

Spatial and temporal changes in the assemblage structure of fishes associated to fish aggregation devices in the Western Mediterranean

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Abstract – We investigated the patterns of occurrence of FAD-associated fish off the coast of Sardinia, Sicily and Majorca (Western Mediterranean). Two working hypotheses are presented to test whether or not “differences exist in fish assemblages at i) the spatial and ii) the temporal level”. Quantitative and qualitative experimental data were obtained from a total of 521 censuses at 17 fish aggregation devices (FAD) using underwater visual observations carried out in Sardinia and Sicily in May–October 2001 and 2002 and a purse seine data set on 3 FADs obtained from a previous investigation carried out in Majorca. The results from the multivariate analysis rejected both hypotheses. In all locations, patterns of fish assemblages were dominated by *Coryphaena hippurus*, *Naucrates ductor*, *Seriola dumerili*, *Balistes carolinensis* and *Trachurus* spp., a pattern evident from examining data at bi-monthly intervals. When the most dominant species highlighted with similarity percentage (SIMPER) analysis were analysed with an analysis of variance (ANOVA), a time effect was clearly apparent and subsequently confirmed for four of these five species (*B. carolinensis* being the exception); the location factor was also found to be relevant (except for the genus *Trachurus*). We concluded that differences noted were principally due to the “time shift” in the occurrence of these species in the three locations, leading to the assumption that a relationship did exist between the gradual but significant shift in seasonal temperature and colonization at the study locations. Defining selected community structure indices was also important because no reference points are actually available for the pelagic environment in the Mediterranean Sea.

Key words: Fish aggregation device (FAD) / Pelagic fish / Association / Distribution / Mediterranean Sea

Résumé – Modifications de la structure, dans l'espace et le temps, de l'assemblage des poissons associés à des dispositifs de concentration en Méditerranée occidentale. Nous étudions les schémas-types de l'occurrence de poissons associés aux dispositifs de concentration (DCP) au large de la Sardaigne, de la Sicile et de Majorque (Méditerranée occidentale). Deux hypothèses sont présentées pour vérifier si des différences existent dans les assemblages de poissons au niveau spatial (1) et temporel (2). Les données expérimentales quantitatives et qualitatives ont été obtenues d'après 521 observations visuelles en plongée, sur 17 DCP effectuées en Sardaigne et Sicile en mai–octobre 2001 et 2002, ainsi que des données de captures effectuées au moyen d'une senne, sur 3 DCP obtenues lors de précédentes investigations menées à Majorque. Sur chacun des sites, les assemblages sont dominés par *Coryphaena hippurus*, *Naucrates ductor*, *Seriola dumerili*, *Balistes carolinensis* et *Trachurus* spp., un schéma évident lorsque l'examen des données est effectué tous les deux mois. Lorsque les espèces dominantes, mises en évidence par le pourcentage de similarité (SIMPER), sont analysées au moyen d'une ANOVA, un effet-temps est clairement apparent et confirmé pour 4 ou 5 espèces (excepté *B. carolinensis*); le facteur-site est également pertinent (excepté pour le genre *Trachurus*). Ainsi, les différences notées sont principalement dues à un décalage dans le temps, dans l'occurrence de ces espèces sur ces 3 sites, conduisant à supposer qu'une relation existe bien entre l'évolution saisonnière, graduelle mais significative, de la température et la colonisation des sites. Définir des indices, sélectionnés, de la structure des communautés de poissons, est important car aucun point de référence n'est disponible pour l'environnement pélagique en Méditerranée.

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1 Introduction

Animate and inanimate objects floating in the sea provide refuge and aggregation for adults and juveniles of pelagic and benthic fish species. Numerous studies have explained this phenomenon as a consequence of several possible behavioural mechanisms including shelter from predators and food supply, as well as schooling and substrata for juveniles undergoing a change of life-style from pelagic to benthic (Gooding and Magnuson 1967; Hunter and Mitchell 1967, 1968).

Fréon and Dagorn (2000) have suggested 16 possible hypotheses to explain associative behaviour for tuna and tuna-like species. They formulated a theory of “meeting points” according to which “fish make use of floating devices to increase the frequency of encounters between isolated individuals and other schools in order to form larger groups and thereby improve the survival of the species”. Their cluster of sixteen hypotheses enables us to gain a better understanding of the processes that influence the attraction of pelagic species to floating objects. In addition to applying to species that are habitually exploited and which therefore require careful management of stocks, the theories also concern species of ecological importance that require protection, and which together form an integral part of the pelagic environment’s biodiversity.

Fish Attraction Devices (FADs) are useful in determining the species and life phases of fish that are difficult to sample using more conventional methods, as well as in improving knowledge of the ecology of less common species (Hunter and Mitchell 1967; Kingsford and Choat 1985; Kingsford 1992). Castro et al. (2002) reported over 333 fish species belonging to 96 families, at both adult or juvenile and larval stages, that habitually aggregated or associated to floating structures (algae, jellied zooplankton, whales, flotsam) or man-made FADs.

In addition to being useful to scientific studies, FADs have also become the basis for numerous small scale and professional pelagic fisheries in many parts of the inter-tropical zones of the Indian and Pacific Ocean and the eastern Atlantic (Hunter and Mitchell 1967; Pallarés et al. 1998; Fonteneau et al. 2000). In the Mediterranean coastal fisheries, the use of FADs is well documented, mainly in the Balearic Islands (Massuti and Morales-Nin 1991; Massuti and Reñones 1994; Deudero et al. 1999), Malta (Galea 1961) and Sicily (Mazzola et al. 1993; Potoschi and Sturiale 1996). These small-scale fisheries target the common dolphinfish (*Coryphaena hippurus*), which is captured mainly in late summer to early autumn.

Although the tendency of fish to aggregate beneath floating objects in the Mediterranean has been well documented, very little is known about the patterns of occurrence and residence of fish assemblages beneath FADs over a wider geographical scale. Such scant knowledge is due to the high time-spatial variability of species that are known for their high mobility, which causes difficulties in planning rigorous sampling designs (Kingsford 1999).

FAD studies have been generally confined to a restricted data set from single locations (Relini et al. 1994; Massuti and Reñones 1994; Potoschi and Sturiale 1996; D’Anna et al. 1999; Deudero et al. 1999; Riera et al. 1999) with data available primarily from commercial catches.

In a recent analysis of the knowledge generated by FAD research, Dempster and Taquet (2004) recognised the need to

look more closely at the spatial and temporal patterns of fish utilization of FADs. In the Atlantic and Pacific oceans, time and spatial variations in pelagic fish under FADs reflect physical changes in the environment, which in turn influence the fish fauna, in particular its lateral movement, reproduction and recruitment (Stephan and Lindquist 1989; Holland et al. 1990; Rountree 1990; Kingsford 1992; Bell and Hall 1994; Buckley and Miller 1994; Kingsford 1999).

