

1Assessing the potential of marine Natura 2000 sites to produce  
2ecosystem-wide effects in rocky reefs: A case study from Sardinia  
3Island (Italy)

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17

## 18Abstract

19Marine biodiversity and the related ecosystem goods and services are declining in many  
20regions of the world. A number of policy measures and tools have been adopted to cope  
21with the current degradation of marine ecosystems. Marine Protected Areas (MPAs) make  
22part of them. In the last decades MPAs – considering all types of MPAs – have  
23dramatically increased worldwide, including in EU waters. Natura 2000 sites are the core  
24of the biodiversity conservation strategy of the EU. To date, more than 25 000 Natura 2000  
25sites, covering >350 000 km<sup>2</sup> at sea, have been declared. They form the most important  
26coordinated system of protected areas in the world. However, there are more and more  
27critical voices questioning their effectiveness and complementarity with other national (e.g.  
28nationally established MPAs), EU (e.g. the Marine Strategy Framework Directive, the  
29Common Fishery Policy) and other international initiatives (e.g. the Ecosystem-Based  
30Approach of the CBD). Using a largely employed indicator of marine coastal ecosystem  
31health, i.e. the fish biomass, we assessed here the ecological effectiveness of Natura 2000  
32sites in Sardinia Island (Italy), used here as a case study area. We compared fish biomass  
33(total fish biomass and that of selected fish) assessed using visual census in rocky reefs.  
34The assessment was performed at 18 protected sites (i.e. 6 fully protected zones within  
35nationally established MPAs and 12 Natura 2000 sites) and in 18 unprotected control sites  
36open to fishing and adjacent to the protected ones. Results show that the highest fish  
37biomass (total values and those related to commercially and ecologically relevant fishes) is  
38by far the one associated to fully protected MPAs, while the average values observed in  
39Natura 2000 sites do not or slightly differ from those observed in control sites. This study  
40shows that Natura 2000 sites do not presently contribute to the ecosystem-wide  
41management and that declaring Natura 2000 sites is a necessary but not sufficient  
42condition to achieve significant ecological benefits. Re-thinking and widening the scope of  
43Natura 2000 sites in EU waters, providing sound management plans and implementing  
44appropriate conservation measures becomes more and more urgent to make it possible  
45for Natura 2000 sites to provide significant ecological and socio-economic benefits.

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47Keywords: marine protected areas, site of community importance, ecological  
48effectiveness, implementation, management, Mediterranean Sea, EU policy

## 49Introduction

50

51 A number of papers and reports published in the last decades have reported an  
52alarming decline of marine biodiversity worldwide (MEA, 2005; Worms et al., 2006). Future  
53scenarios appear, indeed, quite negative as a consequence of multiple and unsustainable  
54human activities coupled with several additional sources of stress, which are responsible  
55for current ocean degradation, especially in coastal areas (Halpern et al., 2008; Micheli et  
56al., 2013; Worms et al., 2006; Bopp et al., 2013). Countries throughout the world seem to  
57be increasingly aware of that, but also of the fact that the mankind holds the power to  
58reverse this negative trend (Guidetti and Danovaro, 2018).

59 Multiple scale actions as well as inter-sectoral and international cooperation,  
60accompanied by the adoption of an ecosystem approach, are thus more and more  
61recommended (Douvere and Ehler, 2009; Guidetti and Danovaro, 2018). The logics to pair  
62large-scale initiatives (e.g. the transnational implementation of SDG, Sustainable  
63Development Goals, targets; see <https://oceanconference.un.org/callforaction>) and  
64regional-local actions (e.g. the creation of effective Marine Protected Areas networks)  
65seems to be the most effective strategy to reverse the ongoing ocean health decline.

66 Marine Protected Areas (MPAs) have been proven to be a valuable tool capable of  
67alleviating the impact of a number of anthropogenic stresses at sea. They can be effective  
68at local and large scales (in the case MPAs are structured in effective networks), and  
69capable of producing many ecological effects and socio-economic benefits (Gaines et al.,  
702010; Sumaila et al., 2000; Sala et al., 2013; Giakoumi et al., 2017).

71 In the last decades MPAs – considering all types of MPAs – have dramatically increased  
72worldwide (Grorud-Colvert and Lubchenco, 2015). In the EU waters, Natura 2000 sites  
73(Nat2000) are the core of the biodiversity conservation strategy of the EU (Evans, 2012).  
74Based on two EU directives (the Habitats and Birds Directives; EC, 1992; EC, 2009), they  
75do not usually include strictly protected zones (e.g. no-take areas), being their main aim to  
76regulate and manage human activities in order to protect core breeding and resting sites  
77for rare and threatened species, and some specific and fragile habitat types  
78([http://ec.europa.eu/environment/nature/natura2000/index\\_en.htm](http://ec.europa.eu/environment/nature/natura2000/index_en.htm)). Using the same  
79legislative tool, therefore, the 28 EU state members have until now declared >25 000  
80Nat2000 sites (terrestrial and marine), covering >350 000 km<sup>2</sup> at sea (EU, 2017). On the  
81whole, the Nat2000 sites represent the largest coordinated system of PAs in the world.

82 Besides the formal framework, nevertheless, Nat2000 sites are more and more  
83 frequently the object of critical voices that 1) question their actual role and effectiveness in  
84 protecting marine biodiversity, and 2) suggest the need for a proper integration into the  
85 wider conservation and environmental EU policy. Meinesz and Blanfuné (2015), for  
86 instance, stated that Nat2000 sites along the Mediterranean French coasts do not include  
87 any regulation of fishing activities potentially impacting marine coastal biodiversity, or any  
88 specific regulation regarding the protection of a species or biotope, with the exception of  
89 the seagrass *Posidonia oceanica*. This latter species, however, is already and may be  
90 better protected thanks to a national law, both within and outside Nat2000 sites. Recently,  
91 Mazaris et al. (2017) reported that the Nat2000 system fails to meet several CBD  
92 (Convention on Biological Diversity, 2011) targets: the relative % of marine surface  
93 covered is extremely variable among member states, deep/offshore marine ecosystems  
94 are underrepresented, and connectivity is not guaranteed at all. In addition, less than 40%  
95 of Nat2000 sites have a management plan and shared Nat2000 sites between member  
96 states are limited (Mazaris et al., 2018). Finally, in spite of the evident implications related  
97 to the implementation of the Nat2000 sites for fisheries (Pedersen et al., 2009), the  
98 initiatives to develop fisheries management measures in Nat2000 sites are extremely  
99 limited. These elements are in clear contrast with the more and more evident ambition of  
100 the Commission for larger scopes of the Nat2000 system, going beyond the Birds and  
101 Habitats Directives (see Fock, 2011).

