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Artificial marine habitats favour a single fish species on a long-term scale: the dominance of *Boops boops* around off-shore fish cages

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Summary: Off-shore fish cages are new artificial habitats that can affect pelagic fish assemblages and constitute an important food source for wild fish assemblages. This aggregation has noticeable ecological consequences in cage areas in impoverished ecosystems such as those in the Canary archipelago (NE Atlantic Ocean). However, this new habitat could be dominated by a single species, reducing its positive ecological effects. Wild fish assemblages associated with an off-shore fish lease on the northeastern coast of Tenerife (Canary Islands) were sampled for six years. Fish assemblage structure beneath fish cages and at controls (>500 m from cages) differed significantly between locations, with 13 times greater abundance at cage locations. These differences were mainly explained by the dominance of bogue (*Boops boops*) around fish cages. This trend was consistent in the long-term throughout the study period (2004-2009), affecting local fisheries. The presence of fish cages significantly altered wild fish assemblages in the study area, enhancing mainly biomass and abundance of one species, bogue, and causing shifts in species composition.

Keywords: off-shore; aquaculture; fisheries; fish; bogue; Canary Islands; Atlantic Ocean.

Los hábitats artificiales marinos favorecen a largo plazo a una única especie: la dominancia de *Boops boops* en las jaulas de acuicultura en mar abierto

Resumen: Las jaulas de acuicultura en mar abierto constituyen un hábitat artificial nuevo que puede afectar a las poblaciones de peces pelágicos porque constituyen una fuente importante de alimentación para las comunidades de peces salvajes. Esta congregación tiene consecuencias ecológicas notables en áreas caracterizadas por ecosistemas empobrecidos como ocurre en el archipiélago canario (Atlántico Noreste). Sin embargo, este nuevo hábitat puede encontrarse dominado por una única especie, limitando sus efectos ecológicos positivos. Las comunidades salvajes de peces asociadas a jaulas en mar abierto localizadas en la costa noreste de la isla de Tenerife (Islas Canarias) fueron muestreadas a lo largo de 6 años. La estructura de la comunidad íctica varió significativamente entre las localidades de las jaulas y los controles (>500 m de distancia de las jaulas), con abundancias que fueron 13 veces superiores en las jaulas. Estas diferencias fueron debidas principalmente a la dominancia de la boga (*Boops boops*) alrededor de las jaulas de acuicultura. Esta tendencia fue consistente a lo largo del período de estudio (2004-2009), afectando a las capturas de los pescadores locales. La presencia de las jaulas de acuicultura afectó de forma significativa las poblaciones de peces en el área de estudio, con un incremento de la biomasa y abundancia de una especie, la boga, que determinó cambios en la composición de las especies.

Palabras clave: mar abierto; acuicultura; capturas; boga; Islas Canarias; océano Atlántico.

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INTRODUCTION

Dominance is of pivotal importance in conservation biology (Soul 1986). Ecological dominance is the degree to which a taxon is more numerous than its

competitors in an ecological community, or makes up more of the total biomass (Dayton 1975). In the marine realm, dominant fish species may consume a high proportion of ecosystem resources, affecting the remaining species directly and indirectly. If a new habitat is

especially suitable for one single species because of new trophic resources, individual fitness can help to increase population through optimal reproduction rates (Berryman 2003).

Artificial reefs and fish attraction devices (FADs) have traditionally been used to enhance populations of target species by favouring both spawners and recruits (Tupper and Boutilier 1997). It has been suggested that fish farms should be managed in a similar way as FADs (Sanchez-Jerez et al. 2011). Fish cages affect the presence, abundance, diet and residence times of wild fish assemblages, attracting a huge variety of species by providing food and refuge from predators (Valle et al. 2007, Boyra et al. 2004, Tuya et al. 2006). Large quantities of lost food pellets and faeces from cages are available to farm-aggregated wild fish (Fernandez-Jover et al. 2008), actually altering biological conditions because of the high food availability (Skog et al. 2003, Fernandez-Jover et al. 2007).

