

Seasonal patterns and diets of wild fish assemblages associated with Mediterranean coastal fish farms

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Fish are attracted to floating structures, including coastal cage fish farms, sometimes in dense aggregations. To understand better the influence of aquaculture on wild fish stocks, we carried out seasonal visual censuses around three southwestern Mediterranean farms over 2 years to assess the temporal patterns of the aggregated fish assemblage. In addition, we analysed the diet of the five most abundant species. Aggregations around all farms were large throughout the year, although species composition and abundance differed among farms and seasons. Fish farms are attractive habitats for certain species of wild fish in specific seasons. Adult fish of reproductive size dominated the assemblages, and stomach content analysis revealed that 66–89% of fish of the five most abundant taxa had consumed food pellets lost from the cages. We estimated that wild fish consume up to 10% of the pellets used at farms, indicating that food is a key attractant. Regional monitoring of farm-associated wild fish assemblages could aid management of the interaction of aquaculture and wild fish resources, because changes in feeding behaviour may have consequences for fish populations and local fisheries.

Keywords: aquaculture impact, Mediterranean, spatial variability, temporal variability, wild fish.

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Introduction

Many fish species, from larvae to adults, are attracted to moored and drifting floating objects (Parin and Fedoryako, 1999). Many natural objects cause this behaviour, including logs (Greenblatt, 1979), jellyfish (Manseuti, 1963; Brodeur, 1998), drift algae (Ida *et al.*, 1967; Safran and Omori, 1990; Kingsford, 1992, 1995), and artificial structures both moored or drifting, including rubbish (Riera *et al.*, 1999), rafts (Heyerdahl, 1950), man-made fish aggregation devices (FADs; Higashi, 1994), oil platforms (Franks, 2000), and coastal sea-cage fish farms (Dempster *et al.*, 2002; Boyra *et al.*, 2004).

Commercially important fish species are attracted to fish farms worldwide, e.g. in the Mediterranean Sea (Dempster *et al.*, 2002, 2005), around the Canary Islands (Boyra *et al.*, 2004), off Scotland (Carss, 1990) and Norway (Bjordal and Skar, 1992), and around Australia (Dempster *et al.*, 2004) and Indonesia (I. H. Sudirman *et al.*, unpublished data). Such concentration of target species (e.g. carangids, mugilids, and sparids) around fish farms may affect local fisheries in several ways (Fernandez-Jover *et al.*, 2007a), but the effects on stocks over a time-scale of years are poorly understood.

Marine finfish culture, principally through the use of sea cages, currently produces some 2.5 million tonnes of fish annually and is widely expected to continue to grow rapidly in coastal regions throughout the world. In the Mediterranean, the production of the two main cultivated species, sea bass and sea bream, has reached $>180\,000\text{ t year}^{-1}$ (FAO, 2006; Federation of European

Aquaculture Producers, www.feap.info/feap). Because of the continuing growth of this industry (FAO, 2007), it is necessary to seek better understanding of the ecological effects of farming on wild fish populations.

As the SW Mediterranean Sea is oligotrophic and fish populations are overexploited (FAO, 2007), any expansion of this industry will require research into how aquaculture and natural living resources interact. Therefore, we investigated the temporal persistence of wild fish around coastal aquaculture. Specifically, we addressed the questions: (i) does the assemblage structure persist over time (seasonally and interannually) and space (e.g. similarity among fish farms); and (ii) to what extent is the trophic behaviour of the aggregating species influenced?

Methods

We looked at the wild fish assemblages associated with three fish farms on the Spanish coast of the southwestern Mediterranean Sea (Figure 1). All three farms cultured gilthead sea bream (*Sparus aurata*) and European sea bass (*Dicentrarchus labrax*). The farm at Campello was 3 km from the coast at an average depth of 28.6 m, and had 14 cages of diameter 15.5 m and depth 17 m producing 300 t of fish per year. The farm at Guardamar was 3.7 km from the shore at a depth of 22.6 m, and had 24 cages of diameter 19 m and depth 15 m producing 1200 t year⁻¹. The farm at Altea was 2.8 km from shore at an average depth of 34 m, and had 12 cages of diameter 25 m and depth 16 m producing 500 t year⁻¹. Water temperature was

