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Case study

Ecosystem response to different management options in Marine Protected Areas (MPA): A case study of intertidal rocky shore communities

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ABSTRACT

Marine Protected Areas (MPA) can be powerful coastal management tools with several specific goals, although there is debate concerning their effectiveness. There is no consensus regarding the ideal size of MPAs, and actually there is some evidence that perhaps size is not as critical as other specific factors in determining their success in terms of populations' protection and ecological functions conservation. On the other hand, depending on the objectives, zones with different classification regimes in terms of rules and uses might enable the maintenance of the intended uses.

At this light, we examined the case of the small (605 002 m^2) rocky shore area of Avencas, near Lisbon, on the Atlantic western Coast of Portugal, which was classified as Biophysical Interest Zone (ZIBA) in 1998, due to its exceptional intertidal biodiversity, after what its protection status became controversial, leading to conflicts with the local population and incompliance with extant regulations. From 2010 efforts were carried out by local authorities to reclassify Avencas as Marine Protected Area, which was achieved in 2016.

Monitoring intertidal communities in a MPA and adjacent areas is an effective and low-cost procedure to evaluate the evolution of the biodiversity of rocky shores. Therefore, antedating the creation of the new MPA, assessments of the ZIBA biodiversity were conducted from January 2013 to December 2015 on a monthly basis. This timeline was selected as a function of a change in visitors' behavior induced from 2013 by several management and outreach initiatives, which increased in a certain extent the user's compliance with regulations.

A positive evolution was expected for density and/or species diversity of the different groups analysed (flora, sessile fauna and mobile fauna) in this three years period. However, a very strong storm occurred in 2014 produced a significant impact and changed large areas of the Avencas rocky shore. As a consequence, results did not display a recognizable recovery pattern of the intertidal communities, and following that extreme event are not even consistent with a hypothesized enhanced recovery capability of the ecosystem in a protected area. This suggests that longer data series are necessary to obtain more robust data regarding natural variability, since alterations caused by extreme events are always likely to occur. Additionally, results illustrate that indeed size matters because it influences the MPA openness, expressed as the ratio of periphery to area, and therefore its susceptibility to external driving forces. Such considerations must be taken into account in any management plan, which in this case should encompass an increase in the intertidal protected area, a new conditioned small-scale fishing regime, and an adequate monitoring programme to evaluate the effectiveness of the new management scheme.

1. Introduction

The Ocean is a living matrix of organisms and nutrients, and small changes in the usages of sensitive coastal areas can degrade its structure and function. Marine Protected Areas (MPAs) constitute coastal management tools that aim to mitigate these threats and can be planned according to different specific objectives (Halpern, 2003). For some protected areas, the conservation objective is to maintain species biodiversity and not to export biomass for fishing purposes. In this case, several zones with distinct classification regimes, i.e., distinct rules and uses, can enable the maintenance of distinct traditional fishing activities (Horta e Costa et al., 2016). Currently there are 13 674 MPAs,

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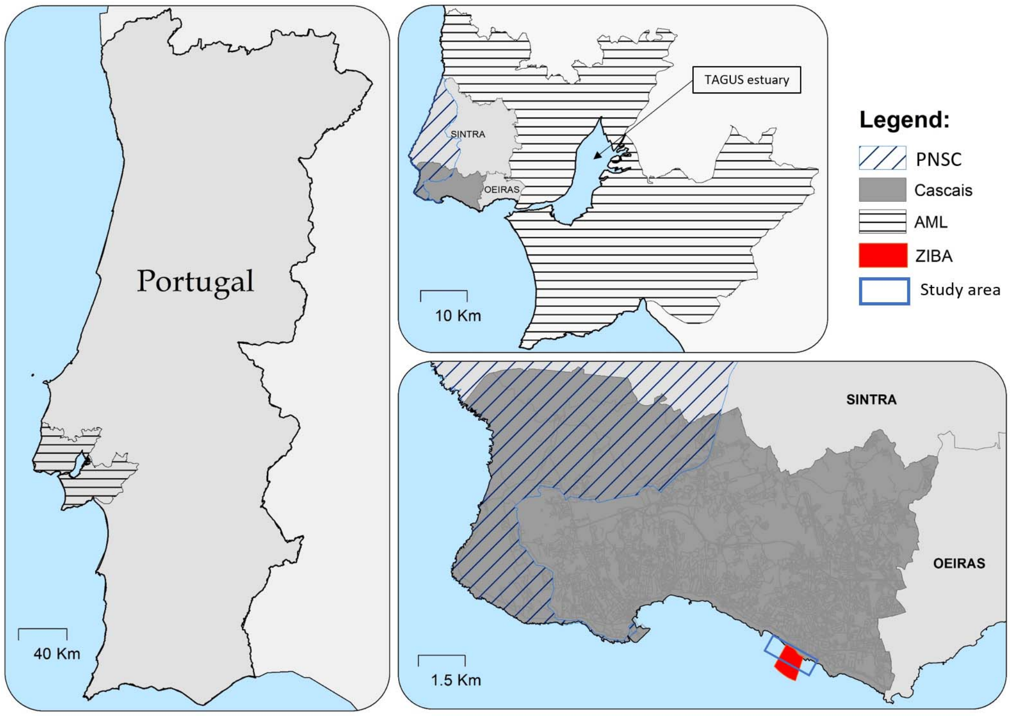

Fig. 1. Location of the study area, including the Biophysical Interest Zone of Avencas (ZIBA) and its position within the Lisbon's Metropolitan area (AML). The Sintra-Cascais National Natural Park (PNSC) is also displayed.