The bogue (*Boops boops*) is gregarious, demersal to benthopelagic and mainly omnivorous (Arechavala-Lopez et al. 2010), living on a variety of habitats (rocky substrates, sandy bare seabeds, seaweeds and seagrass meadows) from 0 to 350 m depth (Froese and Pauly 2007). It is an important prey for many piscivorous species (Kalogirou et al. 2012). In the Canary Islands the bogue has been traditionally fished to use as live bait for tuna (e.g. skipjack, *Katsuwonus pelamis*) (Ramos et al. 1995) and it has recently been used as a component of octopus diet in reared conditions (Estefanell et al. 2011). Therefore, this is of some ecological and economic importance for Canary coastal habitats.

In the Canary fish farms it has been previously observed that some species, including bogue, are short-term (<1 year) dominant components (Boyra et al. 2004, Tuya et al. 2006). There is a recognition that it is important to deal with the prediction of human influence in key marine communities such as fish assemblages by testing ecological concepts through the observation of interannual temporal patterns.

In the present study we analysed the temporal trend of fish population aggregated to fish farms over six years (2004-2009), with the general aim of defining the temporal patterns of fish abundance during the study period, focussing especially on changes in community dominance. The main aims were (i) to define changes in fish assemblage composition by comparing fish cages and control areas; and (ii) to test whether bogue can be considered a dominant species and evaluate the importance of fish cages as a new pelagic habitat for bogue by comparing temporal trends from the establishment of aquaculture.

MATERIALS AND METHODS

Study site

The present study was conducted in an open fish cage located at Iguete de San Andrés (NE Tenerife, coordinates 28°31'30"N 16°09'20"W). In the study area, two fish leases (ca. 10000 m² surface area) were situated >300 m off the coast and both leases con-

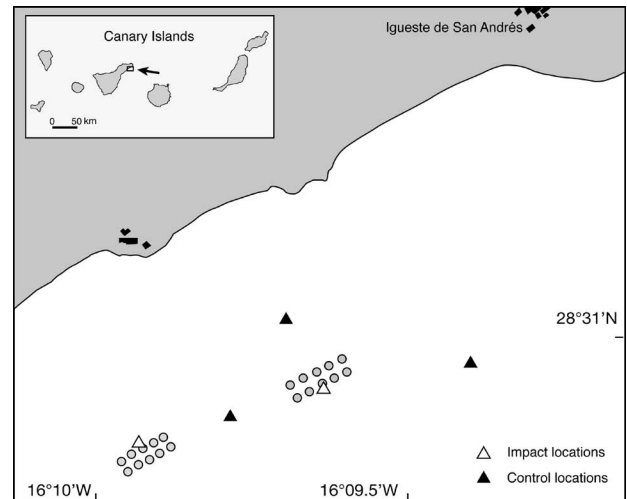


Fig. 1. – Map of the study area showing sampling locations.

sisted of ten 20-m-diameter cages (Fig. 1). Species cultured in the studied fish cages were gilt-head sea bream (*Sparus aurata*) (200 t) and sea bass (*Dicentrarchus labrax*) (150 t) from 2004 to 2007. From 2007 to 2009, 450 t were cultured in the studied fish leases (250 t of *S. aurata* (250 t) and 200 t of *D. labrax*). Fishes were fed both by hand and automatically using commercial, pelleted and extruded diets with an average nutrient content (on a dry weight basis) of 49% protein, 18.5% fat, 22% carbohydrate, 7.9% nitrogen and 1.08% phosphorus.

Each fish cage had a diameter of 20 m and reached a depth of 10 m. Fish cages were installed on seabeds at a depth of 25-28 m and their temperature throughout the year ranged from 18°C in January to 22°C in September. Currents had a mean value of 7-8 cm s⁻¹ in the water column (unpubl. data). There are no extensive seagrass meadows in the study area, only small patches of the seagrasses *Cymodocea nodosa* and *Halophila decipiens*. Rocky substrates are scarce in the subtidal but dominate in the intertidal of the study bay.

