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## Changes in Demersal Wild Fish Aggregations Beneath a Sea-cage Fish Farm after the Cessation of Farming

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1 **Changes in demersal wild fish aggregations beneath a sea-cage fish**  
2 **farm after the cessation of farming**

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13 Running headline: Changes in wild fish aggregations

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## ABSTRACT

25

26 Demersal, non-cryptic, wild fish were counted in replicate 100 m<sup>2</sup> transects beneath a  
27 floating sea-cage fish farm and two nearby sandy locations at Gran Canaria (Canary  
28 Islands, eastern Atlantic) four times before and after the cessation of farming. Cessation  
29 of farming involved the removal of farmed fish and ceasing of the daily feeding,  
30 although farm structures (cages and moorings) remained. A “beyond-BACI” sampling  
31 design provided the framework to detect the effect of the cessation of farming, which  
32 produced qualitative and quantitative changes in the composition and structure of the  
33 fish assemblages beneath the sea-cage fish farm compared with two nearby controls.  
34 The aggregative effect on wild fish due to the existence of the farm decreased from  
35 approximately 50 times compared to nearby controls when the farm was in full  
36 operation to <2 times when only the farm structures remained. Abundances of POM  
37 feeders (large-sized mugilids), large benthic chondrichthyid rays and *Pagellus* spp.  
38 declined markedly at the fish farm after the cessation of farming, suggesting that the  
39 removal of daily feeding was responsible for their disappearance. In contrast,  
40 abundances of herbivores, benthic macro- and meso-carnivores were similar beneath the  
41 fish farm both before and after the cessation of farming. Benthic macro-carnivores,  
42 however, were more abundant beneath the sea-cages compared to control locations,  
43 supporting the hypothesis that the increase in the physical structure beneath farms plays  
44 a role in aggregating these species. Sparids occurred beneath the sea-cages only after the  
45 cessation of farming, while the two natural control locations did not show differences  
46 from before to after the cessation of farming. Overall, the results show that the wild fish  
47 assemblage beneath the farm partially changed after the cessation of farming to a more  
48 natural state, approaching the assemblages observed at the control sites.

49

50 Key words: wild fish; aquaculture; impact; recovery; fish farm; Canary Islands.

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## INTRODUCTION

54 Since initial development of sea-cage aquaculture in the early 1980s, the number of sea-  
55 cage fish farms has increased rapidly throughout coastal areas of the world (Ferlin &  
56 LaCroix, 2000) to produce almost 2.5 million tons of fish each year (FAO, 2003). The  
57 environmental impacts of operating sea-cage fish farms are well described and include  
58 impacts on biogeochemical processes, seagrasses and benthic communities, and transfer  
59 of antibiotics to the environment (Iwama, 1991; Rönenberg *et al.*, 1992; Ruiz *et al.*,  
60 2001). Numerous studies have also described the recovery of benthic habitats after the  
61 cessation of farming (e.g. Karakassis *et al.*, 1999; Brooks *et al.*, 2004); however, in  
62 comparison, no study has investigated the effects of the cessation of farming on  
63 aggregations of wild fish closely associated with farms. While operating, fish farms  
64 dramatically increase the presence, abundance and biomass of wild demersal and  
65 pelagic fish in their immediate vicinity compared to control nearby areas (Carss, 1990;  
66 Dempster *et al.*, 2002; Boyra *et al.*, 2004; Dempster *et al.*, 2004; Dempster *et al.*, 2005;  
67 Tuya *et al.*, 2005).