102 Nowadays, for the reasons exposed above, Nat2000 sites do not seem to be capable of  
103 effectively contributing to the ecosystem-wide marine protection policy of the EU or to  
104 properly integrate the Marine Strategy Framework Directive (MSFD) and Common Fishery  
105 Policy (CFP) objectives, with some studies that have been published stressing the serious  
106 risk that specific fishing activities could impede the attainment of the conservation  
107 objectives of the Nat2000 sites (Pedersen et al., 2009).

108 While several features of Nat2000 system (e.g., the spatial properties; Mazaris et al.  
109 2018) have been studied both for the terrestrial and (to a lesser extent) the marine  
110 counterpart, their effectiveness in preserving and/or restoring marine biodiversity has  
111 never been investigated. In order to eventually re-think and widen their role into the wider  
112 and evolving conservation EU policy framework, it is crucial and timely to improve the body  
113 of evidence about whether or not Nat2000 sites can contribute to ecosystem-wide  
114 conservation.

115 Fish assemblages are largely used for evaluating the effectiveness of any type of MPA,  
116for a number of reasons: i) fish can be easily assessed using non-destructive methods  
117(Harmelin-Vivien et al., 1985; Caldwell et al., 2016); ii) fish clearly respond to the  
118implementation of protection/management measures (Guidetti et al., 2008; Graham et al.,  
1192014; Guidetti et al., 2014; Giakoumi et al., 2017); iii) fish are effective indicators of socio-  
120economic MPA benefits, e.g. those related to fisheries and tourism (Kerwath et al., 2013;  
121Di Franco et al., 2016; Sala et al., 2016; Gill et al., 2017); iv) fish are commonly used as  
122indicators of ecosystem health and are linked to the provision of crucial ecosystem goods  
123and services (Pauly et al., 1998; Micheli et al., 2004; Leenhardt et al., 2015).

124 Being the EU waters subjected to multiple anthropogenic sources of stress and impacts  
125capable of producing community- and ecosystem-wide alterations (Coll et al., 2012;  
126Fenberg et al., 2012; Micheli et al., 2013; Katsanevakis et al., 2015), it becomes urgent to  
127know whether Nat2000 sites, in combination with other EU or national initiatives (e.g.  
128MSFD, CFP, nationally established MPAs), have the potential to provide an adequate  
129protection to natural marine assemblages and ecosystems, while safeguarding the  
130sustainability of fisheries and other human activities.

131 The present study aims, therefore, to evaluate the effectiveness of Nat2000 along the  
132coasts of Sardinia Island (Mediterranean Sea, Italy), used here as a case study area, by  
133assessing and comparing coastal fish assemblages sampled in Nat2000 sites, in fully  
134protected (i.e. no-take) MPAs and in adjacent control sites.

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## 137 **Materials and methods**

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### 139 *Sampling area and methods*

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141 Fish assemblages were assessed at 18 locations situated along the coasts of Sardinia  
142Island (Italy; Mediterranean Sea). Six fully protected (i.e. no-take) locations within  
143nationally established MPAs (FP-MPA: “Tavolara-Punta Coda Cavallo”, “Capo Carbonara”,  
144“Penisola del Sinis-Isola di Mal di Ventre”, “Capo Caccia-Isola Piana”, “Isola dell’Asinara”  
145and “Parco Nazionale dell’Arcipelago di Maddalena”) and 12 Nat2000 sites (“Capo Figari  
146ed Isola Figarolo”, “Berchida e Bidderosa”, “Golfo di Orosei”, “Capo di Pula”, “Promontorio,  
147dune e zona umida di Porto Pino”, “Isola di San Pietro”, “Costa di Nebida”, “Stagno di  
148Putzu Idu”, “Entrotterra e zona costiera tra Bosa, Capo Marangiu e Porto Tangone”, “Coste

149e Isolette a Nord-Ovest della Sardegna”, “Monte Russu” and “Capo Testa”) were sampled,  
150along with adjacent sites open to fishing (regulated by national/regional laws) and used as  
151controls (Fig. 1). With “Nat2000” we mean here Nat2000 sites that do not overlap with  
152other MPA types. Two ‘protected’ and two ‘unprotected’ stations were sampled at each of  
153the 18 sampling locations. Three fish visual assessments were performed underwater on  
154rocky reefs at 5-12 m depth, along 3 replicate strip transects of 25×5 m at each station, for  
155a total of 216 visual census (i.e. replicates).

156 Most of sampling sites were sampled between mid-June and mid-August 2016. Data  
157from the Maddalena, Capo Caccia and Asinara MPA were gathered in August-September  
1582011, 2015 and 2017, respectively.

159 Visual censuses were performed on rocky substrates where other substrate types, like  
160sand or seagrasses, represented less than 15% in cover (both within and around  
161transects). Along each transect, the diver swam one way at constant speed (approximately  
1624 meters/min.), identifying and recording the number and size of each fish encountered.  
163Fish density was estimated by counting single specimens to a maximum of ten individuals,  
164whereas classes of abundance (11–30, 31–50, 51–100, 101–200, 201–500, >500  
165individuals) were used for larger schools. Fish size (total length: TL) was recorded within  
1662-cm size classes for most of the species, and within 5-cm size classes for large-sized  
167species such as *Epinephelus marginatus*. Fish wet mass (hereafter called biomass) was  
168estimated from size data by means of length-weight relationships from the available  
169literature (Froese and Pauly, 2012).

170 We focused on biomass data of fish associated with rocky reefs because: (1) fish  
171biomass is recognized as the most responsive indicator of the conservation status of fish  
172assemblages as it inherently integrates both density and size (Sandin et al. 2008; Guidetti  
173et al., 2014); (2) rocky reefs are the most common habitat protected within coastal MPAs in  
174the Mediterranean Sea; (3) previous studies showed that rocky reefs host the most of fish  
175targeted by fishing and therefore these fish assemblages more clearly respond to  
176protection from fishing than others (see Guidetti et al., 2008 and references therein).