Rapid visual count of fishes

Total counts around cages were considered inappropriate as independent replicates due to obvious circling of cages by fishes. Instead, we conducted 5-min rapid visual counts (Kingsford and Battershill 1998) using SCUBA beginning at the centre of each sampling location and proceeding through the adjoining water mass. A total of six visual counts were conducted each time at each sampling location. Each count covered a volume of ca. 11250 m³ (15 m wide × 15 m deep × 50 m long) at each location. Visibility was high, varying from 20 to 50 m on days when counts were performed and sea surface remained constant at all locations during the sampling campaign. Each count was made with two divers. The first diver concentrated on estimating the abundance of the dominant species, which were counted in groups of 1, 2-5, 6-10, 11-30, 31-50, 51-100, 101-200, 201-500 and >500 to minimize error (Harmelin-Vivien et al. 1985). The second diver followed slightly behind the first and specifically looked

for less obvious cryptic species and smaller individuals that may have been missed by the first diver. Counts of both divers were summed.

Monitoring programme

The monitoring programme was conducted over six years, from December 2004 to September 2009 during ten sampling campaigns (1 December 2004 [1st], April 2005 [2nd], August 2005 [3rd], December 2006 [4th], May 2007 [5th], December 2007 [6th], May 2008 [7th], December 2008 [8th], April 2009 [9th] and September 2009 [10th] at each sampling location). Five locations were sampled throughout the study period (2004-2009), two located beneath the fish cages (“Impact”, 25-28 m depth) and three over 500 m away that were not influenced by the cages (“control”, 20-30 m depth) (Fig. 1). All sampling sites (impact and controls) were located on sandy bare seabeds with similar grain-size characteristics.

Statistical analyses

Non-parametric multivariate techniques were used to compare fish assemblages from impact and control locations, as well as, sampling times throughout the study period. All multivariate analyses were performed using the PRIMER statistical package (Clarke and Gorley 2006). Data were fourth-root transformed to weight the contributions of scarce species in the similarity coefficient (Clarke 1993). Similarity matrices were calculated using the Bray-Curtis similarity coefficient (Clarke and Warwick 1994). Non-metric MDS (n-MDS) was used as the ordination method to represent differences in fish composition between sampling groups (impact and control) throughout the study period. Taxa that had more influence on similarities of both location groups (impact and control) and dissimilarities between these groups of assemblages were calculated using the similarity percentages (SIMPER) procedure (Clarke 1993) to identify species responsible for the differences between groups (impact vs control). Permutational multivariate analysis of variance (PERMANOVA) was applied to test for differences in fish assemblage structure, considering Year (2004-2009) and Impact (impact and control) as fixed factors.

Additionally, for analysing the temporal trend of bogue over the six-year period (2004-2009), bogue abundance was fitted by generalized additive models (GAM). This term includes any GLM estimated by quadratically penalized (possibly quasi-) likelihood maximization, using the MGCV package routines of R (www.r-project.org) (Wood 2011). The GAM regression technique consists of fitting smooth additive functions for each covariate included in the model structure. The smooth functions are linear combinations of a finite number of basis cubic spline functions, with the smoothness of the function estimated by minimizing the generalized cross-validation criterion (Wood 2011) that balances the goodness-of-fit and the smoothness of the functions. To avoid overfit-

ting, we constrained the number of basic functions to at most three. We regressed each campaign variations of bogue abundances throughout the study period (2004-2009).