68 The persistent artificial input of food and possible chemical attraction due to the  
69 presence of typically 100s of tons of farmed fish may influence which species of wild  
70 fish associate with farms (Dempster *et al.*, 2002). These factors, in addition to the  
71 enhanced habitat complexity or ‘artificial reef’ effect, have been considered as  
72 responsible for the increase in demersal wild fish abundances relative to nearby sandy  
73 bottoms (Boyra *et al.*, 2004; Tuya *et al.*, 2005) with an overall effect size of 1 to 2  
74 orders of magnitude. However, no study has empirically assessed the relative

75 importance of each of these factors involved in the attraction of different fish species  
76 around coastal aquaculture installations. In this context, we took advantage of the  
77 cessation of farming at a sea-cage fish farm at Gran Canaria (Canary Islands, eastern  
78 Atlantic Ocean) where the entire farm infrastructure was left intact. This allowed us to  
79 separate the attractive effect caused by the persistent artificial food input and the  
80 chemical attraction due to the presence of farmed fish, from the attractive effect caused  
81 by the increased structural complexity of the habitat, which has been shown to play a  
82 major role in structuring fish assemblages on shallow soft bottoms at temperate latitudes  
83 (Guidetti, 2000; Guidetti & Bussotti, 2002; Tuya *et al.*, 2005). Boyra *et al.* (2004)  
84 demonstrated that this fish farm caused local aggregation of wild coastal fish through a  
85 “post-impact” sampling design (*sensu* Glasby, 1997), with differences in the  
86 abundances of some species compared to nearby sandy locations (controls).

87 We aimed to detect changes in the composition and abundance of sub-adult and adult  
88 demersal wild fish assemblages associated with a sea-cage fish farm ‘before’ and ‘after’  
89 the cessation of farming, by establishing the temporal and spatial persistence of the  
90 differences between the ‘impacted’ location (the fish farm) and two nearby sandy  
91 locations as controls, following the appropriate criteria of a “beyond-BACI” design  
92 (*sensu* Underwood, 1992, 1993, 1994). More specifically, we hypothesized that (1) fish  
93 assemblages beneath the sea-cage fish farm would differ significantly before and after  
94 farming ended compared with control locations; whereas (2) assemblages at control  
95 locations before and after farming ended would be relatively consistent through time.

96

97

## MATERIALS AND METHODS

98

### AREA OF STUDY AND EXPERIMENTAL DESIGN

99 The study was conducted around the ‘Arguineguín’ farm located 300 m off the  
100 southern coast of Gran Canaria (Canary Islands, 28°N, eastern Atlantic, Fig. 1) in 9 to  
101 11 m of water (Boyra *et al.*, 2004). The farm cultured both gilthead sea bream (*Sparus*  
102 *aurata* Linnaeus, 1758) and European seabass (*Dicentrarchus labrax* Linnaeus, 1758)  
103 and operated from June 1993 to June 2003, when the aquaculture company went  
104 bankrupt. The farm complex comprised 12 cages and produced an average of more than  
105 180 t yr<sup>-1</sup>. The entire farm infrastructure, including the majority of sea-cages and all  
106 mooring devices, was left untouched after farming ceased. The cages were situated  
107 above a sandy bottom covered by sparse patches of the seagrass *Cymodocea nodosa*  
108 *Ucria* (Ascherson) and the green algae *Caulerpa* spp. The cessation of farming in June  
109 2003 was considered as the ‘impact’, which consisted of the removal of all farmed fish  
110 and termination of the daily input of food pellets. As a result, the term ‘impact’ used in  
111 this paper differs to the classical ‘disturbance’ concept, as it describes a reduction of a  
112 human-induced perturbation of the marine environment.

113 Selection of impact and control locations and sites within locations followed an  
114 asymmetrical “beyond BACI” sampling design. The mechanisms and the logical  
115 structure of these analyses, as well as the potential to detect both temporal and spatial  
116 disturbances, have been widely discussed and demonstrated (Underwood, 1991, 1992,  
117 1993, 1994; Kingsford & Battershill, 1998). Lack of nearby sea-cage fish farms  
118 prevented the use of a more ‘formal’ set of controls, where farming should have been  
119 monitored through time. We therefore were able to solely select nearby soft bottoms as  
120 control locations; two controls (nearby sandy locations located between 600-1000 m  
121 away from the sea-cage fish farm) and one impact location (the sea-cage farm) were  
122 thus established. To increase the spatial replication, we randomly sampled two sites  
123 within each of these locations approximately 40 to 80 m apart. Temporal replication

