existência de diferenças na abundância de *E. cranchii*, nas amostras recolhidas. Foram considerados três factores, o nível de protecção da área (ATP e APP), a profundidade (junto ao fundo e à superfície) e o tempo (Abril, Julho e Setembro). Para além dos factores principais foram consideradas todas as interações possíveis.

Todos os factores principais considerados mostraram ser significativos. Verificou-se uma maior abundância na ATP, com cerca de 77 % de indivíduos amostrados, podendo esta diferença estar relacionada com o menor impacto das actividades antropogénicas. No que diz respeito à profundidade, 88 % do total de *E. cranchii* amostrados encontraram-se junto ao fundo, o que pode dever-se ao facto desta espécie ser bentónica. Durante os meses de amostragem, o maior pico de abundância de *E. cranchii* foi registado em Julho, representado por 77 % do total de indivíduos.

Adicionalmente, verificou-se uma interação significativa entre o tempo e o nível de protecção no que respeita à abundância de *E. cranchii* sugerindo-se que a abundância desta espécie não apresentou a mesma tendência temporal em cada uma das áreas.

Em suma, as AMP podem ser vistas como uma valiosa ferramenta mas ainda assim não devem ser consideradas como a única solução, uma vez que podem existir outros efeitos a grande escala e subsequentes mudanças em comunidades das áreas costeiras que podem influenciar a distribuição e abundância de espécies marinhas.

Palavras-Chave: *AMP, Parque Marinho da Arrábida, Crustáceos decápodes, Eualus cranchii, SMURFs.*

Table of contents

Abstract.....	v
Resumo	vi
List of Figures.....	ix
List of Tables	ix
Acknowledgments	x
1. Introduction	1
Coastal Zones	1
Marine Protected Areas (MPAs)	1
MPAs and human activities.....	2
Decapod crustacean larvae	3
Recruitment	4
Aim of the study	5
2. Materials & Methods.....	7
Study site	7
Sampling design and data collection	8
Laboratorial procedures.....	9
Eualus cranchii (Leach, 1817 [in Leach, 1815-1875]).....	10
Data analysis.....	10
3. Results	11
4. Discussion	16
Future research	20
Conclusion.....	21
References	22
Appendix	32

List of Figures

- Figure 1.** Map of the Arrábida Marine Park with zoning implemented by the management plan. Zoning: BA – Buffer areas; PPA – Partially protected areas, FPA – Fully-protected area (divided in FPA1 and FPA2 due to the transitory phase of the management plan implementation) (Horta *et al.* 2013)8
- Figure 2.** Map of Arrábida with the location of the collected samples (Modified from: Maria Klein)9
- Figure 3.** Percentage of the collected individuals regarding their infraorder, comparing with the individuals of the species *E. cranchii*. (*E. cranchii* belongs to the infraorder Caridea but that is not imposed in this graph).11
- Figure 4.** Total abundance of *E. cranchii* collected in the fully- and partially- protected areas, per each month.12
- Figure 5.** Total abundance of *E. cranchii* collected in the fully- and –partially protected areas among all months.12
- Figure 6.** Total abundance of *E. cranchii* collected at the surface and bottom, among all months. 13
- Figure 7.** Total abundance of *E. cranchii* collected per each month, related with each fully- and partially- protected area. FPA (Fully Protected Area), PPA (Partially Protected Area).14
- Figure 8.** Total abundance of *E. cranchii* collected in the fully- and partially- protected areas, related with the two different depths (bottom and surface). FPA (Fully Protected Area), PPA (Partially Protected Area).14

List of Tables

- Table 1.** Effects of Months, Area and Depth on the abundance of *E. cranchii*. Values were compared by a Three-Way ANOVA test.....15

Acknowledgments

I would sincerely like to thank my supervisors Prof. Dr. Margarida Castro and Dr. Cátia Bartilotti for their time and guidance given throughout my work. A special thank you to Cátia Bartilotti that had to deal with desperate e-mails and was always there to give solutions and guide me through this thesis.

To my dearest family in Faro that were my biggest support throughout these two years. Obrigada Mizu, Eli, Ani, Ni, Zosi and Nico.

To my beloved friends Ana Leonardo and Alex Rigo, you were the cherry on top of the cake in the last months of this journey. Saudinha da boa e até já maracujá!

Um obrigada do fundo do coração à minha mãe e ao meu pai. Sem eles...

Last, but not least, I would like to give a special thank you to all decapod crustaceans included in this thesis.

You didn't die in vain 😊

1. Introduction

Coastal Zones

Coastal areas are highly impacted by human socioeconomic activities and human-induced changes that can threaten coastal ecosystems (Pernetta & Milliman 1995; R. K. Turner, S. Subak 1996) through pollution, overexploitation of living marine resources, habitat degradation and destruction and climate change (Harley *et al.* 2006; Halpern *et al.* 2008; Jackson 2008). Such changes impact many habitats, species and span over different trophic levels (Lubchenco *et al.* 2003; Browman & Stergiou 2004). Since marine reserves are believed to protect all species and habitats from potentially harmful human activities, they are considered a crucial tool for ecosystem-based management and may offer good prospects for the attenuation of some of the threats that affect coastal systems (Worm *et al.* 2006).

Marine reserves are an important subdivision of Marine Protected Areas (MPAs) and they are defined as ‘areas of the ocean completely protected from all extractive and destructive activities, except activities necessary for monitoring or research (Lubchenco *et al.* 2003). Marine reserves can, in the long term, become control areas for the effects of fishing and other influences on populations and ecosystems (Pelletier *et al.* 2008).

Marine Protected Areas (MPAs)

MPAs have been frequently mentioned as a beneficial tool for a multiplicity of fisheries management problems connected with the maintenance of exploited stocks, improvement of fisheries yields, conservation of biodiversity and other societal goals (Costanza *et al.* 1998; Murawski 2007; Roberts *et al.* 2001; Field *et al.* 2006; Gerber *et al.* 2003). MPAs often aim at protecting entire communities and ecosystems through the limitation or total exclusion of human activities (Fraschetti *et al.* 2011). Different MPAs differ in their regulations and their value for conservation varies substantially, based on the level of protection defined (Mora *et al.* 2006; Lester & Halpern 2008).

The creation of an MPA can lead to improvements in the ecosystem such as the restoration of habitats and fish stocks (Horta & Costa *et al.* 2013). The level of stakeholder

participation in a MPA management is positively correlated with the biological gains obtained (Pollnac & Crawford 2000).

Thus, the development of solutions to resolve socioeconomic concerns arising from the implementation of an MPA, should be a central priority, even if the benefits from the MPA occur in the long-term (Charles & Wilson 2008).

MPAs and human activities

It has become clear that humans have achieved crucial control and influence in terms of shaping marine assemblages, transforming the physical environment where organisms live and directly or indirectly impacting populations and assemblages (Botsford *et al.* 1997; Vitousek *et al.* 1997). The past few decades have witnessed a growing awareness that fishes and invertebrates can not only be severely depleted, but also be threatened with extinction through overexploitation (e.g. Pauly *et al.* 1998).

Furthermore, fisheries have an impact on non-target species and habitat, interfering with the food web structure and species interactions (Micheli *et al.* 2001), affecting the marine systems globally over historical times (Myers & Worm 2003; Pandolfi *et al.* 2003). Thus, human activities in the marine environment must be recognized as an important factor which directly influences species dynamics and indirectly triggers effects that change the structure of whole assemblages (Charles & Wilson 2008).

Within MPAs, human activities are strongly regulated by the implementation of restrictions and these areas can serve as control sites to evaluate human impacts on populations and whole assemblages. Research studies comparing marine reserves with contiguous areas having no fishing (e.g. Halpern *et al.* 2008) or reduced fishing levels (e.g. Jennings & Polunin 1996) have demonstrated that controlling fisheries in general result in greater abundance, biomass, average body size and a higher diversity of coastal marine species. These effects vary with life histories and exploitation levels of the species. Follow up studies, after the implementation of MPAs, found that species targeted by fishermen reach larger sizes or occupy higher trophic levels near marine reserves (Mosquera *et al.* 2000; Micheli *et al.* 2004).

Greater effects are expected when fishing pressure is high before protection (Micheli *et al.* 2004; Tetreault & Ambrose 2007; Lester *et al.* 2009), and the scale of those effects is

coupled to species composition, size, trophic level, mobility, habitat dependence and commercial value (Pelletier *et al.* 2008; Claudet *et al.* 2010).

MPAs are, at the present time, one of the most promising tools to integrate conservation with fisheries management and are being implemented globally (Schmidt 1997), especially in coastal zones exposed to human pressure (Limousin 1995). In mainland Portugal, the Arrábida MPA (created by Decree-Law nº 6221/76) was one of the first marine protected areas and its main goals are to preserve coastal biodiversity and to provide a tool for fisheries management. Expected outcomes include: recovery of habitats, promotion of scientific research, encouragement of environmental awareness and education, promote nature oriented tourism and sustainable development, and promote economic and cultural regional activities such as the traditional longline fishery (Gonçalves *et al.* 2002).

These goals may enhance commercial stocks and neighboring areas can benefit from adults' migration (Goñi *et al.* 2008) or larvae spillover of a vast range of marine species (Pelc *et al.* 2010).

Decapod crustacean larvae

There is no group of living animals or plants that displays such a vast range of morphologic diversity as the Crustaceans (Martin & Davis 2001). It is estimated that, among Metazoa, the crustaceans are the fourth most diverse group. Amongst them, decapods have been subjected to innumerable studies due to the economic importance of many species (Martin & Davis 2001), and their importance as food for many fishery resources (dos Santos 1999).

The majority of marine decapod species have a complex life history with a biphasic life cycle: a planktonic larval phase coupled with a benthic adult phase (e.g. Anger 2001). The pelagic larva may differ from the juvenile and adult in morphology and habits and is part of the meroplankton. During their planktonic life stage it can pass through many larval stages whose complexity varies among species, spending from hours to years in the pelagic environment before joining the parental population after settlement (Anger 2001). Decapod crustacean larvae can constitute up to 90 % of the total zooplankton (Anger 2001; McConaugha 1992), underlining their protagonist role, not only as prey of

carnivorous species, but also as consumers of small size plankton (Anger 2001). The feeding behavior of decapod crustacean larvae largely depends on the species and larval stage. They can be detritivores, herbivores, carnivores and omnivores (Le Vay *et al.* 2001), however phytoplankton is considered one of the most important sources of food for these larvae (Anger 2001), especially in the earlier larval stages (Emmerson 1984). In addition, polychaetes, mollusk larvae, cladocerans, copepods and echinoderms larvae serve as potential food sources for decapods (Anger 2001).

