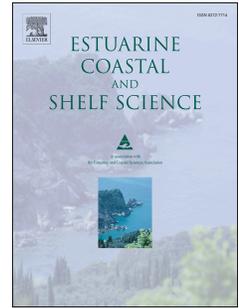


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Potential retention effect at fish farms boosts zooplankton abundance

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## 1 Potential retention effect at fish farms boosts zooplankton abundance

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### 7 ABSTRACT:

8 Coastal aquaculture activities influence wild macrofauna in natural environments due to the  
9 introduction of artificial structures, such as floating cages, that provide structural complexity in  
10 the pelagic system. This alters the abundance and distribution of the affected species and also  
11 their feeding behaviour and diet. Despite this, the effects of coastal aquaculture on  
12 zooplankton assemblages and the potential changes in their abundance and distribution  
13 remain largely unstudied. Traditional plankton sampling hauls between the farm mooring  
14 systems entail some practical difficulties. As an alternative, light traps were deployed at 2  
15 farms in the SW Mediterranean during a whole warm season. Total zooplankton capture by  
16 traps at farms was higher than at control locations on every sampling night. It ranged from 3 to  
17 10 times higher for the taxonomic groups: bivalvia, cladocera, cumacea, fish early-life-stages,  
18 gastropoda, polychaeta and tanaidacea; 10 to 20 times higher for amphipoda, chaetognatha,  
19 isopoda, mysidacea and ostracoda, and 22 times higher for copepoda and the crustacean  
20 juvenile stages zoea and megalopa. Permutational analysis showed significant differences for  
21 the most abundant zooplankton groups (copepoda, crustacean larvae, chaetognatha,  
22 cladocera, mysidacea and polychaeta). This marked incremental increase in zooplankton taxa  
23 at farms was consistent, irrespective of the changing environmental variables registered every  
24 night. Reasons for the greater abundance of zooplankton at farms are discussed, although  
25 results suggest a retention effect caused by cage structures rather than active attraction  
26 through physical or chemical cues.

### 27 Introduction

28 Over the last three decades, fish-farming cages have rapidly developed throughout the world  
29 (FAO 2014, Belias et al. 2007). In the Mediterranean Sea, gilthead seabream (*Sparus aurata*)  
30 and European seabass (*Dicentrarchus labrax*) are intensively farmed in most of the countries  
31 (FAO 2014, Magill et al. 2006). It is well known that fish farming interacts with the marine

32 environment at various spatial and temporal scales and generates variable shifts in  
33 composition of benthic (Karakassis et al. 2000, Mirto et al. 2010) and pelagic assemblages  
34 (Dempster et al. 2002). These changes are related to the organic enrichment derived from  
35 excess of uneaten food and fish excretions, chemical pollution from medicines and antifouling  
36 products, genetic effects and non-native species introductions (Dempster et al. 2002, Holmer  
37 et al. 2007, Borja et al. 2009, Fernandez-Gonzalez and Sanchez-Jerez 2011).

38 Moreover, the deployment of these massive artificial structures in the pelagic environment  
39 may provoke severe changes in the wild biota composition, from phytoplankton (Dalsgaard  
40 and Jensen 2006) to macrofauna (Carss 1990, Franks 2000, Dempster et al. 2012) and  
41 megafauna (Díaz López and Bernal Shirai 2007, Arechavala-Lopez et al. 2014, 2015). Complex  
42 artificial structures drive changes in the behaviour or physiology of affected species  
43 (Fernandez-Jover et al. 2007a) but in turn, adult species aggregated to the fish farm  
44 environment may alter chemical or nutrient dynamics in the pelagic (Fernandez-Jover et al.  
45 2007b) or benthic systems (Katz et al. 2002). It is noteworthy that the influence of coastal fish  
46 farms on ichthyofauna is not strictly limited to adult fish, since juvenile fish from several  
47 different families generally use farm structures as settlement grounds, with potential  
48 consequences for their physiology and growth (Fernandez-Jover et al. 2009, Fernandez-Jover  
49 and Sanchez-Jerez 2014). The forces driving this behaviour have already been investigated, like  
50 for instance the food availability for juvenile fish in the water column around farms. It was  
51 found that resources may be at least as accessible as they are in traditional settlement  
52 environments such as natural shallow rocky shores. The main prey of aggregated juvenile fish  
53 are typical zooplankton taxa, *e.g.* adult and juvenile copepods, cladocerans, nauplius larvae or  
54 amphipods (Fernandez-Jover et al. 2009).

55 In the SW Mediterranean, it has already been corroborated using light traps that European  
56 seabass and gilt-head bream farms favour the presence (among others) of holoplanktonic  
57 amphipods in the pelagic environment. In this way, Fernandez-Gonzalez et al. (2014) detected  
58 an abundant community of planktonic amphipods at farms when compared to environments  
59 where these structures were absent, comprising strictly pelagic species and also benthic and  
60 fouling-community species that apparently undertake incursions into the pelagic zone at night.  
61 Therefore, the higher presence of a common prey may act as an enhancing factor favouring  
62 the abundance of early life-stages of different fish species. In this sense, farm nutrients release  
63 is also thought to increase plankton communities in oligotrophic environments (Tsagaraki et al.  
64 2013).

65 Light devices have been traditionally used for capturing early life-stages of fish (Faber 1981;  
66 Floyd et al. 1984; Doherty 1987), but also with the objective of studying zooplankton  
67 communities (Miller and Shanks 2004; Shaw et al. 2007; Tor et al. 2010; Fernandez-Gonzalez et  
68 al. 2014; Sigurdsson et al. 2014). Furthermore, the relationship between artificial light  
69 attraction and zooplankton has already been studied at farms; McConell et al. (2010) detected  
70 a higher presence of zooplankton communities at salmon farms illuminated during the whole  
71 night, finding that abundances of invertebrates, like bivalves or gastropods, as well as some  
72 larval and juvenile fish species, were greater at night-lit farms. However, the zooplankton  
73 communities at non-illuminated farms were not compared with areas not influenced by  
74 aquaculture activities, including the potential prey availability for early life-stages of fish.

75 Consequently, we relied on light traps to achieve four main objectives, to: i) assess their  
76 suitability for the study of zooplankton and early life-stages of fish at sites where traditional  
77 sampling tools such as plankton hauls are difficult to employ, and to determine if zooplankton  
78 taxa abundances vary in response to a fish farm environment, ii) evaluate changes through  
79 time in zooplankton taxonomic composition at two farms during a whole warm season, and  
80 finally iii) estimate if the abundance and family composition of early life-stages of fish are  
81 different at farms compared to control locations.