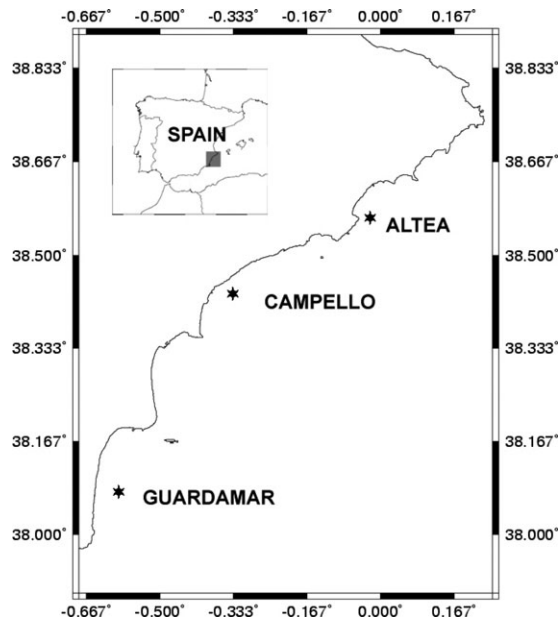


Figure 1. Map of the location of the three fish farms studied.

measured 15 m deep each day that a farm census was carried out. The maximum temperature, 27°C, was reached in summer 2005, and the minimum, 12°C, in winter of the same year.

Visual census

To estimate the biomass of the different fish species aggregating around the cages, to reduce count bias (Ribeiro *et al.*, 2005), trained divers conducted rapid visual counts (RVCs; Kingsford and Battershill, 1998) using scuba, following the method of Dempster *et al.* (2002). At each farm, fish were counted on three randomly chosen days over a period of 2 months every season for 2 years from winter 2004 to autumn 2005 (January and February for winter, April and May for spring, August and September for summer, and October and November for autumn). Six 5-min RVCs were conducted on each occasion within the farm complex. All counts were made between 09:00 and 11:00, and each count covered a volume of $\sim 11\,250\text{ m}^3$ (15-m wide \times 15-m deep \times 50-m long), after which fish abundance was standardized to $10\,000\text{ m}^3$.

To estimate visibility, we took horizontal Secchi disc readings on each sampling day. One diver held the Secchi disc whereas the other swam away with a tape measure to determine the Secchi distance. Only days with a visibility $> 15\text{ m}$ were sampled. During counts, a ruler was used to estimate the average total length (TL) of each group of fish. Count data were entered into the ecoCEN program (Bayle-Sempere *et al.*, 2002), conversions to biomass being carried out using published length-weight relationships from the area of the study (Valle *et al.*, 2002) and FishBase (<http://www.fishbase.org>). Visual counts can have limitations, invariably underestimating fish numbers (Sale and Sharp, 1983) and underestimating or overestimating 'diver-negative' and 'diver-positive' fish species, respectively (Thresher and Gunn, 1986). However, such potential biases should have been consistent between farms and times.

Size structure and stomach content analysis

To correct visually estimated sizes and to carry out stomach content analysis, the most abundant taxa (*Boops boops*, mugilids, *Trachinotus ovatus*, *Trachurus mediterraneus*, and *Sardinella aurita*) were caught by spear from February 2004 to November 2005. All fish were iced after landing and analysed within 5 h. Individuals were measured (TL) and weighed after removing the stomach contents. The stomach contents were analysed to determine the proportion of fish that had consumed food pellets, and the weight of pellets ingested.

Statistical treatment

We tested whether assemblages of fish associated with farms would differ among times of the year and farms. The experimental design incorporated four factors: season (Spring, Summer, Autumn, and Winter), year (2004 and 2005), farm (Guardamar, Campello, and Altea), and day (three different days per season). Six censuses were carried out each sampling day. Season and Year were considered as fixed and orthogonal factors, and Farm and Day as random effects, the latter nested in Season, Year, and Farm. Before ANOVA, heterogeneity of variance was tested with Cochran's C-test and data were subsequently $\log(x + 1)$ transformed (Underwood, 1997). *Post hoc* Student–Newman–Kuel's (SNK) tests were used if significant differences were found.

Non-parametric multivariate techniques were used to compare the species composition of the assemblages. All multivariate analyses were performed using the PRIMER statistical package. Triangular similarity matrices were calculated using the Bray–Curtis similarity coefficient (Clarke and Warwick, 1994). Non-metric multidimensional scaling (nMDS) was used as the ordination method. A permutation test (PERMANOVA) was used to assess the significance of the overall species composition among the considered sources of variation (Anderson, 2004).