corresponding to 2.07% of the oceanic area worldwide (MPAtlas, 2016). However, despite the high number of classified areas several doubts arise concerning their effectiveness (Fraschetti et al., 2005). A total of 1624 Km^2 of European waters are Marine Reserves, wile 124 000 Km^2 are MPAs with a lower classification status (Fenberg et al., 2012). Most European marine reserves are small and 92% of them have areas smaller than 50 Km^2; for example, in the Mediterranean Sea, MPAs are in average 4 Km^2 (Halpern, 2003). MPA ideal size is not consensual and it has been suggested that size is less critical than other specific factors for the protection of the populations. For habitat forming organisms and bio-constructors, even small MPAs can have an effect in the protection of the physical structures and ecological functions of such habitats, like reproduction of fish and invertebrates (Halpern, 2003). The increase in dimension and density, biomass, and species diversity inside a MPA is also registered both European and world wide, reconnecting trophic networks at a community level (Fenberg et al., 2012; Francour et al., 2001; Shears and Babcock, 2002). However, these results are strongly dependent of the elapsed time since the creation of the MPA, its effective management (Claudet et al., 2008), the area design, and the ecology of the protected species (Fenberg et al., 2012). MPAs can be effective management tools at a local scale, especially when located at a tidal area with a wide range of micro habitats. The identification of these specific habitat and its protection regime, is an approach that could increase the proportion of protected species (Banks and Skilleter, 2002; Francour et al., 2001). At a global scale a MPA could only be effective if: it is representative of the biogeographical area; works as a network and 20% of the total area is a "no fishing" area (Boersma and Parrish, 1999). In the Mediterranean region, the creation of a MPA based on little or null scientific information and with scarce interaction with local agents and their needs is still the rule (Fraschetti et al., 2005; Guidetti et al., 2008). As a consequence, the local population looks at marine conservation as an obstacle to economic development, leading to a non-compliance of the established regulations of the MPA (Frachetti et al., 2009).

The rocky shore area of Avencas, located in the Cascais council, near Lisbon, on the Atlantic western Coast of Portugal, was classified as Biophysical Interest Zone (ZIBA) in 1998, in the scope of the Coastal Zone Management Plan Cidadela – São Julião da Barra (POOC Cidadela - São Julião da Barra, 1998) due to its exceptional intertidal biodiversity. This protection status became controversial, leading to conflicts with the local population and incompliance with extant regulations. From 2010, efforts were carried out by local authorities to reclassify Avencas as Marine Protected Area, to be managed by the Environmental Municipal Company of Cascais, which was achieved in 2016 (POOC Cidadela - São Julião da Barra, 2016). Along with the public participation sessions conducted to gather proposals for the new regulations, several environmental awareness activities were carried out close to the scholar community and the visitors. Guided tours, information points, visitation pathways and communication campaigns improved the knowledge about the environmental importance of the ZIBA and contributed to a greater compliance with the regulation, particularly by the fishing community (Ferreira et al., 2015). In this particular case, monthly biological surveying by municipal technicians is vital, not only to check for any changes in the intertidal communities but also to keep a close contact with beach users.

Marine Protected Areas tend to maintain ecosystems equilibrium when their protection regime promotes both species richness and density, the eradication of pollution sources, and reduces human pressure (Worachananant et al., 2007), for instance increasing their resilience in relation to the impacts of ocean storms. The opportunity to test such assumptions, occurred during the study period; from 5 to 7 of January 2014, the Portuguese shores were heavily impacted by the storm named as "*Hercules*", which triggered strong sea waves with long periods, run-ups between 6–9 m, and inundation depths mostly under 1 m, corresponding to a classification of meteorological tsunami (Santos et al., 2014). Damages included the destruction of coastal protection structures, roads, and sand dunes.

The present work had two main objectives: *i)* evaluate if the biodiversity in the ZIBA area responded positively to a greater compliance with the regulations observed since 2012; and *ii)* compare the development of the intertidal communities following the storm *Hercules* inside and outside the ZIBA area to assess possible differences in recovery rates.

2. Material and methods

2.1. Study area

The ZIBA area, located on the west of Portugal, in the Cascais municipality, near Lisbon, covers an area of 605 002 m^2 (Fig. 1), of which 111 232 m^2 are intertidal, including terrestrial and marine biotopes up to 15 m deep. The following limitations to human activities were implemented in the ZIBA area: no aquaculture activities, no water motor sports, no fishing or spearfishing, and no collection of animals of any kind, except for scientific studies duly authorized (POOC Cidadela - S. Julião da Barra, 1998). The ZIBA area is characterized by extended calcareous rocky platforms, which constitute large surfaces of irregular shape due to its nodular structure, clearly visible along several hundred meters during low tide. Such surfaces, essentially due to its irregularity, enable the existence of a distinctive intertidal habitat in the area. Maritime agitation is highly energetic and has unique characteristics close to Cascais, due to its location close to the mouth of the Tagus estuary (Fig. 1) and consequent exposition to strong tidal movements.

It was recorded a positive behavior change of ZIBAs users in the Summer of 2013, after the implementation of the management measures in the Summer of 2012 (placement of information spots, creation of rope pathways to order the visitors and public participations assemblies to inform and involve the public). There were also significant differences regarding the behavior of the sports fishing community, increasing the compliance with the existing regulation (Ferreira et al., 2015).

2.2. Sampling strategy

The field study was carried out between January 2013 and December 2015, samples being collected monthly in intertidal shores. Four sampling sections were considered: two inside the Biophysical Interest Zone of Avencas (B and D) and two outside (A and E) (Fig. 2), which were stratified in supratidal and middle-intertidal zones. The four sampling sections have similar biophysical conditions, differing only in the protection status (Faria and Ferreira, 2013) At each sampling point, 10 m long transects were considered, scanning areas of 1 m^2 on each side of the transect to estimate the population density of mobile species. Regarding the sessile species (flora and fauna), the coverage percentage of the different species was assessed through the observation of quadrats with 2500 cm^2 divided in 1 cm^2 subsets (Table 1). Animals were identified to the species level whenever possible, or at least to the family level, while regarding the flora species were classified to the phylum level (rhodophyta, chlorophyta, phaeophyta) or as lichen. Areas defined as supratidal zones of each sampling section (A, B, C and D) are considerably smaller than the areas defined for the middle-intertidal zones. Therefore, a 3000 m^2 and 6000 m^2 quotient was used respectively for the supratidal and middle-intertidal zones, in order to define the number of replicates observed monthly in each section (Table 1).