## 82 **Material and methods**

### 83 *Study area and sampling effort*

84 This study was carried out in coastal waters, in Guardamar del Segura bay (Alicante, Spain: 38°  
85 5' 7.45" N; 0° 35' 51.40" W) from 12th June to 10th October 2012, the warm period in the  
86 Western Mediterranean. Sampling was conducted at two fish farms (Fig. 1A) producing  
87 seabass (*Dicentrarchus labrax*) and seabream (*Sparus aurata*), and two control areas, on 16  
88 arbitrarily chosen nights. Control samples were also taken randomly within the bay with the  
89 condition that they were at least 2 km away from the nearest fish farm and at a minimum  
90 depth of 23 m, which was reached at least 3 km away from the shore. All four localities (2  
91 control and 2 farms) were located 3–4 km offshore at depths ranging from 23 to 30 m. Each  
92 farm consisted of 18 rings with a diameter of 19 or 25 m and cage nets reaching depths from  
93 12 to 15 m, enclosing a cage volume up to 7400 m<sup>3</sup>. Changes in abundances and species  
94 composition in the plankton population were investigated by sampling farm and control areas  
95 with light traps.

96 Light-trap design used in this study was a modification of that employed by Floyd et al. (1984)  
97 and Kissick (1993), which consisted of a plexiglas collection chamber measuring 40 x 40 x 40  
98 cm, with eight panels forming four funnel-shaped entrances 3 mm wide. The light source was a  
99 hand diving-torch (Led Lenser D14, 150 lumen) coupled to a white plastic container that  
100 produced a diffuse point of illumination.

101 The light-trap technique provides selective sampling, since results are biased towards  
102 photophilic species. However, it has traditionally been used for various purposes, generally  
103 aimed at capturing zooplankton species, most frequently early life-stages of fish (e.g. Floyd et  
104 al. 1984; Doherty 1987). Additionally, it is useful in studies at places with difficult access or  
105 where habitual sampling methods such as plankton hauls are inconvenient. Specifically,  
106 oblique hauls may become logistically problematic. Researchers that still decided to deploy  
107 nets between the cages had to limit sampling to vertical hauls or small purse seines (McConell  
108 et al. 2010); light traps thus seem an appropriate alternative for sampling in logistically  
109 difficult habitats (Chicharo et al. 2009).

110 Traps were suspended at approx. 20 m above the sea bottom, at 4 m below an anchored buoy  
111 (Fig. 1B). They were deployed after sunset for approximately 1 h, recording deployment and  
112 retrieval times to the nearest minute (for later standardisation to individuals per traps per  
113 hour), and their contents then removed. Due to logistical constraints we were only able to  
114 sample one site during one single night (*i.e.* all samples from Control 1 and Farm 1 were  
115 sampled on one specific night and Control 2 and Farm 2 on a different night). Every night two  
116 traps were deployed approximately at the same time at the cages and two at control site and  
117 every one of them was retrieved three times during the whole night, making a total of six  
118 control and six farm samples considering each as one replicate. Traps were moved 20 to 30 m  
119 after retrieval, and a period of at least 30 min was allowed prior to next deployment. At  
120 recovery time, traps were raised slowly to allow filtration of the chamber content through the  
121 250  $\mu\text{m}$ -mesh bottom of the collection cup. Material retained was preserved in 4% formalin  
122 seawater solution. In the laboratory, samples were sorted, counted and the main plankton  
123 groups identified. Fish individuals were measured to the nearest 0.1 mm and identified to  
124 family level using published literature (Russell 1976, Sabatés 1988, Arias and Drake 1990,  
125 Fahay 2007, Ré and Meneses 2008, Lecaillon et al. 2012).

126 Environmental variables were obtained or measured *in situ* in order to include them in the  
127 design as covariables with the objective of inferring if their fluctuations had a significant  
128 influence on the zooplankton assemblages studied, and thus cope with the environmental

129 variability inherent to a study that spanned five months. They were: Water temperature, Day  
130 of lunar month (DLM), Moon illumination, State of the sea (wave height in m), Time to  
131 moonrise, Time since sunset, Time between sunset and moonrise, Time from the nearest high  
132 tide, and Cloud cover. The exact rising and setting times for the moon and sun and the  
133 percentage of moon illumination were taken from <http://www.timeanddate.com/>. Current  
134 direction and velocity were also added as predictor variables. The average direction and  
135 velocity during the previous 24 hours before every sampling night was obtained from the  
136 historical data recorded by the national government in the region (<http://www.puertos.es>).  
137 Hourly current data, which was provided as magnitude and direction vectors were averaged  
138 for the previous 24 hours prior to sampling and then simplified into four vectors corresponding  
139 to main current directions NNE-SSW, ENE-WSW, ESE-WNW and SSE-NNW, taking positive and  
140 negative values for every direction (e.g. positive values for currents with direction NNE,  
141 between 45-90°, and negative for currents towards SSW between 180-225°).

#### 142 *Plankton hauls*

143 To assess the suitability and potential biases of light traps when sampling zooplankton and  
144 early life-stages of fishes, plankton hauls were performed. A conical plankton net 0.6 m in  
145 diameter and 250 mm mesh was connected to a flowmeter (model 2030 General Oceanics),  
146 and towed at a depth of 1 to 5 m for four minutes at low speed (3 knots). Four double-oblique  
147 plankton hauls were taken each sampling night in order to cover a similar depth to the light  
148 traps. At the end of each trawl, the net was washed down with seawater and the retained  
149 material preserved in 4% formalin seawater solution. Plankton net samples were standardised  
150 to the number of individuals collected per 100 m<sup>3</sup>. Light trap selectivity was estimated  
151 according to the formula:  $E = (r_i - p_i) / (r_i + p_i)$ , based on Ivlev's index (E; Ivlev 1961), where  $r_i$  is  
152 the percentage of the species  $i$  in the trap and  $p_i$  the percentage of the species  $i$  in the  
153 environment (plankton tows). This index varies from +1.0 to -1.0, where positive values  
154 indicate attraction and negative values avoidance.

#### 155 *Data analysis*

156 Light trap samples were standardised to catch per unit effort (CPUE, *i.e.* individuals caught per  
157 hour and trap). Periodic environmental variables such as those related to the lunar cycle (Days  
158 of the lunar month, Time to moonrise and Time from the nearest high tide) were transformed  
159 using both the sine and cosine of the independent variable (Bell et al. 1995 and references  
160 therein). The circular periods were 29.53 d for the lunar cycle, 24.83 h for the lunar day and  
161 12.42 h for the tidal period. The nominal zero for the lunar cycle was considered at new moon.

