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EPIBENTHIC MACROFAUNA ON AN ARTIFICIAL REEF OF THE NORTHERN ADRIATIC SEA: A FIVE-YEARS PHOTOGRAPHIC MONITORING

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ABSTRACT

Artificial reefs (ARs) are man-made structures used with the aim of improving fisheries and increasing natural production of biological resources. In 2006 an AR made of three types of modules was sunk near an underwater sewage outfall. The objectives of the project were: (a) to use the AR to restock some target species of commercial interest and (b) to promote biodiversity in selected areas. The epibenthic macrofauna that had settled on this AR was annually monitored for five years (2007- 2011) using non-destructive photographic methods. A total of 88 taxa from 8 phyla were identified, with a predominance of Porifera, Mollusca and Ascidiacea. Among the types of modules used to construct the AR, polyethylene panel nets were functional for bivalve settlement in the first year, whereas concrete structures seemed to perform best in promoting biodiversity in terms of species richness in the long term. Nevertheless, the 5-year monitoring period was too short to speculate on the stability or homeostasis of communities settled on the AR in terms of ecological succession.

Key words: artificial reefs, macrozoobenthos, Adriatic Sea, photographic monitoring

LA MACROFAUNA EPIBENTONICA DI UNA BARRIERA ARTIFICIALE SOMMERSA DELL'ALTO ADRIATICO: RISULTATI DI UN MONITORAGGIO FOTOGRAFICO QUINQUENNALE

SINTESI

Le barriere artificiali (BA) sono strutture solitamente utilizzate per incrementare le rese di pesca. Nel 2006 è stata realizzata una BA, costruita con tre diverse tipologie di moduli e situata in prossimità di un dotto fognario sottomarino. Gli obiettivi del progetto erano: (a) sperimentare la BA per il ripopolamento di alcune specie di interesse commerciale e (b) promuovere la biodiversità. La macrofauna epibentonica insediata su questa BA è stata monitorata a cadenza annuale durante 5 anni (2007-2011) per mezzo di rilievi fotografici. Complessivamente sono stati identificati 88 taxa appartenenti ad 8 phyla, in cui i Porifera, Mollusca ed Ascidiacea sono stati prevalenti. I pannelli in rete di polietilene sono stati efficaci durante il primo anno per l'insediamento dei molluschi bivalvi, mentre nel lungo periodo il cemento si è dimostrato il più efficace per promuovere la biodiversità in termini di ricchezza specifica. Il monitoraggio di 5 anni comunque non è stato del tutto soddisfacente per trarre conclusioni sulla successione ecologica della comunità insediata sulla BA.

Parole chiave: Barriere artificiali, macrozoobenthos, mare Adriatico, monitoraggio fotografico

INTRODUCTION

Artificial reefs (ARs) are man-made structures that have long been used with the aim of improving fisheries by concentrating fish and increasing the natural production of biological resources (Bohnsack & Sutherland, 1985). Parenzan (1957) was one of the first scientists to suggest the use of artificial structures as a tool to increase fishery production in oligotrophic environments by sinking wrecks and testing ad hoc experimental areas (Parenzan, 1986). In Italy the first AR was made in December 1970, when a team of recreational fishermen, without any scientific support, obtained the permission to sink 1,300 cars at depth between 35 and 50 m in order to discourage trawling and to improve recreational fishing (Relini & Orsi Relini, 1989). The first scientifically oriented AR was built in 1974 in the Adriatic Sea, with stones and concrete blocks (Bombace, 1989). After about 40 years, Fabi *et al.* (2011) reported more than 70 ARs along the Italian coast, most of them built thanks to the financial support of the European Community.

In the oligotrophic waters of the Mediterranean, ARs have been used mainly to protect *Posidonia oceanica* meadows from illegal trawling and to increase habitat complexity and species diversity (Relini *et al.*, 1994; Gonzalez-Correa *et al.*, 2005; Ponti *et al.*, 2015). In contrast, in the eutrophic waters of the central and northern Adriatic, ARs have been used to increase fishery yields (Bombace *et al.*, 1994; Bombace *et al.*, 1997). Concrete, pebbles, limestone rocks, and PVC are the most common materials used to build ARs (Toledo *et al.*, 2020 and references therein). The concrete is frequently used because it is cheap and allows the realization of different structures in terms of shape and size. In addition, concrete is resistant to chemical and physical marine actions, thus ensuring long duration (Fabi *et al.*, 2011; Ponti *et al.*, 2015).

ARs are intentionally placed on the seafloor with the goal of imitating the function of a natural reef, therefore most studies after the installation of an AR are focused on the ecological succession of benthic organisms on these manmade substrates (Toledo *et al.*, 2020 and references therein). The colonization process can be broadly divided in early and late succession: the former is associated with the first organisms that settle on the ARs, including organized microorganisms creating microbial mats or biofilms; the latter is characterized by the arrival of more complex organisms, which in turn attract predator species from further up the trophic chain (Herbert *et al.*, 2017; Toledo *et al.*, 2020 and references therein).

The AR analyzed in the present study was based on guidelines developed as part of the project ADRI. BLU (2006). This project addressed the sustainable management of fisheries activities and resources in the northern Adriatic Sea. More information on the project is available on internet in Italian. The specific objectives of the project were: (a) to use the AR in

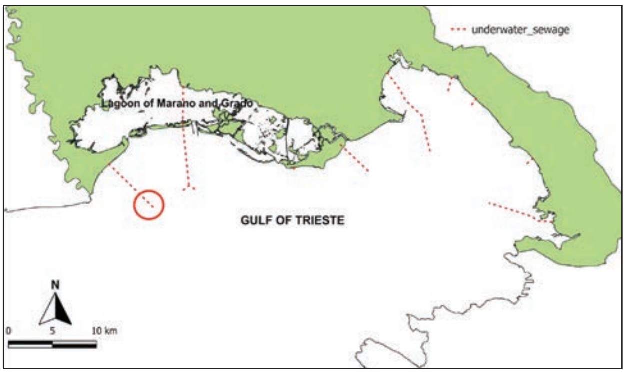

Fig. 1: Map of the study area, the circle indicates the terminal tract of Lignano Sabbiadoro sewage outfall.
Sl. 1: Zemljevid obravnavanega območja z označenim delom terminala kanalizacije mesta Lignano Sabbiadoro (krogec).

