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Treball de Fi de Grau

Astrospartus mediterraneus (Echinodermata: Ophiuroidea) in the Cap de Creus marine area: Ecological characterization of an emblematic species

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Grau en Biologia

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Agraïments

M'agradaria començar agafant com a referència l'eslògan de Google Acadèmic que és el següent: Sobre les espatlles de gegants. Aquest eslògan resumeix com m'he sentit jo en durant el transcurs d'aquest treball.

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Així que de tot cor, GRÀCIES

Resum

Títol: *Astrospartus mediterraneus (Echinodermata: Ophiuroidea) in the Cap de Creus marine area: Ecological characterization of an emblematic species*
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Data: Gener 2020
Paraules clau: Astrospartus mediterraneus*, equinoderm, ofiura, distribució geogràfica, distribució batimètrica, creixement poblacional, Cap de Creus, NO Mar Mediterrani*

A l'any 2016, es va començar a detectar un creixement poblacional mai abans observat de l'espècie *Astrospartus mediterraneus* als caladors artesanals del Cap de Creus (Girona, NO). És una espècie pertanyent a la classe Ophiuroidea, considerada la classe més diversa del fílum dels equinoderms. Tanmateix, estem al capdavant d'una espècie poc coneguda i amb poques observacions associades abans d'aquest creixement. És per això, que l'objectiu d'aquest treball és aportar dades ecològiques sobre aquest ofiuroïdeu per tal d'omplir els buits de coneixement d'aquesta espècie.

Entre l'abril i l'agost del 2018, en el marc del projecte MITICAP, es van fotografiar un total de 466 individus que van ser pescats durant les sortides de pesca amb els pescadors artesanals de les confraries de Cadaqués i del Port de la Selva, les fotografies dels quals van ser analitzades per obtenir una estructura de talles de les poblacions de l'espècie i també per obtenir la seva distribució geogràfica i batimètrica. A més, es va realitzar l'enregistrament de 19 videotranssectes per mitjà de càmeres de vídeo ROV (Vehicle submarí operat remotament) dels els quals es van analitzar amb l'objectiu d'obtenir la seva distribució geogràfica i batimètrica a més d'obtenir la relació que estableix l'espècie amb el medi on viu.

Aquest estudi aporta per primera vegada informació sobre la distribució geogràfica i batimètrica, l'estructura de talles i sobre com *A. mediterraneus* es relaciona amb el medi que l'envolta.

Els resultats obtinguts mostren que l'espècie té una àmplia distribució dins de la zona mostrejada, on va ser detectada a partir dels 35 metres de profunditat, i que els individus s'han trobat majoritàriament disposats sobre gorgònies. L'estructura de mides obtinguda suggeriria que les poblacions d' *A. mediterraneus* al Cap de Creus són relativament joves.

Aquest estudi proporciona informació ecològica de l'espècie, la qual pot servir com a referència per altres casos on també es vulgui estudiar l'*Astrospartus mediterraneus*.

Summary

Title: *Astrospartus mediterraneus (Echinodermata: Ophiuroidea) in the Cap de Creus marine area: Ecological characterization of an emblematic species*
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Date: January 2020
Keywords: Astrospartus mediterraneus*, echinoderm, ophiura, geographical distribution, bathymetrical distribution, size distribution, population growth, Cap de Creus, NW Mediterranean Sea*

Since 2016, a population growth of *Astrospartus mediterraneus* was detected for the first time in the Cap de Creus marine area (Girona, NW). This species belongs to Ophiuroidea class, considered the largest class of Echinodermata Phylum. However, it is considered an unknown basket star species with few observations in the area before the population growth. Therefore, the aim of the study is to assess the ecology of this ophiuroid to deepen the knowledge of this species.

Between April and August of 2018, within the framework of MITICAP project, 466 individuals which were by-catch during the artisanal fishing, were photographed and analysed in order to obtain the size frequency distribution of its populations and obtain the geographical and bathymetrical distribution. Moreover, 19 videotransects recorded by means of ROV (Remoted Operated Vehicle) video cameras, were analysed to assess the geographic and bathymetric distribution and determinate the relationship between *A.mediterraneus* and the environment.

This study is the first work about the geographic, the bathymetric and the size frequency distribution of the species and how it relates with the environment.

Results show that *A. mediterraneus* had a wide geographic distribution along the sampled area, where it inhabits depths higher than 35 meters. All individuals were mainly found over gorgonians and size structure suggests that *A. mediterraneus* populations are young. This study provides ecological data about the study species potentially providing a reference for other studies about *Astrospartus mediterraneus*.

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1. Introduction

1.1. Introducing the Echinodermata Phylum

Echinodermata is an exclusive marine invertebrate phylum composed by around 7.000 living species and 13.000 fossil species (Pawson, 2007). Currently, the phylum is divided in 5 classes, those being: Asteroidea (sea stars and sea daisies), Ophiuroidea (brittle stars, basket stars and snake stars), Echinoidea (sea urchins, heart urchins and sand dollars), Holothuroidea (sea cucumbers) and Crinoidea (feather stars and sea lilies), (Byrne & O'Hara, 2017) (**Fig.1)**.

Fig.1. Representative classes of echinoderms. **A)** Sea stars (Asteroidea); **B)** Crinoid (Crinoidea); **C)** Sea urchin (Echinoidea); **D)** Sea cucumber (Holothuroidea); **E)** Brittle stars (Ophiuroidea). (**Source:** Ecología Verde, 2019)

Echinodermata are of paramount importance for marine ecosystems, as they play a key role in its communities' structure (Hooker, Solís-Marín, & Lleellish, 2005) and cover wide range of depths, habitats, feeding and reproduction strategies (Chammem, Ben Souissi, & Pérez-Ruzafa, 2019).

Regarding their feeding behaviour, echinoderms have developed a wide arrange of strategies adapted to the different environments they inhabit. The most common strategy is that of suspensive feeding, for which echinoderms feed on suspended particles, phyto- and/or zooplankton that they capture from the water column (Brusca, R.C. and Brusca, 2003). Other feeding mechanisms include the predation on other invertebrates like crustaceans, mollusca or gastropods (Dearborn, Edwards, & Fratt, 1991; Beddingfield &

McClintock, 1993); scavenging on the remaining' of dead organisms (McClintock, 1994; Brusca, R.C. and Brusca, 2003) grazing, eating benthic algae and plants (Contreras & Castilla, 1987); or even as deposit feeders, feeding on the organic matter that drift down through the water column and deposit on the seafloor (Massine, 1982).

Echinoderms have sexual and asexual reproduction although not all groups have both kinds of reproduction. Since all species in this phylum have sexual reproduction, asexual reproduction occurs only in holothuroidea, asteroidea, ophiuroidea and echinoidea classes (Balser, 2004). There are two mechanisms of asexual reproduction: fission and fragmentation (Alves, Pereira, & Ventura, 2002; Dolmatov, 2014), whose aim is regenerate "lost" parts and generate new individuals from divided parts of the original ones (Brusca, R.C. and Brusca, 2003). Regarding the sexual reproduction, most of the species are dioecious (they only have one gender per individual), but some species can be hermaphrodites (they have both genders in one individual) (Vail, 1987; Brusca, R.C. and Brusca, 2003). The purpose of sexual reproduction is generate larval organisms to allow colonization to new habitats (Alves et al., 2002).

Regarding their ecological importance, it is known that Echinodermata contributes to wide array of different ecological functions. They are known to contribute to inorganic and organic carbon cycling, being a huge storage of calcite ($CaCO_3$) due the high biomass that they represent in the marine real (e.g. Migne et al., 1998; Ellis and Rogers, 2000; Ruhl 2007). Moreover, when individuals die, there is a direct release of carbon to the sediments where it becomes available for other organisms (Lebrato et al., 2010). Besides the contribution to carbon cycle, during feeding and locomotion activities echinoderms can rework the soil and the sediments increasing the heterogeneity and oxygen circulation (Lohrer et al., 2005; Vardaro, Ruhl, & Smith, 2009). This bioturbation contributes to the maintenance of sediment biodiversity and to the totally absorption of benthonic oxygen (e.g. Smith et al., 2008). It is also known that they have a paramount role in food webs due to their wide feeding strategies (Solís-Marín & Laguarda, 1998). As so, a removal or an increase in echinoderm's abundances could have some harmful effects on the oceans ecosystems, as the outbreak of some Echinodermata species have been observed to highly impact, disturb and radically change their habitats (Tegner & Dayton, 2000; Rotjan & Lewis, 2008).

Finally, structure and dynamics of echinoderms populations and communities are determined by physical, chemical and biological factors (Barry & Dayton, 1991) like temperature, salinity or hydrodynamics (Drouin, Himmelman & Béland, 1985; Tyler, Young & Clarke, 2000), availability of food resource (Menge, 1992), predation (e.g. Sala, 1997) and competition relationships (Hagen & Mann, 1992), and also diseases (Hagen, 1999), yet they are still poorly understood (Calero, Ramos, & Ramil, 2018).

1.1.1. The Mediterranean Basket Star, *Astrospartus mediterraneus* (Risso, 1826)

With 2064 known species, the ophiuroidea class is the largest class into the Echinodermata phylum (Stöhr, O'Hara & Thuy, 2019), from which *Astrospartus mediterraneus* (Risso, 1826) is the sole representative of the gorgonocephalidae family (order euryalida) in the Mediterranean Sea (Ocaña & Perez-Ruzafa, 2004). The main difference between ophiuroids and other echinoderms is that they have the central disc clearly set off from arms (Stöhr, O'Hara & Thuy, 2012).

Astrospartus mediterraneus (**Fig.2**) is a suspension feeder and it is found over gorgonians and sponges (Zibrowius, 1978). A mitochondrial genome work showed that our species has the smallest genome (16.238 pair of bases) of the Gorgonocephalidae family, and thus, has one of the best preserved genome between other ophiuroid families (Galaska, Li, Kocot, Mahon, & Halanych, 2019).

According to World Register of Marine Species (WoRMS), in the Mediterranean the species is distributed mainly in the following main areas: Gulf of Lion (Françe and Spain) and Ligurian Sea (Italy); Napoles (Italy); and Aegean Sea (Greek and Anatolian peninsulas) and Ioian Sea (Albania, Italy, Greece) (Stöhr, O'Hara & Thuy, 2020), being an endemic echinoderm species. Nevertheless, its population dynamics and habitat selection patterns still remain unknown.

Fig.2. Study species: *Astrospartus mediterraneus***.** **a)** Front view; **b)** Back view.

1.2.Current situation of *A. mediterraneus* in the Cap de Creus marine area

The presence of *A. mediterraneus* in the Cap de Creus area (Gulf of Lion) had already been known since decades ago (Mallol, 2010), yet with just a few sightings, being considered as rare as in other areas of the Mediterranean (Zibrowius, 1978).

