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Article

The Role of Fish Aggregating Devices (FADs) in Juvenile Fish Dispersal along the North-Western Coast of Sicily

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Abstract: Fish aggregating devices (FADs) are used worldwide to attract fish. Previous studies revealed that FADs affect the distribution and dispersal patterns of juvenile fish species during their life stage under floating objects. In this study, we hypothesised that a system of FADs arranged along an inshore–offshore gradient could favour the approach of young fish associated with FADs towards coastal habitats, using individual FADs as stepping stones. Our findings suggest that FAD systems might exert two different effects on juvenile fish distribution: (a) offshore FADs tend to retain associated fish for longer periods of time compared with coastal FADs, (b) coastal FADs favour the transition of fishes from the pelagic to the benthic domain. Furthermore, in order to obtain more information on the dynamic and movement patterns of the young-of-the-year (YOY) *Seriola dumerili* and *Caranx crysos* associated with FADs, tagging experiments and underwater visual censuses were conducted. The two juvenile species tagged and released under FADs placed at different distances from the coast showed different movement patterns. *S. dumerili* exhibited low FAD fidelity and large movements, while *C. crysos* showed high fidelity to the site. The results of the two research approaches confirm that FADs affect the dispersal of species toward the coast and their correct use could help to improve the sustainable management of these coastal fish resources.

Keywords: fish aggregating devices (FADs); tagging; visual census; juvenile post larvae fish

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1. Introduction

The distribution of some juvenile and adult fish species is affected by floating objects. It has been observed that high densities of fish aggregate around drifting algae, driftwood, jellyfish, and man-made objects such as rafts and artificial reefs [1]. For this reason, flotsam and other fish aggregating devices (FADs) have historically been used by fishermen to improve pelagic fish yields [2]. With the growing importance of flotsam and FADs in commercial fisheries [2,3], scientific investigations to better understand both the composition of fish assemblages associated with FADs and the causes of such association have increased rapidly in recent years [4–6]. Research included the study of fish assemblage composition, fish feeding habits, and temporal trends of juvenile settlement around FADs [7–10]. Some results suggested that FADs might modify the feeding regime of some fish species, leading to poor growth conditions and survival rates. In addition, FADs seem to have a negative effect on fish distribution because of the so-called trap-effect that disrupts migratory patterns [11–14]. No harmful effects have instead been assumed in terms of reduced settlement of fish in their natural places for pelagic species (e.g., *C. hyppurus*). Although the role played by FADs in the marine environment has been studied for many decades, knowledge about their importance as a tool to increase coastal fish resources is very scarce.

In Sicily, the use of traditional FADs, called "cannizzi", is linked exclusively to the presence of economically important pelagic fish species commonly present along the coast, such as the greater amberjack *Seriola dumerili* (Risso, 1810) and the dolphinfish *Coryphaena hippurus* (Linnaeus, 1758) [15,16]. In this area, FADs are usually set at sea by fishermen in August. The commercial catch begins in September and ends in January [16,17]. Traditional FADs consist of palm leaves tied to floating objects (plastic bottles or polystyrene bodies) for easy positioning, and are anchored with a rope to large stones (Figure 1a).