124 was included before and after the impact by randomly selecting 4 sampling times 2  
125 years before (from May 2000 until June 2001), and 4 times 2 years after (from April  
126 2005 to May 2005) the impact. As a result, our asymmetrical design involved sampling  
127 two control and one perturbed location before and after the cessation of farming at  
128 several nested temporal and spatial scales.

129

### 130 ESTIMATION OF FISH ASSEMBLAGES AND ECOLOGICAL FISH 131 CATEGORIES

132 Sub-adult and adult demersal, non-cryptic, fish populations (> 5 cm total length) were  
133 sampled by visual counts (Boyra *et al.*, 2004; Tuya *et al.*, 2005). At each sampling time,  
134 four replicate 100 m<sup>2</sup> transects were randomly censused during daylight hours at each  
135 site within each location. Consequently, a total of 192 transects were made throughout  
136 the study. The abundance of fish species was recorded by a SCUBA diver using a  
137 modification of the method of Harmelin-Vivien *et al.* (1985). Therefore, when fishes  
138 were grouped in schools larger than 20 individuals, their numbers were estimated  
139 according to six abundance classes (20-40, 40-70, 70-150, 150-300, 300-700, >700).

140 Groups of fishes with similar ecological requirements were aggregated into six  
141 categories (*sensu* Guidetti *et al.*, 2003), defined on the basis of their feeding behaviour  
142 and spatial organization around the farm: (1) POM feeders: particulate organic matter  
143 feeders (large-sized fish within the family Mugilidae); (2) SPA: meso- and  
144 macrocarnivorous sparids (the genera *Diplodus* and *Pagrus*, *Lithognathus mormyrus*,  
145 *SpondylIOSoma cantharus* Linnaeus, 1758, and *Oblada melanura* Linnaeus, 1758) – this  
146 group did not include *Sparus aurata*; (3) HERB: herbivorous fish (*Sarpa salpa*  
147 Linnaeus, 1758, and *Sparisoma cretense* Linnaeus, 1758); (4) BENMESO: benthो-  
148 demersal meso-carnivores usually found as solitary individuals (*Bothus podas*

149 Delaroche, 1809, *Canthigaster rostrata* Bloch, 1786, *Chelidonichthys lastoviza*  
150 Bonnaterre, 1788, *Mullus surmuletus* Linnaeus, 1758, *Sphoeroides marmoratus* Lowe,  
151 1838, *Xyrichthys novacula* Linnaeus, 1758); (5) BENMACRO: benthic-demersal macro-  
152 carnivores usually found as solitary individuals (the genera *Synodus* and *Trachinus*); (6)  
153 RAYS: large-sized benthic chondrichthyes (*Dasyatis* spp., *Gymnura altavela* Linnaeus,  
154 1758, *Myliobatis aquila* Linnaeus, 1758, *Squatina squatina* Linnaeus, 1758, *Taenuria*  
155 *grabata* Linnaeus, 1758). In addition, *Pagellus* spp. was analysed individually, as it was  
156 the most important taxa contributing to differences between controls and the sea-cage  
157 fish farm in the previous “post-impact” study (Boyra *et al.*, 2004). We also analysed  
158 individually the gilthead sea bream *Sparus aurata*, since observed specimens probably  
159 escaped from the cages. Occasional species (observed in less than 3% of the counts) and  
160 pelagic schooling species with high spatial and temporal patchiness (e.g. *Sardina* spp.,  
161 *Boop boops* Linnaeus, 1758) were not included in the analysis.

