BULLETIN OF MARINE SCIENCE, 78(1): 39–56, 2006

FEEDING BEHAVIOR OF THREE COMMON FISHES AT AN ARTIFICIAL REEF IN THE NORTHERN ADRIATIC SEA

Gianna Fabi, Sarine Manoukian, and Alessandra Spagnolo

ABSTRACT

The trophic role played by the Senigallia artificial reef (northern Adriatic Sea) in the diet of three finfish (*Sciaena umbra* Linnaeus, 1758, *Diplodus annularis* Linnaeus, 1758, and *Lithognathus mormyrus* Linnaeus, 1758) was investigated seasonally from 1997 to 1999. The gut contents of each species were compared with the benthic communities on the manmade structures, in the surrounding soft bottom, inside and outside the reef, as well as at an open-sea control site. Due to low fish densities in winter and spring, only summer and fall data were considered. The vertical walls of the manmade structures were colonized by hard-substrate species, while the horizontal surfaces accumulated sediment and developed a community of soft-bottom organisms. The community inhabiting the soft seabed included primarily mollusks and polychaetes. All of the three fish species fed on hard/soft-bottom organisms and mostly preferred crustaceans (decapods), although *L. mormyrus* and *D. annularis* also fed on considerable quantities of mollusks and cnidarians, respectively. The artificial structures provided the main source of food for the three fishes and the link with the reef declined from *S. umbra* to *D. annularis* to *L. mormyrus*.

Many studies have documented higher fish abundance and biomass, and higher catch rates at artificial reefs compared with randomly selected soft bottom control areas (Bohnsack et al., 1991; Bombace et al., 1993; Jensen et al., 2000; Wilson et al., 2003). Nevertheless, questions persist about the role played by artificial reefs in producing new fish biomass versus attracting and aggregating fish from surrounding areas (Polovina, 1991; Santos et al., 1996; Harmelin and Bellan-Santini, 1997; Pickering and Whitmarsh, 1997; Powers et al., 2003). Starting with the hypothesis that additional substrate provides supplementary food resources supporting attached or motile benthic organisms, which are the primary prey items for the reef fish community, several authors attempted to assess the contribution of artificial reefs to new biomass production by investigating whether fish forage on organisms growing on the reef (Badalamenti et al., 1993; Johnson et al., 1994; Lindquist et al., 1994; Ardizzone et al., 1997; Fabi et al., 1998; Relini et al., 2002). Some gut content studies indicate that fish did not feed directly on reef-associated prey items, while others found that several fish species fed on the biota living on reefs or mixtures of hard and soft bottom prey (Badalamenti et al., 1993; Johnson et al., 1994; Lindquist at al., 1994; Collins and Jensen, 1996; Ardizzone et al., 1997; Relini et al., 2002). Possible trophic relationships with the benthic communities on and around manmade structures were suggested in a study on the diet composition of the brown meager, *Sciaena umbra* Linnaeus, 1758 (Fabi et al., 1998). On the basis of this preliminary evidence, the aim of this study was to examine feeding ecology of three species (*S. umbra*, *Diplodus annularis* Linnaeus, 1758, and *Lithognathus mormyrus* Linnaeus, 1758), which represent some of the main components of reef fish assemblages in the northern Adriatic Sea. To do this, we compared the gut contents of the fish around a concrete artificial reef with the macrobenthic communities on, inside, and outside of the reef.

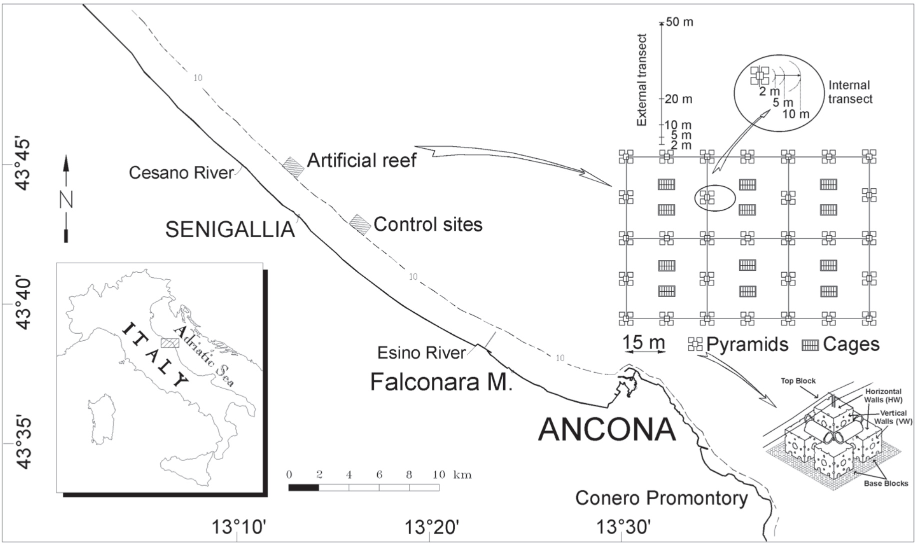

Figure 1. Location of the Senigallia artificial reef and the control sites along the northern Adriatic coast with a perspective view of the concrete pyramids, which constitute the reef. The sampling scheme utilized to collect the soft bottom benthic communities inside (internal transect) and outside (external transect) the reef is also reported.

Materials and Methods

Study Area.—The study was conducted from April 1997 to March 1999 at the Senigallia artificial reef (northern Adriatic Sea), deployed in 1987 at a depth of 12.5 m, about 1.2 nmi offshore on a sandy-mud seabed away from natural hard substrates. The reef consists of 29 pyramids, each made of five 2-m cubic concrete blocks, and 12 concrete cages ($6 \times 4 \times 5$ m) for shellfish culture placed in a rectangular arrangement (Fig. 1). The water temperature ranges from 7 °C in winter to 26–27 °C in summer, without a significant difference between surface and bottom layers. The reef is in an eutrophic marine area, receiving nutrient-rich freshwater from the nearby Cesano River and, sometimes, from the Po River. It is exposed to winds between NW and SE and currents that run parallel to the shoreline in the same direction with average daily intensity that often exceeds 25 cm s^{-1}.

Benthic Community Sampling.—The benthic community that had settled on both the concrete pyramids and to the soft seabed inside and outside of the reef was investigated seasonally, with a total of eight surveys conducted over the two study years.

Hard Substrate Samples.—SCUBA divers scraped 400 cm^2 sample squares from the vertical walls (VW) of the base and the top blocks (Fig. 1) of two randomly selected pyramids. Their horizontal surfaces (HW), which were covered by a thin layer of sandy-mud sediment, were sampled (400 cm^2 squares) with a suction sampler in addition to scraping. Two replicates both from the HW and VW of the base and top blocks of each pyramid were taken at each survey for a total of 16 samples.

Soft Bottom Samples.—The suction sampler was also used to investigate the soft bottom macrozoobenthos. Samples were collected both inside and outside the reef along four transects at increasing distances from the structures, as well as at two open-sea control sites without hard substrates (Fig. 1). A 1600 cm^2 square was used three times at each station to obtain a single sample (96 L). A total of 18 soft bottom samples were collected at each survey.

The biological samples were extracted using 0.5 mm mesh sieves and fixed in 5% formalin. All organisms were sorted through stereo and binocular microscopes, identified to the lowest possible taxonomic level, and their number and weight were recorded.

Fish Collection.—In total, 33 fish collections were carried out monthly and/or fortnightly inside the reef to catch the three target fish using a bottom trammel net, which was lowered into the water at dusk and hauled in at dawn.

All individuals of each target species were measured to the nearest 0.5 cm total length (TL) and dissected for analysis of gut contents. Stomachs were removed by excising the esophagus behind the oral cavity and the intestine just posterior to the pyloric caeca and immediately preserved in a 10% formalin solution. Relative stomach fullness (R) was recorded as integers representing empty stomachs (0), stomachs with trace contents in their lower side (1), stomachs with trace contents along their walls (2) and stomachs that were 50%, 75%, or 100% full (3–5; Vesey and Langford, 1985). Prey items found inside all stomachs with an R value from 1 to 5 were identified to the highest taxonomic resolution possible, counted, and weighed.