RESULTS

Fish assemblage structure

A total of 66672 fishes were observed during the study period (2004-2009) at the five sampling locations (impact and control). Bogue (*Boops boops*) was the dominant species (93.89%), followed by black seabream (*Spondylisoma cantharus*; 1.85%) and white kingfish (*Pseudocaranx dentex*, 0.44%). The remaining species (36 taxa) were very scarce (<300 individuals). Species richness was higher at impact (13.2±1.06 taxa, mean±SE) than at control locations (8.22±1.5 taxa) (Table 1). The most common species in Impact locations were bogue (*B. boops*), black seabream (*S. cantharus*), white kingfish (*P. dentex*) and sharpnose puffer (*Canthigaster capistratus*). At control locations they were bogue (*B. boops*) and black seabream (*S. cantharus*). Differences between impact and control locations were more pronounced in terms of abundances since fishes were concentrated around fish cages (6207.6±1816.4 ind 11250 m⁻³, mean±SE), approximately 13 times more than at control locations (456.9±257.8 ind 11250 m⁻³) (Table 1). Bogue was present only at control locations of three campaigns throughout the study period, ranging in dominance (contribution to the overall fish abundance) from 50.84% in December 2007 to 96.52% in May 2008. In the impact group, bogue was present in all sampling campaigns, with the exception of May 2007. Bogue dominance varied from 69.65% in December 2004 to 98.97% in April 2009 (Table 1). Shannon diversity showed the opposite pattern of fish abundances, with higher values at control (1.13±0.2) than at impact locations (0.54±0.13) (Table 1) because of the

Table 1. – Overall species fish richness (S; number of species), fish abundance (A; number of individuals per 11250 m⁻³), *Boops boops* relative abundance (%Bb) and Shannon diversity (H') at control and impact locations throughout the study period (2004-09).

	Campaign	S	A	%Bb	H'
Control	December-04	3	3	0	1.09
	April-05	9	107	0	1.47
	August-05	18	2556	67.68	0.97
	December-06	7	56	0	1.59
	May-07	5	9	0	1.52
	December-07	11	1104	50.84	0.45
	May-08	6	518	96.52	0.19
	December-08	10	66	0	2.09
	April-09	2	11	0	0.30
	September-09	5	139	0	0.79
Impact	December-04	8	201	69.65	1.09
	April-05	16	1093	70.25	1.17
	August-05	15	6246	88.05	0.57
	December-06	13	3641	90.61	0.50
	May-07	7	74	0	0.84
	December-07	17	15596	98.64	0.98
	May-08	14	9633	97.88	0.16
	December-08	16	8690	97.05	0.19
	April-09	12	14549	98.97	0.73
	September-09	14	2353	87.53	0.70

Table 2. – Results of PERMANOVA testing for differences in fish assemblage structure during study years (“Year” fixed factor) and between locations (“Impact”, fixed factor). Significant differences (p<0.01) are highlighted in bold. Results of pairwise comparisons between locations for each year are included as a result of a significant interaction between Year and Impact.

Source	df	SS	MS	Pseudo-F	p	Pairwise tests
Year	5	66594	13319	96.246	0.001	2004<2005, 2006<2007-2009
Impact	1	53967	53967	38.999	0.001	
Year × Impact	5	23375	4675	33.783	0.001	
Res	234	3.24E+05	1383.8			
Total	245	4.88E+09				

dominance of few species. Shannon diversity in the control group ranged from 0.30±0.11 in April 2009 to 2.09±1.18 in December 2008, whereas in the impact group it ranged from 0.16±0.09 in May 2008 to 1.17±0.67 in April 2005 (Table 1).

SIMPER analysis showed higher similarity at impact locations (32.57%) than at control locations (7.64%). A total of seven fish species were the most important contributors to the impact group similarity (*Boops boops*, *Canthigaster capistrata*, *Bothus podas*, *Trachinus draco*, *Sphoeroides marmoratus*, *Dasyatis pastinaca* and *Taeniura grabata*), though most of the contribution to the assemblage homogeneity was provided by the bogue (55.43%). This species overwhelmingly dominated the overall fish abundance and thus changed the whole assemblage structure. The similarity in the control group was mainly due to *Trachinus draco*, which was responsible for 27.60% of homogeneity, followed by *Sphoeroides marmoratus* (20.75%).

