Vol. 242: 237–252, 2002 | MARINE ECOLOGY PROGRESS SERIES Mar Ecol Prog Ser | Published October 25

Attraction of wild fish to sea-cage fish farms in the south-western Mediterranean Sea: spatial and short-term temporal variability

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ABSTRACT: Aggregations of wild fish were counted around 9 floating sea-cage fish farms along a 300 km stretch of the Spanish coastline in the south-western Mediterranean Sea. Each fish farm cultivated *Sparus aurata* and *Dicentrarchus labrax* in 6 to 16 floating sea cages between 10 m and 7.4 km from the coast. During September and October 2001, assemblages of fish were counted on 3 separate days at each of 9 farms. Six 5 min rapid visual counts using SCUBA and covering 11 250 m^3 were performed within each farm complex and at open water control sites 200 m distant from farms. Abundance (52 to 2837×), biomass (2.8 to 1126×) and number of species (1.6 to 14×) were greater in fish farm counts than control counts at all locations. Twenty-seven species were recorded at fish farms, with 2 families, Sparidae (12 species) and Carangidae (4 species), being particularly abundant. Over 85% of farm-associated fish were of adult size. Assemblages of wild fish differed greatly between farms separated by 10s to 100s of km, although there was some evidence to suggest that similar assemblages occur at farms separated by 100s of m to several km. Abundance, biomass and number of species differed among fish farms, with all 3 variables negatively correlated with distance of farms from shore and positively correlated with size of farms. Limited variability of wild fish assemblages and abundance of the dominant taxa at each farm among times sampled indicated some degree of temporal stability on a scale of several weeks. Due to the strong aggregative effect of fish farms, possible residence of fishes for periods of weeks to months and the prohibition of fishing within farm leasehold areas, we suggest that coastal sea-cage fish farms may act as small (up to 160 000 m^2), pelagic marine protected areas (MPAs). Furthermore, at farms where wild fish are abundant, ecological interactions that may influence both wild fish stocks and the impact of farms must be considered.

KEY WORDS: Aquaculture · Wild fish · Fish farm · Sea-cage · Fish Aggregation Device · Marine Protected Area · Mediterranean Sea

INTRODUCTION

Natural and artificial Fish Aggregation Devices (FADs) in open water are widely recognised for their capacity to attract pelagic fishes (e.g. Hunter & Mitchell 1967, Deudero et al. 1999). Coastal fish farms may be analogous to large FADs; the floating cages provide structure in the pelagic environment like FADs, and the unused portion of feed that falls through the cages (Phillips et al. 1985) probably enhances the attractive effect (Bjordal & Skar 1992). Fish farms may affect the presence, abundance, residence times and diet of fishes in a given area (Carss 1990, Bjordal & Skar 1992) but despite the obvious potential for attraction, little is known about the ecological effects on wild fish assemblages.

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Two previous studies have investigated assemblages of wild fish associated with marine fish farms. Carss (1990) found large differences in the composition and abundance of fishes associated with 3 marine *Oncorhynchus mykiss* farms, compared with assemblages at nearby control sites for each farm. Saithe *Pollachius virens* were particularly abundant close to farms. Likewise, Bjordal & Skar (1992) demonstrated that large groups of saithe occurred around a Norwegian fish farm, and based on the results of a tagging study, that individual fish resided for 1 to 7 mo. Both these studies were made at cold-water temperate locations (55 to 60° N); no publication has addressed the effects of fish farms at lower latitudes, or over a broad spatial scale of 100s of km, where the species likely to associate with farms may differ markedly.

Since the initial development of sea cage aquaculture in the early 1980s, the number of sea-cage fish farms has increased rapidly in coastal waters of the Mediterranean Sea (Ferlin & LaCroix 2000). In Greece and Spain alone, over 350 coastal fish farms operate (Theodorou 1999, Sanchez-Mata & Mora 2000). Several species are cultured throughout the Mediterranean, with gilt-head sea bream *Sparus aurata* and European sea bass *Dicentrarchus labrax* particularly widespread. Production of these 2 species has increased dramatically in the last 10 yr (Ferlin & La Croix 2000). In 1999, 57 000 t of *S. aurata* and 40 000 t of *D. labrax* were produced (FAO 1999), with the combined total predicted to exceed 100 000 t in 2000 (www.feap.org/press_releases.html). As the number of fish farms increases, so does the potential for impacts on the distribution and abundance of wild fish species.

In this study, we sought to determine if the abundance, biomass and species diversity of wild fish were greater around mixed *Sparus aurata* and *Dicentrarchus labrax* farms than at nearby open water control locations. Further, we investigated whether the assemblage composition of wild fishes associated with fish farms differed between locations separated by 100s of m to 100s of km and whether assemblages at farms were persistent for weeks to months.

MATERIALS AND METHODS

Locations studied. We counted fish at 9 fish farms spread along 300 km of the Spanish coast in the southwestern Mediterranean Sea during September and October 2001 (Fig. 1). All fish farms cultivated both *Sparus aurata* and *Dicentrarchus labrax* in separate cages. The number of cages (15 m diameter, net depth = 10 to 15 m) used at farms varied from 6 to 16. Distance from the coast varied from 10 m to 7.4 km, and water depth varied from 12 to 40 m. Specific characteristics for each location are given in Table 1. One of the locations, San Pedro East, differed from other locations in that 4 × 90 m diameter cages containing northern bluefin tuna *Thunnus thynnus* were located within the same farm complex, approximately 200 m from the *S. aurata* and *D. labrax* cages.

Rapid visual counts of fishes. Estimates of wild fish populations are subject to method specific biases and limitations (Harmelin-Vivien et al. 1985). Visual counts are subject to 2 major problems: inaccurate identification of taxa underwater where assemblages are diverse and underestimation of the abundance of cryptic species. Around coastal sea-cage fish farms, neither of these 2 constraints applies due to the low diversity of assemblages at each location and the absence of complex habitat which might harbour cryptic species. Moreover, in environments where large mobile fishes are important, their populations and biomass are better estimated visually than by other methods (Harmelin-Vivien & Francour 1992). Visual counts do have specific limitations, invariably underestimating fish numbers (Sale & Sharp 1983) and underestimating or overestimating 'diver-negative' and 'diver-positive' fish species, respectively (Thresher & Gunn 1986). However, potential biases should be consistent between locations.

Table 1. Physical and environmental characteristics of the 9 Mediterranean *Sparus aurata* and *Dicentrarchus labrax* farms

Location	Position	Distance from shore (m)	Years in operation before Sep 2001	Depth (m)	Number of cages
Altea	38° 34.271′ N, 000° 02.068′ W	2778	0.5	30	6
Villajoiosa	38° 29.862′ N, 000° 12.050′ W	1800	3.3	32	16
El Campello	38° 25.234′ N, 000° 20.886′ W	3200	4.5	30	13
Guardamar	38° 05.743′ N, 000° 36.341′ W	3704	1.2	21	15
San Pedro West	37° 38.951′ N, 000° 41.767′ W	4500	1.8	37	10
San Pedro East	37° 49.113′ N, 000° 44.599′ W	7408	0.3	40	6
Aguilas North	37° 24.785′ N, 001° 31.938′ W	550	1.0	35	12
Aguilas South	37° 24.726′ N, 001° 32.226′ W	550	1.8	40	12
Aguilas Inshore	37° 24.504′ N, 001° 33.569′ W	10	12.7	12	16

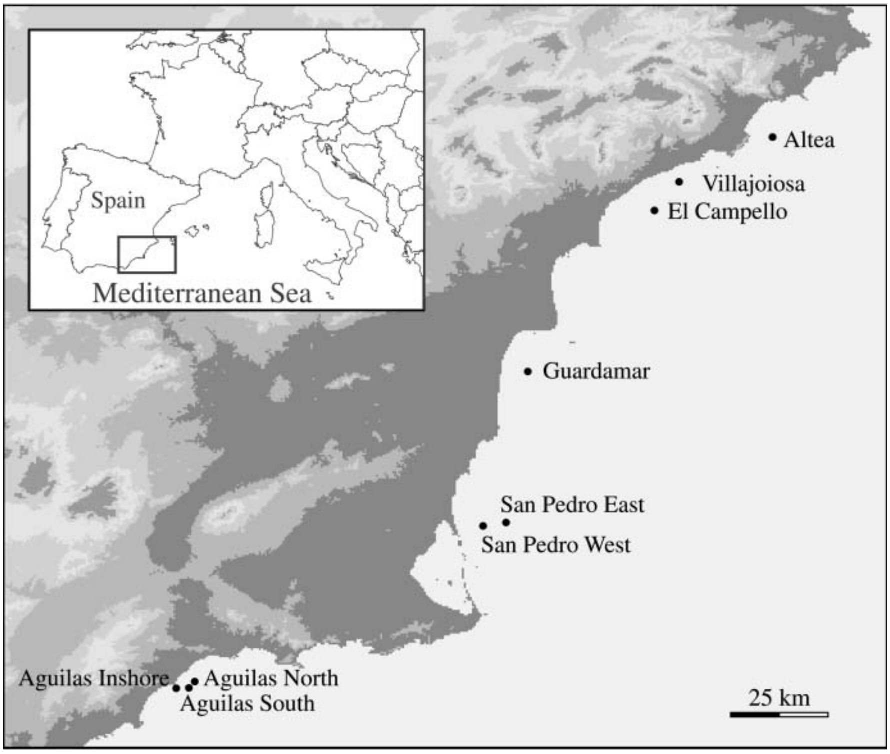

Fig. 1. Map of the 9 study locations along the south-east coast of Spain in the Mediterranean Sea