In this study, we considered the role of FADs as observatories for the epi-pelagic ecosystem and as tools to assess and compare fish assemblages over wide spatial scales among three islands in the Western Mediterranean basin: Sardinia, Sicily and Majorca (Balearic Islands).

In Sardinia and Sicily, a total of 521 observations at 17 different FADs were collected over a two-year period using the visual observation technique. To better understand the seasonal occurrence of FAD-induced fish distributions on a wider geographical scale, we needed and sought additional information. We therefore analysed a data set of 70 net samples from 3 FADs collected in a previous investigation in waters off Majorca (Deudero et al. 1999). Thus, the objectives of this research are to compare and contrast the spatial and temporal variation of fish assemblages associated with FADs.

2 Materials and methods

2.1 Study sites and FAD construction

Data were collected at three locations in the Western Mediterranean (Fig. 1). In Sardinia, 8 FADs were deployed off the north of the Gulf of Oristano (central-western Sardinia) at the coordinates 40°04′/40°06′N-08°20′/08°16′E. These FADs consisted of three palm leaves (*Phoenix canariensis*) and were anchored to the bottom with a 30–40 kg tuff block on a 5 mm polypropylene line. The FADs were lined up in an East-West direction 400 m apart, with two buoys attached to each FAD. The first was placed on the surface to increase buoyancy and ease of location, while the second was positioned 5 m below the surface so the anchor line could be recovered if the shallow array were damaged by shipping or bad weather. The FAD arrays were deployed within 10 km of shore at depths of 70 to 110 m where the sea bottom consists of a wide, gently sloping continental shelf whose edge is located at around 18–22 km from the shoreline, in correspondence with the 180–200 m isobaths. The substratum is characterized by coarse sand and thin shingle and rubble, with some rocky outcrops lined up in a north-south direction that reach to depths of up to 50 m.

In Sicily, 9 FADs were deployed in the Gulf of Castellamare (North West of Sicily) at the coordinates 38°03′/38°05′N-12°58′/12°56′E. Here too, the FADs consisted of palm leaves and were anchored to the bottom with a 40 kg tuff block by means of a 5 mm polypropylene line. In an area where the seabed consists mainly of coarse sand and thin shingle, they were lined up in a North-South direction (within 7 km from the coast) at a depth range of 70–100 m and spaced 400 m apart.

In Majorca (off the island’s east coast), one group of 3 FADs was monitored at a location 7 km from the shoreline on

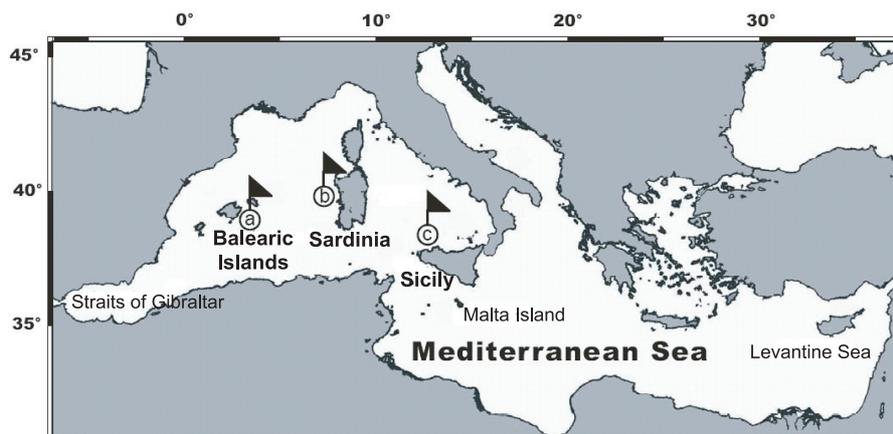


Fig. 1. Map of the Mediterranean Sea showing the three locations where fish aggregation devices (FADs) were deployed: a) Majorca; b) Sardinia; c) Sicily.

the 200 m isobath, in front of Portocolom harbour at the coordinates $39^{\circ}19'/39^{\circ}21'N-03^{\circ}18'/03^{\circ}24'E$. The FADs, consisting mainly of palm leaves and bush branches, were spaced at between 200–400 m. The chief characteristic of this chosen location is the presence of a narrow continental shelf and a steep slope, reaching to a depth of 1000 m at less than 20 km from the shoreline. The arrays used in Majorca were quite similar to the typical FADs used by local fishermen in the common dolphinfish commercial fishery (Massuti and Morales-Nin 1991).

2.2 Data collection

In Sardinia and Sicily, fish assemblages associated with FADs were studied by means of monthly and fortnightly direct visual observations (Wickham and Russel 1973; Drew et al. 1976; Harmelin et al. 1985; Harmelin-Vivien and Francour 1992; Dolloff et al. 1996; Nelson 2003) from May to October in 2001 and 2002. These techniques represent a widely adopted data collection method used in studies of FADs, particularly to estimate abundance and biomass of large mobile fishes (Dempster and Taquet 2004).

The visual observations were conducted by two experienced SCUBA divers during the day between 9–12 h a.m.

Each count was replicated by the two divers using 5 mins of counts as the best unit of sampling for pelagic fishes (Dempster 2005).

The census was carried out as though the FAD were in the center of a virtual cylinder (Fig. 2). The divers surveyed each FAD by gradually approaching the array and circling it at a depth of about 12 m from a distance of at least 10–15 m. The fish were subdivided as follows: “intranatant” (less than 0.5 m from the object), “extranantant” (between 0.5 and 2 m from the object) and “circumnatant” (further than 2 m from the object), according to Parin and Fedoryako’s definitions (1999). They were identified, counted and recorded on a special Plexiglas board. With this technique the degree of accuracy of visual observations of population estimates depends principally on water visibility, the behaviour and size of the fish associated with the objects and the experience of the diver (Relini et al. 1994; Harvey et al. 2004). During each sampling, hori-

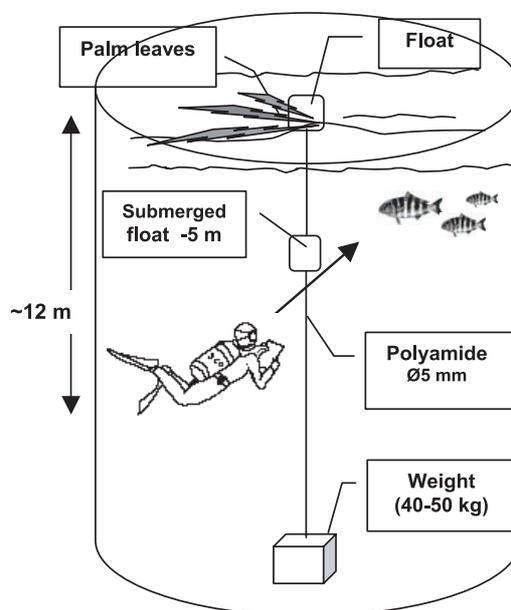


Fig. 2. Design of the fish aggregation devices (FADs) and the visual census technique adopted in Sardinia and Sicily.

zontal underwater visibility was measured with a Secchi disk and had to be high so as to ensure the correct identification of species and to count individual fish from a minimum distance of 2 meters.