Data Analysis.—*Benthic Communities.*—After initial tests indicated no differences among samples within seasons (ANOSIM, R ~0; P > 0.05), the samples collected in each season on HW and VW of the two pyramids were considered replicates. The same was done with the correspondent stations placed along the internal and external transects, and the control stations.

Total species richness (S) was computed as the total number of species collected in each season and at each sampling site. Mean abundance (number of ind dm^{-2}; N) was also calculated per season and station.

For both hard and soft substrates, similarities among the sampling stations in each season were evaluated through the hierarchical agglomerative clustering, employing group-average sorting of PRIMER software package (Clarke and Warwick, 1994).

Fish Feeding Behavior.—The percentage of empty foreguts (*%V* = vacuity coefficient; Hyslop, 1980) was seasonally calculated for each target fish. Since the comparison between the cumulative prey items and progressive number of analyzed stomachs showed that the number of available specimens in winter and spring were not sufficient to obtain a good knowledge of the fish feeding behavior, only summer and fall data were considered.

The frequency of occurrence (*%F*), numerical percentage (*%N*), and percentage by wet weight (*%W*) of each food item in all stomachs were computed to describe the quantitative importance of each prey group in the diet. These indices were combined to determine the prey utilization by the Relative Importance Index for each prey item (*RI;* George and Hadley, 1979; Hyslop, 1980), defined as:

$$RI = \frac{(\%F + \%N + \%W) \times 100}{\sum_{i=1}^{S} (\%F + \%N + \%W)}$$

Preferences in the diet of *S. umbra, D. annularis,* and *L. mormyrus* were evaluated using the Linear Food Selection Index (*L;* Strauss, 1979) that gives food selectivity for each prey:

$$L = r_i - p_i$$

where r_i and p_i are the relative proportions of a prey item in the diet and in the whole benthic community, respectively. The index ranges from –1 to +1, with positive values indicating preference and negative indicating avoidance or inaccessibility, and zero is the expected value for random or neutral feeding.

Food niche breadth was calculated for the three fish in each season using Levins Index (Krebs, 1998), given as:

$$B_A = \frac{\left(1 \Big/ \sum_{i=1}^{n} r_i^2\right) - 1}{n-1}$$

where B_A is the standardized Levins Index by the number of prey items n and r_i is the relative proportion of each item in the diet. Values of B_A close to 1.0 indicate that the resources are equidistributed (generalist behavior), while diet concentration in one or few items will generate B_A values close to zero (specialist behavior).

Feeding overlap within each target species between seasons and within each season among the three fish was evaluated using Schoener Index (*α;* Schoener, 1974):

$$\alpha = 1 - \frac{1}{2}\sum_{i=1}^{n}\left|r_i^x - r_i^y\right|$$

where r_i^x and r_i^y are the relative proportions of a prey item in the diet of fish x and fish y, respectively. Diet overlap was computed both at a taxonomic group and at a species level. It was considered low (0.00–0.29), moderate (0.30–0.59), or high (≥ 0.60) following Langton (1982).

Comparison Between Benthic Communities and Food Items.—Site clusters underlined by hierarchical analysis on the hard substrate and soft bottom benthic communities were considered to evaluate the possible linkage between the diet composition of the three fish and the different habitats. Spatial distribution of every prey item was described according to its relative proportion in each site classification and season. Overall contribution of the investigated habitats to the feeding behavior of the three fish was finally assessed by summarizing the relative occurrence of the prey found in each of them. Food items not found anywhere were labeled as not found (NF) items.

Results

Benthic Communities.—The benthic communities on the manmade structures had lower S values on VW than on HW in both seasons (Table 1). The former were colonized by hard substrate species, particularly by filter feeders such as bivalves, hydroids, and barnacles. In addition, soft bottom, deposit, and suspension feeders (especially mollusks) were found on the latter due to the thin layer of sandy-mud sediment settled on them. Mean abundances tended to be higher on VW than on HW (Table 1). Cluster analysis confirmed these differences by grouping the surfaces according to their orientation at similarity levels > 70% in both seasons.

The soft bottom infauna tended to have highest S values inside the reef (Table 2). Soft-bottom species dominated everywhere; in addition, a few hard-bottom organisms were recorded at the inner sites. Summer and fall abundances were similar

Table 1. Total species richness (S) and mean abundance (N; number of individuals dm^{-2} ± standard error) obtained in summer and fall both for horizontal (HW) and vertical (VW) walls of the concrete artificial reef pyramids.

	HW		VW	
	Summer	Fall	Summer	Fall
S	95	82	85	79
N	145.8 ± 18.3	248.9 ± 37.3	225.2 ± 65.5	310.8 ± 79.3

Table 2. Total benthic species richness (S) and mean abundance (N; number of ind dm^{-2} ± standard errors) obtained in summer and fall at the open sea control sites, at the sampling stations of the external transects (E; 50, 20, 10, 5, and 2 m from an outer pyramid) and at the sampling sites of internal transects (I; 2, 5, and 10, m far from a central pyramid).

			External transects										Internal transects					
			E50		E20		E10		E5		E2		I2		I5		I10	
	Summer	Fall	Summer	Fall	Summer	Fall	Summer	Fall	Summer	Fall	Summer	Fall	Summer	Fall	Summer	Fall	Summer	Fall
S	47	50	57	48	43	44	42	43	44	32	57	32	57	53	64	64	63	56
N	13.5 ± 2.9	11.4 ± 6.0	9.3 ± 2.2	18.4 ± 8.4	11.0 ± 3.6	11.4 ± 2.4	9.7 ± 3.8	8.0 ± 2.9	8.0 ± 1.7	8.2 ± 5.9	18.3 ± 9.7	4.0 ± 0.8	8.3 ± 5.3	11.5 ± 3.2	18.4 ± 8.6	8.5 ± 3.2	15.7 ± 3.4	9.4 ± 3.8

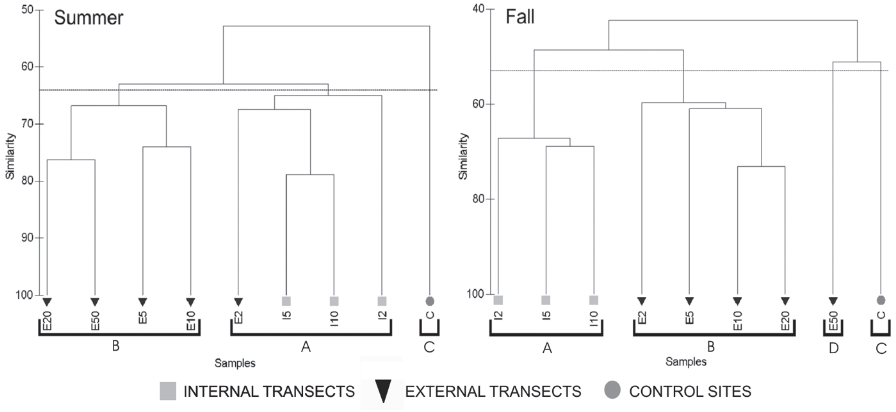

Figure 2. Dendrograms of hierarchical clustering using group-average linking of the sampling stations along the internal (I2, I5, and I10) and external (E2, E5, E10, E20, and E50) transects and at control sites (C) in summer and fall. The site groups separated at 64% (A, B, and C) and 53% (A, B, C, and D) similarity threshold (dotted line) in summer and fall respectively are indicated.

along the inner and outer transects (Table 2) with a general decrease in the fall. Three and four clusters were identified in summer and fall, respectively, practically splitting the inner from the outer sites at high similarity levels (Fig. 2).

