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Influence of Levantine Artificial Reefs on the fish assemblage of the surrounding seabed

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Abstract

Four Artificial Reef (AR) units were deployed at a 20m depth on a flat hard substrate 3 km west of Haifa, Israel and then surveyed for fish for 12 months. AR units supported 20 times the biomass of control quadrates and their enrichment impact was still significant at a radius of 13m away from units. The 13m values were also significantly higher than those of quadrates adjacent to units, suggesting the existence of a halo of relative depletion within the outer enrichment halo. The main species contributing to this pattern was the migrant herbivore Siganus rivulatus. A decrease in grazing resources is thus suggested as an explanation for creation of this halo. The most consistent AR residents were also Lessepsian migrants - Sargocentron rubrum, nocturnal predators which displayed high microhabitat fidelity and a steady increase in density. The 6 species of migrants recorded accounted for 65.3% of the commercially exploitable biomass and 25.2% of the specimens in the AR site. Other constant AR residents were the groupers Epinephelus costae and Epinephelus marginatus, which are rare and commercially important species. Site protection from fishing and storms were found to be of utmost importance, and design and deployment considerations are discussed.

Keywords: Artificial reefs; Mediterranean Levantine basin; Fish assemblage; Lessepsian migration; Influence radius; Production vs. attraction.

Introduction

The magnitude of the world fishery yield makes the practice of deployment, monitoring and harvesting Artificial Reefs (ARs) a subject of active interest globally (BOHNSACK & SUTHERLAND, 1985). Today ARs are used for diverse applications even though the principal one remains enhancement of the fishing yields. This enhancement, however, is not to be taken for granted, as ARs are assumed to function in a combination of two mechanisms: aggregation of scattered specimens and secondary biomass production through increased survival and growth of juveniles (e.g., BOHNSACK & SUTHERLAND, 1985; PRATT, 1994; BOHNSACK *et al.,*

1997; SEAMAN, 2000; JENSEN *et al.* 2000; JENSEN, 2002; OSENBERG *et al.,* 2002). An AR may even entirely deplete stocks by merely concentrating the fishing effort (POLOVINA, 1989). This conflict has been dubbed the 'attraction production debate'. Yet, there are great variations in ARs and the behaviour of different species of fish may vary depending on the locations, occasions and conditions of the ARs and thus the predominating mechanism (attraction or production) varies accordingly (e.g., SPANIER, 1996). One of the main goals of ongoing AR research is to spatially and temporally chart these differences in order to gain a deeper understanding of the mechanisms through which ARs attract and facilitate the production of fish. Recruitment is a key factor which has to be quantified in order to study an AR's ability to produce new individuals. Recruitment is the addition of new individuals to populations or to successive life-cycle stages within populations (CALEY *et al.,* 1996). As ARs depend greatly on import (both juvenile recruitment and addition of adults) from nearby existing stocks, a study of their inter-relations with the ecotone is indispensable.

Fish and invertebrates use both natural and artificial surfaces for shelter, feeding, spawning, energy economy and orientation (BOHNSACK *et al.,* 1994; CARR & HIXON, 1997). Their accumulation around ARs is a stupendous outcome of behavioural ecology. Nevertheless, a great portion of the enhanced biomass comes from materials consumed in forage areas outside the AR complex. Depending on each species' association with the AR and its foraging range and behavioural patterns, feeding halos are formed around the AR (BOHNSACK, 1989; CARR & HIXON, 1997; BORTONE *et al.,* 2000; SHENG, 2000). These halos are critical to sustaining the AR biomass. Their radii indisputably vary with AR size, design, material, location, depth and distance from natural relief – both the supply source of adult settlers and potential gene pool (CARR & HIXON, 1997). TURNER *et al.* (1969) suggested leaving 15-18m diameter open spaces between AR units. STONE *et al.* (1979) noted that an AR placed within 25 m of a natural habitat recruited juveniles, and did not reduce the population of the existing natural reef. OGAWA (1982) concluded that for benthic species influence radii change from 1-100m and recommended 'a few meters' as a good choice for distance between AR and natural habitat. For pelagic fishes he determined this radius stretches up to 800m. FRAZER and LINDBERG (1994) proposed a 60m gap between units. For hard substrate habitats in the southeastern Mediterranean, SPANIER (2000a) has suggested $3m^3$ of AR for every $1000m^2$ of seabed as optimal AR density. Assuming three separate $1m^3$ cubic units per $1000m^2$, a 10.3m influence radius is to be expected. The present study focuses on these close-range inter-relations between fish and ARs in the eastern Mediterranean. As this basin is comparatively poor in both nutrients and fishing yields (e.g., SAURNIA, 1973; BERMAN *et al.,* 1984, AZOV, 1986; HERUT *et al.,* 2000), ARs are a subject of great interest in its waters. Relative scarcity of fish is also presumed to result in vacant ecological niches, which allow species of Indo-Pacific origin that migrate into the Levantine basin from the Red Sea through the Suez Canal (GOLANI, 1998) to establish and develop permanent and considerable populations. This phenomenon, called Lessepsian migration, has intensified in recent years and fish of Red Sea origin were observed as far as Sardinia (PAIS *et al.,* 2007). Species from tropical origin are con-

sidered more competitive than autochthonous Atlanto-Mediterranean species (GOLANI, 1998). Thus, the appearance of a Lessepsian migrant in the Levant basin may result in a competitive exclusion of indigenous species or their displacement to another habitat or depth range (e.g., SPANIER & GALIL, 1991). The present study also demonstrates how small AR units can provide an in situ look at Lessepsian migrants in their vicinity.

Previous studies in nearby sites showed AR deployment to concentrate fish in larger amounts and diversity than surrounding natural reefs (SPANIER, 2000a; 2000b; SPANIER *et al.,* 1983; 1985a; 1985b; 1989; 1990). The present study set out to examine the nature in which deployment of small AR units affects the ichthyofauna of the surrounding seabed.

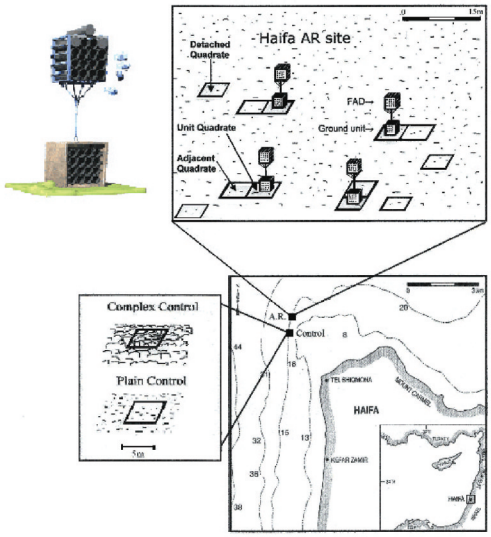

Fig. 1: Haifa AR Location map and illustration of the deployment scheme (map adapted from SPANIER *et al.* 1989, with permission).