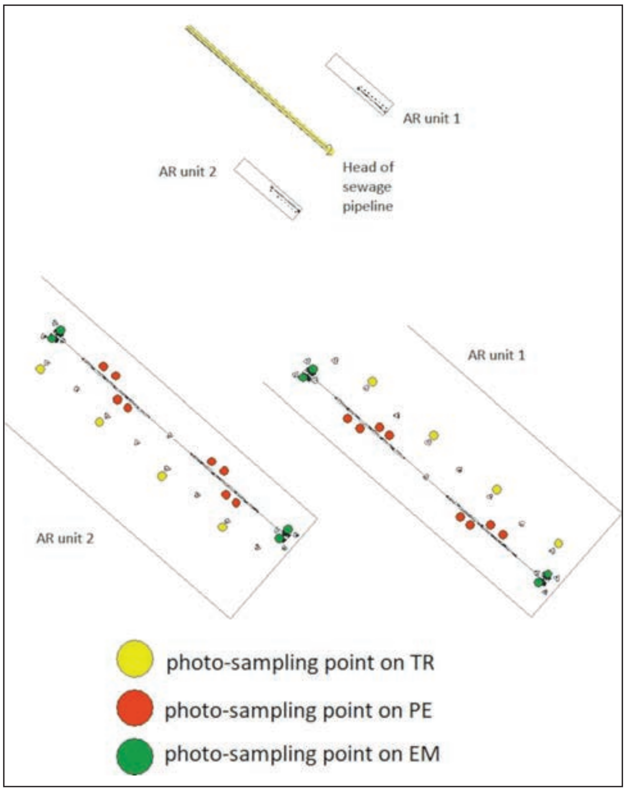

Fig. 2: Particular of the terminal tract of the sewage outfall, location of the AR units and photo sampling points.
Sl. 2: Del terminala kanalizacije, lega UPG in vzorčevalne postaje fotografskega monitoringa.

Fig. 3: a) Tecnoreef® pyramid (TR); b) Ecomare pyramids (EM); c) Polyethylene net for scallops settlement (PE) (photos: Arpa FVG).
Sl. 3: a) Tecnoreef® piramida (TR); b) Ecomare piramide (EM); c) Polietilenska mreža za naseljevanje pokrovač (PE) (fotografije: Arpa FVG).

order to restock some target species of commercial interest, such as pectinid bivalves, and (b) to promote biodiversity in some selected areas, such the Gulf of Trieste for the Region Friuli-Venezia Giulia. In this context, in 2006, an AR was sunk three miles off Lignano Sabbiadoro, near an underwater sewage outfall (Solis-Weiss et al., 2007, and references therein), and the settled macrofauna was monitored annually for the following five years (2007- 2011) using photographic methods based on a guide specifically developed within this project (Arpa FVG, 2007; Bettoso *et al.*, 2023). The photographic method is less accurate than other sampling techniques, but has the advantage of being non-destructive, fast, and efficient enough to monitor the evolution of epibenthic communities on the AR with a good benefit-cost ratio. In the present work the results of this photographic monitoring are presented.

MATERIAL AND METHODS

Study area

The AR was located in the Gulf of Trieste, the northernmost part of the Adriatic Sea (Fig. 1). It is a shallow semi-enclosed basin (max depth 25 m), characterized by the largest tidal amplitudes and the lowest winter temperatures in the Mediterranean Sea (Boicourt *et al.*, 1999), high temperature and salinity variations, and important stratification of the water column (Stravisi, 1983). The hydrodynamism is related mainly to the ascending eastern current coming from the Istrian coast. The general circulation pattern is predominantly counterclockwise in the lower layer and clockwise in the surface layer. This circulation, especially in the surface layer can be modulated by prevailing winds from

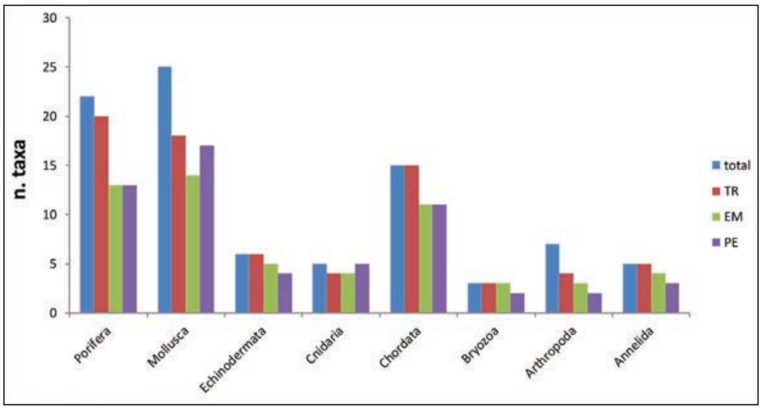

Fig. 4: Taxa richness (TR, Tecnoreef; EM, ecomare; PE, polyethylene).
Sl. 4: Pestrost taksonov (TR, Tecnoreef; EM, ecomare; PE, polietilenska mreža).

