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Effects on faunistic composition and population characteristics of decapod crustaceans after the implementation of a fisheries no-take area in the NW Mediterranean

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Summary: The establishment of fisheries no-take areas is considered an effective method for the recovery of populations of exploited species and their habitats. Here we study the faunistic composition of decapod crustaceans after the implementation of a no-take area in the Gulf of Roses (NW Mediterranean) in 2014. We studied the occurrence (presence/absence) and density of all decapod crustaceans sampled by trawling inside and outside a no-take area from March 2015 to July 2018. Sizes were assessed for all common species. A total of 33 species of decapod crustaceans were recorded. Four species showed significantly higher occurrences in the no-take area and three in the open area, while significantly higher densities were found for four species in the no-take area and three in the open area. Multivariate analysis showed marked differences between the no-take area and the open area, while also showing that the two areas were undergoing a divergence. The comparison of sizes between the two zones showed species-specific patterns that in many cases showed that both the smallest and the largest individuals were present in the no-take area, suggesting that the closing of this area would be important for recruitment and juvenile development, as well as for protection of large-sized individuals. All evidence indicates that the establishment of the no-take area has led to an improvement in biodiversity and species population descriptors.

Keywords: no-take areas; decapod crustaceans; biodiversity; demersal fisheries.

Efectos sobre la composición faunística y características poblacionales de crustáceos decápodos posteriormente a la implementación de una zona cerrada a la pesca en el Mediterráneo noroccidental

Resumen: La creación de áreas restringidas a la pesca se considera un método efectivo para la recuperación de las poblaciones de especies comerciales y sus hábitats. En el presente trabajo se estudia la composición faunística referente a los crustáceos decápodos después de la implementación de un área cerrada a la pesca en el golfo de Roses en 2014. Se han estudiado las pautas de presencia y abundancia de los crustáceos decápodos muestreados con arte de arrastre comercial en el interior y exterior del área cerrada a la pesca entre marzo 2015 y julio 2018. Se detectó un total de 33 especies de crustáceos decápodos. Tanto en las presencias como en las abundancias se detectaron diferencias significativas entre las dos zonas. Se determinó la talla individual de los individuos capturados o de una submuestra. Cuatro especies mostraron una presencia significativamente mayor en el área cerrada a la pesca, mientras que tres lo hicieron en el área abierta. Respecto a las densidades, cuatro especies mostraron valores significativamente mayores en el área protegida, mientras que tres lo hicieron en la abierta. Un análisis multivariante mostró claramente la existencia de diferencias significativas entre las dos zonas, mostrando también que las dos áreas se encuentran en proceso de divergencia. La comparación de tallas entre las dos zonas presentó pautas específicas para cada especie que mayoritariamente indicaron que tanto los individuos de menor talla como los de mayor talla se presentaban en el área cerrada a la pesca, sugiriendo que el cierre de esta zona sería relevante para el reclutamiento y desarrollo juvenil, así como para la protección de los ejemplares de mayor talla. Las evidencias indican que el establecimiento del área cerrada a la pesca está implicando un proceso de conservación de la biodiversidad y mejora del estado de las poblaciones presentes.

Palabras clave: áreas cerradas a la pesca; crustáceos decápodos; biodiversidad; pesquerías demersales.

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INTRODUCTION

Trawl fisheries are poorly selective methods of catching target species living on the bottom of the sea. Along with adult individuals, which are usually the target of the fishery, juveniles of both target and unwanted species are also captured and therefore have an impact not only on the objective populations but also on the rest of the community. However, not all species are affected in the same way. Some may be more vulnerable and others may be more resilient (Dimech et al. 2012, García de Vinuesa et al. 2020). Additionally, some of them may be key species for the proper functioning of the ecosystem. Therefore, within an ecosystem approach to fisheries, the species composition of the areas, their dynamics, and the role of bycatch species need to be known to achieve a correct understanding and management of the fisheries.

Many of the bycatch species present in trawling discards are poorly known, given their scarceness and/or their lack of commercial interest, although many of them co-occur in the same exploited community and belong to the energy pathways of the ecosystem (Abelló et al. 2002, Demestre et al. 2018). With these considerations in mind, this study was intended to detect whether the establishment of a no-take area on soft bottoms of the NW Mediterranean continental shelf was able to promote biodiversity conservation, protect fisheries target species and, accordingly, promote population spillover in an area where Mediterranean hake (*Merluccius merluccius*) is the main target species. The home port of the trawl fleet working in the area is Roses, a town in NE Catalonia, with around 22 vessels, most of them of an overall length of over 20 m, and annual trawl catches in this area are over 1500 t (Martín et al. 2014). The study area included two differentiated, adjacent zones within a homogeneous continental shelf sector. One of the zones was closed to trawling previously to the start of the sampling, while the adjacent area remained open to trawling.

Several similar actions have been carried out in the Mediterranean Sea. Dimarchopoulou et al. (2018) studied three areas in the northeastern Mediterranean with different fishing intensities 40 years after the establishment of a fisheries no-take area, with results showing that both sizes and biomass of the main commercial species were higher in the areas where fishing effort was lower. However, this was not the case for other, non-commercial species, except for those with a high discard level. Consoli et al. (2013) reported that five years after the creation of a marine protected area, significant differences could be already appreciated in the larger commercial species, but not in smaller-sized fish species or in species with a low or null commercial interest. Halpern et al. 2010) showed that both conservation and fisheries objectives can be met if suitable collaborative management designs are implemented.

In this context, the present study focused on the decapod crustacean taxocoenosis present in a recently created no-take area in the NW Mediterranean Sea. This zoological group comprises both target and bycatch species that are usually strongly linked to the bottom and are therefore properly sampled by the commercial bottom trawl gears.