Materials and Methods

Artificial Reef – Location and Structure

Four 1.2m sided cubical steel reinforced-concrete structures, weighing 1500kg in water were used as ground units. 16 sections of 25 cm diameter polyethylene pipes were fitted into each such structure. Floating units, or FADs (Fish Attracting Devices), were tethered to the ground units. These were 1m steel profile cubes, into which 16 polyethylene pipes were similarly fitted. Without the concrete ballast, they supplied 160kg of buoyancy. The AR field was composed of four such double units of a ground unit and a FAD suspended 10m above the seafloor (Fig.1). Typical seafloor property was of the flattest ground with as little complexity as possible. Distances between units were 25-40m, which enabled the whole 4 unit field to be monitored within one dive and were presumed far enough to avoid overlapping influence radii. A site with the suitable properties was located 3km NW of the Carmel promontory at 32˚51′02′′N - 034˚56′33′′E. Twelve 5X5m rope frames were laid in the AR field as survey quadrates: Four were set one around each ground unit (unit quadrates). The next four were set alongside them (adjacent quadrates) and the last four 13m (C-T-C) away from units (detached quadrates). Two more frames were set as controls on similar hard substrate, 500m to the south of the AR field on a rocky substrate at the same depth as the AR units (Fig. 1) at 32˚50′46′′N – 034˚56′27′′E. These control quadrates varied morphologically – one represented complex control features with dense porous outcrops of 0.4-0.8m height, much like those of a complex natural reef. The second had plain control features, with few small 0.1m outcrops, representing similar bathymetry to that on which AR units and survey quadrates were deployed.

Data collection

Fourteen surveys were conducted by two divers as point count surveys, adapted from SHENG (2000) during 7 sub-seasons: summer 2004 – summer 2005. Each count lasted 2 minutes per quadrate. One diver concentrated on quantifying the bigger schools of fish and the more abundant species, the other on identification of rare and cryptic species. After the completion of the visual census, a third diver recorded the fish and macro-invertebrates on video and still photography for later aid in taxonomy, comparisons and study. Survey results were written on pre-designed PVC slates in order to save time underwater and then transferred to excel sheets for processing. Underwater visibility was measured using both horizontal (at the seafloor) and vertical secchi disk depth. Water temperatures were measured by a Nitrox Suunto Solution gauge. Currents were measured with an Interocean S4 current meter. Video and still photo records were examined by ichthyologists and compared with data from LYTHGOE and LYTHGOE (1971) and GOLANI and DAROM (1999), to identify cryptic species and back up *in situ* counts. Fourteen census sorties were executed in a back to back day format. Data was pooled from each such pair of consecutive surveys and then into 7 seasonal data sets. All surveys were executed at the same time of day (between 0900 and 1200). Biomass estimates were shown to facilitate approximation of the magnitude of AR fauna (BORTONE *et al.,* 2000) and were therefore employed in the present study.

Statistical analysis

Biomass estimates of fish in the AR site were based on diver records of L_T in cm, taken *in situ,* and a later calculation via Length-Weight Tables in FROESE and PAULY (2006) from the nearest sighting of the species to Haifa. Shannon's species diversity index (H') was calculated for the quadrates according to SHANNON (1948): $H' = \Sigma (Pi*\ln Pi)$, where Pi represents the proportion of the i'th species.

For inter-quadrate comparisons, data was pooled from all surveys for every quadrate type. A non-parametric Wilcoxon signed rank-test was employed (WILCOXON, 1945) in order to determine whether differences in abundance, species richness, biomass and diversity were significant between quadrate pairs and a level of $P<0.05$ was determined as significant for comparison.

Results

Thirty species belonging to 18 families were observed during surveys (Table 1). Twenty seven of the species were recorded in AR unit quadrates, as opposed to only 11 and 18 species in the plain and complex control quadrates respectively (representing similar seabed to AR deployment site with no AR unit, and a high-relief natural reef). Unit quadrates also supported a mean of 85.7 specimens and a mean biomass of 237g/m^2 per survey, whereas plain and complex control quadrates held a mean of only 15 and 36.4 specimens and a mean biomass of 18 and 68.1g/m^2 respectively. The abundance, species richness, Shannon's diversity index and estimated biomass of fish in the site during the 7 seasons are presented in Figures 2a-d. Values peaked during the first summer and autumn in the post deployment phase, then declined during winter and increased again the following summer. Unit quadrates generally displayed higher abundance, richness and biomass values than both control quadrates and ad-

Table 1
List of species recorded in The AR and FAD site and their total abundance, including origin, trophic level, estimated biomass and feeding habits.

Family	Common Name	Scientific Name	Total No. of fish observed	Origin[a]	Trophic Level[b]	Estimated Biomass in g/specimen[c]	Feeding Habits[d]
Muraenidae	Brown moray	*Gymnothorax unicolor* (Delaroche)	7	A	3.4	645.2	Car – Fish, Cru
Muraenidae	Mediterranean moray	*Muraena helena* Linneaus	12	A	4.2	531.2	Car- Fish, Cru
Clupeidae	Round Sardinella[e]	*Sardinella aurita* Valenciennes	710	C	3	26.2	Z- Cru, some fish
Fistulariidae	Cornetfish	*Fistularia commersonii* Ruppell	1	R	4.3	288	Car – fish
Holocentridae	Red Squirrelfish	*Sargocentron rubrum* (Forsskål)	302	R	3.5	150.7	Car- Inv, Cru, Mol.
Serranidae	Golden grouper	*Epinephelus costae* Steindachner	56	A	3.9	515.3	Car – mostly fish
Serranidae	Dusky grouper	*Epinephelus marginatus* (Lowe, 1834)	9	A	3.7	587	Car- Cru, some fish
Serranidae	Comber	*Serranus cabrilla* (Linneaus)	7	A	3.3	44.3	Car- Fish, Inv
Serranidae	Painted comber	*Serranus scriba* (Linneaus)	22	A	3.8	117.7	Car – Fish, Inv
Apogonidae	Cardinal fish	*Apogon imberbis* (Linneaus)	1	A	3.9	13.3	Z + Inv, Cru
Carangidae	Shrimp's Scade	*Alepes djedaba* (Forsskål)	655	R	3.3	42.2	Z
Mullidae	Striped red mullet	*Mullus surmuletus* Linneaus	19	A	3.4	103.7	Car – Fish, Cru, Mol, Worms
Mullidae	Brownband goatfish	*Upeneus pori* BEN-TUVIA & Golani	2	R	3.3	77.6	Car - Inv, Cru
Centracanthidae	Blotched picarel	*Spicara maena* (Linneaus)	34	A	4.2	34	Car- Inv
Centracanthidae	Picarel	*Spicara smaris* (Linneaus)	27	A	3	36.4	Car- Inv
Pomacentridae	Mediterranean Damsel fish[f]	*Chromis chromis* (Linneaus)	2966	A	3	21.1	Z
Sparidae	Zebra sea bream	*Diplodus cervinus* Lowe	2	A	3	284	Car – Fish, Mol, Cru
Sparidae	Two-banded sea bream	*Diplodus vulgaris* (G. Saint Hilaire)	249	A	3.2	63.3	Car - worms, cru
Sparidae	Axillary sea bream	*Pagellus acarne* Risso	15	A	3.5	52.6	Car- Inv, fish
Sparidae	Blue-spotted sea bream	*Pagrus coeruleostictus* (Valenciennes)	72	A	3.8	380.5	Car/Her

(continued)

Table 1 (continued)