Feeding Behavior.—A total of 560 stomachs (221 *S. umbra*, 231 *D. annularis*, and 108 *L. mormyrus*) was examined (Table 3). The highest V was found in the striped seabream *L. mormyrus* (68.5%), and the lowest in the brown meager, *S. umbra* (36.2%). An intermediate value was observed for the annular seabream, *D. annularis* (44.6%). In total, 51 taxa were found in the stomachs of *S. umbra*, 39 and 28 in those of *D. annularis* and *L. mormyrus*, respectively. All three fish showed a more diversified diet in summer (Tables 4, 5, 6).

RI revealed that crustaceans, dominated by decapods, formed the largest diet component for *S. umbra* and *D. annularis* in both seasons. They were by far the most important food item for the brown meagre (summer: 87.99%; fall: 66.25%), but were of equal importance as cnidarians for the annular seabream in fall. On the other hand, crustaceans and mollusks always had the same relevance in the diet of striped seabream.

In terms of species, the most important prey of the three fish was the decapod, *Liocarcinus vernalis* (Risso, 1827) (Tables 4, 5, 6). In summer, another important prey item in the dietary composition of *S. umbra* was the amphipod *Elasmopus rapax* A. Costa, 1853 followed by the decapod *Athanas nitescens* (Leach, 1814). The

Table 3. Number of fish caught in each season, total length (TL) range, relative stomach fullness (R), and vacuity coefficient (%V) of the stomachs of the three target species. R values: 0 = empty stomach; 1 = stomach with trace contents in its lower side; 2 = stomach with trace contents along its walls; 3 = 50% full stomach; 4 = 75% full stomach; 5 = 100% full stomach.

Species	Season	Number of individuals	TL range (cm)	R						%V
				0	1	2	3	4	5	
Sciaena umbra	Summer	143	19–35	56	20	11	11	11	34	39.2
	Fall	78	15–36	24	7	9	3	12	23	30.8
Diplodus annularis	Summer	122	10–23	49	19	8	7	14	26	40.2
	Fall	108	8–23	54	14	8	7	7	18	50.0
Lithognathus mormyrus	Summer	43	14–31	31	2	2	-	3	5	72.1
	Fall	65	15–34	43	9	2	3	1	7	66.2

Table 4. Frequency of occurrence (%F), percentage by number (%N), percentage by weight (%W), and Relative Importance Index (%RI) obtained for each prey item recorded in the stomach contents of *Sciaena umbra*. * = < 0.01.

Group	Taxon	Summer				Fall			
		%F	%N	%W	%RI	%F	%N	%W	%RI
Cnidarians									
Anthozoans	Actiniaria nd	1.15	0.07	0.02	0.27				
Hydrozoans	*Obelia dichotoma* Linnaeus 1758	1.15	0.07	*	0.27				
Mollusks									
Bivalves	*Corbula gibba* (Olivi, 1792)	1.15	0.07	0.01	0.27				
	Mytilus galloprovincialis Lamarck, 1819	2.30	0.29	0.13	0.60				
	Spisula subtruncata (Da Costa, 1778)	1.15	0.15	0.10	0.31				
Cephalopods	*Sepia officinalis* Linnaeus, 1758	1.15	0.07	0.80	0.44				
	Sepiola rondeleti Leach, 1817	1.15	0.07	0.13	0.30				
Gastropods	*Nassarius incrassatus* (Stroem, 1768)	4.60	0.29	0.04	1.08				
	Nassarius reticulatus (Linnaeus, 1758)	1.15	0.15	0.02	0.29				
Polychaetes	*Marphysa sanguinea* (Montagu, 1815)					25.95	11.93	35.31	19.18
	Nepthys hystricis Mc Intosh, 1900					1.85	1.83	1.17	1.27
	Polychaeta juv	1.15	0.07	0.03	0.27				
Crustaceans									
Amphipods	*Ampelisca intermedia* Bellan-Santini & Diviacco,1990	1.15	0.07	*	0.27				
	Amphipoda nd	1.15	0.07	*	0.27				
	Corophium acherusicum A. Costa, 1851	4.60	0.59	0.01	1.14				
	Elasmopus rapax A. Costa, 1853	14.94	56.07	5.39	16.74	5.56	1.38	0.01	1.82
Decapods	*Alpheus dentipes* Guérin-Méneville, 1832	11.49	1.32	0.88	3.00	11.11	5.05	0.47	4.36
	Alpheus glaber (Olivi, 1792)	2.30	0.29	0.41	0.66				
	Athanas nitescens (Leach, 1814)	35.63	9.35	4.73	10.89	12.96	9.17	0.26	5.87
	Brachiura nd	3.45	0.29	0.67	0.97	3.70	0.92	0.24	1.27
	Brachynotus gemmellari (Risso, 1839)	10.34	0.81	3.97	3.32	12.96	5.50	6.50	6.54
	Diogenes pugilator (Roux, 1829)	1.15	0.07	0.18	0.31				
	Galathea spp.					1.85	0.46	0.05	0.62
	Liocarcinus vernalis (Risso, 1827)	31.03	9.57	57.26	21.45	25.93	22.94	33.32	21.54
	Lysmata seticaudata (Risso, 1816)	4.60	0.52	4.97	2.21				
	Macropodia rostrata (Linnaeus, 1761)					1.85	0.46	0.07	0.62
	Natantia nd	4.60	0.37	0.19	1.13	18.52	5.50	0.56	6.44
	Paguridea nd	1.15	0.07	0.86	0.46				
	Palaemon serratus (Pennant, 1777)					9.26	4.13	7.76	5.54
	Philocheras monacanthus (Holthuis, 1961)	11.49	2.06	0.51	3.08				
	Pilumnus hirtellus (Linnaeus, 1761)	10.34	0.74	4.74	3.47	3.70	0.92	4.41	2.37
	Pisidia longicornis (Linnaeus, 1767)	1.15	0.07	0.03	0.27				
	Pisidia longimana (Risso, 1816)	21.84	2.65	3.94	6.23	3.70	0.92	0.28	1.29
	Processa edulis (Risso, 1816)	20.69	4.78	1.75	5.97	5.56	5.96	0.20	3.07
	Processa spp.	2.30	0.59	0.16	0.67	3.70	8.72	0.60	3.41
	Thoralus cranchii (Leach, 1817)	20.69	6.03	1.73	6.24	9.26	5.05	0.14	3.79
	Upogebia pusilla (Petagna, 1792)	1.15	0.07	0.49	0.38				
	Upogebia tipica (Nardo, 1819)	3.45	0.29	1.31	1.11	3.70	0.92	0.15	1.25
	Xantho poressa (Olivi,1792)					1.85	0.46	0.07	0.62
Isopods	Cirolanidae nd	1.15	0.07	0.04	0.28	1.85	0.92	*	0.73
	Jaeropsis spp.	1.15	0.07	*	0.27				
Mysidiaceans	Mysidiacea nd	1.15	0.07	0.01	0.27				
	Siriella spp.	1.15	0.15	0.02	0.29				
Echinoderms									
Echinoids	Echinoidea nd	3.45	0.22	0.93	1.01				
	Schizaster canaliferus Lamarck, 1816					3.70	0.92	2.19	1.79
Ophiuroids	*Ophiura* spp.	2.30	0.29	0.03	0.57	1.85	0.46	*	0.61
Osteichthyes	*Callionymus rissoi* Lesueur, 1814	4.60	0.66	2.23	1.64	5.56	2.29	0.85	2.28
	Gobidae nd					1.85	1.38	1.05	1.12
	Osteichthyes nd	3.45	0.22	0.47	0.91	1.85	0.46	2.90	1.37
	Pomatoschistus spp.					1.85	1.38	1.43	1.22
	Soleidae nd	1.15	0.15	0.82	0.46				

Table 5. Frequency of occurrence (%F), percentage by number (%N), percentage by weight (%W), and Relative Importance Index (%RI) obtained for each prey item recorded in the stomach contents of *Diplodus annularis*. * = < 0.01.