To obtain a better estimation of the visual counts carried out in Sardinia and Sicily, video recordings were conducted in each FAD using a 3 CCD digital camera (Sony TRV 900) protected in an underwater casing (Gates, San Diego Ca). Video tapes were reviewed in slow motion or stop-frame modes to identify and count the fish on each sampling. Video-shots were analysed on a PC using video editing software (Fast Forward Video Inc.). This technique has previously been applied to benthic fish studies to improve the accuracy and precision of visual observations by the diver (Francour et al. 1999; Harvey et al. 2004).

Data from Majorca is from a survey carried out from May to October in 1995 and 1996 (Deudero et al. 1999), collected fortnightly by an experimental purse seine net 64 m in length, 14 m in height, and mesh size of 2 mm. Fishing operations were conducted during the daytime, between 7–12 a.m.

Hunter and Mitchell (1968) compared data from net captures, automated photography and direct visual observations and found that the visual observations agreed well with the other methods, and provided behavioural information not available with the other methods. For purposes of data analysis, we assumed that because the range of action of the diver at each FAD covered a 10 m radius at around 12 m in depth, these measurements corresponded to the experimental net (64 m in length equal to a range of 10 m and 14 m in height). Thus, the SCUBA diver and the experimental purse seine net would be collecting and monitoring fish in the same volume of water. However, it must be assumed there will be some bias in the estimate of abundance due to the difference in measurements using experimental net and visual census techniques, not so much with regard to estimating the abundance of intransients, but in particular for extranatants and circumnatants, species who inhabit a wider area and are thus more likely to escape from the net.

2.3 Data analysis

Eight FADs were censused over 30 different sampling dates in Sardinia for a total of 224 fish counts; nine FADs were censused on 34 sampling dates in Sicily for a total of 297 fish counts and three FADs were sampled on 25 sampling dates in Majorca to give a total of 70 net samples. All data were arranged in a species/location/date/ matrix to average out the abundance (number of individuals) of the replications (number of FADs visited each sampling day) in each location and to standardize for one FAD.

2.4 Community structure

The fish communities observed at each location were described using abundance (N), the Shannon-Weaver diversity index (H') (Shannon and Weaver 1949), and the Pielou evenness index (J') (Pielou 1966). The average (m), standard deviation (SD) and the frequency (f %) of the species were calculated for each location, with total species abundance (N) being indicated by the total number of specimens (visual or net)/species censused. Taxa richness (S), or the total number of distinct taxa is a method of measurement that reflects the health of the community through collecting and measuring the variety of taxa present.

2.5 Fish assemblages: statistical analyses

The two working hypotheses stated that 1) there were no differences in the fish assemblages among locations associated with floating objects sampled at the same time; and 2) no differences in fish assemblages existed between times at each location studied.

Our timescale analysis was based on recordings taken and grouped together at *monthly* and *bimonthly* intervals using T_5 , T_6 , T_7 , T_8 , T_9 , T_{10} , as the *monthly* time factor (T_5 = May, T_6 = June, T_n where n = month) and T_a , T_b , T_c , as a *bimonthly* time factor (T_a = May-June; T_b = July-August; T_c = September-October). The spatial scale considered for *location* is indicated as SA, SY and M (SA = Sardinia; SY = Sicily; M = Majorca).

Multivariate data of relative fish abundance were analysed with one-way ANOSIM (Clarke 1993) to test the null hypothesis 1 and 2 on the basis of different spatial and time scales. Comparisons were based on the calculation of Bray-Curtis similarity values (SBC) (Bray and Curtis 1957).

Differences among locations, as well as among time factors within each location, were represented by 2-dimensional plots with non-metric multidimensional scaling ordinations (nMDS) considering locations and time centroids (Clarke 1993; Clarke and Warwick 1994). Stress values are shown for each nMDS plot to indicate the goodness of fit between the distances among points implied by nMDS and the matrix data input.

These indicated that the smaller the stress, the better the representation (stress <0.15 is good; <0.10 is ideal) (Clarke 1993).

SIMPER analysis (cut off 90%) (Clarke 1993) enabled us to identify the “important taxa” that contributed to overall diversity in each location.

Univariate data of dominant taxa highlighted with SIMPER were then analysed with two-way ANOVA to verify spatial-temporal effects on fish abundance.

Prior to performing ANOVA, data were transformed to normalize distributions and equalize variances (Snedecor and Cochran 1967). The log transformation $Y = \log_{10}(X + 1)$ was employed. Prior to conducting these analyses, we tested for homogeneity of variance with Cochran's C test. Data were processed using PRIMER v5 (software package from Plymouth Marine Lab. UK) and Brodgar v2.4.5 (Highland Statistic Ltd. UK).

3 Results

3.1 Community structure

A total of 10006 specimens belonging to nine families were identified to the nearest taxon (Table 1), grouped into 14 species and one genus. In terms of absolute abundance, more than 96% of total composition was represented by the following seven species: *Trachurus* spp. with 4128 specimens (f = 41.26%) followed by the common dolphinfish, *Coryphaena hippurus*, with 2409 specimens (f = 24.08%), greater amberjack, *Seriola dumerili* with 1465 (f = 14.64%), pilot fish, *Naucrates ductor* with 718 (f = 7.18%), blue runner, *Caranx crysos* with 651 (f = 6.51%), and the European anchovy, *Engraulis encrasicolus* with 246 (f = 2.46%).

In Sardinia, 2537 fish were counted during underwater visual observations. More than 95% of these were *S. dumerili*, *C. hippurus*, *N. ductor*, *E. encrasicolus*, *Trachurus* spp., and *Sardina pilchardus* (Table 2). In Sicily, a total of 3758 specimens were counted. In terms of distribution of the abundances *C. hippurus*, *Trachurus* spp. *C. crysos*, *S. dumerili* and *N. ductor* represented more than 97% of the total sample

Table 1. List of the fish species associated with fish aggregation devices found in waters on continental shelf of Sardinia (SA), Sicily (SY) and Majorca (M).

