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ARTICLE

The influence of habitat complexity on fish assemblages associated with extractive platforms in the central Mediterranean Sea

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ABSTRACT

In this work the influence of habitat complexity on fish assemblages associated with extractive platforms in the Mediterranean Sea was investigated. More specifically, at large spatial scale we tested the differences in fish assemblage between 4-legs vs 8-legs platforms, whereas at medium scale we evaluated, within each platform, the differences between internal structures with increasing complexity degrees (respectively: the water volume without any pillar - complexity "0"; the junction of two pillars - "1"; the junction of four pillars - "2"). Both univariate and multivariate analyses showed highly significant differences for each of the tested factors, as well as for their interaction. In general, at both medium and large spatial scales, mean species richness and abundance were positively correlated with the increasing habitat complexity with the highest values associated with 8-legs platforms and with the most complex internal structures within each platform. According to our findings, a more complex structure is able to attract more fish species and specimens than a less complex one, supporting previous studies carried out on different man-made structures outside the Mediterranean Sea. The study will integrate the still poor available knowledge baseline on the attractive potential of extractive platforms with strong implications for the environmental management under the incoming light of decommission in the basin.

Key words: Artificial habitat; Underwater Visual Census; gas platform; species richness.

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INTRODUCTION

Habitat complexity is defined as the heterogeneity in the arrangement of physical structure in the habitat surveyed (*sensu* Lassau and Hochuli, 2004) and it represents one among the most important ecological factor in shaping structure and community dynamics. Among others, it influences fish abundance, diversity in terms of species richness and composition (Jones, 1988; Bell and Galzin, 1984; Roberts and Ormond, 1987; Bell *et al.,* 1991; Hixon and Beets, 1993; Warfe and Barmuta, 2004; Harvey *et al.,* 2005; Willis *et al.,* 2005; Mangano *et al.,* 2017).

A particular relationship has been reported for several natural environments between the habitat complexity and animal community structure or assemblage compositions (*i.e.* both numbers of individuals and numbers of species; Luckhurst and Luckhurst, 1978; Roberts and Ormond, 1987; McClanahan, 1994; McCormick, 1994; Öhman and Rajasuriya, 1998; Gratwicke and Speight, 2005; Garcia Charton and Pérez Ruzafa, 2008; Porporato *et al.,* 2014; Mangano *et al.,* 2015). The main mechanism invoked to explain it, is a reduction of predation pressure due to the increased amount of refuge available to prey species (Hixon and Beets, 1993; Macpherson, 1994; Caley and St. John, 1996; Almany, 2004a). Increase in available refuges due to enhanced substrate topography also has been shown to reduce competition for space (Hixon and Menge, 1991; Almany, 2004b) as well as adding to niche dimensionality (MacArthur and Levins, 1967), both of which potentially increase fish abundance and distribution. The same pattern among spatial complexity, fish abundance and species richness has also been reported for artificial habitats such as, for instance, extractive platforms (Chang *et al.,* 1977; Higo *et al.,* 1980; Buckley, 1982; Shulman, 1984; Chandler *et al.,* 1985; Roberts and Ormond, 1987; Gorham and Alevizon, 1989; Hixon and Beets, 1989; Bohnsack *et al.,* 1991; Love and York, 2006). Surprisingly, the largest amount of these evidence has been collected outside the Mediterranean Sea, where in spite of the large number of oil and gas extractive platforms, this aspect is still poorly studied (Fabi *et al.,* 2002, 2004; Consoli *et al.,* 2007, 2013; Andaloro *et al.,* 2011, 2012; Scarcella *et al.,* 2011; Mangano and Sarà, 2017).

The extraction of fossil fuels from offshore fields has strongly increased over the last decades to meet the global growing demand for energy (Ghisel, 1997; Terlizzi *et al.,* 2008), this implies that the number of offshore platforms has increased the world over and, most probably, it will further increase in the future (De Luca, 1999; Pulsipher and Daniel, 2000).