Group	Taxon	Summer				Fall			
		%F	%N	%W	%RI	%F	%N	%W	%RI
Cnidarians									
Anthozoans	Actiniaria nd	4.11	1.86	2.00	2.49	9.26	6.10	11.77	8.88
	Calliactis parasitica (Couch, 1842)	6.85	5.12	9.68	6.75				
Hydrozoans	*Bougainvillia ramosa* (Van Beneden, 1844)	1.37	0.47	0.05	0.59	1.85	1.22	0.20	1.07
	Obelia dichotoma Linnaeus 1758	12.33	7.44	1.75	6.71	27.78	30.49	5.40	20.83
Nemerteans	Nemertea nd					1.85	1.22	1.36	1.45
Mollusks									
Bivalves	Bivalvia juv	4.11	1.40	3.54	2.82				
	Corbula gibba (Olivi, 1792)	1.37	0.47	0.71	0.79				
	Mytilus galloprovincialis Lamarck, 1819	2.74	0.93	1.93	1.75				
Cephalopods	*Sepiola rondeleti* Leach, 1817	1.37	0.47	5.76	2.37				
Gastropods	*Nassarius mutabilis* (Linnaeus, 1758)	12.33	8.37	4.98	8.01	1.85	6.10	4.29	4.01
	Nassarius pygmaeus (Lamarck, 1822)	1.37	0.47	0.05	0.59				
	Philine aperta (Linnaeus, 1767)	2.74	1.40	1.27	1.69				
Polychaetes									
	Pherusa monilifera (Delle Chjaie, 1841)	1.37	0.47	0.11	0.92				
	Phyllodoce mucosa (Oersted,1843)	1.37	0.93	0.02	0.72				
	Polychaeta juv					3.70	7.32	0.57	3.79
	Polydora ciliata (Johnston, 1838)	1.37	1.86	0.03	1.02				
	Pomatoceros triqueter (Linnaeus, 1767)	1.37	0.47	0.12	0.61				
	Terebellidae nd					1.85	1.22	4.97	2.63
Crustaceans									
Amphipods	*Ampelisca intermedia* Bellan-Santini & Diviacco,1990					1.85	1.22	*	1.01
	Corophium acherusicum A. Costa, 1851	4.11	13.49	0.02	5.50	1.85	1.22	*	1.01
	Gammaridae nd					1.85	1.22	*	1.01
	Ischyrocerus inexpectatus Ruffo, 1959	1.37	1.86	*	1.01				
	Stenothoe valida Dana, 1855	1.37	13.02	0.06	4.51				
Decapods	Brachiura nd	2.74	1.40	0.69	1.50				
	Diogenes pugilator (Roux, 1829)	5.48	2.33	3.69	3.59	1.85	1.22	0.35	1.12
	Liocarcinus maculatus (Risso, 1827)	1.37	0.93	2.36	1.45				
	Liocarcinus vernalis (Risso, 1827)	17.81	14.88	46.67	24.76	12.96	10.98	40.77	21.18
	Natantia nd	2.74	0.93	1.02	1.46	3.70	2.44	0.70	2.24
	Pilumnus hirtellus (Linnaeus, 1761)					1.85	1.22	2.51	1.83
Isopods	Cirolanidae nd	8.22	11.16	1.68	6.57	7.41	7.32	0.11	4.86
	Cymothoidae nd	1.37	0.47	0.22	0.64				
	Flabellifera nd					1.85	1.22	0.02	1.01
	Isopoda nd	2.74	0.93	0.04	1.16	1.85	1.22	0.92	1.31
	Limnoridae nd					1.85	1.22	0.51	1.17
	Rocinela dumerili (Lucas, 1849)	2.74	0.93	0.26	1.23	1.85	1.22	0.02	1.01
Echinoderms									
Ophiuroids	*Amphiura chiajei* Forbes, 1843					1.85	1.22	2.47	1.81
Holothurians	Holothuroidea nd	1.37	0.47	0.05	0.59	3.70	2.44	0.62	2.21
Osteichthyes	Osteichthyes nd	6.85	2.33	5.64	4.62	9.26	6.10	11.39	8.75
	Soleidae nd	4.11	2.79	4.58	3.58	1.85	4.88	11.05	5.82

Table 6. Frequency of occurrence (%F), percentage by number (%N), percentage by weight (%W), and Relative Importance Index (%RI) obtained for each prey item recorded in the stomach contents of *Lithognathus mormyrus*.

Group	Taxon	Summer				Fall			
		%F	%N	%W	%RI	%F	%N	%W	%RI
Cnidarians									
Anthozoans	Actiniaria nd	8.33	1.49	14.48	5.61				
Hydrozoans	*Tubularia crocea* Agassiz 1862	8.33	1.49	0.84	2.46				
Mollusks									
Bivalves	*Chamelea gallina* (Linnaeus, 1758)					4.55	3.33	0.61	2.87
	Corbula gibba (Olivi, 1792)	8.33	1.49	1.76	2.67	13.64	16.67	6.25	12.37
	Dosinia lupinus (Linnaeus, 1758)	8.33	2.99	9.11	4.71				
	Ensis spp.					4.55	3.33	5.03	4.37
	Mysella bidentata (Montagu, 1803)					4.55	13.33	0.06	6.07
	Mytilus galloprovincialis Lamarck, 1819	8.33	1.49	1.18	2.54				
	Nucula nucleus (Linnaeus, 1758)	8.33	4.48	1.69	3.35				
	Paphia aurea (Gmelin, 1791)	25.00	14.93	12.97	12.21				
	Spisula subtruncata (Da Costa, 1778)	16.67	7.46	2.07	6.05	9.09	10.00	0.98	6.79
Gastropods	*Nassarius pygmaeus* (Lamarck, 1822)	16.67	20.90	0.73	8.84	4.55	3.33	0.79	2.94
	Nassarius reticulatus (Linnaeus, 1758)	8.33	11.94	1.43	5.01	4.55	3.33	0.85	2.95
	Nudibranchia nd					4.55	3.33	3.75	3.93
Polychaetes									
	Glycera unicornis Savigny, 1818	8.33	1.49	0.03	2.28				
	Lumbrineris gracilis (Ehlers, 1868)	8.33	1.49	0.01	2.27				
	Polychaeta juv	8.33	2.99	0.01	2.61				
	Polydora ciliata (Johnston, 1838)	16.67	5.97	0.03	5.23	9.09	13.33	0.08	7.62
	Sabellaria spinulosa Leuckart, 1849					4.55	3.33	0.09	2.70
Crustaceans									
Amphipods	*Ampelisca diadema* (A. Costa, 1851)	8.33	1.49	0.01	2.27				
	Amphipoda nd					4.55	3.33	0.01	2.67
	Corophium acherusicum A. Costa, 1851	8.33	1.49	0.06	2.28				
Cirripeds	*Balanus improvisus* Darwin, 1854	8.33	1.49	0.02	2.27				
Decapods	*Liocarcinus vernalis* (Risso, 1827)	33.33	8.96	53.33	22.06	18.18	16.67	64.09	33.49
	Paguridea nd					4.55	3.33	17.09	8.45
	Processa spp.	8.33	2.99	0.16	2.65				
Echinoderms									
Echinoides	*Schizaster canaliferus* Lamarck, 1816					4.55	3.33	0.33	2.78
Ophiuroides	*Amphiura chiajei* Forbes, 1843	8.33	2.99	0.09	2.63				

polychaete *Marphysa sanguinea* (Montagu, 1815) reached a similar RI to that of *L. vernalis* in fall (Table 4). The gastropod *Nassarius mutabilis* (Linnaeus, 1758) and the hydroid *Obelia dichotoma* Linnaeus, 1758 were the secondary major prey of *D. annularis* in summer and fall respectively. The former was clearly less important than *L. vernalis*, while the latter had a similar RI (Table 5). Finally, the diet of *L. mormyrus* was restricted to many fewer food items with *Paphia aurea* (Gmelin, 1791) and *Corbula gibba* (Olivi, 1792) as secondary relevant prey in summer and fall, respectively (Table 6). *Nassarius pygmaeus* (Lamarck, 1822), *Nassarius reticulatus* (Linnaeus, 1758), and unidentified Actiniaria also played an important role in the summer diet of *L. mormyrus*.