Family	Species	May			June			July			August			Sept.			Oct.		
		SA	SY	M	SA	SY	M	SA	SY	M	SA	SY	M	SA	SY	M	SA	SY	M
Balistidae	<i>Balistes carolinensis</i> Gmelin 1788	•			•			•			•			•			•		
Carangidae	<i>Caranx crysos</i> (Mitchill, 1815)										•			•					•
	<i>Naucrates ductor</i> (Linnaeus, 1758)	•			•			•	•	•	•	•	•	•	•	•	•	•	•
	<i>Seriola dumerili</i> (Risso, 1810)				•			•	•	•	•	•	•	•	•	•	•	•	•
	<i>Seriola fasciata</i> (Block, 1793)													•					•
	<i>Trachurus</i> spp.	•	•	•	•	•	•	•	•	•			•	•		•			•
Centrolophidae	<i>Centrolophus niger</i> (Gmelin, 1788)				•						•								
	<i>Schedophilus ovalis</i> (Cuvier, 1833)				•			•			•								•
Clupeidae	<i>Sardina pilchardus</i> (Walbaum, 1792)							•			•								
Coryphaenidae	<i>Coryphaena hippurus</i> (Linnaeus, 1758)							•		•	•		•	•	•	•	•	•	•
Engraulidae	<i>Engraulis encrasicolus</i> (Linnaeus, 1758)							•		•	•		•	•	•	•	•	•	•
Scombridae	<i>Thunnus alalunga</i> (Bonnaterre, 1788)																		•
	<i>Thunnus thynnus</i> (Linnaeus, 1758)							•			•			•	•				•
Serranidae	<i>Polyprion americanus</i> (Bloch and Schneider, 1801)				•		•	•		•		•		•				•	•
Sparidae	<i>Boops boops</i> (Linnaeus, 1758)	•									•								

Table 2. Total abundance of the fish species associated with fish aggregation devices (FADs) by locations.

Species	SA				SY				M			
	N	f(%)	m	SD	N	f(%)	m	SD	N	f(%)	m	SD
<i>Boops boops</i>	37	1.45	2.45	6.47	-	-	-	-	-	-	-	-
<i>Balistes carolinensis</i>	40	1.57	2.65	3.47	32	0.86	0.98	1.79	10	0.27	0.40	1.2
<i>Caranx crysos</i>	-	-	-	-	651	17.33	19.73	42.01	-	-	-	-
<i>Coryphaena hippurus</i>	786	30.99	52.41	68.9	1454	38.69	44.06	82.15	169	4.55	6.76	19.2
<i>Centrolophus niger</i>	-	-	-	-	1	0.01	0.02	0.09	9	0.24	0.36	1.8
<i>Engraulis encrasicolus</i>	244	9.63	16.28	25.1	-	-	-	-	2	0.05	0.08	0.4
<i>Naucrates ductor</i>	258	10.17	17.21	19.7	293	7.80	8.88	12.59	167	4.50	6.68	23.3
<i>Polyprion americanus</i>	27	1.06	1.79	4.25	2	0.04	0.05	0.19	9	0.24	0.36	0.9
<i>Seriola dumerili</i>	921	36.29	61.38	72.1	486	12.94	14.74	18.45	58	1.56	2.32	6.5
<i>Seriola fasciata</i>	2	0.09	0.16	0.42	4	0.09	0.11	0.44	-	-	-	-
<i>Schedophilus ovalis</i>	-	-	-	-	-	-	-	-	13	0.35	0.52	1.7
<i>Sardina pilchardus</i>	98	3.86	6.53	17.9	-	-	-	-	-	-	-	-
<i>Thunnus alalunga</i>	-	-	-	-	-	-	-	-	8	0.22	0.32	1.6
<i>Thunnus thynnus</i>	-	-	-	-	63	1.68	1.91	3.64	1	0.03	0.04	0.2
<i>Trachurus trachurus</i>	-	-	-	-	-	-	-	-	33	0.89	1.32	4.2
<i>Trachurus</i> spp.	124	4.88	8.26	15.5	772	20.56	23.41	48.65	3232	87.09	129.28	342.3

observed (Table 2). Finally, in Majorca 3711 specimens were collected, of which 87% were represented by the genus *Trachurus*, followed by *C. hippurus* ($f = 4.55\%$) and *N. ductor* ($f = 4.50\%$) (Table 2).

Total species richness was $S = 13$, the Shannon-Weaver index was $H' = 1.57$ and Pielou's index $J' = 0.581$.

Majorca had the highest richness value ($S = 12$) and the lowest Shannon-Weaver index ($H' = 0.592$), while the Pielou was $J' = 0.24$. This value indicates the dominance of a few species, a typical case of a monotonous community with *Trachurus* spp. the most numerous of all. Sicily and Sardinia showed very similar values ($S = 10$; $H' = 1.58$; $J' = 0.69$ and $S = 10$; $H' = 1.64$; $J' = 0.71$ respectively). Indeed the Pielou index values in these two islands indicated a balanced distribution of specimens among species. In summer, (both in Sicily and Sardinia) seasonal distribution of Shannon-Weaver

and Pielou indices registered the highest values ($H' = 1.55$ and $J' = 0.74$; $H' = 1.97$ and $J' = 0.89$ respectively), while at the Majorca site highest values were in autumn ($H' = 0.95$ and $J' = 0.49$). The highest number of taxa ($S = 13$) was recorded in August, as shown by the monthly presence of fish (Table 1).

3.2 Fish assemblage

3.2.1 The "monthly" factor

The null hypothesis that *monthly* fish assemblages were similar within each location was rejected for T_5 ($R = 0.75$, $p < 0.001$), T_6 ($R = 0.61$, $p < 0.001$), T_7 ($R = 0.32$, $p < 0.001$), T_8 ($R = 0.53$, $p < 0.001$), and T_9 ($R = 0.67$, $p < 0.001$), while no significant difference was obtained for T_{10} ($R = 0.19$, $p > 0.05$). Nevertheless, once the location