Results

Structure of associated wild fish assemblage

In all, 33 fish taxa belonging to 17 families were observed in close association with the cages; the most abundant (10 of 33) were present at all three localities (Table 1). In the first year, 24 species were found, and in the second year, 29. The most abundant families were the Clupeidae, Sparidae, Mugilidae, and Carangidae. The number of species seen per season and farm varied between 7 and 16 (Figure 2), with lowest values in winter. Of the 33 species seen, 23 were commercial target species.

Large aggregations of fish persisted around the installations throughout the 2-year period of sampling, with biomasses ranging from 13 to $14\,450\text{ kg per }10\,000\text{ m}^3$ (Figure 3), but with significant spatial differences related to the sampled year (Year \times Farm interaction, $p < 0.05$; Table 2). Seasonal changes were different for each year (Season \times Year interaction, $p < 0.01$; Table 2). Differences between the 2 years were particularly evident at the Guardamar farm, with a greater aggregation biomass during the second year. At the Altea farm, the aggregation peaked in autumn 2005, principally through the presence of large schools of *S. aurita*. In contrast, the fish biomass at Campello did not fluctuate as greatly as at the other two localities (Figure 3).

PERMANOVA indicated that differences in biomasses between farms were significant ($p < 0.01$), and that significant differences also existed among seasons within years ($p < 0.01$). The MDS analysis showed that the winter assemblage structures of the

Table 1. Species biomass (kg 10 000 m⁻³) ± s.e. for the average of the 2 years of sampling at the three fish farms.

Taxon	Guardamar	Campello	Altea
Atherinidae			
<i>Atherina hepsetus</i> *	0.01 ± 0.01	-	-
Balistidae			
<i>Balistes capriscus</i>	0.01 ± 0.01	0.05 ± 0.02	0.01 ± 0.01
Carangidae			
<i>Lichia amia</i> *	-	-	0.04 ± 0.04
<i>Naucrates ductor</i>	-	0.01 ± 0.01	-
<i>Seriola dumerili</i> *	0.06 ± 0.06	0.04 ± 0.02	0.17 ± 0.07
<i>Trachinotus ovatus</i> *	41.23 ± 9.18	0.02 ± 0.02	70.3 ± 11.34
<i>Trachurus mediterraneus</i> *	8.68 ± 2.58	29.08 ± 4.81	4.7 ± 0.84
Centracanthidae			
<i>Spicara maena</i>	-	-	0.02 ± 0.02
<i>Spicara smaris</i>	0.18 ± 0.15	-	-
Coryphaenidae			
<i>Coryphaena hippurus</i> *	-	-	0.03 ± 0.03
Clupeidae			
<i>Sardinella aurita</i> *	3.87 ± 0.9	1.91 ± 1.14	1954.36 ± 1458.95
Dasyatidae			
<i>Dasyatis pastinaca</i> *	-	0.23 ± 0.19	-
Engraulidae			
<i>Engraulis encrasicolus</i> *	-	-	0.01 ± 0.01
Labridae			
<i>Labrus viridis</i>	-	0.01 ± 0.01	-
Moronidae			
<i>Dicentrarchus labrax</i> *	-	-	0.02 ± 0.01
Mugilidae			
<i>Mugilidae</i> *	116.03 ± 20.47	0.01 ± 0.01	15.27 ± 2.44
Myliobatidae			
<i>Myliobatis aquila</i> *	0.21 ± 0.14	-	0.07 ± 0.04
Pomatomidae			
<i>Pomatomus saltatrix</i> *	9.16 ± 5.22	0.01 ± 0.01	7.09 ± 1.81
Scombridae			
<i>Auxis rochei</i> *	-	0.05 ± 0.03	-
<i>Sarda sarda</i> *	-	-	0.02 ± 0.02
<i>Thunnus thynnus</i> *	-	7.72 ± 5.44	-
Serranidae			
<i>Serranus cabrilla</i>	-	0.01 ± 0.01	0.01 ± 0.01
Sparidae			