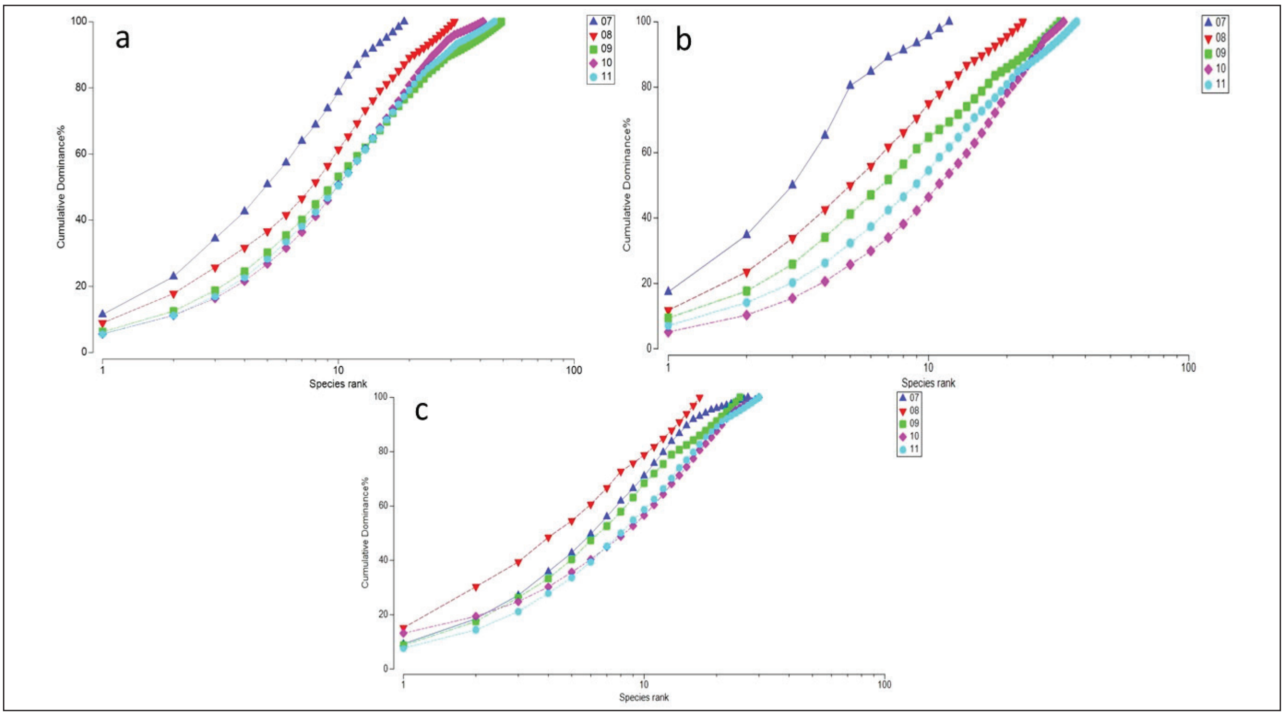

Fig. 5: a) K-dominance curves for Tecnoreef (TR), b) K-dominance curves for ecomare (EM); c) K-dominance curves for polyethylene net (PE).
Sl. 5: Krivulje K-dominance za Tecnoreef (TR), b) krivulje K-dominance za ecomare (EM); c) krivulje K-dominance za polietilensko mrežo (PE).

eastern quadrants such as Bora (Stravisi, 1983). The sediments are quite varied, from sands with beachrocks to muds, predominantly detritical, and the associated biocoenoses of the Gulf belong mainly to the DC (Détritique Côtier), DE (Détritique Envasé) and VTC (Vases Terrigènes Côtières) biocoenoses, as defined by Pérès & Picard (1964) (Solis-Weiss *et al.*, 2001).

The AR was deployed in August/September 2006 about 3 nautical miles off Lignano Sabbiadoro near the underwater sewage outfall (Fig. 1), where anchoring and fishery are forbidden. The site is located at 16 m depth, where the sediment consists of pelitic sand and very sandy pelite, and benthic community of the soft bottom is mainly represented by the biocoenosis of Coastal Detritic (DC) (Solis-Weiss *et al.*, 2007). The AR consisted of

Tab. 1: Taxa richness year by year on every AR module (TR – Tecnoreef, EM – ecomare, PE – polyethylene net) and Mann-Kendall test (ns – not significant, in bold – upward trend).
Tab. 1: Pestrost taksonov v posameznih letih na vsakem UPG modulu (TR – Tecnoreef, EM – ecomare, PE – polietilenska mreža) in Mann-Kendallov test (ns – ni statistično značilen, mastni tisk – trend naraščanja).

TR	**2007**	**2008**	**2009**	**2010**	**2011**	**Mann-Kendall**
tot	19	31	49	41	46	ns
Porifera	1	6	13	11	16	**0.042**
Mollusca	8	8	10	7	9	ns
Echinodermata	5	2	3	5	2	ns
Cnidaria	0	2	3	2	3	ns
Chordata	3	9	12	12	9	ns
Bryozoa	0	1	2	2	3	**0.0083**
Arthropoda	0	1	3	0	1	ns
Annelida	2	2	3	2	3	ns
EM	**2007**	**2008**	**2009**	**2010**	**2011**	
tot	12	23	32	33	37	**0.0083**
Porifera	2	4	8	7	8	**0.042**
Mollusca	7	5	8	7	10	ns
Echinodermata	0	2	3	3	2	ns
Cnidaria	0	1	2	2	3	**0.0083**
Chordata	2	8	7	9	5	ns
Bryozoa	0	1	2	2	3	**0.0083**
Arthropoda	0	1	0	1	2	ns
Annelida	1	1	2	2	4	**0.042**
PE	**2007**	**2008**	**2009**	**2010**	**2011**	
tot	27	17	25	30	30	ns
Porifera	1	1	7	7	11	**0.042**
Mollusca	12	3	6	8	5	ns
Echinodermata	3	0	1	2	2	ns
Cnidaria	2	3	3	2	3	ns
Chordata	6	6	5	6	4	ns
Bryozoa	0	1	1	2	2	**0.042**
Arthropoda	1	0	0	1	0	ns
Annelida	2	3	2	2	3	ns