Descriptions of decapod larval communities are still rare for most places around the world (Brandao *et al.* 2013; Landeira *et al.* 2012). Nearshore communities, in estuarine or coastal waters, which represent more accessible ecosystems and hence can be monitored with less cost, are usually characterized with a focus on the spatial and temporal distribution of decapod larvae (Torres *et al.* 2014). There has been widespread interest in explaining variations in larval supply rates, especially in productive shelf areas (e.g. Queiroga *et al.* 2007). Larvae from decapod species associated with the continental shelf and slope tend to have a wide spatial offshore distribution, while those from coastal and nearshore areas are usually found much closer to the coast (e.g. Dos Santos *et al.* 2008; Miller & Morgan 2013).

The planktonic larval phase represents the most important period within the species life cycle, because mobile larvae can be transported from several meters to hundreds of kilometers, genetically connecting distant regions (Domingues *et al.* 2010). The extent of vertical larval distribution and migration changes during larval ontogeny (e.g. Zeldis & Jillett 1982; Shanks 1986, 1995) and is relevant to determine retention over the shelf and eventual recruitment (e.g. Shanks & Brink 2005). After the planktonic phase, the larvae have to return to the appropriate habitat for settlement (Abelló & Guerao 1999; Shanks 1998).

Recruitment

Recruitment can be defined as the reposition of the adult population with the input of new individuals, as a result of the reproduction and growth processes (Queiroga *et al.* 2007). Although recruitment is not completely understood, it is known that the transition of an individual decapod to the sea floor during settlement is generally irreversible, meaning

that the ‘decision’ of where and when to settle is crucial and larvae are known to use a range of environmental cues that help them to choose a suitable place to settle (Crisp 1974). These impulses can be of a chemical nature (such as certain compounds released by conspecifics or a favored food source) or physical stimuli (including the sound of waves, light intensity or substratum roughness) (Crisp 1974; Koehl & Hadfield 2010).

A second feature, typical for marine larvae, is that they tend to develop through a *precompetent* period, during which they often feed and grow but are thought to be incapable of settling and complete metamorphosis, after which they attain *competence* to settle under appropriate conditions (Hadfield *et al.* 2001; Jackson & Strathmann 1981). Although the *precompetent* period tends not to be clearly defined, it is assumed that the selective advantage of the *precompetent* period is to ensure that the individual is sufficiently well developed to survive and prosper on the sea floor (Jackson & Strathmann 1981). Larval recruitment is influenced by larval transport to suitable habitats by Ocean currents, which can be facilitated by winds and internal waves (Shanks 1985). Recruitment success depends on the number of larvae and juveniles that survive the planktonic phase (McConaugha 1992; Sandifer 1975) and are transported to the settlement sites (Caddy 1986).

Decapod crustaceans are a suitable group for studying the interaction of recruitment processes, habitat selection and post-larval mortality, due to their mobility, complex life cycles and population dynamics (Squires 1990). Because of their abundance and high taxonomic and trophic diversity, they play a major ecological role in the dynamics of coastal benthic ecosystems (e.g. Ingle & Clark 2008).

The knowledge and taxonomic identification of the larval development stages of a species are important requirements to study larval ecology, behavior, dispersion and recruitment (Anger 2006).

Aim of the study

This study is the first of its kind, as it aims to compare the abundance and distribution of a decapod crustacean species in the MPA of the Arrábida Marine Park on the west coast of Portugal, among two differently protected areas, the Fully Protected Area (FPA) and the Partially Protected Area (PPA). The individuals of the species of *Eualus cranchii*

where chosen as a model. Sampling took place in the months of April, July and September of 2013, at the two sites (FPA and PPA) and at two different depths, in order to understand the effects of the Marine Protected Area in both temporal and spatial distribution patterns of this species.

The main issues to investigate were:

- (1) Whether the abundance of *E. cranchii* increases within the Fully Protected Area, where anthropogenic activities are prohibited;
- (2) Whether the abundance of the species is related to other factors such as depth;
- (3) How *E. cranchii* abundance varies throughout the sampling period in relation to each protected area and depth.

2. Materials & Methods

Study site

The Arrábida MPA (Portugal) was created by Decree-Law n° 622176 in 1998 but management measures were only published seven years later. It is considered an area of high marine biodiversity, including numerous commercially important species (Costa *et al.* 2013). The coast along Arrábida has been the stage of intense and varied human use for many decades (Carneiro 2011). The MPA has a wide scope of objectives concerning both conservation and fisheries management: to preserve biodiversity and recover overexploited resources; to recover habitats; to promote scientific research; to encourage environmental awareness and education; to support progressive adaptation of the general rules of effluent emission; to promote nature oriented tourism and sustainable development and to promote economic and cultural regional activities such as the traditional longline fishery (Gonçalves *et al.* 2002). Protected from the dominant northern winds, the coastline is characterized by high rocky cliffs alternated by sheltered bays (Ribeiro 2004). It is worth pointing out that this coast is located near the large metropolitan area of Lisbon which makes it highly susceptible to intense pressures from leisure and economic activities. Some of these human activities, including fisheries and tourism, are of high local importance, both socially and economically (Horta & Costa *et al.* 2013).

The Arrábida MPA management plan imposes limits and restrictions to various activities, namely to the local small-scale fisheries which have a high socio-economic importance in the area (Batista *et al.* 2011). Dredging, trawling, discards, hand-collecting fishing and capture of any marine organism using scuba-diving gear are not allowed.

The management plan was approved in August 2005 and multiple areas with different levels of protection have been designated (Fig. 1): a fully-protected area (FPA) totaling 4 km²; four partially-protected areas (PPA) totaling 21 km²; and three buffer areas (BA) encompassing 28 km². The FPA is a no-take, no-go area, except for research, monitoring and educational purposes. In the PPAs, artisanal fishing using traps and jigs is allowed but no extractive recreational activities (i.e. angling) are permitted (Horta & Costa *et al.* 2013).

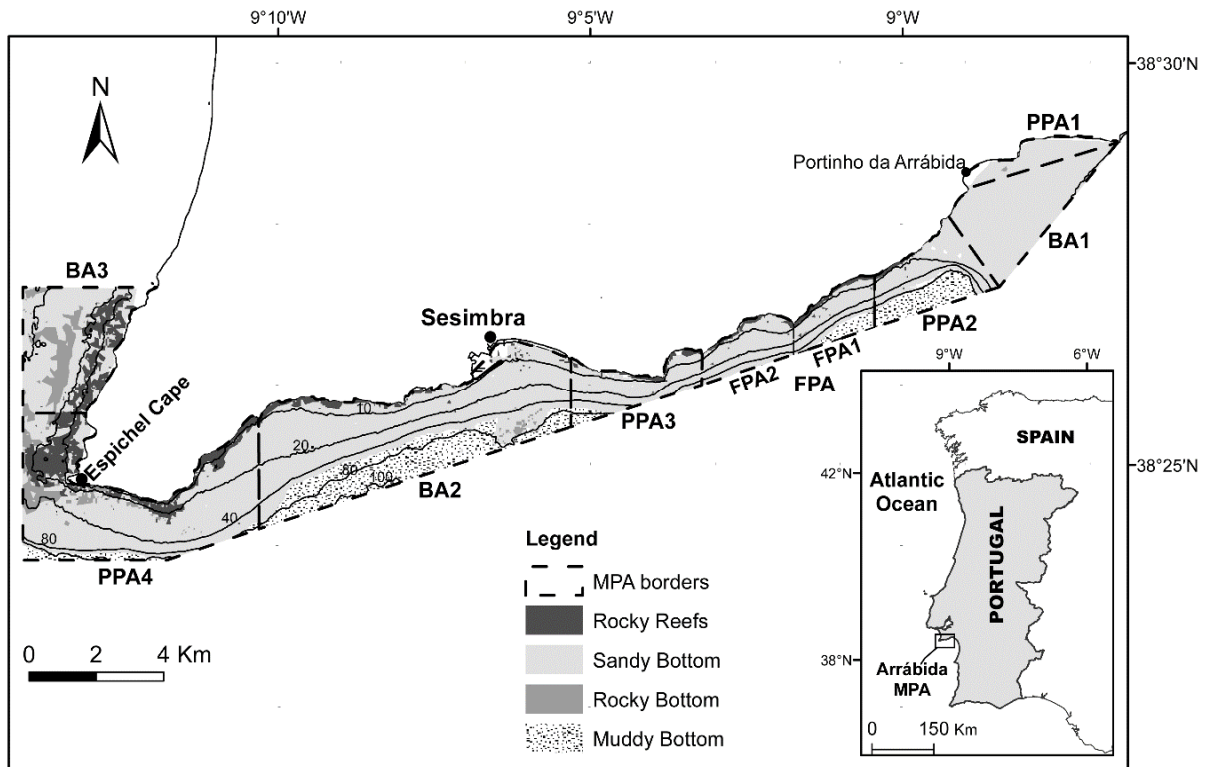


Figure 1. Map of the Arrábida Marine Park with zonation implemented by the management plan. Zoning: BA – Buffer areas; PPA – Partially protected areas, FPA – Fully-protected area (divided in FPA1 and FPA2 due to the transitory phase of the management plan implementation) (Horta *et al.* 2013).

Sampling design and data collection

Sampling was undertaken prior to this study as part of a larger campaign in the framework of the Matrix project (PTDC/MAR/115226/2009), with the objective of understanding connectivity patterns in temperate reef fish communities.

The samples were taken during the months of April, July and September of 2013 in the Fully Protected Area (FPA) and Partially Protected Area (PPA) of the Arrábida Marine Park, Portugal (38°26'18.92"N, 9°02'12.11"W) (Fig. 2). At both sites four replicates of Standard Monitoring Units for Recruitment of Fish (SMURFs) were deployed below the surface, located about 20 m apart.