The Cap de Creus area has been studied for many years, and many studies have been performed on different topics like hydrodynamics (e.g. Millot, 1990), geomorphology of the submarine canyons (e.g. Lastras et al., 2007), biological communities (e.g. Madurell et al., 2012), biological interactions in the deep-sea area (e.g. Ambroso et al., 2013) and natural and human impacts (e.g. (Ulses, Estournel, Bonnin, Durrieu de Madron, & Marsalei, 2008; Clark et al., 2016). All these studies allowed a high knowledge of this area and nowadays it is well characterized due all the research effort. However, previous studies based on video transects did not register the presence of *A.mediterraneus* in a wide sampled area of Cap de Creus (Gori, personal communication, 2009; Dominguez, 2018).

Nevertheless, in 2016, a possible population burst of this species was inferred by artisanal fishermen of Cadaqués and Port de la Selva (Cap de Creus, Girona), as the species started appearing commonly as an unwanted by-catch. This fact has started to be noticed as a problem for the artisanal fisheries since a large number of individuals become entangled in the fishing networks causing an unknown economic impact. Furthermore, it is worth to mention that blooms of the species were recently detected in Banyuls area (France) (Grinyó, personal communication, 2019) and in Italy coasts (Lorenzo, personal communication, 2019).

The absence of previous studies on this species' ecology has created a special interest for the scientific community that considers urgent and necessary to investigate this phenomenon. As so, for all that has been said, the aim of the present study is to contribute to the research and knowledge of this ophiuroid and mainly focuses on the ecological characterization of the population of *A.mediterraneus* in the area of Cap de Creus.

2. Objectives

The present study aims to provide new ecological data about an unknown, rare, and emblematic Mediterranean ophiuroid:, the basket star or *Astrospartus mediterraneus*, which populations in the marine area of Cap de Creus (Gulf of Lyons, NW Mediterranean Basin) have seen a recent skyrocketing increase. The main objectives of the study are:

1) To determine the geographic and bathymetric distribution of the species in the study area.
2) To analyse the morphology and the size-distribution frequency of the by-catched populations.
3) To determine the relationship of the populations with the environmental factors.

3. Materials and methods

3.1. Study area

The studied area of is located at the marine area of Cap de Creus, in the north-western region of the Mediterranean Sea (42º19'12"N, 03º19'34"E). This area is formed by a complex network of submarine canyons, being Cap de Creus canyon the south-westernmost in the Golf of Lions margin (Ribó, Puig, Palanques, & Lo Iacono, 2011). The canyon axis has a northwest to southeast orientation, reaching the continental shelf its maximal depth in 2200 m (Orejas et al., 2009).

There is a general water circulation from NE to SW due to the Northern current (DeGeest et al., 2008). Northern winds (Tramontane and Mistral) are dominant in this marine area (Ulses et al., 2008). Tramontane promotes occidental coastal downwelling, while Mistral promotes northern coastal downwelling (Millot, 1990). These winds are cold and dry, having a cooling effect in winter. They are also responsible of dense water origin (Ulses et al., 2008). Moreover, the main discharge of fresh water comes from the Rhone river, although other small rivers can occasionally deliver fresh water, being the primary off-shelf sediment in the Cap de Creus area (DeGeest et al., 2008; Ulses et al., 2008). Being between 80 and 90% of continental shelf sediments are provided by this river (Courp & Monaco, 1990).

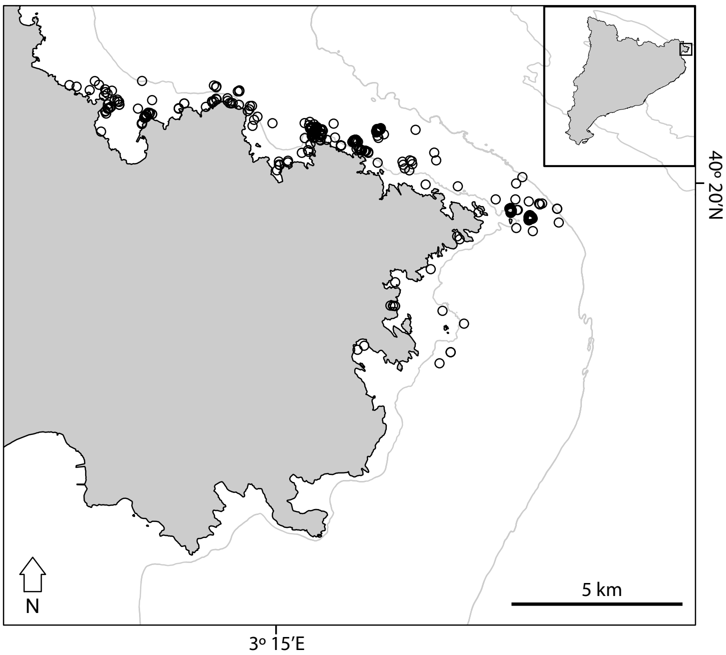


Fig. 3. Map of study area of Cap de Creus which shows every studied station in the Cap de Creus where *A.mediterraneus* was found.

3.2. Data collection

3.2.1. Video recording and video analyses

A total of 19 video transects were recorded during the last five days in July of 2018 with the Atlantic Explorer vessel. The transect lengths ranged from 174.03 m to 1154.66 m long, with a total distance of 9 km covered, with video transects recorded between 11.5 m and 80 m depth (See **Annex 1**). All video resources were recorded using a remoted operated vehicle (ROV), model ROV Perseo, operated by the technical staff of the company QStar ROV. The device was equipped with a high definition (HD) camera for all video transects, with an additional 4K camera for 11 of them, depth sensors and two parallel lasers beams that provided a fixed scale (30 cm between each laser), used in subsequent video analyses. All video transects were recorded in digital format. The emplacement of the transects was established with the help provided by the fishermen, accordingly to their most frequented fishing grounds.

Video transects were provided by the Research Group of Benthic Suspension Feeders from Institut of Marine Sciences (ICM) – CSIC.

The video transects were analysed by subdividing them in sampling unit of $2m^2$ to allow for a finer scale analysis. This choice is justified by previous studies in these area as well as other studies with benthic marine fauna in the Mediterranean (e.g. Grinyó et al., 2016; Dominguez, 2018).

Video transect analyses were carried out with Final Cut Pro 7 software (Apple Inc.). The transect onset was determined once the ROV get over the seabed and started moving in straight line following the ground line. For every individual of *Astrospartus mediterraneus* observed the following information was recorded: the elapsed time since the beginning of the video, the real time, the depth, its substrate (epiphyte organisms, rocky bottoms or sandy and muddy substrates) and the geographical coordinates. Along the video analysis, the type of substrate and its slope were registered too. The non-profitable sequences (e.g dusty ones) were discarded.

Time reference was previously transformed into a known position (P=t*v), where (t) is the time which every individual was found and (v) the velocity of the ROV. To calculate this data, firstly, the total time of each transect was transformed into seconds (s). The total length was previously known in meters (m). Then, distance (m) was divided by the total time (s) (V=Distance (m)/Total time (s)). All these data were obtained following the methodology as in Grinyó et al. (2016).

All video analyses were entirely performed by the Mireia Montasell, the author of this final degree project.

3.2.3. Photo gathering and photo analyses

A total of 410 photographs of 466 individuals of by-catched *Astrospartus mediterraneus* were taken onboard of the fishermen's boats during the last months of spring and summer months (April, May, June, July, August) of 2018. Photos were taken onboard using a digital camera and a scale element was used for scaling the photograph for the following morphometric analyses. For each fishing outing, the correspondence associated data was collected: researcher name, date, fisherman data, environmental data (wind, sea conditions, hour of departure), information about the boat and fishing gear data (fishing ground name, type of gear, main objective fishing species, draft date, coordinates).

The photo analyses were carried out with Macnification v.1.8 (Orbicule). For each individual, the diameter, the perimeter and the area of the central disc was measured.

All these data were exported to an excel file. There, the average of the fifth diameters and the standard deviation (SD) for each individual was calculated, and the perimeter and area were annotated. This data collection would be used to do morphometric analyses and size-frequency distribution.

Besides these morphometric data, quantitative data (e.g. abundance) was also obtained from *A.mediterraneus* counting. These data would be used to do both its geographic and bathymetric distribution.

Photographs were provided by the research group Benthic Suspension Feeders form ICM– CSIC. The analysis of these photos was entirely performed by the Mireia Montasell, the author of this final degree project.

3.3. Geographical distribution and bathymetrical distribution

Geographical distribution of the study species was carried out plotting a georeferenced map of densities and abundances, obtained from the video analyses and fishing data, respectively. To generate the map, the R software platform (R core team) was used and *raster* (Robert, 2016)*, sp* (Bivand et al., 2013) *and rgdal* (Bivand et al., 2017) packages were needed.

In order to conduct the bathymetrical distribution, all the bathymetric range sampled was subdivided into 5 m interval, all the range depth sampled; in video analyses (25–80 m) and fishing data (30–100 m). Each unit sampling is within these interval depths. Then, boxplots and bagplots were generated using the R software platform (R core team) and *aplpack* (Wolf, 2019) package was needed to carry out the bagplots. These two kind of plots show the distribution frequency of numerical data, in the present study, this numerical data represents the density and abundance of *A.mediterraneus* in every depth range interval.

Boxplot are widely used and standardized graphical displays, which are based a five-number summary: the minimum (lowest data point excluding any outliers; represented as the lower whisker), the maximum (the largest data point excluding any outliers; represented as the upper whisker), the sample median (50th Percentile, represented as a black line draw inside the box), and the first (25th Percentile) and third (75th Percentile) quartiles (represented as the lower and upper part of the box respectively). Additionally, outliers are represented as circles (Rousseeuw, Ruts, & Tukey, 1999). On the other hand, a Bagplot is multidimensional representation of a series of boxplots, for which the "depth median" is the centerpoint, which is surrounded by the "bag" containing the n/2 observations. Outside the bag there is the "fence", which magnifies the bag by a factor of 3. Observations between the bag and the fence are marked by a red line, whereas observations outside the fence are flagged as outliers and represented as red dots (Rousseeuw et al., 1999).

3.4. Morphological analyses and size-distribution frequency

In total, 466 individuals were analysed, and the mean diameter, perimeter and area were taken as morphological data. Firstly, a Pearson correlation test was done between diameter and perimeter by means *cor.test* (R Core team) function to use one of these morphometric data to the following analyses.