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 (RVCs; Kingsford & Battershill 1998) using SCUBA, beginning at 1 cage, proceeding through the adjoining water mass and finishing at a second cage. Each count covered a volume of approximately 11 250 m^3 (15 m wide × 15 m deep × 50 m long). Counts were conducted at depths varying from 5 to 10 m, allowing for the water column from the surface to the bottom of the cage to be searched effectively. Fish were rarely observed in the colder water below the thermocline, which was typically found at 15 to 20 m. Visibility varied from 15 to 30 m on days when counts were performed and surface water temperature varied little (between 22 and 24°C) at all locations.

Each count was made with 2 divers. The first diver concentrated on estimating the abundance of the dominant species present. Fish were counted in groups of 1, 2–5, 6–10, 11–30, 31–50, 51–100, 101–200, 201–500 and 500+ to minimise error, based on the method of Harmelin-Vivien et al. (1985), and the average total length (TL) of each group was noted. The second diver followed slightly behind the first and specifically looked for both highly mobile species and smaller, less obvious fish that may have been missed by the first diver. A ruler was used to estimate the average total lengths of groups of fishes observed. For *Trachinotus ovatus* (mean ± SE = 32.9 ± 3.7 cm, 43 fish) and *Sardinella aurita* (30.3 ± 1.4 cm, 50 fish) estimated TLs were checked by sampling fish at Villajoiosa on 20 to 21 and 25 September 2001, respectively. Count data were entered into the ecoCEN program (Bayle-Sempere et al. 2001), where abundance by species and size class for each count were calculated. Conversions to biomass were made for each species using ecoCEN, based on published length-weight relationships.

Experimental design. At each farm, fish were counted at 3 random times over a period of 2 mo. Six 5 min counts were conducted each time within the farm complex. An equal number of counts (6) were performed at a control location at 200 m distance from each farm, beyond the leasehold area. These counts controlled for the entire attractive effect of the farm; the study was not designed to separate the effects of attraction by the cage structures, the unused portion of fish food or chemical cues produced by the farmed fish.

Univariate statistical analysis. The initial analysis of variance (ANOVA) design for comparisons between farms and open-water controls had the factors Impact/Control, Locations, and Times nested in Locations. However, due to the predominance of 0 counts at control locations, this analysis was unnecessary. We simplified the design to the factors Location (random) and Times nested in Location (random).

Prior to ANOVA, heterogeneity of variance was tested with Cochran's *C*-test. Data were $\sqrt{x+1}$ transformed if variances were significantly different at p = 0.05, and $\ln(x+1)$ transformed if variance was still heterogeneous. Where variance remained heterogeneous, untransformed data were analysed, as ANOVA is robust to heterogeneity of variances, particularly for large balanced experiments (Underwood 1997).

Assemblage analysis of wild fish associated with fish farms. Non-parametric multivariate techniques were used to compare assemblages among locations and times within locations. All multivariate analyses were performed using the PRIMER statistical package. Prior to calculating the similarity matrices, the data were pooled by summing the 6 RVCs for each time, to reduce the stress of MDS representation, and fourth root transformed, to weight the contributions of common and rare species in the similarity coefficient (Clarke 1993). Triangular similarity matrices were calculated using the Bray-Curtis similarity coefficient (Clarke & Warwick 1994). Non-metric multidimensional scaling (nMDS) was used as the ordination method. Variables that had more influence on similarities within groups and dissimilarities among groups of locations, determined by ANOSIM (analysis of similarity), were calculated using the SIMPER (similarity percentages) procedure (Warwick et al. 1990, Clarke 1993).

The ANOSIM permutation test was used to assess the significance of differences between locations and among times within locations (Clarke & Green 1988, Clarke 1993). ANOSIM produces a global *R* value (= test statistic) based on average similarities within replicate samples and average similarities between different samples. *R* lies in the range (–1,1), but will usually fall between 0 and 1, indicating some degree of discrimination between locations. It is a useful comparative measure of the degree of similarities among locations, though the main interest usually centres on whether it is significantly different from zero (Clarke & Warwick 1994).

We tested the hypothesis that fish assemblages at farms located close to each other (100s of m to several km) would be more similar than farms located further apart (10s to 100s of km). A measure of the overall assemblage dissimilarity between all combinations of farms was available from the dissimilarities generated by ANOSIM. The Bray-Curtis dissimilarities (*R*-values) of each paired comparison were regressed against the shortest distance between pairs of farms.

Species and size classes for univariate and assemblage analyses. Most of the species observed fell within a similar size range, so differentiation into separate size classes for analysis was unnecessary. However, some species were clearly represented by 2 distinct size cohorts of juvenile and large fish. We divided 6 taxa—*Boops boops*, Mugilidae, *Sarpa salpa*, *Oblada melanura*, *Trachinotus ovatus*, and *Trachurus* sp.—into 2 size classes, to differentiate between adult and juvenile fish before undertaking the multivariate and univariate analyses. For ANOVA, we chose the 9 most abundant species by size classes, which were in descending order: *B. boops* >15 cm (no. = 139 187), *Sardinella aurita* (no. = 120 447), *T. ovatus* >20 cm (no. = 58 878), *Trachurus* sp. >20 cm (no. = 30 715), *T. ovatus* <20 cm (no. = 22 104), Mugilidae >20 cm (no. = 20 297), *O. melanura* >20 cm (no. = 19 378), *O. melanura* <20 cm (no. = 16 830), and Mugilidae <20 cm (no. = 16 293). Furthermore, we selected *Seriola dumerili* (no. = 662) for analysis as it was a species common to many fish farms.

Relationships between fish farm characteristics and abundance, biomass and species diversity. Linear regressions were used to test for patterns that may have explained variability in the abundance, biomass and species diversity between farms. Age of the farm (yr), number of cages, distance from shore (m), and water depth (m) as in Table 1 were regressed against the 3 above parameters.

RESULTS

Comparison of fish farm and control locations

Fish farm counts had greater abundance (52 to 2837×), biomass (2.8 to 1126×) and number of fish species (1.6 to 14×) than control counts at all locations (Fig. 2). During the study, 28 species belonging to 14 families were recorded (Table 2). Two families, Carangidae (4 species) and Sparidae (12 species), were represented by numerous species. In the 162 five min counts conducted at fish farm locations, 466 344 fish belonging to 27 species were recorded. In contrast, in the 162 five min control counts, 2072 fish belonging to 14 species were seen. Fourteen species only occurred at fish farms, 13 species were seen in both farm and control counts, and 1 species (*Mola mola*, 1 individual) was only seen at 1 control location. *Sardinella aurita* was the most common species observed in the control counts, although the number per count (20 to 200 individuals) was far less than at fish farm locations.

Similarities within and dissimilarities between assemblage groups

The 2-dimensional nMDS plot (Fig. 3) based on abundances of species revealed clear separation of 5 major groups with distinct fish assemblages separated by less than 40% similarity in the Bray-Curtis similarity dendrogram. The 5 discrete groups were: Group 1, Altea, Villajoiosa and Guardamar; Group 2, El Campello; Group 3, San Pedro West and San Pedro East; Group 4, Aguilas North and Aguilas South; and Group 5, Aguilas Inshore.

The average similarity between samples within groups was high in all cases (Group 1 = 66.1%, Group 2 = 68.8%, Group 3 = 52.8%, Group 4 = 85.3%, Group 5 = 82.8%). SIMPER analysis of the contributions of individual species to group similarity indicated that the 3 groups encompassing multiple locations were characterised by similar abundances of relatively few taxa. Group 1 encompassed 3 locations (Altea, Villajoiosa and Guardamar) and 3 taxa (*Sardinella aurita*, *Trachinotus ovatus* >20 cm and *Trachurus* sp. >20 cm) accounted for 73.5% of the cumulative similarity (28, 26.1 and 19.3% respectively). For Group 3, the 2 locations at San Pedro, 82% of group similarity was accounted for by Mugilidae <20 cm, *Seriola dumerili*, and *Boops boops* >15 cm (47.1, 20.7 and 14.2% respectively). Aguilas North and Aguilas South (Group 4) were largely defined (76.3% cumulative similarity) by *B. boops* >15 cm (26.1%), *S. aurita* (17.9%), *Oblada melanura* >20 cm (16.2%), and *T. ovatus* <20 cm (16.2%).