Continued

Table 1. Continued

Taxon	Guardamar	Campello	Altea
<i>Boops boops</i>	0.25 ± 0.09	34.52 ± 7.37	9.42 ± 1.51
<i>Diplodus cervinus</i> *	0.01 ± 0.01	0.01 ± 0.01	-
<i>Diplodus puntazzo</i> *	-	0.01 ± 0.01	-
<i>Diplodus sargus</i> *	0.23 ± 0.21	0.05 ± 0.02	0.01 ± 0.01
<i>Diplodus vulgaris</i> *	-	5.52 ± 1.87	-
<i>Oblada melanura</i>	0.02 ± 0.01	4.04 ± 1.1	0.05 ± 0.02
<i>Pagellus erythrinus</i> *	0.01 ± 0.01	0.01 ± 0.01	-
<i>Sarpa salpa</i>	0.07 ± 0.07	-	-
<i>Sparus aurata</i> *	-	-	0.01 ± 0.01
<i>Spondylisoma cantharus</i>	-	0.25 ± 0.14	-
Sphyraenidae			
<i>Sphyraena sphyraena</i> *	0.02 ± 0.01	3.87 ± 2.04	-

*Species of commercial interest.

different farms were more similar between them than the other seasons (Figure 4; the straight line separates winter assemblages from most others). In contrast, similarities between the other seasons within farms were mainly attributable to the locality factor (i.e. spatial variability), because they tended to cluster together in the MDS representation.

Spatial and temporal variation of the main aggregated species

There were substantial differences in the assemblage structure among farms; several species showed affinity to a single farm. *Boops boops* was very abundant at the Campello farm during winter and spring, but with differences in the magnitude of the aggregation (Figure 3). *Oblada melanura* also aggregated mainly around the Campello farm (with a peak biomass of

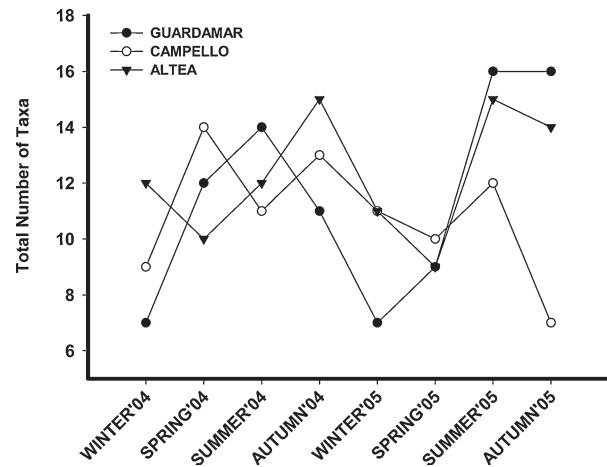


Figure 2. Total number of taxa that appeared at each farm by season, 2004 and 2005.