To understand the size-distribution frequency of the populations, histograms were produced to visually represent the data, whereas skewness and kurtosis tests were performed to better understand the said populations. It was determined that each population was a single fishing event (fishing station), while only populations over 10 individuals were considered suitable for the analyses, as lower values could compromise the skewness and kurtosis tests. Size-distribution histograms were produced for each population by grouping the individuals by diameter (categories 0–1 cm, 1–2 cm, 2–3 cm, 3–4 cm, 5–6 cm and 6+ cm) and plotting the histograms by means of *fdth* library (Faria et al., 2016).

Additionally, the skewness and kurtosis for each suitable population was calculated by means of *agostino.test* (Komsta & Novomestky, 2012*)* and *anscombe.test* (Anscombe & Glynn, 1983) respectively, both inside the *moments* library available in R software platform. Skewness is a measure that evaluates the symmetry of a distribution based on its mean (Linares et al., 2018). So, if the *p-value* is significant (*p-value* < 0.05), data distribution does not follow the symmetry, thus, the distribution is asymmetric. If values are positive, data show a dominance of small-size organisms, but if there are negative values, large organisms' prevalence in population distribution. In the other hand, kurtosis measure the peakedness of a distribution near its central model (Linares et al., 2018). So, if the *p-value* is significant (*p-value* < 0.05), a particular size prevalence inside the population given.

3.5. Relation with environmental factors (ANOVA)

Astrospartus mediterraneus densities were tested against the selected environmental variables, those being depth, (10–30 m, 30–50 m, 50–70 m, 70–90 m) substrate (Soft sediments, cobbles and pebbles, rock), slope (Horizontal, slopping, vertical), Derailed Fishing Gear (DFGs, subdivided into DFGs/m2) and ecosystem engineers (ENs; Soft corals, gorgonian forest, barren grounds)) as the categorical variables and the data inside the brackets are the following categories. These densities were tested by means of an Analysis of Variance (ANOVA), followed by a *post-hoc* Pairwise test to assess their importance as habitat in regard to *A. mediterraneus* populations. Nevertheless, before ANOVA it was made a Shapiro-Wilk test to check the normality of the data and homoscedasticity test to check the variance homogeny where both tests were performed by means *shapiro.test* (Gonzalez-Estrada & Villasenor-Alva, 2013) for normality test and *bartlett.test* (Savchev & Nason, 2018). The aim of this statistic analyses is to compare the differences between the mean of each category. The null hypothesis of these tests is that there is no effect of each variable regarding to the distribution of the species. As so, a significative *p-value* (equal or lower than 0.05; *p-value* ≤ 0.05) for the ANOVA test would indicate that the evaluated variables presented statistical differences between their groups, whereas the Pairwise test allowed to determine between which groups these differences were both tests were performed with R software by means of the *aov* function (Chambers et al., 1992) and the *pairwise.t.test* (R Core Team, 2019).

To better represent the selected environmental variables in a graphic environment, those where represented by means of a scatterplot graphic performed by *ggplot* function inside the *ggplot2* package (Wickham et al., 2019) in R software platform. Scatterplots are simple diagram which display values for typically two variables for a set of data. Additionally, if the points are coded (e.g. color/size), additional variables can be displayed. As so, all scatterplot represents the abundance of *Astrospartus mediterraneus* (Y axis) against depth (X axis), whereas points are sized in relation to *A.mediterraneus*' density on a given point. Finally, a scatterplot with its points coloured was produced for the 4 left environmental variables tested (Substrate, slope, DFGs, ENs), with points coloured in accordance.

4. Results

4.1. Geographic and bathymetrical distribution

Regarding its geographical distribution, *Astrospartus mediterraneus*, was distributed along the northern and eastern part of the Cap de Creus marine area. However, its biggests populations are found at the north west of the area where the species showed densier aggregations than in the other sampled points (**Fig.4a**). Even so, the greatest abundances (over 75 individuals) occurred in just a few points, which were spread along the entire sampled area (**Fig.4a**). All the sampled points were close to the coastal line and located at the 50 m depth isobath.

In the other hand, density maps from the video transects, found the highest aggregations at the north area, close to Port de la Selva fishing ground (**Fig.4b**), where the highest abundances of fishing events were also recorded **(Fig.4a)**. Nevertheless, the video transsects also showed dense populations of *A.mediterraneus* towards the Maça d'Oros Island, at the vertex of the cape, whereas any specimen was recorded in fishing events on the area. This could respond to a bias in the fishing evet data, as fewer fishing events were performed at this area.

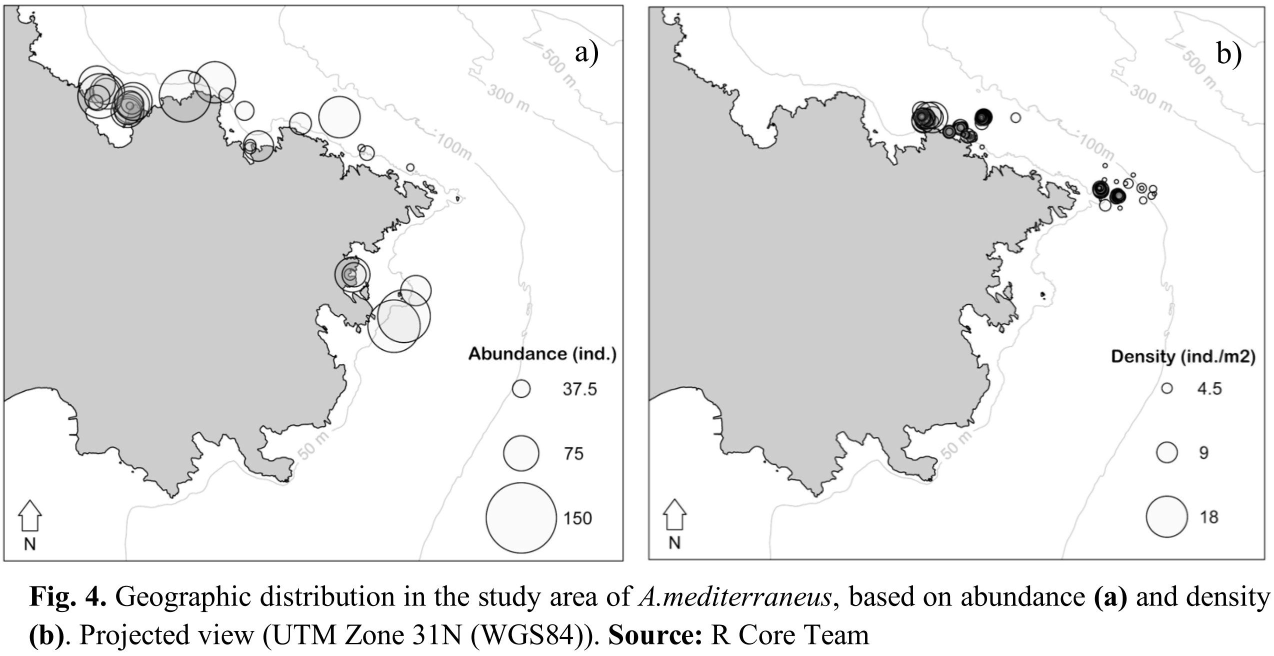


Fig. 4. Geographic distribution in the study area of *A.mediterraneus*, based on abundance **(a)** and density **(b)**. Projected view (UTM Zone 31N (WGS84)). **Source:** R Core Team

As Figure 5 shows, bathymetrical distribution of *A.mediterraneus* showed a clearly prevalence for a depth range between 50 and 80 m. Density boxplots (**Fig.5a**) and abundance boxplots (**Fig.5b**) showed the presence of individuals concentrated between 35–80 m and 40–85 m respectively. Specifically, a clear increase in abundance can be found 65–75 m depth and while not as clear cut in the abundance graphs, the same tendency can be observed in the density graphics. Nevertheless, the density boxplots and the bagplot between 50–90 m depth present a high number of outliers, with densities of up to 15 ind./m^2. In abundance boxplots (**Fig.5b**) the maximum abundance registered are between two depths ranges (from 65—75 m) and outliers present in these boxplots are represented into these depths. Following these abundances, between the 45–65 m there are registers of approximately 20 individuals per interval depth. Finally, depth ranges between in 25—55, and 85–90–95 m depth show the lowest values both in terms of density and abundance.
Furthermore, bagplot graphics (**Figs.5c; 5d**) complement boxplot graphics to help to understand better the results. In order to simplify the previous data showed by means boxplots (**Figs.5a; 5b**) to a single graphic that contains all data.

Density bagplot (**Fig.5c**), showed an increasing density of the species between the 35 and 80 m depth. The bulk of values in abundance bagplot (**Fig.5d**) are focused between 45 to 70 m depth, a narrower range than densities values of the graphics commented below. Additionally, values deeper than 80 m depth are regarded as outliers in the bagplot.

A global view of bathymetrical distribution shows the study species depth range begins at 35 m and ends at 100 m. However, the highest densities and abundances are concentrated towards 55 to 80 m.