162

## 163 MULTIVARIATE STATISTICAL ANALYSIS

164 To visualize the extent of differences among assemblages before and after the impact  
165 and among the farm and control locations, non-metric multidimensional scaling (MDS)  
166 was selected as an ordination technique to generate a two-dimensional plot using the  
167 PRIMER statistical package (Clarke, 1993). Prior to calculating the similarity matrix,  
168 the data were pooled by summing the 4 counts at each site within each location and  
169 sampling time. Data were then fourth root transformed to weight the contributions of  
170 common and rare species in the similarity coefficient, and a triangular similarity matrix  
171 was calculated using the Bray-Curtis similarity coefficient (Clarke, 1993; Clarke &  
172 Warwick, 1994). Average dissimilarities between the fish farm and the two controls  
173 were calculated by means of the SIMPER procedure (Clarke, 1993) before and after the



174 cessation of farming. A two-way crossed ANOSIM (Clarke, 1993) was used to examine  
175 the significance of the differences on the overall fish dataset among the three locations  
176 before and after the cessation of farming.

177

## 178 UNIVARIATE STATISTICAL ANALYSIS

179 Following the criteria appropriate for “beyond-BACI” designs, four-way  
180 asymmetrical ANOVA models were used to compare mean abundances of each fish  
181 category between the two periods (“before” and “after”), among times within each  
182 period, among the three locations (including “impact vs. controls” and “between  
183 controls”) and between sites within locations (Underwood, 1993, 1994, 1997). First, we  
184 analysed all data as though there were no asymmetries. Second, we re-analysed the data  
185 while omitting the perturbed location. The asymmetrical components were further  
186 calculated by subtractions and additions of components. The “impact vs. controls” term  
187 was considered fixed, while the term “between controls” was random. Sites were  
188 randomly nested within locations. The two analyses were carried out as a fully  
189 orthogonal design of “before vs. after”, “locations” and its nested “sites”, and “times”  
190 within “before” or “after”. The interpretation of statistical interactions following  
191 Underwood’s indications (Underwood, 1993, 1994, 1997) was used to assess the effect  
192 of the considered experimental factors. Prior to ANOVA, Cochran’s test was used to  
193 test for heterogeneity of variances. In all cases, data was transformed to  $\ln(x + 1)$  to  
194 achieve homogeneity of variances.

195

196

## RESULTS

197 A total of 15204 fishes comprising 15 families and 23 fish taxa were recorded for the  
198 studied sea-cage fish farm and the two adjacent natural control locations throughout the

199 study (Table I). Demersal fish were 45 – 52 times more abundant beneath the farm  
200 compared with the two nearby control locations during the period when the farm was in  
201 full operation. In contrast, abundances of fish were only 1.6 – 1.8 times higher beneath  
202 the farm than the controls after farming ceased. *Pagellus* spp. (n = 11308 fish) and POM  
203 feeders within the Mugilidae family (n = 1164) were the most abundant taxa at the sea-  
204 cage fish farm before the cessation of farming, while *Synodus* spp. (n = 82) and  
205 *Trachinus draco* Linnaeus, 1758 (n = 46) within the macro-carnivores were the most  
206 abundant species after the cessation of farming. The sparids *Spondyliosoma cantharus*  
207 (n = 343) and *Diplodus annularis* Linnaeus, 1758 (n = 336) dominated in terms of  
208 abundance in the two controls before and after the cessation of farming. Table I lists the  
209 overall abundance of each fish taxa recorded at the sea-cage fish farm and the two  
210 controls before and after the cessation of farming.