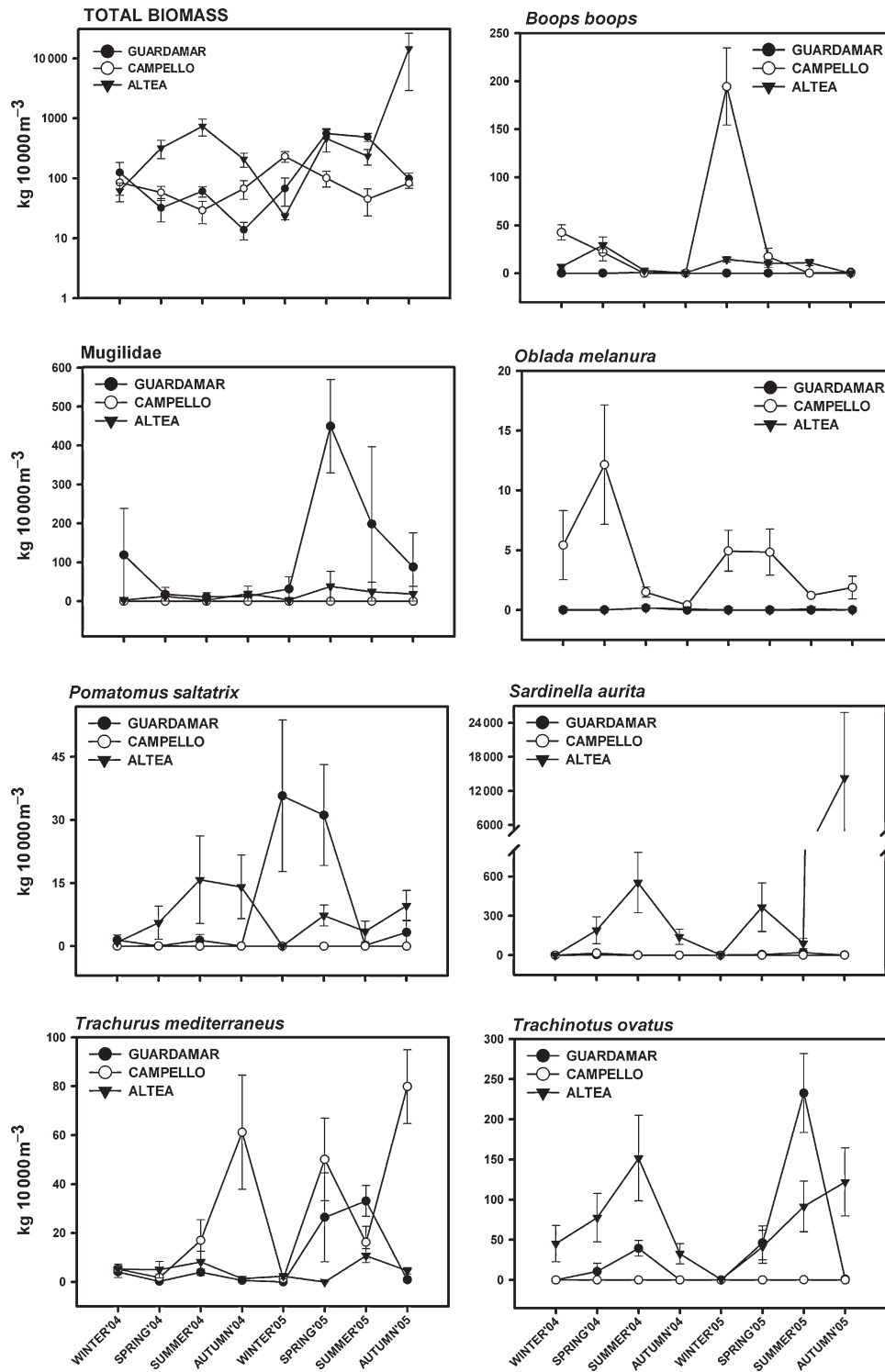


Figure 3. Total biomass and biomass for the main species at the three different farms (mean ± s.e. per 10 000 m³). The total biomass of the aggregation is shown on a logarithmic scale.

12.1 ± 4.9 kg per 10 000 m³ in spring 2004). *Trachurus mediterraneus* was also very abundant at Campello, but biomass varied greatly with season, with highest levels during the warmer seasons. The species was also present at Guardamar, especially during spring and summer 2005 (Figure 3).

Mugilids were a key component of the assemblage associated with Guardamar, especially in spring and summer, but were not common at the other farms (Figure 3). There were interannual differences; biomass peaked at nearly 500 kg per 10 000 m³ in spring 2005. At the Altea farm, *S. aurita* dominated (Figure 3),

Table 2. Analysis of variance (ANOVA) of total biomass, and biomass of the most abundant species.

Parameter	Degrees of freedom	Value of ANOVA F-statistic			
		Biomass	<i>Boops boops</i>	Mugilidae	<i>Oblada melanura</i>
Se	3	0.1	1.5	1.7	0.8
Ye	1	2.7	1.9	1.5	2
Fa	2	6.4**	16.2	232.7***	40.5***
D(Se × Ye × Fa)	48	2.6	6.9***	1.5*	4.1***
Se × Ye	3	0.3**	0.5	1.6	2.4
Se × Fa	6	3.5	10.8	2.1*	1
Ye × Fa	2	3.3*	3.5*	11.8***	4.5
Se × Ye × Fa	6	1.3	2.9*	1.4	0.3*
Residual	360				

		<i>Sardinella aurita</i>	<i>Trachinotus ovatus</i>	<i>T. mediterraneus</i>	<i>Pomatomus saltatrix</i>
Se	3	1.2	3.1	4.7*	0.4
Ye	1	0.2	0.9	0.02	1.5
Fa	2	33.0***	68.4***	3.3*	37.8***
D(Se × Ye × Fa)	48	3.1***	3.5***	2.7***	1.2
Se × Ye	3	1.8	2.7	1	2.3
Se × Fa	6	3.1*	4.4**	1.72	1.1
Ye × Fa	2	0.7	6.9**	12.3***	5.5*
Se × Ye × Fa	6	3.4**	5.4***	5.7***	0.8
Residual	360				

Se, season; Ye, year; Fa, farm; D, day. All data were log (x + 1) transformed. D(Se × Ye × Fa) means that Day is nested in Season, Year, and Farm.