Bogue was the most important species for explaining the dissimilarity between the two groups (91.43% dissimilarity), with a contribution of 30.89%. The remaining fish were scarcely responsible for the dissimilarity, with low percentages per species (<10%). Bogue dominated fish assemblages at control locations (70% of abundance), but the percentage of dominance was lower than at impact sites (96% of abundance) and other species (e.g. black seabream (*Spondyliosoma cantharus*)) contributed significantly to the overall fish structure (Table 1).

Temporal changes in fish abundance

Similarity in caged stations within each year ranged from 5.25% (2004) to 69.68% (2006). Bogue contributed consistently throughout the study period at caged

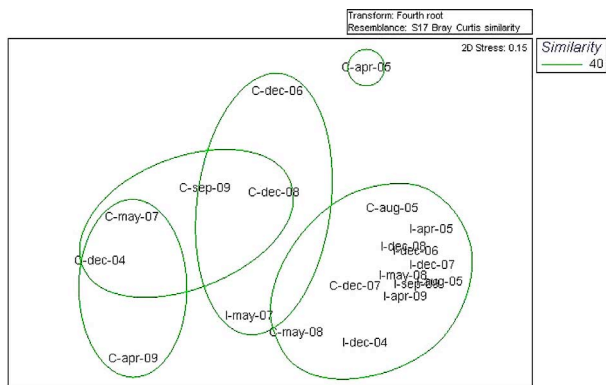


Fig. 2. – n-MDS of sampling campaigns considering months and years. I, impact locations; C, control locations. Circles indicate 40% similarity.

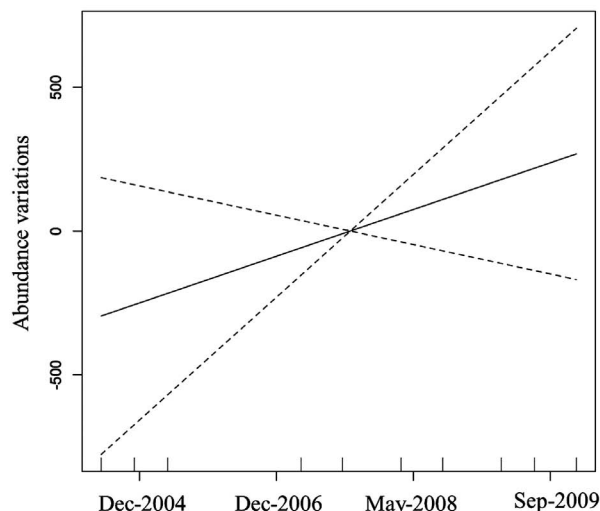


Fig. 3. Temporal trend of *Boops boops* population modelled by GAM during the study period (2004-2009).

stations from 48.58% (2007) to 97.85% (2008), with a mean contribution of 78.25%. The abundance variations of bogue were the main factors responsible for dissimilarities at caged stations among years, varying from 53.31% (2005-2006) to 96.89% (2004-2007).

Highly significant differences were obtained in the Year×Impact interaction (Table 2). Fish assemblage structure was significantly different between locations beneath fish cages and controls (Impact Pseudo-F=96.246, p=0.001), but these differences showed interannual variations (Year×Impact, Pseudo F=33.783, p=0.001) (Table 2, Fig. 2). Temporal variability was more pronounced at control locations (5 different groups) due to low fish abundances and aggregated distribution. Impact locations were included in one group, except in May 2007 (Fig. 2).

The analysis of the temporal trend of the bogue population by GAM showed an increasing pattern over the study period (Fig. 3), especially due to the high abundances of bogue in the last sampling years (2007-2009).