Family	Common Name	Scientific Name	Total No. of fish observed	Origin[a]	Trophic Level[b]	Estimated Biomass in g/specimen[c]	Feeding Habits[d]
Labridae	Rainbow wrasse[f]	*Coris julis* (Linneaus)	1547	A	3.2	14.1	Z
Labridae	Axillary Wrasse	*Symphodus mediterraneus* (Linneaus)	44	A	3.1	5.1	Car – Mol, Cru, Inv
Labridae	Five-spotted wrasse	*Symphodus roissali* (Risso)	44	A	3.5	9	Car – Mol, Inv, Cru
Labridae	Peacock Wrasse	*Symphodus tinca* (Linneaus)	1	A	3.5	31	Car – Mol, Inv, Cru
Labridae	Ornate wrasse	*Thalassoma pavo* (Linneaus)	562	A	3.5	26.3	Car – Mol, Cru
Scaridae	Parrot fish	*Sparisoma cretenese* (Linneaus)	57	A	2.9	64.2	Her/Car
Gobiidae	Bucchich's goby	*Gobius bucchichi* Steindachner	2	A	3.1	6.7	Her-Car - Alg, Inv, Cru
Blennidae	Unidentified Blenny	*Parablennius sp.*		A		5-10	Car – Inv.
Siganidae	Dusky spinefoot[f]	*Siganus luridus* (Rüppell)	129	R	2	171	Her – Alg
Siganidae	Marbled spinefootf	*Siganus rivulatus* Forsskål	394	R	2	124.9	Her – Alg
Monacanthidae	Filefish/ Reticulated leatherjacket	*Stephanolepis diaspros* Fraser-Bruner	25	R	2.8	46.6	Car- Inv

Z = Zooplanktivore; Car = Carnivore; Her = Herbivore; Inv.=Invertebrates; Mol.=Mollusks; Cru=Crustaceans; Alg = Algae

[a] Origin: A = Atlantic-Mediterranean; R = Red Sea (Indo-Pacific); C = Cosmopolitan

[b] Trophic level Data – as per FROESE and PAULY (2005)

[c] Biomass was estimated using L-W Tables from FROESE and PAULY (2006)

[d] Feeding Habits, as per GOLANI and DAROM (1999), LYTHGOE and LYTHGOE (1971) and FROESE and PAULY (2006): Z = Zooplanktivore; Car = Carnivore; Her = Herbivore; Inv.=Invertebrates; Mol.=Mollusks; Cru=Crustaceans; Alg = Algae

[e] Observed exclusively around the FADs

[f] Observed around the FADs and the AR units

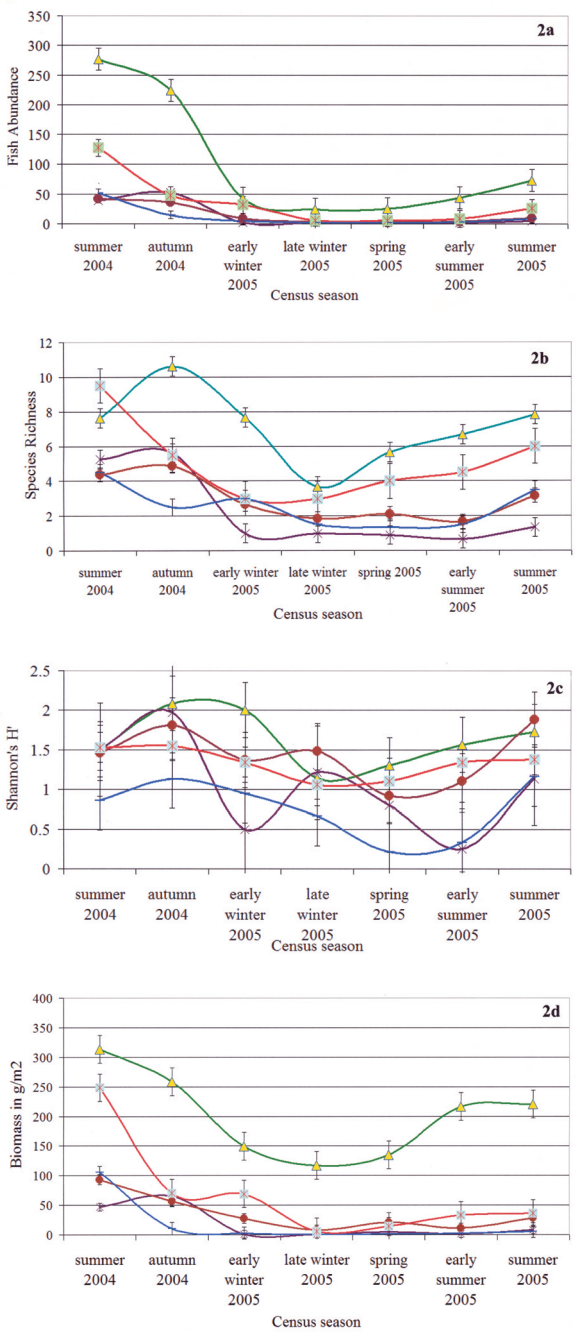

Fig. 2a-d: Mean Fish Abundance, Species Richness, Shannon's Diversity Index and Biomass ± S.E. during 12 months of census (divided into 7 sub-seasons) in the Haifa AR Site quadrates: Unit quadrate, Adjacent quadrate, Detached quadrate, Complex control, Plain control.

jacent and detached quadrates, with Shannon's diversity index values showing a greater variability (Fig. 2c). AR ecotone (adjacent and detached quadrates) normally displayed slightly higher values than the plain control, although complex control values exceeded those of the ecotone (Fig. 2).

Thirteen species were of commercial importance (according to SNOVSKY and SHAPIRO 2003), thirteen were piscivores and only two were obligatory herbivores –*Siganus rivulatus* Forsskål, and *S. luridus* (Rüppell), both Lessepsian migrants. Seven of the 30 species observed were of Red Sea origin. Lessepsian migrant percentage, calculated for the 6 benthic species recorded in surveys, is presented in Figure 3. A separate "inner unit" data series is presented, to underline the massive presence of the Red squirrelfish *Sargocentron rubrum* (Forsskål) in the inner AR assemblage. Along with another migrant – the Filefish, *Stephanolepis diaspros* Fraser-Bruner, Red-Sea species accounted for the majority of individuals observed inside AR units (Fig. 3). *S. diaspros* was, much like *S. rubrum,* closely associated with the AR units, however only single specimens or couples were recorded and their numbers did not increase with time. *F. commersonii* was recorded hovering in close proximity and parallel to quadrate lines, presumably mimicking them for camouflage. The detached quadrates assemblage, also showing a large proportion of migrants (Fig. 3), was comprised mostly of *S. rivulatus* specimens, usually observed in motion, displaying foraging behavior. *S. rivulatus* was also the only migrant species observed in control quadrates.

AR unit quadrates were compared with the complex control, in order to determine whether the AR provides a superior habitat to that of a natural fully- developed reef (Table 2). They were indeed found to have significantly higher diversity and biomass (Wilcoxon, P=0.047) than complex control (Wilcoxon P=0.006). Unit quadrates also carried almost 3 times the abundance and 50% more species than complex control quadrates, however differences for abun-

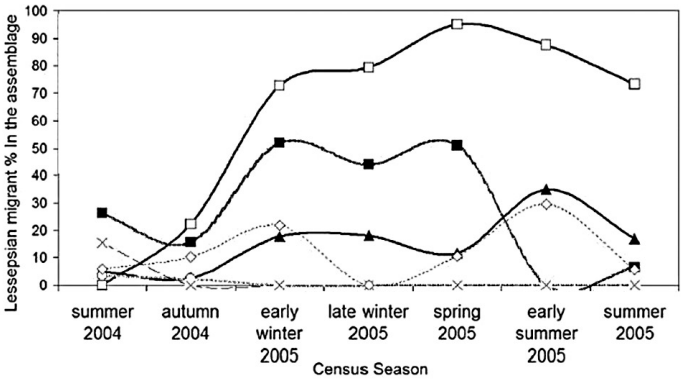

Fig. 3: Mean Lessepsian migrants percentage during 12 months of census in Haifa AR site in the study quadrates: Inner unit, Unit quadrate, Adjacent quadrate, Plain control, Complex control. Detached quadrate.