Dissimilarities between the 5 groups were usually due to large differences in the abundance of a few of the major taxa (Table 3). Abundant *Trachinotus ovatus* >20 cm were important in differentiating Group 1 from all other groups. Differences in *Sardinella aurita* abundance also distinguished Group 1 from Groups 2, 3 and 5. *Oblada melanura* <20 cm were involved in separating Group 2 from Groups 1, 3 and 5. *Boops boops* >15 cm were influential in delineating Group 3 from Groups 1, 2 and 4. For Group 4, where *B. boops* >15 cm were particularly abundant, this taxa contributed the greatest percentage of dissimilarity to all other groups. Two taxa, *Pagellus acarne* and Mugilidae >20 cm, contributed much of the dissimilarity between group 5 and other groups.

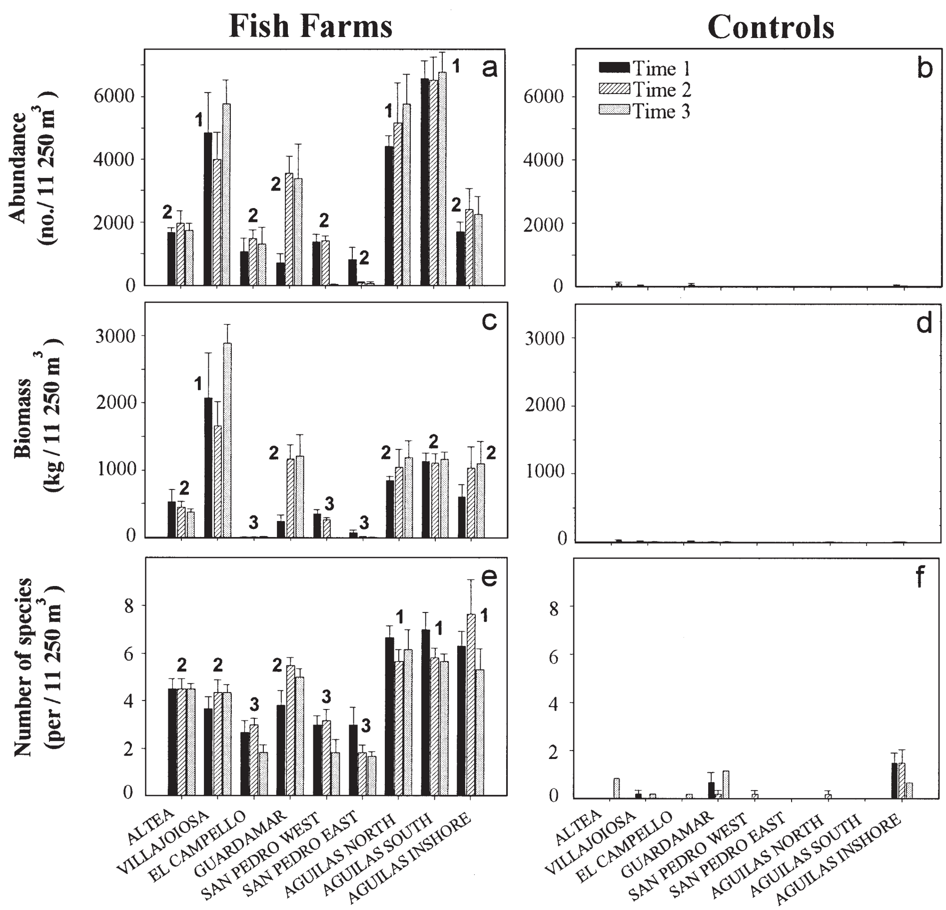

Fig. 2. Abundance, biomass (kg) and number of species of wild fish per 11 250 m^3 for the 3 times sampled at the 9 fish farm and control locations. Bars give the mean ± SE of 6 rapid visual counts of an 11 250 m^3 volume. Locations labeled with the same numeral (above bars) do not differ significantly ($p > 0.05$) in post hoc Student-Newman-Keuls tests

Table 2. Abundance of wild fish species per 11 250 m^3 for the 3 sampling times at the 9 Mediterranean fish farms. Numbers are the mean ± SE of 18 rapid visual counts

	Altea	Villajoiosa	El Campello	Guardamar	San Pedro West	San Pedro East	Aguilas North	Aguilas South	Aguilas Inshore
Clupeidae									
Sardinella aurita	1256 ± 123.4	2302.7 ± 336	0	399.4 ± 199.2	8.89 ± 3.88	0	555.6 ± 147.5	2168.9 ± 233.4	0
Belonidae									
Belone belone	1.1 ± 1.1	2.22 ± 2.22	0	1.11 ± 1.11	0.3 ± 0.3	5.33 ± 2.95	0	0	0
Moronidae									
Dicentrarchus labrax	0	1.6 ± 1.6	0	0	0.2 ± 0.2	0	1.22 ± 0.6	0.6 ± 0.4	122 ± 65.6
Pomatomidae									
Pomatomus saltator	16.7 ± 11.4	25.4 ± 13.5	0.2 ± 0.1	109.1 ± −64.2	0	0	0	0	0
Carangidae									
Lichia amia	0.1 ± 0.1	0	0	0	0	0	0	0	0
Seriola dumerili	13.3 ± 4.8	0.1 ± 0.1	0.1 ± 0.1	1.3 ± 0.3	8.3 ± 3.8	13.2 ± 3.7	0.1 ± 0.1	0.4 ± 0.3	0
Trachinotus ovatus <20 cm	0	0	0.7 ± 0.5	0	0	0	373 ± 61	854 ± 79.8	0
Trachinotus ovatus >20 cm	65.1 ± 13.4	2498.6 ± 354	0	706.1 ± 140.26	0	0	0.7 ± 0.3	0.5 ± 0.3	0
Trachurus sp. <20 cm	0	0	5 ± 2.9	0	0	0	0	0	0
Trachurus sp. >20 cm	416.7 ± 73.9	10.6 ± 5	0	1157.8 ± 243	0	81.1 ± 60.2	0.5 ± 0.3	0.1 ± 0.1	39.6 ± 18
Coryphaenidae									
Coryphaena hippurus	0	0.1 ± 0.1	0	0.1 ± 0.1	0	0.2 ± 0.2	0	2.2 ± 2.2	0
Sparidae									
Boops boops <15 cm	0	0	41.1 ± 41.1	0	0	0	0	0	0
Boops boops >15 cm	0	0	0	0	901.8 ± 179.4	155.6 ± 86.5	3647.1 ± 525	3028.7 ± 228.9	0
Diplodus annularis	0	0	0	0	0	0	0	0	161.4 ± 48.3
Diplodus cervinus	0	0	0	0	0	0	0	0	0.2 ± 0.1
Diplodus puntazzo	0	0	0.1 ± 0.1	0.1 ± 0.1	0	0	0	0	0
Diplodus sargus	0	0	0.2 ± 0.2	0.2 ± 0.2	0	0	0.1 ± 0.1	0	2.3 ± 2.2
Diplodus vulgaris	0	0	0	0	0	0	2.6 ± 1.2	0.2 ± 0.2	0.1 ± 0.1
Lithognathus mormyrus	0	0	0	0	0	0	0	0	62 ± 24.1
Oblada melanura <20 cm	0	0.7 ± 0.4	884 ± 235	0	0	0	0	0	50.3 ± 22.9
Oblada melanura >20 cm	0	0	1.1 ± 1.1	0	0	0	452.6 ± 143.9	493.6 ± 140.3	129.3 ± 42.3
Pagellus acarne	0	0	0	0	0	0	0	0	227.3 ± 86.9
Sarpa salpa <28 cm	0.1 ± 0.1	0	0	0	0	0	0	0	3.1 ± 2.7
Sarpa salpa >28 cm	0	0.1 ± 0.1	0	0	0	0	0.6 ± 0.4	0.6 ± 0.4	50.8 ± 15.9
Sparus aurata	0	0.9 ± 0.8	0.1 ± 0.1	0.1 ± 0.1	0.6 ± 0.3	2.7 ± 1.7	0.9 ± 0.5	3.6 ± 2.4	1.3 ± 0.5
Spondyliosoma cantharus	0	0	0	0	0	0	0	0.1 ± 0.1	0
Centracanthidae									
Spicara maena	0	0	0	0	0	0	2.2 ± 2.2	0	0
Pomacentridae									
Chromis chromis	0	0	0	0	0	0	0	0	2.2 ± 2.2
Scombridae									
Thunnus thynnus	0	0	0	0	0	0	0.1 ± 0.1	0	0
Sphyraenidae									
Sphyraena sphyraena	0	0	0.1 ± 0.1	0	0	0	0	0	0.8 ± 0.8
Mugilidae									
Mugilidae <20 cm	21 ± 8.7	10.2 ± 5.9	334.8 ± 79.4	45.7 ± 18	26 ± 6	68.33 ± 22.5	10 ± 5.2	6.6 ± 4.6	382.6 ± 117
Mugilidae >20 cm	0	8.3 ± 8.3	2.9 ± 2.7	130.2 ± 63.3	0	0	65.9 ± 22	60.3 ± 18.6	859.9 ± 143
Atherinidae									
Atherina hepsetus	0	0	0.9 ± 0.9	0	0	0	0	0	0