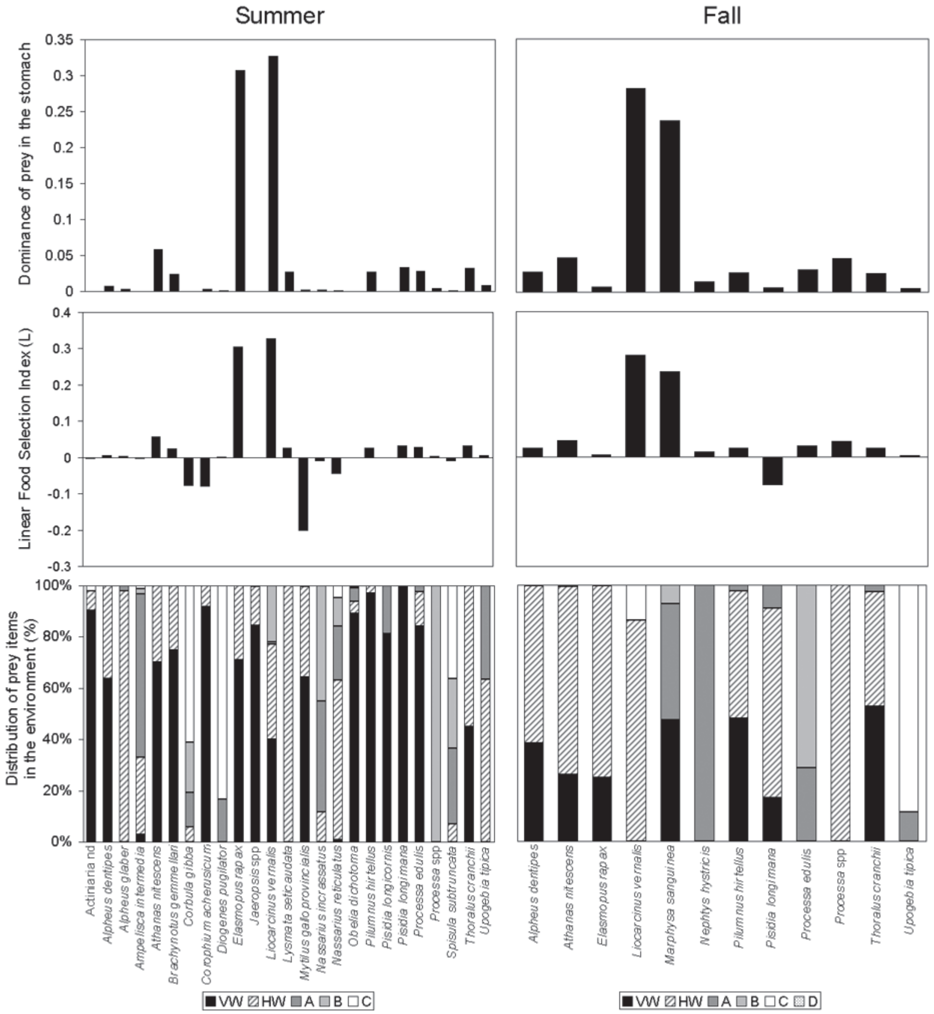

Figure 3. Dominance of prey in the stomachs and Linear Food Selection Index calculated for *Sciaena umbra* in summer and fall. The relative distribution of prey items in the environment in the two seasons is also reported according to the habitat seasonal clusters. VW = vertical walls; HW = horizontal walls. Summer: A = I2, I5, I10, E2; B = E5, E10, E20, E50; C = control sites. Fall: A = I2, I5, I10; B = E2, E5, E10, E20; C = control sites; D = E50.

Besides being eaten in large quantities, *L. vernalis* was also preferentially selected by the three target species in both seasons (Figs. 3, 4, and 5). The same occurred with the above mentioned secondary prey items for each fish and season. In contrast, other food items [i.e., *Corophium acherusicum* Costa, 1851 and *Chamelea gallina* (Linnaeus, 1758)] were not preferentially selected, while *Mytilus galloprovincialis* Lamarck, 1819 was avoided.

Seasonal changes in macrobenthic communities affected the diet and prey selection of the two seabreams. The quantity of *O. dichotoma* consumed by *D. annularis*, for example, increased from summer to fall when the density of this hydroid was very high on both VW (22.5 ± 15.7 ind dm^{-2}) and HW (5.2 ± 1.3 ind dm^{-2}) in comparison to the previous season (VW: 0.9 ± 0.3 ind dm^{-2}; HW: 0.1 ± 0.0 ind dm^{-2}; Fig. 4).

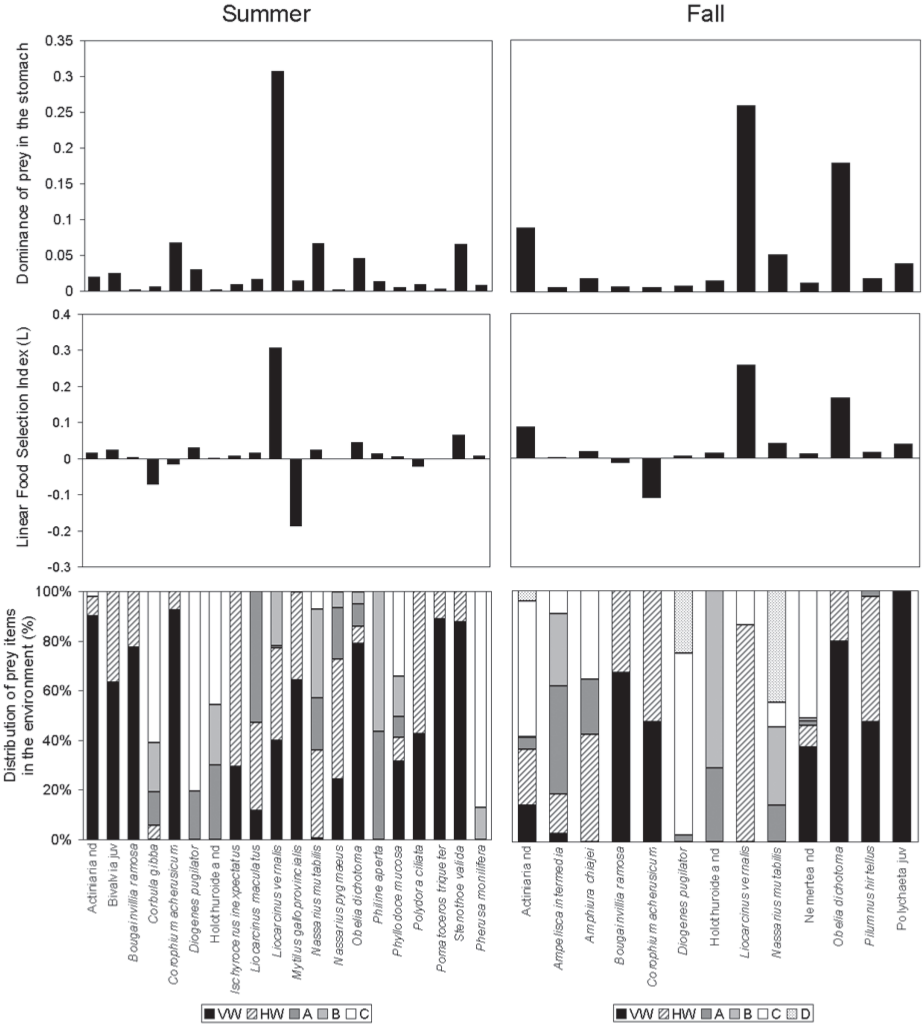

Figure 4. Dominance of prey in the stomachs and Linear Food Selection Index calculated for *Diplodus annularis* in summer and fall. The distribution of prey items in the environment in the two seasons is also reported according to the habitat seasonal clusters. VW = vertical walls; HW = horizontal walls. Summer: A = I2, I5, I10, E2; B = E5, E10, E20, E50; C = control sites. Fall: A = I2, I5, I10; B = E2, E5, E10, E20; C = control sites; D = E50.