The establishment of the closed area was promoted by the fishers themselves within a co-management strategy implemented to improve sustainability, because the proportion of capture of undersized juvenile hake was high on the continental shelf, especially at depths of around 120-140 m (Balcells et al. 2016, Recasens et al. 2016), and hake catches were decreasing (Sala-Coromina et al. 2021). It was assumed that fisheries no-take areas could act as reservoirs that could export hake biomass (and that of other species) to adjacent areas, especially in areas with a high proportion of juvenile fish. The creation of closed areas for this purpose has been considered one of the most useful management tools for protecting and recovering habitats and their associated biological communities (Gell and Roberts 2003, Rodriguez-Rodriguez et al. 2015). It is also expected that juveniles could also increase in number and biomass in the protected area, and therefore be exported through behavioural spillover to the adjacent non-protected areas (Dimarchopoulou et al. 2018, Consoli et al. 2013, De Juan et al. 2011).

The present study, within the framework of a fisheries research action aimed at implementing management measures to take care of the hake fishery in the northwestern Mediterranean (Recasens et al. 2016), makes a qualitative and quantitative assessment the faunistic composition of decapod crustaceans inside and outside a no-take area closed to trawling, and analyses any possible differences in species size structure. We aimed to provide information on the biodiversity, species population structure and dynamics of the system that might be useful to apply within an ecosystem approach to fisheries.

MATERIAL AND METHODS

Study area

Field work was carried out in the Gulf of Roses (Catalonia, NW Mediterranean), where an area closed to fisheries was established using co-management measures agreed by both fishers and the administration. Its geographical coordinates are 42°11.0’N 3°25.0’E, 42°11.0’N 3°26.5’E, 42°09.0’N 3°27.0’E, 42°07.0’N 3°27.0’E, 42°4.5’N 3°27.0’E, 42°04.5’N 3°23.5’E, 42°07.0’N 3°23.5’E, 42°09.5’N 3°24.0’E and 42°11.0’N 3°25.0’E. The area was closed in 2014 (Balcells et al. 2016). Local fishers agreed on the precise area to close according to their previous knowledge of the occurrence of high concentrations of juvenile hake. This trawling ground was located on the continental shelf at depths of between 120 and 140 m and covered an area of 51.35 km^2 (Fig. 1). It represented 2.7% of the current hake trawl-fishing area of the Roses fleet. Within this no-take area, no fishing activities of any kind are permitted, except for experimental monitoring samplings.

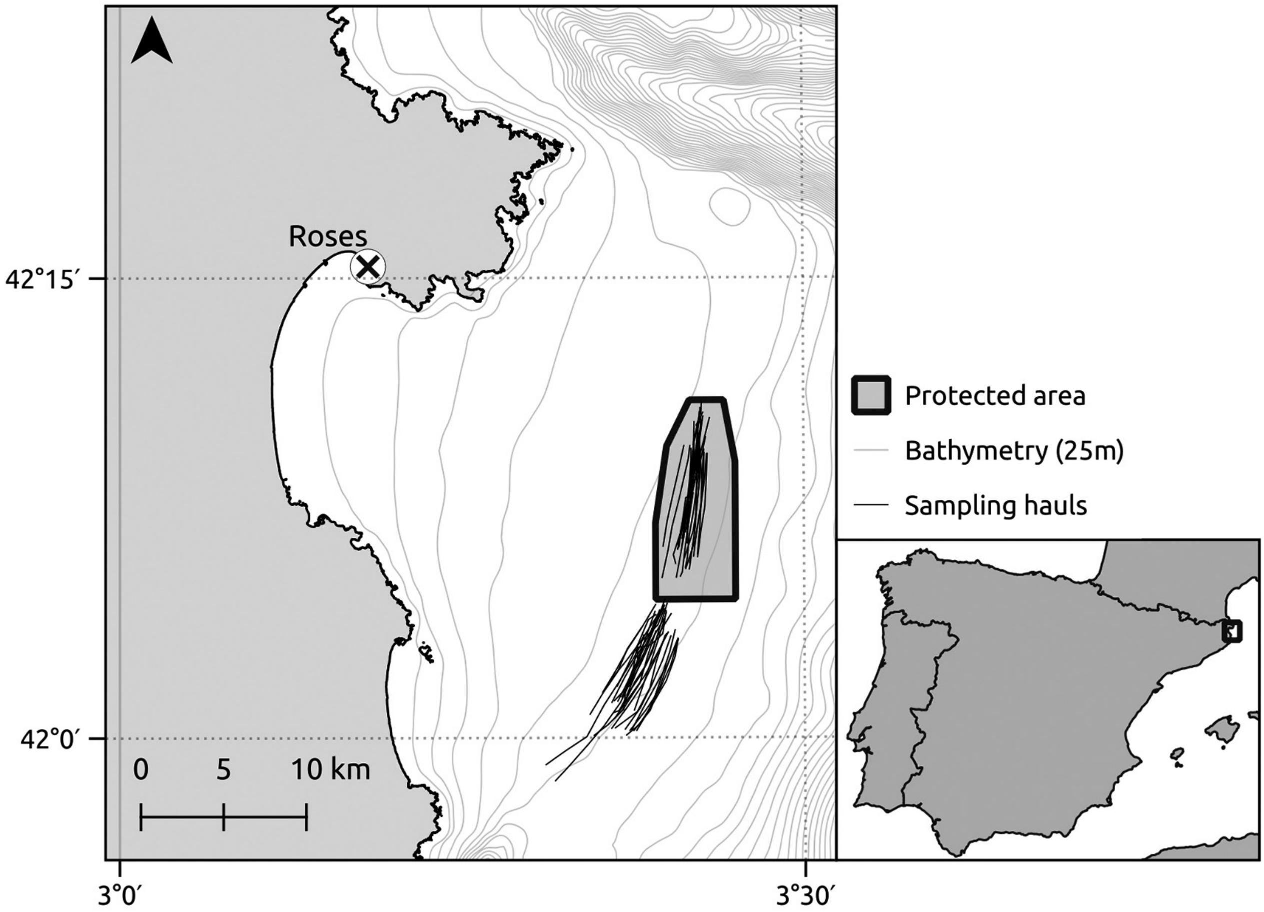

Fig. 1. – Location of the study area (Gulf of Roses, Catalonia, Spain), with indication of the no-take area (closed polygon) and the area open to the fishery. Bathymetry lines in 25 m intervals.