162 In order to evaluate the influence of floating aquaculture facilities on nocturnal abundances,  
163 data from trap captures were analysed according to a 3-factor hierarchical design: 'C-F' (fixed;  
164 two levels: Control and Farm); 'Site' (random; two levels) and 'Day' (random; eight levels), with  
165 six replicates for each treatment. Due to bad weather conditions, three replicates on day 1 and  
166 eight on day 5 could not be sampled. Consequently, data were analysed using PERMANOVA,  
167 which is robust even when there are unequal numbers of replicate samples within each factor  
168 level of the design (*i.e.* unbalanced designs; Anderson et al. 2008). The analysis was performed  
169 over the Bray–Curtis dissimilarities matrix (Euclidean distance matrix in the case of univariate  
170 analyses) of the transformed data, applying a log (x+1) transformation (Anderson 2001a,  
171 McArdle & Anderson 2001) using 4999 random permutations of residuals under a reduced  
172 model (Anderson 2001b), with appropriate units as required by the design (Anderson & ter  
173 Braak 2003).

174 Previously, the distance-based linear model (DistLM) was used to search for the group of  
175 environmental variables that best explained the distance matrix based on the overall taxa  
176 assemblage data and each taxonomic group separately, in a way comparable to multiple  
177 regression (Anderson et al., 2008). The Akaike information criterion (AIC) and  $R^2$  were used to  
178 choose the best model from all possible combinations of variables. Statistical significance  
179 (after 4999 permutations) and percentage contribution of each variable alone, ignoring all  
180 other variables, were obtained from marginal tests. This routine showed that environmental  
181 variables explained a very low proportion of variability found in the traps (never more than  
182 0.6%). Despite this, a few variables exerted a significant influence on the planktonic  
183 assemblages and were therefore included as covariables in the permutational multi- and  
184 univariate analyses of variance (PERMANOVAs) explained in the previous paragraph.  
185 Consequently, the covariables included were: Htidal, Temperature, DLM, Sea State,  
186 Sunset/Rise, TM(h) and Current Directions NNE-SSW and NNW-SSE. Statistical analyses were  
187 performed using PRIMER-E software (PRIMER software; Clarke & Gorley 2006) with the add-on  
188 package PERMANOVA+ (Anderson et al. 2008).

## 189 **Results**

190 Comparing plankton hauls and light-trap captures, Ivlev's selectivity index showed that traps,  
191 when compared to plankton tows, tended to overestimate the presence of isopoda,  
192 polychaeta, mysidacea, ostracoda and zoea larvae with  $E$  values that ranged between 0.92 and  
193 0.57 (Fig. 2). On the other hand, results pointed to an underestimation of such taxa as  
194 pteropoda, appendicularia, larvae planula, bivalves, cnidaria, cladocerans, tunicates, larvae

195 nauplii and gasteropoda, with values between -0.75 and -0.37. Finally, for the groups  
196 amphipoda, copepoda, chaetognatha, fish and tanaidacea, values were close to 0 (between  
197 +0.10 and -0.21), showing results very similar to those found in plankton nets. Regarding fish,  
198 light traps tended to capture juvenile individuals, while plankton nets mainly captured  
199 preflexion and flexion larvae, thus not allowing the calculation of the selectivity index for  
200 osteichthyes.

201 Sea current direction varied mainly between ENE and WSW during the whole sampling period.  
202 Light traps captured a total number of zooplankton individuals of  $526 \pm 117 \text{ ind} \cdot \text{trap}^{-1} \cdot \text{h}^{-1}$   
203 (mean  $\pm$  standard deviation) at control sites versus  $12044 \pm 2400 \text{ ind} \cdot \text{trap}^{-1} \cdot \text{h}^{-1}$  in light traps  
204 deployed at fish farms (averaging all control and all farm samples). The higher abundance of  
205 total zooplankton individuals in the light traps situated at farms was consistent at the two  
206 control and two farm sites (Table 1). In order, the most abundant taxonomic groups were  
207 copepoda, with an abundance of  $392 \pm 92.7 \text{ ind} \cdot \text{trap}^{-1} \cdot \text{h}^{-1}$  at control sites and  $9235 \pm 2023 \text{ ind}$   
208  $\cdot \text{trap}^{-1} \cdot \text{h}^{-1}$  at farms, and larval crustacea including zoea and megalopa stages, with  $100 \pm 26.6$   
209 and  $2343 \pm 432 \text{ ind} \cdot \text{trap}^{-1} \cdot \text{h}^{-1}$  at control sites and farms respectively. Additional groups were  
210 found with tens of individuals per hour, like cladocera, mysidacea, chaetognatha, polychaeta,  
211 ostracoda, isopoda and pteropoda (Table 1). Relatively, copepods reached 71.9% and 85.9% of  
212 total captured individuals at control and farm locations respectively, followed by larval  
213 crustacea (19.0% at control and 17.8% at farms) and cladocerans with 5.1% and 1.3% at  
214 control and farm locations respectively.

215 The maximum number of individuals captured at a single trap during one haul was 148,735,  
216 due to an especially high abundance of copepoda and zoea larvae during the 10<sup>th</sup> of July at  
217 farm site 1. In contrast, it was notable that only  $14 \text{ ind} \cdot \text{trap}^{-1} \cdot \text{h}^{-1}$  were found inside a light  
218 trap on the 10<sup>th</sup> of October at a control site.

219 This higher abundance of total individuals at farm sites was supported by the multivariate  
220 analysis (PERMANOVA) of the taxonomic composition of the assemblage. The environmental  
221 features that stood out in the DistLM analysis were added as covariables, in order to control  
222 this source of variability (see Material and Methods section). The PERMANOVA showed a  
223 significant differentiation between farm and control sites (Table 2,  $p$ -value  $< 0.01$ ). The high  
224 variability between days ( $p$ -value  $< 0.01$ ) did not impede the detection of significant  
225 differences for the main factor.

226 The differences between the amount of individuals captured in control and farm areas were  
227 consistent throughout the study period. Every sampled day, the average total capture was

228 higher in the traps situated near fish farm structures (Fig. 3; Table 1). On evaluating separately  
229 the different taxonomic components of the zooplankton assemblage, this pattern was also  
230 coherent for the most abundant taxa. Abundance at farms was on average 3 to 10 times higher  
231 for the taxonomic groups: bivalvia, cladocera, cumacea, fish, gastropoda, polychaeta and  
232 tanaidacea; 10 to 20 times higher for amphipoda, chaetognatha, isopoda, mysidacea and  
233 ostracoda, and notably, 22 times higher for copepoda and the crustacean juvenile stages zoea  
234 and megalopa (Fig. 3; Table 1).