*Significant at p < 0.05.

**Significant at p < 0.01.

***Significant at p < 0.001.

with very high biomasses in summer 2004 and spring and autumn 2005.

Pomatomus saltatrix and *T. ovatus* were abundant at both Guardamar and Altea farms (Figure 3). The former species

peaked at Guardamar during winter and spring 2005 (35.7 ± 17.8 and 31.1 ± 12.1 kg per 10 000 m³, respectively), but was rare at the Campello farm. The latter aggregated at high levels in summer 2004 at Altea (151.2 ± 53.2 kg per 10 000 m³) and in summer 2005 at Guardamar (232.5 ± 49.2 kg per 10 000 m³). Finally, the highest levels of *T. mediterraneus* were at Campello in autumn 2005, some 79.8 ± 15.1 kg per 10 000 m³ (Figure 3).

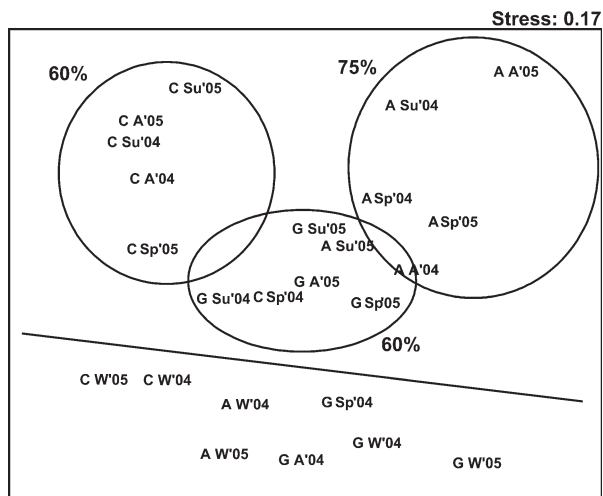


Figure 4. nMDS of wild fish aggregations around the three fish farms. Plots show relative similarities among aggregations pooled within year, season, and farm. The first letter of every point indicates the locality (A, Altea; C, Campello; G, Guardamar) and that is followed by the season and year (W, winter; Sp, Spring; Su, summer; A, autumn of 2004 and 2005). Circles with percentages (Bray–Curtis similarities) enclose major groups with similarities greater than the given percentage. A straight line separates winter assemblages from most others at a similarity level of 45%.

Stomach content analysis

The most abundant taxa of fish aggregating around the cages, *B. boops*, mugilids, *T. ovatus*, *T. mediterraneus*, and *S. aurita*, had all consumed substantial amounts of the pellets fed to the farmed stock (Table 3). *Trachurus mediterraneus* was the species with the lowest proportion of presence of food pellets in the stomachs; 66% of captured individuals. The highest proportion was detected for *B. boops*: 89% of individuals had pellets in their gut contents. Mugilids were the taxa that consumed pellets in greatest quantity. The average wet weight in the stomachs for this group was 8.99 g, nearly 1.4% of the average weight of the individuals fished for gut contents analysis; cf. 0.35% for *T. mediterraneus* and 0.33% for *B. boops*.

Discussion

Wild fish aggregation characteristics and variability

We detected large and temporally persistent aggregations of wild fish around sea cages during our study, indicating that fish farms provide highly attractive habitat for wild fish in the Mediterranean Sea throughout the year, though with considerable seasonal variation in the composition of assemblages. We found 33 different species of fish associated with the three farms studied,

Table 3. Stomach content analysis of the most abundant species.

