

## Short communication

# Contribution of artificial reefs to the diet of the white sea bream (*Diplodus sargus*)

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An evaluation of the trophic relationship between *Diplodus sargus* and artificial reefs (ARs) in the Algarve (southern Portugal) is based on a comparison of stomach contents and the macrobenthic communities present at the AR and in surrounding sandy bottom areas. Only adult white sea bream were observed in the vicinity of the ARs. The percentage of items found in the stomach that were characteristic of AR hard substratum was high (67%). Although the diet contained a wide variety of items, namely reef algae, invertebrates (crustaceans, gastropods, and bivalves), and fish, *Balanus amphitrite* and *Gibbula* spp. contributed most to the diet. The diet of *D. sargus* was strongly associated with prey availability on the AR, so highlighting the importance of these artificial habitats to the species. It seems that these artificial feeding areas, owing to their extent and benthic production, are enhancing the local *D. sargus* stock and hence the fishery.

**Keywords:** Algarve (Portugal), artificial reefs, diet, *Diplodus sargus*, feeding ecology.

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## Introduction

Artificial reefs (ARs) can be part of a solution to some of the problems concerning coastal resources, ecosystems, and fisheries, and in many countries, these man-made structures are an important tool of management (Bohnsack and Sutherland, 1985; Polovina, 1994; Jensen, 2002). The Algarve (southern Portugal) ARs were conceived with several objectives in mind, including the enhancement of fish populations and the improvement of nearshore fisheries (Monteiro and Santos, 2000). Algarve ARs now cover 43.5 km<sup>2</sup> and are the largest artificial habitat (productive type) in European waters.

AR structures provide a hard substratum (HS) for the settlement of benthic prey, contributing to the creation of new feeding areas, and consequently increase trophic efficiency (Bombace, 1989) on formerly less productive, sandy seabeds (Leewis *et al.*, 1997). In terms of AR deployment, their productivity relies on the assumption that AR surfaces provide additional critical habitat which increases the environmental carrying capacity, and hence enhances the abundance and biomass of marine biota (Polovina, 1994). Nevertheless, some doubts persist as to whether ARs contribute to the production of new fish biomass or attract fish from surrounding areas without actually increasing total biomass (Bohnsack and Sutherland, 1985). Stomach content studies have been carried out aiming to clarify the importance of AR production as potential feeding areas for fish, especially AR-resident fish (Lindquist *et al.*, 1994). Some studies highlight the importance of AR habitats for fish foraging (Pike and Lindquist, 1994; Relini *et al.*, 2002), and others report

that fish feed primarily on adjacent sandy seabeds (Lindquist *et al.*, 1994; Pepe *et al.*, 1996).

For some species, ARs can serve as spawning areas or as refuge rather than as feeding areas. For those species that feed at ARs, man-made structures that produce significant benthic biomass may be useful to support fish biomass recovery. Therefore, knowledge of the trophic ecology of reef ichthyofauna is important in understanding the dependence of species on an AR's benthic production and in evaluating the importance of such structures for the maintenance of fish populations. This means that the use of ARs to enhance any fishery requires the understanding of the ecological role of reefs in supporting exploited fish assemblages. Studies on the feeding ecology and trophic interactions of ARs and fish are scarce (Pepe *et al.*, 1998; Relini *et al.*, 2002; Fabi *et al.*, 2006), and none have been made in southern Portugal. This scarcity of information is notable, because addressing it may shed light on whether the biological production of Algarve ARs contributes to an increase in fish biomass and consequently to local fisheries enhancement.

*Diplodus sargus*, a species with a coastal rocky reef distribution ranging from the Mediterranean to the eastern Atlantic (from the Bay of Biscay to South Africa), is important commercially. It is also one of the most abundant and frequent species found at ARs (Santos *et al.*, 2005). Although several aspects of its feeding ecology have been studied (Baldó and Drake, 2002; Mariani *et al.*, 2002; Figueiredo *et al.*, 2005), little attention has been paid to its trophic relationship with ARs (Pepe *et al.*, 1998). Here, our aim is to evaluate the contribution of Algarve ARs to the diet of *D. sargus*.