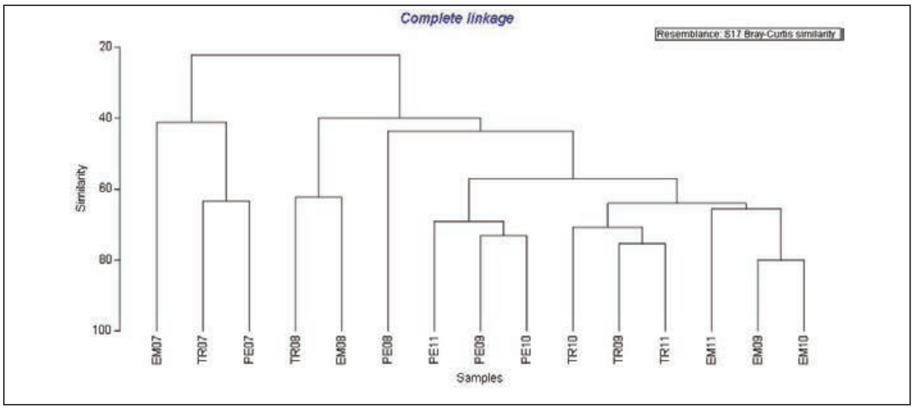

Fig. 6: Dendrogram on the basis of years (07-11) and AR module (TR, EM, PE).
Sl. 6: Dendrogram na podlagi različnih let (07-11) in modula AR (TR, EM, PE).

two different units (hereafter AR units) placed on both sides of the sewage duct, at a distance of 500 m from the end section of the sewer (Fig. 2). These AR units were made of three different types of artificial modules (hereafter AR modules) placed in a symmentrical and specular way with respect to the sewer (Fig. 2). These modules were: 30 pyramids made of concrete slabs (TR – declared "sea-friendly" by the producer Tecnoreef®, manifactured using only natural components, without synthetic additives; pH – 9; 180 cm height) (Fig. 3a); 4 pyramids made of PVC tubes (EM – Ecomare, diameter of tubes is 100 cm and pyramid high is 273 cm) (Fig. 3b); 4 sets of polyethylene panel nets (PE) (mesh size 40 mm, length 100 m, height 300 cm, width 100 cm) used for the settlement of scallop larvae (Fig. 3c).

Sampling and analysis

Epibenthic faunal communities on the AR were surveyed once a year using SCUBA photo-sampling (Fujifilm Finepix F30 model). Pictures of a 50x50 cm (2,500 cm^2) quadrat (divided in 4 subquadrats) were taken at 16 points for each unit (4 for TR, 4 for EM, and 8 for PE) for a total of 32 sampling points (displayed in Fig. 2). Animals that were readily identifiable in the photographs were determined to the lowest possible taxonomic level, whereas those not easily recognizable at the species level were collected and stored for determination at the laboratory (Bettoso *et al.*, 2023). The first survey took place in June 2007, nine months after the sinking of the AR, and was repeated each spring/summer until 2011, for a total of 132 quadrats analysed. Cluster, K-dominance curves and SIMPER analysis (Clarke and Warwick, 2001) were performed on presence/absence data subdivided for type of AR module and year of sampling. Mann Kendall test was applied to statistically assess if there is a monotonic upward or downward trend of the variable of interest over time.

RESULTS

A total of 88 taxa of epibenthic invertebrates, belonging to 8 phyla, were detected by photo sampling, of which 75 were recorded on concrete pyramids (TR), 57 in both PVC pyramids (EM) and polyethylene panel nets (PE). The most abundant phyla in terms of taxa richness were Mollusca followed by Porifera and Chordata, the latter represented by class Ascidiacea. The same pattern was observed considering the three types of AR modules separately, except for TR, where Porifera slightly outweigh Mollusca (Fig. 4). The highest taxa richness was observed on TR modules for all phyla except for Cnidaria, showing the highest richness on PE modules (Fig. 4). Considering the total number of taxa, an increase with time was observed only for EM (Mann-Kendall test, Tab. 1). Considering the different phyla separately, Porifera and Bryozoa were the only groups to show an increasing trend in richness values in all types of AR modules (Tab. 1).

The K-dominance curves generated for TR showed decreasing dominance from 2007 to 2008, whereas curves for 2009, 2010 and 2011 showed a comparable shape (Fig. 5a). Similar pattern was observed for EM, although the curves from 2009 to 2011 intersect at one point (Fig. 5b). For PE, the shape of the curve for 2007 was more similar to the curves for 2009-2011, whereas the curve for 2008 was the steepest and showed the highest dominance (Fig. 5c).

The dendrogram clearly separated the first survey of 2007 (Group A: EM07, TR07, PE07) at a similarity level of about 20%, whereas the Group B included TR08 and EM08 surveyed in 2008. The remaining clusters (2009-2011) were grouped at a similarity level of about 60%, except PE08 which was grouped apart (Group C). The cluster 2009-2011 was subdivided on the basis of the type of

Tab. 2: SIMPER analysis performed on clusters of the dendrogram (cut off 50%).
Tab. 2: SIMPERjeva analiza posameznih gruč na dendrogramu (rez na nivoju 50%).