177

#### 178 *Data analyses*

179 The effects of different protection levels on fish biomass variables were analyzed using  
180univariate techniques. ‘Protection’ (PR) was considered as a fixed factor (3 levels: FP-  
181MPA, Nat2000, unprotected control), and ‘Station’ (ST) was a random factor (2 levels)  
182nested in each level of PR. The 6 variables taken into consideration are: total fish biomass,

183that of most relevant categories (High and Low-Null Commercial Importance fishes;  
184indicated hereinafter as H CI and L-N CI) and that of some fish species ecologically  
185important and targeted by commercial and recreational fishing (the dusky grouper  
186*Epinephelus marginatus*, the brown meager *Sciaena umbra*, the sea breams *Diplodus*  
187*sargus* and *D. vulgaris*; these latter fishes have been pooled and named hereinafter as  
188*Diplodus* spp.). This selection of relevant variables is in agreement with the available  
189literature suggesting that fishery targeted fish have the potential to respond more clearly to  
190the effectiveness of management measures (Guidetti et al., 2014).

191 Univariate PERMANOVA based on Euclidean distance measure (Terlizzi et al., 2007)  
192was used in order to avoid any assumption about the distribution of the variables  
193(Anderson et al., 2001). In this analysis P-values associated with F statistics are obtained  
194by permutation. The PRIMER 6 and Permanova + B20 package (Plymouth Marine  
195Laboratory) was used to perform the analyses (Clarke and Gorley, 2006).

196 Methods derived from meta-analysis were used to examine and summarize the general  
197response of fish to protection. As visual censuses were done at several protected (FP-MPA  
198and Nat2000) and unprotected (control) stations, mean values were used to approximate  
199average conditions in space (see Guidetti and Sala, 2007). We examined the response to  
200protection on the 6 fish biomass variables mentioned above. We quantified the effects of  
201protection *versus* control conditions as the natural logarithm of the ratio between the  
202values of each response variable (i.e. total fish biomass) in protected and control  
203conditions as response ratios (lnRR; Hedges and Olkin, 1985; Micheli et al., 2004). Data  
204were thus normalized and the response to protection examined independently of the  
205absolute biomasses at each location. As estimations of average values can be affected by  
206sampling effort, we calculated weighted means using the natural logarithm of the total area  
207covered by the censuses from which the estimates were obtained (Mosquera et al., 2000).  
208Positive RRs indicate greater biomass in protected than in control conditions, whereas  
209negative values indicate greater values in control conditions compared to protected ones.  
210A ratio of zero, instead, means that the biomass is similar between protected and control  
211conditions. Averages of the mean RRs were considered significantly different from zero  
212(i.e. there is a significant protection effect) when the 95% confidence limits around the  
213mean do not overlap with zero (Micheli, 1999 and references therein).

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## 217 Results

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219 The visual inspection of the graphs reporting the average values of fish biomass reveals  
220a common general pattern: total fish biomass, that of H CI and L-N CI fishes, and that of  
221relevant species (*E. marginatus*, *S. umbra*, *Diplodus* spp.) are generally highest in FP-  
222MPAs, followed by Nat2000 sites, and lowest at controls (Fig. 2).

223 Statistical analyses (univariate PERMANOVAs) show that none of the 6 fish biomass  
224variables considered in this study varied significantly at the spatial scale of stations (Tab.  
2251). Total fish biomass, that of H CI fish, and that of *E. marginatus* and *Diplodus* spp.  
226significantly changed in relation to the protection level, with the highest average values  
227observed in FP-MPAs. Pair-wise post-hoc tests showed that total fish biomass and that of  
228*E. marginatus* were statistically highest at FP-MPAs, followed by Nat2000, with the lowest  
229average values observed at control sites. Average values of H CI and *Diplodus* spp. were  
230significantly higher at FP-MPAs than at Nat2000 and control sites, with no statistical  
231difference between Nat2000 sites and controls. Conversely, biomass of L-N CI fish and *S.*  
232*umbra* did not change with the protection level (Tab. 1).

233 In terms of RR, one important point to stress is the non-negligible variability observed  
234among FP-MPAs and among Nat2000 sites. Just as an example, lnRRs of the total fish  
235biomass greatly varied among FP-MPAs, with one value that was clearly negative, while  
236lnRRs calculated for Nat2000 sites are approximately equally distributed from one side to  
237the other of the zero value (Fig. 3).

238 Across all FP-MPAs combined, average RRs concerning all 6 fish biomass variables  
239taken into account in the present study showed positive values (with lnRR ranging from 0.6  
240to 4.8) (Fig. 4). For the 6 variables the confidence intervals (95% CI) did not overlap the  
241zero value, which means that differences are statistically significant.

242 Across all Nat2000 sites combined, instead, all 6 variables but the biomass of *E.*  
243*marginatus* did not show any significant pattern, although a general tendency seems to  
244emerge, showing larger values in Nat2000 sites than in control sites. As far as Nat2000  
245sites are concerned, only the biomass of *E. marginatus* was significantly higher in Nat2000  
246compared to control sites (lnRR=2.19±1.76; 95% CI). For the 5 other fish biomass  
247variables, conversely, the confidence intervals (95% CI) overlap the zero value, which  
248means that differences are not statistically significant.

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## 251 Discussion and conclusions

252 This study, in a nutshell, shows that FP-MPAs preserve more effectively fish  
253 assemblages than Nat2000 sites. This result comes out by comparing the biomass of i)  
254 whole fish assemblages, ii) fish of high commercial importance and iii) a few relevant  
255 species (the dusky grouper *E. marginatus* and the sea breams *Diplodus sargus* and *D.*  
256 *vulgaris*) in FP-MPAs, Nat 2000 sites and control sites. The sole status of Nat2000 site,  
257 therefore, does not seem to guarantee an effective management and any significant  
258 ecological effect. The tendency for slightly higher values in Nat2000 sites compared to  
259 controls (except for *E. marginatus*) is more likely to attribute, in agreement with the  
260 available literature (Friedlander et al., 2013; Edgar et al., 2014), to the isolation and  
261 distance of some Nat2000 from fishing ports and villages than to an effect of conservation  
262 measures. From this point of view, the choice of the “Regione Sardinia” (the public  
263 institution responsible for the management of Nat2000 sites) to establish some Nat2000  
264 marine sites within the borders of previously established MPAs seem to be a solution that  
265 guarantees an effective management of these Nat2000 sites. Conversely, the mere  
266 declaration of a Nat2000 sites does not seem to ensure any significant effect.