Table 2

Quadrate pair comparison: Wilcoxon two-sample signed-rank test scores and summary statistics for mean no. of fish/quadrate (Abundance), mean no. of species/quadrate (Richness), mean Shannon's Diversity Index (H') (Diversity) and estimated mean biomass of fish, drawn from Species Length-Weight tables (FROESE and PAULI, 2006). * Significant effects (P < 0.05) are indicated.

Quadrate Pair	Variable	Mean	St. Dev.	N	Mean Score	Statistic	z	p
Unit Quadrate - Complex Control	Abundance	85.70 29.20	61.78 42.98	31 8	21.10 15.75	126	1.166	0.1218
	Richness	7.64 5.20	2.87 3.16	56 10	32.36 39.90	399	1.1506	0.125
	Diversity	1.36 1.17	0.39 0.34	56 10	31.82 42.90	429	1.6736	0.0471*
	Biomass	5.17 1.32	2.41 1.76	31 8	10.88 10.88	87	2.5216	0.0058*
Detached Quadrate - Plain Control	Abundance	17.70 10.60	20.78 19.28	16 8	13.69 10.13	81	1.1411	0.1269
	Richness	4.08 2.70	2.12 1.57	25 10	20.00 13.00	130	1.8412	0.0328*
	Diversity	1.03 0.70	0.41 0.45	25 10	20.20 12.50	125	1.9941	0.0231*
	Biomass	1.15 0.33	1.28 0.79	16 8	15.56 6.38	51	2.9713	0.0015*
Detached Quadrate - Adjacent Quadrate	Abundance	17.70 16.11	20.78 21.30	16 13	18.66 10.50	136	2.5555	0.0053*
	Richness	4.08 3.55	2.12 2.65	25 22	26.46 21.20	467	1.3215	0.0932
	Diversity	1.03 0.78	0.41 0.57	25 22	27.26 20.30	447	1.732	0.0416*
	Biomass	1.15 0.58	1.28 0.76	16 13	19.25 9.77	127	2.9615	0.0015*

dance and richness were not statistically significant (Wilcoxon, P=0.121 and 0.125 respectively). In order to determine attraction radius, detached quadrates were compared to plain control, and then to adjacent quadrates (Table 2). Richness, diversity and biomass values were significantly (Wilcoxon, P=0.03, 0.023 and 0.001 respectively) higher in detached quadrates than in plain control; but surprisingly, abundance diversity and biomass (Wilcoxon, P=0.005, 0.042 and 0.001 respectively) were also significantly higher in detached quadrates than adjacent ones (Table 2). During summer, the great number of fish shoaling around units occasionally 'spilled' into adjacent quadrates and yet in 19 out of a total of 25 observations in which both quadrates were surveyed, more specimens were recorded in detached quadrates than adjacent ones.

The most common fish in surveys were the Mediterranean damselfish, *Chromis chromis* (Linneaus) (Table 1), most of which were observed shoaling in great proximity to AR units. The Rainbow wrasse *Coris julis* (Linneaus) and the Ornate wrasse *Thalassoma pavo* (Linneaus) were also very common in surveys, however they were not as tightly grouped around AR units as *C. chromis* were. Other common fish (Table 1) included the Two-banded sea bream, *Diplodus vulgaris* (G. Saint Hilaire), and the Blue-spotted sea bream, *Pagrus coeruleostictus* (Valenciennes), as well as the Painted comber, *Serranus scriba* (Linneaus). All Sparids and Serranids were common around AR units in summer and autumn but disappeared completely in winter and spring.

The larger predators found in unit crevices were the Brown moray, *Gymnothorax unicolour* (Delaroche), the Mediterranean moray, *Muraena Helena* Linneaus, the Gold blotch grouper, *Epinephelus costae* Steindachner and the Dusky Grouper, *Epinephelus marginatus* Bloch and Schneider. Figure 4 displays the patterns exhibited by the most common dominant large predators, i.e. the groupers and squirrelfish, in the AR unit quadrates throughout the study period, contrasted with water temperature. Groupers lurked mostly in the lower rows of pipes inside units or in the crevices formed under AR units before scouring closed them. Like squirrelfish, none were viewed over flat substrate and were altogether absent from non-AR quadrates. Groupers reached a maximum of 12 fairly large individuals (30-50cm L_T) inhabiting AR units in the early winter of 2005. By this stage, specimens could be individually identified by their size, color patterns and choice of microhabitat within units. This changed when in the spring of 2005, the numbers of groupers in the site dropped within 48 hours from nine specimens in 28.2.05 to none in 2.3.05 (Fig. 4). *E. marginatus* was never sighted again after this date and all *E. costae* observed hereafter were relatively small (max. 25cm L_T). In contrast to groupers, the number of *S. rubrum,* (302 observations – Table 1) grew steadily with time throughout the study period (Fig. 4).

Damselfish, wrasse and rabbitfish juveniles were recorded almost exclusively in the warm seasons (Fig. 5), following their spawning period in spring and summer. Juveniles of *C. chromis* were observed exclusively within 1m of the structures.

The four FADs showed little resilience to winter storms. The FADs caused ground units to scour, flip or altogether break into pieces. Therefore, the FAD units were removed after only five months at sea.

The species composition of the FADs in these five months is displayed in Figure 6. In summer they were occupied by

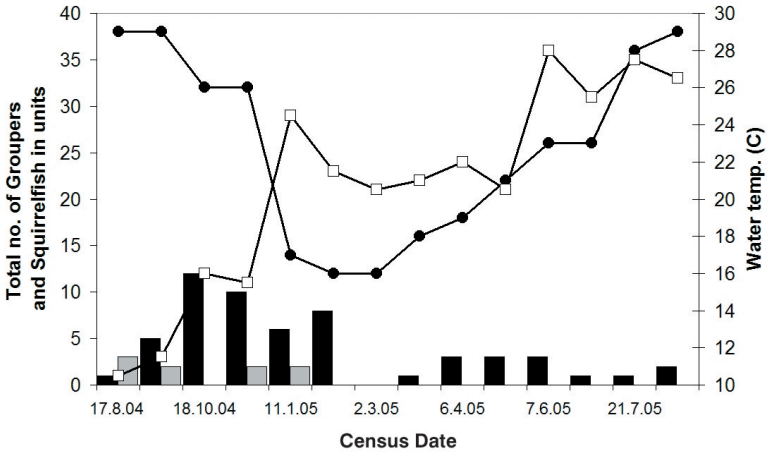

Fig. 4: Total abundance of AR residents - *Epinephelus marginatus* and *E. costae* as well as *Sargocentron rubrum* vs. water temperatures.