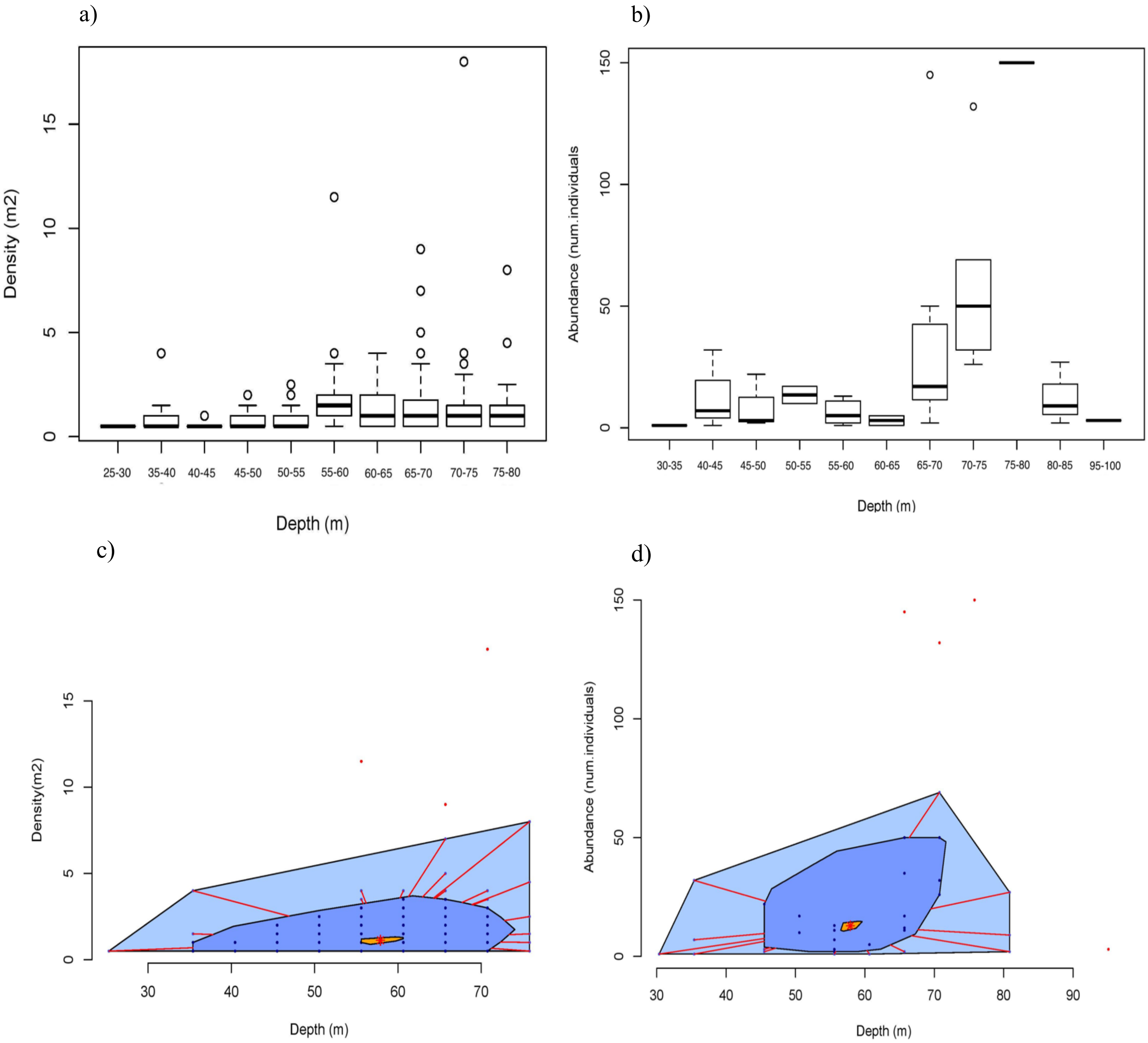


Fig.5. Bathymetrical distribution of *Astrospartus mediterraneus***. Boxplots** represents the density **(a)** and abundance **(b)** of the species at each interval depth. Black line inside the boxes represent de median density **(a)** and abundance **(b)** value; the side lines represent the lower (25%) and upper quartile (75%); the whiskers represent the minimum and maximum values excluding the outliers; and dots represent the outlier values. **Bagplots** represents the density **(c)** and abundance **(d)** of the species including all the interval depth range. Orange bag with an asterisk represents the median of depth value; Dark blue polygon (bag) represents the 50% of values; Light blue polygon (fence) represents the values which are not inside the 50% and there are not outliers; Red dots represent the outlier values; Red lines connect the fence dots with the inner polygon (bag).

4.2. Size-distribution frequency population and morphology

A high correlation (R^2 = 0.9585842) was found between the morphometric variables diameter and perimeter. Therefore, diameter was preferred over perimeter to performed the histograms for the size-frequency distribution of each population (**Fig.6**). Every fishing station where *A.mediterraneus* were by-catched in numbers equal or higher to 10 was considered a single population, for a total of 10 populations evaluated. Messina fishing station population was chose as an example due to the highest number of individuals by-catched which biggest number of individuals are more suitable for the analyses than the populations with lower number of individuals. However, consider all *Astrospartus* by-catched as a single population it was not considered due to the interest of having each population characterized for future population monitoring, other populations are showed at **Annex 2**.

Most population found had a size-frequency between 2 and 3 cm of central disc diameter, followed by size classes between 1 and 2 cm and 3 to 4 cm were the second and third more abundant categories and, altogether, these categories represented up to 80–95 % of all the individuals in almost all of the evaluated populations (**Fig.6**). Size classes comprised between 4 to 6 cm, represented percentages lower than 10%, whereas 0 to 1 cm and over 6 cm sizes classes represented less than 5% for all populations. Size-distribution showed a significantly positive skewed populations (*p-value*= $2.964e^{-08}$ of skewness test; *p-value* < 0.05) with a dominance by small to medium size classes. Moreover, kurtosis test showed a significantly peakedness (*p-value*= $6.223e_{-}^{05}$; *p-value* < 0.05) with a clearly size prevalence of 2–3cm individuals.

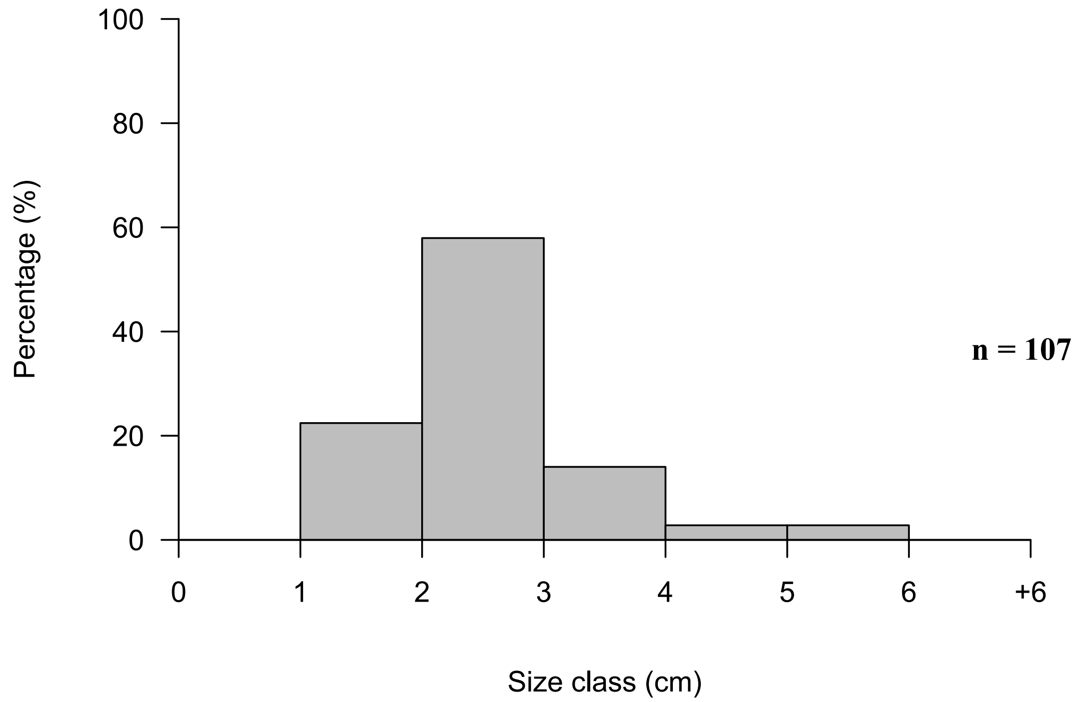


Fig.6. Example representation of size-frequency distribution of *A.mediterraneus* population in Messina (24/04/18) fishing ground station; Net 1. Number of individuals are showed in (n). For graphics regarding the other populations, see **Annex 2**.

4.3. Relationship with environmental factors

Normality test and homoscedasticity test were both non-significative (*p-value* = 0.409; *p-value* = 0.245), respectively. As so, both tests confirm that there was significative differences between each variable tested of the *A.mediterraneus* in the Cap de Creus.

All environmental variables except DFGs were found present statically significant differences between their evaluated categories and the abundance of *A.mediterraneus* (see **Table 1**). For each category tested for the depth categorical variable, there was only one depth range (50–70 vs 70–90) which had not significative differences (F'= 62; *p-value* = 0.001112). Furthermore, substrate variable as it is showed in **Table 1**, there was no significative differences between the mean of rock and cobbles and pebbles category (F'= 75.564; *p-value* = 0.04811). Finally, the ecosystem engineer's categorical variable, showed significant differences between Barren Ground vs. Soft Corals (F'= 31.36; *p=value* = 0.01257).

Table. 1. Relationship of A.mediterraneus with environmental factors. Environmental factors include: Depth, Substrate (Rock, Soft Sediments and Cobbels and Pebbels), Slope (Horizontal, Slopping and Vertical), Ecosystem Engineers (ENs) (Barren Grounds, Soft Corals and Gorgonian Forests) and Derailed fishing gears (DFGs) (0,1,2 and 3). Significance levels for Categories tested by means an ANOVA pairwaised are represented as follows: * (p-value < 0.05) ** (p-value < 0.01) *** (p-value < 0.001)

Factors	**Categories tested**	**F**	**p-value**
Depth			
	10-30 vs. 30-50	62	0.001112**
	10-30 vs. 50-70	213	2.2e-16***
	10-30 vs. 70-90	55	0.000865***
	30-50 vs. 50-70	241.89	8.812e-09***
	30-50 vs. 70-90	59.559	0.007446**
	50-70 vs. 70-90	62.608	0.4084
Substrate			
	Rock vs. Soft Sediments	295	2.2e-16***
	Rock vs. Cobbles and Pebbles	75.564	0.04811
	Cobbles and Pebbles vs. Soft Sediments	33	9.884e-05***
Slope			
	Horizontal vs. Slopping	254	0.0008149***
	Horizontal vs. Vertical	254	0.0008149***
	Slopping vs. Vertical	254	0.0008149***
ENs			
	Barren Grounds vs. Soft Corals	31.36	0.01257
	Gorgonian Forests vs. Soft Corals	133.81	1.56e-08***
	Barren Grounds vs. Gorgonian Forests	41.206	0.007819**
DFGs			
	0 vs. 1	45.32	0.4081
	0 vs. 2	106.42	0.2151
	0 vs. 3	34.56	0.1154
	1 vs. 2	90.34	0.02762
	1 vs. 3	253	0.03225
	2 vs. 3	36.503	0.01183

In this regard, there is a clear density increase for *A.mediterraneus* in waters of the continental shelf (from 50 m depth). Nevertheless, *A.mediterraneus* populations between 50–70 and 70–90 m depth showed no significative differences (F'= 62; *p-value* = 0.001112), both possessing the highest density values (**Fig7a-d**). Furthermore, a clear environmental pattern was observed, with *Astrospartus* significatively occurring towards rocky substrates over cobbles and pebbles and soft substrates (**Fig.7a)**.