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Then, understanding the role played by offshore platforms in shaping multi-level marine ecosystem's dynamics is becoming pressing as offshore platforms are acquiring increasing importance worldwide for its implications on marine biodiversity (Mangano and Sarà, 2017). The aim of the present study was to evaluate the influence of habitat complexity on fish assemblages associated with extractive platforms in the Ionian Sea (Mediterranean Sea). The obtained outcomes integrate the still poor available knowledge baseline on the attractive potential of these human-made structures with interesting rebounds for the environmental management in a context foreseen of decommission in the basin. In doing so, we tested whether different complexity degrees affected the associated fish assemblages across two different spatial scales. Accordingly, 1) we tested the difference in fish assemblage at large scale (~10 Km) between two different levels of complexity (4-legs *vs* 8-legs platforms) and 2), at medium scale (~100 m) testing the difference in fish assemblage between internal structures, of such platforms, with different spatial complexity.

METHODS

Study sites

The study was carried out during one week in May 2006 at three offshore gas platforms (Luna A, Luna B and Hera Lacinia) located in the southern Ionian Sea (Central Mediterranean Sea) respectively, 5.3, 6.2 and 2.6 Km offshore (Fig. 1). Two of them (Luna A and Luna B) were 8-leg platforms while the third one (H. Lacinia) was a 4-leg platform. All these platforms lie on a sandy seabed and are fixed to the sea floor by concrete or steel legs, which are connected by an assemblage of cross beams. The platforms were colonized by several foulers that generally provide crevices, refuges and food to cryptic and nekto-benthic fish species. The most abundant sessile species was the bivalve *Mytilus galloprovincialis* followed by balanids, *Ostrea* sp., and *Arbacia lixula* (P. Consoli, *personal observation*).

Habitat complexity

For each of the three platforms, internal structures with increasing complexity degrees (hereafter complexity 0, 1 and 2; Fig. 2), were identified and corresponded to: 0=the water volume without any pillar; 1=the junction of two pillars; and 2=the junction of four pillars, respectively.

Fish species and their abundances were recorded by Underwater Visual Censuses (UVC) by deploying the "Mobile Point Count" (MPC) technique performed at a depth between 0 and 12 meters. This technique, specifically designed for offshore platforms by Rilov and Benayahu (2000) and applied by Consoli *et al.* (2007, 2013) and Andaloro *et al.* (2011, 2012) in the Mediterranean Sea, was chosen as it is highly reliable in studying species strictly associated with the pillars and to detect benthic and cryptic species (Andaloro *et al.,* 2011, 2012; Consoli *et al.,* 2007, 2013). The diver, turning around each unit and looking at towards the pillar, counted all fishes occurring up to 3 m from the pillar. First, the diver recorded the more conspicuous and easily identifiable fishes from a maximum distance of 3 meters from the pillar (so that to have an entire view of the census unit) and then straight after, approached to the pillar, and counted the benthic and crypto-benthic species.

The total censused volume for complexity 0 corresponded to a cylinder of 7 m of diameter and 6 m height (~231 m^3). As regard complexity 1 and 2, the censused water volume was obtained subtracting the volume of the pillars (1 m of diameter) from 231 m^3. The resulting volumes for complexities 1 and 2 were 224 and 219 m^3, respectively. As a main consequence, data of abundance were standardized to the maximum censused volume (231 m^3) in order to compare censuses performed next to the different spatial complexity structures. Forty-

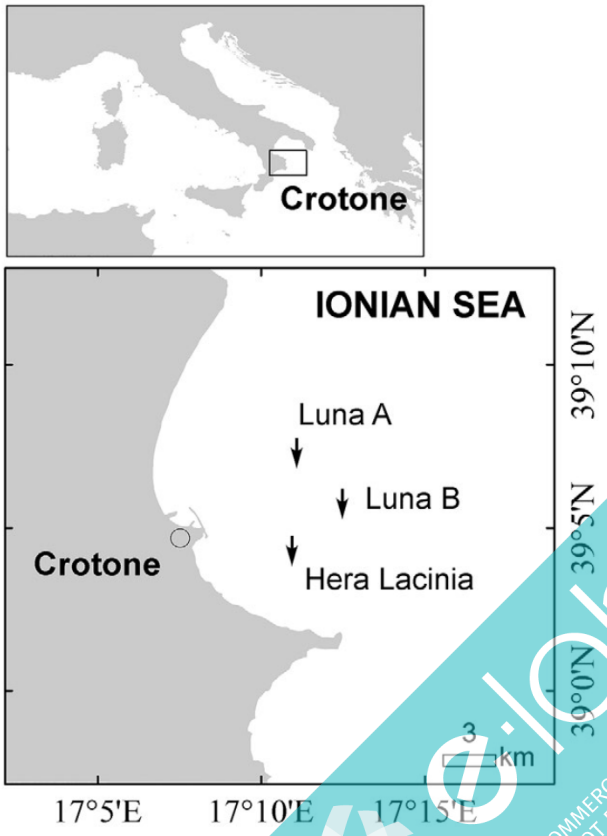


Fig. 1. Study area located in the Ionian Sea off Crotone (Calabria, Italy).