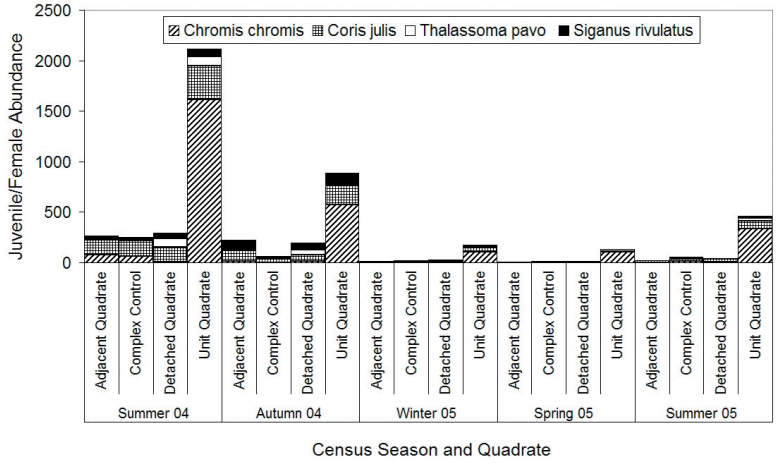

Fig. 5: Juveniles/females recorded in censuses. *Siganus rivulatus* and *Chromis chromis* figures refer to juveniles (easily distinguishable by size and colour) whereas females of the wrasses *Thalassoma pavo* and *Coris julis* may highly resemble juveniles in both size and morphology.

only one species – The Lessepsian migrant Shrimp scad, *Alepes djedaba* (Forsskål). Within a couple of months it was joined by large shoals of Round Sardinella, *Sardinella aurita* Valenciennes, as well as *C. chromis,* which were observed ascending from bottom units. When winter storms first hit the site, FADs were lowered, as a protective

measure, to only 5m above the seafloor and this apparently enabled species more closely associated with the benthos, such as *S. rivulatus* and *C. julis* to ascend to FADs (Fig. 6). The enlarged surface area of FADs facilitated settlement of a thick epybiota, mostly of the Pearl oyster, *Pinctada radiata* (Leach). No fish were observed feeding on it and none were viewed under or inside the FADs.

Discussion

Artificial Reef unit deployment was found to affect the fish assemblage in different intensities and radii for different species. AR units themselves provided habitats for several species that were rare or absent from other quadrates. These were mostly cryptic species and/or nocturnal carnivores, but also juveniles of reef-associated species. Units were shown to significantly raise the ecotone carrying capacity for fishes. Although capacity exceeded that of a flat control site, it did not match that of the complex control (Fig. 1 and Table 2). This means absolute enhancement occurred at <3m, except during summer, when the increase in abundance and richness caused spillover into adjacent quadrates. Detached quadrates, located 13m away from the units showed significantly greater richness, diversity and biomass than the flat, plain control site (Table 2). Thus, AR induced enrichment was still discernible at this distance. Nevertheless, these detached quadrates displayed significantly higher values than those of quadrates adjacent to AR units. This finding suggests the existence of a halo of relative depletion within the outer enrichment halo. The prominent species exhibiting behaviour which fitted this pattern was the Lessepsian herbivore *S. rivulatus.* Unlike its congener *S. luridus,* more frequently observed in AR unit quadrates, *S. rivulatus* was observed in schools of 5-20 specimens, grazing farther away from units. It is therefore suggested that upon sensing unit presence directly (by sight, lateral line, and/or smell) these fish elect to approach to within 1-2m and benefit from shoaling advantages (e.g. PITCHER *et al.* 1982). It is further speculated that they used AR units as navigational benchmarks (e.g.

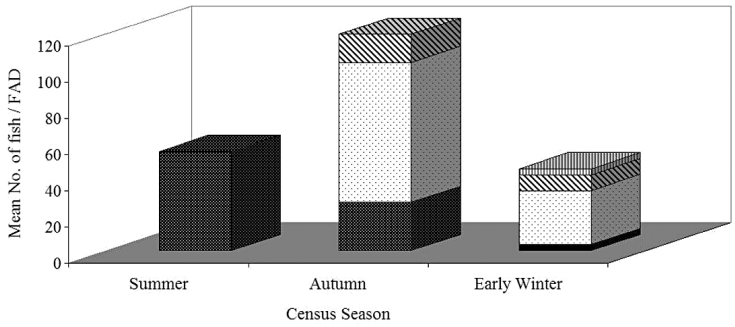

Fig. 6: Species composition and density recorded for the Fish Aggregating Devices in Haifa AR site before FADs were lost in winter storms - *Coris julis, Chromis chromis, Sardinella aurita, Alepes djedaba, Siganus rivulatus.*

BRAITHWHAITE, 1998) in their grazing excursions into the ecotone, when near AR resources were exhausted.

The attractive properties of AR units towards the 20m depth Eastern Mediterranean fauna were demonstrated at first by a post deployment overshoot, in the summer of 2004. This type of overshoot has been described in previous AR studies (BOHNSACK and SUTHERLAND, 1985; MORENO *et al.,* 1994). It is thought to represent an early curiosity of fish towards the newly established habitat, prior to reaching a seasonal, dynamic equilibrium.

In the ensuing winter some species declined in numbers while others disappeared altogether. The following summer saw most of them return, although in slightly lower numbers. BOMBACE (1989) and BOMBACE *et al.* (1994) suggested that in the Adriatic Sea, the decrease in winter species richness is due to migration into deeper water. This phenomenon is documented for groupers along the Israeli coast as well (DIAMANT *et al.,* 1986; GOLANI and DAROM, 1999; ARONOV and GOREN, 2003). It may account for the winter decline in grouper numbers (Fig. 4) as well lower abundances of other species. Most notable among these was the sparid population, which vanished in the cold season and recuperated the following summer.

Nonetheless, had vertical migration been the reason for grouper decline, why did their population fail to recover the following summer as the sparids' did? No climatic changes were noted during this period, the current was weak (0.1Kn.), water temperature albeit low at 16°C, remained steady (Fig. 4) and visibility was excellent (horizontal Secchi depth >30m). Water temperatures had dropped 2 months prior to this survey (Fig. 4), and with it AR biomass and the abundance of many of the groupers' prey items (Fig. 2a). Why then had vertical migration not occurred earlier? Enquiries among local fishermen suggested an alternative explanation. The site was familiar to SCUBA divers and was visited quite often by spear fishermen. It is highly probable then that the disappearance of its larger inhabitants was indeed fishing related. Grouper absence from control quadrates stressed these overexploited species' demand for additional relief and complexity. Nevertheless, unless protected from fishing, such habitat erection is futile. As recommended by PITCHER and SEAMAN (2000), AR deployment in no-take zones can and should play a positive role in future restoration and fishery management programs. This is also the case in the Levant region (SPANIER, 2000a) where site protection must be given high priority, so that ARs can produce, rather than merely attract, fish.

In contrast to the groupers, the population of *S. rubrum* continued to grow throughout the study period (Fig. 4). Squirrelfish are not as highly prized as groupers, due to their smaller size, hard scales and sharp dorsal spines (GOLANI and DAROM, 1999). They are thus not targeted by spearfishermen. Consequently, they have been able to establish themselves as dominant Levantine cave and AR dwellers in recent decades (GOLANI and BEN-TUVIA, 1985; DIAMANT *et al.,* 1986; SPANIER *et al.,* 1989; SPANIER and GALIL, 1991; SPANIER, 2000a,b; BARICHE *et al.,* 2004; GOREN and GALIL, 2005). So far as diurnal species are concerned, however, the most frequent protagonists of the assemblage were wrasses and damselfish. *C. julis, T. pavo* and *C. chromis* (Table 1), are similar to the most abundant species found by AZZURRO *et al.* (2007) in an AR in the Straits of Sicily.