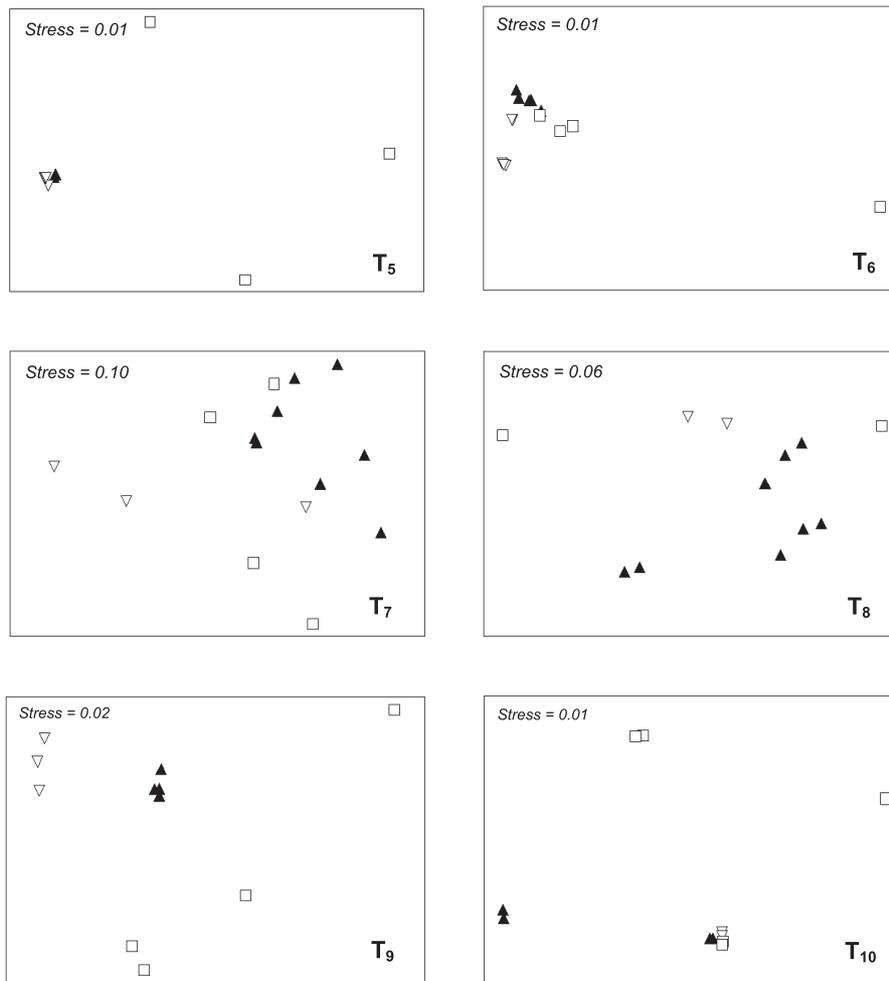


Fig. 3. Non-parametric multi dimensional scaling (nMDS) plots representing differences in fish assemblages among *locations* (SA = ▽; SI = ▲; M = □) examined on a *monthly* basis (T₅ = May; T₆ = June; T₇ = July; T₈ = August; T₉ = September; T₁₀ = October).

centroids were ordered by nMDS, representing differences in fish assemblages among locations, they are not distinctly separate from each other and much overlapping occurs among groups (Fig. 3). As observed for each month, we rejected the null hypothesis that no differences exist in fish assemblage within each location: Sardinia ($R = 0.62, p < 0.001$), Sicily ($R = 0.52, p < 0.001$), and Majorca ($R = 0.32, p < 0.001$), using the *monthly* factor scale. MDS representation for each location showed that centroids are not distinctly separate and there is much overlap (Fig. 4).

3.2.2 The “bimonthly” factor

We analyzed bimonthly grouped data in order to check whether a better fit occurred than for the monthly data. Results agreed better with the seasonal occurrence of FAD fish assemblages recorded during other investigations in the Mediterranean Sea (Deudero et al. 1999). We again rejected the null hypothesis that no differences exist in the fish assemblages associated with FADs among locations considered at *bimonthly* intervals. Results of the analysis of similarity global

tests, ANOSIM, within *bimonthly* groups, were highly significant for T_a ($R = 0.54, p < 0.001$), T_b ($R = 0.31, p < 0.001$), and T_c ($R = 0.30, p < 0.001$).

Average dissimilarity in community structure among locations within each time group showed higher values (high distance) in the pair-wise comparison between Sardinia and Majorca in all *bimonthly* groups: T_a, T_b and T_c (97.95, 92.13 and 77.79, respectively). The lowest value (low distance) was found in the comparison between Sardinia and Sicily in T_c (59.23). Note also that in the last *bimonthly* group, T_c, all dissimilarity values are lower than in the other groups, which indicated that in the autumn months we registered smaller differences between fish communities in the locations compared (Table 3).

The ordination of each *bimonthly* group of centroids by nMDS plots is quite separate from each other in the T_a and T_c groups (Fig. 5). Furthermore, the stress values were <0.09, so the plots adequately represented the segregation of centroids between locations. In T_b (summer months), centroids are characterized by an overlap in similarity and the stress value is high (0.15). The resulting plot can be explained by the mixed

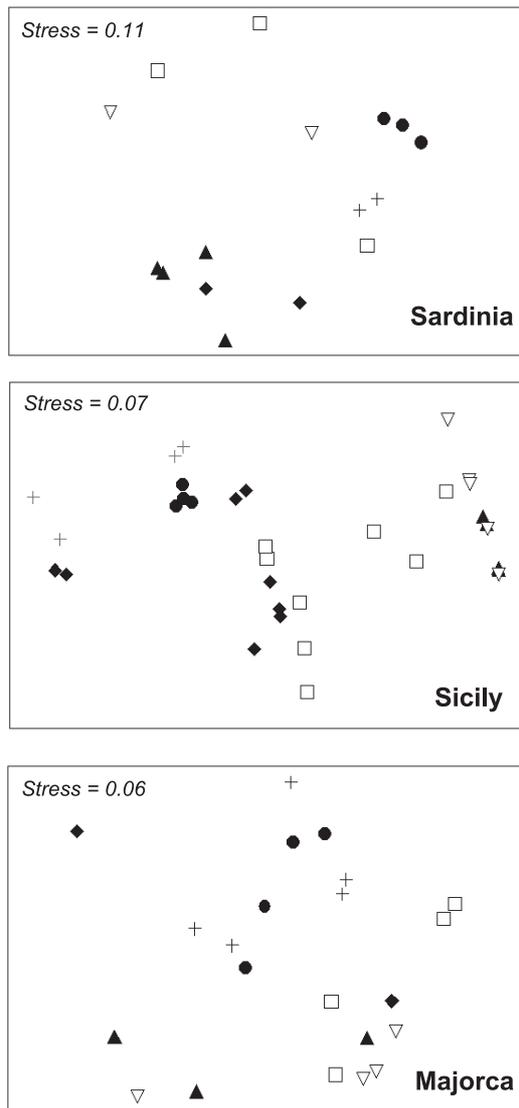


Fig. 4. Non-parametric multi dimensional scaling (nMDS) plots representing differences in *monthly* fish assemblages ($T_5 = \blacktriangle$; $T_6 = \nabla$; $T_7 = \square$; $T_8 = \blacklozenge$; $T_9 = \bullet$; $T_{10} = +$) at each *location*.

species distribution during the summer months, as identified in the SIMPER analyses.