	Group A 2007 (TR, EM, PE)		**Group B 2008 (TR, EM)**		**Group C 2008 (PE)**
POR	*Crambe crambe*	POR	*Crambe crambe*	CNI	*Cereus pedunculatus*
MOL	*Hexaplex trunculus*	POR	*Ulosa digitata*	ANN	Serpulidae indet.
MOL	*Ostrea edulis*	MOL	*Hexaplex trunculus*	CHO	*Phallusia mammillata*
MOL	*Mimachlamys varia*	MOL	*Ostrea edulis*	CHO	*Styela plicata*
MOL	*Pinna nobilis*	ANN	Serpulidae indet.	CHO	*Didemnum lahillei*
MOL	*Mytilus galloprovincialis*	CHO	*Didemnum lahillei*		
MOL	*Flexopecten glaber*	CHO	*Phallusia mammillata*		
ANN	Serpulidae indet.	CHO	*Phallusia fumigata*		
CHO	*Phallusia mammillata*	CHO	*Diplosoma listerianum*		
CHO	*Botryllus schlosseri*				
	Group D 2009-2011 (TR)		**Group E 2009-2011 (EM)**		**Group F 2009-2011 (PE)**
POR	*Crambe crambe*	POR	*Crambe crambe*	POR	*Crambe crambe*
POR	*Dysidea fragilis*	POR	*Dysidea fragilis*	POR	*Ulosa digitata*
POR	*Haliclona (Reniera) mediterranea*	POR	*Haliclona (Reniera) mediterranea*	POR	*Dysidea fragilis*
POR	*Phorbas fictitius*	POR	*Ulosa digitata*	POR	*Haliclona (Reniera) mediterranea*
POR	*Dictyonella incisa*	CNI	*Cereus pedunculatus*	CNI	*Epizoanthus* sp.
POR	*Ulosa digitata*	MOL	*Hexaplex trunculus*	CNI	*Cereus pedunculatus*
CNI	*Cereus pedunculatus*	MOL	*Ostrea edulis*	MOL	*Hexaplex trunculus*
MOL	*Hexaplex trunculus*	MOL	*Anomia ephippium*	MOL	*Ostrea edulis*
MOL	*Ostrea edulis*	MOL	*Mimachlamys varia*	MOL	*Anomia ephippium*
MOL	*Mimachlamys varia*	ANN	Serpulidae indet.	MOL	*Mytilus galloprovincialis*
ANN	Serpulidae indet.	BRY	Bryozoa indet.	ANN	Serpulidae indet.
BRY	Bryozoa indet.	BRY	*Schizobrachiella sanguinea*	BRY	Bryozoa indet.
BRY	*Schizobrachiella sanguinea*	ECH	*Ocnus planci*	ECH	*Ophiothrix fragilis*
ECH	*Ocnus planci*	CHO	*Phallusia mammillata*	CHO	*Didemnum lahillei*
CHO	*Microcosmus* sp.	CHO	*Phallusia fumigata*	CHO	*Diplosoma listerianum*
CHO	*Didemnum lahillei*	CHO	*Didemnum lahillei*		
CHO	*Diplosoma listerianum*	CHO	*Microcosmus* sp.		

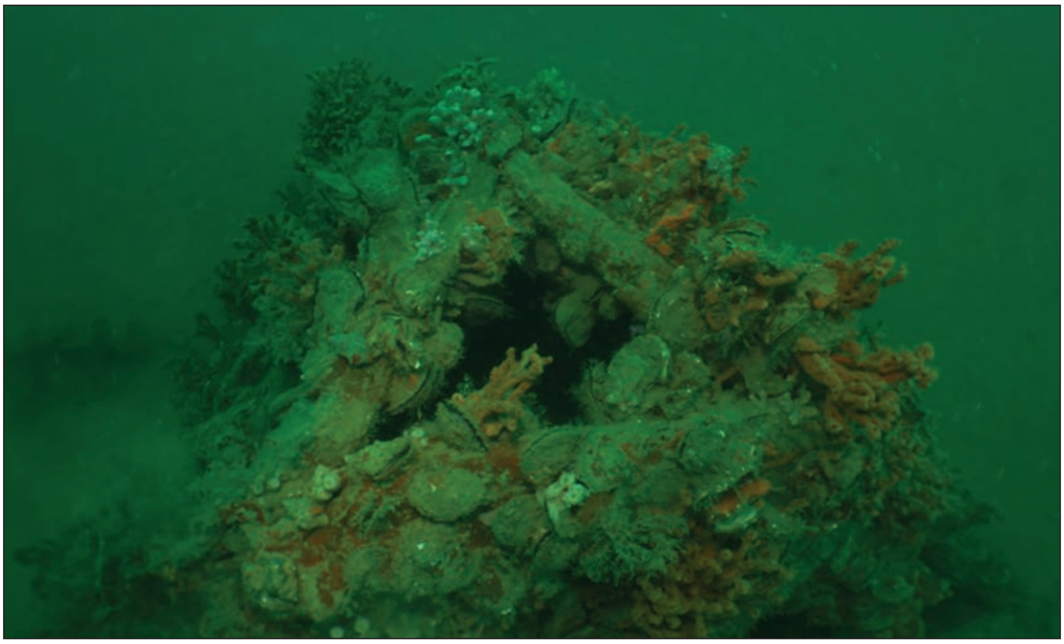

Fig. 7: Tecnoreef pyramid (TR) in 2015 (photo: G. Pessa).
Sl. 7: Tecnoreef piramida (TR) leta 2015 (foto: G. Pessa).

AR modules rather than years (Group D: TR09, TR10, TR11; Group E: EM09, EM10, EM11; Group F: PE09, PE10, PE11) (Fig. 6).