211

## 212 MULTIVARIATE RESULTS

213 The two-dimensional MDS (Fig. 2) revealed a clear-cut separation of the sites  
214 beneath the fish farm throughout the four sampling times before the cessation of  
215 farming (left-side of the plot) from the sites within the two control locations throughout  
216 the four sampling times before and after the cessation of farming (right-side of the plot).  
217 ANOSIM permutational tests detected that these differences were significant ( $P < 0.01$ ,  
218 Table II). Sites beneath the fish farm throughout the four sampling times after the  
219 cessation of farming lie in the middle of the two above-mentioned groups, indicating a  
220 ‘transition’ in the structure of the fish assemblage towards control locations. However,  
221 differences in the structure of the fish assemblages between the fish farm and the two  
222 controls were persistent after the cessation of farming, as indicated by pairwise  
223 comparisons using the ANOSIM permutational test ( $P < 0.01$ , Table II). This change in

224 the structure of the demersal fish assemblage beneath the sea-cages of the fish farm can  
225 be appreciated when comparing the average dissimilarities between the fish farm and  
226 the two controls before and after the cessation of farming (Table II). For example,  
227 average dissimilarity between the fish farm and control 1 was reduced from 98.8 to  
228 86.1%. It is worth noting, moreover, how sites within the two control locations are  
229 randomly spread throughout the right-side of the ordination space (Fig. 2), highlighting  
230 the broad natural variation in the structure of fish assemblages at the control locations  
231 before and after the considered 'impact'.

232

### 233 UNIVARIATE RESULTS

234 While the sea-cage fish farm was operating, abundances of the benthic-demersal  
235 meso and macro-carnivorous fish categories and *Pagellus* spp. varied between the two  
236 control locations [Figs. 3(d), 3(e), 3(g), Table III: "T(Bef) X C" was significant]. In the  
237 same period, significant differences were observed between the sea-cage fish farm and  
238 the average of the two controls for the mean abundances of the POM feeders, RAYS,  
239 *Pagellus* spp. and *Sparus aurata* [Figs. 3(a), 3(f), 3(g), 3(h), Table III: "T(Bef) X I" was  
240 significant]. Therefore, all of these taxa showed short-term temporal variability before  
241 the cessation of farming.

242 POM feeders, RAYS, and the gilt-head sea bream, *Sparus aurata*, were more  
243 abundant at the sea-cage fish farm before the cessation of farming compared to the two  
244 controls [Figs. 3(a), 3(f), 3(h)], and almost completely disappeared after the cessation of  
245 farming compared to controls [Figs. 3(a), 3(f), 3(h), Table III: "T(Bef) X I vs. T(Aft) X  
246 I" were significant, whereas "T(Bef) X C vs. T(Aft) X C" were non-significant]. Mean  
247 abundances of *Pagellus* spp. similarly decreased significantly after the cessation of  
248 farming at the sea-cage fish farm compared to controls [Fig. 3(g), Table III: "T(Bef) X I

249 vs. T(Aft) X I” and “T(Bef) X I vs. T(Bef) X C” were significant, whereas “T(Bef) X C  
250 vs. T(Aft) X C” was non-significant”, although this species showed short-term  
251 temporal variability between controls before the cessation of farming (Table III, factor  
252 “T(Bef) X C” was significant). As a result, we detected significant decreases in the  
253 mean abundances of POM feeders, RAYS, *Sparus aurata*, and *Pagellus* spp. at the sea-  
254 cage fish farm after the cessation of farming, while no differences existed between  
255 before and after the cessation of farming at control locations for these taxa.

256 Short-term temporal variability for the sparids before the end of farming was  
257 negligible (Table III: “T(Bef) X C”, “T(Bef) X I” were non-significant). Abundances of  
258 this group increased significantly after the cessation of farming at the sea-cage fish  
259 farm, with no before/after interactions between controls [Fig. 3(b), Table III: “B X I”  
260 was significant, while “B X C” was non-significant]. In fact, all sparids were observed  
261 at the sea-cage fish farm after the finalization of farming [Fig. 3(b), Table I], while  
262 control locations did not differ from before to after the cessation of farming (Table III:  
263 “T(Bef) X C vs. T(Aft) X C” was non-significant).