The aim of the final analysis was to identify differences among *bimonthly* groups in each location so as to test the last hypothesis. Here too, the null hypothesis that *bimonthly* fish assemblages were similar within each location was rejected for Sardinia ($R = 0.379$, $p < 0.001$), Sicily ($R = 0.616$, $p < 0.001$), and Majorca ($R = 0.407$, $p < 0.001$). This was also confirmed by nMDS plots that showed separate centroids within each location (Fig. 6). The average dissimilarity between fish groups was always higher in the pair-wise comparison between T_a/T_c (May-June vs. September-October) (Table 3). The highest value was obtained in Sicily (100) followed by Majorca (99.90) and Sardinia (88.19).

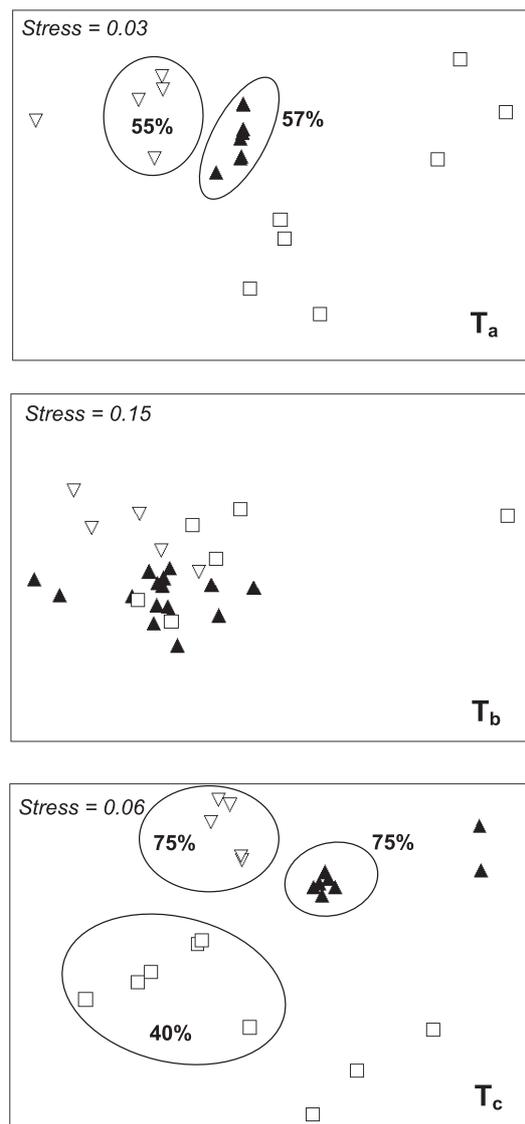


Fig. 5. Non-parametric multi dimensional scaling (nMDS) plots representing differences in fish assemblages between *locations* ($SA = \nabla$; $SI = \blacktriangle$; $M = \square$) examined on a *bimonthly* basis ($T_a =$ May-June; $T_b =$ July-August; $T_c =$ September-October). Similarities of groups (circles with percentages) within the nMDS plot were determined from a Bray–Curtis similarity dendrogram and were used to determine distinct assemblages. A similarity level of 0.30 was used to define the major *location* groups (note: in summer months (T_b) no assemblage groups were distinguished).

Table 3. Values of average dissimilarity ($1 - S_{BC}$) in fish associated with FADs among locations within *bimonthly* groups and among *bimonthly* groups within *locations*. Highest values were identified in the pairwise comparisons Sardinia vs. Majorca (SA/M) and summer vs. autumn months (T_a/T_c) (in italic).

	Among locations				Among bimonthly groups		
	SA/SY	SA/M	SY/M		T_a/T_b	T_a/T_c	T_b/T_c
T_a	79.83	97.95	90.83	SA	80.09	<i>88.19</i>	85.99
T_b	88.25	92.13	82.56	SY	88.25	<i>100</i>	83.59
T_c	59.23	77.79	77.71	M	85.68	<i>99.90</i>	97.77

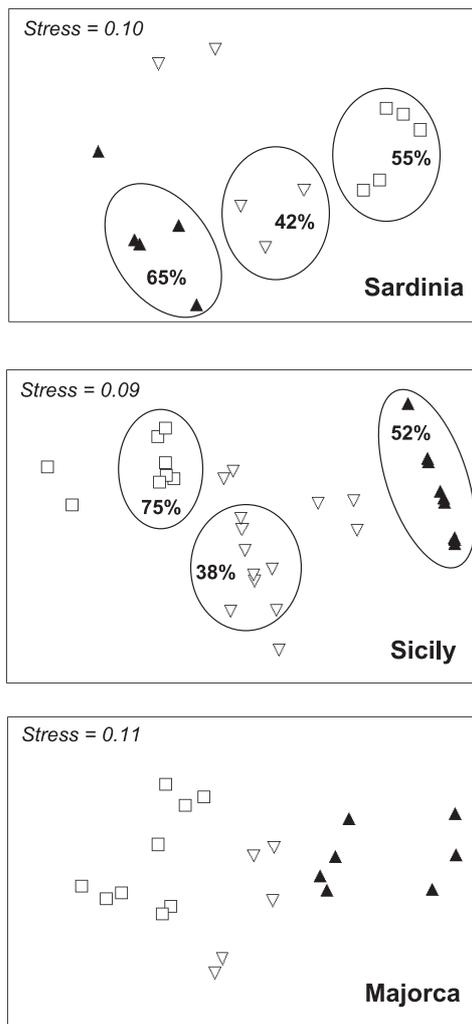


Fig. 6. Non-parametric multi dimensional scaling (nMDS) plots representing differences in *bimonthly* fish assemblages ($T_a = \blacktriangle$; $T_b = \nabla$; $T_c = \square$) at each *location*. Similarities of groups (circles with percentages) within the nMDS plot were determined from a Bray–Curtis similarity dendrogram and were used to determine distinct assemblages. A similarity level of 0.30 was used to define the major *bimonthly* groups.

3.3 Important taxonomic group and ANOVA

According to SIMPER analysis in T_a (May–June), *Trachurus* spp. was important in all pairwise comparisons. Individuals belonging to this genus were most dominant in FAD fish assemblages in Sicily and Majorca during the spring months, but were less so in Sardinia where the dominant species was *N. ductor*. In T_b (July–August), *N. ductor* was still the most present in Sardinia, while *S. dumerili* dominated Sicily with a high value (79.64). This species was also present in Majorca where the dominant genus was always *Trachurus*. The last *bimonthly* group, T_c , (September–October) was characterized by the presence in all locations of *C. hippurus*, a species that registered similar values in Sardinia and Sicily, but was highest in Majorca (Table 4).

Table 4. Important taxa identified with SIMPER analysis and similarity values (S_{BC}) by location, within *bimonthly* groups.