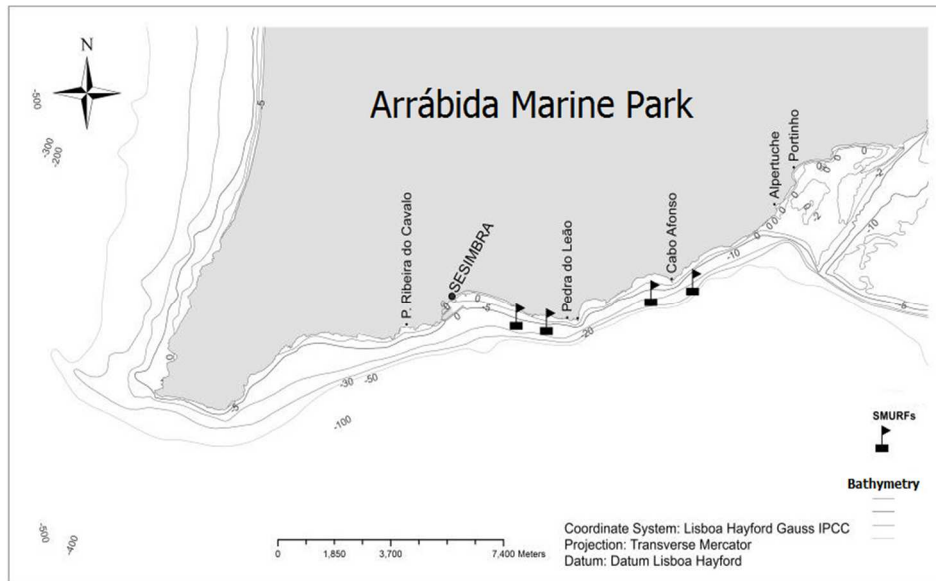


Figure 2. Map of Arrábida MPA with the location of the collected sites (Modified from: Maria Klein).

The SMURFs consisted of a cylindrically rolled green outer gardening fence filled with plastic snow to create substrate, designed according to Ammann (2004). The SMURFs were placed 100 m off-shore from the nearest rocky reef, each one attached along a vertical mooring line, one approximately 2-3 m below the surface and one on the seafloor at 14 m depth (with a tidal range of 3 m).

SMURFs in the water column were collected every two weeks by scuba-divers using a Benthic Ichthyofaunal Net for Coral/Kelp environments (BINCKE) (Ammann 2004). For benthic SMURFs a glove oil anesthetic solution was sprayed into the artificial substrate and after this the SMURF was shaken above a collecting net (1 mm mesh size). Onboard, SMURFs were rinsed over the net to remove concealed animals before they were put back in the water. The samples were stored in 80% ethanol.

Some samples were lost, at both sites and depths, due to sabotage or strong currents.

Laboratorial procedures

Decapods collected in the SMURFs were counted and identified to the infraorder level using a stereomicroscope LEICA S8AP0. After sorting, the decapod crustaceans were kept in 80 % ethanol. Since caridean shrimps were the most abundant animals in the samples, a second identification of the individuals to the lowest taxonomic level possible

was made, according to the adequate taxonomical keys (Lagardère 1971; dos Santos & González-Gordillo 2004). Individuals that could not be identified due to damages (caused by the collecting method, smashing, etc.) were registered as non-identified (n.i.).

Eualus cranchii (Leach, 1817 [in Leach, 1815-1875])

Eualus cranchii was chosen as the study targeted species once it was found to be the most abundant species in the samples (Annex I).

The individuals of this species are around 2.2 cm total length (Zariquiey-Álvarez 1968). The coloration varies, generally they are semi-transparent with red, yellow, orange or black chromatophores spread on the thoracic appendices and body. The ventral region of the carapace has a dark-red coloration and occasionally a dark-green color (Calado & Narciso 2002).

Sexual maturity is reached when the length of the carapace reaches 3.3 mm (Zariquiey-Álvarez 1968). Females are ovigerous from March to December (Zariquiey-Álvarez 1968) and produce eggs of about 0.39 x 0.52 mm. The larval phase is constituted by nine zoea and one decapodid (Lebour 1936).

E. cranchii can be found in the oriental region of the North Atlantic Ocean and in the Mediterranean basin (Lagardère 1975; Zariquiey-Álvarez 1968). The species is generally benthonic, being found under rocks, in holes or in between algae and seagrass beds. Individuals are usually present in the intertidal zone up to a depth of 40 m, however this species also can be found in depths of 130 m (Neves 1990).

Data analysis

Statistical analysis was done using Microsoft Excel 2013 and the software RStudio (Version 3.1.0.). Data were log transformed (\log_{x+1}) in order to homogenize the variance. Subsequently a Three-Way ANOVA with all possible interactions was performed and significance was considered for *p-values* < 0.01. For significant factors, the levels were compared using orthogonal contrast.

3. Results

A total of 2651 individual were identified. Of these, 1565 were the juveniles or adults of *Eualus cranchii*, representing 59 % of the total individuals collected. Other species belonging to the infraorder Caridea (caridean shrimps) were collected as well as the infraorders Brachyura (crabs, n=205), Achelata (lobsters, n=137) and Anomura (hermit crabs, n=80). These groups represented respectively 25 %, 8 %, 5 % and 3 % of the collected samples. The total individuals of the infraorder Caridea, including *E. cranchii*, represented 84 % of the collected individuals (Fig. 3).

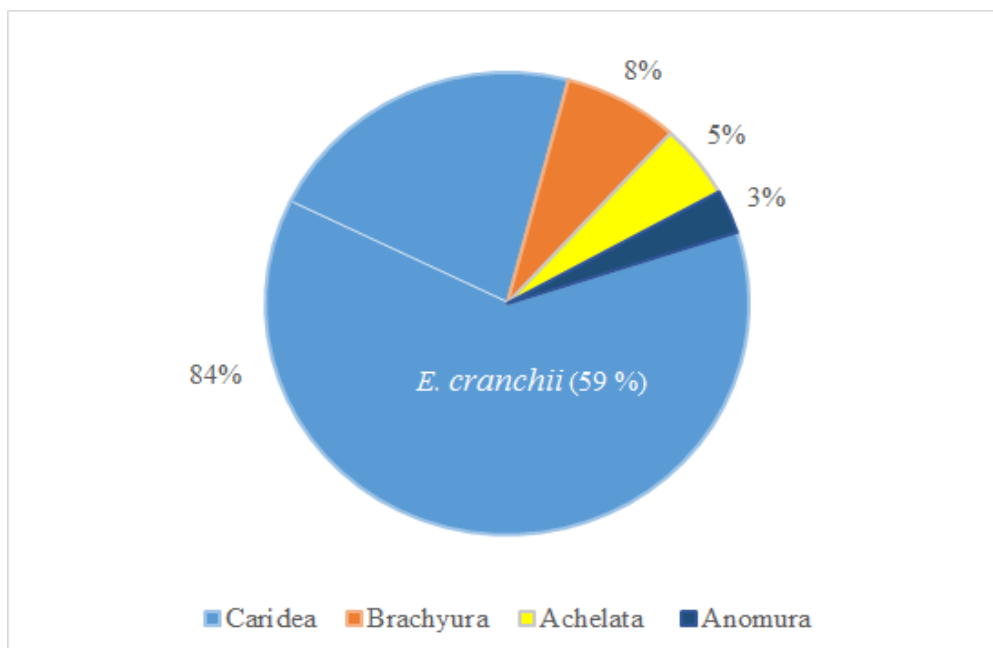


Figure 3. Percentage of the collected individuals regarding their infraorder. (*E. cranchii* belongs to the infraorder Caridea, being representing 59 % of 84 % of Caridea).

The Three-Way ANOVA showed that all main factors were significant. The abundance of *E. cranchii* was significantly greater in July, relative to April and September ($p < 0.0001$, Table 1). Figure 4 shows a significantly greater abundance in the month of July, with a total of 1204 individuals, followed by the month of September, where 232 individuals were collected and finally, the month of April with a total of 129 individuals. The mean number of specimens in each month is indicated by red dots in the figure: April (mean=16.125), July (mean=150.5) and September (mean=29).

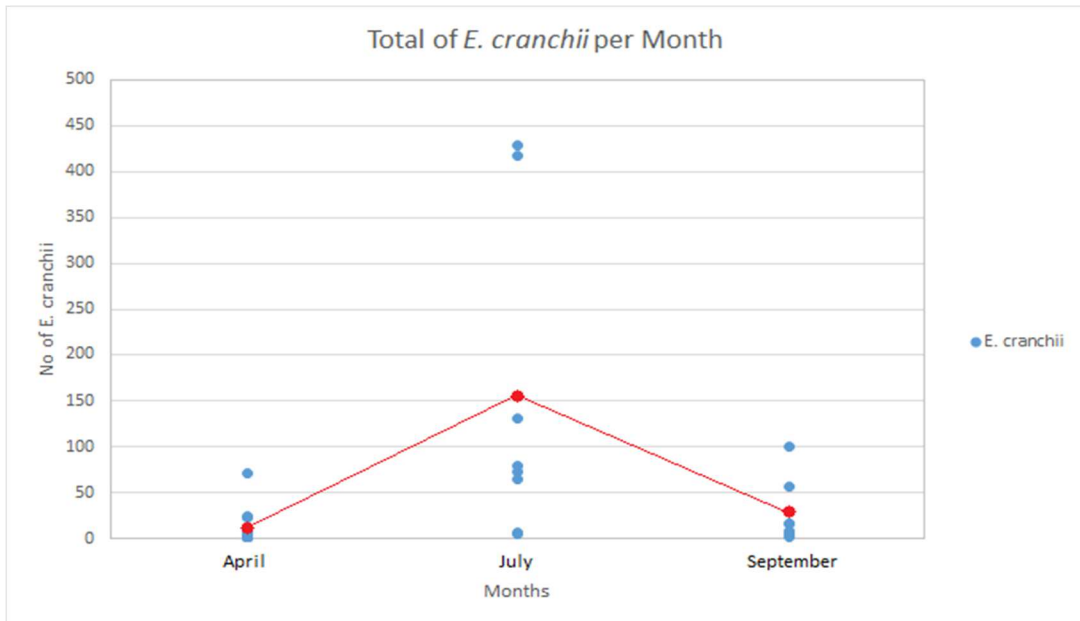


Figure 4. Total abundance of *E. cranchii* collected in the fully- and partially- protected areas, per each month.