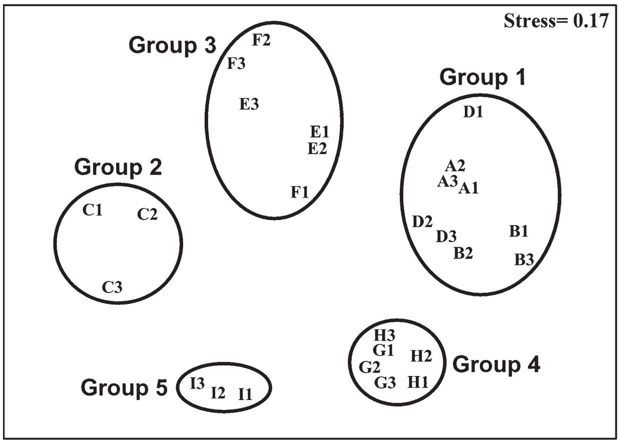

Fig. 3. Non-parametric multi-dimensional scaling plot of wild fish communities at 9 Mediterranean fish farms. A = Altea, B = Villajoiosa, C = El Campello, D = Guardamar, E = San Pedro West, F = San Pedro East, G = Aguilas North, H = Aguilas South, I = Aguilas Inshore. Numbers 1, 2, and 3 refer to the 3 times sampled

Spatial and temporal variability of wild fish assemblages around fish farms

ANOSIM indicated that differences in fish assemblages among locations were significant ($R_{global} = 0.78$, $p < 0.0001$). Pairwise comparisons between all locations gave highly significant *R*-values, which were usually greater than 0.6, indicating that differences were large. Bray-Curtis dissimilarity plotted against distance between each pair of farms revealed that assemblages at farms separated by 10s of km were more similar than at farms separated by 100s of km ($F_{1,34} = 10.1$, $p = 0.003$, $r^2 = 0.23$; Fig. 4). However, smaller values of *R*, indicating a higher degree of similarity between fish assemblages, were found between Aguilas North and Aguilas South ($R = 0.24$) and San Pedro West and San Pedro East ($R = 0.21$), indicating that similar assemblages sometimes occur between farms separated by 100s of m to km.

Significant differences in the fish assemblage among times existed at Guardamar (Time $1 \neq 2 = 3$, $R = 0.46$) and San Pedro West (Time $1 = 2 \neq 3$, $R = 0.66$). Differences between times also existed at Villajoiosa (Time $1 = 2 \neq 3$, $R = 0.13$), El Campello (Time $1 = 2 \neq 3$, $R = 0.15$), and San Pedro East (Time $1 = 3 \neq 2$, $R = 0.26$), although the smaller *R*-values indicate smaller differences than at Guardamar and San Pedro West. No differences between times were detected for Altea ($R = -0.10$), Aguilas North ($R = 0.03$), Aguilas South ($R = 0.01$) and Aguilas Inshore ($R = 0.04$).

Differences between farms in abundance, biomass and species diversity

The size of the attractive effect of fish farms, in terms of abundance, biomass and number of species, differed among locations (Table 4). Post hoc Student-Newman-Keuls (SNK) tests indicated that abundance per 5 min count was higher at Aguilas South (mean ± SE = 6620.8 ± 350.7), Aguilas North (5113.1 ± 520.1) and Villajoiosa (4861.4 ± 570.9) than at all other locations,

Table 3. Contributions of the dominant taxa to overall dissimilarities between major community groups identified by multi-dimensional scaling. Group 1 = Altea, Villajoiosa and Guardamar; Group 2 = El Campello; Group 3 = San Pedro West and San Pedro East; Group 4 = Aguilas North and Aguilas South; Group 5 = Aguilas Inshore. Percentage contributions to the cumulative dissimilarity of each pairwise group comparison from SIMPER analysis are given for the 4 most important taxa (ranked in order). See Table 2 for full species names

	Group 2		Group 3		Group 4		Group 5	
	O. melanura <20 cm	16.7	*T. ovatus* >20 cm	21.3	*B. boops* >15 cm	20.5	*S. aurita*	11.1
Group 1	*S. aurita*	16.6	*S. aurita*	20.3	*T. ovatus* <20 cm	13.1	*T. ovatus* >20 cm	10.4
	T. ovatus >20 cm	15.6	*Trachurus* sp. >20 cm	15.4	*O. melanura* <20 cm	12.5	Mugilidae >20 cm	9.0
	Trachurus sp. >20 cm	12.3	*B. boops* >15 cm	10.8	*T. ovatus* >20 cm	11.3	*P. acarne*	7.6
			O. melanura <20 cm	28.2	*B. boops* >15 cm	18.3	Mugilidae >20 cm	12.1
	Group 2		*B. boops* >15 cm	12.4	*S. aurita*	13.8	*P. acarne*	9.6
			Mugilidae <20 cm	8.9	*T. ovatus* <20 cm	12.8	*D. annularis*	9.4
			Trachurus sp. >20 cm	6.7	*O. melanura* >20 cm	10.7	*O. melanura* <20 cm	8.2
					B. boops >15 cm	16.6	Mugilidae >20 cm	13.6
			Group 3		*S. aurita*	16.5	*P. acarne*	9.1
					T. ovatus <20 cm	16.1	*D. annularis*	8.9
					O. melanura >20 cm	15.4	*O. melanura* <20 cm	8.1
							B. boops >15 cm	15.4
					Group 4		*S. aurita*	11.7
							T. ovatus <20 cm	9.9
							P. acarne	7.3

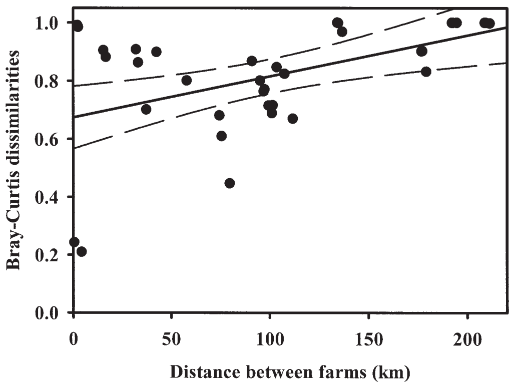

Fig. 4. Relationships between Bray-Curtis dissimilarities for each pair of farms comparison against the shortest distance (km) between pairs of farms. The bold line gives the regression, with dashed lines indicating the upper and lower 95% confidence intervals

where abundance per count was less than 2500 individuals (Fig. 2a). Biomass per 5 min count was significantly higher at Villajoiosa (2206 ± 282.7 kg) than at Aguilas South (1134 ± 70.8), Aguilas North (1029 ± 121.4), Aguilas Inshore (915 ± 164), Guardamar (870 ± 161.1) and Altea (450 ± 66.3), which were in turn significantly higher than San Pedro West (206.6 ± 42.4), San Pedro East (30.1 ± 13.9), and El Campello (7.6 ± 1.9) (Fig. 2c). The greatest number of species per count occurred at the 3 Aguilas locations, Inshore (6.4 ± 0.61), South (6.2 ± 0.32) and North (6.2 ± 0.35), which were significantly higher than Guardamar (4.8 ± 0.30), Altea (4.5 ± 0.20) and Villajoiosa (4.1 ± 0.27) (Fig. 2e). The number of species was particularly small at San Pedro West (2.7 ± 0.29), El Campello (2.5 ± 0.23) and San Pedro East (2.2 ± 0.29), and SNK tests separated these locations from Guardamar, Altea and Villajoiosa.