Table 1
Number of 2500 cm^2 squares monthly observed (replicates) at each sampling section, which varied proportionally as a function of the supratidal and middle-intertidal areas in each of the sampling sections.

Zone	Area (m^2)	No. of Squares	No. of Transepts
Supratidal			
A	10 327	3	3
B	4 012	1	1
D	6 500	2	2
E	5 500	2	2
Middle-intertidal			
A	21 843	4	4
B	17 700	3	3
D	20 000	3	3
E	25 350	4	4

2.3. Data analysis

The supratidal and middle-intertidal zones were analysed separately since sampling had been previously stratified as a function of clear

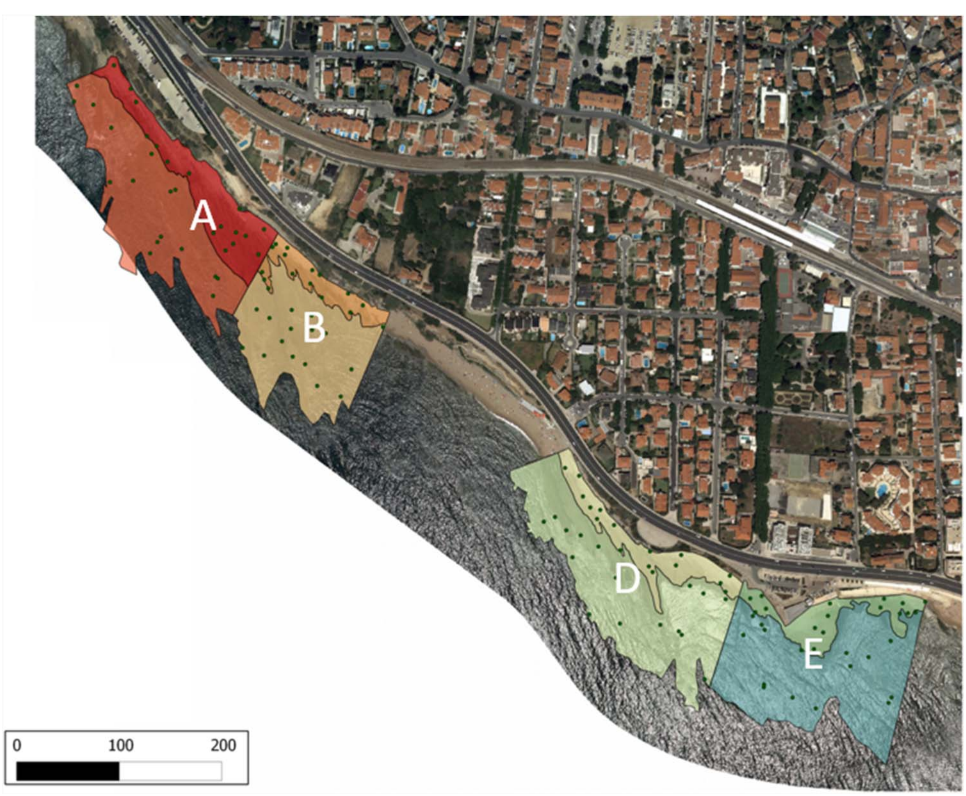

Fig. 2. Sampling design in the study area: Four sampling sections (A, B, D, E), which were stratified in supratidal and middle-intertidal areas. Sections B and D were located inside the ZIBA, while sections A and E were located outside the ZIBA.

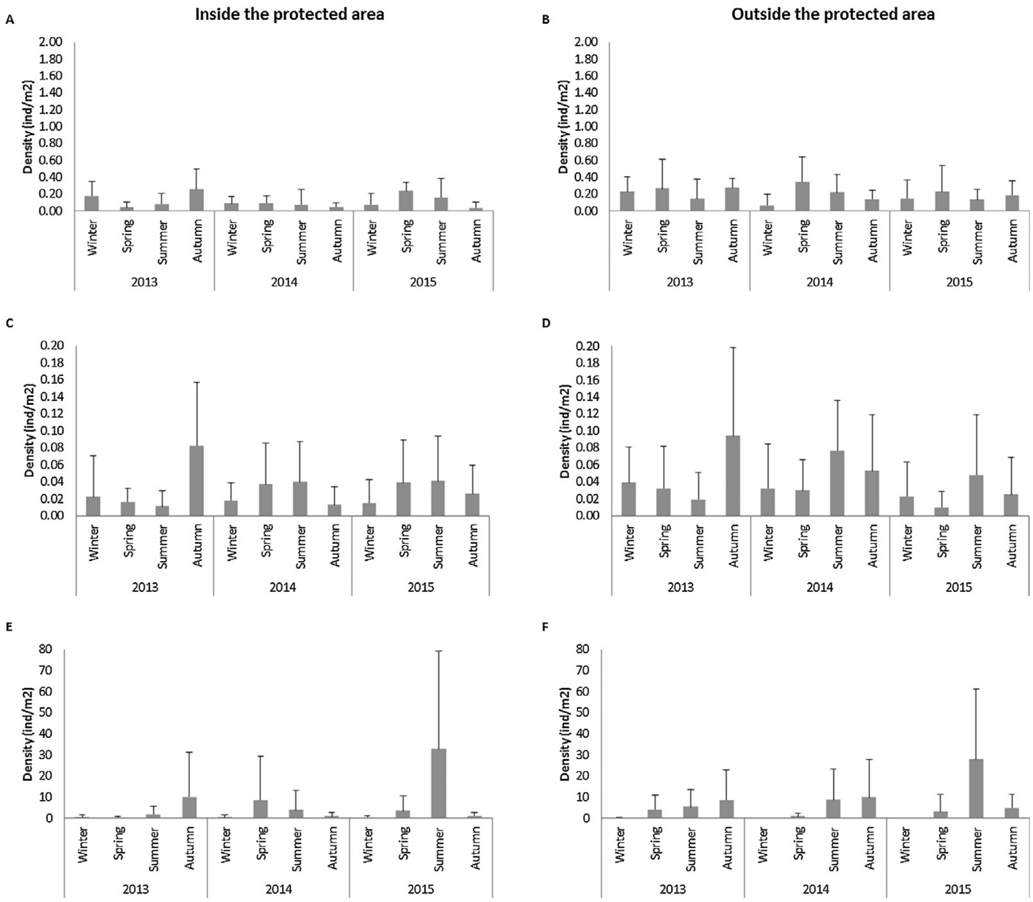

Fig. 3. Average species' densities ± standard deviation (individuals/m^2) at the supratidal zone, both inside and outside the protected area; A and B – Flora; C and D – Sessile faunal species; E and F – Mobile faunal species.