Secondly, *E. cranchii* had a significantly higher abundance in the FPA relative to the PPA ($p = 0.0004$, Table 1). Figure 5 shows the abundance of *E. cranchii* in the FPA (n=1204) compared to the PPA (n=361).

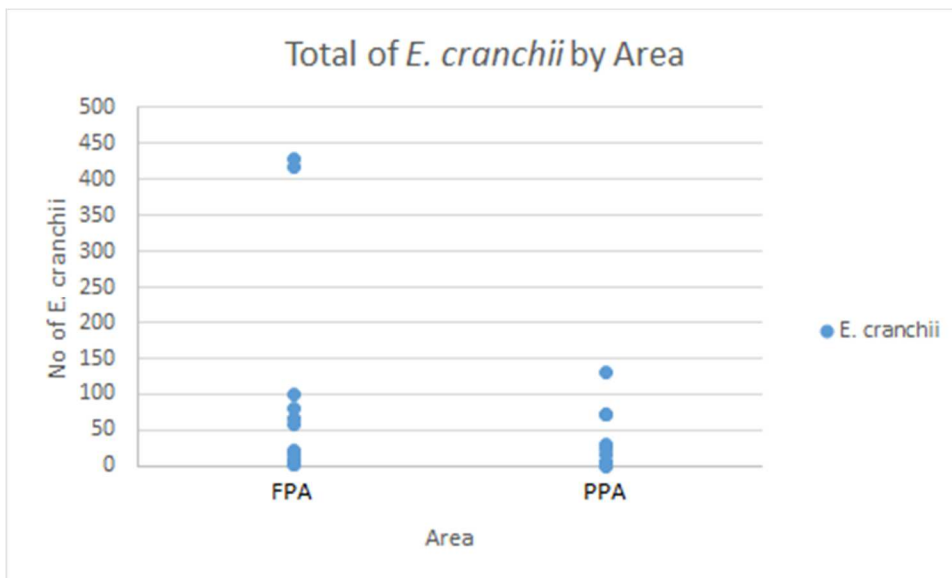


Figure 5. Total abundance of *E. cranchii* collected in the fully (FPA) - and – partially (PPA) protected areas, among all months.

Regarding depth, *E. cranchii* showed a significantly greater abundance at the bottom, with a total of 1375 individuals, while at the surface only 190 individuals were collected (Fig. 6) ($p < 0.0001$, Table 1).

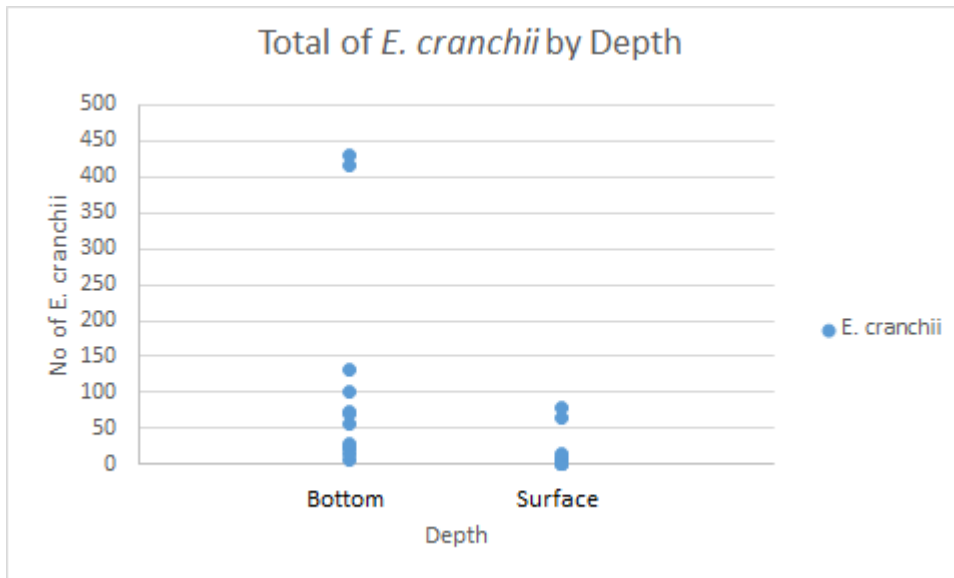


Figure 6. Total abundance of *E. cranchii* collected at the surface and bottom, among all months.

The interaction of time and protection level was also significant ($p = 0.002$, Table 1). The FPA was characterized by a higher abundance of *E. cranchii* in the months of July (n=990) and September (n=181), while in April the PPA was the one who presented more individuals (n=96; Fig. 7). The lowest number of individuals was found in the FPA in April (n=33; Fig. 7). When relating the abundance of *E. cranchii* in each area to the month of sampling, April showed to have a significantly lower abundance in the FPA (n=33) than in the PPA (n=96), followed by July with the greatest abundance in the FPA (n=990) and PPA (n=214) and finally September with the greater abundance in the FPA (n=181) than in the PPA (n=51) (Fig. 7).

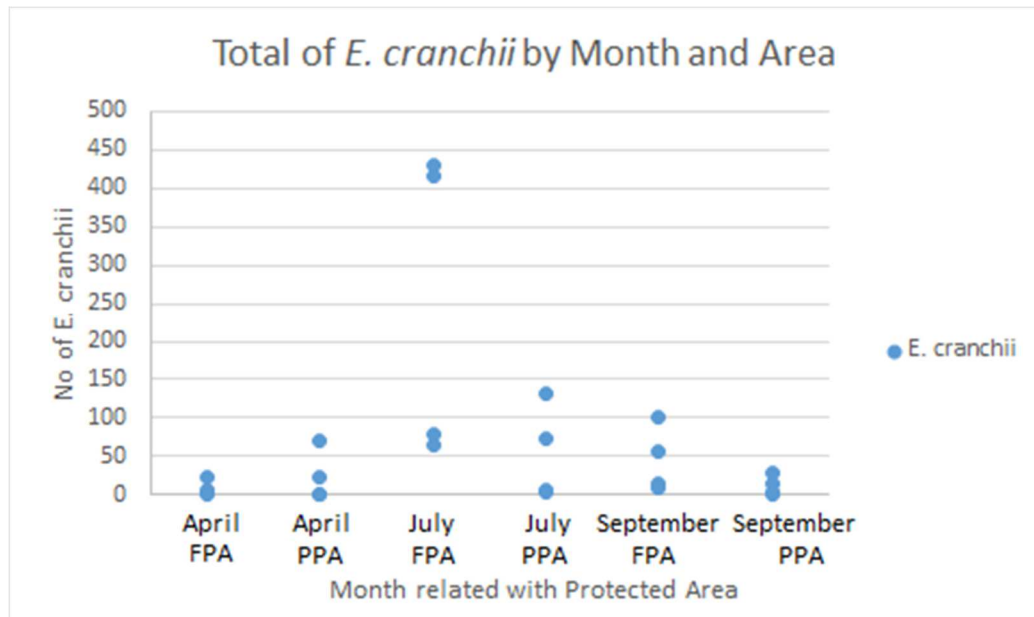


Figure 7. Total abundance of *E. cranchii* collected per each month, related with each fully- and partially- protected area. FPA (Fully Protected Area), PPA (Partially Protected Area).

The comparison between the protected areas relative to different depths showed that both areas were characterized by a significantly greater abundance of *E. cranchii* at the bottom. However, the FPA that had more individuals at this depth (n=1032) than in the PPA (n=343) (Fig. 8). The Three-Way ANOVA test revealed that there were no significant differences within the effect of the interaction between area and depth on the abundance of *E. cranchii* ($p = 0.0368$, Table 1).

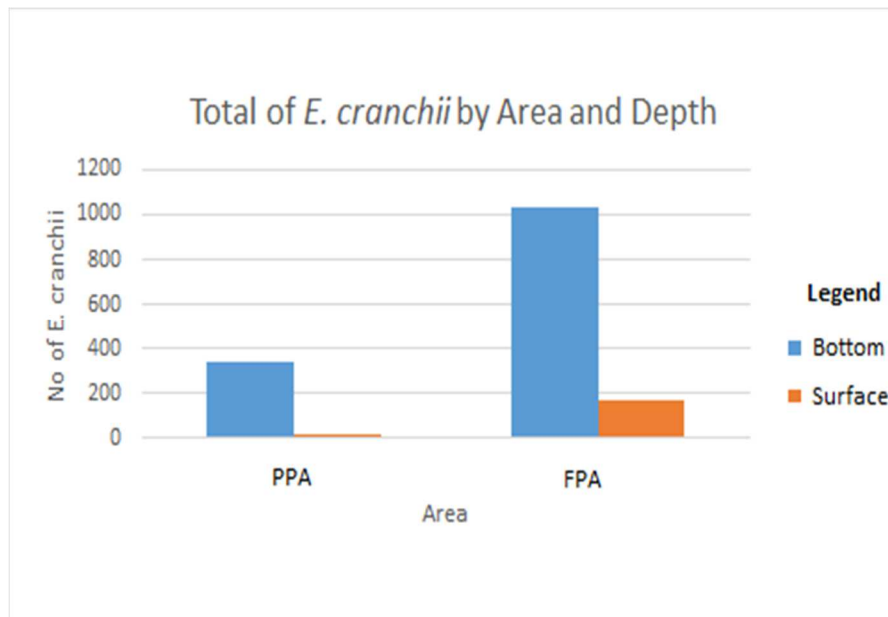


Figure 8. Total abundance of *E. cranchii* collected in the fully- and partially- protected areas, related with the two different depths (bottom and surface). FPA (Fully Protected Area), PPA

The effect of the interactions between months and depth in the abundance of *E. cranchii* were not significant different ($p = 0.4538$, Table 1) and the same occurred with the interaction between month, area and depth ($p = 0.2369$, Table 1).

Table 1. Effects of Months, Area and Depth on the abundance of *E. cranchii*. Values were compared by a Three-Way ANOVA test.