Taxon	n	% pellets	TL (cm)	Total weight of fish (g)	Weight pellets (g)	Pellets/body weight (%)
<i>Boops boops</i>	59	90	31.45 (0.43)	374.71 (11.3)	1.24 (0.15)	0.33
Mugilidae	64	78	52.44 (0.94)	1 714.9 (76.96)	8.99 (1.97)	1.40
<i>Sardinella aurita</i>	10	80	26.04 (0.58)	181.5 (20.06)	0.45 (0.20)	0.24
<i>Trachurus mediterraneus</i>	69	67	32.32 (1.03)	375.74 (20.41)	1.37 (0.28)	0.35
<i>Trachinotus ovatus</i>	46	80	31.78 (0.55)	308.6 (13.62)	2.68 (0.29)	0.86

Values in parenthesis are standard errors. *n*, number of individuals analysed; % pellets, percentage of individuals with food pellets in the stomach; weight pellets, average wet weight (g) of pellets present in the stomachs; pellets/body weight, relationship between the weight of pellets in the stomach and the total weight of the fish (g).

belonging mainly to the Clupeidae, Sparidae, Mugilidae, and Carangidae. Combining this total number with similar observations from Dempster *et al.* (2002, 2005) during one season (autumn) yields a total of 39 pelagic species associated with sea cages in the southwestern Mediterranean Sea. Many of the aggregating species are targeted by local fisheries, so fish farms may affect the distribution of these exploited populations on a regional scale.

Variation in the species composition of assemblages and the dominant species of the aggregations was high among farms. Except for *B. boops*, there were always significant differences in the biomass of aggregated species, showing that assemblages differed among farms separated by tens of kilometres owing to the dominance of different species at the three farms. This suggests that fish assemblages around farms change depending on environmental conditions, such as coastal morphology, distance to the coast, currents, and depth, farm characteristics, such as the quantity of feed being lost, and the composition of the fish fauna in surrounding waters. From the visual census results, it was clear that assemblages varied with season, though this was not detected by the statistical analysis (ANOVA), except *T. mediterraneus*. Mugilids and *B. boops* were dominant in winter, and *T. mediterraneus* and *S. aurita* in summer and autumn. These results are similar to those of Valle *et al.* (2007) at a single farm during 1 year and confirm a high level of consistency in assemblage in terms of species composition between years. At subtropical latitudes, seasonal changes in fish assemblages may be less pronounced, as found by Boyra *et al.* (2004) in the Canary Islands. Substantial seasonal changes in fish assemblages are more common in temperate marine environments (Letourneur *et al.*, 2001) than in ecosystems with more stable environmental conditions. Despite the maximum water temperatures, the increased quantity of food pellets given to the cultivated species and therefore high food pellet availability for wild fish during summer did not correspond to the highest aggregated fish biomass. Therefore, in addition to the availability of food being a factor that attracts wild fish (Tuya *et al.*, 2006), other factors must be involved in determining the composition and size of assemblages around fish farms. Such factors could include reproductive behaviour or seasonal migrations of wild fish between offshore and coastal areas.

FADs introduce spatial habitat complexity into areas where it is largely absent, perhaps making such areas attractive to certain fish species and increasing fish abundance and biomass there. Fish farms likely have enhanced attractive properties compared with standard FADs because of the continuous input of artificial food. An average fish farm producing 1100 t year⁻¹ of sea bream uses ~2000 t of pellets. Although the level of pellet loss from cages is poorly known for the culture of sea bream and sea bass, estimates of 5–20% have

been made for Atlantic salmon culture (Gowen and Bradbury, 1987), which is a large (100–400 t) and concentrated trophic resource for many species. Therefore, it is predictable that the main aggregated species use food pellets heavily as a trophic resource because of their high protein and fat composition. The carnivorous Mediterranean horse mackerel, *T. mediterraneus*, consume mainly juvenile fish and crustaceans in the wild, but depend almost entirely on food pellets when they aggregate around fish farms (Fernandez-Jover *et al.*, 2007a).

It is not only fish that are feeding directly on lost food pellets that aggregate around farms. Predators such as *Sphyræna sphyræna*, *Coryphaena hippurus*, *Thunnus thynnus*, and *P. saltatrix* were observed frequently around the cages. *Pomatomus saltatrix* preyed extensively on the aggregating wild *S. aurita* (PS-J *et al.*, unpublished data). Clearly, greater aggregations of potential prey increase predation success (Connell, 2000). Therefore, predators such as those listed above, and others, may feed more efficiently around fish farms than in natural pelagic environments.