267 Another aspect coming out from these data is the ample variability of the results within  
268 each level of protection, in particular considering the results of FP-MPAs. Such a variability  
269 in terms of ecological effectiveness of FP-MPAs can be the result of multiple factors acting  
270 locally, such as the design, the organization, the management, the rule enforcement, etc.,  
271 which may vary among MPAs, something which well known in the Mediterranean context  
272 (Guidetti et al., 2008; Sala et al., 2012; Giakoumi et al., 2017).

273 As it is the case of Nat2000 sampled in Sardinia in this study, Nat2000 sites do not  
274 usually include fully protected (i.e. no-take) zones. Consequently, the fact fish biomass  
275 (especially that of fish species targeted by fishing) is higher in FP-MPAs is an expected  
276 outcome. Conversely, the very small or inexistent differences between Nat2000 and  
277 controls deserves major attention. The point is that some fish are key species playing  
278 pivotal roles at community level. The dusky grouper is one of the largest predator in  
279 coastal Mediterranean ecosystems (Sala, 2004; Guidetti and Micheli, 2011; Conдини et al.,  
280 2017). This species is plays a major community-wide ecological role, as it is usually the  
281 case for large predators in nature (Ray et al., 2005). However, except for limited areas  
282 benefiting from effective conservation measures (like the well managed and enforced FP-

283MPAs; Giakoumi et al., 2017), this species displays a progressive decline through time in  
284the Mediterranean due to the impact of fishing (Guidetti and Micheli, 2011). Similarly, the  
285ecological role of *Diplodus* fish has been demonstrated to be crucial for the preservation of  
286macroalgal beds in Mediterranean rocky reefs (Sala et al., 1998). Via their predation upon  
287sea urchins, *Diplodus* fish significantly contribute to control sea urchin populations and  
288their (over)grazing upon macroalgae, thus preventing the formation of the so-called  
289barrens (i.e. bare rocks; Sala et al., 1998; Guidetti, 2006). The recovery of *Diplodus* fishes  
290within effective MPAs can trigger a cascading effect: more abundant and larger *Diplodus*  
291populations reduce sea urchin populations abundance and their grazing rate, which allows  
292the recovery of macroalgal forests (Guidetti, 2006), which are, on their turn, crucial  
293habitats for many juvenile coastal fishes (Thiriet et al., 2016). The results of this study,  
294therefore, go well beyond the results about having more or less fish, but have community-  
295and ecosystem-wide implications.

296 Although the main objective of Nat2000 sites is to protect the habitats and species  
297included in the EU Birds and Habitats Directives, it becomes urgent to integrate this  
298objective in other more recent EU initiatives, principally the Marine Strategy Framework  
299Directive (MSFD) and the Common Fisheries Policy (CFP). The MSFD, whose initial  
300implementation phase started in 2012, has the main aim to achieve the so-called “Good  
301Environmental Status” (GES) in EU marine waters by 2020. The CFP is a reform launched  
302by the EU Commission in 2013 aiming at achieving a good status for all commercial stocks  
303exploited in EU waters by 2020. Both MSFD and CFP aim at contributing to achieve GES  
304and fisheries sustainability via an ecosystem-based approach (Garcia et al., 2003) where  
305MPAs (all types, Nat2000 sites included) are seen as pivotal tools (Fenberg et al., 2012).  
306Until now any consideration about fishing in Nat2000 has been done considering its  
307potentials impacts on the species and habitats included e.g. in the Habitat Directive. It is  
308time to change this perspective, making possible for marine Nat2000 sites to contribute  
309more significantly to the ecosystem-wide conservation policies in EU waters.

310 Re-thinking and widening the role of Nat2000 is vitally important, but to do that properly  
311it would be desirable that at EU level the site selection, the organization, the management  
312and monitoring of Nat2000 sites would be harmonized and standardized. This is a crucial  
313step to avoid, for instance, what happens to the nationally established MPAs in EU waters,  
314where the different countries have created MPAs very different in terms of design, mission,  
315goals, management, infrastructures, staffs, funding, regulations and zoning, enforcement,

316 monitoring system, etc. (Scianna et al., submitted). This situation represents the major  
317 limitation to the development of a coherent network of MPAs. Strictly concerning Nat2000  
318 sites, the lack of a systematic planning process, the fact that in most cases the Nat2000  
319 sites covering marine surfaces are mere extensions of terrestrial sites into the sea, the  
320 scarce consideration of specific marine conservation needs, the lack of management plans  
321 for most cases, and the general lack of political will of member states towards the real  
322 protection of EU marine waters (the mere declaration of protected surfaces is useless if  
323 management and enforcement remain poor if not inexistent) make these tools until now  
324 poorly effective (Meinesz and Blanfuné, 2015; PISCO and UNS, 2016; Mazaris et al.,  
325 2017). These elements justify to some extent the diffuse opinion that in the EU (and  
326 Mediterranean) context, i) we are far from building an actually coherent, connected and  
327 effective network of MPAs, and that ii) there is a urgent need for a major harmonization  
328 and standardization of the available conservation tools (Mazaris et al., 2018; Scianna et  
329 al., submitted).

330 In consideration of all this, it appears clear that, if the establishment of (M)PA networks  
331 is a crucial step in the path towards the conservation of ecological mechanisms and the  
332 support of ecosystem functions, focusing solely on coverage targets (e.g. protecting 10%  
333 of marine waters by 2020) is likely to be get a substantial failure. Nat2000 marine sites  
334 should thus evolve and meet not merely extension criteria but also the key features and  
335 high quality criteria constituting the solid base for an effective networks of MPAs. To  
336 achieve effective conservation, policy and decision makers should chiefly guarantee the  
337 effective management of the currently designated Nat2000 sites by integrating them in the  
338 wider EU policy, rather than keep enlarging the declared “protected” surfaces. Once this  
339 perspective change is accepted, then, management measures in Nat2000 sites could be  
340 extended to fisheries regulations and to other human activities representing a potential risk  
341 to marine ecosystems. Even though Nat2000 sites, as any other MPA type, cannot be a  
342 panacea against any form of marine community alteration, they could play a role, aside  
343 other MPA types, e.g. in limiting the spread of invasive species in the era of climate  
344 change (Gallardo et al. 2017), provided they are effectively managed.

345 These issues do corroborate the increasing need to integrate the Habitat and Bird  
346 Directive objectives within other more recent EU initiatives, principally the Marine Strategy  
347 Framework Directive (MSFD) and the Common Fisheries Policy (CFP), which, altogether

348could increase the chances to achieve a Good Environmental and Fishery status in EU  
349waters.