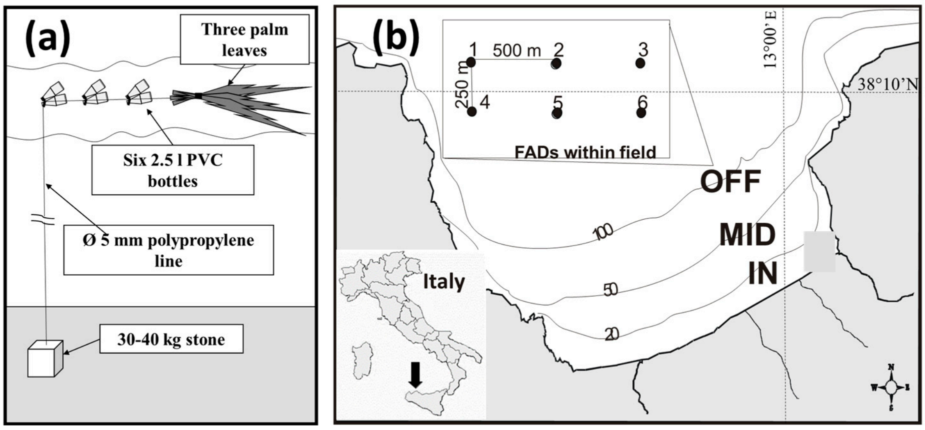

Figure 1. (**a**) Scheme of FAD setup used in this study; (**b**) Study Area. OFF (offshore), MID (mid-shore) and IN (inshore) indicate the three FAD fields.

In Sicily, the FAD systems are usually arranged in parallel arrays stretching up to 40 km from the coast. Each array, consisting of numerous FADs, is approximately 1 km apart. The deepest FADs are anchored at depths exceeding 1500 m. The wide swinging of the ropes used for anchoring results in large movements of the FADs that make them difficult for fishermen to locate. For this reason, fishermen prefer to arrange the FADs in parallel lines that represent navigational routes and make them easier to find.

At the beginning of the 20th century, this fishery relied on a few boats, each equipped with only a few FADs [18]. However, in a short time, thanks to the modernisation of fleets, characterised by ever-larger motorised boats, and the ever-increasing demand for fish, fishing with FADs has developed enormously. According to a census carried out in 1996 in the Sicilian fisheries, an average of 19,000 FADs are used annually [19]. This high number of FADs, which have been placed in the sea annually for at least 50 years, has given rise to the hypothesis that these artificial structures can have an effect on the distribution of fish. This hypothesis is supported by the fact that FADs provide protection for juvenile fish species, increasing their life success [6].

Previous studies revealed that FADs, placed along an inshore–offshore gradient, are able to affect both fish movement patterns and distribution and recruitment at coastal reefs [19,20]. This evidence has increased scientific interest in better understanding the dynamics of fish approaching the coast and their movement behaviour during the life stage associated with FADs.

The present study aims to test whether the floating component of FADs, arranged in a wide inshore–offshore gradient, affects the distribution pattern of some fish species in coastal habitats. Specifically, assuming that the post-larvae fish arrive from offshore areas, two hypotheses have been formulated: (1) FADs located at a large distance from the coast are the first to attract fish, leading them towards those anchored near the coast; if this hypothesis is true, then the average fish abundances should decrease over time at the offshore FADs and increase at the inshore ones. (2) Alternatively, offshore FADs block the further dispersal of fish towards the coast; if this is true there will be a higher average abundance of fish at offshore FADs than at the coastal ones. In order to test these hypotheses, underwater visual census and tagging experiments were conducted on fish species associated with experimental FAD fields. Results of this study deal only with the floating component of the FAD structure.

2. Materials and Methods

The Gulf of Castellammare (38°03′ N 12°54′ E) is located on the north-western coast of Sicily (Southern Tyrrhenian sea, Italy: Figure 1b). Its coastline is over 70 km long and covers an area of about 300 km^2. The eastern and western sides are characterized by steep cliffs, while the central side shows narrow sandy beaches.

To verify the abovementioned hypotheses, in the period between April and December 2011, three arrays of 6 FADs each, built with the same materials and techniques used by artisanal fishermen (Figure 1a), were arranged at increasing distances from the coast. The 3 arrays were located as follows: inshore (IN) (1.6 km from the coast; 20–25 m depth), mid-shore (MID) (2.6 km nm from the coast; 50–55 m depth), and offshore (OFF) (5.2 km from the coast; 100–110 m depth). Each array included FADs arranged at 500 and 250 m distance from each other to form a square (Figure 1b).