	<i>Eualus cranchii</i> abundance		
	df	F	P-value
Months	2	42.76	<0.0001
Area	1	24.02	0.0004
Months*Area	2	10.02	0.0028
Depth	1	118.21	<0.0001
Months*Depth	2	0.84	0.4538
Area*Depth	1	5.51	0.0368
Months*Area*Depth	2	1.63	0.2369

4. Discussion

An important objective in marine ecology studies is the understanding of the population dynamics of organisms with complex life cycles such as decapods. This study represents the first known attempt to describe the distribution of a decapod crustacean, *Eualus cranchii*, in a Marine Protected Area, the Arrábida Marine Park. Since no study has been conducted on recruitment processes of this species, available studies, of well-studied crustacean species from other marine regions, were reviewed and comparisons were made about possible similarities or patterns in the effects of protection for this group of crustaceans.

The highest larval abundance in this study was recorded in July, represented by 77 % of the total individuals sampled, followed by September and the lowest abundance was found in April. The results of this study showed significant differences in *E. cranchii* abundance throughout the three months sampled. Although, in São Torpes bay (Paula 1987), Gulf of Marseille (Bourdillon-Casanova & d'Endoume 1960) and the Adriatic Sea (Kurian 1956), *E. cranchii* larvae are present throughout all the year. A study by dos Santos (1999) observed the presence of the larvae (nine zoeal stages and one decapodid) practically all-year, with higher peaks of abundance in March/April and June/July in the Portuguese coast. We can assume that *E. cranchii* juveniles collected in July may be the recruits of the larvae hatched in April that already completed their larval development, considering the long larval series in this species. Among carideans the larvae hatch as a shrimp-like zoea form that passes through a variable number of stages, nine in the particular case of *E. cranchii*, and gradually acquire the characteristics of the decapodid phase. The same happens with the transition from the decapodid to the juvenile.

It is important to consider the temporal disparity between the start of the larval production and subsequent settlement and recruitment in decapod species, as observed in the crab *Carcinus maenas* (e.g. Marta-Almeida *et al.* 2006). The results of this study may have been inconsistent due to the possible inadequacy of the SMURFs to estimate abundance (Amaral & Paula 2007). Although the collectors did not show a great species diversity, collector testing is only practical at times of high settlement intensity, since at other times results may be unreliable due to high variability in catch numbers (Phillips *et al.* 2001) have proven that artificial settlement substrates can strongly interfere with the natural substrate (Paula *et al.* 2006). Despite all limitations, we assume that possible bias will

only affect the estimation of absolute abundance and we consider that differences in abundance obtained with the same collectors represent real variations with respect to the tested factors. In other words, the trends are considered valid and independent of SMURFs introduced bias.

Since there are no before-after control impact (BACI) data about this species for the Arrábida Marine Park, it is interesting to compare the abundance of this species within both fully- and partially- protected areas, in order to investigate the possible effects of the different protection regimes on the abundance of *E. cranchii*. Halpern (2013) showed that, on average, the abundance of invertebrates in a FPA was nearly the triple when compared to the values in the unprotected areas. However, it is important to remember that these values vary considerably and cannot be used to predict how a specific marine reserve will affect particular organisms and communities. A further study within an MPA, in the southern UK, revealed that the abundance of the European lobster within the FPA increased by 127% showing levels five times higher than near and far control areas. This fact is relevant, since higher larval abundance increases recruitment and consequently the adult stock (Moland *et al.* 2013).

Although in both cases the FPA had significant positive effects on decapods, these results cannot be generalized and used to predict possible outcomes in other reserves as additional factors such as habitat type, larval ecology and size and age of the MPA may affect the success of FPAs (Claudet *et al.* 2008). On the contrary, a review by Planes *et al.* (2000) about the Mediterranean littoral fish and several lobster species from other marine regions, concluded that recruitment success inside MPAs is likely to be negatively affected by the MPA status because predators are more abundant and will reduce the survival of recruits. It is concluded that whether recruitment in MPAs would be favored or not will depend on: self-recruitment of the protected population, level of increase of larval supply within the MPA, and extent of nursery habitats inside the MPA.

Regarding the two depth levels considered, 88 % of the total *E. cranchii* species settled at the bottom. These results may be a consequence of the ecology of *E. cranchii*, a benthonic species usually living under rocks, in holes and between seagrass beds (D'Udekem d'Acoz 1999). The findings can also be related with the daily vertical migrations performed by the larvae. Several studies revealed that decapod larvae tend to perform diel vertical migrations, ascending to the surface after sunset and returning to the bottom at sunrise (e.g. Dos Santos *et al.* 2008). In this study sampling was always done

during the day, thus the obtained results are in accordance with the referred migration pattern. Diel vertical migrations present several advantages such as predation avoidance, better feeding conditions and reduction of physiologic stress (Thorp & Covich 2009) and keep larvae in water column zones which maximize their survival, dispersion and colonization to new habitats (Cronin & Forward 1986). Furthermore, the settling decapodid will have access to benthic food sources and custom habits, and thus, does not depend on the plankton alone (Anger 2001).

The effect of the interaction between time and depth on the abundance of *E. cranchii* was not significant, and the same applies for the interaction between protection level and depth and the interaction between time, protection level and depth. This suggests time changes showed the same trend with depth, and that higher abundances were consistently found on the bottom for both protection levels.

Recruitment is influenced by larval flow and several factors come into action. Currents may influence, either directly or indirectly, the development and survival of larvae and recruits (e.g. Anger 2001; Katsaros & Buettner 1969; Bello 1997). As emphasized by Stockhausen (2000) for the Caribbean spiny lobster, even the simplest current regimes can create a spatially structured environment where sites become differentially connected through larval movements and flows. Some locations may receive more larvae than others and certain sites may be more important to population persistence than others. Since currents can create a spatially structured world, even in the absence of variation in habitat quality, different locations may have different value with respect to both conservation and resource management (Gaines *et al.* 2003).

In this study the environmental factors were not taken into account. Nevertheless, the study areas were quite close and the samples were obtained at similar depths and distances from the coast and no major differences in circulation patterns or current intensity were expected, at least to the extent of significantly affecting the comparison of abundances with respect to the tested factors. Santinho (2009) revealed that the abundance of *E. cranchii* larvae in Cascais Bay did not show any correlation with environmental conditions such as temperature, salinity, light intensity and dissolved O₂.

As previously mentioned, sampling was undertaken prior to this study as part of a larger campaign, with the purpose of collecting fish-larvae recruits with SMURFs (Standard Monitoring Units for Recruitment of Fish), artificial settlement substrates that were

created to monitor recruitment of temperate coastal rocky fish along the Californian shoreline (Ammann 2004). This method proved to be efficient when sampling rockfish recruits settling to kelp forests. However, the efficiency of SMURFs has never been tested for decapod crustacean species. The results of this study suggest that SMURFs are appropriate for sampling adults and juveniles of small crustaceans, but their adequacy to sample recruits was not proven. The absence of recruits could also be the result of low sample resolution in terms of the space covered and the results from this study suggest that it may be an inappropriate method for this purpose, since the samples did not show a great species diversity. Additionally, SMURFs did not collect recruits, but juveniles and adults instead. Although other sampling strategies were not evaluated in this work, and no control methodology was used, it is hypothesized that the sampled habitats were suitable for juveniles and adults, though this overlap of habitat may have been due to low sampling resolution at the small spatial scale (Pallas *et al.* 2006).

A potential reason for the occurrence of decapod crustacean species in the artificial structures is possibly linked to the search for refuge and to their carnivorous and/or detritivorous feeding behavior (Gaudêncio & Cabral 2007). Some of these species show relatively little active swimming behavior, which means they may search for shelter in cobbles and crevices near the artificial structure (Pallas *et al.* 2006). Some species recorded in the artificial structure were carnivores (Gaudêncio & Cabral 2007) or scavengers (Dolbeth *et al.* 2006) which possibly migrated from the surrounding area, being attracted by higher food availability. All these observations agree with the fact that any artificial structure produces a discontinuity of species abundance by providing a hard substrate that alters the initial state, thus creating the conditions for the establishment of new ecosystems (Terlizzi *et al.* 2008; Manoukian *et al.* 2010).

One potential problem of the use of passive collectors to catch crustaceans is that larval densities on artificial settlement substrates (ASS) may not reflect real settlement densities since larvae that are not competent to settle can cling to the collectors. If many larvae adhere to the ASS only temporarily, estimates of larval abundance can also be biased since the rate of emigration may vary in time and space as a result of light conditions, tidal phase, or prevailing larval density on the collector. The possibility that the ASS may simulate a transitional substrate for post-larvae has rarely been reflected in other studies (Goodrich *et al.* 1989; Olmi III *et al.* 1990) and has never been investigated. Similarly,

the potential problem of predation on collectors had little discussion and, as far as it is known, was never assessed.

Furthermore, the SMURFs were submerged for 14 days which may be too long to obtain information on recruitment. High losses of shore crabs were found in ASS that were immersed longer than 12 h and the losses increased with increasing immersion time in Gullmarsfjord (Western Sweden). These results suggest that the association of larvae to the ASS may be completely temporary and after a delay of less than 24h all shrimps may have left the ASS. Thus, ASSs used for periods longer than 12 h do not yield a useful integrated estimate of shrimp larval supply (Moksnes & Wennhage 2001).

Overall, coastal zones around the world represent a habitat for many benthic marine species with a dispersive larval phase. The study of their populations is particularly difficult because of generally poor information regarding basic aspects of distribution, abundance and fate of their larvae. A better understanding of factors affecting the demography of these organisms is not just of scientific relevance, but is also important when considering that many of these species are either important commercially or serve as prey for species with a commercial value (Tuck & Possingham 2000).

Improved sampling methods, with a better coverage in space and time and the introduction of control sites, is crucial to enhance the knowledge of *E. cranchii*'s abundance and distribution in Arrábida MPA, in order to better evaluate the impact of FPAs on this species.

Future research

Given the present data limitations, further experimentation with a more intense sampling effort is necessary in order to build a solid database to understand the abundance pattern of *E. cranchii* and the importance of MPA. Such studies should also provide information on other species of commercial interest known to occur in the region, such as the spiny lobster, *Palinurus elephas*.