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359

## 360 Literature

361 Anderson M (2001) A new method for non-parametric multivariate analysis of variance.  
362 *Austral Ecol.* 26: 32–46.

363 Bopp, L., Resplandy, L., Orr, J. C., Doney, S. C., Dunne, J. P., Gehlen, M., Halloran, P.,  
364 Heinze, C., Ilyina, T., Séférian, R., Tjiputra, J., and Vichi, M.: Multiple stressors of ocean  
365 ecosystems in the 21st century: projections with CMIP5 models, *Biogeosciences*, 10,  
366 6225–6245, <https://doi.org/10.5194/bg-10-6225-2013>, 2013.

367 Caldwell ZR, Zgliczynski BJ, Williams GJ, Sandin SA (2016) Reef Fish Survey Techniques:  
368 Assessing the Potential for Standardizing Methodologies. *PLoS ONE* 11(4): e0153066.  
369 <https://doi.org/10.1371/journal.pone.0153066>

370 CBD. 2011. Convention on Biological Diversity: The Strategic Plan for Biodiversity 2011-  
371 2020 and the Aichi Biodiversity Targets. Available from: <http://www.cbd.int/sp/targets/>.

372 Clarke KR, Gorley RN (2006) *PRIMER v6: User Manual/Tutorial*. PRIMER-E, Plymouth.

373 Coll, M., Piroddi, C., Albouy, C., Ben Rais Lasram, F., Cheung, W. W. L., Christensen, V.,  
374 Karpouzi, V. S., Guilhaumon, F., Mouillot, D., Paleczny, M., Palomares, M. L., Steenbeek,  
375 J., Trujillo, P., Watson, R. and Pauly, D. (2012), The Mediterranean Sea under siege:  
376 spatial overlap between marine biodiversity, cumulative threats and marine reserves.  
377 *Global Ecology and Biogeography*, 21: 465–480. doi:10.1111/j.1466-8238.2011.00697.x

378 Condini, M.V., García-Charton, J.A. & Garcia, A.M. *Rev Fish Biol Fisheries* (2017).  
379 <https://doi.org/10.1007/s11160-017-9502-1>

380 EC. 1992. Council Directive on the conservation of natural habitats and of wild fauna and  
381 flora. European Commission, Directive 92/ 43/EEC, OJ L 206.

382 EC. 2009. Directive of the European Parliament and the Council on the conservation of  
383 wild birds. European Commission, Directive 2009/147/EC, OJ L 20.

384 EC. 2016. European Commission. Nature and Biodiversity Newsletter. Available from  
385 [http://ec.europa.eu/environment/nature/info/pubs/natura2000nl\\_en.htm](http://ec.europa.eu/environment/nature/info/pubs/natura2000nl_en.htm) (accessed January  
386 2017).

387 Froese R, Pauly D (2012) *FishBase*. World Wide Web electronic publication.  
388 [www.fishbase.org](http://www.fishbase.org).

389 Garcia, S.M.; Zerbi, A.; Aliaume, C.; Do Chi, T.; Lasserre, G., 2003. The ecosystem  
390 approach to fisheries. Issues, terminology, principles, institutional foundations,  
391 implementation and outlook. *FAO Fisheries Technical Paper*. No. 443. Rome, FAO. 71 p.

392 Gill D.A., Mascia M.B., Ahmadi G.N., Glew L., Lester S.E., Barnes M. et al. 2017.  
393 Capacity shortfalls hinder the performance of marine protected areas globally. *Nature*,  
394 543(7647), 665-9.

395Graham J. Edgar, Rick D. Stuart-Smith, Trevor J. Willis, Stuart Kininmonth, Susan C.  
396Baker, Stuart Banks, Neville S. Barrett, Mikel A. Becerro, Anthony T. F. Bernard, Just  
397Berkhout, Colin D. Buxton, Stuart J. Campbell, Antonia T. Cooper, Marlene Davey, Sophie  
398C. Edgar, Günter Försterra, David E. Galván, Alejo J. Irigoyen, David J. Kushner, Rodrigo  
399Moura, P. Ed Parnell, Nick T. Shears, German Soler, Elisabeth M. A. Strain & Russell J.  
400Thomson. 2014. Global conservation outcomes depend on marine protected areas with  
401five key features. *Nature* 506, 216–220.

402Evans, D. 2012. Building the European Union's Natura 2000 network. *Nature*  
403*Conservation*, 1: 11–26.

404Fenberg P.B., Ashworth J.S., Caselle J., Claudet J., Clemence M., Gaines S., García-  
405Charton J.A., Gonçalves E., Grorud-Colvert K., Guidetti P., Jenkins S., Jones P., Lester S.,  
406McAllen R., Moland E., Planes S., Sørensen T.K., 2012. The science of European marine  
407reserves: status, efficacy, and future needs. *Marine Policy*, 36: 1012-1021.

408Friedlander, A. M., Ballesteros, E., Beets, J., Berkenpas, E., Gaymer, C. F., Gorny, M. and  
409Sala, E. (2013), Effects of isolation and fishing on the marine ecosystems of Easter Island  
410and Salas y Gómez, Chile. *Aquatic Conserv: Mar. Freshw. Ecosyst.*, 23: 515–531.  
411doi:10.1002/aqc.2333

412Gallardo B, Aldridge DC, Gonzalez-Moreno P, et al. Protected areas offer refuge from  
413invasive species spreading under climate change. *Glob Change Biol.* 2017;23:5331–5343.  
414<https://doi.org/10.1111/gcb.13798>

415Guidetti P., 2006. Marine reserves reestablish lost predatory interactions and cause  
416community changes in rocky reefs. *Ecological Applications*, 16 (3): 963-976.

417Guidetti P., Micheli F., 2011. Art serving marine conservation. *Frontiers in Ecology and the*  
418*Environment*, 9, 374-375.

419Harmelin-Vivien, M. L., J. G. Harmelin, C. Chauvet, C. Duval, R. Galzin, P. Lejeune, G.  
420Barnabe, F. Blanc, R. Chevalier, J. Duclerc, and G. Lasserre. 1985. Evaluation des  
421peuplements et populations de poissons. Méthodes et problèmes. *Revue Ecologie (Terre*  
422*et Vie)* 40:467–539.

423Katsanevakis, S., Levin, N., Coll, M., Giakoumi, S., Shkedi, D., Mackelworth, P., Levy, R. et  
424al. 2015. Marine conservation challenges in an era of economic crisis and geopolitical  
425instability: the case of the Mediterranean Sea. *Marine Policy*, 51: 31–39.