## Material and methods

### Study site and sampling

The experiment was carried out in the Faro/Ancão AR system, located off Faro (southern Portugal) on a sandy seabed, at depths ranging from 16 to 37 m. The system was deployed in 1990 and enlarged in 2003. It occupies an area of 12.2 km<sup>2</sup> and has a total of 174 reef sets, of which 156 are small modules. Each of the latter consists of 35 cubic concrete units (2.7 m<sup>3</sup> each). Data collection was carried out at four of the oldest reef groups, FP1, FP3, FP5, and FP7, which were deployed in 1990 at depths of 19–21 m. The distance from the AR to the nearest rocky site, a small natural reef, is about 2.3 km.

All fish were caught at the AR by spearfishing between 2002 and 2004, on a monthly basis and with an effort of two to three fishing days per month. Spearfishing was carried out during the morning (08:00–11:00) by two divers. In all, 64 dives and 48 visual census surveys were carried out. Fish behaviour and size were recorded according to the stationary point count technique, as described by Santos *et al.* (2005).

### Data analyses

Data on the Faro/Ancão AR benthic and ichthyofauna communities have been reported previously (Santos *et al.*, 2005; Boaventura *et al.*, 2006; Moura *et al.*, 2006). However, in order to gather more data regarding AR communities, *in situ* observations were carried out focusing on large mobile macrobenthic invertebrates and seaweeds. To characterize the soft-bottom macrobenthic community, sandy seabed samples were collected every three months during the study period. The samples were collected both inside the reef modules and outside the reefs along a transect at increasing distances (0, 1, 3, 5, and 20 m from the reef edge). Divers collected three 0.02 m<sup>2</sup> corer samples, to depths of 15 cm at each sampling site.

Fish were measured to the nearest millimetre below. The stomachs were cut off at the oesophagus and pylorus. All prey items were separated by taxon, counted and weighed to the nearest 0.01 g. Depending on the level of digestion, prey items were identified to species or to the lowest possible taxon. The colonial taxa, hydrozoans and bryozoans, and plants were not counted, so the numerical value attributed to those prey items was 1. Barnacles were counted based on their opercular pair structures, tergum, and scutum plaques.

AR and sandy seabed communities were compared in terms of the total abundance, and diversity [Shannon–Wiener index:  $H'$  ( $\log_2$ )] through one-way ANOVA ( $F$ -test). Prior to ANOVA, tests for normality (Anderson–Darling test) and homogeneity of variance (Bartlett's method) among treatments were carried out (Zar, 1996). ANOSIM (Bray–Curtis similarity matrix) was used to compare AR and sandy macrobenthic fauna (fourth-root transformation of the number of individuals per m<sup>2</sup>) (Clark and Warwick, 1994). The mean number of items per stomach, the mean number of items and the percentage of items preyed on per stomach, by season, were also compared using ANOVA (Zar, 1996). Seasonal diversity of *D. sargus* diet was also tested. All univariate statistical analyses were carried out using Statistica V6.0 software, with a significance level of  $\alpha = 0.05$ .

Dietary composition was assessed through mean numerical percentage (%N), mean weight percentage (%W), and frequency of occurrence (%FO) of each prey taxon, following Hyslop (1980). To evaluate the diet of *D. sargus* we used: (i) the vacuity coefficient

(Hureau, 1970), (ii) the feeding coefficient ( $Q$ ) (Hureau, 1970), and (iii) the index of relative importance (IRI) (Pinkas *et al.*, 1971). Sigurdsson and Astthorsson (1991) scales were used to measure stomach fullness and the state of prey digestion.

Because the units of measurement for soft seabed and AR species (number m<sup>-2</sup>, and cover percentage in the case of colonial species) is different from that of stomach contents (number of items per stomach), data were transformed to presence/absence, in order to construct a Bray–Curtis similarity matrix for multidimensional scaling (MDS) analysis. Stomach contents and data on sandy seabed macrofauna (three samples per trimester) were pooled by season. Species of both AR and soft seabed samples were then used to assess items' provenance. All multivariate analyses were performed using the statistical package PRIMER (Clark and Warwick, 1994).

## Results

*Diplodus sargus* was present at a high FO (67%) at the AR. Spearheaded specimens ranged in size between 20.6 and 53.6 cm (mean  $35.43 \pm 6.65$  cm). *In situ* visual census revealed an absence of juveniles (<20 cm total length) at the AR.