CHARBONNEL *et al.* (2002) deduced that the increased density and biomass of predators in a north Mediterranean AR did not result solely from the increased food availability offered by surfaces of the AR, but from sheltering in the interstices as well. The present AR data concurs with this model, as inner and under unit crevices of AR units were indeed densely and rapidly inhabited by squirrelfish (Figs. 2 and 4) and other larger predators. SEAMAN (2000) noted that in the south-east Mediterranean, with no sea-grass meadows, a filter feeder dominated AR is likely to develop. The importance of herbivores will thus diminish, whereas predation intensity will increase. Despite an active presence in the vicinity of AR units, herbivores were not observed feeding directly off units. Grazing activity, most notably for *S. rivulatus,* was indeed observed mostly in the ecotone. Nevertheless, these Lessepsian herbivores' wide range diets and their ability to feed off various indigenous biogenic resources (STERGIOU, 1988), do contribute significantly to herbivory in the ARs of the Levantine basin.

When assemblages of two natural rocky habitats and a small Mediterranean AR were compared in the mid 1980s (DIAMANT *et al.,* 1986), Red Sea migrant species constituted only 7.4% of the fish, but contributed >20% of the standing crop. SPANIER (2000a,) has found migrants constituted 16.7% of the species composition in tire ARs deployed in 1985 on a similar substrate at the same depth and 18.9% in the same ARs in 1995 (SPANIER 2000b). GOLANI *et al.* (2007), using rotenone ichthyocide in rocky coastal littoral found a 12.16% migrant species ratio. In the present AR study, the percentage of migrant species was 22.6%. A newcomer to the assemblage was the Blue spotted cornet fish, *Fistularia commersonii* Rüppell, recently detected in the Mediterranean (GOLANI *et al.,* 2002) and by now common throughout the Levantine basin (KARACHLE *et al.,* 2004; PAIS *et al.* 2007). A single winter observation was made of the Brownband goatfish, Upeneus pori Ben-Tuvia and Golani. Although it habitually prefers soft bottoms (LYTHGOE and LYTHGOE, 1971; GOLANI and DAROM, 1999), it was recorded over the sandstone ridge, in vicinity to ARs and further contributed to the increase in Lessepsian species richness. Migrants accounted for 25.2% of total specimens and 65.3% of the commercially exploitable biomass in AR quadrates.

The higher figures of the present study may be explained by differences in the sampling methods and/or habitat depth. Additional explanations can originate in the higher efficacy of ichthyocide in exposing cryptic species (mainly members of the families bleniidae and gobiidae). Since most of these species are indigenous, they decrease the relative proportion of Lessepsian species. However, the large migrant proportions may also point to two trends: a spatial one, which reflects a competitive edge migrants have over indigenous species in AR sites, similar to the one demonstrated by TYRRELL and BYERS (2007) for fowling species, and a temporal trend - the increase in time of the rate of Lessepsian colonization.

Other than *S. rubrum,* the other foremost migrants to benefit from AR presence were rabbitfish. In their original, Indo-Pacific habitat, rabbitfish are found in small schools in shallow water close to the bottom (FROESE and PAULY, 2006). They feed on a wide range of benthic algae (trophic level 2 – Table 1) and their success as migrants is attributed to the scarcity of indigenous herbivores in the Levant (LUNDBERG and GOLANI, 1995;

BARICHE *et al.,* 2004). Their high feeding intensity and high competitive potential (STERGIOU, 1988) have enabled them to become dominant in the Levantine herbivore niche. The absence of the indigenous herbivore Saupe, *Sarpa salpa* (Linnaeus), which was not sighted in this study, as well as its absence from the Israeli fishing yield reports in recent years (SNOVSKY and SHAPIRO, 2003) provides some support to the hypothesis raised by BARICHE *et al.* (2004) regarding its exclusion by rabbitfish.

Large numbers of juveniles, mostly damselfish, were very closely associated with the structures in summer (Fig. 5). This close range interaction stressed the advantage of AR units over natural reef control sites in their role as nurseries. Mediterranean reefs are non-living rocky outcrops and thus resemble ARs in temperate or less stable environments (SEAMAN, 2000). Whereas tropical reef recruitment is chiefly governed by juvenile fish, reefs in temperate seas gravitate towards adult colonization (SEAMAN and SPRAGUE, 1991). Our findings, however, detected large numbers of damselfish and wrasse juveniles during the warm season. Therefore, since the seasonal temperature gradient in the Levantine basin is so acute (from 15˚C in winter to 30˚C in summer) and since the appearance of juveniles was witnessed only in the warm season, it is suggested that a seasonally alternating recruitment mechanism took place in the AR field: a limited temperate adult recruitment to the assemblage every winter-spring and a more sub-tropical like juvenile recruitment every summer-autumn. This is possibly a magnification of the similar mechanism occurring in natural reefs, as the only record of *C. chromis* juveniles (n=11) other than in unit quadrates was in great proximity (<1m) to a large rocky outcrop in the complex control in the summer of 2004.

The short duration of the FAD study did not allow a complete colonization pattern to be described and only partial conclusions can be drawn. During summer, FADs attracted schools as big as 110 specimens of the Lessepsian Shrimp scad, *A. djedaba* (Fig. 6). Its dominance as well as the utter lack of indigenous pelagic fishes near FADs may be evident of the susceptibility of the Mediterranean Sea to the Lessepsian invasion. It was joined in autumn by the transient Round sardinella, *S. aurita,* as well the demersal damselfish *C. chromis.* FADs were then lowered to 15m depth in an attempt to prevent unit destruction after the first winter storm. The assemblage then became more heterogeneous when at this height, rabbitfish and wrasses joined the damselfish to ascend from ground AR units to the FADs. Since natural depth distribution of all three necto-benthic species does not limit them to 20m (GOLANI and DAROM, 1999; FROESE and PAULY, 2006), an isobath must exist therefore, between 4-10m above the seafloor, below which fish relate to FADs as close enough to function as a single structure. This ascent also supports the hypothesis that vertical relief plays a key role in AR's success as habitat (RILOV and BENAYAHU, 2000). In contrast to bottom units, the lack of fish inside FADs suggests it was not shelter from predation fishes sought, but current lee, as suggested for fish larvae by LINDQUIST *et al.* (2005). This dominance in biomass of species not trophically dependent on the bio-fowling accumulated on FADs is also in accordance with findings by DEUDERO *et al.* (1999).

The present study was carried out over only 12 months of sampling. MONTEIRO and SANTOS (2000) found the cumulative

species richness in a Portuguese AR took 5 years to reach the succession plateau. CHARBONNEL *et al.* (2000) found that an AR assemblage still evolved and density and biomass continued to grow after 7 years. RELINI *et al.* (2002) reported species diversity and richness were still steadily increasing even after 10 years. However, GOLANI *et al.* (2007) as well as DIAMANT *et al.* (1986) demonstrated that after a complete defaunation, it only took ARs along the Israeli coast 1 year to return to pre-defaunation values. The data gathered for the Haifa AR project, although it provided some good basic and comparative figures, was insufficient for long-term predictions of ecological processes. For example – the decline in both adult and juvenile numbers over the study period can only be fully understood in a multi-annual study. A longer duration of data collection is therefore highly advised.

Twenty years ago, BOHNSACK and SUTHERLAND (1985) termed AR construction 'more of an art than a science' and stressed the need for inexpensive, effective, long-lasting, easily handled, easily transported structures. Marine structures are by and large planned to withstand storms of a certain repetition probability, based on the probability of a worse storm occurring during the suggested period. Structure resilience, cost-benefit and potential damage considerations must be taken into account in these planning stages. The concrete structures used as ground units in the Haifa AR project were originally prefabricated sewer ponds. They were thus cheap and relatively small and were easily fitted with the pipes for enhanced complexity.