426S. E. Kerwath, Henning Winker, Albrecht Götz & Colin G. Attwood, 2013. Marine protected  
427area improves yield without disadvantaging fishers. *Nature Communications* volume 4,  
428Article number: 2347. doi:10.1038/ncomms3347

429Leenhardt, P., Low, N., Pascal, N., Micheli, F. & Claudet, J., 2015. The role of marine  
430protected areas in providing ecosystem services. In *Aquatic functional biodiversity: An*  
431*ecological and evolutionary perspective* (eds. Belgrano, A., Woodward, G. & Jacob, U.)  
432(Elsevier, 2015).

433Mazaris, A. D., Almpnidou, V., Giakoumi, S., and Katsanevakis, S. 2017. Gaps and  
434challenges of the European network of protected sites in the marine realm. ICES Journal  
435of Marine Science, 75, 190–198. <https://doi.org/10.1093/icesjms/fsx125>

436Alexandre Meinesz, Aurélie Blanfuné, 2015. 1983–2013:Development of marine protected  
437areas along the French Mediterranean coasts and perspectives for achievement of the  
438Aichi target. *Marine Policy* 54:10–16

439Micheli, F., Halpern, B. S., Botsford, L. W. & Warner, R. R., 2004. Trajectories and  
440correlates of community change in no-take marine reserves. *Ecol. Appl.* 14, 1709–1723.

441Micheli, F., S. Walbridge, B. Halpern, S. Ciriaco, F. Ferretti, S. Frascchetti, L. Njkaer, R.  
442Lewison, A. Rosenberg. 2013. Cumulative human impacts on Mediterranean and Black  
443Sea marine ecosystems: assessing current pressures and opportunities. *PLoS ONE* 8(12):  
444e79889

445Pauly, D., V. Christensen, J. Dalsgaard, R. Froese, and F. Torres Jr. 1998. Fishing down  
446marine food webs. *Science* 279:860-863

447Pedersen, S. A., Fock, H., Krause, J., Pusch, C., Sell, A. L., Böttcher, U., Rogers, S. I.,  
448Skořld, M., Skov, H., Podolska, M., Piet, G. J., and Rice, J. C. 2009. Natura 2000 sites and  
449fisheries in German offshore waters. *ICES Journal of Marine Science*, 66: 155–169.

450Ray JC, Reford KH, Steneck RS, Berger J, 2005. Large carnivores and the conservation of  
451biodiversity. Island Press, 526 pp.

452Sala, E., C. F. Boudouresque, and M. L. Harmelin-Vivien. 1998. Fishing, trophic cascades,  
453and the structure of algal assemblages: evaluation of an old but untested paradigm. *Oikos*  
45482:425-439.

455Sala, E. 2004. The past and present topology and structure of Mediterranean subtidal  
456rocky-shore food webs. *Ecosystems* 7:333–340.

457Sala E, Costello C, Dougherty D, Heal G, Kelleher K, Murray JH, et al. (2013) A General  
458Business Model for Marine Reserves. *PLoS ONE* 8(4): e58799.  
459<https://doi.org/10.1371/journal.pone.0058799>

460Enric Sala, Christopher Costello, Jaime De Bourbon Parme, Marco Fiorese, Geoff Heal,  
461Kieran Kelleher, Russell Moffitt, Lance Morgan, Jayne Plunkett, Kristin D.Rechberger,  
462Andrew A. Rosenberg, Rashid Sumaila, 2016. Fish banks: An economic model to scale  
463marine conservation. *Marine Policy* 73: 154–161  
464

465Sandin SA, Smith JE, DeMartini EE, Dinsdale EA, Donner SD, Friedlander AM, et al.  
466Baselines and degradation of coral reefs in the northern Line Islands. *PloS one*.  
4672008;3(2):e1548  
468

469Terlizzi A, Anderson MJ, Frascchetti S, Benedetti-Cecchi L (2007) Scales of spatial variation  
470in Mediterranean subtidal sessile assemblages at different depths. *Mar. Ecol. Prog. Ser.*  
471332: 25–39.

472Thiriet PD, Di Franco A, ChemineÂe A, Guidetti P, Bianchimani O, Basthard-Bogain S, et  
473al. (2016) Abundance and Diversity of Crypto- and Necto-Benthic Coastal Fish Are Higher  
474in Marine Forests than in Structurally Less Complex Macroalgal Assemblages. PLoS ONE  
47511(10): e0164121. doi:10.1371/journal.pone.0164121

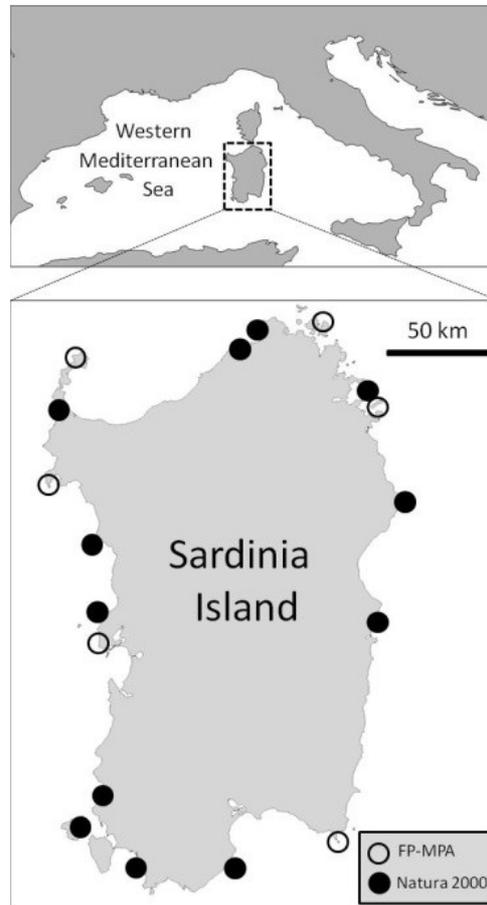
476Ussif Rashid Sumaila [Sylvie Gu nette](#) [Jackie Alder](#) [Ratana Chuenpagdee](#), 2000.  
477Addressing ecosystem effects of fishing using marine protected areas ICES Journal of  
478Marine Science, Volume 57, Issue 3, 1 June 2000, Pages 752–760,  
479<https://doi.org/10.1006/jmsc.2000.0732>  
480