Table 4. ANOVAs comparing abundance, biomass, number of species and abundance of the 10 dominant taxa at 9 fish farm locations and 3 times nested within locations. *Significant at p = 0.05; **p = 0.01; ***p = 0.001; ^{ns}no significant difference. NT: no transformation performed

	df	Abundance		Biomass		Number of species	
		MS	*F*	MS	*F*	MS	*F*
Location	8	8844.7	15.76***	232.3***	15.41***	50.08	16.9***
Time (Location)	18	561.2	3.06**	2.475*	1.95*	2.96	1.55^{ns}
Residual	135	183.2		1.269		1.91	
Cochran's test		0.1009^{ns}		0.3463**		0.237**	
Transformation		Squared root		NT		NT	

	df	*Sardinella aurita*		*Trachurus* sp. >20 cm		*Trachinotus ovatus* <20 cm		*Trachinotus ovatus* >20 cm	
		MS	*F*	MS	*F*	MS	*F*	MS	*F*
Location	8	15.92 10^6	41.12***	2.69 10^6	5.29**	1.58 10^6	36.61***	12.5 10^6	33.16**
Time (Location)	18	0.39 10^6	0.77^{ns}	0.51 10^6	5.84***	0.04 10^6	2.52**	0.38 10^6	1.35^{ns}
Residual	135	0.50 10^6		0.09 10^6		0.02 10^6		0.28 10^6	
Cochran's test		0.195**		0.3763**		0.4078**		0.6322**	
Transformation		NT		NT		NT		NT	

	df	*Seriola dumerili*		*Oblada melanura* <20 cm		*Oblada melanura* >20 cm	
		MS	*F*	MS	*F*	MS	*F*
Location	8	609.2	2.74*	47.83	12.5***	0.76 10^6	35.48***
Time (Location)	18	221.9	2.52**	3.83	2.52**	0.02 10^6	0.23^{ns}
Residual	135	88.07		1.52		0.09 10^6	
Cochran's test		0.462**		0.6344**		0.2102**	
Transformation		NT		NT		NT	

	df	*Boops boops* >15 cm		Mugilidae <20 cm		Mugilidae >20 cm	
		MS	*F*	MS	*F*	MS	*F*
Location	8	37.5 10^6	28.89***	41.07	7.51***	1.40 10^6	19.55*
Time (Location)	18	1.29 10^6	1.96*	5.47	1.41^{ns}	0.07 10^6	1.5^{ns}
Residual	135	0.66 10^6		3.86		0.05 10^6	
Cochran's test		0.4126**		0.0974^{ns}		0.326**	
Transformation		NT		Log (x+1)		NT	

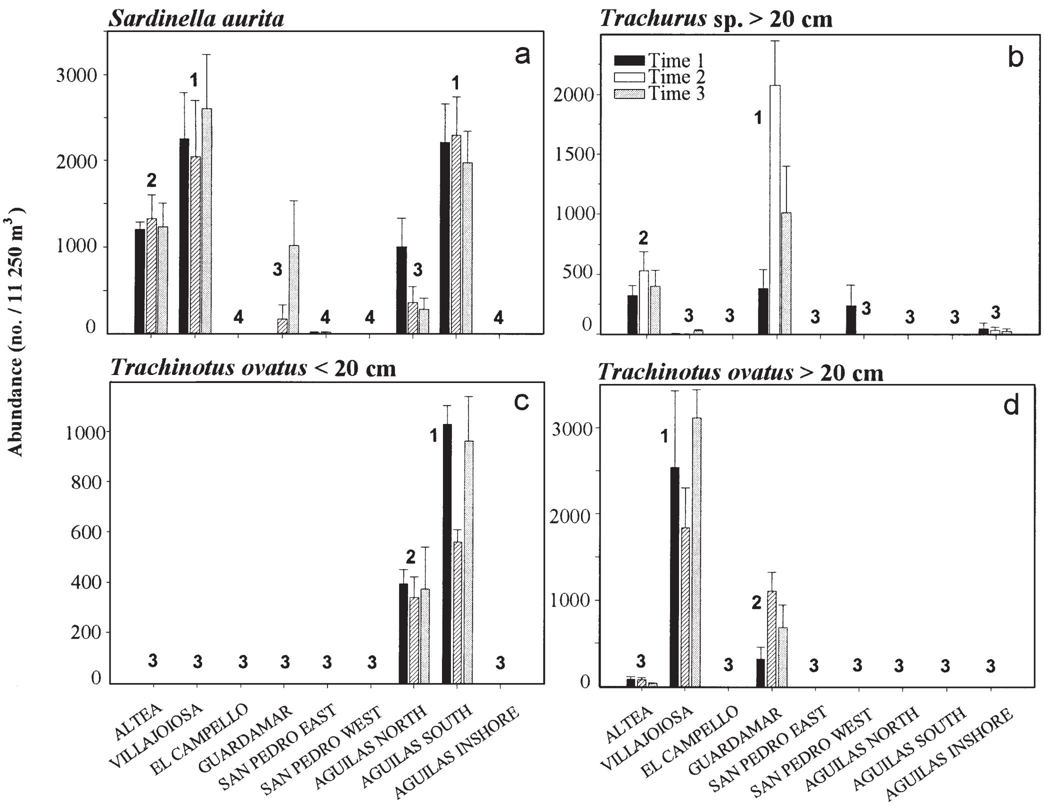

Fig. 5. Abundance of (a) *Sardinella aurita*, (b) *Trachurus* sp. >20 cm, (c) *Trachinotus ovatus* <20 cm, and (d) *T. ovatus* >20 cm per 11 250 m^3 for 3 sampling times at the 9 fish farm locations. Bars give the mean ± SE of 6 rapid visual counts of an 11 250 m^3 volume. Locations labeled with the same numeral (above the bars) do not differ significantly ($p > 0.05$) in post hoc Student-Newman-Keuls tests

Differences in abundance of dominant species between farms

Abundance of all 10 dominant taxa differed among locations (Table 4) and no single taxon was an important part of the assemblage associated with fish farms at all locations. *Sardinella aurita* was particularly abundant at Villajoiosa (mean ± SE = 2303 ± 335.8 per 5 min count) and Aguilas South (2169 ± 233.4) (Fig. 5a). SNK tests separated Altea (1256 ± 123.4) from these 2 locations and from Aguilas North (556 ± 147.5) and Guardamar (399 ± 199.2), where abundance was significantly smaller. Very few *S. aurita* occurred at San Pedro West (9 ± 3.9) and none were seen at El Campello, San Pedro East and Aguilas Inshore.

Abundance of *Trachurus* sp. >20 cm at Guardamar (n = 1158 ± 243) was higher than at Altea (417 ± 73.9), and these 2 locations were separated from all others by the SNK tests (Fig. 5b). *Trachinotus ovatus* <20 cm were only important at Aguilas South (854 ± 79.8) and Aguilas North (373 ± 61) (Fig. 5c). In contrast, *T. ovatus* >20 cm were extremely abundant at Villajoiosa (2499 ± 354.2), with abundances significantly lower at Guardamar (706 ± 140.3) and lower again at Altea (65 ± 14) (Fig. 5d). *Seriola dumerili* occurred in higher numbers at Altea (13 ± 4.8), San Pedro East (13 ± 3.7), and San Pedro West (8 ± 3.9), than at all other locations (Fig. 6a). *Oblada melanura* <20 cm were only abundant at El Campello (884 ± 235), with small groups seen at Aguilas Inshore (50 ± 22.9) (Fig. 6c).

Oblada melanura >20 cm occurred in similar numbers at Aguilas South (494 ± 140.3) and Aguilas North (453 ± 143.9), and were significantly less abundant at Aguilas Inshore (129 ± 42.8) (Fig. 6d). Highest abundance of *Boops boops* also occurred at Aguilas North (3647 ± 525) and Aguilas South (3029 ± 228.9) (Fig. 6b). SNK tests indicated that abundance at these 2 locations was significantly greater than at San Pedro West (901 ± 179.4), which in turn differed from all other locations. Mugilidae <20 cm were abundant at Aguilas Inshore (383 ± 116.8) and El Campello (335 ± 79.4), with significantly smaller numbers at all other locations (Fig. 6e). In contrast, Mugilidae >20 cm were clearly most abundant at Aguilas Inshore (860 ± 142.8), with significant numbers also observed at Guardamar (130 ± 63.3) (Fig. 6f).