Field and laboratory sampling

After the closure of the area, several biological sampling operations of varying intensity were carried out in both the no-take and open areas from 2015 to 2018 with the aim of analysing the temporal changes of the hake population. The closing of the area to trawling and other extractive activities was promoted by the local fishers (Confraria de Roses) together with the Catalan Fisheries Department (DGPAM - Generalitat de Catalunya). Fishers and the administration agreed to the involvement of the Institute of Marine Sciences (ICM-CSIC) to perform collaborative scientific monitoring.

During the first year of sampling, four experimental sampling hauls were conducted per month on board local fishing vessels from March 2015 to January 2016 to try to consider seasonality. After the first-year results, it was decided that the schedule was worth continuing. However, for financial reasons, no more samplings could be done again until January 2016, when they were re-scheduled to be bimonthly, accounting for seasonality but at a lower temporal resolution. Samplings were carried out from July 2017 to July 2018. All samplings were performed in the morning, in daylight, according to the country regulations. On each sampling day, two hauls were performed inside the no-take area and two outside, in an adjacent zone where trawl fishing was allowed. A total of 76 valid hauls were performed (38 in each area, open and no-take). These were conducted within the same bathymetric range (120-140 m), using the same trawl gear characteristics (OTMS, 40 mm square mesh size). All hauls had a duration of one hour. All commercial species were identified on board, counted and measured. Size measurements for all—or a representative subsample of—commercial fish (total length to the lowest 0.5 cm) and crustaceans (carapace length or width to the lowest 1.0 mm) were obtained directly on board. Total weight by commercial species was obtained on land. A representative sample of the discard fraction was taken to the laboratory, where its faunistic composition, number of individuals and weight by species were obtained. Individual sizes and other species-specific biological information, such as sex, occurrence of ovigerous females, gonad maturity and moult stage were also obtained for most species. Density data (in number of individuals per square km) were normalized using GPS positions, vessel speed and average horizontal opening of the gear to calculate the swept area by haul. An estimation of the total catch

Table 1. – List of the decapod crustacean species captured during this study.

Suborder/Infraorder	Family	Species
Dendrobranchiata	Penaeidae	*Parapenaeus longirostris* (Lucas, 1846)
-	Solenoceridae	*Solenocera membranacea* (Risso, 1816)
Caridea	Alpheidae	*Alpheus glaber* (Olivi, 1792)
-	Processidae	*Processa canaliculata* Leach, 1815
-	-	*Processa nouveli* Al-Adhub and Williamson, 1975
-	Pandalidae	*Chlorotocus crassicornis* (A. Costa, 1871)
-	-	*Plesionika heterocarpus* (A. Costa, 1871)
-	Crangonidae	*Aegaeon lacazei* (Gourret, 1887)
-	-	*Philocheras echinulatus* (M. Sars, 1862)
-	-	*Pontophilus spinosus* (Leach, 1815)
-	Palaemonidae	*Typton spongicola* O.G. Costa, 1844
Achelata	Palinuridae	*Palinurus elephas* (J.C. Fabricius, 1787)
Astacidea	Nephropidae	*Nephrops norvegicus* (Linnaeus, 1758)
Anomura	Galatheidae	*Galathea dispersa* Bate, 1859
-	Galatheidae	*Galathea intermedia* Lilljeborg, 1851
-	Munididae	*Munida intermedia* A. Milne-Edwards and Bouvier, 1899
-	-	*Munida rugosa* (Fabricius, 1775)
-	-	*Munida speciosa* von Martens, 1878
-	Diogenidae	*Dardanus arrosor* (Herbst, 1796)
-	Paguridae	*Anapagurus laevis* (Bell, 1845)
-	-	*Pagurus cuanensis* Bell, 1845
-	-	*Pagurus excavatus* (Herbst, 1791)
-	-	*Pagurus prideaux* Leach, 1815
Brachyura	Homolidae	*Homola barbata* (J.C. Fabricius, 1793)
-	Inachidae	*Inachus dorsettensis* (Pennant, 1777)
-	-	*Inachus leptochirus* Leach, 1817
-	-	*Macropodia tenuirostris* (Leach, 1814 [in Leach, 1813-1815])
-	Dorippidae	*Medorippe lanata* (Linnaeus, 1767)
-	Polybiidae	*Liocarcinus depurator* (Linnaeus, 1758)
-	-	*Macropipus tuberculatus* (Roux, 1830)
-	Pilumnidae	*Pilumnus spinifer* H.-M. Edwards, 1834
-	Goneplacidae	*Goneplax rhomboides* (Linnaeus, 1758)
-	Pinnotheridae	*Nepinnotheres pinnotheres* (Linnaeus, 1758)

in weight, in addition to that of the commercial species, was taken directly on board by considering the number of standard fish-boxes collected.