SIMPER analysis was used to identify the most representative species for each cluster of the dendrogram (Tab. 2). *Crambe crambe* was the first Porifera species recorded on the AR and was found every year and on all types of AR modules, except PE in 2008. In the second year, *Ulosa digitata* was detected on TR and EM and was observed on all types of AR modules in all subsequent years. *Dysidea fragilis* and *Haliclona (Reniera) mediterranea* were among characteristic species from 2009 onwards. SIMPER identified two more species of Porifera only on TR (group D) (Tab. 2). Considering phylum Annelida, the taxon Serpulidae was constantly found in every year and all types of AR modules. The phylum Mollusca was mainly represented by bivalves and had the highest number of characteristic species in 2007. *Flexopecten glaber* and *Pinna nobilis* were recorded only during the first year, whereas the gastropod *Hexaplex trunculus* and the oyster *Ostrea edulis* characterized all groups of dendrogram, except the group C (PE in 2008) where no molluscs were identified by SIMPER analysis. *Mytilus galloprovincialis* was included in the group F (PE 2009-11) and *Mimachlamys varia* in those D and E (TR and EM 2009-11). The phylum Cnidaria was represented mainly by *Cereus pedunculatus*, being characteristic of group C on PE in 2008 and in all types of AR modules from 2009 to 2011. The Chordata Ascidiacea were characteristic in all cluster groups. It is interesting to note the exclusive presence of *Botryllus schlosseri* in 2007 and the particular abundance of *Phallusia mammillata* in 2007 and 2008 on all types of AR. *Didemnum lahillei* was among characteristic species from 2008 onwards (Tab. 2).

DISCUSSION AND CONCLUSIONS

The Gulf of Trieste is characterized by various environmental and anthropogenic pressures that affect benthic communities, such as periodic "mare sporco" phenomena (mucilage aggregations), episodes of hypoxia and anoxia, significant riverine inflow, intense maritime traffic, intensive fishery, mariculture and others (Stachowitsch & Fuchs, 1995; Solis-Weiss *et al*., 2004). These pressures could lead to changes in the soft- and hard-bottom benthic communities, at least in terms of succession (Mavrič *et al*., 2010).

A recent census of ARs in the Adriatic Sea recorded a total of 47 sites along the Italian coast, 8 of which are located in the Gulf of Trieste (Minelli *et al*., 2021). The oldest AR of the gulf was built in 1978 inside the Miramare Marine Protected Area in Trieste, while the last one was established near mussel farms on the maritime border Italy-Slovenia (Project EcoSea, 2016). The site for the present work, near the sewage outfall off Lignano Sabbiadoro was selected to avoid damage to the AR and sewage pipeline from anchoring and fishing, and because this area is characterized by the presence of pelitic sand or very sandy pelite. In fact, this sediment texture is suitable to prevent the sinking

Fig. 8: Smooth scallops (**Flexopecten glaber*****) and*** *Spirobranchus triqueter* ***settled on polyethylene nets (PE) (photo: Arpa FVG).***
Sl. 8: Gladka pokrovača (**Flexopecten glaber*****) in*** *Spirobranchus triqueter* ***sta se naselila na polietilensko mrežo (PE) (foto: Arpa FVG).***

Fig. 9: Smooth scallops (**F. glaber*****) on sea floor nearby polyethylene nets (photo: Arpa FVG).***
Sl. 9: Gladka pokrovača (**F. glaber*****) na morskem dnu v bližini polietilenskih mrež (foto: Arpa FVG).***

of AR modules into the seafloor and the accumulation of muddy sediment on the AR, which could inhibit the development and diversification of epibenthic organisms. In addition, the proximity of natural rocky outcrops (locally knows as Trezze) very rich in term of epibenthic fauna (Lipej *et al*., 2016; Bettoso *et al*., 2023), could represent a good larval source for the settlement of species common in coralligenous biotopes. According to Ponti *et al.* (2015) the environmental conditions are the main drivers of the recruitment processes on ARs. In particular, the sedimentation rate seemed the most important in the establishment of different benthic assemblages and therefore in the ecological effectiveness of the ARs (Ponti *et al*., 2015). In the present study the area off Lignano Sabbiadoro shows a heterogeneous sediment texture: AR modules are located on prevailing sandy sediment close to the rocky outcrops, but just 1 Nm toward the coast the sediment becomes muddy due to the pelitic belt originated by the Tagliamento river mouth. Thus, this zone can be considered a transitional habitat between areas with high sedimentation rate and coralligenous biotopes.

A total of 88 taxa belonging to 8 phyla, identified for the present work on the AR by photographic monitoring only, is a high number when compared to the 196 taxa of epibenthic invertebrates recorded by Bettoso *et al.* (2023) using the same method on 45 natural rocky outcrops not far from the study area. Porifera, Mollusca and Ascidiacea predominated on the AR, as well as on those natural rocky outcrops (Bettoso *et al.*, 2023). The faunal component on the AR dominated over macroflora, because the site was at 16 m depth with recurring events of water turbidity. The same was observed for the natural rocky outcrops (Bettoso *et al.*, 2023). So, the proximity of the sewage pipeline did not seem to have a negative impact on the epibenthic fauna settled on the AR. Consistently, no negative impact had been observed on the soft bottom macrofauna near the same sewage outfall by Solis-Weiss *et al.* (2007).

According to Ponti *et al*. (2015) the shape and materials of ARs were of little importance in determining the structure of the benthic assemblage. Conversely, in the present work, some differences between the types of AR modules deployed were observed. In particular, TR showed overall higher richness values compared to EM and PE (Fig. 4).