Nevertheless, when coupled with the FAD units, they proved inadequate for use as ARs, as their life span was only 3-5 months. The relative longevity (over 3 years so far) of the two remaining bottom units, once severed from their FADs, advises against such a tether of bottom to midwater structures in the future.

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References

ARONOV, A. & GOREN, M., 2003. Variation in aggregation behaviour and anatomy resulting from differences in degree of sperm competition in groupers (Epinephelinae, Serranidae). *Israel Journal of Zoology,* 49: 72.

AZOV, Y., 1986. Seasonal patterns of phytoplankton productivity and abundance in near shore oligotrophic water of the Levant Basin (Mediterranean). *Journal of Plankton Research,* 8: 41-53.

AZZURRO, E., PAIS, A., CONSOLI, P. & ANDALORO, F., 2007. Evaluating day–night changes in shallow Mediterranean rocky reef fish assemblages by visual census. *Marine Biology,* 151: 2245-2253.

BARICHE, M., LETOURNEUR, Y. & HARMELIN-VIVIEN, M., 2004. Tem-

poral fluctuations and settlement patterns of native and Lessepsian herbivorous fish on the Lebanese coast (Eastern Mediterranean). *Environmental Biology of Fishes* 70: 81-90.

BERMAN, T., TOWNSEND, D. W., EL-SAYED, S. Z., TREES, C. C. & AZOV, Y., 1984. Optical transparency, chlorophyll and primary production in the eastern Mediterranean near the Israeli coast. *Oceanologica Acta* 9: 439-447.

BOHNSACK, J. A., 1989. Are high densities of fish at artificial reefs the result of habitat limitation or behavioural preference? *Bulletin of Marine Science* 44: 631-645.

BOHNSACK, J. A. & SUTHERLAND, D. L., 1985. Artificial reef research: a review with recommendations for future priorities *Bulletin of Marine Science* 37: 11-39.

BOHNSACK, J. A., HARPER, D. E., MCCLELLAN, D. B. & HULSBECK, M., 1994. Effects of reef size on colonization and assemblage structure of fish at artificial reefs off southeastern Florida, U.S.A. *Bulletin of Marine Science.* 55: 796-823.

BOHNSACK, J. A., ECKLUND, A. M. & SZMANT, A. M., 1997. Artificial reef research: Is there more than the attraction-production issue? *Fisheries* 22: 14-16.

BOMBACE, G. 1989. Artificial Reefs in the Mediterranean Sea. *Bulletin of marine Science* 44: 1023-1042.

BOMBACE, G., FABI, L., FIORENTINI, L. & SPERANZA, S., 1994. Analysis of the efficacy of ARs located in five different areas of the Adriatic Sea. *Bulletin of Marine Science* 55: 559-580.

BORTONE, S. A., SAMOYLIS, M. A. & FRANCOUR, P., 2000. Fish and macroinvertebrate evaluation methods. In: Seaman, W.J. (ed.) *Artificial Reef Evaluation with Application to Natural Marine Habitats.* CRC Press, Boca Raton, Florida 127-164.

BRAITHWHAITE, V. A., 1998 Spatial memory, landmark use and orientation in fish. In: Healy, S. (ed.) *Spatial Representation in Animals.* 86-102.

CALEY, M. J., CARR, M. H., HIXON, M. A., HUGHES, T. P., JONES, G. P. & MENGE, B. A., 1996. Recruitment and the local dynamics of open marine populations. *Annual Review of Ecological Systems* 27: 477-500.

CARR, M. H. & HIXON, M. A., 1997. Artificial reefs: the importance of comparisons with natural reefs. *Fisheries* 22: 28-33.

CHARBONNELL, E., FRANCOUR, P., HARMELIN, D. O. & BACHET, F., 2000. Effects of artificial reef design on associated fish assemblages in the Côte Bleue marine park (Mediterranean Sea, France). In: Jensen, A.C., Collins, K.J. and Lockwood, A.P.M. (eds) *Artificial Reefs in European Seas.* Kluwer Academic Publishers, Dordrecht, Netherlands. 365-377.

CHARBONNEL, E., SERRE, C., RUITTON, S., HARMELIN, J. G. & JENSEN, A., 2002. Effects of increased habitat complexity on fish assemblages associated with large artificial reefs units (French Mediterranean coast). ICES *Journal of Marine Science* 50: 208-213.

DEUDERO, S. C., MERELLA, P., MORALES-NIN, B., MASSUTI, E. & ALEMANY, F., 1999. Fish communities associated with FADs. *Scientia Marina* 63: 199-207.

DIAMANT, A., BEN-TUVIA, A., BARANES, A. & GOLANI, D., 1986. An analysis of rocky coastal eastern

Mediterranean fish assemblages and a comparison with small adjacent artificial reef. *Journal of Experimental Marine Biology and Ecology* 97: 269-285.

FRAZER, T. K. & LINDBERG, W. J., 1994. Refuge spacing similarly affects reef associated species from three phyla. *Bulletin of Marine Science* 55: 388-400.

FROESE, R. & PAULY, D. (Eds) 2006. FishBase. World Wide Web electronic publication. www.fishbase.org, version (06/2006).\

GOLANI, D., 1998. Impact of Red Sea fish migrants through the Suez Canal on the aquatic environment of the eastern Mediterranean. *Yale F&ES Bulletin* 103: 375-387.

GOLANI, D. & BEN-TUVIA, A., 1985. The biology of the Indo-Pacific squirrelfish, S. rubrum, a Suez Canal migrant to the eastern Mediterranean. Journal of Fish Biology 27: 249-258.

GOLANI, D. & DAROM, D., 1999. *Handbook of the Fishes of Israel,* Keter Publishing Jerusalem, Israel. 269.

GOLANI, D., ORSI RELINI, L., MASSUTI, E. & QUINGARD, J. P., 2002. *CIESM Atlas of Exotic Species in the Mediterranean.* CIESM Publishers, Monaco. 256.

GOLANI, D., REEF-MOTRO, R., EKSHTEIN, S., BARANES, A. & DIAMANT, A., 2007. Ichthyofauna of the rocky coastal littoral of the Israeli Mediterranean, with reference to the paucity of Red Sea (Lessepsian) migrants in this habitat. *Marine Biology Research* 3: 333-341.

GOREN, M. & GALIL, B., 2005. A review of changes in the fish assemblages of Levantine inland and marine ecosystems following the introduction of non-native fish. *Journal of Applied Ichthyology* 21: 364

HERUT, B., ALMOGI-LABIN, A., JANNINK, N. & GERTMAN, I., 2000 The seasonal dynamics of nutrient and chlorophyll a concentrations on the SE Mediterranean shelf-slope. *Oceanologica Acta* 23: 771 – 782.

JENSEN, A. C., 2002. Artificial reefs of Europe: perspective and future. ICES *Journal of Marine Science* 59: 3-13.

JENSEN, A. C., COLLINS, K. J. & LOCKWOOD, A. P. M. (eds.) 2000. *Artificial Reefs in European Seas.* Kluwer Academic Publishers, Dordrecht, Netherlands. 508.

KARACHLE, P. K., TRIANTAPHYLLIDIS, C. & STERGIOU, K. I., 2004. Bluespotted cornetfish *Fistularia commersonii* Rüppell, 1838: a Lessepsian sprinter. *Acta Ichtiologica et Piscatoria* 34: 103-108.