The size of reference was carapace length in shrimps (Penaeoidea and Caridea), Achelata, Astacidea and Anomura, while in crabs (Brachyura), carapace width was measured, except in those species with long lateral spines, such as *M. tuberculatus,* for which it was considered that carapace length was a more reliable proxy of size. Size was measured in mm using a digital Vernier caliper with a precision of 0.1 mm. An estimate of the size at maturity for most species was obtained from data collected from present and other fisheries research surveys performed in the western Mediterranean (Abelló et al. 2002; unpublished), based on the occurrence of ovigerous females or on gonad development in dendrobranchiate shrimps.

Statistical analysis

A chi-squared test was used to assess whether the percentage occurrence of each species inside and outside the no-take area was significantly different (p=0.05). To analyse densities inside and outside the no-take area, the non-parametric Mann-Whitney test was applied, because the occurrence of species in only

Table 2. – Total number of occurrences for each species, percentage occurrence of the species Inside and outside the no-take area, chi-squared value (p=0.05) obtained in the comparisons to test for a significantly higher occurrence in each area.

SPECIES	Total Occurrences	I (%)	O (%)	Chi^2	Significantly higher occurrence	Maturity size
Macropodia tenuirostris	57	43.9	56.1	3.19	-	9
Parapenaeus longirostris	48	31.3	68.8	17.55	Outside	20
Dardanus arrosor	47	66	34	12.05	Inside	55
Pagurus prideaux	47	70.2	29.8	19.33	Inside	6
Liocarcinus depurator	44	50	50	0.00	-	15
Macropipus tuberculatus	30	63.3	36.7	3.47	-	19
Pagurus excavatus	29	51.7	48.3	0.05	-	5
Medorippe lanata	25	40	60	1.47	-	20
Solenocera membranacea	17	58.8	41.2	0.68	-	10
Chlorotocus crassicornis	16	50	50	0.00	-	7
Goneplax rhomboides	16	12.5	87.5	11.32	Outside	7
Alpheus glaber	14	28.6	71.4	3.13	-	n.a.
Inachus dorsettensis	13	61.5	38.5	0.83	-	7
Munida rugosa	12	83.3	16.7	6.30	Inside	n.a.
Galathea dispersa	11	36.4	63.6	0.95	-	n.a.
Nephrops norvegicus	11	18.2	81.8	5.19	Outside	21
Typton spongicola	10	80	20	4.13	Inside	n.a.
Plesionika heterocarpus	6	16.7	83.3	2.89	-	8
Palinurus elephas	5	60	40	0.21	-	n.a.
Aegaeon lacazei	3	100	0	3.12	-	n.a.
Inachus leptochirus	3	66.7	33.3	0.35	-	n.a.
Pontophilus spinosus	3	100	0	3.12	-	n.a.
Processa nouveli	3	0	100	3.12	-	n.a.
Munida speciosa	2	100	0	2.05	-	8
Anapagurus laevis	1	100	0	1.01	-	n.a.
Galathea intermedia	1	0	100	1.01	-	n.a.
Homola barbata	1	0	100	1.01	-	21
Munida intermedia	1	100	0	1.01	-	15
Nepinnotheres pinnotheres	1	0	100	1.01	-	n.a.
Pagurus cuanensis	1	100	0	1.01	-	4
Philocheras echinulatus	1	100	0	1.01	-	n.a.
Pilumnus spinifer	1	100	0	1.01	-	n.a.
Processa canaliculata	1	0	100	1.00	-	n.a.
Total number of species: 33						

INSIDE:29 OUTSIDE: 25

one of the categorized areas—i.e. species occurring only in the no-take area or only in the open area, as is the case in many uncommon species—did not allow parametric tests to be applied. In species with more than 30 individuals measured, mean sizes were compared using a t-test. Multivariate analyses were performed using the Past software (Hammer et al. 2001). Non-metric multidimensional analysis (MDS) was applied to the density table of species by sample to allow visualization of inter-sample relationships based on similarity between their faunistic composition and species relative abundance; density data were previously transformed (log(n+1)). One-way Permanova was used to test for the presence of significant differences between the two groups of samples (inside or outside the no-take area). Simper analysis was used to detect the main species responsible for the differences detected between the two groups of samples.

Table 3. – Mean densities (n km^{-2}) and biomass (g km^{-2}) inside (I) and outside (O) the no-take area, Mann-Whitney test p-values on densities, and areas with significantly higher density. Significant p-values and corresponding species are shown in bold.