differences in species composition and populations density at each zone. In each sampling section, the average density was estimated (individuals per m^2) of the intertidal community mobile faunal species and sessile fauna and flora species in winter (Jan, Feb, Mar), spring (Apr, May, Jun), summer (Jul, Aug, Sep), and autumn (Oct, Nov, Dec) situations. A tentative graphical analysis was carried out to assess trends emerging from data preliminary analysis. Densities of sessile species were calculated through the methodology described by Deepananda and Macusi (2012), which allows the transformation of percentages of coverage in density values for each species. The Shannon-Wienner (H') (Shannon, 1948) and the Pielou (J') (Pielou, 1966) indices were equally calculated to evaluate changes in community's diversity along the study period.

In order to test the hypothesis that the community density changes spatially (between sampling sections) and seasonally, a three–way PERMANOVA analysis (Anderson et al., 2008) was carried out with the following crossed factor design: "season", "year" and "area" as fixed factors, with respectively: four (winter, spring, summer and autumn), three (2013, 2014 and 2015) and two levels (outside and inside the ZIBA). Density data were square root transformed to decrease scale differences between the weights of the most and the less abundant species in the analysis. The PERMANOVA test was applied to the matrix obtained using the Bray-Curtis similarity coefficient, which includes a virtual dummy variable being 1 for all objects (Clarke et al., 2006).

Furthermore, a three-way PERMANOVA was applied to test the null hypotheses that no significant spatial (between sampling sections) and temporal (between years and seasons) differences existed regarding values the diversity indices (H' and J) estimated. PERMANOVA was used as an alternative to ANOVA since its assumptions were not met, even after data transformation. All PERMANOVA tests were conducted on Euclidean-distance similarity matrices and the residuals were permutated under a reduced model (9999 permutations). The null hypothesis was rejected when the significance level p was < 0.05 (if the number of permutation was lower than 150, the Monte Carlo permutation p was used). Whenever significant differences were detected, these were examined using *a posteriori* pairwise comparisons, using 9999 permutations under a reduced model (Clarke and Green, 1988; Clarke and Warwick, 2001).

3. Results

When analysing the different species densities inside *and* outside the protected area, the graphical analysis of data from the supratidal zone (Fig. 3) does not show a homogeneous pattern. Nevertheless, PERMANOVA results show a significant increase in the average density of mobile fauna species and flora outside the protected area (Table 2). Additionally, mobile fauna species display significant (PERMANOVA – see Tables 2 and 3) inter-seasonal fluctuations (Fig. 3–E and F), exhibiting higher densities in summer and lower densities in winter, a pattern usually found in intertidal communities, but inter-annual differences were not significant. Similar results were obtained with regard to the sessile faunal species (Table 2).

Graphical analysis of data from the middle-intertidal zone shows an increased flora density in 2014, when the Hercules storm occurred, followed by a decrease in 2015 (Fig. 4–A and B). On the contrary, sessile fauna species exhibited higher values in 2015 (Fig. 4–C and D). Regarding flora, PERMANOVA (Tables 2 and 3) results confirmed the occurrence of significant inter-annual differences, as suggested by the graphical analysis, but no significant inter-annual differences were recorded with regard to sessile faunal species (Table 2). Mobile fauna exhibited differences inside and outside of the protected area in 2013 and 2015 (Tables 2 and 3). Densities were higher inside the protected area in 2013, but just the contrary was observed in 2015 (Fig. 4–E and F).

Table 2
Details of the three-factor PERMANOVA test ("year" with 3 levels, "season" with 4 levels and "area" with 2 levels, as fixed factors) for all variables analysed. Bold values stand for significant differences ($p < 0.05$).