235 On every sampling night, abundance was always higher for copepods and crustacean larvae at  
236 farms. For the rest of the taxonomic groups this pattern was quite similar, since only during a  
237 single sampling day, and not always the same day, more individuals were obtained at control  
238 sites for polychaetes, chaetognaths and mysidaceans and for two days only for cladocera (Fig.  
239 3). As for fish, differences in the total amount of captured individuals were not that evident.  
240 Nonetheless, on 13 out of 16 days, captures at farms outnumbered those at control sites (Fig.  
241 3). On applying PERMANOVA to every single taxonomic group, these patterns were reinforced  
242 by showing significant differences between the two levels of the main factor –farm and  
243 control– in the experimental design (Table 2). Specifically, chaetognaths, cladocerans,  
244 copepods, crustacean larvae, mysidaceans and polychaetes were found at significantly higher  
245 abundances at farms. All of the PERMANOVA analyses included the covariables found to  
246 significantly influence the variability of zooplankton abundance.

247 A high variability was found depending on the sampling night; considering the averaged count  
248 within single dates, the difference between the day with the lowest zooplankton abundance  
249 and the highest ranged between  $64.6 \pm 24.2$  to  $3861 \pm 1165$  ind · trap<sup>-1</sup> · h<sup>-1</sup> for the samples  
250 taken at control sites and  $90.6 \pm 30.6$  to  $67979 \pm 16048$  ind · trap<sup>-1</sup> · h<sup>-1</sup> at farm sites. This  
251 marked variability among days was reflected in the PERMANOVA test, since this factor (Day)  
252 appeared as significantly different for all the analysed groups. This variability, however, was  
253 not an impediment for detecting the differences at Farm vs. Control level. Additionally,  
254 regarding time within each sampling night, the Time-since-sunset variable was not identified as  
255 significant by the DistLM analysis, thus showing a probably steady concentration of  
256 zooplankton during every night.

257 Taking into account the size of trapped fish, probably only the individuals with a sufficient  
258 swimming capacity to surpass currents and actively enter the traps were found inside them.  
259 This was inferred from the mean size of captured individuals;  $21.99 \pm 1.43$  and  $18.43 \pm 6.8$   
260 mean standard length (mm SL) at control and farm locations respectively. The most abundant

261 family was Engraulidae with 22 vs 71 fish captured at control and farm locations respectively.  
262 They presented an average size of  $21.67 \pm 0.76$  mm SL at control and  $19.64 \pm 0.40$  mm SL at  
263 farm locations (Fig. 4), finding no significant differences between treatments at this level. Thus,  
264 *Engraulis encrasicolus* was the most abundant species with a presence of  $0.41 \pm 0.12$  ind  $\cdot$  trap<sup>-1</sup>  
265  $\cdot$  h<sup>-1</sup> and  $0.93 \pm 0.19$  ind  $\cdot$  trap<sup>-1</sup>  $\cdot$  h<sup>-1</sup> at control and farm traps respectively, followed by  
266 sparids, with an average capture of  $0.16 \pm 0.15$  and  $0.15 \pm 0.04$  ind  $\cdot$  trap<sup>-1</sup>  $\cdot$  h<sup>-1</sup>, at control and  
267 farms. Other fish families were found in the traps, such as atherinids, blenniids, carangids,  
268 clupeids, mugilids and pomatomids, but with very low numbers that never exceed  $0.08$  ind  $\cdot$   
269 trap<sup>-1</sup>  $\cdot$  h<sup>-1</sup>.

## 270 Discussion

271 A higher abundance of zooplankton in the pelagic zone around coastal facilities farming  
272 seabass and seabream in the SW Mediterranean was detected through the deployment of light  
273 trap devices. This pattern was consistent at two different farms and throughout the whole  
274 study period. Analysis of the different taxonomic groups in the zooplankton community  
275 revealed that this is a generalised effect for the vast majority of plankton groups, since  
276 abundances were several times higher around cages compared to control locations without  
277 aquaculture influence. Particularly, copepods and crustacean larva abundance was more than  
278 20 times higher around farms than at control locations.

279 Analysis of results showed that certain groups had an augmented photophilic behaviour when  
280 comparing their proportional abundance with that of plankton tows, assuming the latter  
281 would reflect a taxonomic composition of zooplankton closer to reality. Therefore, it was  
282 concluded that traps overestimated taxa like isopoda, polychaeta, mysidacea or zoea and  
283 underestimated others like pteropoda or apendicularia. These groups were found in low  
284 numbers, accounting for less than 1% of the total faunal composition. An exception to this was  
285 of course zoea larvae, which were the second most abundant taxa and one of the groups  
286 responsible for the differences between farm and control locations. Consequently, results  
287 obtained using the light trap model used in this work should always be interpreted carefully,  
288 bearing in mind the potential biases regarding these taxa. However, it is clear that this bias  
289 occurred likewise at both control and farm locations and therefore the generalised pattern of a  
290 higher abundance at farm sites for all the taxonomical groups is consistent irrespective of the  
291 sampling methodology. In the case of fish captures, the number of individuals captured by the  
292 plankton nets was 3.5 times higher than that of traps but of very different size, since traps  
293 tended to capture juvenile fish and plankton nets caught larval individuals. Consequently, light