The cluster showed that those differences are not evident immediately after the deployment of the AR (in 2007 all AR modules are clustered together), but from 2009 on, when benthic communities are clustered by type of modules rather than by years. On TR and EM total taxa richness increased from 2007 to 2008, mainly due to Porifera and Ascidiacea. From the third year (2009) the number of taxa did not increase on any AR module (Tab. 1). Dominance decreased for 2007 to 2009, and did not changed in the subsequent years on both TR and EM. Unfortunately the photographic monitoring on epibenthic fauna lasted only 5 years and further observations on the variability and/or stability on this community was not possible. Nevertheless, some pictures taken in 2015 on TR modules showed an assemblage with oysters, sponges and tunicates clearly observable (Fig. 7).

In the first year of monitoring the richness of bivalves was much higher on polyethylene panel nets (PE) than on concrete pyramids (TR) and PVC pyramids (EM). However, the permanent immersion of PE did not allow similar settlement of scallops and other bivalve

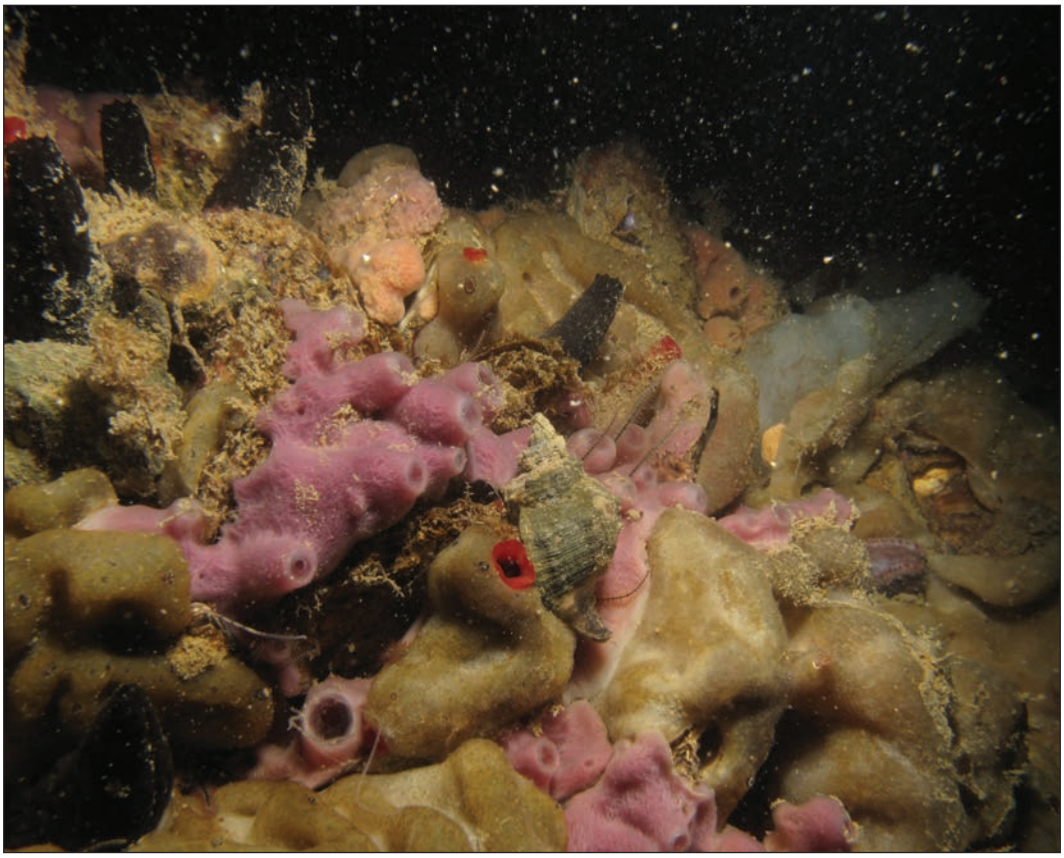

Fig. 10: Macrofauna assemblage on concrete plates (TR) in 2009 with the presence of the sponge *Haliclona (Reniera) mediterranea* ***(photo: Arpa FVG).***
Sl. 10: Združba makrofavne na betonskih ploščah (TR) v letu 2009 s spužvo *Haliclona (Reniera) mediterranea* ***(foto: Arpa FVG).***

in subsequent years as in 2007. On PE a decrease in richness was observed from 2007 to 2008 (Tab. 1), and at the same time dominance increased (Fig. 5c).

Polyethylene panel nets (PE) were specifically deployed to test the settlement of scallops, particularly for the smooth scallop *Flexopecten glaber*. This species is a very appreciated fisheries resource in the northern Adriatic Sea. It is usually caught together with *Pecten jacobaeus* by *rapido*, a type of beam trawl, used only in Adriatic Sea, with a very severe impact on benthic communities and whose use should be better regulated (Giovanardi *et al.*, 1998). The effectiveness of panel nets or collector bags as substratum for the settlement of *F. glaber* pediveligers has been successfully tested in other areas of the Gulf of Trieste (Orel & Zamboni, 2003). A massive production of this resource was found on PE also in the present study (Fig. 8). After 10 months from the immersion of 400 m of these panel nets, the smooth scallops reached a commercial size with an average density on the seafloor of 17 ind. m^{-2} and an estimated total biomass of 6,597 kg (Fig. 9) (Arpa FVG, 2007). Nevertheless, the effectiveness of panel nets for larval settlement of the smooth scallops, the queen scallop *Aequipecten opercularis* and other bivalves requires a clean substrate and a correct period of immersion for each species in order to detect the massive swarming of larvae (Orel & Zamboni, 2003). For instance, the period between June and September was considered the best for the captation of the variegated scallop *Mimachlamys varia* in the central Adriatic (Marguš *et al.*, 1993).