The geographical coordinates detected by GPS were annotated for each FAD. During the whole study period, professional and recreational fishing activities were banned within the experimental area.

2.1. Underwater Visual Census

Underwater visual censuses were carried out on three FADs chosen at random in each array on three dates chosen on the basis of the association period of the species [18]. In each census, the relative abundances were recorded for three size classes of juveniles *Balistes capriscus, Caranx crysos, Seriola dumerili*, and *Trachurus* sp. The three size classes considered for the three species were: small (up to 10 cm), medium (from 10.1 to 14 cm), and large (greater than 15). A three-way analysis of variance (ANOVA) was computed on the abundance of each species according to the following fixed and orthogonal factors: (i) DISTANCE FROM THE COAST, three levels, OFF, MID, IN; SIZE CLASS, three levels, small, medium and large; (iii) and PERIOD, three levels, T1 (i.e., early association. This coincides with fish arrival at FADs, and it lasts about 3 weeks), T2 (i.e., the period following fish arrival at FADs. This period lasts about 4 weeks), and T3 (i.e., last stage of fish association before fish leaves the FADs. This period lasts about 4 weeks) [16]. The homogeneity of the variance was tested through the Cochran test [21,22] and, when necessary, data were transformed. Significant terms relevant to the hypothesis were investigated through the Student Newman–Keuls (SNK) method. The analyses were computed using GMAV 5.0 (University of Sydney) software.

2.2. Tagging Experiment

The tagging experiment was conducted on *S. dumerili* and *C. crysos* which, together, represent the most abundant species of the fish assemblage associated with Mediterranean FADs, respectively, in the summer-autumn and winter seasons [16]. These two species are resistant to manipulation and tagging as reported in other studies. The tagging experiment was carried out on 26 August 2001 for *S. dumerili* and 7 November 2001 for *C. crysos*. For *S. dumerili* in the sites OFF and MID, two hauls were made using a purse seine net at two FADs chosen for their central position, OFF2 and MID2. For *C. crysos*, a tagging experiment was performed using the same approach but fish were tagged only at FAD MID2. As soon as they were on board, fish were placed in three tanks of about 60 L volume filled with sea water and equipped with a water-circulation system. Tagging was performed using a fine fabric (INC) model small-needle-equipped gun (Figure 2). In order to identify *S. dumerili* tagged on OFF and MID FADs, tags of different colour were used. Fish were measured and subsequently tagged. Furthermore, in order to test for differences in movements in relation to size, fish smaller than 12 cm were tagged with tags ending in a 4 × 8 mm rectangles, while larger individuals were marked with a common "spaghetti" T-bar. Fish were released into the same FADs where they were caught by a scuba diver. Five consecutive underwater visual censuses (UVC) were performed on all of the 18 FADs of the study area (Table 1). The tagging experiment was advertised to fishermen operating in the local fisheries. In order to calculate the distance moved from the releasing to the sighting sites, the geographical coordinates, taken via GPS, were represented cartographically by the use of a GIS software.

Figure 2. Tagging of a *Caranxs crysos* individual using a fine fabric gun (INC).

Table 1. List of type and colour of tag used in the tagging experiment and percentage of sightings of tagged fish in the following censuses. SP = spaghetti tag, RE = rectangular tags, *n* = numbers of individuals tagged.

Hours after Release				2–3	22–24	49–50	71–73	95–97	318–319
Species	**Type**	**Colour**	***n* Tot**	**Percentage of Sighting**					
S. dumerili	SP	White	57	68.4	21.0	3.5	15.7	10.2	2.5
S. dumerili	RE	White	7	57.1	0	0	0	0	0
S. dumerili	SP	Green	32	28.1	9.3	0	9.3	0	0
C. crysos	SP	White	24	98.5	97.3	98.1	96.5	97.5	nd
C. crysos	RE	White	6	100	100	98.3	97.2	97.8	nd
Total	Total		126						