294 traps may not be an appropriate tool for monitoring early life-stages of fish at farms, with the  
295 potential exception of families abundant in the Mediterranean like engraulidae or sparidae.  
296 More representative surveys might be obtained if the trapping effort were increased through a  
297 higher number of light traps or longer illumination periods and battery life. Other studies have  
298 previously used various light-trap models to study the plankton community, with similar  
299 results to this work regarding the groups captured. For instance, the crustaceans zoea and  
300 megalopa usually appear in high numbers inside light traps (Miller and Shanks 2004;  
301 Sigurdsson et al. 2014). Furthermore, the relationship between light and farms has been  
302 studied at salmon farms in British Columbia, Canada, where some farms are illuminated during  
303 the night in order to suppress gonadal development (Hay et al. 2004). Specifically, through the  
304 use of plankton hauls and purse seines, McConell et al. (2010) assessed the zooplankton  
305 dynamics at illuminated farms, detecting markedly higher abundances of gastropods and  
306 bivalves, but also copepods, polychaetes (mainly Spionidae) and nauplius larvae as well as 5  
307 species of larval fish and 2 of juvenile fish. However, the higher abundance of zooplankton at  
308 farms is not only restricted to illuminated facilities, because it has been corroborated  
309 elsewhere that the presence of pelagic invertebrates is also greater in the water column at  
310 non-illuminated farms compared to control locations. In this vein, Fernandez-Gonzalez et al.  
311 (2014) concluded that the abundant concentration of planktonic amphipods at farms is the  
312 combined result of the input from strictly pelagic species, individuals from fouling communities  
313 living on the farm structures, and migrant amphipods from soft sediments. Daily vertical  
314 migration from nearby benthic communities could be one of the driving forces that increase  
315 abundance of invertebrates around fish farms (Sanchez-Jerez et al. 1999). Bearing this in mind,  
316 the lack of significant differences for total fish composition and the Engraulidae family could be  
317 due to an actual lack of differences, to the low efficacy of our survey design to capture fish or  
318 to a general low abundance of fish in the region and time of sampling. Nonetheless, these low  
319 capture numbers are not surprising considering the relative low abundance of larval and  
320 juvenile fish in oligotrophic regions like the SW Mediterranean (Sabatés et al. 2003, Kehayias  
321 et al. 2008, López-Sanz et al. 2009, Tor et al. 2010, Félix-Hackradt et al. 2013), when compared  
322 to more productive regions (Carassou et al. 2009, Shaw et al. 2007, López-Sanz et al. 2009,  
323 Sabatés et al. 2003, Tor et al. 2010).

324 Nevertheless, high presence and diversity of juvenile fish closely associated with the farms  
325 have already been demonstrated at different SW Mediterranean farms, including those  
326 studied in this work (Fernandez-Jover et al. 2009, Fernandez-Jover and Sanchez-Jerez 2014).  
327 The reasons behind the selection of these artificial habitats by fish as settlement sites remain

328 unclear, but some of the consequences have been outlined, for instance a change in the fatty  
329 acid profile of several fish species (Fernandez-Jover et al. 2009), as well as potential effects on  
330 fish growth noticed through otolith analysis (Fernandez-Jover and Sanchez-Jerez 2014).  
331 Additionally, the higher zooplankton abundance at the cages may also promote the attraction  
332 and permanence of juvenile fish at farm sites, given that the different species of juvenile fish  
333 settled at farms actively feed on it (Fernandez-Jover et al. 2009, Fernandez-Jover and Sanchez-  
334 Jerez 2014). Further studies should be carried out to elucidate the reasons for this higher  
335 abundance of zooplankton at farms, and its repercussions. However, we suggest that  
336 attraction by chemical cues may be of little importance due to the limited swimming capacity  
337 of the zooplankton detected. It is more likely the result of the physical retention of plankton  
338 dragged towards the farms by currents (see Klebert et al. 2013).

339 The structural framework of the farms, including nets, mooring systems and tons of cultivated  
340 fish, modifies the local oceanographic dynamics by reducing current velocity, and consequently  
341 favours retention of particles like plankton. This hydrodynamic effect of aquaculture structures  
342 occurs both at fish cages (Panchang et al. 1997, Madin et al. 2010, Klebert et al. 2013) and  
343 mussel farms (Plew et al. 2005, O'Donncha et al. 2013, Cranford et al. 2014). This could raise  
344 the concentration of pelagic zooplankton, also promoting the rapid colonisation of farm  
345 structures by a rich diverse fouling community (Green and Grizzle 2007, Madin et al. 2009).  
346 Additionally, zooplankton taxon diversity at control sites did not substantially differ from those  
347 at farms (because differences were mainly due to the relatively higher abundances at the  
348 aquaculture facilities but not to differences in groups composition). This also supports the  
349 hypothesis of plankton retention by farm structures rather than a selective attraction by  
350 chemical or physical cues. Various authors have proposed a rapid transfer of nutrients up the  
351 food web at farms, which could also have influenced the present results. In this way, in the  
352 Aegean Sea, Pitta et al. (2009) undertook dialysis bag experiments near fish farms in order to  
353 selectively withdraw grazers from some of these bioassays, concluding that the usual lack of  
354 detection of high levels of chlorophyll *a* in oligotrophic waters around farms may be a  
355 consequence of rapid transfer of nutrients up the food web, reinforced by intense grazing  
356 activity. Our results showing a notable abundance of zooplankton around farms would support  
357 this conclusion. Nutrients originating at farms may also stimulate the development of an  
358 abundant zooplankton community, due to the greater food availability in the form of  
359 particulate organic matter (POM) derived from aquaculture wastes (Koppelman et al. 2009).  
360 This POM is consumed by zooplankton, since specific distinguishable fatty acids in the food  
361 pellets are incorporated into the trophic web, as detected via analysis of the lipid profile of

362 zooplankton and juvenile fish (Fernandez-Jover et al. 2009). Thus, pelagic communities may be  
363 assimilating and taking advantage of POM in the same way as found for fouling species  
364 (Gonzalez-Silvera et al. 2015). The present data indicate a sharp rise in the population of  
365 zooplankton groups around aquaculture cages in SW Mediterranean coastal waters, including  
366 a tendency towards higher fish larva numbers in the case of engraulids and sparids. To our  
367 knowledge, the main driving factor of this enhanced abundance could be a general retention  
368 of the plankton particles as a result of modified hydrodynamics at farms, but other synergistic  
369 factors such as the action of physical and chemical cues or efficient flow of nutrients up the  
370 food web may also be involved. Modification of planktonic communities at farms may entail  
371 consequences for nutrient cycling, rapid development of fouling and its associated fauna on  
372 the farm structures, and also for trophic relationships between the components of the food  
373 chain.