264 Temporal trends in the mean abundances of the herbivorous fish was similar among  
265 the three locations before the cessation of farming [Fig. 3(c), Table III: “T(Bef) X C”  
266 and “T(Bef) X I were non-significant], despite the observation of a large group of *Sarpa*  
267 *salpa* at the fourth sampling time [Fig. 3(c)]. Moreover, temporal trends in mean  
268 abundances of the herbivores did not differ significantly between the two controls, as  
269 well as between their average trends and that at the sea-cage fish farms from before to  
270 after the cessation of farming (Table III: “B X C” and “B X I” were non-significant).  
271 Consequently, no change was detected throughout the study for the mean abundances of  
272 the herbivorous group.

273 Control locations showed different trends in the mean abundances of the bentho-  
274 demersal meso and macro-carnivores from before to after the cessation of farming  
275 [Figs. 3(d), 3(e), Table III: “T(Bef) X C vs. T(Aft) X C” was significant]. For the  
276 bentho-demersal meso-carnivorous group, temporal variability, at both short and long-  
277 scales, was largely attributable to the observation of large groups of *Mullus surmuletus*  
278 in the first sampling time before the cessation of farming [Fig. 3(d)]. However, for both  
279 the bentho-demersal meso and macro-carnivores, we observed similar abundances at the  
280 sea-cage fish farm before and after the cessation of farming [Figs. 3(d), 3(e)], resulting  
281 in the lack of significance of all the potentially affected terms in the ANOVA (Table III:  
282 “T(Bef) X I”, “T(Bef) X I vs. T(Aft) X I”, “T(Bef) X I vs. T(Bef) X C”, “B X I vs. B X  
283 C” were non-significant”). We therefore did not register a significant change in the  
284 mean abundances of the meso and macro-carnivorous categories at the sea-cage fish  
285 farm throughout the study. However, mean abundances of the bentho-demersal macro-  
286 carnivores were larger at the sea-cage fish farm compared to the two controls over the  
287 entire study period [Fig. 3(e)].

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289

## DISCUSSION

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The cessation of farming produced qualitative and quantitative changes in the composition and structure of the demersal, non-cryptic, wild fish assemblages beneath the sea-cage fish farm at Arguineguín (Gran Canaria Island) compared with nearby control locations under the influence of natural variability. The significant differences caused by the cessation of farming were clearly species or group-specific. The different taxa and ecological categories of wild fish considered by our study responded differentially to the finalization of farming. Abundances of POM feeders, RAYS, *Pagellus* spp. and *Sparus aurata* declined significantly, whereas fish within the HERB,

298 The benthic-demersal meso and macro-carnivores were not significantly affected by the  
299 cessation of farming.

300 In terms of overall abundance of wild fish, the aggregative effect due to the existence of  
301 the farm decreased from approximately 50 times compared to nearby controls when the  
302 farm was in full operation to <2 times when only the farm structures remained.  
303 Therefore, the 'daily feeding and presence of caged fish' effect was far stronger than the  
304 added structure due to cages and moorings or 'artificial reef' effect in aggregating wild  
305 demersal fish at the farm. This result implies that aggregations of demersal wild fish  
306 may decrease markedly if levels of food loss and POM output to the environment from  
307 operating farms are reduced.

308

#### 309 WILD FISH AFFECTED BY THE CESSATION OF FARMING AT THE FISH 310 FARM

311 The attraction and increase in the abundances of demersal wild fish populations to  
312 soft bottoms beneath sea-cage fish farms in temperate latitudes seems to be mediated by  
313 the persistent artificial food input and the chemical attraction due to the presence of  
314 farmed fish, in addition to the increase in habitat complexity (Dempster *et al.*, 2002;  
315 Boyra *et al.*, 2004; Tuya *et al.*, 2005). Apparently, the great attraction of POM feeders,  
316 large chondrichthyid rays, and *Pagellus* spp. is due to either the input of food  
317 originating from the farm into the system or the presence of tons of farmed fish.