	May–June (T_a)	July–August (T_b)	Sept.–Oct. (T_c)
SA	<i>N. ductor</i> (42.87) <i>Trachurus</i> spp. (29.80) <i>B. carolinensis</i> (22.26) <i>S. dumerili</i> (2.82) <i>E. encrasicolus</i> (1.76)	<i>N. ductor</i> (51.13) <i>S. pilchardus</i> (13.30) <i>P. americanus</i> (11.51) <i>B. carolinensis</i> (8.36) <i>S. dumerili</i> (5.90)	<i>C. hippurus</i> (55.36) <i>S. dumerili</i> (37.27) <i>E. encrasicolus</i> (4.51) <i>N. ductor</i> (2.36)
SY	<i>Trachurus</i> spp. (100)	<i>S. dumerili</i> (79.64) <i>N. ductor</i> (7.53) <i>Trachurus</i> spp. (5.41) <i>C. hippurus</i> (3.86) <i>C. crysos</i> (3.09) <i>T. thynnus</i> (0.36)	<i>C. hippurus</i> (55.40) <i>C. crysos</i> (29.42) <i>N. ductor</i> (8.75) <i>S. dumerili</i> (2.82) <i>T. thynnus</i> (2.02) <i>B. carolinensis</i> (1.56)
M	<i>Trachurus</i> spp. (68.41) <i>S. ovalis</i> (31.41)	<i>Trachurus</i> spp. (56.40) <i>S. dumerili</i> (41.62) <i>P. americanus</i> (1.66)	<i>C. hippurus</i> (71.94) <i>N. ductor</i> (27.09)

ANOVA results highlighted the greatly significant differences owing to the time effect on *C. hippurus*, *S. dumerili*, *Trachurus* spp. and *N. ductor*; but not for *B. carolinensis*. The location effect was significant for all the species, especially for *S. dumerili* ($p < 0.001$), while those belonging to the *Trachurus* genus show no relationship with this factor (Table 5).

4 Discussion

Kingsford (1999) reported several factors that can influence temporal and spatial variation in the distribution and abundance of fish around FADs. Temporal variations on a monthly scale are explained by variations in the physical environment (temperature, salinity, currents) and others that are ecological factors (migration, food availability, predation, recruitment and fishing pressure). In this study the multivariate approach showed dissimilarity between the locations and time groups. In both instances though, the null hypothesis was rejected. With regard to the time factor, FAD-associated fish assemblages in all locations studied seemed to be related to a bimonthly pattern and involved five main taxa: *S. dumerili*, *C. hippurus*, *N. ductor*, *B. carolinensis* and *Trachurus* spp.

The greatest differences in community structure were identified between the spring and autumn months in all locations. This result is readily explained by the species response to the annual temperature cycle in the Mediterranean that affects the pattern of assemblage of four of the five taxa (the permanent resident *B. carolinensis* is not affected by the time factor). Differences found between locations were principally due to the effect of “time shift” in the occurrence of these species and the different composition of their abundances.

There is evidence that higher sea-surface temperatures in spring contribute to early movements of migratory marine fish to spawning grounds (Ware and Tanasichuk 1989; Carscadden et al. 1997).

Some fish have temperature-dependent gonadal development (Ware and Tanasichuk 1989; Carscadden et al. 1997;

Table 5. Results of 2-way ANOVA testing for time and location effects conducted on abundances of five fish species identified with SIMPER analysis.

Source of variation	df	<i>Coryphaena hippurus</i>		<i>Naucrates ductor</i>		<i>Seriola dumerili</i>		<i>Trachurus</i> spp.		<i>Balistes carolinensis</i>	
		MS	F	MS	F	MS	F	MS	F	MS	F
Location	2	0.53	4.80*	0.50	5.34**	1.44	18.32***	0.74	2.78 ns	0.046	6.92**
Time	2	6.53	58.64***	0.46	4.85*	1.12	14.36***	3.28	12.27***	0.013	2.03 ns
Time x Location	4	0.39	3.52*	0.18	1.98 ns	0.75	9.60***	0.54	2.03 ns	0.059	8.97***
Residuals	74	0.11		0.095		0.078		0.267		0.006	
Cochran test (C)		C = 0.41*		C = 0.37*		C = 0.29*		C = 0.48*		C = 0.41*	

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; ns = no significant difference.

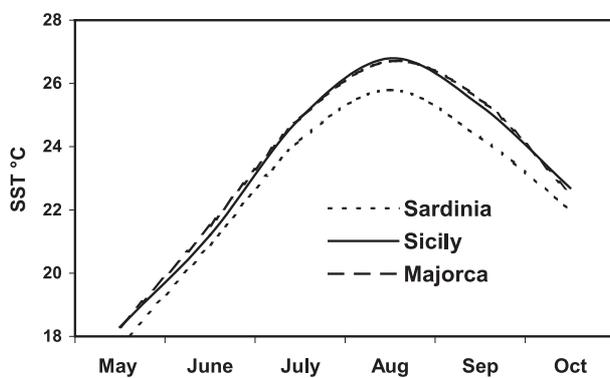


Fig. 7. Patterns of seasonal temperature fluctuations at the study areas (Sea Surface Temperatures) during the sampling period (www.rsmas.miami.edu).

Wells and Rooker 2004) and so become ready to spawn, and hence migrate earlier in warmer years. These patterns, which refer specifically to *S. dumerili* and *C. hippurus*, demonstrate a shift in habitat colonization related to the physiological preferences of the species, as reported in other studies (Norton 1999; Wells and Rooker 2004).

In the Western Mediterranean during May–October, sea-surface temperatures tend to fluctuate over a wide range, with values for Sardinia being slightly lower than Majorca and Sicily, where values are similar (Fig. 7). The slight differences in temperature that are observable simultaneously between locations could result in a shift in the colonization of FADs. In fact, for aquatic ectotherms, seasonal rises in temperature can serve as an important cue in the timing of migration (Verwey 1949) and for synchronizing reproduction with the seasonal increase in abundance of food (Cushing 1982). So the temperature factor could justify the considerable variation in the fish community structure between Sardinia and Majorca, but not the differences between Sardinia and Sicily and those between Sicily and Majorca. We believe there is a multiple effect due to the temperature shift and the characteristics of the biota, which are very similar in Sicily and Sardinia but different in Majorca because the FADs were deployed at depths of 200 meters.

As is known, sea surface temperature and current speed seems to be significantly related to the catch rates of dolphin-

fish in the recreational fishery on FADs off the NSW coast of Australia (Folpp and Lowry 2006).