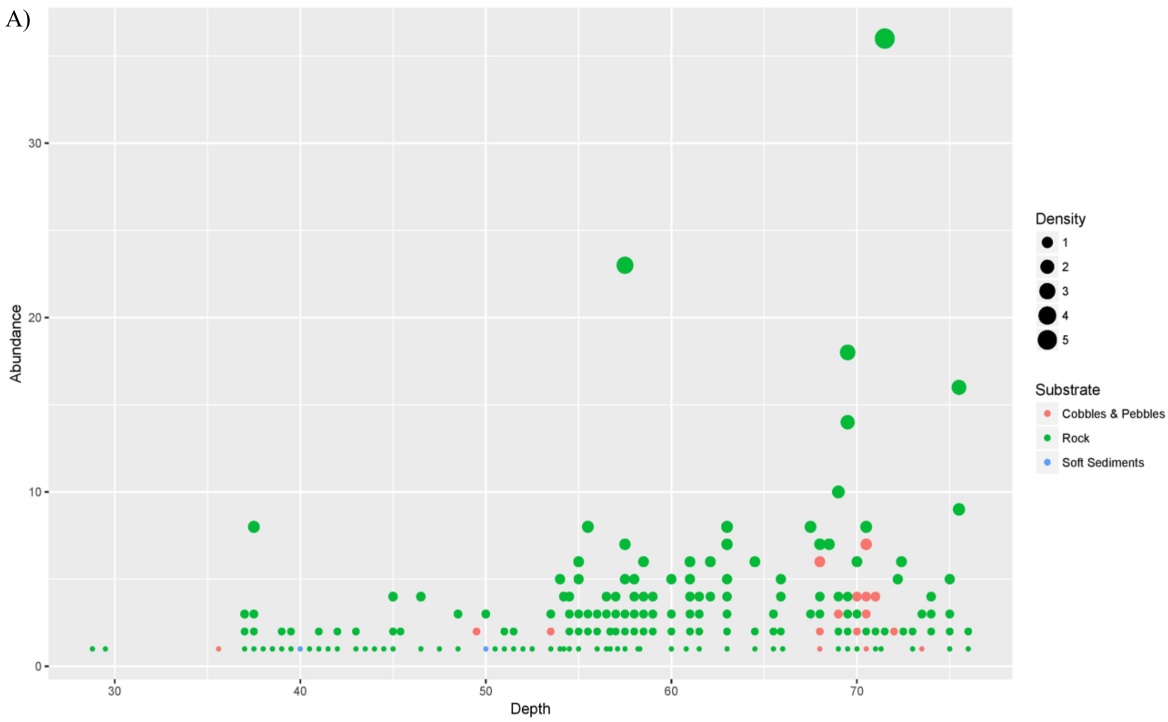


Fig.7a. Scatterplots graphics showing the relationship between the abundance of *A.mediterraneus* and the environmental variables. Each point shows the density of the study species with depth. The coloured points indicate the relation with the **type of substrate**: *Red:* Cobbels and Pebbels; *Green:* Rock; Blue: Soft Sediments.

Regarding the relationship among the species abundance and other environmental factors, there was a clear prevalence of the species for the gorgonian forests, (**Fig.7b**). However, the species was also recorded on habitats dominated by soft corals and barren grounds, although with considerably lower densities (**Fig.7b**).

Slope, as an environmental factor, showed more variety of preferences (**Fig.7c**). However, the species is mostly found in slopping areas, which commonly overlapped with the gorgonian forest habitats (**Fig.7b**). Finally, some areas of the shallowest waters are dominated by a vertical walls, which barely occur in deeper waters (**Fig.7c**).

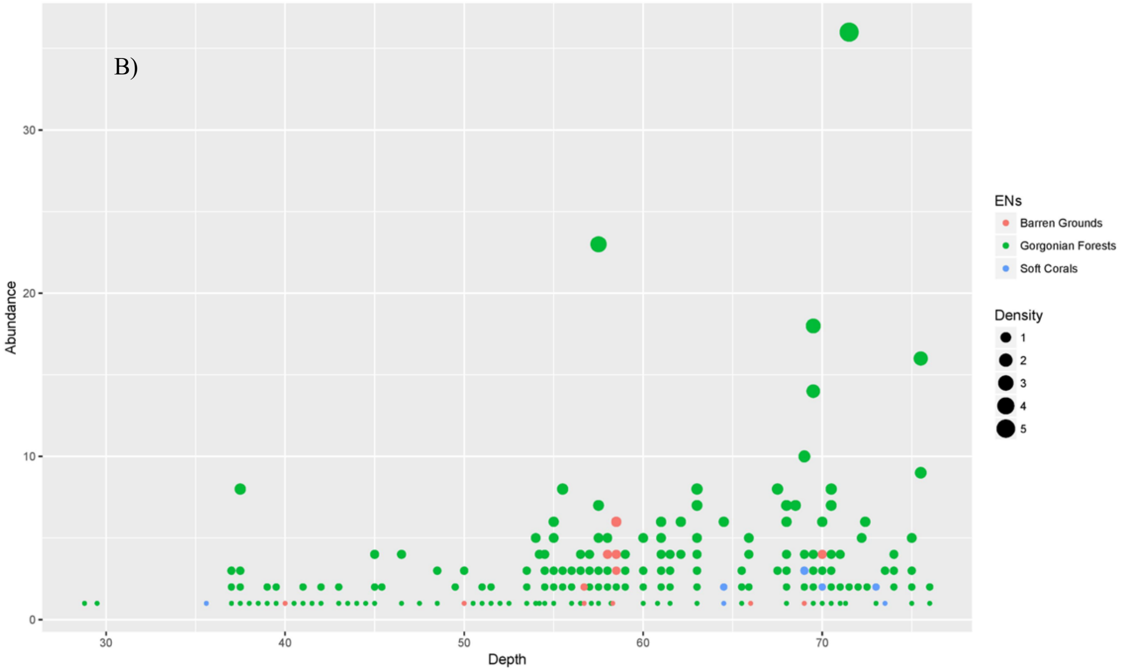


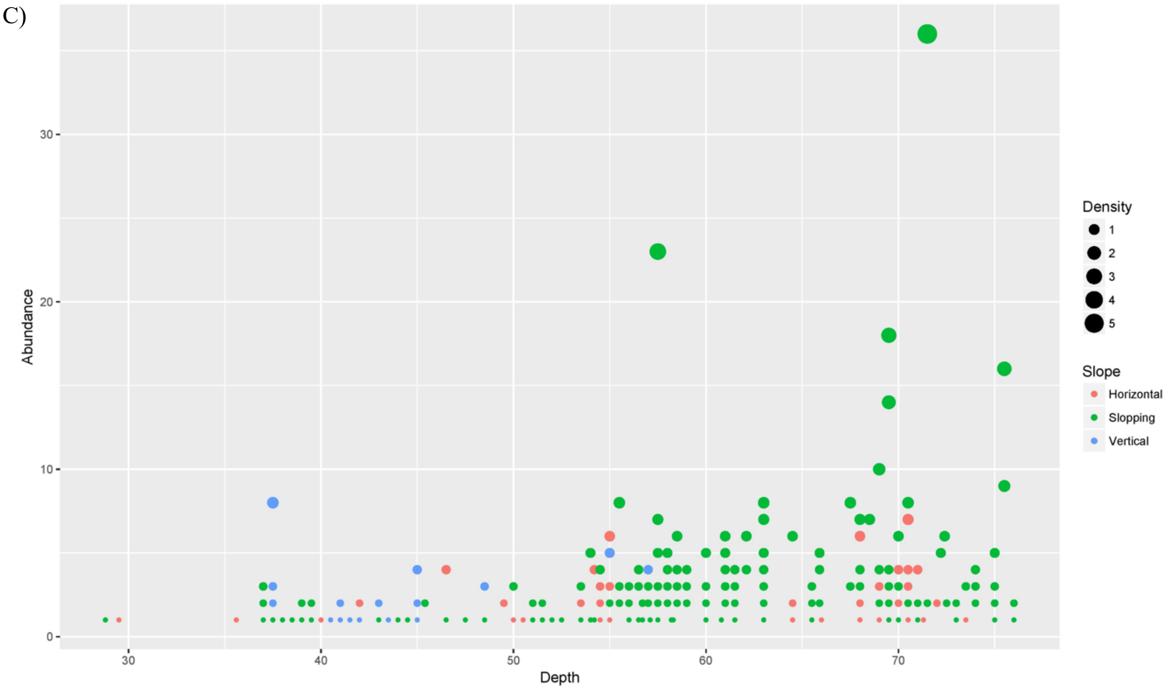
Fig.5b. Scatterplots graphics showing the relationship between the abundance of *A.mediterraneus* and the environmental variables (continuation). Each point shows the density of the study species with depth. The coloured points indicate the relation with the **Ecosystem engineers** (ENs): *Red:* Barren Grounds; *Green:* Gorgonian forests; *Blue:* Soft Corals.

Some areas of the shallowest waters were dominated by a vertical sloping, and the gorgonian forests were the mainly engineer ecosystem. However, this type of slope did not occur frequently in deeper waters (**Fig.7c**).

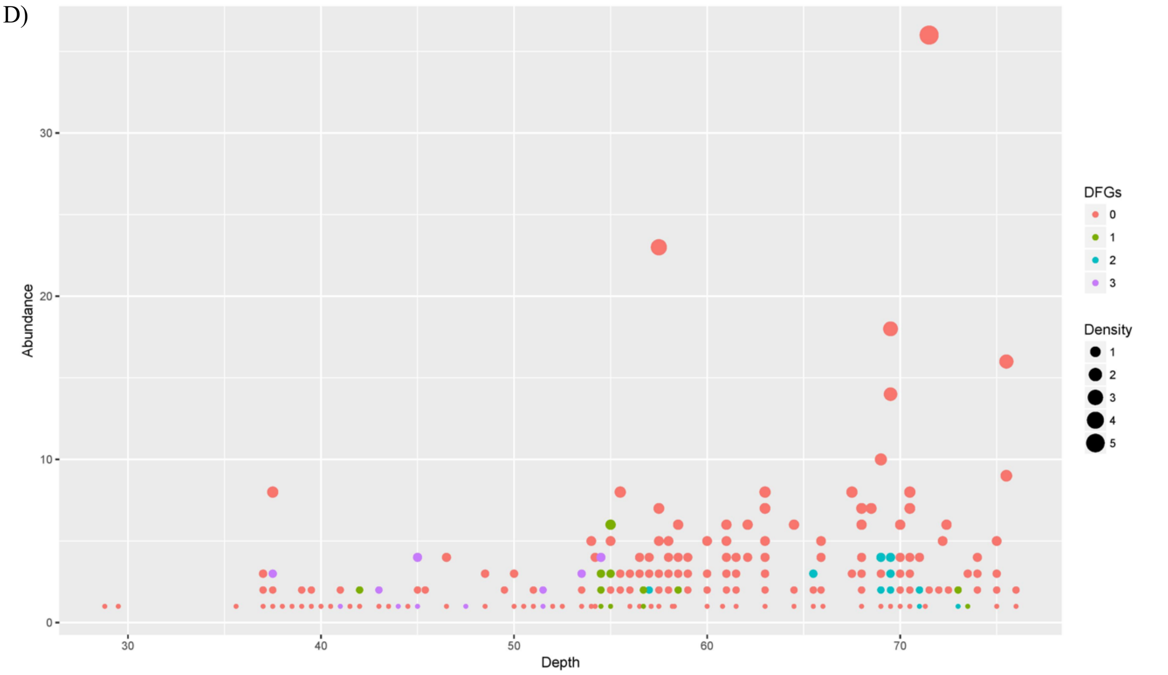
Finally, lost fishing gears showed a non-significant results between *A.mediterraneus* densities and the frequency of this gears (**Fig.7d**). The shallowest specimens showed the biggest relationship, where the greatest number of lost gears are in these waters, yet no relation could be observed between both (**Fig.7d**), most likely due to the low frequency of fishing gears observed in the study area.