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377

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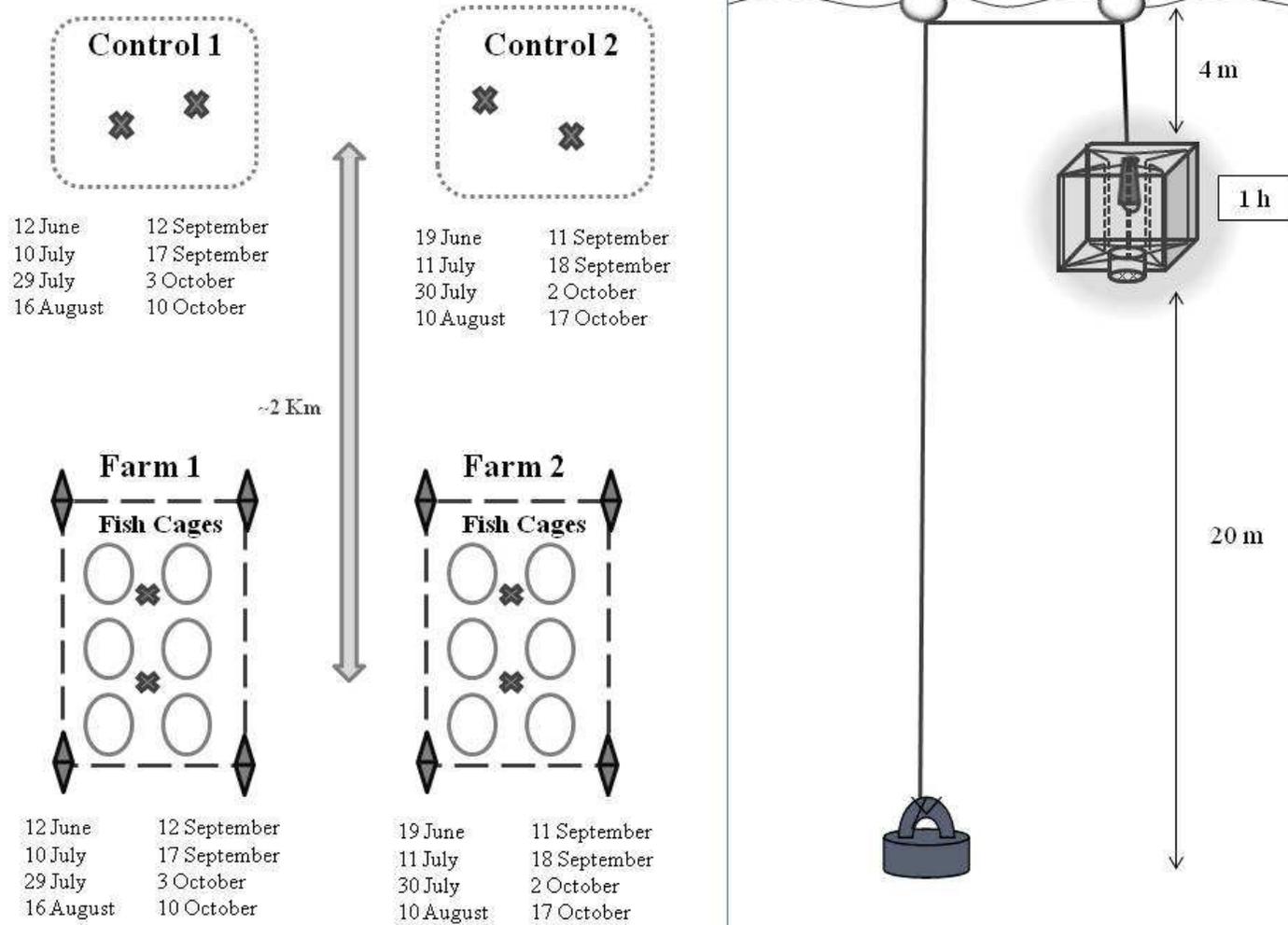
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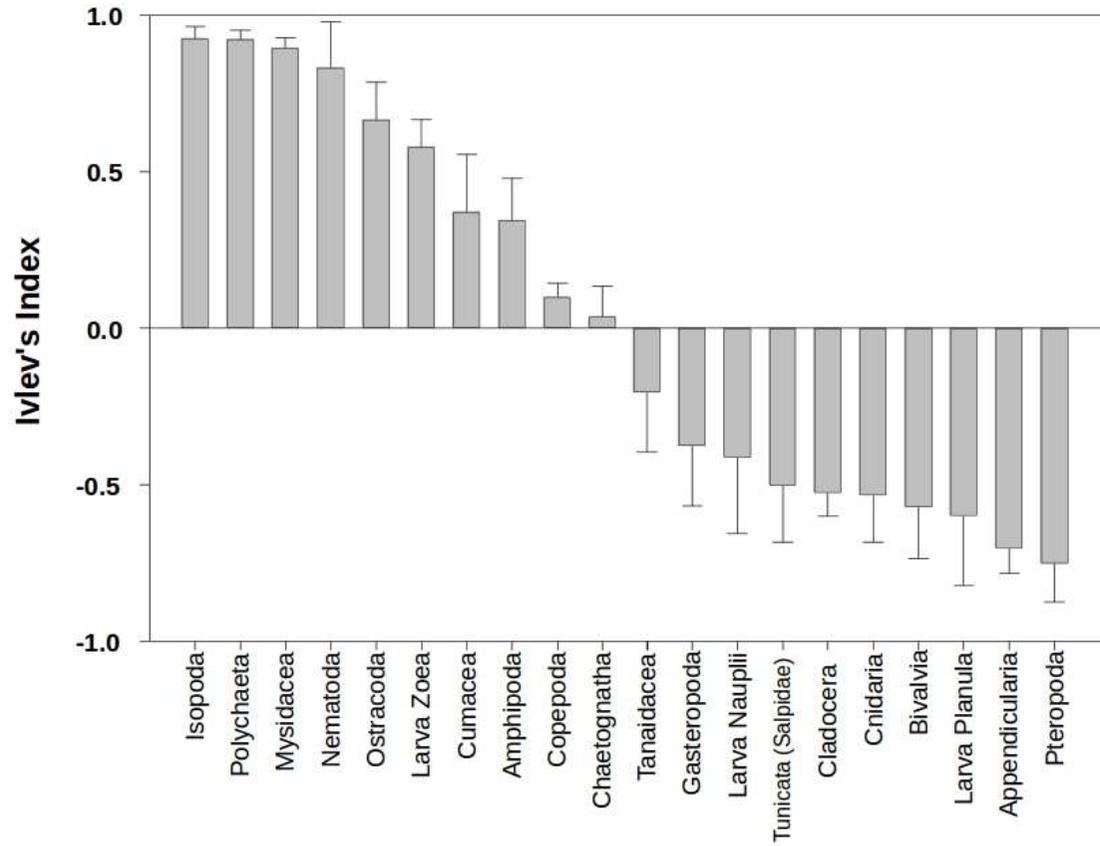
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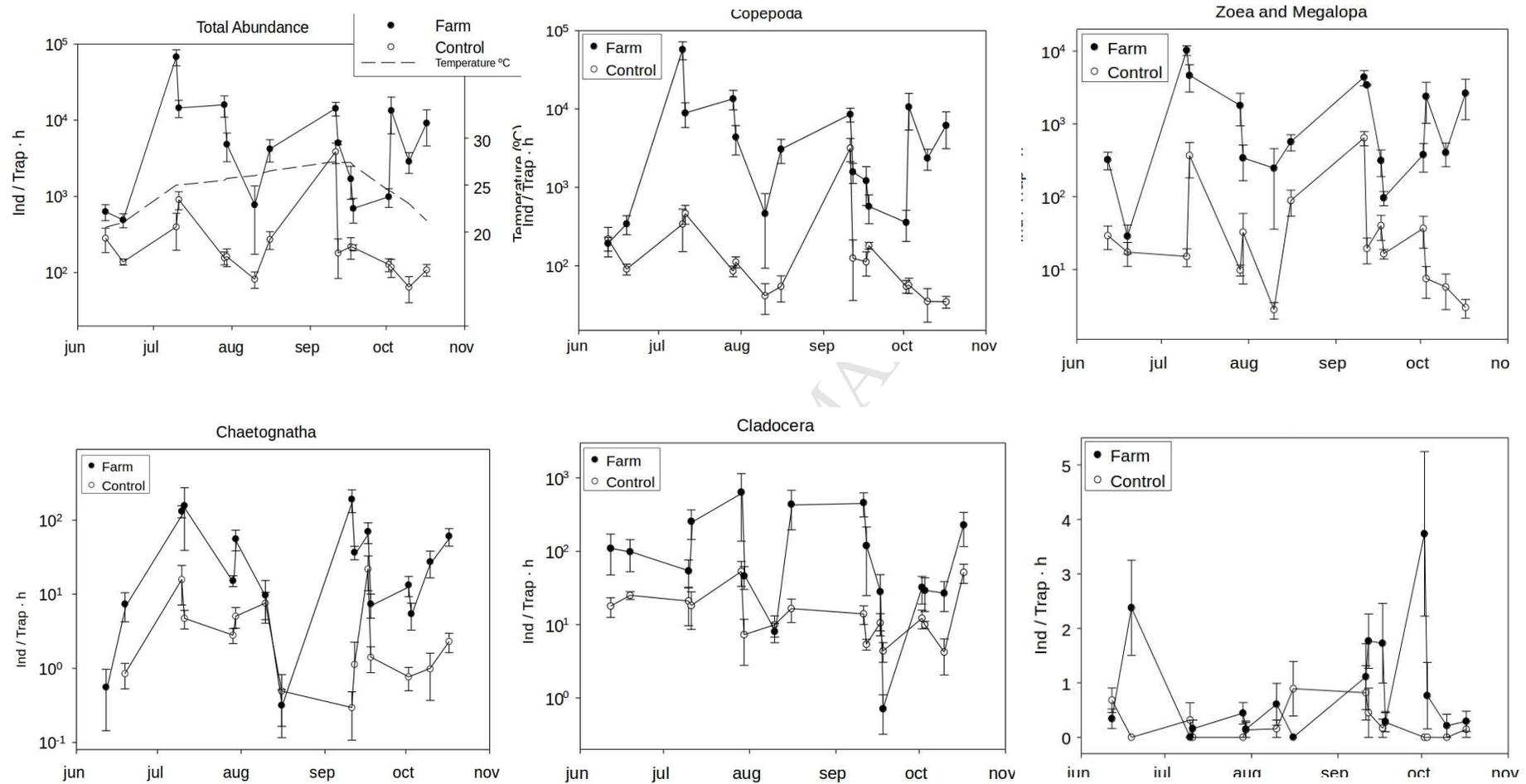
Figure 1. Sampling design of control and farm sites, showing the sampling days at each site (A) and diagram of light trap deployment (B). The design in Figure A was repeated 3 times, making a total of 6 replicates each night. Each cross represents a light trap.