481

482 Figures

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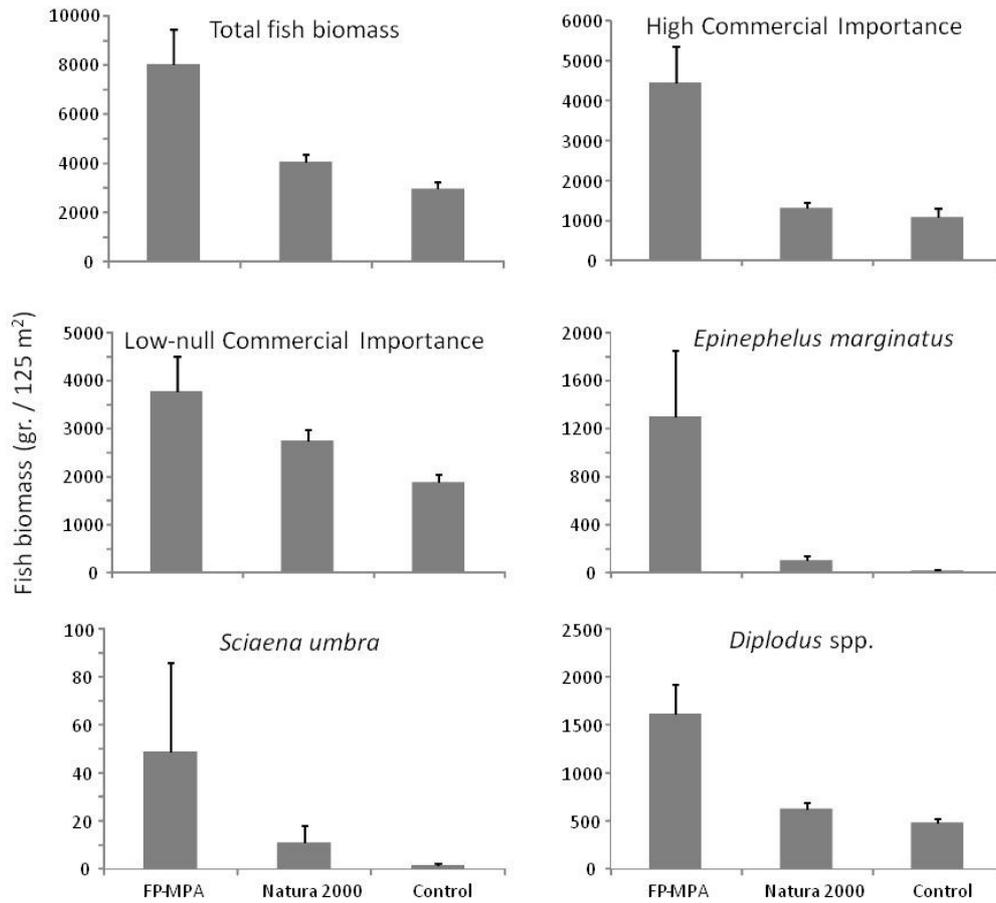
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486 Fig. 1 – Sampling locations around Sardinia Island: FP-MPA=fully protected Marine  
487 Protected Area; Natura 2000=Natura 2000 site.

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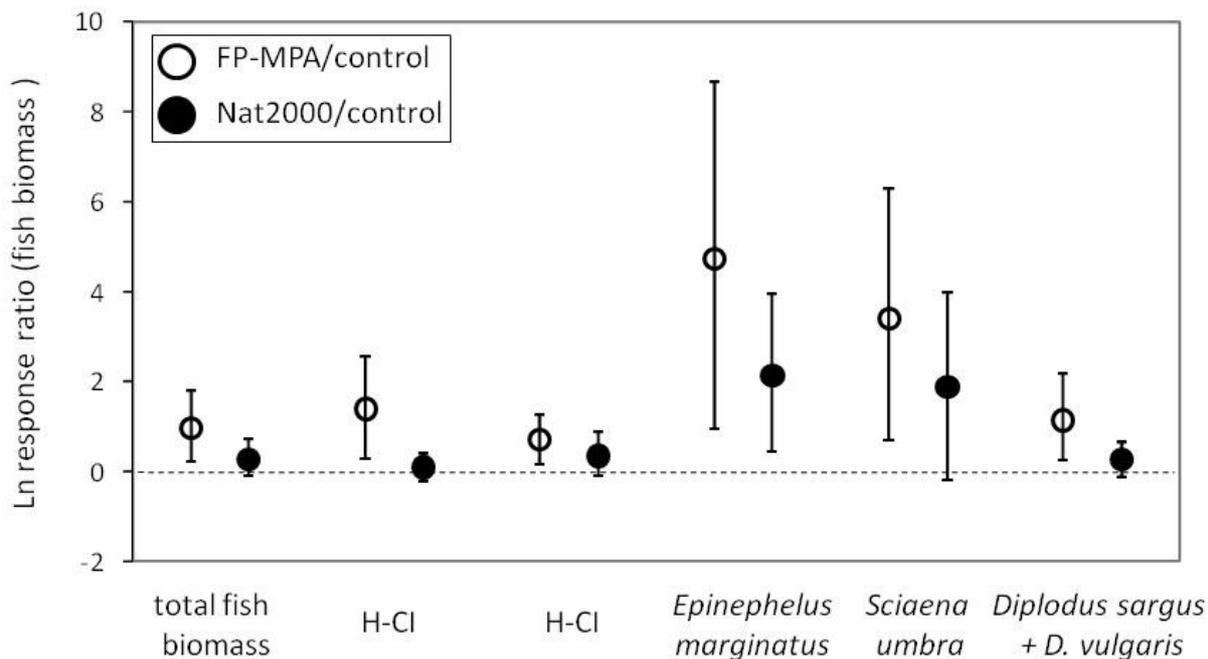


489

490Fig. 2 – Fish biomass (mean±SE) assessed at the sampling locations under different  
 491conditions of protection: FP-MPA=fully protected Marine Protected Areas; Natura  
 4922000=Natura 2000 sites; Control=areas open to fishing according to national/regional  
 493laws.