3. Results

The results of the four ANOVAs performed on the studied species showed highly significant differences ($p < 0.01$) in the interaction between the three fixed factors considered. In the period T1, no significant differences were found between the three distances for all species with the exception of *C. crysos* for the medium size class, for which the MID and IN distances showed greater abundances than the OFF distance (Figure 3). At period T2, the small class of *B. capriscus* showed significantly greater abundances in OFF and MID distances compared to IN, while for the large class, significantly greater abundances were found in the OFF distance compared to the MID and IN distances (Figure 3). The mean abundances of *C. crysos* at period T2 were significantly greater in the small class at the IN distance compared to the MID and OFF ones and, in the medium class, at the IN and MID distances compared to OFF one. At period T2, in the medium size class, the mean abundances of *S. dumerili* were significantly greater in the OFF FADs than in the MID and IN ones (Figure 3). In the period T3, mean abundances were significantly higher in the

OFF distance than in the MID and IN distances, except for all size classes of *C. crysos*, the large size class of *B. capriscus* and *S. dumerili* and the medium size class of Trachurus sp. (Figure 3).

A total of 126 amberjacks were tagged in the FAD area using two colours and tag shapes (Table 1). At the OFF2 site, the average sighting percentage of amberjacks tagged with a spaghetti tag was 20.27% (±26.4 SD) with a peak of 68.42% recorded at the first UVC (2–3 h) and a minimum value at the UVC made after 318–319 h. At the same site, the average sighting percentage of amberjacks marked with small TAG was 9.52% (±21.6 SD) although a single sighting was performed with a percentage of 57.14% at the first census (2–3 h). Regarding the individuals marked at MID2, the average percentage re-sighted in the subsequent UCV was 7.81% (±13.5 SD) with a maximum at the first census of 28.1% (2–3 h). At the OFF site, at least one sighting was made for each UVC carried out (O% = 100) while at the MID and IN sites the percentages of occurrence were, respectively, 50.00% and 16.67%. *C. crysos* always showed a higher percentage of re-sighting at the five visual censuses for both sizes.

The amberjacks tagged at OFF2 were spotted in a period ranging from 72 to 319 h from release. A total of five sightings of single individuals were always recorded at the FAD OFF field with distances from 206 to 407 m covered (Table 2). An amberjack was caught 2748 h after tagging on a coastal artificial reef at a distance of 6104 m (Table 2). The amberjacks released at MID2 showed a re-sighting in each of the three FAD arrays after 72 h from releasing, covering distances ranging from 559 m to 2165 m (Table 2). Additionally, in this case there was an amberjack caught in the coastal areas near a wreck sunk at a depth of 17 m after 2773 h from release and at a distance of 2723 form release site (Table 2). No movement was revealed for individuals of *C. crysos*, which were always found in the same FAD of the release, thus showing a high site fidelity.

Table 2. List of sites of FAD release, sighting, and distance (in meters) travelled by tagged fishes in the successive controls.

FADs			Hours after Release						
Specie	**Release**	**Sighting**	**2–3**	**22–24**	**49–50**	**71–73**	**95–97**	**318–319**	**2400-6500 /390**
S. dumerili	OFF2	OFF1	0	0	0	216	0	0	0
S. dumerili	OFF2	OFF3	0	0	0	0	204	0	0
S. dumerili	OFF2	OFF5	0	0	0	296	296	296	0
S. dumerili	OFF2	OFF6	0	0	0	0	407	0	0
S. dumerili	OFF2	Art. Reef	0	0	0	0	0	0	6104
S. dumerili	MID2	MID6	0	0	0	559	0	0	0
S. dumerili	MID2	OFF5	0	0	0	2165	0	0	0
S. dumerili	MID2	IN2	0	0	0	1806	0	0	0
S. dumerili	MID2	Wreck	0	0	0	0	0	0	2723
C. crysos	MID2	MID2	0	0	0	0	0	nd	nd