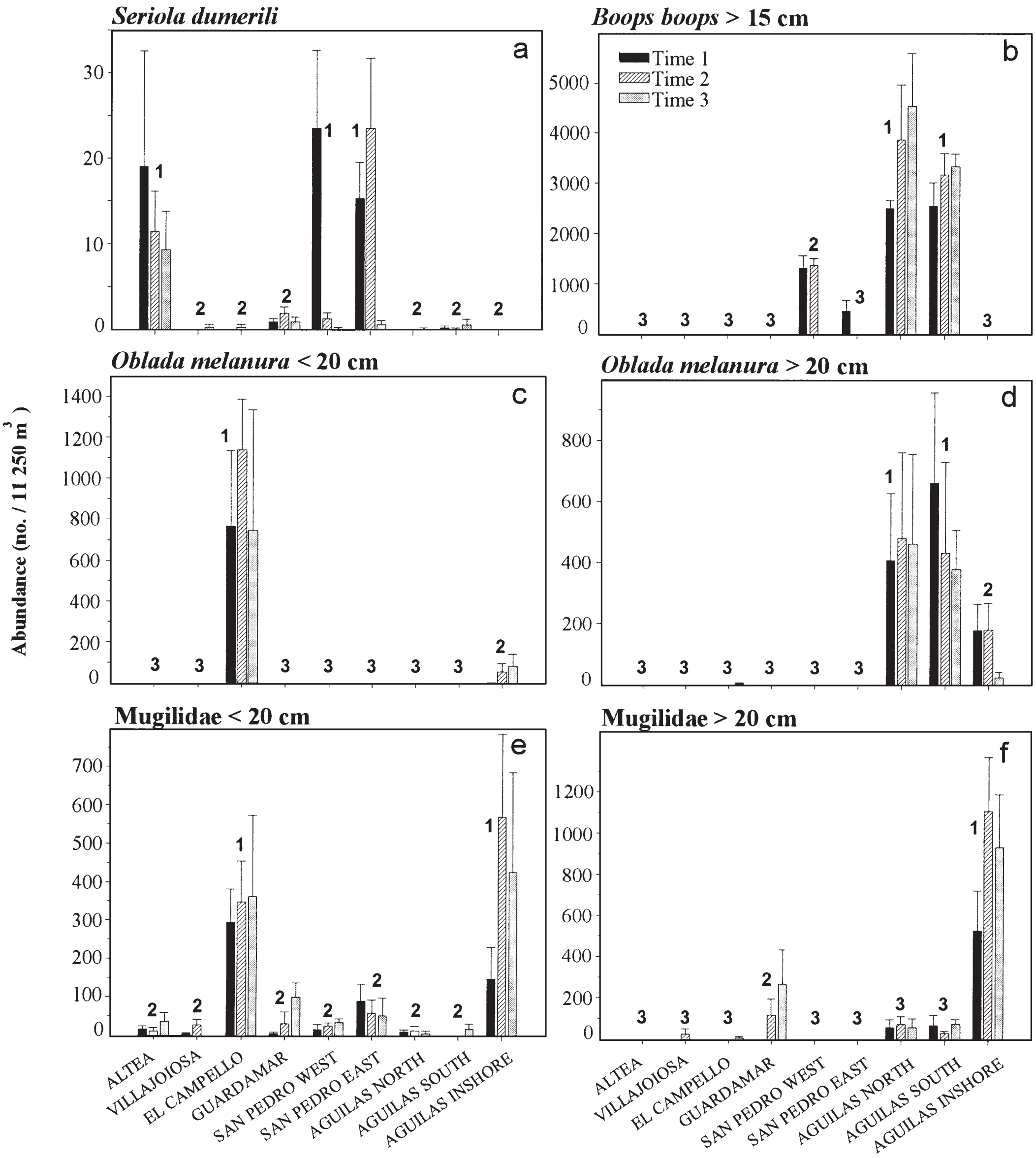

Fig. 6. Abundance of (a) *Seriola dumerili*, (b) *Boops boops* >20 cm, (c) *Oblada melanura* <20 cm, (d) *Oblada melanura* >20 cm, (e) Mugilidae <20 cm and (f) Mugilidae >20 cm per 11 250 m^3 for the 3 sampling times at the 9 fish farm locations. Bars give the mean ± SE of 6 rapid visual counts of an 11 250 m^3 volume. Locations labeled with the same numeral (above bars) do not differ significantly ($p > 0.05$) in post hoc Student-Newman-Keuls tests

Short-term temporal variability of dominant species within farms

Abundance and biomass differed among times although the number of species did not differ significantly among times at all locations (Table 4). There were no differences in abundance of 5 of the dominant taxa between the 3 times sampled: *Sardinella aurita*, *Trachinotus ovatus* >20 cm, *Oblada melanura* >20 cm, Mugilidae <20 cm, and Mugilidae >20 cm (Figs. 5a,d & 6d–f). In contrast, abundances differed among times for *Trachurus* sp. >20 cm (Fig. 5b), *T. ovatus* <20 cm (Fig. 5c), *Seriola dumerili* (Fig. 6a), *O. melanura* <20 cm (Fig. 6c), and *Boops boops* >15 cm (Fig. 6b).

Size classes of dominant taxa associated with fish farms

Size class information for 2 of the most abundant species at fish farms, *Sardinella aurita* and *Trachurus* sp., indicated that only adults were present (Fig. 7a,b).

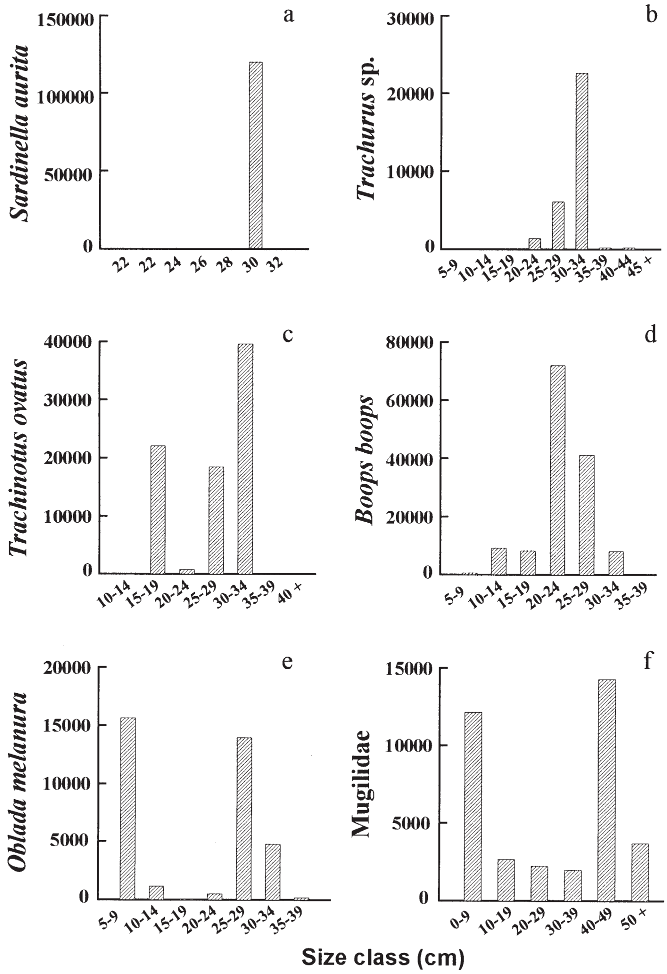

Fig. 7. Size-frequency distributions of the 6 most abundant taxa of wild fish associated with fish farms: (a) *Sardinella aurita*, (b) *Trachurus* sp., (c) *Trachinotus ovatus*, (d) *Boops boops*, (e) *Oblada melanura*, and (f) Mugilidae. Bars are pooled for all counts at all times

Similarly, *Boops boops* were represented predominantly by fish in the larger size categories (>20 cm, Fig. 7d). In contrast, 2 distinct size frequency peaks, representing juveniles and adults, were evident for *Trachinotus ovatus* (Fig. 7c), *Oblada melanura* (Fig. 7e) and Mugilidae (Fig. 7f). Overall, 85.8 % of farm-associated wild fish were of adult size.

Relationships between abundance, biomass and species diversity of wild fish and farm characteristics

Abundance ($F_{1,25} = 22.9$, $p < 0.001$, $r^2 = 0.48$), biomass ($F_{1,25} = 11.6$, $p < 0.01$, $r^2 = 0.32$) and number of fish species ($F_{1,25} = 48.3$, $p < 0.001$, $r^2 = 0.66$) decreased with increasing distance of farms from shore (Fig. 8a–c). Significant relationships were also found between the number of farm cages and abundance ($F_{1,25} = 4.9$, $p < 0.05$, $r^2 = 0.16$), biomass ($F_{1,25} = 13.1$, $p < 0.001$, $r^2 = 0.34$) and number of fish species ($F_{1,25} = 5.1$, $p < 0.05$, $r^2 = 0.17$) (Fig. 8d–f). All 3 variables increased as the number of cages increased. In contrast, age of the farms and water depth were not significantly related to any of these variables.

DISCUSSION

Attraction of wild fishes by fish farms

We have demonstrated that coastal sea-cage fish farms attract wild fish in great number and biomass. Dramatically larger abundance, biomass and number of species at all fish farm locations compared to control locations clearly indicate the attractive effect of fish farms to wild fish (Fig. 2). Our results differ greatly to those of Carss (1990), who compared abundance and biomass of wild fish around fish farms and control sites in Scottish Lochs. While Carss (1990) found a 'farm effect', only 10s to 100s of fish equivalent to 10s of kg in biomass were caught in each replicate. In contrast, 1 to 3 orders of magnitude more fish were recorded in our replicate RVCs, which typically resulted in 10^3 to 10^4 individuals and 10^2 to 10^3 kg. This difference may be largely due to greater attraction of wild fish to fish farms in the warm temperate waters of the Mediterranean. However, the difference may also be due in part to the different sampling techniques used (seine net catches and RVCs). While no study comparing techniques for estimating wild fish populations around fish farms exists, net sampling typically underestimates abundance and biomass of mobile fishes in other habitats (Harmelin-Vivien & Francour 1992). Such sampling bias may be amplified in the context of fish farms, as net sampling directly beneath the cages, where fish are most abundant, is not possible due to the array of mooring blocks and ropes.