554 Figure 2. Ivlev's Index (E) showing light trap selectivity estimated according to the formula:  $E = (r_i - p_i) / (r_i + p_i)$ , where  $r_i$  is the percentage of the species  $i$  in the trap and  $p_i$   
 555 the percentage of the species  $i$  in the environment (plankton tows). This index varies from +1.0 to -1.0, positive values indicate selectivity and negative values avoidance.  
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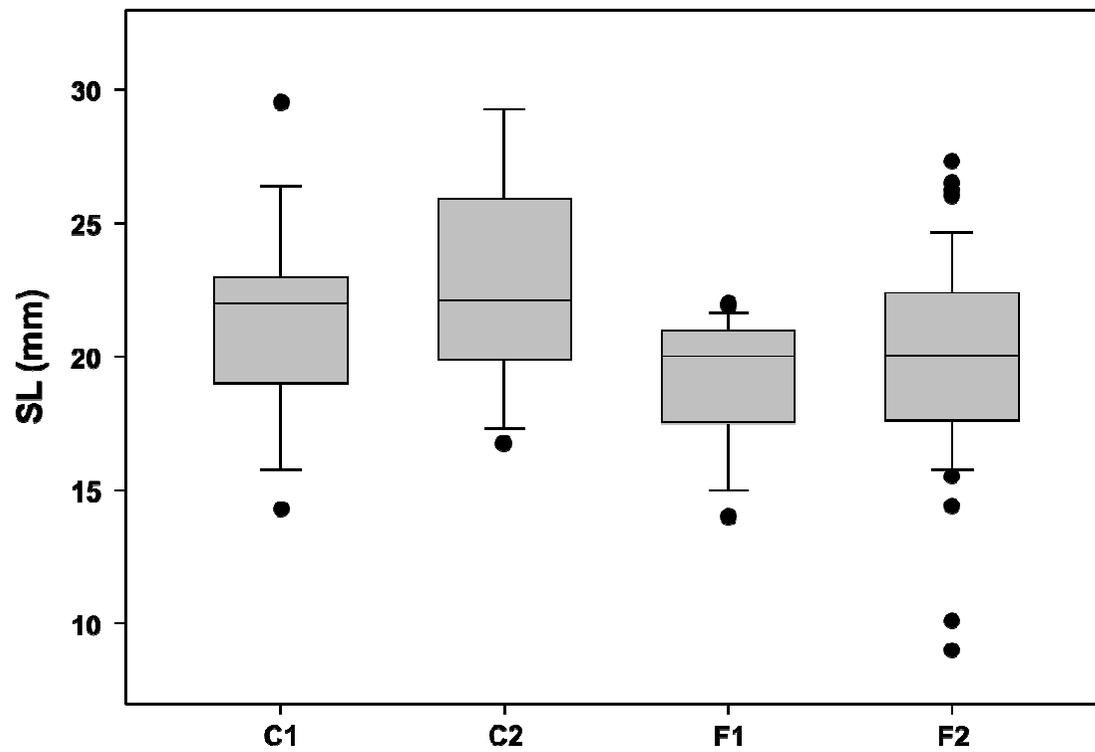