	Source of variation	Degree of Freedom	Sum of Squares	Mean Squares	Pseudo-F	P (perm)
Flora supratidal						
Average density	Year	2	444.64	222.32	0.46755	0.7897
	Season	3	1144.3	381.42	0.80216	0.5821
	Area	1	1443.5	1443.5	3.0357	**0.046**
	Year × Season	6	4977.9	829.65	1.7448	0.0538
	Year × Area	2	257.5	128.75	0.27077	0.9132
	Season × Area	3	2333.5	777.85	1.6359	0.1247
	Year × Season × Area	6	2090.2	348.37	0.73264	0.7309
	Residual	114	54206	475.5		
	Total	137	66773			
J	Year	2	0.19247	9.6234E-2	0.68391	0.5057
	Season	3	7.3425	2.4475	17.394	**0.0001**
	Area	1	7.5189E-2	7.5189E-2	0.53434	0.4728
	Year × Season	6	1.0802	0.18004	1.2795	0.2711
	Year × Area	2	0.26111	0.13055	0.92781	0.4047
	Season × Area	3	5.9477E-2	1.9826E-2	0.14089	0.9316
	Year × Season × Area	6	0.37577	6.2628E-2	0.44508	0.8409
	Residual	114	16.041	0.14071		
	Total	137	25.321			
H'	Year	2	2.3036E-2	1.1518E-2	0.14323	0.8704
	Season	3	3.6603	1.2201	15.172	**0.0001**
	Area	1	4.8201E-2	4.8201E-2	0.59939	0.446
	Year × Season	6	0.49303	8.2172E-2	1.0218	0.4211
	Year × Area	2	0.13548	6.7738E-2	0.84234	0.428
	Season × Area	3	7.7939E-2	2.598E-2	0.32307	0.8039
	Year × Season × Area	6	0.26032	4.3387E-2	0.53953	0.7797
	Residual	114	9.1675	8.0416E-2		
	Total	137	13.808			
Flora – middle-intertidal						
Average density	Year	2	2193.8	1096.9	3.9818	**0.001**
	Season	3	4259.8	1419.9	5.1545	**0.0001**
	Area	1	354.94	354.94	1.2885	0.2887
	Year × Season	6	1492.6	248.77	0.90307	0.5671
	Year × Area	2	510.32	255.16	0.92625	0.4761
	Season × Area	3	164.41	54.803	0.19894	0.9804
	Year × Season × Area	6	737.29	122.88	0.44607	0.9618
	Residual	114	31404	275.48		
	Total	137	40972			
J	Year	2	0.19247	9.6234E-2	0.68391	0.5013
	Season	3	7.3425	2.4475	17.394	0.0001
	Area	1	7.5189E-2	7.5189E-2	0.53434	0.4696
	Year × Season	6	1.0802	0.18004	1.2795	0.2732
	Year × Area	2	0.26111	0.13055	0.92781	0.3963
	Season × Area	3	5.9477E-2	1.9826E-2	0.14089	0.9371
	Year × Season × Area	6	0.37577	6.2628E-2	0.44508	0.8421
	Residual	114	16.041	0.14071		
	Total	137	25.321			
H'	Year	2	2.3036E-2	1.1518E-2	0.14323	0.8694
	Season	3	3.6603	1.2201	15.172	**0.0001**
	Area	1	4.8201E-2	4.8201E-2	0.59939	0.4444
	Year × Season	6	0.49303	8.2172E-2	1.0218	0.4175
	Year × Area	2	0.13548	6.7738E-2	0.84234	0.432
	Season × Area	3	7.7939E-2	2.598E-2	0.32307	0.8087
	Year × Season × Area	6	0.26032	4.3387E-2	0.53953	0.7712
	Residual	114	9.1675	8.0416E-2		
	Total	137	13.808			
Sessile Fauna supratidal						
Average density	Year	2	1239.9	619.93	0.87139	0.4485
	Season	3	2242.2	747.41	1.0506	0.3808
	Area	1	222.69	222.69	0.31302	0.7677
	Year × Season	6	6226.8	1037.8	1.4588	0.1524
	Year × Area	2	1474.4	737.21	1.0362	0.365
	Season × Area	3	723.56	241.19	0.33902	0.9234
	Year × Season × Area	6	2245.7	374.29	0.52612	0.8872
	Residual	114	81102	711.42		
	Total	137	95463			
J	Year	2	4.626E-2	2.313E-2	0.34874	0.7145
	Season	3	0.13152	4.3841E-2	0.661	0.5867

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Table 2 *(continued)*

	Source of variation	Degree of Freedom	Sum of Squares	Mean Squares	Pseudo-F	P (perm)
	Area	1	6.652E-3	6.652E-3	0.10029	0.7542
	Year × Season	6	0.43491	7.2486E-2	1.0929	0.3751
	Year × Area	2	0.14261	7.1307E-2	1.0751	0.3533
	Season × Area	3	0.10287	3.4289E-2	0.51698	0.6755
	Year × Season × Area	6	0.67097	0.11183	1.686	0.1318
	Residual	114	7.5611	6.6325E-2		
	Total	137	9.106			
H’	Year	2	2.2226E-2	1.1113E-2	0.34874	0.7104
	Season	3	6.3191E-2	2.1064E-2	0.661	0.5819
	Area	1	3.196E-3	3.196E-3	0.10029	0.7521
	Year × Season	6	0.20896	3.4826E-2	1.0929	0.368
	Year × Area	2	6.8519E-2	3.426E-2	1.0751	0.3498
	Season × Area	3	4.9423E-2	1.6474E-2	0.51698	0.6758
	Year × Season × Area	6	0.32237	5.3728E-2	1.686	0.1299
	Residual	114	3.6328	3.1866E-2		
	Total	137	4.375			
Sessile Fauna – middle-intertidal						
Average density	Year	2	2844.9	1422.5	1.7295	0.1192
	Season	3	2322.2	774.07	0.94115	0.4618
	Area	1	1042.6	1042.6	1.2677	0.2526
	Year × Season	6	5300	883.34	1.074	0.3555
	Year × Area	2	1331.4	665.68	0.80936	0.526
	Season × Area	3	1819.5	606.49	0.7374	0.6418
	Year × Season × Area	6	2665.7	444.29	0.54018	0.9346
	Residual	114	93762	822.47		
	Total	137	1.1127E5			
J	Year	2	0.29229	0.14615	1.667	0.193
	Season	3	0.66146	0.22049	2.5149	0.0604
	Area	1	0.56834	0.56834	6.4826	**0.014**
	Year × Season	6	0.75584	0.12597	1.4369	0.2114
	Year × Area	2	0.16932	8.4659E-2	0.96564	0.3815
	Season × Area	3	0.21761	7.2536E-2	0.82736	0.4812
	Year × Season × Area	6	1.0379	0.17298	1.9731	0.0749
	Residual	114	9.9946	8.7672E-2		
	Total	137	13.649			
H’	Year	2	0.24686	0.12343	2.339	0.098
	Season	3	0.48452	0.16151	3.0606	**0.0287**
	Area	1	0.24232	0.24232	4.5921	**0.035**
	Year × Season	6	0.60819	0.10136	1.9209	0.0836
	Year × Area	2	6.0452E-2	3.0226E-2	0.57279	0.5735
	Season × Area	3	8.2672E-2	2.7557E-2	0.52222	0.671
	Year × Season × Area	6	0.53773	8.9621E-2	1.6983	0.1289
	Residual	114	6.0157	5.277E-2		
	Total	137	8.2664			
Mobile Fauna supratidal						
Average density	Year	2	2139.6	1069.8	0.58568	0.6932
	Season	3	26204	8734.6	4.782	**0.0007**
	Area	1	6174.4	6174.4	3.3803	**0.0336**
	Year × Season	6	7016.5	1169.4	0.64022	0.8284
	Year × Area	2	1557.6	778.81	0.42638	0.8302
	Season × Area	3	7408.9	2469.6	1.3521	0.2217
	Year × Season × Area	6	5441.8	906.97	0.49654	0.9383
	Residual	114	2.0823E5	1826.6		
	Total	137	2.6513E5			
J	Year	2	0.36317	0.18159	2.0826	0.1268
	Season	3	0.86588	0.28863	3.3102	**0.0226**
	Area	1	0.50844	0.50844	5.8311	**0.0168**
	Year × Season	6	0.55828	9.3046E-2	1.0671	0.3856
	Year × Area	2	0.28812	0.14406	1.6522	0.1971
	Season × Area	3	0.51521	0.17174	1.9696	0.1229
	Year × Season × Area	6	0.34899	5.8165E-2	0.66708	0.6795
	Residual	114	9.9401	8.7194E-2		
	Total	137	13.357			
H’	Year	2	0.30741	0.1537	2.4903	0.0888
	Season	3	0.63219	0.21073	3.4142	**0.0195**
	Area	1	0.26011	0.26011	4.2142	**0.0421**
	Year × Season	6	0.41576	6.9293E-2	1.1227	0.3592
	Year × Area	2	0.22892	0.11446	1.8545	0.1605
	Season × Area	3	0.34969	0.11656	1.8885	0.136
	Year × Season × Area	6	0.19717	3.2861E-2	0.5324	0.7876