SPECIES	Mean density (I) (n km^{-2})	Mean density (O) (n km^{-2})	M-W (p-value)	Area with significantly higher density	Mean biomass (I) (g km^{-2})	Mean biomass (O) (g km^{-2})
Aegaeon lacazei	15.7	0	0.4989	-	210.3	0.0
Alpheus glaber	9	6.2	0.1275	-	6.5	16.3
Anapagurus laevis	1.8	0	0.3237	-	70.5	0.0
Chlorotocus crassicornis	58.9	8	0.8709	-	94.7	94.7
Dardanus arrosor	109.6	12.9	**0.0005**	I	1189.2	613.8
Galathea dispersa	13.2	5.1	0.4050	-	21.2	37.0
Galathea intermedia	0	0.2	0.3237	-	0.0	3.2
Goneplax rhomboides	2.2	8.6	**0.0021**	O	2.9	20.5
Homola barbata	0	0.2	0.3237	-	0.0	2.3
Inachus dorsettensis	48.8	5.4	0.3404	-	88.9	55.6
Inachus leptochirus	6.1	0.3	0.556	-	102.0	51.0
Liocarcinus depurator	114.8	32.6	0.4546	-	335.5	335.5
Macropipus tuberculatus	54.1	9.2	**0.0474**	I	388.1	224.7
Macropodia tenuirostris	220	123.5	0.6794	-	142.6	182.5
Medorippe lanata	26.2	20	0.4225	-	306.4	459.6
Munida intermedia	4	0	0.3237	-	2017.6	0.0
Munida rugosa	15.6	0.6	**0.0138**	I	424.0	84.8
Munida speciosa	12.2	0	0.1587	-	1178.4	0.0
Nephrops norvegicus	0.3	1.6	**0.0268**	O	103.3	465.0
Nepinnotheres pinnotheres	0	1	0.3237	-	0.0	19.1
Pagurus cuanensis	3.4	0	0.3237	-	79.7	0.0
Pagurus excavatus	44.7	15.8	0.5671	-	418.5	390.6
Pagurus prideaux	1537.2	33.1	**0.0001**	I	7924.1	3361.8
Palinurus elephas	0.5	0.3	0.6634	-	2696.0	1797.4
Parapenaeus longirostris	38.8	373	**0.0007**	O	643.4	1415.4
Philocheras echinulatus	5.5	0	0.3237	-	214.4	0.0
Pilumnus spinifer	1.7	0	0.3237	-	33.2	0.0
Plesionika heterocarpus	4.2	6.8	0.1013	-	13.0	65.2
Pontophilus spinosus	10.7	0	0.0826	-	210.7	0.0
Processa canaliculata	0	0.2	0.3237	-	0.0	8.5
Processa nouveli	0	2	0.0826	-	0.0	19.5
Solenocera membranacea	29.7	5.1	0.358	-	75.7	53.0
Typton spongicola	11.7	1.1	**0.0462**	I	19.8	4.9

RESULTS

Faunistic characteristics

During the sampling operations a total of 33 species of decapod crustaceans were obtained, of which 2 were Penaeoidea prawns, 9 Caridea shrimps, 1 Achelata, 1 Astacidea, 10 Anomura, and 10 Brachyura (Table 1).

Occurrences (presence/absence)

Overall, a total of 29 decapod crustacean species were detected inside the no-take area and 25 outside the no-take area, while 20 occurred both inside and outside the no-take area.

Table 2 shows the percentage occurrence of the species inside (I) and outside (O) the fisheries no-take area. Seven of the 33 species collected showed a significantly (p=0.05) preferred area of occurrence, either inside or outside. The rest of the species (26) showed no significant differences in their differential occurrence inside or outside the no-take area.

Four species showed significantly higher occurrences (Table 2) inside the fisheries no-take area: the hermit crabs *Dardanus arrosor* and *Pagurus prideaux*, the squat lobster *Munida rugosa*, and the sponge shrimp

Table 4. – Joint characterization of species according to the significance of their occurrences (Occ) and density (Dens) inside (I) and outside (O) the no-take area. Dash indicates non-significant differences.

Species	Occ	Dens	Species	Occ	Dens
Aegaeon lacazei	-	-	*Munida speciosa*	-	-
Alpheus glaber	-	-	*Nephrops norvegicus*	O	O
Anapagurus laevis	-	-	*Nepinnotheres pinnotheres*	-	-
Chlorotocus crassicornis	-	-	*Pagurus cuanensis*	-	-
Dardanus arrosor	I	I	*Pagurus excavatus*	-	-
Galathea dispersa	-	-	*Pagurus prideaux*	I	I
Galathea intermedia	-	-	*Palinurus elephas*	-	-
Goneplax rhomboides	O	O	*Parapenaeus longirostris*	O	O
Homola barbata	-	-	*Philocheras echinulatus*	-	-
Inachus dorsettensis	-	-	*Pilumnus spinifer*	-	-
Inachus leptochirus	-	-	*Plesionika heterocarpus*	-	-
Liocarcinus depurator	-	-	*Pontophilus spinosus*	-	-
Macropipus tuberculatus	-	I	*Processa canaliculata*	-	-
Macropodia tenuirostris	-	-	*Processa nouveli*	-	-
Medorippe lanata	-	-	*Solenocera membranacea*	-	-
Munida intermedia	-	-	*Typton spongicola*	I	I
Munida rugosa	I	I			

Typton spongicola. The three species that showed significantly higher occurrences outside the no-take area were the penaeid shrimp *Parapenaeus longirostris*, the crab *Goneplax romboides* and the Norway lobster *Nephrops norvegicus*. Both *P. longirostris* and *N. norvegicus* are target species of the fishery.

Other common species (>10 occurrences) showed no preference (Table 2) for either of the two areas: *Macropodia tenuirostris, Liocarcinus depurator, Macropipus tuberculatus, Pagurus excavatus, Medorippe lanata, Solenocera membranacea, Chlorotocus crassicornis, Alpheus glaber, Inachus dorsettensis* and *Galathea dispersa.*

The occurrences of many other species were relatively low (<10), and we considered that they could not be properly classified into any of the two studied compartments. These were *Plesionika heterocarpus, Palinurus elephas, Aegaeon lacazei, Inachus leptochirus, Pontophilus spinosus, Processa nouveli, Munida speciosa, Anapagurus laevis, Galathea intermedia, Homola barbata, Munida intermedia, Nepinnotheres pinnotheres, Pagurus cuanensis, Philocheras echinulatus, Pilumnus spinifer* and *Processa canaliculata.*