Such feeding behavior was also observed for *L. mormyrus*. In fact, the quantity of *N. reticulatus* consumed by the striped seabream clearly declined and L became negative in the fall when the density of this gastropod decreased, especially on HW (Fig. 5). In contrast, although *C. gibba* was similarly abundant in both seasons, striped seabream ate this bivalve in large quantities only in fall when the abundance of the most preferred prey items dropped. At that point, L became positive, indicating a preferential selection for this species in this season.

An overall evaluation of the role played in the trophic behavior of the three fish by the different habitats defined by seasonal cluster analysis indicated that *S. umbra* caught about 70% of its prey items on the pyramids, with a considerable shift of feed-

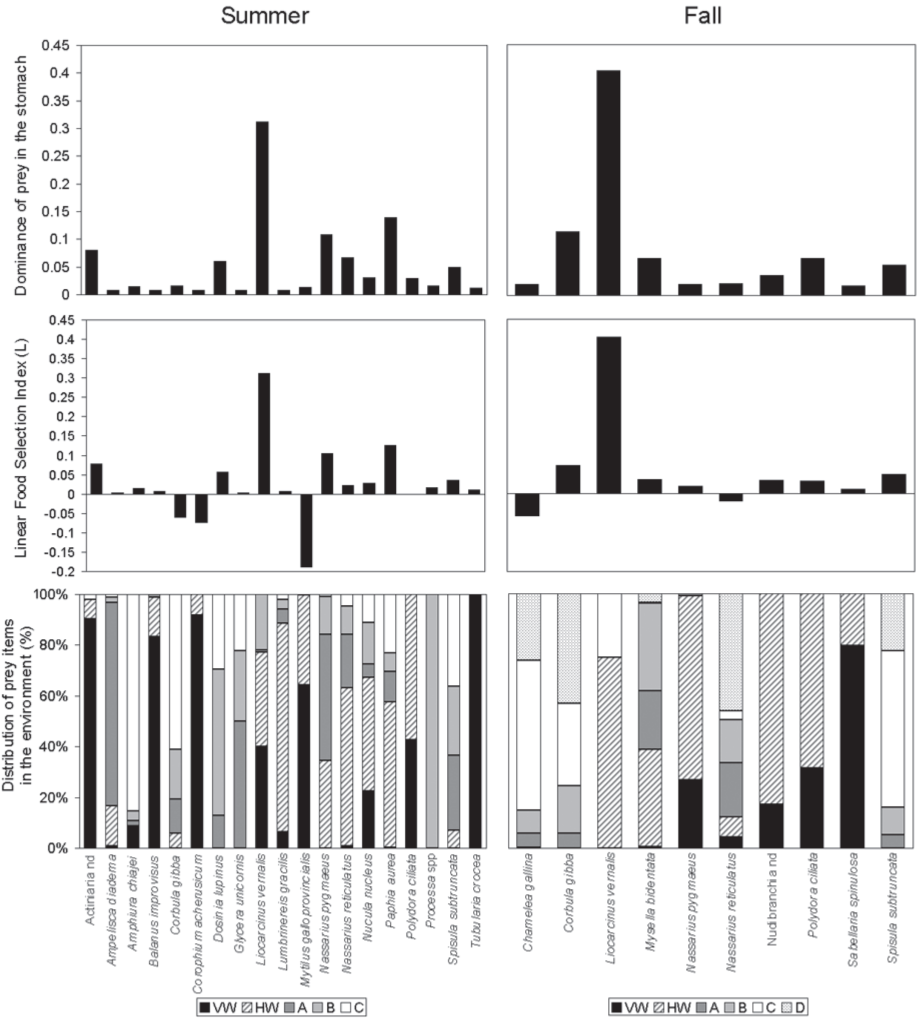

Figure 5. Dominance of prey in the stomachs and Linear Food Selection Index calculated for *Lithognathus mormyrus* in summer and fall. The distribution of prey items in the environment in the two seasons is also reported according to the habitat seasonal clusters. VW = vertical walls; HW = horizontal walls. Summer: A = I2, I5, I10, E2; B = E5, E10, E20, E50; C = control sites. Fall: A = I2, I5, I10; B = E2, E5, E10, E20; C = control sites; D = E50.

ing habitat selection from VW to HW in fall according to a change in the distribution of the main food items (Figs. 3, 6). The contribution of the soft bottom inside the reef increased from 9.99% to 16.14% from summer to fall. At the same time, the contribution of the external transects and C sites decreased in importance by half.

Diplodus annularis and *L. mormyrus* gained 50%–57% of their nutrition from the artificial structures, although they also fed outside the reef and at C sites (Fig. 6). This portion appeared particularly consistent for the striped seabream, rising from 29.76% in summer to 40.95% in fall. The role of the different environments in the diet of *D. annularis*, instead, stayed almost unchanged in the two seasons (Fig. 6).

Sciaena umbra showed a more specialist trophic behavior in summer in comparison to fall, while *L. mormyrus* was more generalist in both seasons (Table 7). Equal

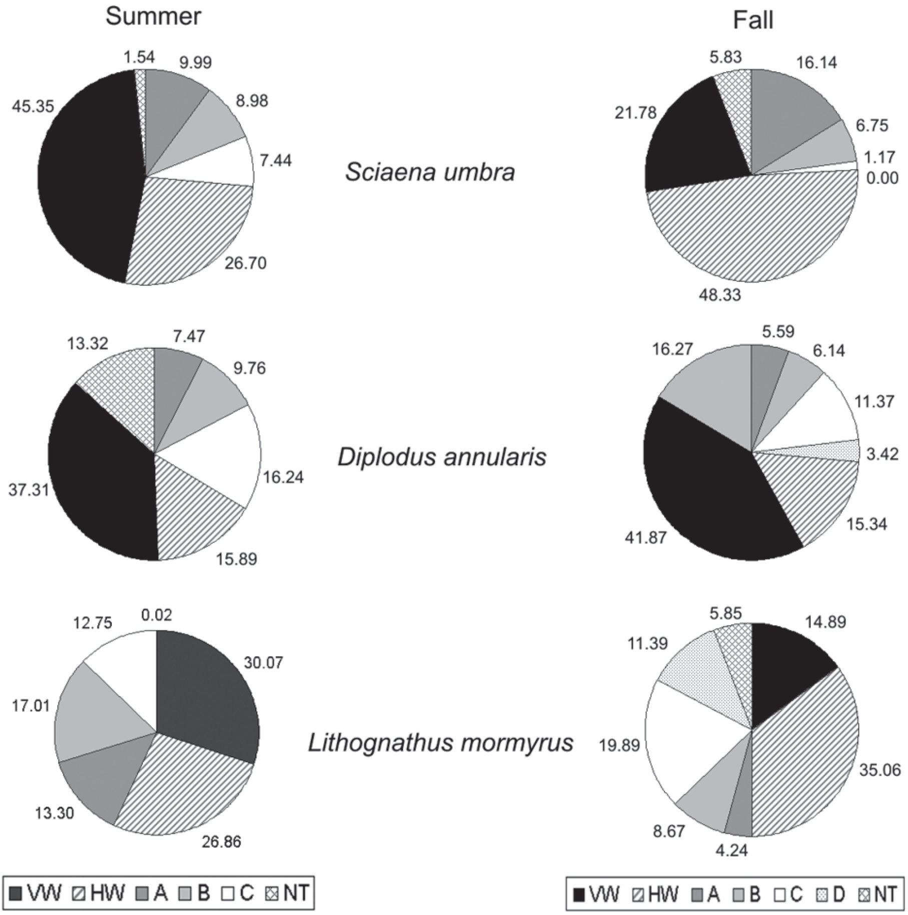

Figure 6. Contribution of the different habitats defined by cluster analysis to the diet of the three target fish. NT = prey items not found in the investigated areas. VW = vertical walls; HW = horizontal walls. Summer: A = I2, I5, I10, E2; B = E5, E10, E20, E50; C = control sites. Fall: A = I2, I5, I10; B = E2, E5, E10, E20; C = control sites; D = E50.

intermediate values of B_A were obtained for *D. annularis* in the two periods. High and moderate feeding overlaps between the two seasons at group and species level, respectively, were observed for all three fish.