To sum up, *Astrospartus mediterraneus* populations presented a high relation with deep rocky substrates, with presence of gorgonian forest, preferentially occurring on slopping areas.

C)



D)



Figs.7c;d. Scatterplots graphics showing the relationship between the abundance of *A.mediterraneus* and the environmental variables (continuation). Each point shows the density of the study species with depth. The coloured points indicate the relation with the **C) Slope.** *Red:* Horizontal; *Green:* Slopping; *Blue:* Vertical; and **D) Number of Derailed Fishing Gears.** *Red:* 0; *Green;* 1; *Blue:* 2; *Purple:* 3.

5. Discussion

As far as we known, no previous work exists about the ecology and distribution of the Mediterranean endemic basket star *Astrospartus mediterraneus*. Few taxonomic works have been done (e.g. Hansson, 2001) and some other studies have registered the presence of the species in the Mediterranean Sea (e.g. Chammem, Ben Souissi, & Pérez-Ruzafa, 2019). Therefore, this study was presumably the first one to characterize this ophiuroid on its natural environment ant to show that *Astrospartus mediterraneus* does not have a random distribution along the sampled area, but instead has a specific habitat requirement and preferences over the substrate.

5.1. *A.mediterraneus* in Cap de Creus: distribution and habitat preference

As part of the objectives under the MITICAP project, a collection of 1800 specimens of *A.mediterraneus* were analysed, considering both the results of the analysis of the video recordings (890 individuals) and the artisanal fishing data collection (910 individuals).

Results showed that *Astrospartus mediterraneus* had a wide distribution in the north part of the sampled area, the Cap de Creus. Highest densities were found on sloping rocky outcrops, where *A.mediterraneus* individuals were found mainly over gorgonians. In these habitats, the most common and abundant in the northern part of Cap de Creus (Sardá, Rossi, Martí, & Gili, 2012), gorgonian forests act as the engineers of the substrate, which provides an increasing habitat complexity and biodiversity (Gili & Coma, 1998). Furthermore, a clear bathymetric distribution was observed, with most of the specimens located between 55 to 80 m depth.

An exhaustive work of dense aggregations of the ophiuroid *Ophiotrix maculata* on the Northwest African slope showed that the highest densities of the specimen were found in Wolof's Seamount (Mauritanian slope area) (Calero et al., 2018). This Seamount is an upwelling area (high productive area), where there is a resuspension of the sediment, increasing the organic particles suspended in water and providing an oxygenation of the waters (increase in the oxygen availability). Such conditions benefit the *O.maculata* ophiuroid species (Calero et al., 2018).

Similar environmental characteristics occur in the Cap de Creus area, which is an upwelling area due to the northern winds (Millot, 1979; DeGeest, 2008). In this area, environmental conditions for below 40 m depth are more stable than shallower waters with lower light irradiance and hydrodynamics and higher food availability (Coma, Ribes, Gili, & Zabala, 2000). As a consequence, there is a prevalence of benthic communities

predominated by benthic suspensive feeders (Zabala & Ballesteros, 1989). In shallower waters, there are both lower densities and abundance values of *A.mediterraneus*. That could be due to two mainly reasons. Firstly, some species of ophiuroids present a cryptical behaviour (organisms that avoid light frequency) to avoid the depredation pressure (Diehl, 1988) and other species are cryptic because the UV radiation damage the larval stages (Adams, 2001). Other studies about the photoperiodic activity pattern of ophiuroids showed a clearly activity increasing during the no-light and weakly light periods (Tsurnamal & Marder, 1966 ;Rosenberg & Lundberg, 2004).
Secondly, it could be related to a low frequency of gorgonian forests communities in the shallow waters due to the environmental characteristics commented above, where temperature variation and stress pressure due to storm periods are lower below the thermocline because of the conditions, which are more stable (Garrabou et al., 2009).

This strong association among basket stars and gorgonians has also been observed in other species such as *Gorgonocephalus arcticus* and *Gorgonocephalus caputmedusae*, which showed a strong association with gorgonian or other kind of protruding substrate (rocks, other living organisms and death organisms) to take an optimal position to subsequently feed on suspended particles (Emson et al., 1991; Rosenberg et al., 2005). Feeding position carried out by these specimens suggests that their arms develop different functions, where 2 arms are used to fix them to the substrate and the other ones are able to capture the suspended particles adopting an opening fan position towards the currents, which let the specimens to take the food in the water column (Emson et al., 1991; Rosenberg et al., 2005). However, it has been seen in predominance of strong water currents, that they aren't able to maintain their feeding position and increase the number of coiled arms (Rosenberg et al., 2005).
On the other hand, no relation between *A.mediterraneus* and the presence of lost fishing gears was observed in the studied area. Fishing gears could not be enough integrated with the environment and could not be suitable as a substrate for the food mechanism required by the gorgonocephalid.

The observed densities and abundances are not high enough to describe these blooms as ophiuroids beds like Aronson (1992) called to in his work. Nevertheless, a checklist of the echinoderms in Tunisia has been done and only 2 individuals of *A.mediterraneus* were observed between 85–100 m (Chammem et al., 2019). There was a clear difference between Cap de Creus area and Tunisia coast in *Astrospartus* abundance which, in the present study there were more than 40 individuals observed at the same depth range. This abundance difference may be explained by the degradation of the observed area (Cap Bon, Northern Tunisia) where some gorgonian populations suffered a high mortality due to the persistence of high temperatures (Ben Mustapha & El Abed, 2001).

The size frequency distribution of *A.mediterraneus* populations in the Cap de Creus area showed a clearly dominance for 2–3 cm diameter size with tails up to 6 cm. The diameters of a population of individuals of *A.mediterraneus* in Mostaganem coast (Algeria) were previously reported, counting with an average size of 9.79 cm (Benzait, Mezali, & Soualili, 2019). This differences among the size of individuals suggested that populations of the species in Cap de Creus were young. Nevertheless, large specimens up to 6cm diameter were also found in the present study indicating the probability of older individuals (Rosenberg et al., 2005). However, there was no reason to thought about stablished and old populations due to a non-previous register of the species though exhaustive studies in the study area (Dominguez, 2018). Furthermore, this bloom was detected 4 years ago, so this may lead us to think that the populations could not be too old.

5.2. *A.mediterraneus* in Cap de Creus: Artisanal fishing bycatch

In the present study a large amount of the analysed individuals of *A.mediterraneus* were collected via by-catch. This phenomenon might be explained as a feeding mechanism behaviour. As it was commented above, the presence of this species showed was significantly related with the most protruding substrate, which provided height to an optimal feeding mechanism (Emson et al., 1991; Rosenberg et al., 2005). As so, the fishing nets could be acting as an alternative substrate to where basket stars attach in order to avoid the competition for feeding with other benthic suspension feeders. Moreover, fishing nets are draft in barren grounds where the species is usually in low abundances, and, therefore, these nets could act as a magnet for the species, increasing the number of the individuals caught via by-catch.

Recently, there are a large number of outbreaks of species belonging to the Echinodermata phylum (Uthicke, Schaffelke, & Byrne, 2009). There are some works that suggest multiple casual factors to explain these outbreaks in this phylum.

One of them, suggest the *predation removal hypothesis* as a potential hypothesis to explain echinoderms populations bloom. *Acanthaster planci* is an example of this hypothesis, which its populations are controlled by their predators and a decreasing of these predator populations could increase the population growth due to the lower predation pressure (Aronson, 1992; Brodie et al., 2005). However, in the present study the *predation removal hypothesis* could not explain the outcrop of the species in the Cap de Creus because there is not enough evidence of a significant predation pressure above *A.mediterraneus*.

Another work about echinoderm outbreaks suggest an uncontrolled growth due to an increasing food supply (eutrophication phenomenon) coming from the river's runoff (Birkeland, 1982; Uthicke et al., 2009).

Although some studies have considered Cap de Creus as an eutrophic area where the highest inputs of nutrients are provided mainly by the Rhone river runoff (Coma et al., 2000; DeGeest et al., 2008). Therefore, the outcrop of the *A.mediterraneus* in the studied area could not be directly related to the eutrophication due to there is not work revealing an increase of the nutrient inputs in the coastal zonation of the sampled area.

In the other hand, there was a largest size frequency population of *A.mediterraneus* in the Algerian coast than the Cap de Creus populations. Algerian coast had warmer waters than our study area (Shaltout & Omstedt, 2014). As so, a study about the reproduction of echinoderms, indicates temperature as an important variable to determine the reproduction timing (Boolotian, 1966; Giese & Pearse, 1974 cited by Herrero-Pérezrul, Bonilla, García-Domínguez, & Cintra-Buenrostro, 1999) being higher temperatures better ones to the reproduction period (Strathmann, 1958; Lessios, 1990 cited by Herrero-Pérezrul, Bonilla, García-Domínguez, & Cintra-Buenrostro, 1999; Brodie et al., 2005). As part of the climate change effects, the temperature of the seawater is globally rising, and this phenomenon could affect in the reproduction periods in northern populations, as the Cap de Creus ones. However, there was not any study about the reproduction and growth of echinoderms in the Cap de Creus area to evaluate the hypothesis commented above.

Finally, despite its aforementioned ecology, there is still a huge gap in knowledge regarding the biology of the species. Which it is of paramount importance to increase the knowledge to stablish a relation between the species and the origin of this bloom.

6. Conclusions

The studied species, *Astrospartus mediterraneus*, presented a large distribution along the sampled area of Cap de Creus, with its highest densities occurring with deep sea gorgonian forests habitat. Moreover, the depth range of *A.mediterraneus*, showed high frequencies from 35 meters and below, with highest densities between 50–80 m, where on this area, there are low light intensity and high food supply conditions which probably determines the distribution of the species. Furthermore, the high relation with gorgonian suggests an optimal feeding mechanism to avoid competition with other suspension feeders for food obtaining.