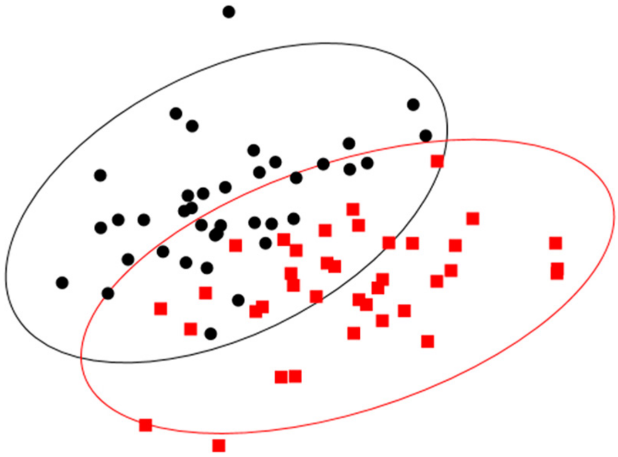

Fig. 2. – Non-metric multidimensional analysis (MDS) run on the matrix of decapod crustacean species densities by sample. Samples taken were categorized according to whether they belonged to the no-take area (black dots,) or to the open area (red squares). Each dot represents one trawl sampling operation. The ellipses shown encompass the area where 95% of the samples within each category would be expected to fall.

Densities

Table 3 shows the mean densities, in number of individuals km^{-2}, of each species inside and outside the fisheries no-take area, with indication of the area where significant differences between densities (if any) occurred.

The hermit crab *Pagurus prideaux* was the species showing the highest mean densities within the no-take area (1537 inds km^{-2}), followed by the crabs *Macropodia tenuirostris* and *Liocarcinus depurator* and the hermit crab *Dardanus arrosor* (all of them with densities higher than 100 inds km^{-2}). Outside the no-take area, the most abundant species were the penaeid shrimp *Parapenaeus longirostris* (373 inds km^{-2}) and the spider crab *Macropodia tenuirostris* (123 inds km^{-2}).

Only 8 of the 33 collected species showed significantly higher densities (Table 3) within either of the

Table 5. – Size statistics by species and zone inside (IN) and outside (OUT) the no-take area, those species with n>30 individuals measured. Species in bold showed significant differences in mean size between zones. N, number of individuals measured; Min, Max, Mean, Median, minimum, maximum, mean, median size; Std err, standard error of the mean; Std dev, Standard deviation; t, Student's t value; p, probability of rejecting the null hypothesis. Sizes, as carapace length (shield length in hermit crabs), in mm for all species but *L. depurator* (carapace width), and size at maturity in mm. Mean sizes larger than maturity size (from Table 2) are shown in bold.

Species	Zone	N	Min	Max	Mean	Median	Std err	Std dev	t	p-value	Maturity size
Dardanus arrosor	IN	60	4.7	18.2	11.3	12.4	0.4	3.1	0.03	0.9766	6
	OUT	27	6.8	15.1	11.3	11.8	0.5	2.4			
Liocarcinus depurator	IN	89	12.7	42.2	**28.9**	29.5	0.5	5.1	–0.9	0.3806	15
	OUT	61	22.6	39.7	**29.7**	30.2	0.5	3.7			
Macropipus tuberculatus	IN	37	13.0	40.0	**21.6**	20.9	0.8	5	–1.8	0.0764	
	OUT	21.0	18.0	29	**22.9**	23.2	0.7	3.4			19
Macropodia tenuirostris	IN	103	8.8	19.6	**13.2**	12.9	0.2	2.3	–2.9	0.0045	9
	OUT	218	6.0	19.8	**14**	13.7	0.2	2.4			
Medorippe lanata	IN	17	15.4	27.8	**21.9**	22	0.7	3	–0.1	0.9485	20
	OUT	34	13.0	27.4	**22**	22.5	0.5	3.2			
Pagurus cuanensis	IN	2	3.8	4.8	**4.3**	4.3	0.5	0.7	–2.8	0.0085	4
	OUT	37	4.7	12.0	**8.1**	7.8	0.3	1.9			
Pagurus excavatus	OUT	23	7.6	14.6	**10.7**	10.7	0.4	1.7			5
Pagurus prideaux	IN	813	6.1	13.7	**9.8**	9.5	0	1.4	–3.8	0.0002	6
	OUT	40	8.2	13.1	**10.6**	10.6	0.2	1.4			
Parapenaeus longirostris	IN	85	16.2	60.0	**24.5**	23.7	0.6	5.8	–0.6	0.5387	20
	OUT	754	12.9	48.8	**26.2**	25.6	0.2	5.1			

areas. Those that showed significantly higher densities inside the fisheries no-take area were the hermit crabs *Dardanus arrosor* and *Pagurus prideaux*, the crab *Macropipus tuberculatus,* the squat lobster *Munida rugosa* and the caridean shrimp *Typton spongicola*. Those with significantly higher densities in the non-restricted area were the crab *Goneplax romboides,* the Norway lobster *Nephrops norvegicus* and the penaeid prawn *Parapenaeus longirostris*.

The species showing the highest degree of occurrence within the no-take area were also those showing the highest densities there (Table 4), while those showing highest occurrences outside the no-take area were also more abundant there, except in the case of the crab *Macropipus tuberculatus*, which did not show any preference in occurrence for either of the two areas, but showed significantly higher densities within the no-take area.

Figure 2 shows the results of the non-metric multidimensional analysis (MDS) run on the density data of species by sample, categorized according to whether they belonged inside or outside the no-take area. This analysis showed the presence of clear differences between samples from inside the no-take area and those from the non-restricted area. The two ellipses shown were calculated to encompass 95% of the samples within each category, and they thus clearly show the occurrence of large differences between the two categories of samples, inside and outside the no-take area. A one-way PERMANOVA showed that the two groups of samples (inside and outside the no-take area) differed significantly (p<0.0001). Additionally, Simper analysis showed that six species accounted for over half the weight for group assignation: namely, the hermit crab *Pagurus prideaux* (12.5%), the penaeid shrimp *Parapenaeus longirostris* (10.3%), the hermit crab *Dardanus arrosor* (8.5%), and the crabs *Macropodia tenuirostris* (7.7%), *Liocarcinus depurator* (7.1%), and *Macropipus tuberculatus* (5.9%). The remaining species contributed with lower levels to the quantitative faunistic differentiation between the two areas.