The usefulness of artificial structures to study recruitment needs a better evaluation, since the imitation of natural settlement conditions may require adaptations to different environmental conditions. Moreover, detailed knowledge about the recruitment of this taxon is extremely important for assessing the effectiveness of man-made ASSs in

enhancing recruitment and serving as a tool for conservation and promotion of biodiversity.

Due to time restrictions only a subset of the available samples was analyzed and therefore future studies should focus on analyzing the remaining samples. Other important areas of research are the understanding of the mechanisms of larval transport (biotic and abiotic factors), attempting to link larval supply, settlement and juvenile recruitment, as well as to understand habitat connectivity, oceanographic characteristics, species life histories, environmental requirements and mobility patterns.

Conclusion

This study aimed to describe the distribution and abundance of *E. cranchii* within the protection effects of Arrábida MPA. The presence of high numbers of juveniles and adults of this species widened the focus of the research to include the juvenile and adult phases. The following could be concluded:

- The highest abundance of *E. cranchii* was found within the FPA, possibly due to the restrictions on anthropogenic activities, indicating that these areas may be useful for enhancement of reproduction and recruitment.
- 88 % of the total *E. cranchii* individuals settled at the bottom which may be related to the fact that this is a benthonic species. Vertical migrations could influence this result as well, since all samples were collected during the day and decapod larvae tend to descend to the seabed at sunrise.
- The highest peak of *E. cranchii* abundance was recorded in July, and it can be assumed that *E. cranchii* juveniles collected in July may be the recruits of the larvae hatched in April that completed their larval development.

The usefulness of SMURFs to quantify the recruitment of decapod crustacean, by measuring the abundance of larvae or post-larvae that settle on the bottom needs further evaluation.

References

- Abelló, P. & Guerao, G., 1999. Temporal variability in the vertical and mesoscale spatial distribution of crab megalopae (Crustacea: Decapoda) in the Northwestern Mediterranean. *Estuarine, Coastal and Shelf Science*, 49: 129–139.
- Amaral, V. & Paula, J., 2007. *Carcinus maenas* (Crustacea: Brachyura): influence of artificial substrate type and patchiness on estimation of megalopae settlement. *Journal of Experimental Marine Biology and Ecology*, 346: 21–27.
- Ammann, A.J., 2004. SMURFs: standard monitoring units for the recruitment of temperate reef fishes. *Journal of Experimental Marine Biology and Ecology*, 299: 135–154.
- Anger, K., 2006. Contributions of larval biology to crustacean research: a review. *Invertebrate Reproduction & Development*, 49: 175–205.
- Anger, K., 2001. *The biology of decapod crustacean larvae*, Crustacean Issues 14, A. A. Balkema Publishers, 419p.
- Marisa I. Batista, M.I, Baeta, F., Costa, M.J. & Cabral, H., 2011. MPA as management tools for small-scale fisheries: The case study of Arrábida Marine Protected Area (Portugal). *Ocean and Coastal Management*, 54: 137–147.
- Bello, M.J., 1997. Species composition and recruitment seasonality of penaeoid shrimps at Bear Cut, Biscayne bay, Florida. Master of Arts Thesis in Marine Affairs and Policy, University of Miami, 62p
- Berkes, F., Colding, J. & Folke, C., 2000. Rediscovery of Traditional Ecological Knowledge as Adaptive Management. *Ecological Applications*, 10: 1251–1262.
- Botsford, L.W., Moloney, C.L., Hastings, A., Largier, J.L., Powell, T.M., Higgins, K. & Quinn, J.F., 1994. The influence of spatially and temporally varying oceanographic conditions on meroplanktonic metapopulations. *Deep Sea Research Part II: Topical Studies in Oceanography*, 41: 107–145.
- Botsford, L.W., Castilla, J.C. & Peterson, C.H., 1997. The management of fisheries and marine ecosystems. *Science*, 277: 509–515.
- Bourdillon-Casanova, L., 1960. *Le méroplancton du Golfe de Marseille: les larves de Crustacés Décapodes*, Recueil des Travaux de la Station Marine d'Endoume, 30, 286p.
- Brandao, M.C., Koettker, A.G. & Freire, A.S., 2013. Abundance and composition of decapod larvae at Saint Paul's Rocks (equatorial Atlantic). *Marine Ecology*, 34: 171–185.

- Browman, H.I. & Stergiou, K.I., 2004. Marine Protected Areas as a central element of ecosystem-based management: defining their location, size and number. *Marine Ecology Progress Series*, 274: 271–272.
- Caddy, J.F., 1986. Modelling stock-recruitment processes in Crustacea: some practical and theoretical perspectives. *Canadian Journal of Fisheries and Aquatic Sciences*, 43: 2330–2344.
- Calado, R. & Narciso, L., 2002. *Camarões e lagostas da costa continental portuguesa*. Câmara Municipal de Cascais, 222p.
- Carneiro, G., 2011. The Luiz Saldanha Marine Park: An overview of conflicting perceptions. *Conservation and Society*, 9: 325–333.
- Charles, A. & Wilson, L., 2008. Human dimensions of Marine Protected Areas. *ICES Journal of Marine Science*, 66: 6–15.
- Christie, P. & White, A.T., 1997. Trends in development of coastal area management in tropical countries: From central to community orientation. *Coastal Management*, 25: 155–181.
- Claudet, J., Osenberg, C. W., Domenici, P., Badalamenti, F., Milazzo, M., Falcón, J. M., Bertocci, I., Benedetti-Cecchi, L., García-Charton, J-A., Goñi, R., Borg, J. A., Forcada, A., de Lucia, G. A., Pérez-Ruzafa, Á., Afonso, P., Brito, A., Guala, I., Le Diréach, L., Sanchez-Jerez, P., Somerfield, P. J. & Planes, S., 2010. Marine reserves: Fish life history and ecological traits matter. *Ecological Applications*, 20: 830–839.
- Claudet, J., Osenberg, C.W., Benedetti-Cecchi, L., Domenici, P., García-Charton, J.A., Pérez-Ruzafa, A., Badalamenti, F., Bayle-Sempere, J., Brito, A., Bulleri, F., Culioli, J.M., Dimech, M., Falcón, J.M., Guala, I., Milazzo, M., Sánchez-Meca, J., Somerfield, P.J., Stobart, B., Vandeperre, F., Valle, C. & Planes, S., 2008. Marine reserves: size and age do matter. *Ecology Letters*, 11: 481–489.
- Costa, B.H.E., Erzini, K., Caselle, J.E., Folhas, H. & Gonçalves¹, E.J., 2013. 'Reserve effect' within a temperate marine protected area in the north-eastern Atlantic (Arrábida Marine Park, Portugal). *Marine Ecology Progress Series*, 481: 11–24.
- Costanza, R., Andrade, F., Antunes, P., van den Belt, M., Boesch, D.F., Catarino, F., Hanna, S., Limburg, K., Low, B., Pereira, J.G., Rayner, S., Santos, R., Wilson, J., & Young, M., 1998. Principles for Sustainable Governance of the Oceans. *Science*, 281: 198–199.
- Crisp, D.J., 1974. Factors influencing the settlement of marine invertebrate larvae. *Chemoreception in marine organisms*, pp.177–265.
- Cronin, T.W. & Forward, R.B., 1986. Vertical migration cycles of crab larvae and their role in larval dispersal. *Bulletin of Marine Science*, 39: 192–201.
- d'Udekem d'Acoz, C., 1999. Inventaire et distribution des crustacés décapodes de l'Atlantique nord-oriental, de la Méditerranée et des eaux continentales adjacentes

au nord de 25 N. *Collection Patrimoines Naturels 40*. Muséum National d'Histoire Naturelle, Paris, 383 p.

- Dolbeth, M., Viegas, I., Martinho, F., Marques, J. C., & Pardal, M. A., 2006. Population structure and species dynamics of *Spisula solida*, *Diogenes pugilator* and *Branchiostoma lanceolatum* along a temporal–spatial gradient in the south coast of Portugal. *Estuarine, Coastal and Shelf Science*, 66: 168–176.
- Domingues, C.P. Creer, S., Taylor, M.I., Queiroga, H. & Carvalho, G.R., 2010. Genetic structure of *Carcinus maenas* within its native range: larval dispersal and oceanographic variability. *Marine Ecology Progress Series*, 410: 111–123.
- Emmerson, W.D., 1984. Predation and energetics of *Penaeus indicus* (Decapoda: Penaeidae) larvae feeding on *Brachionus plicatilis* and *Artemia* nauplii. *Aquaculture*, 38: 201–209.
- Field, J.C., Punt, A.E., Methot, R.D. & Thomson, C.J., 2006. Does MPA mean 'Major Problem for Assessments'? Considering the consequences of place-based management systems. *Fish and Fisheries*, 7: 284–302.
- Fraschetti, S., Claudet, J. & Grouard-Colvert, K., 2011. Management - transitioning from single-sector management to ecosystem-based management: what can marine protected areas offer. In Claudet, J. (Ed.) *Marine protected areas: a multidisciplinary approach*, pp.11–34. Cambridge University Press.
- Gaines, S.D., Gaylord, B. & Largier, J.L., 2003. Avoiding current oversights in marine reserve design. *Ecological Applications*, 13: 32–46.
- Gaudêncio, M.J. & Cabral, H.N., 2007. Trophic structure of macrobenthos in the Tagus estuary and adjacent coastal shelf. *Hydrobiologia*, 587: 241–251.
- Gerber, L.R., Botsford, L.W., Hastings, A., Possingham, H.P., Gaines, S.D., Stephen R. Palumbi, S.R. & Andelman, S., 2003. Population Models for Marine Reserve Design: a Retrospective and Prospective Synthesis. *Ecological Applications*, 13: 47–64.
- Giménez, L. & Dick, S., 2007. Settlement of shore crab *Carcinus maenas* on a mesotidal open habitat as a function of transport mechanisms. *Marine Ecology Progress Series*, 338: 159–168.
- Gonçalves, E.J., Henriques, M. & Almada, V.C., 2002. Use of a Temperate Reef-Fish Community To Identify Priorities in the Establishment of a Marine Protected Area. In Beumer, J., Grant, A. and Smith, D. (eds), *Aquatic Protected Areas: What Works Best And How Do We Know?* pp.261–272. Proceedings of the World Congress on Aquatic Protected Areas, (Cairns, Australia, August 2002), Australian Society for Fish Biology.
- Gonçalves, E.J., Henriques, M. & Almada, V.C., 2002. Use of temperate reef fish community to identify priorities in the establishment of a marine protected area. In Beumer, J. P., Grant, A. & Smith, D. C. (Eds). *Aquatic protected areas: What works*