558 Figure 3. Average abundance  $\pm$  standard error of the total zooplankton abundance and the main taxonomic groups found in the light traps at farm and control locations  
 559 during a warm season in two SW Mediterranean fish farms. Note the different scales of the y-axis for each subpanel.  
 560



561

562 Figure 4. Boxplot of the standard length of *Engraulis encrasicolus* individuals captured at the four sampling sites. Boxes indicate 1<sup>st</sup> and 3<sup>rd</sup> quartiles, horizontal line shows  
563 median values, whiskers mark extreme values and points represent the outliers.  
564



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566

567 Table 1. Total abundance (individuals  $\cdot$  trap<sup>-1</sup>  $\cdot$  h<sup>-1</sup>  $\pm$  standard error) in the light traps  
 568 deployed at control and farm sites.  
 569

	CONTROL SITES		FARM SITES	
	Site 1	Site 2	Site 1	Site 2
Amphipoda	0.69±0.22	0.43±0.12	17.4±8.8	2.6±0.58
Apendicularia	5.1±1.5	4.6±0.94	2±0.45	4.5±1.2
Bivalvia	0.08±0.06	0.25±0.13	0.35±0.18	0.19±0.14
Cephalopoda		0.03±0.03		
Cladocera	22.5±4.3	20.8±3.7	230±98.4	170±41.6
Cnidaria	0.49±0.24	0.56±0.21	0.06±0.04	0.15±0.07
Copepoda	163±39.9	581±181	13833±3823	4458±969
Cumacea	0.37±0.11	3.3±1.3	4.2±0.84	7.2±2.2
Echinoderm larvae		0.02±0.02		
Planula larvae	0.02±0.02			
Veliger larvae			0.02±0.02	
Fish eggs	0.25±0.09	0.24±0.09	0.24±0.1	0.12±0.06
Total fish	0.88±0.47	0.52±0.22	0.95±0.17	1.68±0.38
Gasteropoda	0.28±0.12	0.76±0.47	0.31±0.16	4.2±3.7
Isopoda	3.3±0.95	2.6±1.5	30±18.3	27.8±10.6
Mysidacea	3.9±0.98	9.9±3.6	32.7±8.3	115±82.3
Nauplius larvae	0.02±0.02	0.02±0.02		0.02±0.02
Nematoda	0.02±0.02		2.2±0.8	0.48±0.18
Non-identified	0.05±0.05	0.03±0.03		0.03±0.02
Ostracoda	2.7±1.4	2.8±1.1	20.4±6.4	44.2±18.3
Polychaeta	17.1±6.3	2.5±0.55	53.9±21.3	29±7.8
Pteropoda	0.3±0.14	0.17±0.14	1.8±1.0	17.5±13.5
Chaetognata	6.1±2.2	3.8±0.72	37.8±9.3	72.6±20.5
Salpidae	0.43±0.27	0.29±0.12		0.14±0.06
Tanaidacea	0.02±0.02	0.18±0.14	0.76±0.35	0.28±0.12
Zoea and megalopa larvae	30.3±6.0	171±50.3	2691±666	1945±533
Total individuals	257±44	806±219	16943±4471	6900±1447

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574 Table 2. Permutational analysis of variance (PERMANOVA) of the multivariate  
 575 taxonomic group composition (Total Fauna Composition and Fish Family  
 576 Composition) and of the univariate analysis of the rest of the taxonomic groups and  
 577 fish families Engraulidae and Sparidae. Environmental variables included in each  
 578 model (indicated in Table 2), have been selected from a previous PERMANOVA test.  
 579 Abbreviations used are: C.F.: Control/Farm, Res: residual, df: degrees of freedom,  
 580 MS: Mean Squares, Pseudo-F: statistical F value as obtained in PERMANOVA  
 581 (PRIMER software) analysis and P (perm): *p*-value obtained through 4999  
 582 permutations.  
 583

	df	MS	Pseudo-F	P (perm)	
<b>Total Fauna Composition</b>	C.F	1	31130	13.42	0.0008
	Site(C.F)	2	2102	10.84	0.374
	Day(Site(C.F))	22	1798	47.06	0.0002
	Res	147	381.99		
	Total	180			
<b>Copepoda</b>	C.F	1	15311	17.91	0.0222
	Site(C.F)	2	827.98	15.41	0.217
	Day(Site(C.F))	26	514.23	43.55	0.0002
	Res	148	118.07		
	Total	180			
<b>Zoea and Macrura</b>	C.F	1	28826	21.61	0.0136
	Site(C.F)	2	1262.7	14.54	0.2244
	Day(Site(C.F))	25	836.28	49.56	0.0002
	Res	149	168.73		
	Total	180			
<b>Cladocera</b>	C.F	1	6165.1	75.01	0.0012
	Site(C.F)	2	81.73	703.81	0.9822
	Day(Site(C.F))	26	1270.3	50.48	0.0002
	Res	148	251.64		
	Total	180			
<b>Chaetognatha</b>	C.F	1	26616	14.63	0.0346
	Site(C.F)	2	1819.4	0.75	0.4888
	Day(Site(C.F))	27	2338.2	89.75	0.0002
	Res	148	260.54		
	Total	180			
<b>Mysidacea</b>	C.F	1	21071	37807.00	0.0056
	Site(C.F)	2	536.37	0.42	0.7188
	Day(Site(C.F))	27	1243.7	37109.00	0.0002
	Res	147	335.16		
	Total	180			
<b>Polychaeta</b>	C.F	1	9878.7	10259	0.0752
	Site(C.F)	2	935.05	25445	0.0876
	Day(Site(C.F))	26	354.2	27506	0.0004
	Res	149	128.77		
	Total	180			
<b>Total Fish</b>	C.F	1	2688.9	97.86	0.0876
	Site(C.F)	2	274.04	0.39	0.6862
	Day(Site(C.F))	28	697.39	29.76	0.0002
	Res	147	234.31		
	Total	180			
<b>Fish Family Composition</b>	C.F	1	2688.9	97.86	0.0876
	Site(C.F)	2	274.04	0.39	0.6862
	Day(Site(C.F))	28	697.39	29.76	0.0002
	Res	147	234.31		
	Total	180			
<b>Engraulidae</b>	C.F	1	1829.8	73.76	0.1122
	Site(C.F)	2	247.77	0.42	0.6696
	Day(Site(C.F))	28	587.25	29.45	0.0002
	Res	149	199.39		
	Total	180			