DISCUSSION

Wild fish aggregation around cages has been described worldwide (Sanchez-Jerez et al. 2011), with assemblages dominated by a limited number of fish species, e.g. *Boops boops* in the Mediterranean Sea and Canary Islands (NE Atlantic Ocean) and *Pollachius virens* in Norwegian fjords. The remaining aggregated species are accessory and scarce (Boyra et al. 2004,

Dempster et al. 2009). However, these structures can be used as a habitat for fishes until they become adults, and recruitment of juveniles is one of the most important interactions between wild fish and cages (Valle et al. 2007).

In the present study, the largest concentrations of wild fish occurred beneath off-shore cages, with an effect size of a 13 times greater abundance at farms compared with controls at a distance of 500 m, mainly due to one single species: bogue (*Boops boops*). The bogue dominated the fish assemblage beneath farms throughout the study period and interannual variations (2004-2009) were observed, with maximum densities in the period 2007-2009, which may be interpreted as a long-term population increase due to the increase of aquaculture production rates in studied fish leases, from 300 t (2004-06) to 450 t (from 2007 to 2009). *Boops boops* dominated throughout the year, being slightly more abundant in spring and summer months (March-September).

In the Mediterranean Sea, bogues are a significant component of wild fish assemblages around off-shore cages (Fernandez-Jover et al. 2008), especially during winter months (January-April) (Valle et al. 2007). Seasonal changes in fish assemblages are less pronounced at subtropical latitudes (e.g. the Canary Islands) (Boyra et al. 2004), possibly due to more stable environmental conditions such as low temperature variations during the year (18-22°C). Our results showed inconsistent seasonal trends, but a progressive increase in bogue abundances was observed throughout the study period, with special emphasis during the last three years (2007-09).

Fish farms concentrate large numbers of predatory species of commercial interest, such as *Coryphaena hippurus*, *Seriola dumerilii*, *Pomatomus saltratrix*, *Dentex dentex* and *Thunnus thynnus* (Dempster et al. 2002, 2005, 2010, Valle et al. 2007), which are attracted by fish aggregations. This attraction has consequences of the utmost importance for local artisanal fisheries (Machias et al. 2006, Fernandez-Jover et al. 2007, 2009, Luna-Perez et al. 2010), and leads to high fishing pressure from commercial and recreational vessels around farms in the western Mediterranean (Arechavala-Lopez et al. 2010, Luna-Perez et al. 2010).

In the Canary Islands, fishes particularly attracted to farms and of commercial interest are *Sphyrna viridensis*, *Pagellus acarne* and carangids (*Trachinotus ovatus*, *Pseudocaranx dentex* and *Seriola* spp.) (Boyra et al. 2004). This attraction is particularly enhanced in areas with a decline of the coastal resources, such as the Canary archipelago, with an overexploitation and severe depletion of fish assemblages (Falcon et al. 1996, Tuya et al. 2005). Even artisanal fisheries shifts are related to these aggregations in the Canary archipelago. For example, the bogue was considered a fishery resource of secondary importance or even used as bait for several tuna species and for experimental octopus culture (Estefanell et al. 2011). However, the bogue is currently considered one of the main catches by artisanal fisheries in the study area (NE Tenerife), with catches of around 800 kg/year (data from fisherman's association in the study area).

The opportunistic behaviour of the bogue provides ecological advantages throughout its life cycle compared with other fish, as has been demonstrated in the present long-term data series (2004-2009). The bogue takes advantage, whenever accessible, of food resources from off-shore fish cages and alternates these periods with natural diet obtained in the surrounded area, as previously observed in the Mediterranean Sea (Arechavala-Lopez et al. 2010).

In short, coastal fish farms attract wild fish, but only a few species such as the bogue are well-adapted to cages and dominated fish assemblages around Canary Island off-shore farms. This adaptive behaviour seems to favour a population increase in the long term (six years) and could have implications for natural predators and local fisheries. Therefore, off-shore fish cages should be taken into account in fisheries management as they may strongly affect fish populations and may have an indirect effect on fish assemblages and the entire coastal ecosystem.

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