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Table 2 *(continued)*

	Source of variation	Degree of Freedom	Sum of Squares	Mean Squares	Pseudo-F	P (perm)
	Residual	114	7.0363	6.1722E-2		
	Total	137	9.3816			
Mobile Fauna – middle-intertidal						
	Season	3	37021	12340	5.3592	**0.0001**
	Area	1	2148.3	2148.3	0.93295	0.4425
	Year × Season	6	16463	2743.8	1.1916	0.2314
	Year × Area	2	11392	5696	2.4737	**0.0103**
	Season × Area	3	8403.4	2801.1	1.2165	0.2505
	Year × Season × Area	6	7031.9	1172	0.50896	0.9853
	Residual	114	2.6251E5	2302.7		
	Total	137	3.5348E5			
J	Year	2	0.54787	0.27394	1.628	0.2007
	Season	3	2.0435	0.68117	4.0483	**0.0101**
	Area	1	1.2519E-2	1.2519E-2	7.4402E-2	0.7896
	Year × Season	6	0.45221	7.5369E-2	0.44793	0.8408
	Year × Area	2	0.294	0.147	0.87364	0.4222
	Season × Area	3	0.81655	0.27218	1.6176	0.1932
	Year × Season × Area	6	0.94874	0.15812	0.93975	0.4596
	Residual	114	19.182	0.16826		
	Total	137	24.351			
H’	Year	2	0.12385	6.1926E-2	0.40892	0.6627
	Season	3	2.1544	0.71812	4.7421	**0.0036**
	Area	1	5.7177E-4	5.7177E-4	3.7757E-3	0.9514
	Year × Season	6	0.44384	7.3973E-2	0.48848	0.8145
	Year × Area	2	7.5959E-2	3.798E-2	0.2508	0.7784
	Season × Area	3	0.81442	0.27147	1.7927	0.1544
	Year × Season × Area	6	0.76058	0.12676	0.83708	0.5495
	Residual	114	17.264	0.15144		
	Total	137	21.656			

Diversity and eveness measures (H’ and J) estimated for supratidal communities exhibited significant seasonal variations (PERMANOVA analysis (Tables 2 and 3), except for sessile fauna, with this last observation not being consistent with natural patterns usually observed in the intertidal communities. Besides, mobile fauna also showed higher values of Ḣand J outside the protected area (Tables 2 and 3). Regarding middle-intertidal communities, seasonal variations were also relatively uncharacteristic (PERMANOVA- Tables 2 and 3), but in this case sessile fauna presented higher diversity and eveness inside the protected area (Tables 2 and 3).

4. Discussion

The comparative analysis of intertidal communities in Marine Protected Areas and in adjacent non protected areas is an effective and cost-efficient procedure to access the effects of the applied protection constrains (Fraschetti et al., 2002). Long term surveys enable this comparative analysis, aiming at the effective management of protected areas; however this type of survey is only possible when there is availability of funding and human resources.

In this case-study, it was expected a positive variation in the intertidal communities diversity and eveness within the ZIBA, between 2013 and 2015, responding positively (increasing density and diversity) to a decrease in anthropogenic pressures, as a result of a greater obedience from different ZIBA users with respect to protected area regulations since 2013 (Ferreira et al., 2015). However, this expectation was only observed with regard to sessile fauna in the middle-intertidal zone, which was not consistent with the outcomes from other comparable studies (Halpern, 2003). Additionally, the seasonal variation of Ḣ and J values has not revealed any consistent pattern regarding a positive response of the communities inside the protected area.

Regarding mobile fauna, densities were higher within the protected in 2013, while the contrary was recorded in 2015. Again, results were not consistent with the hypothesis that a greater recovery capability would be observed inside the protected area (Halpern, 2003).

It is known that heterogeneous spatial distributions of species in intertidal communities greatly depend on physical factors such as wave exposure, shores slope, and substrate complexity, along with competition, predation and herbivory (Benedetti-Cecchi et al., 2003). Although it can be argued that such physical factors could have locally concealed the response of biological communities inside and outside the protected area, that is difficult to demonstrate since their influence and interactions are difficult to measure and may originate scale dependent differences (e.g. cm or Km) (Zamprogno et al., 2012).