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eight censuses were performed for each level of medium scale complexity at each platform, leading to a total of 432 observations in the data set.

Statistical analyses

The sampling design included 2 factors:

i) Large Scale Complexity (LSC) was a fixed factor in the analysis with 2 levels of large-scale complexities (as expressed by: 4-leg and 8-leg platforms).
ii) Medium Scale Complexity (MSC) was a fixed factor in the analysis with 3 levels: complexity 0, 1 and 2 according to the rationale presented before and represented in Fig. 2.

On this basis, a two-ways Permutational Analysis of Variance (PERMANOVA; Anderson, 2001, McArdle and Anderson, 2001) was performed on abundance data to test the null hypothesis of no significant differences between fish assemblages associated with increasing habitat complexities, at two different spatial scales. The analysis was based on Bray-Curtis dissimilarities, calculated on log-transformed fish assemblage matrix. Each term of the analysis was tested using 9999 random permutations of appropriate units (Anderson and ter Braak, 2003). Significant terms that were relevant to our hypothesis were investigated using *a posteriori* pair-wise comparison with the PERMANOVA *t*-statistic and 9999 permutations.

Furthermore, we tested the effect of response variables on community metrics and in doing so, we modelled overall fish abundance and species richness through a Permutational univariate analyses of Variance (PERMANOVA; Anderson, 2001; McArdle and Anderson, 2001). Here we used the Euclidean distance instead the Bray-Curtis similarity index. Thus, the same F-statistics were calculated, but P-values were obtained by permutation. Finally, the SIMPER similarity percentage procedure (Clarke, 1993) was used to identify the fish species that most contributed to the differences among spatial complexities at medium and large spatial scale. All the analyses were performed using PRIMER 6 software package with PERMANOVA+add-on (Anderson *et al.,* 2008).

RESULTS

In Tab. 1 mean abundances and standard errors of each species are showed for LSC and MSC factors. Overall 15 fish taxa belonging to 6 families were recorded in the study area. Most of the recorded species were nekto-benthonic, while only 5 pelagic species were observed.

In term of species richness, Sparids were the most important family being represented by six species whereas the most abundant species were *Boops boops*, *Anthias anthias* and *Chromis chromis*.

PERMANOVA of the total fish assemblage (abundance data) showed highly significant differences for each factor considered in the analysis (Tab. 2) and also for the interaction between factors LSC and MSC (PERMANOVA, P=0.001). Furthermore, pairwise comparisons showed that significant differences occurred between fish assemblages in every MSC comparisons within each LSC level (P<0.001). The greatest *t*-values were observed between MSC 0-level and 2-level at both 4- and 8-legs platforms (t=3.85 and t=5.26, respectively; Tab. 2).

PERMANOVA on overall abundance and species richness mirrored the results of multivariate analysis (Tab. 2). According to the large-scale complexity, the highest values of both metrics were associated with 8-legs platforms (S=2.62 and 1.58, N=237 and 56, respectively at 8-legs and 4-legs platforms; Fig. 3).