- best and how do we know? Proceedings of the world congress on aquatic protected areas (pp. 261-272). Cairns, Australia.
- Goñi, R. *et al.*, 2008. Spillover from six western Mediterranean marine protected areas: Evidence from artisanal fisheries. *Marine Ecology Progress Series*, 366: 159–174.
- Goodrich, D.M., van Montfrans, J. & Orth, R.J., 1989. Blue crab megalopal influx to Chesapeake Bay: evidence for a wind-driven mechanism. *Estuarine, Coastal and Shelf Science*, 29: 247–260.
- Hadfield, M.G., Carpizo-Ituarte, E.J., del Carmen, K. & Nedved, B.T., 2001. Metamorphic competence, a major adaptive convergence in marine invertebrate larvae. *American Zoologist*, 41: 1123–1131.
- Halpern, B.S., Walbridge, S., Selkoe, K.A., Kappel, C.V., Micheli, F., D'Agrosa, C., Bruno, J.F., Casey, K.S., Ebert, C., Fox, H.E., Fujita, R., Heinemann, D., Lenihan, H.S., Madin, H.M.P., Perry, M.T., Selig, E.R., Steneck, R. & Watson, R., 2008. A global map of human impact on marine ecosystems. *Science*, 319: 948–952.
- Halpern, B.S., 2003. The Impact of Marine Reserves : Do Reserves Work and Does Reserve Size Matter ? *Ecological Applications* 13: 117-137.
- Harley, C.D., Randall Hughes, A., Hultgren, K.M., Miner, B.G., Sorte, C.J., Thornber, C.S., Rodriguez, L.F., Tomanek, L. & Williams, S.L., 2006. The impacts of climate change in coastal marine systems. *Ecology Letters*, 9: 228–241.
- Horta e Costa B., Batista, M.I., Gonçalves, L., Erzini, K. & Caselle, J.E., 2013. Fishers' Behaviour in Response to the Implementation of a Marine Protected Area. *PLoS ONE* 8(6): e65057. doi:10.1371/journal.pone.0065057.
- Ingle, R.W. & Clark, P.F., 2008. First reported occurrences of the marbled crab, *Pachygrapsus marmoratus* (Crustacea: Brachyura: Grapsoidea) in southern coastal waters of the British Isles. *Marine Biodiversity Records*, 1, 26.
- Jackson, G.A. & Strathmann, R.R., 1981. Larval mortality from offshore mixing as a link between precompetent and competent periods of development. *American Naturalist*, 118: 16–26.
- Jackson, J.B.C., 2008. Colloquium paper: ecological extinction and evolution in the brave new ocean. *Proceedings of the National Academy of Sciences of the United States of America*, 105: 11458–11465.
- Jennings, S. & Polunin, N.V.C., 1996. Effects of Fishing Effort and Catch Rate Upon the Structure and Biomass of Fijian Reef Fish Communities. *Journal of Applied Ecology*, 33: 400–412.
- Johnson, W.S. & Allen, D.M., 2012. *Zooplankton of the Atlantic and Gulf coasts: a guide to their identification and ecology*. Johns Hopkins University Press, 472p.

- Katsaros, K. & Buettner, K.J.K., 1969. Influence of rainfall on temperature and salinity of the ocean surface. *Journal of Applied Meteorology*, 8: 15–18.
- Koehl, M.A.R. & Hadfield, M.G., 2010. Hydrodynamics of larval settlement from a larva's point of view. *Integrative and Comparative Biology*, 50: 539–551.
- Kurian, C. V., 1956. *Larvae of decapod Crustacea from the Adriatic Sea*, Acta Adriatica Volume 6, Split. Institut za oceanografiju i ribarstvo, 109p.
- Lagardère, J.-P., 1975. Recherches sur l'alimentation des crevettes bathypelagiques du talus continental du Golfe de Gascogne. *Revue des Travaux de l'Institut des Pêches Maritimes*, 39: 213–229.
- Lagardère, J.-P., 1971. Les Crevettes des Côtes du Maroc. *Travaux de l'Institut Scientifique Chérifien et de la Faculté des Sciences, sér. Zool.*, 36, 6-140.
- Landeira, J.M., Lozano-Soldevilla, F. & Hernández-León, S., 2013. Temporal and alongshore distribution of decapod larvae in the oceanic island of Gran Canaria (NW Africa). *Journal of Plankton Research*, 35; 309-322.
- Lester, S.E. *et al.*, 2009. Biological effects within no-take marine reserves: A global synthesis. *Marine Ecology Progress Series*, 384: 33–46.
- Lester, S.E. & Halpern, B.S., 2008. Biological responses in marine no-take reserves versus partially protected areas. *Marine Ecology Progress Series*, 367: 49-56.
- Limousin, M.Z., 1995. Efectos biológicos de la creación de una reserva marina: el caso de las islas Medes. In Guirado Romero, J.S. (coord.) *La gestión de los espacios marinos en el Mediterráneo Occidental: actas de la VII Aula de Ecología: Almería, 9-20 de diciembre, 1992*, pp. 55–103. Instituto de Estudios Almerienses.
- Lubchenco, J., Palumbi, S.R., Gaines, S.D. & Andelman, S., 2003. Plugging a Hole in the Ocean: The Emerging Science of Marine Reserves. *Ecological Applications*, 13: 3-7.
- Manoukian, S., Spagnolo, A., Scarcella, G., Punzo, E., Angelini, R. & Fabi, G., 2010. Effects of two offshore gas platforms on soft-bottom benthic communities (northwestern Adriatic Sea, Italy). *Marine Environmental Research*, 70: 402–410.
- Marta-Almeida, M., Dubert, J., Peliz, A. & Queiroga, H., 2006. Influence of vertical migration pattern on retention of crab larvae in a seasonal upwelling system. *Marine Ecology Progress Series*, 307: 1-19.
- Martin, J.W. & Davis, G.E., 2001. An updated classification of the recent Crustacea. Science Series 39, Natural History Museum of Los Angeles County, 124p.
- McConaughy, J.R., 1992. Decapod larvae: dispersal, mortality, and ecology. A working hypothesis. *American Zoologist*, 32: 512–523.

- Micheli, F. *et al.*, 2001. Human alteration of food webs. In M.E. Soulé and G. Orians Conservation *biology research priorities for the next decade*, pp.31–57. Island Press, Washington.
- Micheli, F., Halpern, B.S., Botsford, J.W. & Warner, R.R., 2004. Trajectories and Correlates of Community Change in No-Take Marine Reserves. *Ecological Applications*, 14; 1709–1723.
- Miller, S.H. & Morgan, S.G., 2013. Interspecific differences in depth preference: regulation of larval transport in an upwelling system. *Marine Ecology. Progress Series*, 476: 301–306.
- Miron, G., Boudreau, B. & Bourget, E., 1995. Use of larval supply in benthic ecology: testing correlations between larval supply and larval settlement. *Marine Ecology Progress Series*, 124:301–305.
- Moksnes, P.O. & Wennhage, H., 2001. Methods for estimating decapod larval supply and settlement: Importance of larval behavior and development stage. *Marine Ecology Progress Series*, 209: 257–273.
- Moland, E., Olsen, E.M., Knutsen, H., Garrigou, P., Espeland, S.H., Kleiven, A.R., André, C. & Knutsen, J.A., 2013. Lobster and cod benefit from small-scale northern marine protected areas: inference from an empirical before–after control–impact study. *Proceedings of the Royal Society B*, 280: 20122679, 9p.
- Mora, C., Andréfouët, S., Costello, M.J., Kranenburg, C., Rollo, A., Veron, J., Gaston, K.J. and Myers, R.A., 2006. Ecology. Coral reefs and the global network of Marine Protected Areas. *Science* 312: 1750–1751.
- Moreira, F.T., Harari, J. & Flores, A.A. V, 2007. Neustonic distribution of decapod planktonic stages and competence of brachyuran megalopae in coastal waters. *Marine and Freshwater Research*, 58: 519–530.
- Mosquera, I., Côté, I.M., Jennings, S. & Reynolds, J.D., 2000. Conservation benefits of marine reserves for fish populations. *Animal Conservation*, 3: 321–332.
- Murawski, S.A., 2007. Ten myths concerning ecosystem approaches to marine resource management. *Marine Policy*, 31: 681–690.
- Myers, R.A. & Worm, B., 2003. Rapid worldwide depletion of predatory fish communities. *Nature*, 423: 280–283.
- Neves, A.M., 1990. On a small collection of Crustacea Decapoda from Sagres (Algarve), *Arquivos do Museu Bocage, Nova Série, I*, 45; 661–695.
- Olmi III, E.J., van Montfrans, J., Lipcius, R.N., Orth, R.J. & Sadler, P.W. 1990. Variation in planktonic availability and settlement of blue crab megalopae in the York River, Virginia. *Bulletin of Marine Science*, 46: 230–243.