318 Food beneath fish farms is available to wild fish in the vicinity as large food pellets  
319 lost through the cage, dead cultured fish, and as a 'soup' of POM of broken pellets and  
320 faeces from caged fish (Dempster *et al.*, 2002, 2005). We observed large mugilids  
321 feeding directly upon this soup of POM at the farm while it was working. The same  
322 pattern seemed to occur for *Pagellus* spp. This genus feeds on a wide variety of food

323 items in the Canarian Archipelago, including worms, molluscs, small crustaceans, small  
324 fish, and algae (Fanlo *et al.*, 1996). The disappearance of both taxa after the cessation of  
325 farming could be indicative of attraction to the fish farm to feed on food pellets not  
326 consumed by caged fish and lost from the cages towards the bottom. Nonetheless, an  
327 important drawback of this approach is the lack of direct quantification of the  
328 consumption of the soup of POM. Further research should focus on this point, for  
329 example, using analyses of gut contents. In the Mediterranean Sea, several POM-  
330 feeding fish species (*Trachurus mediterraneus* Necrasov, 1966, *Trachinotus ovatus*  
331 Linnaeus, 1758, *Sardinella aurita* Valenciennes, 1847, *Boops boops*, large mugilids)  
332 consume food available around farms (Dempster *et al.*, 2002), and when they occur in  
333 high abundances they may greatly influence the dynamics of nutrient flows (Vita *et al.*,  
334 2004; Dempster *et al.*, 2005).

335 Large-sized rays were also abundant beneath the sea-cage fish farm while it  
336 operated; high concentrations of rays beneath farms are typical in the Canarian  
337 Archipelago (Boyra *et al.*, 2004; Dempster *et al.*, 2005; Tuya *et al.*, 2005). We do not  
338 know if these rays fed upon lost feed, as well as on benthic infauna as they typically do  
339 (Gray *et al.*, 1997; Ebert & Cowley, 2003), when they foraged on the bottom. However,  
340 we saw several specimens feeding on dead cultured fish during the study. Their  
341 disappearance beneath the farm after fish culturing activities ceased may have been in  
342 response to the loss of this source of large food items.

343 Small escapes of caged fish (10s to 100s of fish) are due to the periodic loss of fish  
344 during harvesting, while mass escapes (1000s to 100000s of fish) are caused by  
345 operational accidents that damage nets or sporadic storms. We observed 10s of gilthead  
346 sea bream (*Sparus aurata*) in some counts at the fish farm before the finalization of  
347 farming, indicating some degree of fidelity of escapees to the fish farm. The lack of

348 observations of individuals after the cessation of farming either resulted from heavy  
349 fishing pressure in the study area or migrations to nearby rocky reefs, which is the  
350 preferred habitat of wild *Sparus aurata* in the Canary Islands (Brito *et al.*, 2002).

351 Finally, sparids occurred beneath the sea-cages only after the cessation of farming,  
352 while they appeared in similar abundances at the two natural control locations both  
353 before and after the cessation of farming. This pattern may be related to the recovery of  
354 a seagrass meadow of the marine phanerogam *Cymodocea nodosa* beneath the sea-cage  
355 fish farm after the end of farming (F. Tuya, pers. obs.), which is typical natural habitat  
356 for sparids such as *Diplodus annularis* and *Spondyliosoma cantharus* in the Canary  
357 Archipelago (Tuya *et al.*, 2005).

358

#### 359 WILD FISH NOT AFFECTED BY THE CESSATION OF FARMING AT THE FISH 360 FARM

361 Both before and after farming ceased, the benthic-demersal macro-carnivores  
362 showed greater mean abundances beneath the sea-cages compared to nearby control  
363 locations. To a lesser degree, a similar pattern was recorded for the benthic-demersal  
364 meso-carnivores. This fact supports the hypothesis that the increase in the physical  
365 structure of the system *per se* plays a partial role in structuring certain nearshore fish  
366 assemblages associated with shallow soft bottoms in warm-temperate environments  
367 (Jenkins & Wheatly, 1998; Guidetti, 2000; Guidetti & Bussotti, 2002; Pihl &  
368 Wennhage, 2002; Tuya *et al.*, 2005) with a relatively consistent effect through time  
369 (lack of differences from before to after the cessation of farming). The increased habitat  
370 complexity due to the sea-cage moorings creates many niches for fishes, providing a  
371 fixed substrate as shelter, and favoring the establishment of epiphytic algae and sessile  
372 invertebrates that are consumed by higher trophic levels such as carnivorous fish (Bell