PE proved to be efficient also for the settlement of the critically endangered species *Pinna nobilis*, but almost all individuals were observed in 2007. So even if the species settles successfully, it probably does not survive in such types of structures. ARs made of plastic nets are recommented as larval captators by IUCN (Kersting & Hendriks, 2019) and have been extensively studied and used in different areas of the Mediterranean since the first mass mortality event of *P. nobilis* in 2016 (Kersting *et al.*, 2020). According to IUCN guidelines the main reproduction period of *P. nobilis* is from May to August and the main settlement period is between July and September (in the western Mediterranean), so collectors are usually deployed in June and removed in October-November (Kersting & Hendriks, 2019). These periods could change depending on environmental conditions (e.g., water temperature) in different years and Mediterranean regions (Kersting & García-March, 2017).

Based on the present work it is not possible to define a clear species succession, although, as the results show, some taxa such as Serpulidae, *Ostrea edulis* and *Crambe crambe* characterized the community every year; other like *Botryllus schlosseri* and *F. glaber* characterized only the first year, while some Porifera species (*e. g. Dysidea fragilis* and *Haliclona (Reniera) mediterranea*) characterized the community from 2009 onward (Fig. 10; SIMPER analysis). Serpulids, like *Spirobranchus triqueter*, are considered among pioneer species (Maggiore & Keppel, 2006; Nicoletti *et al*., 2007) able to drive the early stages of settlement, because of encroaching on clear surfaces (D'Anna *et al*., 2000; Moura *et al*., 2004) such ARs or molluscan shells (Fig. 8). Their dominance at the early stage of succession seems dependent on the timing of immersion of the AR. In fact, according to a recent research serpulids were dominant on plates placed in summer and autumn, while they were overweighed by bryozoans on plates placed in winter and spring (Fortič *et al*., 2021). About bivalves the settlement of *F. glaber* was above discussed, whereas the employment of artificial substrates can drive the production of the oyster *O. edulis* and the blue mussel *Mytilus galloprovincialis* (Fabi *et al*., 1989; Ardizzone *at al*., 1989). Oysters resulted very abundant on the Lignano AR and reached a commercial size (>70 gr) after 14 months from the deployment of structures (Arpa FVG, 2007), a shorter time compared to other areas in the Gulf of Trieste where about 23 months are needed (Orel & Zamboni, 2003). The following project Ecosea used the same sets of AR modules for further experiment on oyster culture. The blue mussel did not show any dominance stage on modules as observed by Nicoletti *et al*. (2007) on the Fregene AR (Tyrrhenian Sea), although it was among characterizing species in 2007 and on PE nets in 2009-2011. *Mytilus* pediveligers are more abundant in the surface layer (Dobretsov & Miron, 2001) and the settlement on the AR could be induced by mussels attached on the ropes, used to link the signal buoys floating on the sea surface. Considering the sponge *C. crambe*, this species is normally settled on shells of bivalves, e.g. *Arca noae, A. opercularis, M. varia*, and gastropods such *Hexaplex trunculus* (Corriero *et al.*, 1991) and it seems possible to farm this species for sponge culture purposes by means of artificial substrates (Padiglia *et al.*, 2018).

The colonial ascidian *B. schlosseri* can be an important driver of benthic community composition, but it strictly depends on local environmental conditions (Sams & Keough, 2012). In the present study it was very frequent in 2007 on all AR modules, whereas it was almost absent in the following years. The sponges *D. fragilis* and *H. mediterranea*, which were constantly recorded since 2009, are considered respectively as common and characteristic in coralligenous habitat (*sensu* Ballesteros, 2006) and were constantly found in assemblages on the rocky outcrops in the Gulf of Trieste (Bettoso *et al.*, 2023).

Based on this 5-year non-destructive monitoring on the AR realized thank to Project ADRI.BLU (2006) it is possible to conclude that the selected site was suitable for epibenthic settlement and in particular for bivalves captation. Nevertheless, according to Taormina *et al.* (2020) a 5-year monitoring is too short to speculate about stability or homeostasis of the AR in term of ecological succession. On regard the modules, polyethylene panel nets (PE) were functional only if employed during bivalve settlement, after this period they should be removed and cleaned for future employment. Considering long term settlement and evolution of epibenthic assemblage, TR seemed to give the best performance in term of species richness if compared to PE and EM, but a longer survey is needed to discriminate between long-term ecological successions and shorter-term variability. Anyway, on our opinion the use of EM and PE should be limited, being made by plastic material.

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EPIBENTOŠKA MAKROFAVNA NA UMETNEM PODVODNEM GREBENU V SEVERNEM JADRANU: PET LETNI FOTOGRAFSKI MONITORING

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POVZETEK

Umetni podvodni grebeni (UPG) so umetne strukture, ki jih uporabljajo z namenom izboljšanja ribištva in povečanje naravne produkcije bioloških virov. Leta 2006 so potopili tri tipe UPG blizu podvodnega iztoka kanalizacije. Cilji projekta so bili: (a) uporaba UPG za repopulacijo nekaterih komercialnih tarčnih vrst in (b) za promocijo biodiverzitete na izbranem območju. V petletnem obdobju (2007-2011) so z nedestruktivnimi fotografskimi metodami letno spremljali epibentoško makrofavno. Določili so 88 taksonov iz 8 debel, med katerimi so prevladovale spužve, mehkužci in kozolnjaki. Med različnimi tipi UPG so bile polietilenske panelne mreže funkcionalne za naseljevanje školjk v prvem letu, medtem ko so se betonske strukture izkazale za najboljše v smislu vrstne pestrosti biodiverzitete v dolgoročnem obdobju. Kakorkoli že, petletno obdobje je bilo prekratko za razumevanje stabilnosti oziroma homeostaze združb, ki so se v smislu ekološke sukcesije naselile na UPG.

Ključne besede: umetni podvodni grebeni, makrozoobentos, Jadransko morje, fotografski monitoring

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