Intraspecific size differences between areas

Table 5 shows size statistics for the eight species with the largest number of measured individuals (N>30). Sizes, and their location inside or outside the no-take area showed species-specific patterns. Minimum sizes were located inside the no-take area in five species: *D. arrosor, L. depurator, M. tuberculatus, P. cuanensis* and *P. prideaux*. Maximum sizes were found inside in six species: *D. arrosor, L. depurator, M. tuberculatus, M. lanata, P. prideaux* and *P. longirostris.* The largest mean and median values were all located outside the no-take area, except in *D. arrosor,* in which mean and median values coincided. Significant differences between mean sizes inside or outside the no-take area were obtained for three of them: *M. tenuirostris*, *P. cuanensis* and *P. prideaux.* In all these species, mean sizes were significantly larger outside the no-take area. In the rest of the analysed species, no significantly different sizes were obtained inside or outside the no-take area. Mean sizes were larger than size at maturity in all these species.

DISCUSSION

This study has reported the occurrence, density, biomass and body size of the decapod crustacean species present in two adjacent areas with similar environmental characteristics, one of them recently closed to fishing activity (Balcells et al. 2016), while the other remained under trawling exploitation. These areas were part of the same trawl-fishing corridor before the implementation of the no-take area and therefore supported a similar fishing effort. The no-take area was mainly expected to diminish juvenile hake mortality and thus enhance juvenile growth and therefore spillover to the adjacent fishing areas. Concomitantly, protection would also affect the overall community with positive effects on substrate damage and increased survival of the rest of the biological community, including the subject of the present study: the decapod crustacean taxocoenosis present in the study area.

With regard to occurrences, the results showed that the crustacean community present in the study area was highly diverse, as a total of 33 species of decapod crustaceans were detected when both the exploited and the non-exploited sectors were considered. This figure represents 86.8% of the decapod fauna known to be present in the 101-150 m depth stratum in trawled areas reported along the whole Mediterranean coasts of the Iberian Peninsula (Abelló et al. 2002). Most species (20) were present in both the open and no-take areas, the rest being found, usually with a lower level of presence, in just one of the two zones. The overall species composition in the two areas was fairly similar, in agreement with the homogeneity of the environment and the relatively short time elapsed since the implementation of the no-take area. Most species, 26 of the 33, showed no significant differences between the two areas, suggesting that the implementation of the no-take area had not (yet) fully affected these 26 species either positively or negatively, but 4 of the 33, namely the hermit crabs *D. arrosor* and *P. prideaux*, the squat lobster *M. rugosa* and the sponge shrimp *T. spongicola*, were found to be significantly more common within the no-take area. These species could therefore be identified as having been favoured by the implementation of the no-take area, as also occurred in the same area for some fish species (Tuset et al. 2021).

Other proxies of positive effects of the implementation of the no-take area were the greater densities and/or larger body sizes for some species, in agreement with most results obtained in other regions where permanent fishing restrictions have been implemented (Dugan and Davis 1993, Piet and Jennings 2005, Dimarchopoulou et al. 2018). The most abundant species in the no-take area in terms of density were *P. prideaux*, *M. tenuirostris*, *L. depurator* and *D. arrosor*, while the most abundant in the open area were *P. longirostris*, *M. tenuirostris*, *P. prideaux* and *L. depurator*. MDS multivariate analysis clearly showed that relevant differences were present between the two studied zones, which would indicate that, starting from a temporal point with identical fishing effort in both adjacent areas, the two communities were in a process of differentiation associated with the establishment of the no-take area, probably as a result of the protection from physical disturbance by trawling in the no-take area (Dugan and Davis 1993). The species that the MDS identified as most contributing to the ecological differentiation were the hermit crabs *P. prideaux* and *D. arrosor*, the penaeid shrimp *P. longirostris*, and the crabs *M. tenuirostris, L. depurator* and *M. tuberculatus*.

The hermit crabs *D. arrosor* and *P. prideaux* carry associated symbiotic anemones on the gastropod shells they use as a shelter, which provide the crabs with additional protection against predators. Anemones may be badly damaged by trawling activity (Gordon et al. 2009), but not usually so the crabs, sheltered within their shells, because they can hide within the gastropod shell and thus avoid most physical damage. Unlike most hermit crabs, *P. prideaux* does not occupy large shells as a shelter (Kaiser et al. 1998), but instead carries a small gastropod shell on the telsons, to which its symbiotic anemone attaches, and it is mainly the anemone rather than the gastropod shell that provides the crab with protection. All this would clearly favour the occurrence of hermit crabs inside the no-take area, as was the case. Related to this feature, Ramsay et al. (1996) and Kaiser et al. (1998) detected that *P. prideaux* did not move into trawled areas to scavenge, as markedly did another hermit crab, *Pagurus bernhardus*, in the same area, even though their diets were similar. The same authors also indicated that *P. prideaux* are more susceptible to physical damage when captured in trawls, and that fishing mortality is higher for this species than for other hermit crabs, which could imply competitive exclusion of this species by other hermit crabs, which seems to be the case in the present study.

The anomuran squat lobster, *Munida rugosa*, also showed a significantly greater presence within the no-take area. Hardly anything is known on the biology and habitat of this species, because it is very scarce in samplings performed on bottoms affected by the trawl fishery (Abelló et al. 1988, 2002), which almost specifically targets soft, sandy and/or muddy bottoms. This species is usually reported from continental shelf rocky areas or close to rocky outcrops, where it has been identified in pictures and videos using remote operated vehicles (Mérillet et al. 2018).