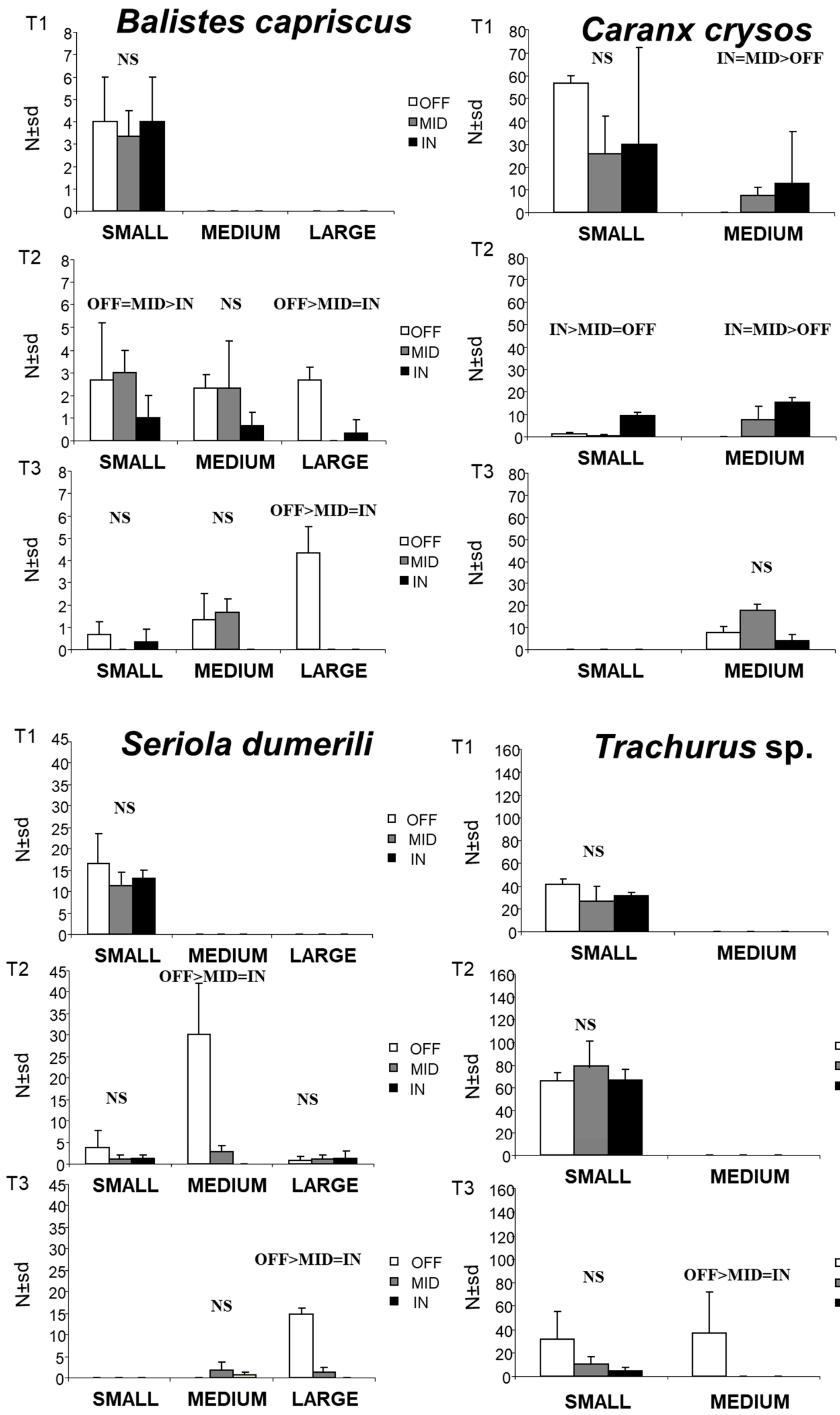

Figure 3. Mean ± sd (standard deviation) of the individual species at the OFF, MID, and IN distances (offshore, mid-shore, inshore) separated for the three periods (T1, T2, T3) and for the three fish size classes: small (up to 10 cm), medium (10.1 to 14 cm), large (greater than 15). The results of pairwise comparisons (SNK test; NS = not significant) are also reported.