Feeding overlap between fish based on group prey items (Table 8) indicated a major similarity for the two seabreams in summer mainly due to decapods and anthozoans (Tables 5, 6). A slightly lower value was obtained between *S. umbra* and *D. annularis* largely due to the importance of decapods and amphipods in the diet of the brown meagre (Tables 4, 5). A more moderate value was found comparing *D. annularis* with *L. mormyrus* that preferentially fed on considerable quantities of bivalves and gastropods (Tables 4, 6). In the fall, feeding overlap between brown meagre and striped seabream increased mainly for decapods and echinoids (Table 8), while *D. annularis* cut off with a 0.44 α value for all the pair-wise comparisons due to the strong dominance of hydroids in its diet. A decrease in α at the species level was observed in both seasons (Table 8) because each fish preyed on different food items within the same taxonomic group (Tables 4, 5, 6).

Table 7. Food niche breadth (Levins Index) per season and diet overlap (Schoener Index) between the two seasons computed for the three target fish.

	Levins Index		Schoener Index	
	Summer	Fall	Group level	Species level
Sciaena umbra	0.08	0.22	0.68	0.50
Diplodus annularis	0.23	0.23	0.68	0.52
Lithognathus mormyrus	0.31	0.30	0.78	0.45

Discussion

Monitoring over multiple years at the artificial reef has demonstrated that brown meagre, *S. umbra*, annular seabream, *D. annularis*, and striped seabream, *L. mormyrus*, comprise the main reef fish assemblage. These species colonized the artificial structures just after deployment and their abundance increased to a plateau during the following years (Fabi et al., 1999). Therefore, besides finding shelter with the artificial reef, they likely established trophic relationships with the reef benthic community. An estimate of prey availability and gut content analysis at species level allowed a better understanding of the different roles played in the diet of these fish by the various habitats —the artificial structures, soft bottom inside and outside the reef, and open sea bottom.

Our results indicate that *S. umbra* is a specialist. Previous studies found that it feeds preferentially on decapods that dominated its diet in summer and fall (Chakroun and Ktari, 1981; Fabi et al., 1998; Froglia and Gramitto, 1998), which is confirmed by our measurement of a high feeding overlap between the two seasons. The lowest B_A value recorded in summer was due to the fact that brown meagre selectively chose *L. vernalis* and *E. rapax* in spite of the greater variety of suitable organisms in the environment than in fall. The replacement of *E. rapax* with *M. sanguinea* in fall, when the former decreased and the latter occurred at very low densities in the environment, reduced seasonal diet overlap at the species level and emphasized the specialist feeding behavior of this fish (specific prey items were selected despite their scarce availability).

The two sparids showed slightly more generalist behaviors compared to the sciaenid, without any particular difference between seasons. In fact, they preyed preferentially not only on decapods (mainly *L. vernalis*), but also on cnidarians and/or mollusks. These results are generally consistent with results in different areas (Froglia, 1977; Badalamenti and Manganaro, 1990; Badalamenti et al., 1993; Badalamenti and D'Anna, 1997; Ruitton et al., 2000; Relini et al., 2002), even though a few of them reported amphipods, cumaceans, and isopods as major dietary groups for *L. mormyrus* instead of decapods, and highlighted the importance of algae or phanerogames in the diet of these two fish. The complete absence of plant food in our study is likely due to the lack of vegetation in our study area, most likely a consequence of frequent high water turbidity.

Both fish appeared to be opportunistic, capable of adapting to environmental variations and exploiting the available food resources, although with different strategies. *Lithognathus mormyrus* focused mainly on decapods and mollusks, turning to other prey only when the preferred ones were scarce. Although *D. annularis* also preferred decapods, it fed on other taxonomic groups (i.e., hydroids), particularly when these

Table 8. Diet overlap (Schoener Index) at group and species level within each season among the three target fish.

	Group level						Species level					
	Summer			Fall			Summer			Fall		
	Sciaena umbra	*Diplodus annularis*	*Lithognathus mormyrus*	*Sciaena umbra*	*Diplodus annularis*	*Lithognathus mormyrus*	*Sciaena umbra*	*Diplodus annularis*	*Lithognathus mormyrus*	*Sciaena umbra*	*Diplodus annularis*	*Lithognathus mormyrus*
Sciaena umbra	1.00			1.00			1.00			1.00		
Diplodus annularis	0.55	1.00		0.44	1.00		0.33	1.00		0.31	1.00	
Lithognathus mormyrus	0.35	0.59	1.00	0.61	0.44	1.00	0.32	0.37	1.00	0.30	0.26	1.00

were abundant. A similar behavior of the annular seabream was found by Relini et al. (2002).

Although most of prey items recorded in the gut contents of the three fish were typical of soft bottom, artificial structures represented the main source of food for them as demonstrated by the fact that most of preferred prey items were exclusively or chiefly found on the manmade substrates. This can be attributed both to the occurrence of soft bottom species in the layer of sand and mud covering the horizontal surfaces of the modules, and to the large abundance of *M. galloprovincialis*, that provided good shelter availability for interstitial species some of which are associated with silt-enriched habitats. However, the three fish did not compete in terms of trophic overlap because, although their diet composition was similar as taxonomic groups, they preferred different species, all of them easily available inside the reef.

According to the affinity towards natural or artificial hard substrates of the target fish, the species-specific trophic behavior of the three fish suggested that the affinity to the reef gradually weakened from *S. umbra* to *D. annularis* to *L. mormyrus*. Brown meagre, indeed, gained its nutrition almost exclusively from the manmade structures. The soft bottom inside the reef provided consistent supplementary food resources in fall, while the outer habitat assumed a consistently marginal role. On the contrary, the outer habitat supplied a good proportion of prey items to the two sparids, especially *L. mormyrus*. A similar trophic linkage between the annular seabream and the benthic communities associated with manmade substrates was also shown along the Mediterranean French coast (Ruitton et al., 2000), in the Ligurian Sea (Relini et al., 2002), and in the Castellammare Gulf, Sicily (Badalamenti and D'Anna, 1997). In contrast, Ardizzone et al. (1997) reported that the preferred feeding sites of *D. annularis* were the sandy bottoms around the reef and not the reef itself in the Central Tyrrhenian Sea. Moreover, they did not identify any particular role played by the artificial substrates in the diet of *L. mormyrus*. Even though the artificial reef did not represent the exclusive source of food of these two sparids, our study suggested that the artificial reef enlarged their feeding spectrum and provided for greater food availability, potentially reducing energy expenditures, especially for *D. annularis*, which tends to remain inside the reef from spring to fall (Fabi and Fiorentini, 1994; Fabi et al., 1999).

These results, together with the catch yield increases reported since the deployment of the artificial reef (Fabi et al., 1999), would suggest that the Senigallia artificial reef can contribute to biomass increases of the three fish species. Due to the small reef size, such an effect appears moderate and restricted to local populations, but it suggests that the deployment of large scale artificial reefs along the Italian coast of the northern Adriatic Sea, such as some of the most recent (0.5–0.8 km^2), may be an useful management instrument to recover overexploited fish stocks.

Acknowledgements

The authors wish to thank MIPAF (Ministero per le Politiche Agricole e Forestali, Italy) who financially supported the study. Many thanks also to the crew of the RV Tecnopesca II of CNR-ISMAR who actively participated in the sampling at sea.