### Macrozoobenthic community of ARs and neighbouring sandy areas

The number of taxa identified over soft substrata (SB) was higher (196) than over hard substratum (HS) (154). The most important groups available for fish foraging were polychaetes (SB = 94; HS = 52), crustaceans (SB = 52; HS = 47), bivalves (SB = 26; HS = 9), and gastropods (SB = 12; HS = 13). Cirripedia, Serpulidae, Bryozoa, and Ascidiacea were the major taxonomical groups that colonized the AR. Among soft seabed species, the most abundant taxa were Nematoda (14%) and Polychaeta (*Pisone* spp. and *Glycera lapidum* accounted for 13.71% and 7.55%, respectively). Despite the high number of taxa found in the soft-bottom macrobenthic community, the mean abundance was significantly higher over the AR HS ( $92\,785 \pm 74\,645\text{ m}^{-2}$ ) than over SB ( $16\,464 \pm 6567\text{ m}^{-2}$ ) (ANOVA:  $p < 0.01$ ). Colonial taxa such as hydrozoans, bryozoans, and barnacles were not considered for the estimation of HS abundance. However, there was no change in Shannon–Wiener's diversity index between HS ( $2.75 \pm 0.32$ ) and SB ( $2.87 \pm 0.33$ ) communities (ANOVA:  $p = 0.29$ ). Statistical analysis showed differences between the macrobenthic structure of the soft seabed and AR communities (ANOSIM:  $r = 0.98$ ;  $p = 0.01$ ).

### Diet

The number of empty stomachs (33 out of 107) was low, reflecting a low feeding coefficient (30%) for this species. All remaining stomachs (74) with contents were analysed: 11 in winter, 12 in spring, 25 in summer, and 26 in autumn. Most (80%) of the sampled stomachs were reasonably full (50–75%) or full (>75%). Most of the prey items found in the stomachs (85%) were not yet digested or just slightly digested, which allowed their identification.

The diet of *D. sargus* contains a wide variety of food items. In all, 14 taxa were identified (Table 1). The most important taxonomic groups contributing to *D. sargus* diet ( $Q$  and IRI) were Crustacea (*Balanus amphitrite*) and Gastropoda, with *Gibbula* spp. also important. Those taxa live at the AR surface. Sandy seabed species were also present in the stomachs (e.g. *Parvicardium scabrum* and *Cassidaria echinophora*). However, compared with the AR species, these species contributed less to the diet of *D. sargus*. Some algae