Comparison with other FAD-associated assemblages in the Mediterranean provides some ability to determine the effect of the floating farm structure itself. The fish species that dominate assemblages around fish farms clearly differ from both natural and artificial FAD-associated assemblages. *Sardinella aurita* were particularly abundant around fish farms; however, Deudero et al. (1999) found higher densities at control locations than at FADs located off Majorca in the western Mediterranean. Sparids, such as *Boops boops* and *Oblada melanura*, were particularly abundant around fish farms (12 species, Table 2) but were largely absent from FADs (Castro et al. 1999, Deudero et al. 1999, Riera et al. 1999). Carangids show particularly strong association with FADs (Kingsford 1993); however, only

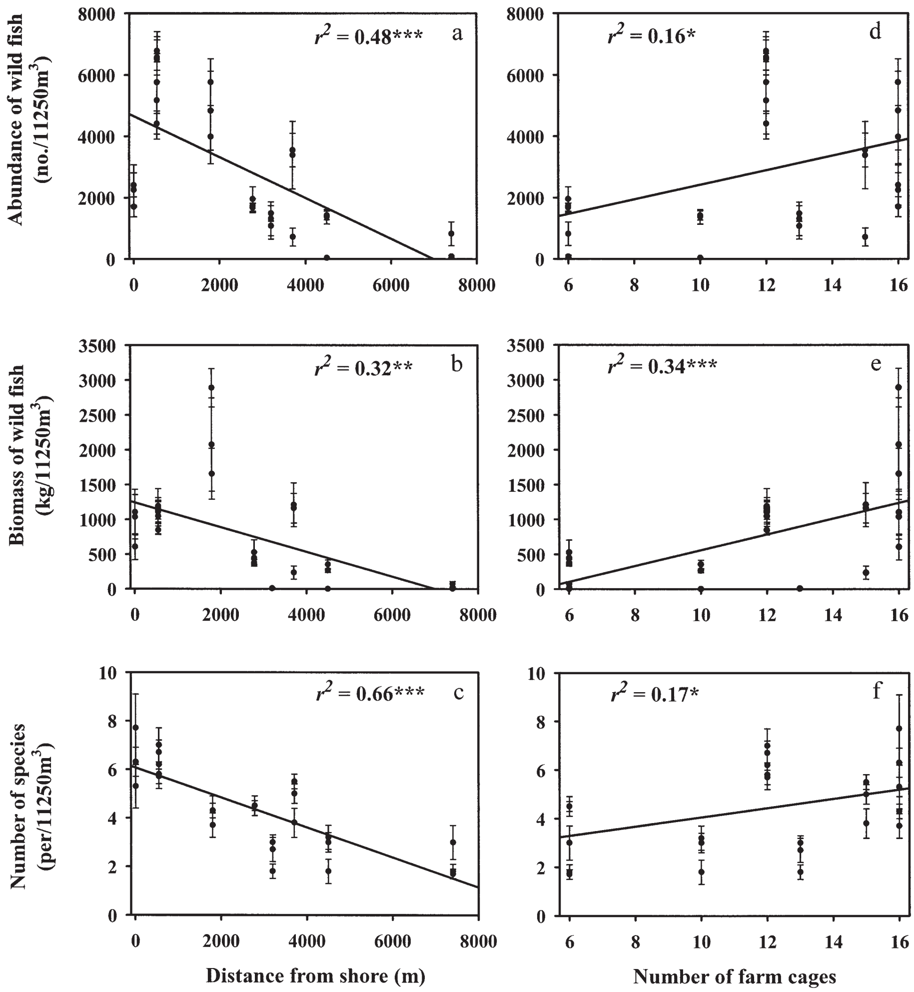

Fig. 8. Linear regressions of abundance, biomass and number of wild fish species per 11 250 m^3 count against distance from shore (m) and number of farm cages. Points are the mean ± SE for the 6 rapid visual counts at each sampling time. *Significant at p = 0.05; **p = 0.01, ***p = 0.001

Trachurus sp. are associated with both farms and FADs in the Mediterranean and FAD-associated fish are usually smaller (<15 cm) than farm-associated fish (>20 cm, Fig. 7b) (Castro et al. 1999, Deudero et al. 1999). Fish farms, therefore, do not act as conventional FADs in attracting wild fish. A combination of the persistent artificial food input and possible chemical attraction from farmed fishes (1 to 3 million per farm) probably greatly influence which species of wild fish associate with farms.

Spatial variability of fish assemblages associated with fish farms

Within the 300 km of coastline encompassed by the study, assemblages of wild fish associated with farms varied greatly (Fig. 3). Differences were large whether farms were separated by 10s of km or 100s of km (Fig. 4), with a tendency for greatest differences between farms 100s of km apart. This may be due to groups of species that are available to associate with farms being locally abundant over scales of 10s of km rather than 100s of km. There is some evidence to suggest that at a finer scale, where farms are located within 100s of m to a few km of each other, similar assemblages occur. Aguilas North and Aguilas South (R = 0.24) and San Pedro West and San Pedro East (R = 0.21) were separated by 0.4 and 4.2 km respectively, indicating that similar assemblages sometimes occur between farms separated by 100s of m to several km (Fig. 4, bottom left). In contrast, pairwise dissimilarities were large between Aguilas Inshore and both Aguilas South and Aguilas North, located only 2 and 2.4 km away respectively (Fig. 4, top left). The farm at Aguilas Inshore was both close to the coast and in shallow water (Table 1), and species usually associated with benthic environments were prominent in counts

(Table 2). As such, the fish assemblage at Aguilas Inshore is unrepresentative of the offshore coastal waters experienced by the other farms and can be regarded as an outlier in this analysis.

Physical and biological factors intrinsic to each farm location may explain some of the variability in associated assemblages of wild fish. Temperature and salinity varied little during the present study and pelleted food fed to farmed fishes was similar at all locations. Water depth and farm age were poor descriptors of any of the wild fish assemblage parameters. In contrast, abundance, biomass and number of species were greater at farms close to shore (Fig. 8), which may be due to their relative proximity to rocky habitat and *Posidonia oceanica* meadows. However, Deudero et al. (1999) found that abundance and biomass of fish were greatest at FADs placed furthest from the coast at Majorca in the Western Mediterranean. Counts at farms with greater numbers of cages tended to have higher abundance, biomass and species diversity (Fig. 8). The number of cages at a farm is an approximate index for both the number of farmed fish present and the amount of unused feed, which may both increase the attractive effect. While the causes of these 2 patterns may be unclear, the patterns themselves may be useful management tools for predicting the extent of wild fish interaction with fish farms.

Short-term temporal variability of fish assemblages associated with fish farms

Both the ANOSIM and ANOVA indicated some differences among times in the fishes associated with farms. Such differences could be due to oceanographic influences or to interactions between species such as predation, which does occur around FADs (Deudero 2001). The occurrence of 2 large storms during the 2 mo study period may have modified conditions at farms between times sampled. Likewise, the presence of large predators, such as *Lichia amia* (0.9 and 1.2 m TL, Altea, no. = 2), *Pomatomus saltator* (1 m, Guardamar) and *Thunnus thynnus* (1.8 m, Aguilas North), may have influenced the abundance of certain fish, particularly juveniles, around fish farms at particular times.

While some differences among times occurred (Figs. 5 & 6), assemblages of fish at most farms were relatively stable (Fig. 2), suggesting that many of the species associated with farms are resident for periods of several weeks. Tagging of *Trachinotus ovatus* (43 fish, 28 to 38 cm TL) at Villajoiosa indicated that some individuals remained within the farm complex for a minimum of between 4 and 10 d (no. = 4 recaptures, unpubl. data). Likewise, Bjordal & Skar (1992) demonstrated that tagged wild saithe *Pollachius virens* were associated with a marine fish farm in Norway for periods of 1 to 7 mo. Residence of species that are seldom found near structure in the pelagic environment, such as *Sardinella aurita*, *Trachinotus ovatus* and *Boops boops*, provides further evidence for the case that such species are attracted to farms by factors other than the structure itself.

Implications for fisheries

Due to the strong aggregative effect of fish farms, possible residence of fishes for periods of weeks to months and the restrictions on fishing which apply within farm leasehold areas, we suggest that coastal sea-cage fish farms may act as small (up to 160 000 m^2) pelagic marine protected areas (MPAs). Controls in the present study were performed 200 m from farm cages and indicated that very few fish were present in waters immediately adjacent to fish farms. Moreover, groups of fish were not seen more than 50 m from cages at any farm. This result is analogous to the association of reef fishes with artificial reefs, where a steep decline in abundance is typically observed at distances of just a few m to 10s of m from the artificial structure (Bohnsack & Sutherland 1985, Sanchez-Jerez & Ramos-Espla 2000).