- Pallas, A., García-Calvo, B., Corgos, A., Bernárdez, C. & Freire, J., 2006. Distribution and habitat use patterns of benthic decapod crustaceans in shallow waters: A comparative approach. *Marine Ecology Progress Series*, 324: 173–184.
- Pandolfi, J.M., Bradbury, R.H., Sala, E., Hughes, T.P., Bjorndal, K.A., Cooke, R.G., McArdle, D., McClenachan, L., Newman, M.J.H. Paredes, G., Warner, R.R. & Jackson, J.B.C., 2003. Global Trajectories of the Long-Term Decline of Coral Reef Ecosystems. *Science* , 301: 955–958.
- Paula, J., 1987. Seasonal distribution of Crustacea Decapoda larvae in S. Torpes bay, South-western Portugal. *Investigacion Pesquera*, 51: 267–275.
- Paula, J., Silva, I.C., Francisco, S.M. & Flores, A.A.V, 2006. The use of artificial benthic collectors for assessment of spatial patterns of settlement of megalopae of *Carcinus maenas* (L.) (Brachyura: Portunidae) in the lower Mira Estuary, Portugal. *Hydrobiologia*, 557: 69–77.
- Pauly, D., Christensen, V., Dalsgaard, J., Froese, R. & Torres Jr., F., 1998. Fishing down marine food webs. *Science*, 279: 860–863.
- Pelca, R.A., Warner, R.R., Gaines, S.D. & Paris, C.B., 2010. Detecting larval export from marine reserves. *Proceedings of the National Academy of Sciences*, 107: 18266–18271.
- Pelletier, D., Claudet, J., Ferraris, J., Benedetti-Cecchi, L. & García-Charton, J.A., 2008. Models and indicators for assessing conservation and fisheries-related effects of marine protected areas. *Canadian Journal of Fisheries and Aquatic Sciences*, 65: 765–779.
- Phillips, B.F., Melville-Smith, R., Cheng, Y.W. & Rossbach, M.R, 2001. Testing collector designs for commercial harvesting of western rock lobster (*Panulirus cygnus*) puerulus. *Marine and Freshwater Research*, 52: 1465–1473.
- Planes, S., Galzin, R., Rubies, A.G., Goñi, ., Harmelin, J.-G., Le Diréach, L., Lenfant, P. & Quetglas, A., 2000. Effects of marine protected areas on recruitment processes with special reference to Mediterranean littoral ecosystems. *Environmental Conservation*, 27: 126–143.
- Pollnac, R.B. & Crawford, B.R., 2001. Discovering Factors that Influence the Success of Community-Based Marine Protected Areas in the Visayas, Philippines. Coastal Management Report 2229. PCAMRD Book Series No. 33. Philippine Council for Aquatic and Marine Research and Development. Los Banos, Laguna, Philippines, and University of Rhode Island, Coastal Resources Center. Narragansett, Rhode Island USA. 30p.
- Pomeroy, R.S., 1995. Community-based and co-management institutions for sustainable coastal fisheries management in Southeast Asia. *Ocean & Coastal Management*, 27: 143–162.

- Queiroga, H., Cruz, T., dos Santos, A., Dubert, J., González-Gordillo, J.I., Paula, J., Peliz, A. & Santos, A.M.P., 2007. Oceanographic and behavioural processes affecting invertebrate larval dispersal and supply in the western Iberia upwelling ecosystem. *Progress in Oceanography*, 74: 174–191.
- Turner, R. K., Subak, S. & Adger, W. N., 1996. Pressures, trends, and impacts in coastal zones: Interactions between socioeconomic and natural systems. *Environmental Management*, 20; 159-173.
- Roberts, C.M., Bohnsack, J.A., Gell, F., Hawkins, J.P. & Goodridge, R., 2001. Effects of marine reserves on adjacent fisheries. *Science*, 294: 1920–1923.
- Sandifer, P.A., 1975. The role of pelagic larvae in recruitment to populations of adult decapod crustaceans in the York River estuary and adjacent lower Chesapeake Bay, Virginia. *Estuarine and Coastal Marine Science*, 3: 269–279.
- Santinho, C.I.A., 2009. *Padrões de distribuição da abundância larvar de crustáceos decápodes na baía de cascais*. Thesis, Master of Science in Marine Biology, University of Algarve, 88p + annex.
- Dos Santos, A., Miguel P. Santos, M.P., Conway, D.V.P., Bartilotti, C., Lourenço, P. & Queiroga, H., 2008. Diel vertical migration of decapod larvae in the Portuguese coastal upwelling ecosystem: Implications for offshore transport. *Marine Ecology Progress Series*, 359: 171–183.
- Dos Santos, A. & González-Gordillo, J.I., 2004. Illustrated keys for the identification of the Pleocyemata (Crustacea: Decapoda) zoeal stages, from the coastal region of south-western Europe. *Journal of the Marine Biological Association of the UK*, 84: 205–227.
- Dos Santos, A.M. de M., 1999. *Larvas de crustáceos decápodes ao largo da costa portuguesa*. Thesis. Ph.D. in Biology. University of Algarve, 278p + annex.
- Schmidt, K.F., 1997. “No-Take” Zones Spark Fisheries Debate. *Science*, 277: 489-491.
- Scholz, A., Bonzon, K., Fujita, R., Benjamin, N., Woodling, N. & Black, P., 2004. Participatory socioeconomic analysis: drawing on fishermen’s knowledge for marine protected area planning in California. *Marine Policy*, 28; 335–349.
- Shanks, A.L., 1998. Abundance of post-larval *Callinectes sapidus*, *Penaeus* spp., *Uca* spp., and *Libinia* spp. collected at an outer coastal site and their cross-shelf transport. *Marine Ecology Progress Series*, 168: 57–69.
- Shanks, A.L., 1985. Behavioral basis of internal-wave-induced shoreward transport of megalopae of the crab *Pachygrapsus crassipes*. *Marine Ecology Progress Series*. 24: 289–295.
- Shanks, A.L., 1995. Mechanisms of cross-shelf dispersal of larval invertebrates and fish. In L. McEdward (ed.) *Ecology of Marine Invertebrate Larvae*, pp.323–367. CRC Press, Boca Raton, FL.

- Shanks, A.L., 1986. Vertical migration and cross-shelf dispersal of larval *Cancer* spp. and *Randallia ornata* (Crustacea: Brachyura) off the coast of southern California. *Marine Biology*, 92: 189–199.
- Shanks, A.L. & Brink, L., 2005. Upwelling, downwelling, and cross-shelf transport of bivalve larvae: test of a hypothesis. *Marine Ecology Progress Series*, 302: 1–12.
- Squires, H.J., 1990. *Decapod Crustacea of the Atlantic coast of Canada*, Canadian Bulletin of Fisheries and Aquatic Sciences, Dept. of Fisheries and Oceans, 532p.
- Stockhausen, W.T., Lipcius, R.N. & Hickey, B.M., 2000. Joint effects of larval dispersal, population regulation, marine reserve design, and exploitation on production and recruitment in the Caribbean spiny lobster. *Bulletin of Marine Science*, 66: 957–990.
- Terlizzi, A., Bevilacqua, S., Scuderi, D., Fiorentino, D., Guarneri, G., Giangrande, A., Licciano, M., Felling, S. & Fraschetti, S., 2008. Effects of offshore platforms on soft-bottom macro-benthic assemblages: a case study in a Mediterranean gas field. *Marine Pollution Bulletin*, 56: 1303–1309.
- Tetreault, I. & Ambrose, R.F., 2007. Temperate Marine Reserves Enhance Targeted but not Untargeted Fishes in Multiple No-Take Mpas. *Ecological Applications*, 17; 2251–2267.
- Thorp, J.H. & Covich, A.P. (eds), 2009. *Ecology and classification of North American Freshwater Invertebrates*, Academic Press, 911p.
- Torres, A.P., Dos Santos, A., Balbín, R., Alemany, F., Massutí, E. & Reglero, P., 2014. Decapod crustacean larval communities in the Balearic Sea (western Mediterranean): Seasonal composition, horizontal and vertical distribution patterns. *Journal of Marine Systems*, 138: 112–126.
- Tuck, G.N. & Possingham, H.P., 2000. Marine protected areas for spatially structured exploited stocks. *Marine Ecology Progress Series*, 192: 89–101.
- Le Vay, L., Jones, D.A., Puello-Cruz, A.C., Sangha, R.S. & Ngamphongsai, C., 2001. Digestion in relation to feeding strategies exhibited by crustacean larvae. *Comparative Biochemistry and Physiology Part A: Molecular & Integrative Physiology*, 128: 621–628.
- Vitousek, P.M., Mooney, H.A., Lubchenco, J. & Melillo, J.M., 1997. Human Domination of Earth's Ecosystems. *Science*, 277: 494–499.
- Worm, B., Barbier, E.B., Beaumont, N., Duffy, J.E., Folke, C., Halpern, B.S., Jackson, J.B.C., Lotze, H.K., Micheli, F., Palumbi, S.R., Sala, E., Selkoe, K.A., Stachowicz, J.J. & Watson, R., 2006. Impacts of Biodiversity Loss on Ocean Ecosystem Services. *Science*, 314: 787–790.
- Zariquiey-Álvarez, R., 1968. Decápodos Ibéricos. *Inv. Pesq*, 32, p.510.

Zeldis, J.R. & Jillett, J.B., 1982. Aggregation of pelagic *Munida gregaria* (Fabricius) (Decapoda, Anomura) by coastal fronts and internal waves. *Journal of Plankton Research*, 4: 839–857.

Appendix

Annex I. Abundance of other infraorders sampled in the SMURFs in each partially (PPA) - and fully (FPA) - protected areas, during the experience period. Here the species *E. cranchii* is not included in the infraorder Caridea.

Sample	Infraorder Abundance				Protected Area
	Caridae	Brachyura	Achelata	Anomura	
25 Apr	56	23	0	0	TPA
25 Apr	11	7	0	0	TPA
25 Apr	35	0	4	0	PPA
25 Apr	27	18	0	8	PPA
25 Apr	37	1	6	0	TPA
25 Apr	19	4	0	1	TPA
25 Apr	10	7	11	0	PPA
25 Apr	17	5	0	2	PPA
30 Jul	30	9	8	0	TPA
30 Jul	11	2	0	9	TPA
30 Jul	20	29	5	0	PPA
30 Jul	26	1	0	0	PPA
30 Jul	16	13	12	4	TPA
30 Jul	67	21	3	1	TPA
30 Jul	44	3	0	0	PPA
30 Jul	36	0	3	0	PPA
23 Sep	26	38	0	7	TPA
23 Sep	37	0	0	0	TPA
23 Sep	48	1	23	0	PPA
23 Sep	13	0	0	32	PPA
23 Sep	35	9	50	0	TPA
23 Sep	26	0	0	11	TPA
23 Sep	17	14	12	5	PPA
23 Sep	0	0	0	0	PPA
Total	664	205	137	80	-