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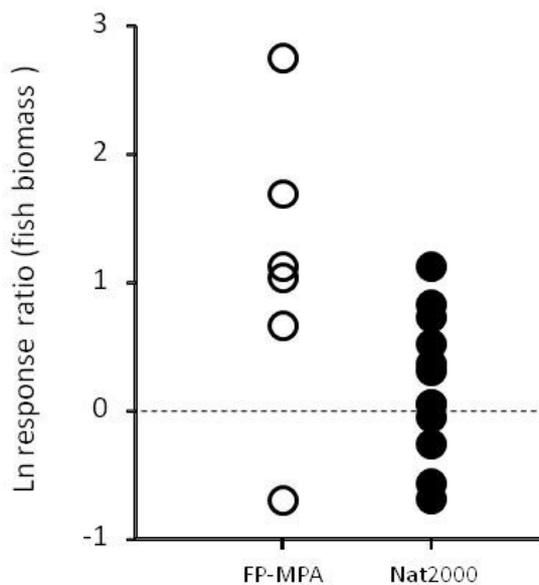
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498 Fig. 3 – Fish response to protection of the 6 variables related to fish biomass, measured  
 499 as the natural log ratio, observed in the 6 FP-MPAs (fully protected Marine Protected  
 500 Areas) and 12 Nat2000 (Natura 2000) sites considered in the present study, compared to  
 501 Control sites (i.e. areas open to fishing according to national/regional laws). Bars indicate  
 502 95% confidence intervals. See methods for more details.

503



504

505 Fig. 4 – Variability in the response of total fish biomass (measured as the natural log ratio)  
 506 observed in the 6 FP-MPAs (fully protected Marine Protected Areas) and 12 Nat2000  
 507 (Natura 2000) sites considered in the present study, compared to Control sites (i.e. areas  
 508 open to fishing according to national/regional laws).

509Tables

510

511Tab. 1 - Summaries of PERMANOVAs and pair-wise analyses testing for differences  
512among protection levels (PR=Protection, 3 levels: MPA=fully protected MPA;  
513N2000=Natura 2000 site; C=control open to fishing) and over the spatial scale of stations  
514(ST=Station, 2 levels). P-values calculated using Montecarlo permutations. NA: not  
515applicable.

Variable	PR	ST(PR)	Pair-wise tests (PR)
Total Biomass	<b>0,004</b>	0,572	FP-MPA>N2000>C
High Commercial Importance	<b>0,000</b>	0,800	FP-MPA>N2000=C
Low-Null Commercial Importance	0,091	0,394	NA
<i>Epinephelus marginatus</i>	<b>0,000</b>	0,985	FP-MPA>N2000>C
<i>Sciaena umbra</i>	0,278	0,159	NA
<i>Diplodus spp.</i>	<b>0,002</b>	0,620	FP-MPA>N2000=C

516

517

## 518Supplementary material

519S1 - Detailed results of two-way PERMANOVAs (and related pair-wise tests, when  
 520appropriate, on the levels of the factor PR) examining (1) total fish biomass; (2) biomass of  
 521High Commercial Important species; (3) biomass of Low-Null Commercial Important  
 522species; (4) biomass of *Epinephelus marginatus*; (5) biomass of *Sciaena umbra*; (6)  
 523biomass of *Diplodus* spp., among the 3 levels of protection (FP-MPAs=fully protected  
 524Marine Protected Areas; Nat2000=Natura 2000 sites; C=controls, i.e. areas open to fishing  
 525according to national/regional laws), and between 2 stations within location. Factors:  
 526PR=protection; ST=station. Significant P-values indicated in bold. See methods for more  
 527details.

## 5281) Total fish biomass.

Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms	P(MC)
PR	2	7,45E+08	3,73E+08	29,984	0,0318	90	<b>0,0043</b>
ST(PR)	3	3,59E+07	1,20E+07	0,67625	0,5786	9942	0,5717
Res	210	3,71E+09	1,77E+07				
Total	215	4,49E+09					

529

Groups	t	P(perm)	Unique perms	P(MC)
FP-MPA, C	6,2234	0,1645	6	<b>0,0031</b>
MPA, Nat2000	4,9716	0,1712	6	<b>0,0148</b>
C, Nat2000	4,2756	0,3338	6	<b>0,0322</b>

530

## 5312) biomass of High Commercial Important species.

Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms	P(MC)
PR	2	3,40E+08	1,70E+08	77,668	0,052	90	<b>0,0001</b>
ST(PR)	3	5,64E+06	1,88E+06	0,33903	0,8025	9939	0,7999
Res	210	1,16E+09	5,55E+06				
Total	215	1,51E+09					

532

Groups	t	P(perm)	Unique perms	P(MC)
FP-MPA, C	9,5236	0,166	6	<b>0,0001</b>
MPA, Nat2000	8,1369	0,165	6	<b>0,0004</b>
C, Nat2000	3,1761	0,168	6	<b>0,0738</b>

533

## 5343) biomass of Low-Null Commercial Important species.

Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms	P(MC)
PR	2	8,42E+07	4,21E+07	5,125	0,0347	90	0,0911
ST(PR)	3	2,47E+07	8,22E+06	1,019	0,3935	9932	0,3937
Res	210	1,69E+09	8,07E+06				
Total	215	1,80E+09					

535

5364) biomass of biomass of *Epinephelus marginatus*.

Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms	P(MC)
PR	2	4,73E+07	2,36E+07	100,28	0,2012	90	<b>0,0001</b>
ST(PR)	3	2,78E+05	92804	0,051314	0,9835	9948	0,9847
Res	210	3,80E+08	1,81E+06				
Total	215	4,27E+08					

537

Groups	t	P(perm)	Unique perms	P(MC)
FP-MPA, C	7,6463	0,3361	6	<b>0,0001</b>
MPA, Nat2000	8,0881	0,3346	6	<b>0,0001</b>
C, Nat2000	4,6589	0,1716	6	<b>0,0276</b>

538

5395) biomass of *Sciaena umbra*.

Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms	P(MC)
PR	2	61165	30583	1,9006	0,2222	90	0,2779
ST(PR)	3	50029	16676	1,7283	0,123	9946	0,1591
Res	210	2,03E+06	9649				
Total	215	2,14E+06					

540

5416) biomass of *Diplodus* spp.

Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms	P(MC)
PR	2	3,60E+07	1,80E+07	39,586	0,0824	90	<b>0,0018</b>
ST(PR)	3	1,29E+06	4,30E+05	0,59464	0,6288	9953	0,6202
Res	210	1,52E+08	7,23E+05				
Total	215	1,89E+08					

542

Groups	t	P(perm)	Unique perms	P(MC)
FP-MPA, C	7,3872	0,1722	6	<b>0,0006</b>
MPA, Nat2000	6,4202	0,1659	6	<b>0,0041</b>
C, Nat2000	1,849	0,3294	6	<b>0,1973</b>

543