**Table 1.** List of the species found in *D. sargus* stomachs.

|                           | Taxon                                       | %N    | %W    | %FO   | Q      | IRI    |
|---------------------------|---------------------------------------------|-------|-------|-------|--------|--------|
| Anthozoa                  | Actinaria <sup>+</sup>                      | 0.72  | 0.36  | 4.05  | 0.26   | 4.38   |
| Bivalvia                  | <i>Anomia ephippium</i> <sup>+</sup>        | 0.96  | 0.11  | 2.7   | 0.1    | 2.89   |
|                           | <i>Hiattella artica</i> <sup>+</sup>        | 0.24  | 0.00  | 1.35  | 0.00   | 0.33   |
|                           | <i>Lima lima</i> <sup>+</sup>               | 0.24  | 0.05  | 1.35  | 0.01   | 0.39   |
|                           | <i>Parvicardium scabrum</i> <sup>-</sup>    | 0.24  | 0.00  | 1.35  | 0.00   | 0.33   |
|                           | Unidentified                                | 0.72  | 0.00  | 4.05  | 0.00   | 2.93   |
| Bryozoa <sup>+</sup>      |                                             | 1.69  | 0.6   | 12.16 | 1.01   | 27.82  |
| Cephalopoda               | <i>Sepia officinalis</i>                    | 0.48  | 12.66 | 2.7   | 6.1    | 35.53  |
| Crustacea                 | Amphipoda                                   | 0.96  | 0.00  | 2.7   | 0.00   | 2.61   |
|                           | Isopoda                                     | 0.24  | 0.00  | 1.35  | 0.00   | 0.33   |
|                           | Decapoda                                    | 0.24  | 1.12  | 1.35  | 0.27   | 1.84   |
|                           | <i>Diogenes pugilator</i>                   | 0.72  | 0.26  | 1.35  | 0.19   | 1.32   |
|                           | <i>Pagurus</i> spp.                         | 0.72  | 0.38  | 4.05  | 0.27   | 4.47   |
|                           | <i>Necura puber</i> <sup>+</sup>            | 1.2   | 1.61  | 6.76  | 1.93   | 18.99  |
|                           | <i>Polybius henslowi</i> <sup>+</sup>       | 0.96  | 1.38  | 5.41  | 1.33   | 12.69  |
|                           | <i>Goneplax rhomboides</i> <sup>+</sup>     | 1.2   | 2.37  | 6.76  | 2.86   | 24.18  |
|                           | <i>Xanthus</i> spp. <sup>+</sup>            | 0.24  | 0.05  | 1.35  | 0.01   | 0.4    |
|                           | <i>Balanus amphitrite</i> <sup>+</sup>      | 18.31 | 2.54  | 17.57 | 46.53  | 366.35 |
| Echinodermata             | Asteroidea                                  | 0.48  | 0.06  | 2.7   | 0.03   | 1.46   |
|                           | Echinoidea                                  | 2.41  | 1.22  | 12.16 | 2.94   | 44.17  |
|                           | Ophiuroidea                                 | 0.48  | 0.09  | 2.7   | 0.04   | 1.55   |
| Porifera <sup>+</sup>     |                                             | 0.48  | 1.49  | 2.7   | 0.72   | 5.32   |
| Foraminifera <sup>+</sup> |                                             | 0.24  | 0.00  | 2.7   | 0.00   | 0.65   |
| Gastropoda                | <i>Cassidaria echinophora</i> <sup>-</sup>  | 0.48  | 1.3   | 2.7   | 0.62   | 4.81   |
|                           | <i>Cerithium vulgatum</i> <sup>-</sup>      | 0.48  | 0.07  | 2.7   | 0.04   | 1.5    |
|                           | <i>Gibbula</i> spp. <sup>+</sup>            | 40.24 | 9.65  | 12.16 | 388.34 | 606.79 |
|                           | <i>Nassarium</i> spp. <sup>+</sup>          | 2.17  | 0.15  | 6.76  | 0.32   | 15.67  |
|                           | <i>Ocenebrina edwardsi</i> <sup>-</sup>     | 0.24  | 0.00  | 1.35  | 0.00   | 0.33   |
|                           | Unidentified                                | 2.65  | 0.38  | 12.16 | 1.01   | 36.88  |
| Hydrozoa <sup>+</sup>     |                                             | 0.24  | 0.00  | 1.35  | 0.00   | 0.33   |
| Nematoda                  |                                             | 0.24  | 0.00  | 1.35  | 0.00   | 0.33   |
| Osteichthyes              | <i>Scomber japonicus</i> <sup>+</sup>       | 0.24  | 15.11 | 1.35  | 3.64   | 20.74  |
|                           | Sparidae <sup>+</sup>                       | 0.24  | 1.26  | 1.35  | 0.3    | 2.03   |
|                           | <i>Trachurus trachurus</i> <sup>+</sup>     | 0.24  | 1.1   | 1.35  | 0.26   | 1.81   |
|                           | Unidentified                                | 0.24  | 3.85  | 1.35  | 0.93   | 5.53   |
| Plantae                   | <i>Zostera marina</i>                       | 3.61  | 12.53 | 20.27 | 45.29  | 327.25 |
|                           | <i>Z. noltii</i>                            | 1.45  | 1.64  | 8.11  | 2.37   | 25.00  |
|                           | <i>Ulva lactuca</i>                         | 1.2   | 5.69  | 6.76  | 13.72  | 93.23  |
|                           | <i>Cystoseira usneoides</i> <sup>+</sup>    | 0.48  | 1.77  | 2.7   | 0.85   | 6.09   |
|                           | <i>Rhodomenia holmesii</i> <sup>+</sup>     | 2.89  | 3.13  | 16.22 | 9.05   | 97.63  |
|                           | <i>Aphanocladia stichidosa</i> <sup>+</sup> | 0.48  | 0.24  | 2.7   | 0.12   | 1.96   |
| Polychaeta                | <i>Polydora hoplura</i> <sup>+</sup>        | 0.24  | 0.00  | 1.35  | 0.00   | 0.33   |
|                           | <i>Serpula vermicularis</i> <sup>+</sup>    | 0.72  | 0.02  | 4.05  | 0.01   | 3.01   |
| Unidentified items        |                                             | 5.78  | 5.34  | 32.43 | 30.91  | 360.91 |

Plus signs indicate taxa found exclusively on AR hard substratum and minus signs taxa found exclusively found on sandy seabed. %N, mean numerical percentage; %W, mean percentage by weight; %FO, percentage frequency of occurrence; Q, feeding coefficient; IRI, index of relative importance.

that colonize the ARs, such as *Cystoseira usneoides* and *Rhodomenia holmesii*, were also recorded in fish stomachs. Other plants, which do not colonize the AR, such as *Zostera* spp. and *Ulva lactuca*, were also frequently present in the stomachs. Bryozoans and hydrozoans, commonly found at the AR, were also observed in the stomachs.