The presence of small sizes showing a prevalence for 2–3 cm size class, indicates that we are probably in front of a young population due to a comparison the specimens from Algerian coasts, showing a recent bloom in Cap de Creus area.

Due to the large quantity of by-catched specimens and the population growth in the last 4 years of the species, it is necessary to highlight the knowledge gap in the biology, the ecology and the distribution patterns about this species.
On overall, this ecological data provides a baseline for future studies about this Mediterranean gorgonocephalid.

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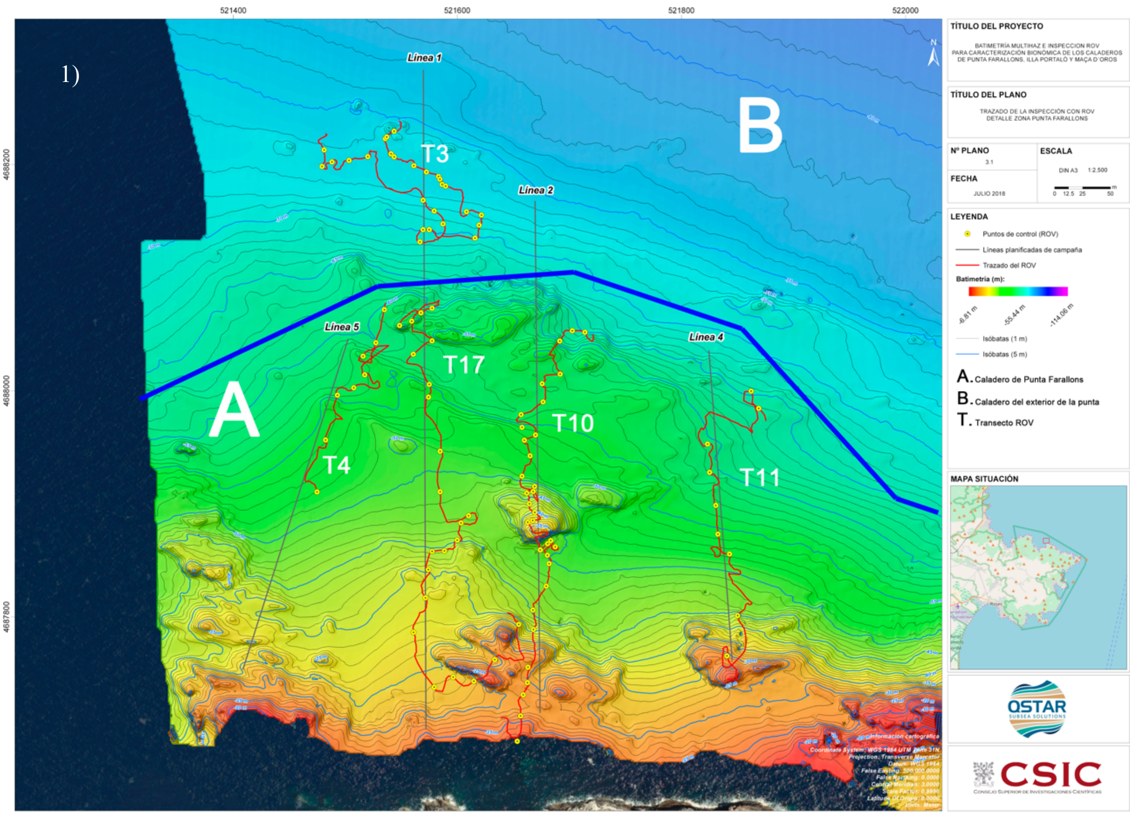
Annex 1



1)
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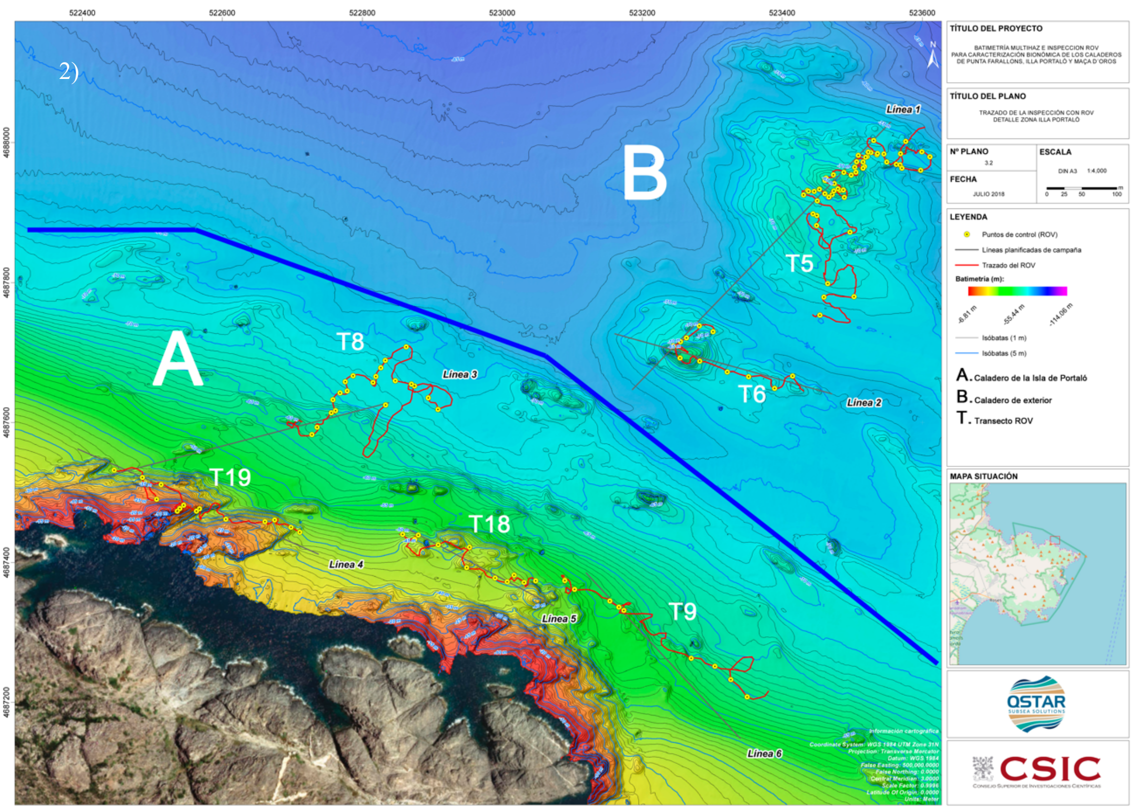
4688000
4687800
Linea 1
Linea 2
Linea 4
Linea 5
A
B
T3
T4
T10
T11
T17
TÍTULO DEL PROYECTO
BATIMETRÍA MULTIHAZ E INSPECCION ROV PARA CARACTERIZACIÓN BIONÓMICA DE LOS CALADEROS DE PUNTA FARALLONS, ILLA PORTALO Y MAÇA D'OROS
TÍTULO DEL PLANO
TRAZADO DE LA INSPECCIÓN CON ROV DETALLE ZONA PUNTA FARALLONS
Nº PLANO
3.1
ESCALA
DIN A3 1:2.500
FECHA
JULIO 2018
LEYENDA
Puntos de control (ROV)
Lineas planificadas de campaña
Trazado del ROV
Batimetría (m):
-6.81 m
-55.44 m
-114.06 m
Isóbatas (1 m)
Isóbatas (5 m)
A. Caladero de Punta Farallons
B. Caladero del exterior de la punta
T. Transecto ROV
MAPA SITUACIÓN
QSTAR
CSIC



2)
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4687200
Linea 1
Linea 2
Linea 3
Linea 4
Linea 5
Linea 6
A
B
T5
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T8
T9
T18
T19
TÍTULO DEL PROYECTO
BATIMETRÍA MULTIHAZ E INSPECCION ROV PARA CARACTERIZACIÓN BIONÓMICA DE LOS CALADEROS DE PUNTA FARALLONS, ILLA PORTALO Y MAÇA D'OROS
TÍTULO DEL PLANO
TRAZADO DE LA INSPECCIÓN CON ROV DETALLE ZONA ILLA PORTALÓ
Nº PLANO
3.2
ESCALA
DIN A3 1:4.000
FECHA
JULIO 2018
LEYENDA
Puntos de control (ROV)
Lineas planificadas de campaña
Trazado del ROV
Batimetría (m):
-6.81 m
-55.44 m
-114.06 m
Isóbatas (1 m)
Isóbatas (5 m)
A. Caladero de la Isla de Portaló
B. Caladero de exterior
T. Transecto ROV
MAPA SITUACIÓN
QSTAR
CSIC

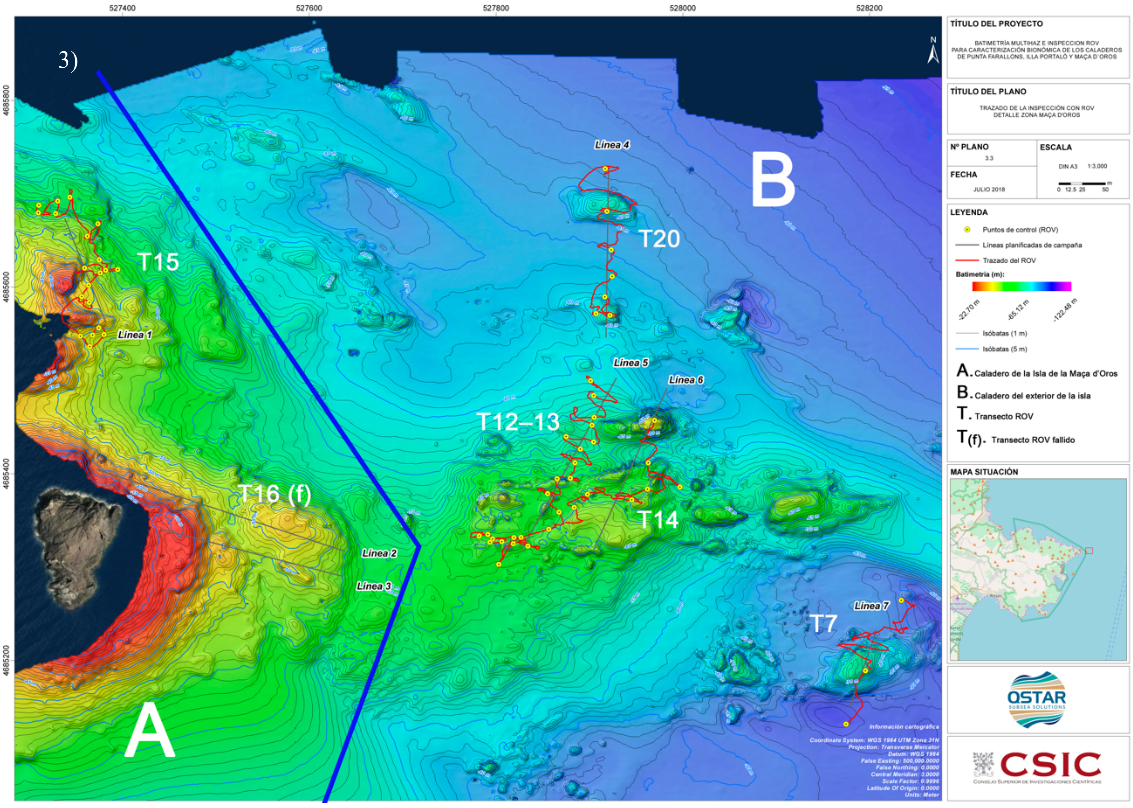
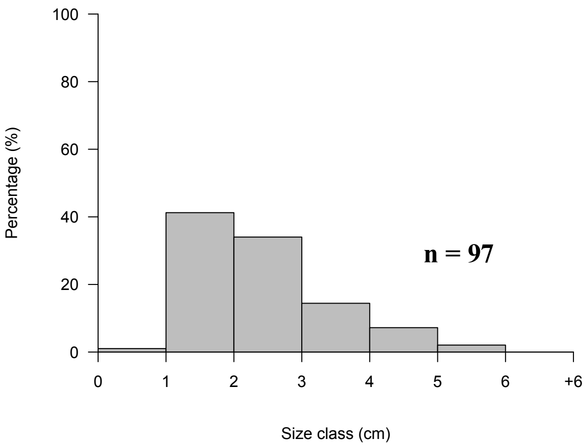