Another possible explanation for the results may lie in the design of this protected area, and actually comparable results were obtained by Fraschetti et al. (2005) for protected areas in the Mediterranean. The ZIBA is a very small protected area, and thus some of the most relevant habitats occurring inside ZIBA are also found immediately outside of it. Of course, in both zones they can provide refuge and nursery spaces to many of the species living in this rocky shore. Since species do not acknowledge borders, due to its small size the “edge effect” between protected vs. unprotected areas may extend to the entire study area. This might have promoted a failure in creating a true differentiated zone inside the ZIBA as a result of its openness and consequent high exchanges in energy, mater, and immigration of species through its borders (Jørgensen et al., 2000; Patrício et al., 2006). This reinforces the notion that adequate size constitutes a key feature that must be taken into consideration when designing a Marine Protected Area (Fraschetti et al., 2005). To optimize their size, the design of Marine Protected Areas should always include a considerable effort to inform the public and promote public participation in the decision-making process, considering the human presence and its activities as an integral part of the system (Fraschetti et al., 2002; Fraschetti et al., 2009; Ferreira et al., 2015).

Results from this study were affected by the *Hercules* ocean storm, which caused an immense impact on the biological communities in the study area, and requires a closer attention. For instance, the algal

Table 3
Details of the pairwise *t*-tests subsequently applied to PERMANOVA tests showing significant differences. Bold values stand for the significant differences ($p < 0.05$).

	Groups	t	P (perm)
Flora supratidal			
Average density (area)	In. Out	1.7423	**0.0467**
J (season)	winter. spring	4.9414	**0.0001**
	winter. summer	4.7018	**0.0001**
	winter. autumn	0.2899	0.7739
	spring. summer	0.121	0.9028
	spring. autumn	5.5308	**0.0001**
	summer. autumn	5.2615	**0.0001**
H' (season)	winter. spring	4.3151	**0.0002**
	winter. summer	4.0291	**0.0003**
	winter. autumn	0.5951	0.5576
	spring. summer	0.49525	0.6157
	spring. autumn	5.4944	**0.0001**
	summer. autumn	5.2615	**0.0001**
Flora – middle-intertidal			
Average density (year)	2013. 2014	0.87238	0.5202
	2013. 2015	2.0352	**0.0099**
	2014. 2015	2.5122	**0.0005**
(season)	winter. spring	2.6112	0.0005
	winter. summer	2.4698	0.0009
	winter. autumn	0.68292	0.6871
	spring. summer	0.91588	0.4744
	spring. autumn	3.0606	**0.0001**
	summer. autumn	2.7152	**0.0008**
J (season)	winter. spring	4.9414	**0.0001**
	winter. summer	4.7018	**0.0002**
	winter. autumn	0.28996	0.7745
	spring. summer	0.121	0.9029
	spring. autumn	5.5308	**0.0001**
	summer. autumn	5.2615	**0.0001**
H' (season)	winter. spring	4.3151	**0.0002**
	winter. summer	4.0291	**0.0002**
	winter. autumn	0.5951	0.5582
	spring. summer	0.49525	0.6166
	spring. autumn	5.4944	**0.0001**
	summer. autumn	5.2615	**0.0001**
Sessile Fauna – middle-intertidal			
J (area)	In. Out	2.5461	**0.0121**
H' (area)	In. Out	2.1429	**0.0362**
(season)	winter. spring	1.3863	0.1714
	winter. summer	0.89792	0.3875
	winter. autumn	1.8273	0.0738
	spring. summer	2.1163	**0.0392**
	spring. autumn	0.50428	0.6279
	summer. autumn	2.4243	**0.0197**
Mobile Fauna – supratidal			
Average density (area)	In. Out	1.8386	**0.0379**
(season)	winter. spring	1.6635	0.0649
	winter. summer	3.3275	**0.0003**
	winter. autumn	3.2481	**0.0001**
	spring. summer	1.8061	0.0534
	spring. autumn	1.798	**0.0389**
	summer. autumn	0.80048	0.5469
J (area)	In. Out	2.4148	**0.0171**
(season)	winter. spring	1.6626	0.1003
	winter. summer	2.6558	**0.008**
	winter. autumn	3.0551	**0.0032**
	spring. summer	0.89283	0.3762
	spring. autumn	1.4835	0.137
	summer. autumn	0.67667	0.4986
H' (area)	In. Out	2.0528	**0.0389**
(season)	winter. spring	1.7329	0.087
	winter. summer	2.7206	**0.0078**
	winter. autumn	3.0303	**0.0034**
	spring. summer	0.72185	0.4857
	spring. autumn	1.5127	0.1364
	summer. autumn	0.95161	0.3422
Mobile Fauna – middle-intertidal			
Average density (season)	winter. spring	2.0407	**0.0031**
	winter. summer	3.8953	**0.0001**
	winter. autumn	1.9634	**0.0065**
	spring. summer	2.3077	**0.0005**
	spring. autumn	1.199	0.2042
	summer. autumn	1.8607	**0.0142**
(year × area) − year	In (2013. 2014)	1.7021	**0.0201**
	In (2013. 2015)	2.0551	**0.0022**
	In (2014. 2015)	0.87322	0.5462
	Out (2013. 2014)	0.9274	0.4928
	Out (2013. 2015)	1.5311	**0.0470**
	Out (2014. 2015)	1.2500	0.1657
(year × area) − area	2013 (In. Out)	1.5959	**0.0274**
	2014 (In. Out)	1.032	0.3508
	2015 (In. Out)	1.5165	0.0511
J (season)	winter. spring	1.6256	0.1095
	winter. summer	3.4923	**0.0014**
	winter. autumn	1.3975	0.1697
	spring. summer	1.9077	0.0652
	spring. autumn	0.17247	0.8613
	summer. autumn	2.0125	**0.0469**
H' (season)	winter. spring	2.0628	**0.0451**
	winter. summer	3.8931	**0.0003**
	winter. autumn	2.0002	0.0532
	spring. summer	1.8812	0.0632
	spring. autumn	3.3398E-2	0.9736
	summer. autumn	1.7714	0.0809