The burrowing polychaete *Polydora hoplura* and tube-building polychaete *Serpula vermicularis*, which is found in AR hard substrata, were also being preyed upon. There were no significant seasonal differences in diet diversity of the diet (Shannon–Wiener mean diversity:  $H' = 1.84 \pm 0.76$ ; ANOVA:  $p = 0.89$ ).

### Feeding dependence on ARs

Most taxa found in fish stomachs were also present at the AR. Of the 39 taxa identified in stomach contents, 19 were found exclusively at the AR, and just three from the sandy surrounding area.

*Diplodus sargus* feeding dependence on the AR varied seasonally (Figure 1a). The number of items found in the diet was greatest in summer (35 items). Prey items were fewest in spring (11). However, neither the mean number of items per stomach (ANOVA:  $p = 0.15$ ), nor the mean number of items per stomach preyed on from the AR (ANOVA:  $p = 0.43$ ) differed between seasons. Results showed that a high percentage of items contributing to the diet of *D. sargus* belong to the AR HS community. These values were slightly higher during winter and spring (74% and 79%, respectively) than in summer and autumn (63% and 65%, respectively). The rest of the diet was items of indeterminate origin, such as echinoderms and species belonging to the sandy macrobenthic community. However, differences between the mean percentages of items present at the AR between seasons were not significant (ANOVA:  $p = 0.16$ ).

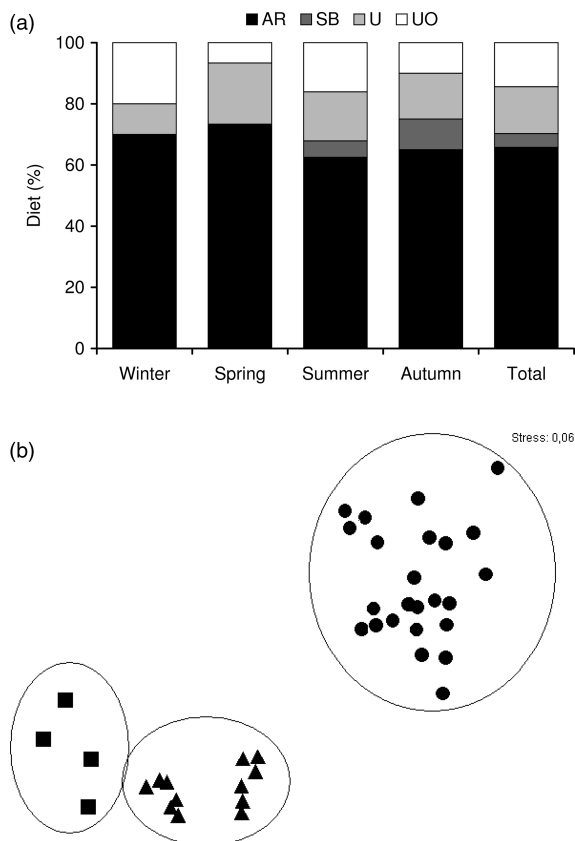
The MDS analysis (Figure 1b) highlights the relationship between the AR macrobenthic community and *D. sargus* diet. Three groups are clearly observed. The diet items are grouped

near the AR items, whereas soft-bottom items are isolated and distant from the other two groups.

### Discussion

Our study was carried out in order to assess the importance of the macrobenthic community of an AR to the diet of *D. sargus*. One of the most important theoretical questions arising from AR deployment is whether the contribution of the food available at ARs (macrobenthic community production) leads to an increase in the biomass of reef fish assemblages. The high FO of *D. sargus* denoted reef fidelity, confirming previous results (Santos *et al.*, 2005), which categorized the species as resident. The absence of juveniles at the AR was not a surprise, because it is known that juveniles prefer shallow rocky areas near the coast and in the Ria Formosa coastal lagoon, an important nursery area for the species, with high juvenile abundance (Monteiro *et al.*, 1990). Additionally, recently tagged, reared, sub-adult *D. sargus* released at the same AR have been recaptured in coastal shallow waters along the south coast and in the Ria Formosa lagoon (Santos *et al.*, 2006).