Fig.1. Maps of videotransects recorded by ROV in Cap de Creus marine area. **1)** Punta dels Forallons area; **2)** Punta del Molí area. **3)** Maça d'Oros Island area. **Source:** QStar

Annex 2

A)



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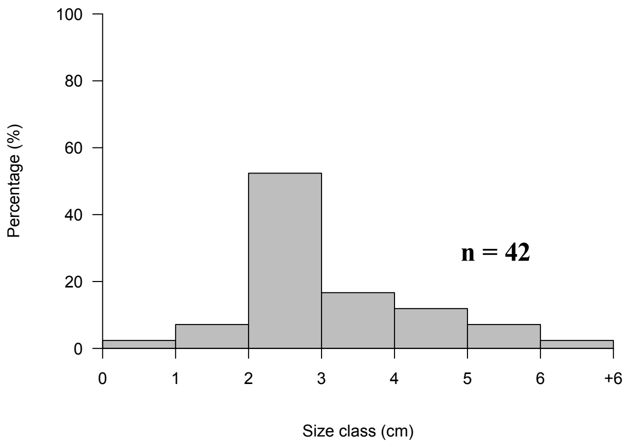

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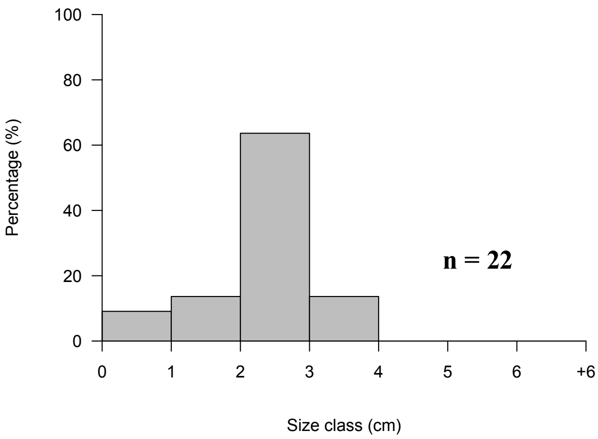

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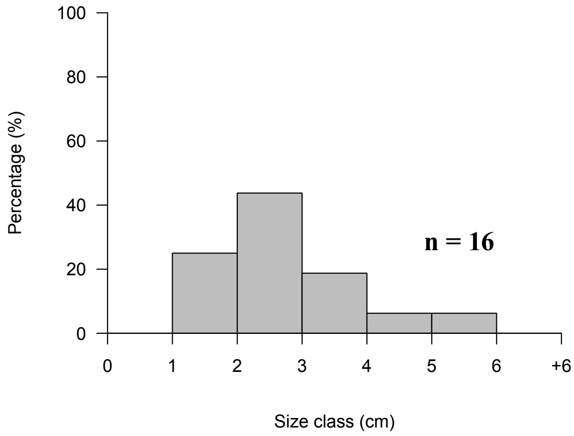

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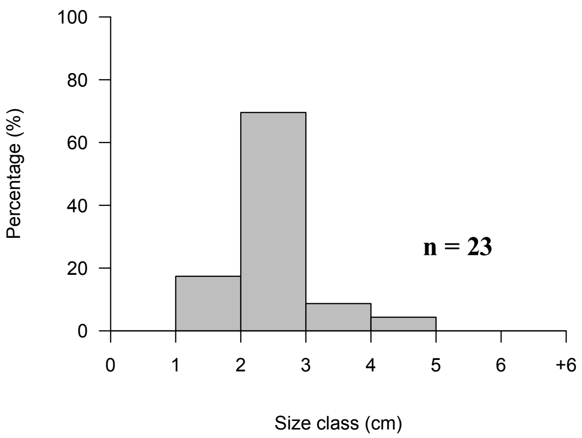

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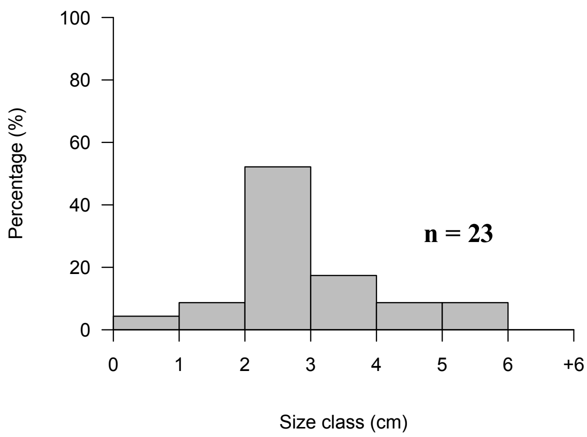

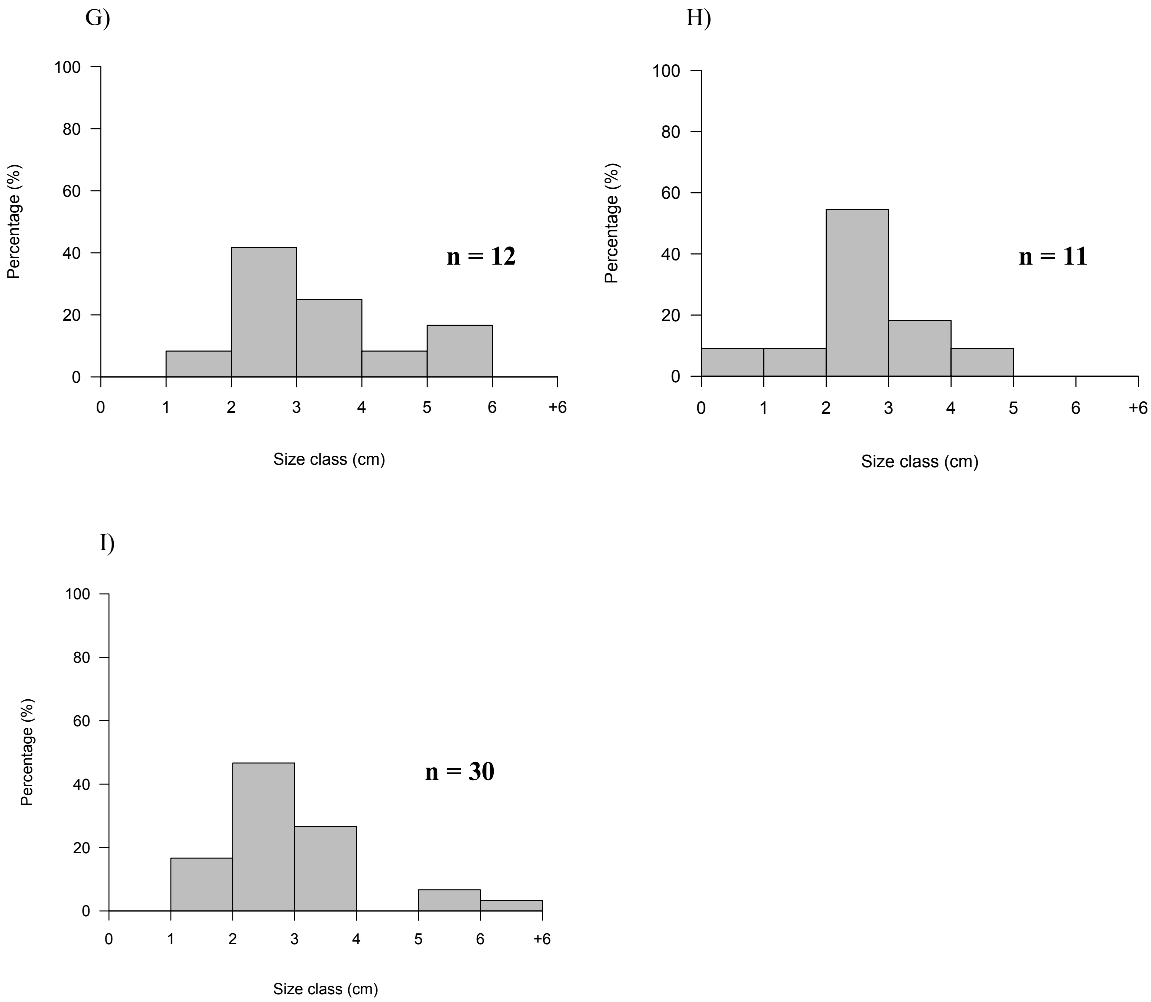

Fig.2. Size-frequency distribution of *A.mediterraneus* based on each fishing net of each fishing station sampled. **A)** Ses Tallades (20/04/18); **B)** Messina (24/04/18) Net 2; **C)** Boc i la Cabra (22/05/18); **D)** Puig Gros (5/06/18); **E)** Fredosa (26/6/18); **F)** Portaló (29/06/18) Net 1; **G)** Portaló (29/6/18) Net 3; **H)** Culip (9/07/18); **I)** Punta dels Tres Frares (13/07/18). Number of individuals are showed in (n).