4. Discussion

Many studies have tried to investigate whether floating or sunk artificial structures can influence the distribution and dispersal of marine fishes. Artificial structures provide suitable habitats mainly for the recruitment of juveniles of different fish species, which may increase the connectivity between adjacent habitats and improve fish dispersal towards the benthic coastal habitat [23,24]. Other studies have shown that the addition of vertical modules to artificial reefs increases their power to recruit juvenile fish along the water column and then bring them to the bottom [25,26]. Another study has further extended the principle of this mechanism by experimenting with a combination of floating FADs anchored in shallow water to an artificial reef [25]. In this arrangement both recruitment and colonization were faster than that observed on the artificial reefs without the presence of FADs. Larval recruits are apparently attracted by the structure nearer to the surface and move toward the available substrate on the bottom. However, the evidence that artificial reefs facilitate a horizontal shift over higher distances or on an inshore–offshore gradient is limited [25].

Our results highlighted that temporal trends in the abundance of *B. capriscus*, *S. dumerili*, and *Trachurus* sp. did not show significant differences for the small fish settlement on the three FAD arrays during the first period (T1). Higher fish abundances and sizes were found at offshore FADs in the subsequent periods (T2 and T3) highlighting the trap effect. As regards *C. crysos*, on the other hand, in the first period, a high variability was recorded for the small size class in the three FAD arrays while higher abundances were found for the medium size class in the FAD array near the coast. In the three studied periods, *C. crysos* showed a strong general decrease in abundance, which was concentrated in the FADs near the coast for both the small and middle classes. It is therefore possible to accept for this species the first hypothesis formulated, which provided for a role of the FADs system for fish approaching the coast. However, the high variability of the abundances suggests caution in interpreting the results. For the other species, it is possible to accept the second hypothesis, that is, offshore FADs block fish movement toward the coast [19].

Tagging and sighting experiments under FADs coupled with an underwater visual census have been successfully carried out on various fish species, including other carangids [7]. A tagging experiment on FAD-associated species carried out on *C. hippurus* and *Seriola lalandi* reported a directed homing behaviour toward FADs. Indeed, both species returned in significantly greater numbers than could be expected if movement from the point of release occurred in a random direction. With approaches other than tagging, evidence of homing to FADs has been demonstrated from distances of 5 to 8 nautical miles for large pelagic species, such as the yellowfin *Thunnus albacares* [9–11] and the bigeye tuna *Thunnus. obesus* [9] and for shorter distances of up to 180 m for small FAD-associated fish such as the unicorn filefish *Alutera monoceros* and black-banded trevally *Seriolina nigrofasciata* [11]. Recapture data for *C. hippurus* and *S. lalandi* indicate they can remain near FADs for days to weeks [7]. Both species appear capable of making excursions from FADs, at least at the scale of hundreds of meters, and returning. In general, the results reported in above-cited literature agree with our finding for the *C. crysos* tagging experiment, which is confirmed to be a species with high site fidelity. Other experiments using acoustic tagging under FADs confirmed the high fidelity to the site for this species [12,13]. On the contrary, our results on *S. dumerili* tagging do not agree with what was found in the literature for other species and in other seas. Surprisingly, this species has a different behaviour, not only when compared with other species of the same family, such as *C. crysos*, but also with other carangids belonging to the same genus, such as *S. lalandi* [7,27]. In fact, the young amberjacks we tagged, after a short period, showed dispersal instead of homing behaviour. This result further supports the role played by FADs in the transfer from the pelagic to the necto-benthonic domain in line with the model proposed by [19] for *S. dumerili*. In fact, an increase in the ERI (effective range of influence) linked to the growth of the species would facilitate the encounter with the substrate and the abandonment of the coastal FADs in shallow water (Figure 4).