373 & Pollard, 1989; Klumpp *et al.*, 1989; Jenkins & Wheatly, 1998; Guidetti, 2000;  
374 Guidetti & Bussotti, 2002). Moreover, sea-cage fish farms act as ‘recruitment points’  
375 for larvae of inshore fish (e.g. *Oblada melanura*; Valle, 2005), and even for decapod  
376 crustaceans (M. Davis unpubl. data; [www.hboi.edu/aqua](http://www.hboi.edu/aqua)). These larvae may be a source  
377 of food for species within the benthic-demersal macrocarnivorous group; stomach  
378 content analyses are needed to test this hypothesis.

379

## 380 IMPLICATIONS FOR MANAGEMENT OF COASTAL FISH FARMS

381 Impacts of sea-cage fish farms on the benthos have been shown to be reversible, to  
382 some extent, after farms have been removed in other areas (e.g. Greece; Karakassis *et*  
383 *al.*, 1999). We show here that the large scale aggregation of wild fish at a coastal fish  
384 farm was also partially reversible after the cessation of farming, with assemblages  
385 returning towards the ‘normal’ state represented by the wild fish assemblages at sandy  
386 sediment control locations after 2 years. An important implication for coastal  
387 management arising from this study is that natural assemblages of wild fish can be  
388 partially restored to particular areas if a fish farm ceases farming. We further  
389 hypothesize that with complete removal of the fish farm cages and mooring structures,  
390 demersal wild fish assemblages would shift further towards those observed at natural  
391 control locations.

392 Marine aquaculture installations have been described as competing for space with  
393 future potential Marine Protected Areas (MPAs) ([www.wwf.org](http://www.wwf.org)). While sea-cage fish  
394 farms may be incompatible with MPAs designed to protect biodiversity as assemblages  
395 shift away from those naturally observed, they may not be incompatible with MPAs  
396 designed to enhance fisheries. An alternative solution to coastal managers adopting a  
397 ‘one-or-the-other’ approach to allowing fish farms or declaring MPAs in a given coastal

398 area may be to adopt a more sophisticated management framework that incorporates  
399 ecological knowledge of the wild fish that associate with farms (Dempster *et al.*, 2002,  
400 2005). This study showed that a fish farm, once farming ended, did not greatly affect  
401 the demersal wild fish assemblage on a sandy bottom for more than a short period (< 2  
402 yr). Further, while farms are in place, they concentrate large numbers of a variety of  
403 demersal fish species which constitute a portion of the available spawning stock  
404 (Dempster *et al.*, 2002; Boyra *et al.*, 2004; Dempster *et al.*, 2005; Tuya *et al.*, 2005; this  
405 study), which is the stated aim of MPAs designed for fisheries purposes. Rather than  
406 competing for space with MPAs designed for fisheries purposes, sea-cage fish farms  
407 should be designated as ‘no-fishing zones’ and incorporated into the management of  
408 coastal areas along with MPA zones. Nineteen farms operated in waters in the Canarian  
409 Islands in 2003 ([www.apromar.es](http://www.apromar.es)); however, no management measures to protect  
410 aggregations of wild fish in their vicinity from fishing are currently in place. Future  
411 management of the impacts of sea-cage aquaculture in the Canarian Archipelago should  
412 consider protection of wild fish aggregations as an option to ensure sustainable  
413 development of the industry.

414

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