The feeding behaviour of aggregating fish can have important ecological consequences. The feeding of wild fish around fish farms diminishes the total waste produced by the cages by 40–80% (Vita *et al.*, 2004; Felsing *et al.*, 2005). Using the stomach content data (the weight of pellets consumed and the percentage of stomachs containing pellets) along with the population estimates from visual counts, we estimate that the five most abundant aggregating wild fish species consumed 2.4 t of pellets at Campello, 70.0 t at Guardamar, and 102.6 t at Altea in a single year of production, i.e. 0.3, 7, and 10.3% of the food used at these three farms, respectively. In addition to the reduction of benthic impact through consumption of pellets, Fernandez-Jover *et al.* (2007b) found that scavenging wild fish reduced organic input to sediments by increasing faecal pellet settlement time and hence increasing the leaching of nutrients into the water column. Moreover, mugilids, which comprise an important proportion of the assemblage described here, decrease the anoxic conditions of sediments beneath farms by bioturbation when feeding (Katz *et al.*, 2002).

Although consumption of lost pellets by wild fish may reduce benthic impacts, there may be other ecological consequences. Fernandez-Jover *et al.* (2007a) detected that the ratio of $\omega 3/\omega 6$ fatty acids was eightfold lower in farm-associated wild Mediterranean horse mackerel than in fish sampled away from the farms, showing that an important physiological change follows the dietary shift. Coupled with this was an increase in tissue fat content and condition, which typically correspond to enhanced spawning capabilities (Izquierdo *et al.*, 2001), although low $\omega 3$ fatty acid levels may negatively affect egg quality and survival of larvae (Fernández-Palacios *et al.*, 1997). Our results suggest that all the abundant planktivorous fish aggregating at

fish farms consumed sufficient lost pellets to be affected in a manner similar to *T. mediterraneus*.

Of the species associating with fish farms over the 2 years of our study, 23 are of commercial interest in the Mediterranean Sea. A significant increase in fisheries landings in an area with intensive fish farming in Greece was detected by Machias *et al.* (2006), opening the possibility for fish farms to be managed to increase wild fish captures on a regional scale. In contrast, Dempster *et al.* (2006) suggest that wild fish aggregating around farms need to be protected from exploitation because most of them are adults of spawning size (Dempster *et al.*, 2002), and wild fish provide a useful “ecosystem service” to farmers through diminishing the impact of lost feed on the benthos. Regional fisheries could benefit if farm-associated wild fish are not fished when they aggregate and have enhanced vulnerability to capture, but can be fished once they have dispersed away from the farms. Our 2-year dataset of fish counts shows dispersal away from farms on a seasonal basis. Conversely, if fishers target the aggregations at the farms, they may function as “ecological traps”, continuously attracting fish from surrounding waters and diminishing their populations through fishing (for a review of ecological traps, see Battin, 2004). If such conditions exist, marine fish farms may inadvertently be a prime example of a large-scale ecological trap in a coastal ecosystem. Increased fishing pressure around the three farms studied here has been noticed by the farm managers, particularly through the escalating deployment of gillnets around farms with sufficient lengths to completely surround the leasehold area, capturing large quantities of fish when they move short distances away from the farm or seasonally migrate. Future research is required to determine the extent and frequency of fish migrations around farms, and the effectiveness of this type of fishing, so that managers can act to avoid farms behaving as ecological traps for wild fish stocks.

Implications for monitoring and management

Our results indicate that wild fish aggregate at fish farms persistently, throughout the year, and that their species composition differs significantly among farms because of the dominance of different species at farms in certain seasons. This indicates that the assemblage composition of a single farm cannot be extrapolated to other farms in the vicinity. Therefore, the regional effects of coastal aquaculture on wild fish should be researched by sampling several fish farms and estimating the type and magnitude of wild fish assemblages associated with them within specific regions. Temporal variability exists at several scales, so monitoring programmes should follow a hierarchical design, with temporal replication at several scales. Aggregating fish consume large quantities of lost food pellets, but pellet consumption is highly species-specific and will vary with assemblage composition from farm to farm. Monitoring of fish assemblages over a regional scale, involving seasonal sampling to detect the presence of ecological or economically important species, is necessary for management of the interactions of fisheries and aquaculture. Further, site planning should incorporate knowledge of the proximity of nursery zones, migratory routes or marine protected areas, because fish farming may stimulate the incursion of wild fish from these areas to the farms because of the greater food availability there. Finally, where wild fish assemblages are significant, they should be protected from fishing by broadening the no-fishing zone around farms, to exploit fully the ecosystem service generated when they

feed on the lost food pellets, and because of their increased vulnerability to fishing when they are concentrated around the cages.

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