Literature Cited

Ardizzone, G. D., A. Belluscio, and A. Somaschini. 1997. Fish colonization and feeding habits on a Mediterranean artificial habitat. Pages 265–273 *in* L.E. Hawkins and S. Hutchinson, eds. Proc. 30th EMBS: the response of marine organisms to their environments. Southampton Oceanography Center, Southampton.

Badalamenti, F. and G. D'Anna. 1997. Ruolo delle strutture artificiali nella rete trofica e nel reclutamento di forme giovanili per la maricoltura. CNR-IRMA Tech. Rep. Ministry of Agriculture, Food and Forestry, Rome. 91 p.

_____________ and A. Manganaro. 1990. Primi dati sul regime alimentare di *L. mormyrus* (Linnaeus, 1758) lungo le coste della Sicilia Nord-orientale. Oebalia, 16 (Suppl.): 575–578.

_____________, G. D'Anna, G. Fazio, M. Gristina, and R. Lipari. 1993. Relazioni trofiche tra quattro specie ittiche catturate su differenti substrati nel Golfo di Castellammare (Sicilia N/O). Biol. Mar. Med. 1: 145–150.

_____________, __________, and S. Riggio. 2000. Artificial reefs in the Gulf of Castellammare (North-West Sicily): a case study. Pages 75–96 *in* A. C. Jensen et al., eds. Artificial reefs in European seas. Kluwer Academic Publ., Dordrecht.

Bohnsack, J. A., D. L. Johnson, and R. F. Ambrose. 1991. Ecology of artificial reefs habitats and fishes. Pages 61–107 *in* W. Seaman, Jr. and L.M. Sprague, eds. Artificial habitats for marine and freshwater fisheries. Academic Press, Inc., San Diego.

Bombace, G., G. Fabi, and L. Fiorentini. 1993. Aspects théoriques et résultats concernants les récifs artificiels réalises en Adriatique. Boll. Ocean. Teor. Appl. 11: 145–154.

Chakroun, N. and M. H. Ktari. 1981. Régime alimentaire des Sciaenidae (Poissons Téléostéens) du Golfe de Tunis. Bull. Inst. Natn. Scient. Tech. Océanogr. Pêche Salammbô 8: 69–80.

Clarke, K. R. and R. M. Warwick. 1994. Change in marine communities: an approach to statistical analysis and interpretation. Natural Environmental Research Council, Plymouth. 144 p.

Collins, K. J. and A. C. Jensen. 1996. Artificial reefs. Pages 259–272 *in* C.P. Summerhayes and S.A. Thorpe, eds. Oceanography – an illustrated guide. Manson Publishing, London.

Fabi, G. and L. Fiorentini. 1994. Comparison between an artificial reef and a control site in the Adriatic sea: analysis of four years of monitoring. Bull. Mar. Sci. 55: 538–558.

_______, F. Grati, F. Luccarini, and M. Panfili. 1999. Indicazioni per la gestione razionale di una barriera artificiale: studio dell'evoluzione del popolamento necto-bentonico. Biol. Mar. Medit. 6: 81–89.

_______, M. Panfili, and A. Spagnolo. 1998. Note on feeding of *Sciaena umbra* L. (Osteichthyes: Sciaenidae) in the central Adriatic sea. Rapp. Comm. Int. Mer Médit. 35: 426–427.

Froglia C. 1977. Feeding of *Lithognathus mormyrus* (L.) in central Adriatic Sea (Pisces, Sparidae). Rapp. Comm. Int. Mer Médit. 24: 95–97.

________ and M. E. Gramitto. 1998. Osservazioni sull'alimentazione di *Sciaena umbra* ed *Umbrina cirrosa* (Pisces, Sciaenidae) in prossimità di barriere artificiali in Adriatico. Biol. Mar. Medit. 5: 100–108.

George, E. and W. F. Hadley. 1979. Food and habitat partitioning between rock bass (*Ambloplites rupestris*) and smallmouth bass (*Micropterus dolomieui*) young of the year. Trans. Am. Fish. Soc. 108: 253–261.

Harmelin, J. G. and D. Bellan-Santini. 1997. Assessment of biomass and production of artificial reef communities. Pages 305–322 *in* A. C. Jensen, ed. European artificial reef research. Proc. 1st EARRN conference, Ancona. Southampton Oceanography Centre, Southampton.

Hyslop, E. J. 1980. Stomach contents analysis-a review of methods and their application. J. Fish. Biol. 17: 411–429.

Jensen, A. C., K. J. Collins, and A. P. M. Lockwood, eds. 2000. Artificial reefs in European seas. Kluwer Academic Publ., Dordrecht. 508 p.

Johnson, T. D., A. M. Barnett, E. E. DeMartini, L. L. Craft, R. F. Ambrose, and L. J. Purcell. 1994. Fish production and habitat utilization on a Southern California artificial reef. Bull. Mar. Sci. 55: 709–723.

Krebs, C. J. 1998. Ecological methodology. Addison Wesley Longman, Menlo Park. 620 p.

Langton, R. W. 1982. Diet overlap between Atlantic cod, *Gadus morhua*, silver hake, *Merluccius biliniaris*, and fifteen other Northwest Atlantic finfish. Fish. Bull. U.S. 80: 745–759.

Lindquist, D. G., L. B. Cahoon, I. E. Clavijo, M. H. Posey, S. K. Bolden, L. A. Pike, S. W. Burk, and P. A. Casrdullo. 1994. Reef fish stomach contents and prey abundance on reef and sand substrata associated with adjacent artificial and natural reefs in Onslow Bay, North Carolina. Bull. Mar. Sci. 55: 308–318.

Pickering, H. and D. Whitmarsh. 1997. Artificial reefs and fisheries exploitation: a review of the “attraction versus production” debate, the influence of design and its significance for policy. Fish. Res. 31: 39–59.

Polovina, J. J. 1991. Fisheries applications and biological impacts of artificial reefs. Pages 153–176 *in* W. Seaman, Jr. and L. M. Sprague, eds. Artificial habitats for marine and freshwater fisheries. Academic Press, Inc., San Diego.

Powers, S. P., J. H. Grabowski, C. H. Peterson, and W. J. Lindberg. 2003. Estimating enhancement of fish production by offshore artificial reefs: uncertainty exhibited by divergent scenarios. Mar. Ecol. Prog. Ser. 264: 265–277.

Relini, G., M. Relini, G. Torchia, and G. De Angelis. 2002. Trophic relationships between fishes and an artificial reef. ICES J. Mar. Sci. 59: S36–S42.

Ruitton, S., P. Francour, and C. F. Boudouresque. 2000. Relationships between algae, benthic herbivorous invertebrates and fishes in rocky sublittoral communities of a temperate sea (Mediterranean). Est. Coast. Shelf Sci. 50: 217–230.

Santos, M. N., C. C. Monteiro, and G. Lasserre. 1996. Finfish attraction and fisheries enhancement on artificial reefs: review. Pages 97–114 *in* A. C. Jensen, ed. European artificial reef research. Southampton Oceanography Center, Southampton.

Schoener, T. W. 1974. Resource partitioning in ecological communities. Science 185: 27–39.

Strauss R. E. 1979. Reliability estimates for Ivlev’s electivity index, the forage ratio and proposed linear index of food selection. Trans. Am. Fish. Soc. 108: 344–352.

Vesey, G. and T. E. Langford. 1985. The biology of the black goby, *Gobius niger* L. in an English south-coast bay. J. Fish. Biol. 27: 417–429.

Wilson, C. A., A. Pierce, and M. W. Miller. 2003. Rigs and reefs: a comparison of the fish communities at two artificial reefs, a production platform, and a natural reef in the northern Gulf of Mexico. Coastal Fisheries Institute, School of the Coast and Environment. Louisiana State University. U.S. Dept. of the Interior, Minerals Mgmt. Service, Gulf of Mexico OCS Region, New Orleans. OCS Study MMS 2003-009. 95 p.

ADDRESS: *Istituto di Scienze Marine, CNR, Largo Fiera della Pesca, 60125 Ancona, Italy. E-mail: <g.fabi@ismar.cnr.it>.*