We recorded the following sequential colonization patterns. In May and June, FADs drew juveniles of *Trachurus* spp., a species typically associated with floating objects. In Majorca *Trachurus* spp represented the entire sample, and in Sicily almost the whole sample except for the presence of *S. ovalis*. In Sardinia, species composition in these months is more diverse due to the presence of *N. ductor* and *Trachurus* spp., together with *B. carolinensis* and *P. americanus*. During the summer months, fish assemblages were quite mixed and it was difficult to separate groups by location. Indeed, looking at the fish assemblages in each location we found a varied species distribution but a few species specifically characterized each location. For example, we noted *C. crysos* in Sicily, *S. pilchardus* in Sardinia, while *S. dumerili* were most dominant in Majorca. In the later period (September–October) we found that *C. hippurus* was the species that characterized FAD assemblages in all locations. In Sardinia and Sicily *C. hippurus* represented a high percentage of the total abundance.

The FAD-associated fish community consists of 10–12 species, and the richness values for studies in the Western Mediterranean Sea agree with others (Relini et al. 1994; Riera et al. 1999; D'Anna et al. 1999). The values of biodiversity index H' , in each location were always very low ($H' < 2$) indicating that the fish communities were lacking in variety of species composition (Vismara 1996). Very little information and data are available to enable us to compare values between similar habitats in the Mediterranean. In the pelagic *Sargassum* community, values were higher ($H' = 2.41$) (Fine 1970) than they were in drifting seaweed in northern Japan ($H' = 2.69$) (Safran and Omori 1990). Fedoryako (1989) found that in tropical ocean zones the highest diversity of fish species was found in drifting macrophytes and in the presence of terrestrial material, but no indices were reported.

In Majorca, we found the highest species richness and the lowest H' index. This is probably due to the high abundance values for *Trachurus* spp. captured with the net, which clearly affected the calculation of the index. In Sardinia and Sicily, community indices were similar, but not fish species composition. Other species contributed to the dissimilarity factor among locations: the Carangid *C. crysos* was observed only

in Sicily, while a number of juveniles of the Centrolophid *Schedophilus ovalis* (Cuvier 1833) appeared to be permanent-residents at Majorca (De Buen 1935; Stefanescu and Massutí 1992; Massutí and Reñones 1994).

The other prominent species, *Centrolophus niger* (Gmelin 1788), is also a member of this family, and was observed at Majorca in May and at Sicily in August. Observations of this species also fluctuated with time.

Juveniles of bluefin tuna, *Thunnus thynnus*, have been the object of other investigations (D'Anna et al. 1999) and we identified them in Sicily, where they are a typical target species for recreational anglers that fish under FADs (Andaloro 2002). This is quite probably explained by the tendency for juveniles to aggregate around floating objects (Fréon and Dagorn 2000) and the presence of a high concentration of immature resident specimens in the sea north of Sicily at the beginning of autumn (Sarà 1965). Only a few specimens of bluefin tuna, *T. thynnus*, were found at the Majorca site in autumn, despite the fact that the southern area of the Balearic Islands is considered one of the most important locations for the presence of larval and juvenile bluefin tuna (Piccinetti et al. 1997; García et al. 2003).

A possible explanation is linked to the technical characteristics of the experimental net, which is not suited to capturing young tuna. Since juveniles tend to swim in deep water, they avoid being caught by the net (Andaloro 2003). Thus, visual counts were more effective in recording the presence of young *T. thynnus* under FADs, and this confirms findings of another survey carried out in Sicily (Sinopoli et al. 2002).

No bluefin tuna were observed at the Sardinia site, which is located on the species' reproductive migration route (Scaccini 1961), even during the autumn when resident fish (around 10–15 kg in weight) are frequently captured by recreational anglers. Our results confirm the occurrence of *T. thynnus* as a FAD associated species, with variable aggregations because they swim at some distance from FADs (Deudero et al. 1999; Andaloro et al. 2002). Other studies have hypothesised that there is a close relationship of bluefin tuna with FADs due to the presence of small intransigent prey in their stomach contents (Sinopoli et al. 2004).

In both Sardinia and Sicily, we observed and recorded juveniles of the lesser amberjack, *Seriola fasciata* (Block 1793) thanks to video-shot analyses and their successful capture. This particular species has been defined as an "Atlantic immigrant" (Quignard and Tomasini 2000), and was first recorded in 1989 in the Balearic Islands (Massutí and Stefanescu 1993), and subsequently fished in the same area in 1993 (Riera et al. 1995), in the Ionian Sea in 1993 (Costa 1999) and southern Tyrrhenian Sea and Sicilian channel in 1994 (Andaloro et al. 2002). It was also found in the Gulf of Gabes (Bradai 2000). Records of young-of-the-year and other size classes representing other age classes found during our studies, suggest that a resident population now exists in the Mediterranean (Andaloro et al. 2005).

In Sardinia, small groups (max 9 specimens beneath one single FAD) of juveniles of the wreckfish, *P. americanus* (~40 cm TL), associated with adults of triggerfish, *B. carolinensis* (~25 cm TL), were observed during summer months. Similar observations were made at Majorca

where solitary specimens of wreckfish were frequently observed beneath FADs.

In their analysis of the stomach contents of wreckfish, Deudero and Morales-Nin (2000) found that the young of *Trachurus* spp. are the main prey of this species. This is of particular importance because it confirms a trophic link between juvenile *P. americanus* and FAD-associated fish species. The size of the specimens observed in Sardinia corresponded with the size of those in the process of recruitment to demersal life (Sedberry et al. 1996, 1998). We also concluded that a recruitment area exists in Sardinia, because adults of wreckfish were captured in the same zone with a bottom long-line during a previous investigation (Addis et al. 1998).

In the Mediterranean most of the studies of fish assemblages associated with moored FADs have employed professional purse seine nets, which require significant logistics for fishing gear, boat and personnel, with all the consequent investment costs. Methods using purse seine nets and other forms of fishing provided the best data on ichthyofauna structure (i.e. size composition, sex), but important additional information were provided by the underwater visual census.

Visual counts are an important experimental approach in ecological studies concerning the role of FADs (Dempster and Taquet 2004) and they have proven to be particularly useful in studies on variability in FAD-associated pelagic fish assemblages and in identifying a correlation between species abundance and seasonal variation in the natural environment (Dempster 2005).

Our results suggest that using visual counts does provide a valid description of the pelagic fish community and both techniques are suitable for investigating fish assemblages associated with FADs. In particular, it is a reliable method of counting not only intranatants and extranatants, which remain within a small distance of the FAD, but also the circumnatants. However, these observations can only be carried in condition of good water transparency. We suggest the routine use of a digital camera and the analyses of video-shots because this method provides an important contribution to confirming observations concerning both species determination and the counts of individual specimens. Information gained through visual observation is cost effective because it provides a satisfactory balance between the cost of the activity and the information obtained.

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