The extent of protection will vary with the behaviour of each particular species; fish that associate closely with the cage structures for long periods will receive greatest protection. Taxa such as *Sardinella aurita*, *Trachinotus ovatus*, *Trachurus* sp., *Oblada melanura*, *Boops boops* and Mugilidae, would be protected from fishing to some extent, although only a longer-term study could determine how long fish remain in the vicinity of fish farms. However, for some species such as *Coryphaena hippurus*, which range over distances of 100s of m around FADs (T. Dempster & M. Kingsford unpubl. data), farms may have the opposite effect of increasing catch rates in surrounding waters. While few *C. hippurus* were recorded during counts, many were taken by recreational anglers around the Altea and Villajoiosa farms.

Fish farms have the potential to increase production of local fisheries, through the combined effects of attraction of large numbers of wild adult fish and their subsequent protection from fishing. Attraction of fish from surrounding waters can be clearly demonstrated. For example, the farm at Altea had only operated for 6 mo before our study and the majority of associated fish were adult *Sardinella aurita* (30 cm), *Trachurus* sp. (30 to 34 cm) and *Trachinotus ovatus* (30 to 38 cm), all size classes which indicate that these fish are at least 1 yr old. Clearly, these fish associated with farms when already of considerable size.

Somatic production or growth of farm-associated fishes is probable due to the increased food around farms. On several occasions, *Sardinella aurita*, *Trachurus* sp., *Trachinotus ovatus*, *Oblada melanura*, *Diplodus puntazzo*, *Sarpa salpa*, *Boops boops* and Mugilidae were directly observed feeding upon food pellets lost through the cages. Consumption of faeces from farmed fish, a behaviour widely observed elsewhere (Robertson 1982), may also occur. Increased production of gametes, or reproductive production, is also likely given that most farm-associated fish are of adult size (Fig. 7). Somatic production may increase the condition of fish and hence promote reproduction and recruitment through raising the spawning stock biomass. Local fisheries may be enhanced through export of adult biomass (somatic) and increased larval supply (reproductive) to surrounding areas (Chiappone & Sullivan 2000). However, a possible effect is that increased production of only those fish species that associate with fish farms could lead to increased abundances of these species, thereby altering the community composition in surrounding waters. Furthermore, association of small juveniles with fish farms may be limited, as they are more likely to be preyed on by the abundant adults present.

Implications for studies of the environmental impacts of fish farms

Research into the environmental effects of marine fish farms is well established and has focused on benthic processes related to increased nutrients in the underlying sediment (Gowen & Bradbury 1987, Wu 1995, Karakassis et al. 1998), impact on seagrasses (Delgado et al. 1997, Katavic & Antolic 1999), and transfer of antibiotics into the marine environment (Kerry et al. 1996, Smith & Samuelsen 1996). Research into the effects upon fishes has received comparatively little attention, particularly in the Mediterranean (Munday et al. 1994). We suggest that ecological effects of fish farms on wild fish deserve greater attention, especially where fish are abundant and the potential for interaction is high. Negative ecological links between aquaculture and wild fish stocks have been widely documented (Naylor et al. 2000), and include transfer of antibiotics used in farm feeds to wild fish (Bjoerklund et al. 1991) and transmission of disease and parasites from caged fishes (Saunders 1991, Johnsen & Jensen 1994, Bjorn et al. 2001).

A common current approach in environmental impact studies of the effects of fish farms on the benthos is to calculate nutrient loading, based on estimates of food loss through the cages and faecal and excretory material from the farmed fishes (Gowen & Bradbury 1987). Estimates of food loss often used in environmental impact assessments of Mediterranean *Sparus aurata* and *Dicentrarchus labrax* farms are derived from the salmon sea cage industry in Northern Europe and North America and vary from 15 to 30% (Phillips et al. 1985, Gowen & Bradbury 1987). Wild fishes may have a modifying effect on the amount of fish food that reaches the sea floor by consuming food that falls through the cages (Gowen & Bradbury 1987), although no estimates of this have been made. Less fish food will reach the bottom and more faeces will be produced instead, changing the nature of farm effluent dispersal. Faecal material drifts further from the cages than food, which sinks rapidly (Gowen & Bradbury 1987). This may be particularly important for placement of fish farms in the Mediterranean, as *Posidonia oceanica* is susceptible to small increases in turbidity (Guidetti & Fabiano 2000). Reduction in *P. oceanica* meadows due to fish farms has been recorded in many areas (Delgado et al. 1997, Katavic & Antolic 1999). Where the biomass of wild fish is high, we suggest that their modifying influence on farm effluent dispersal must be considered.

Large-scale escapes of farmed fish and subsequent detrimental effects on wild fish stocks through mixing with escapees have been demonstrated, particularly for salmonids in Northern Europe (Gausen & Moen 1991, Crozier 2000). In our study, few *Sparus aurata* and *Dicentrarchus labrax* escapees were observed at 8 of the 9 locations (Table 2). However, *D. labrax* escapees (n = 2261) constituted a significant proportion of the assemblage at Aguilas Inshore for 2 of the 3 times sampled, indicating some degree of fidelity of escapees to the farm complex. In contrast, Carss (1990) captured few escapees around *Oncorhynchus mykiss* farms in 3 Scottish Lochs and concluded that while escapes must occur, escaped fish do not remain near farms for long. Small escapes (<1000 fish) are generally due to the loss of adult fish during harvesting, although mass escapes (10 000 to >100 000 fish) of whole cages are also possible during storms. We know of 1 such escape in the study area at a farm not included in the present study. In the Mediterranean, where wild *Sparus aurata* and *Dicentrarchus labrax* are subject to heavy fishing pressure, mass escapes have the potential to affect the genetic composition of natural stocks.

Future research into the effects of fish farms on wild fish species

Seasonal and annual variability in fish assemblages is an important component of variation that is not addressed by this study. Associative behaviour of fish may differ with ontogenetic stage (Hunter & Mitchell

1967) and the presence of certain species is often influenced by physical factors such as water temperature (Norton 1999); both of these influences will vary with season and affect the type and size of species that associate with fish farms. Only studies encompassing several locations and years can address questions concerning seasonal variability.

The approach used in this study (RVCs) enabled us to compare fish assemblages among farms and to infer changes in patterns of abundance over time. However, detailed information on wild fish use of fish farms requires an individual-based approach. Knowledge of residence times and movement of fish around farms is important in determining the extent and duration of protection from fishing. Furthermore, estimates of wild fish movements are needed to calculate their role in modifying farm effluent dispersal. Ultra-sonic tags with subsequent remote recapture generate information on movement, home range, residence times and feeding behaviour (Lowry & Suthers 1998), and seem particularly applicable to questions regarding fish behaviour in coastal fish farm settings.

Sea-cage fish farms are rapidly increasing in number throughout coastal areas of the world. Given the magnitude of the attractive effect of fish farms and the great differences between locations over a scale of 100s of km, demonstrated in the present study, there is a clear need for baseline information on the fishes that associate in coastal regions where farms are common. In the Mediterranean Sea, over 100 000 t of *Sparus aurata* and *Dicentrarchus labrax* were produced in sea-cage fish farms in 1999 (FAO 1999). Five countries dominated production: Greece (56 512 t), Turkey (12 000 t), Italy (11 400 t), Spain (7244 t), and France (4258 t). In Greece, there are over 250 coastal fish farms in operation (Theodorou 1999) and Spain has approximately 100 (Sanchez-Mata & Mora 2000). Norway produces over 600 000 t of Atlantic salmon each year (www.feap.org/press_releases.html), much of it in coastal fish farms, yet estimates of wild fish populations associated with farms are lacking. It is in these countries where the potential for interaction of wild fish with fish farms is high and further research is imperative.

Acknowledgements. We are grateful to the following fish farm companies who gave us access and provided boat time for the study: Cudomar, Culmarex, Blue and Green, Martorres, Gramamed and Viveros Marinos Alba-Hermanos Lopez. We thank C. Barbera-Cebrian for assistance during sampling. The manuscript was improved by comments from M. Kingsford (James Cook University), M. Holloway and K. Pitt (University of Sydney) and several anonymous reviewers. The study was funded by the Unidad de Biologia Marina at the University of Alicante. Travel to Spain for TD was funded by a James Kently Memorial Scholarship from the University of Sydney.

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Editorial responsibility: Otto Kinne (Editor), Oldendorf/Luhe, Germany

Submitted: February 4, 2002; Accepted: May 7, 2002
Proofs received from author(s): September 12, 2002