coverage suffered a drastic change from 2014 to 2015, while an increase of sessile fauna was observed in 2015 (although insufficient to be considered significant by PERMANOVA). A possible explanation is that the strong rarefaction of the rocky shore communities, as a consequence of physical disturbances caused by *Hercules,* led to a typical succession pattern of rapid colonization by the algal species (Benedetti-Cecchi and Cinelli, 1996). This resembles, up to a certain extent, to a re-colonization field experiment. For instance, Patrício et al. (2006), also on the Western Coast of Portugal, found that small areas (625 cm^2) artificially disturbed totally recovered in just 6 months; additionally the experiment also illustrated that the presence of algal structures increased the surface availability and complexity of the substrate. The same result was obtained for the habitat forming blue mussel, barnacles or limpets (Kim and DeWreede, 1996; Koivisto and Westerbom, 2010; Thompson et al., 2002;). Evidently, in the current case, disturbance caused by *Hercules* distressed a very large area. Early algae colonizers (usually green algae) may have attracted herbivore species, whose pressure may have led to the subsequent decrease of the algal coverage (Benedetti-Cecchi and Cinelli, 1996). Rocky shore intertidal communities can exist in a number of apparently stable states, which may persist for periods (e.g. 7–13 years), greatly exceeding the turnover time of the resident populations (Dye, 1998). However, post disturbance equilibria may be fragile, and distressed communities may remain unstable for long periods (Dye, 1998).

Results suggest that longer data series are necessary to obtain a more robust dataset regarding natural variability, since alterations caused by extreme events are always likely to occur, and additionally illustrate that indeed MPAs size matters because it influences openness, expressed as the ratio of periphery to area (Jørgensen et al., 2000; Patrício et al., 2006), and therefore its susceptibility to external driving forces. The ideal monitoring programme should enable the monthly survey of the intertidal rocky shore, with two senior observers, for a minimum period of 10 years. This monitoring programme is only achievable if the entity responsible for the management of the Marine Protected Area establishes this survey as an essential activity for the objectives of the MPA, allocating internal human resources and funding for this purpose.

Regarding the ZIBA, there is a deficit of information for the period before its classification as MPA, and such considerations must be taken into account in any management plan, which in this case should encompass an increase in the intertidal protected area, a new conditioned

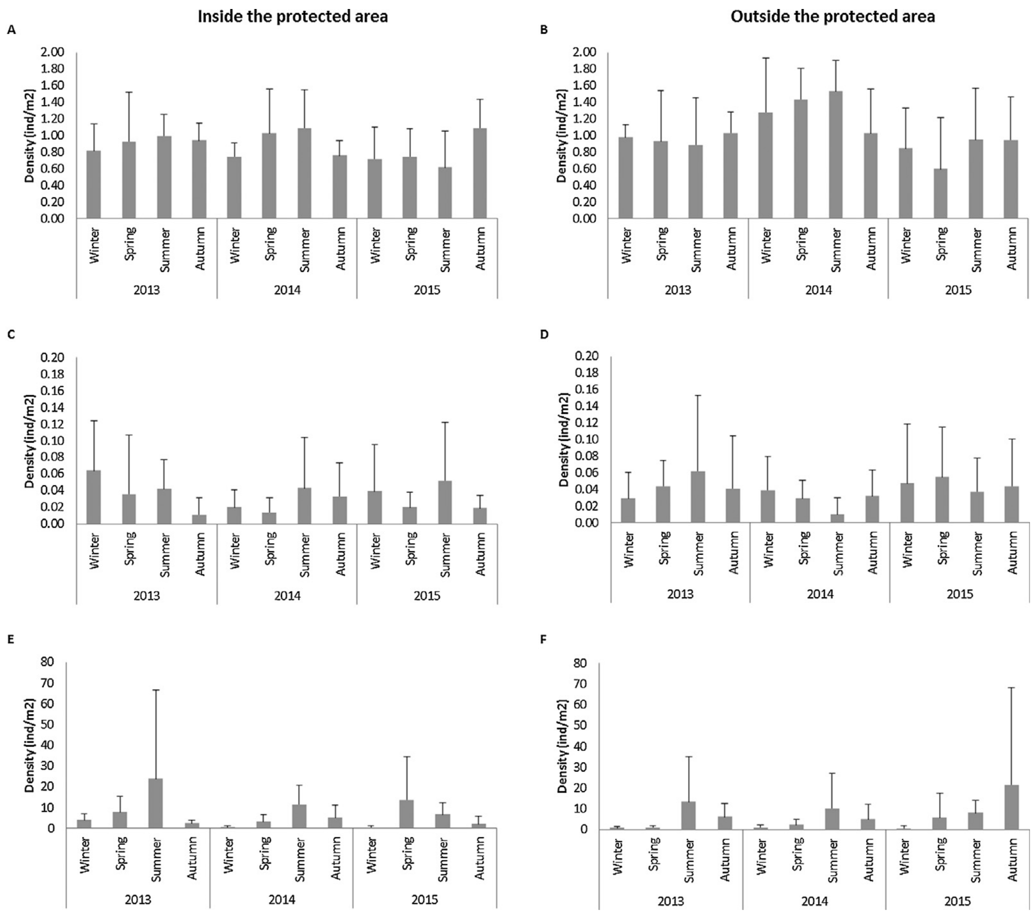

Fig. 4. Average species' densities ± standard deviation (individuals/m^2) at the middle-intertidal zone, both inside and outside the protected area; A and B – Flora; C and D – Sessile faunal species; E and F – Mobile faunal species.

small-scale fishing regime (passing from a "no-take regime" to a conditioned fishing regime is challenging and innovative), and an adequate monitoring programme to evaluate the effectiveness of the new management scheme.

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