Our results suggest that *D. sargus* benefits from ARs, using them as areas where food is plentiful. In fact, most of the prey we found belong to the AR benthic community. This highlights the importance for *D. sargus* of artificial habitats, which in this case cover an area of 12.21 km<sup>2</sup>, at depths ranging from 17 to 24 m, in a 36 km<sup>2</sup> zone where natural reefs are scarce (occupying just 2.7 km<sup>2</sup>). Moreover, the stomach vacuity index was low, with the fullness and digestion levels showing that most stomachs were almost full and that feeding activity was recent. The AR's contribution to the diet of *D. sargus* was mainly through crustaceans, barnacles (*B. amphitrite*), and gastropods (*Gibbula* spp.), which were the dominant food items found in the stomachs. The presence of some polychaetes (*P. hoplura* and *S. vermicularis*) in the stomachs demonstrates that fish forage over hard substrata, because those species are common in artificial habitats (Boaventura *et al.*, 2006). *Diplodus sargus* also feeds on algae which grow on AR hard substrata (e.g. *R. holmesii*), and on seaweeds (e.g. *Zostera noltii*) that are brought by currents and deposited on the AR blocks. Our results show that *D. sargus* takes a wide variety of prey, as reported previously by Figueiredo *et al.* (2005). Those authors classified *D. sargus* as a generalist, opportunistic, and remarkably omnivorous species. In contrast to our results, Pepe *et al.* (1998) showed that the diet of *D. sargus* was mainly sandy macrobenthic species of bivalves, gastropods, and echinoderms. However, the ARs of the area of that study (northwestern Sicily, Italy) are located close to a field of sea grass (*Cymodocea nodosa*), which was the main food item found in the fish stomachs. According to Pepe *et al.* (1998), the AR was more important as a refuge than as a feeding area. Nonetheless, Hueckel and Buckley (1987) showed that while fish may initially come to an AR for shelter or orientation, they soon become foragers on reef-produced items. *Diplodus sargus* is able to take advantage of the environments they colonize/inhabit. Therefore, as suggested by Baldó and Drake (2002), feeding on AR macrofauna can be, among other reasons, a consequence of the available macrobenthic community rather than a feeding preference. The importance of ARs for fish diet has also been recorded in other studies (Donaldson and Clavijo, 1994; Pike and Lindquist, 1994). *Diplodus D. annularis* obviously depends on AR fauna because the dominant prey items were crustaceans, amphipods, and decapods belonging to the AR community (Relini *et al.*,



**Figure 1.** (a) Relative contribution of the different items (based on the number) found in *D. sargus* stomachs by season: AR, artificial reef species; SB, sandy seabed species; U, unidentified species; UO, species of indeterminate origin. (b) MDS ordination inferred from the macrobenthic communities from the AR and surrounding soft bottom, as well as from the diet of *D. sargus*. Filled circles, soft seabed species; triangles, artificial reef species; squares, diet.

2002). Pepe *et al.* (1996) found that serpulid polychaetes were the most important prey of *D. vulgaris* foraging over AR HS.

According to Bohnsack's (1989) predictions, the biomass production and catches will increase as some function of the amount of AR material deployment. However, AR maturity and production is not immediate, and a lag before significant AR production and consequently fishery enhancement is to be expected. Hueckel and Buckley (1987) found that as an AR ages, food resources and predator populations associated with the reef also increase. When well-designed, located and constructed, with an adequate quantity of stable and durable substratum, man-made reefs can, in theory, be equally as productive as naturally occurring hard-substrata habitats, limited only by the lifespan of the materials utilized in their construction. Given the material used in the construction of the Algarve ARs, the structures in place could remain productive for several hundred years. Therefore, among the potential benefits of these man-made reefs, is enhancement of the availability of food for many years. Steimle *et al.* (2002) reported the importance of habitat AR value to enhance benthic productivity. This is also the case for the Algarve coast, for which it has been shown that ARs contribute to the increase of local biological production (Boaventura *et al.*, 2006; Moura *et al.*, 2006).

We have demonstrated that *D. sargus* uses the available biomass produced at the AR as food. Therefore, energy is transferred from the AR to the fish, and is used for fish growth, movement, and reproduction. Because of *D. sargus* reef fidelity and the large size of the Algarve artificial habitats (covering more than 47 km<sup>2</sup>), it is reasonable to expect that these man-made structures will enhance the local fishery. Hopefully, this predicted enhancement of the *D. sargus* fishery will be confirmed in future through analysis of the evolution of the landings.

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