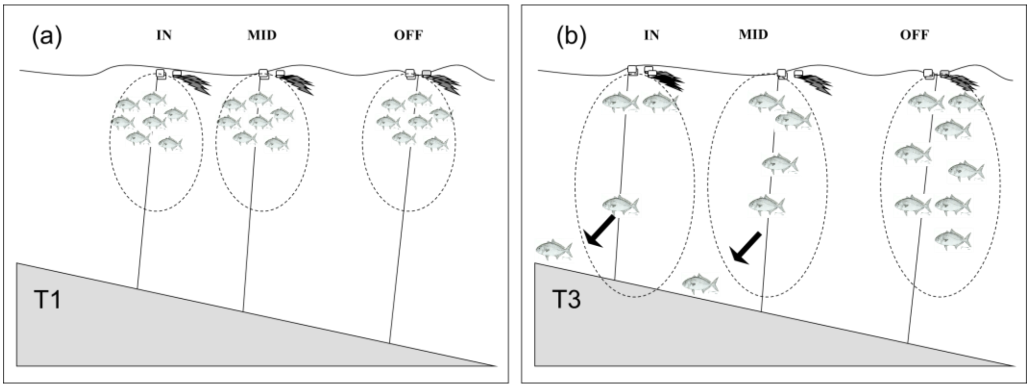

Figure 4. Redrawn from [18]. Possible explanation of the observed pattern for *Bailistes capriscus*, *Seriola dumerili*, and *Thachurus thracurus*, (**a**) At an earlier stage (T1) small-sized YOYs have a small ERI (dotted circle), which constrains them to the immediate vicinity of FADs. (**b**) Later, when fish grow (T3), ERI also increases and fish associated to IN and MID FADs may have a greater possibility of encountering a more suitable habitat while at OFF FADs, where ERI is smaller than the distance from the bottom, fish may thus remain associated longer and unnaturally to FADs.

The dynamics model of the domain change based on the variation in the ERI does not fit well with the results of the tagging experiment for *C. crysos*. This is in line with the high fidelity to FADs found for this species. Previous data showed that *C. crysos* under the FADs can make movements, but always along the anchor line (a behaviour known as 'turn up and down' [5]) and to a lesser extent making circles around the FAD, as characterizes *S. dumerili.* It therefore seems that this species is more wary of making movements away from a physical reference [5]. However, the evidence remains that in our experiment about 20 juveniles of *C. crysos* always remained associated with the same FADs and did not move like *S. dumerili*. A hypothetical answer could be that the latter species can make larger movements and be ready to leave FADs at a larger size than the individuals tagged in this study. Further experiments with the tagging of larger individuals will be needed to implement the model.

The results of our study suggest that a more rational use of FADs, and in particular of their positioning closer to the coast, could play an important role for an effective management of these species in areas easily accessible by fishermen [28–30]. However, it is necessary to better investigate some aspects, such as by further quantifying the effectiveness of these devices and the permanence of species after the recruitment processes. In fact, our tagging experiments on *S. dumerili* indicate their permanence in coastal areas only for short periods after the abandonment of the FADs. In this period, the species retained by FADs in coastal environments represent an additional resource available for small-scale fisheries [28].

This study contributes to enriching knowledge on the effects of FAD use in Mediterranean marine ecosystems. The use of anchored FADs in the Mediterranean sea has increased over the last 30 years, from a few hundred to around 60,000 per year throughout the whole basin [31]. In addition to the already highlighted effects on epipelagic biodiversity [5,6,19,32], several environmental problems related to the large release of marine litter have also emerged [33–35]. For these reasons, the use of FADs requires specific regulation to make their use environmentally sustainable.

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Conflicts of Interest: The authors declare no conflict of interest.

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