LINDQUIST, D. C., SHAW, R. F. & HERNANDEZ, F. J., 2005. Distribution patterns of larval and juvenile fishes at offshore petroleum platforms in the north-central Gulf of Mexico. *Estuarine, Coastal and Shelf Science* 62: 655-665.

LUNDBERG, B. & GOLANI, D., 1995. Diet adaptations of Lessepsian migrant Rabbitfish, *Siganus luridus* and *S. rivulatus,* to the algal resources of the Mediterranean coast of Israel. *Marine Ecology* 16: 73.

LYTHGOE, J. & LYTHGOE, G., 1971. *Fishes of the sea.* Blandford Press, London UK. 320.

MONTEIRO, C. C. & SANTOS, M. N., 2000. Portuguese artificial reefs. In: Jensen, A.C., Collins, K.J. and Lockwood, A.P.M (eds.) *Artificial reefs in European Seas.* Kluwer Academic Publishers, Dordrecht, Netherlands 249-261.

MORENO, I., ROCA, I., REÑONES, O., COLL, C. & SALAMANCA, M., 1994. Artificial reef program in Balearic waters (Western Mediterranean). *Bulletin of Marine Science* 55: 667-671.

OGAWA, Y., 1982. Jinko gyosho, tsukiiso and marine organisms. *Japanese artificial reef technology technical report* 604: 42-48. Aquabio, Inc., 2957 Sunset Blvd., Bellair Bluffs, Fl.

OSENBERG, C.W., ST. MARY, C. M., WILSON, J.A. & LINDBERG, W. J., 2002. A quantitative framework to evaluate the attraction–production controversy. *ICES Journal of Marine Science* 59: 214-221.

PAIS, A., MERELLA, P., FOLLESA, M. C. & GARIPPA, G., 2007. Westward range expansion of the Lessepsian migrant *Fistularia commersonii* (Fistulariidae) in the Mediterranean Sea, with notes on its parasites. *Journal of Fish Biology* 70: 269-277.

PITCHER, T. J., MAGURRAN A. E. & WINFIELD, I. J., 1982. Fish in larger shoals find food faster. *Behavioral Ecology and Sociobiology* 10:149-151.

PITCHER, T. J. & SEAMAN, W.J., 2000. Petrarch's principle: how protected human-made-reefs can help the reconstruction of fisheries and marine ecosystems. *Fish and fisheries,* 1:73-81.

POLOVINA, J. J., 1989. Artificial reefs: nothing more than benthic fish aggregators. *California Cooperative Oceanic Fisheries Investigations* 30: 37-39.

PRATT, J. A., 1994. Artificial habitats and ecosystem restoration: managing for the future. *Bulletin of Marine Science* 55: 268-275.

RELINI, G., RELINI, M., TORCHIA, G. & PALANDRI, G., 2002. Ten years of censuses of fish fauna on the Loano artificial reef. ICES *Journal of Marine Science* 59: 132-137.

RILOV, G. & BENAYAHU, Y., 2000. Fish assemblage on natural versus vertical artificial reefs: the rehabilitation perspective. *Marine Biology* 136: 931-942

SAURNIA, A., 1973. La production primaire planctonique en Méditerranée. *Newsletter of Cooperation Investment. Mediterranean, Species Issue,* 5: 1-128.

SEAMAN, W. J., 2000. *Artificial Reef Evaluation with Application to Natural Marine habitats.* CRC Press, Boca Raton, Florida, US. 246.

SEAMAN, W. J. & SPRAGUE, L. M., 1991. *Artificial Habitats for Marine and Freshwater Fisheries.* Academic Press, London, UK. 285.

SHANNON, C. E., 1948. A mathematical theory of communication. *Bell System Technical Journal* 27: 379-423

SHENG, Y. P., 2000. Physical characteristics and engineering at reef sites In: Seaman, W.J. (ed.) *Artificial Reef Evaluation with Application to Natural Marine Habitats.* CRC Press, Boca Raton, Florida, US. 51-94.

SNOVSKY, G. & SHAPIRO, J. (eds.) 2003. *Israel fisheries in figures,* State of Israel. Ministry of Agriculture – Department of Fisheries

SPANIER, E., 1996. Assessment of habitat selection behavior in macro-organisms on artificial reefs. In: Jensen, A.C. (ed.) *European Artificial Reef Research - Proceedings of the 1st EARRN (European Artificial Reef Research Network).* Ancona, Italy. Southampton Oceanographic Centre, UK, 323-336.,

SPANIER, E., 2000a. Artificial reefs off the Mediterranean coast of Israel. In: Jensen, A.C., Collins, K.J. and Lockwood, A.P.M (eds.) *Artificial reefs in European Seas.* Kluwer Academic Publishers, Dordrecht, Netherlands. 1-19.

SPANIER, E., 2000b. Changes in the ichthyofauna of an artificial reef in the southeastern Mediterranean in one decade. *Scientia Marina* 64: 279-284.

SPANIER, E. & GALIL, B. S. 1991. Lessepsian migration: a continuous biogeographical process. *Endeavour* 15: 102-106.

SPANIER, E., PISANTY, S. & TOM, M. 1983. Artificial reef in the eastern Mediterranean, preliminary results. In: Shuval, H. (ed.) *Developments in Ecology and Environmental Quality Vol. II.* Balaban ISS. Philadelphia, 317-325.

SPANIER, E., TOM, M. & PISANTY, S. 1985a. Enhancement of fish recruitment by artificial enrichment of man-made reefs in the southeastern Mediterranean. *Bulletin of Marine Science,* 37: 356-363.

SPANIER, E., TOM, M., PISANTY, S., BREITSTEIN, S., TUR-CASPA, Y. & ALMOG, G., 1985b. Development of artificial habitats for commercial species and open sea fish culturing in the southeastern Mediterranean. *Proceedings of the joint international scientific diving symposium October 31 to November 3, 1985.* Academy of Underwater Sciences, La Jolla, California, 123-135.

SPANIER, E., PISANTY, S., TOM, M. & ALMOG SHTAYER, G., 1989. The fish assemblage on a coralligenous shallow shelf off the Mediterranean coast of Northern Israel. *Journal of Fish Biology* 35: 641-649.

SPANIER, E., TOM, M., PISANTY, S. & ALMOG SHTAYER, G., 1990. Artificial reefs in the low productive marine environment of the southeastern Mediterranean. P.S.Z.N.I: *Marine Ecology,* 11: 61-75.

STERGIOU, K. I., 1988. Feeding habits of the Lessepsian migrant *Siganus luridus* in the Eastern Mediterranean, its new environment. *Journal of Fish Biology* 33: 531-543.

STONE, R. B., PRATT, H. L., PARKER, R. O. & DAVIS, G. E., 1979. A comparison of fish populations on an artificial and a natural reef in the Florida Keys. *Marine Fisheries Review* 41: 1-11.

TURNER, C. H., EBERT, E. E. & GIVAN, R. R., 1969. Man-made reef ecology. *California Department of Fish and Game Fisheries Bulletin* 146: 221.

TYRRELL, M. & BYERS, J. E., 2007. Do artificial substrates favor non-indigenous fouling species over native species? *Journal of Experimental Marine Biology and Ecology* 342: 54-60.

WILCOXON, F., 1945. Individual Comparisons by Ranking Methods. *Biometrics Bulletin* 1: 80-83.

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