Occasional species, despite their faunistic relevance, are assumed to have a lower impact on the ecology of the community, because their densities are usually low. However, the occasional species *T. spongicola* or *M. rugosa* were significantly commoner in the no-take area. Their occurrence in this area markedly contributed to the ecological differentiation of the two zones and favoured ecological interrelationships among the species. This would support ecological stability, especially in non-trawled areas. *T. spongicola* and its associated sponge, *Desmacidon fruticosum* (Levi and Vacelet 1958), are probably the most important species for three-dimensional structuring of the soft-bottom environment in the study area. They are both highly fragile species that are highly affected by trawling activities (Stoner and Titgen 2003), but they have however shown a high resilience effect once their habitat is protected from physical damage by trawling. Their recovery in the no-take area would be clearly favourable not only for them to survive, as the results clearly show, but also to provide stability and three-dimensionality for the whole community to re-develop.

Just three species showed a significantly higher presence in the area open to trawling. These were the penaeid shrimp *P. longirostris*, which has epibenthic/nektobenthic habits, the crab *G. rhomboides* and the Norway lobster *N. norvegicus,* the last two species with epibenthic and burrowing habits (Rice and Chapman 1971). The precise reason why these species showed this higher occurrence in the open area rather than in the no-take area is not yet clear, but because the no-take and open areas are contiguous and within the same muddy habitat, their significantly higher occurrence is probably related to some sort of benefit they obtain that is favoured by the trawling activity, such as an increase in damaged potential prey and therefore a concomitant increase in scavenging habits. *P. longirostris* is known to prey mainly on benthic bivalves, polychaetes, crustaceans and foraminifera (Kapiris 2004, Nouar et al. 2011), which are prone to being damaged by the trawl net, so they become more available to predators and scavengers.

N. norvegicus and *G. rhomboides* share the behavioural characteristic of being rather sedentary, because they inhabit burrows dug into the mud and remain therein during their non-active phase (Rice and Chapman 1971). They possess a strong rhythmic behaviour, particularly the Norway lobster (Atkinson and Naylor 1973), with nocturnal activity at these relatively shallow continental shelf depths, while they are active during the day on the muddy bottoms of the upper slope, which they also inhabit (Aguzzi et al. 2003). This differential catchability probably protects the Norway lobster continental shelf populations, because most of the population remain in their burrows, during trawling, which takes place during daytime. An additional feature also shared by these two species is their reported occasional scavenging habits (Bozzano and Sardá 2002), which may be enhanced by trawling. Another aspect that can affect occurrence and abundance differentially is the respective home/foraging range of each individual species. These effects, if any, should be more evident in slow-moving, territorial species than in active, highly mobile species (Bender et al. 2021). A non-negligible effect could also be that trawling removes larger predators and may therefore allow smaller species and juveniles to increase their survival aas well as improve their biological condition (Dimarchopoulou et al. 2018).

The rest of the collected species showed no preference for either of the two areas. This may be because the study area had not yet evolved sufficiently to show significant differentiation (Kaiser et al. 2006). In other areas, both the overall surface of the no-take areas and the time elapsed since their closure have been shown to influence their efficiency for population protection (Claudet et al. 2008).

From the strictly fisheries point of view, decapod crustaceans are not the main target species of the study area, but they are important commercialized bycatches of the trawl fishery, especially in the case of the penaeid shrimp *P. longirostris* and the Norway lobster *N. norvegicus.* Crawfish, *Palinurus elephas,* occurred more frequently in the no-take area, although not significantly because of their scarceness, but they probably also benefit from the fishing closure. Regular monitoring and analysis of the population state of both target and bycatch species would therefore be a useful tool for producing adaptive management measures for species of fishing interest and for the habitats they inhabit.

Most species showed no significant differences in size between the no-take and open areas. This was particularly evident in species known to show a high degree of swimming activity, such as the shrimp *P. longirostris* and the portunid swimming crabs *L. depurator* and *M. tuberculatus*. The large, well-protected hermit crabs *D. arrosor* showed no significant size differences, because the gastropod shells they use may provide them with protection and allow them, to a certain degree, to inhabit the trawled area (Williams and McDermott 2004).

Significant differences between mean sizes inside and outside the no-take area were found in three species, namely *Macropodia tenuirostris*, *Pagurus prideaux* and *Pagurus cuanensis*, with sizes being significantly larger outside the no-take area in all of them. Additionally, the largest individuals were found inside in six out of eight species, and the smallest individuals were also found inside in five out of eight species. This probably indicates that the no-take area acts as a recruitment and/or juvenile development area for these species, as well as offering growth protection allowing individuals to reach larger sizes. Spillover of larger individuals may therefore take place for some of these species from the no-take area to the open area. In the rest of the analysed species, no significantly different sizes were observed between the areas, which probably indicates that the no-take area was not acting differentially as a recruitment or juvenile development area for these species, or that the species mobility was higher, and individuals could easily exchange habitats. Nevertheless, the success of the policy concerning crustacean sizes may not yet be fully ascertained, because the present results suggest that ecosystemic differences were just starting to become differentiated. Complementary and periodic samplings of biological and ecological key aspects, such as faunistic richness, species sizes and key biological information, such as reproduction, growth and behaviour, will be needed to properly monitor the differentiation between the two habitats over time, and to determine the role of no-take areas in the performance of the fishery, since all evidence indicates that the establishment of the no-take area is in the temporal process of recovering biodiversity and biological population fitness.

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