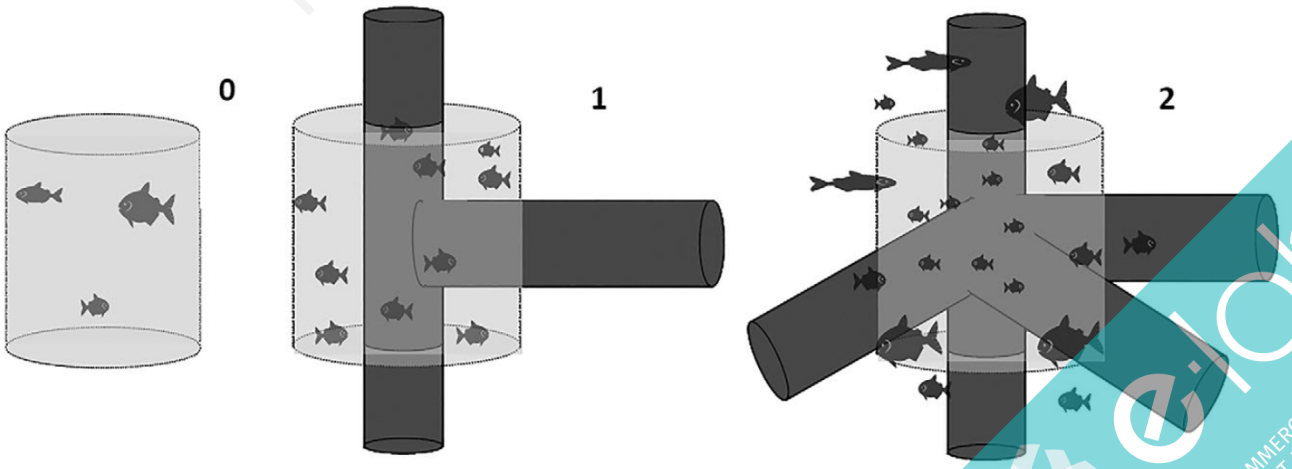


Fig. 2. Internal structures with increasing degrees of complexity; identified and corresponded to: 0=the water volume without any pillar; 1=the junction of two pillars; and 2=the junction of four pillars, respectively.

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As regards mean species richness, significant differences were found, at each platform, among MSC levels (Tab. 2) and the highest values were always associated with structures of Compl 2 (Fig. 3; Tab. 2). Looking at the *t* value, the greatest differences occurred between complexity 0 - 2 (t=17.747 and t=9.7555, at 8-legs and 4-legs platforms, respectively, Tab. 2).

A similar pattern was observed, at 8-legs platforms, also for the mean abundance, whereas, at the 4-legs platform, the highest value was associated with level 0 of MSC (Compl 0; Fig. 3).

SIMPER procedure pinpointed some fish taxa as the major contributors to the dissimilarities among spatial complexities. High densities of *Boops boops*, *Anthias anthias* and *Chromis chromis* characterized the censuses carried out nearby the most complex structures, both at large and medium spatial scale (Tab. 3).

DISCUSSION

Fish assemblages associated with increasing habitat complexities showed differences in terms of species richness, abundance and assemblages structure. This

Tab. 1. Mean species abundances and standard errors (± SE) per sample unit (230.91 m^3) for each level (Compl 0, 1 and 2) of complexity factors at 4-legs *vs* 8-legs platforms.

Platform complexity	Ecological category	LSC MSC	4-legs						8-legs					
			Compl 0		Compl 1		Compl 2		Compl 0		Compl 1		Compl 2	
			Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Anthias anthias	NB								31.53	11.85	86.14	14.39	187.00	21.95
Boops boops	P		30.00	6.99	24.54	8.88	23.84	6.29	31.31	7.04	56.85	11.60	137.29	19.23
Chromis chromis	NB		0.42	0.42	1.83	0.62	18.90	5.21	5.81	1.78	18.77	3.05	57.75	7.92
Diplodus sargus	NB						0.07	0.04			0.01	0.01	0.01	0.01
Diplodus vulgaris	NB				0.02	0.02	0.51	0.16	0.94	0.38	0.82	0.31	1.01	0.22
Oblada melanura	P		0.94	0.59	0.09	0.09	0.81	0.46	13.69	4.10	0.43	0.43	0.92	0.83
Sarpa salpa	NB								0.04	0.04			0.01	0.01
Seriola dumerili	P				0.02	0.02								
Serranus cabrilla	NB				0.02	0.02	0.11	0.06					0.01	0.01
Serranus scriba	NB												0.02	0.02
Spicara flexuosa	P		26.15	9.12	13.00	5.17	14.06	5.92	4.24	1.39	13.58	5.48	32.69	7.91
Spondyliosoma cantharus	NB								0.02	0.01	0.02	0.02	0.10	0.04
Thalassoma pavo	NB				1.35	0.48	1.74	0.46	0.01	0.01	2.74	0.59	10.98	1.42
Trachurus spp.	P		9.38	4.25	0.86	0.60	0.44	0.44	1.77	1.12	1.92	1.15	13.44	6.66

LSC, large scale complexity; MSC, medium scale complexity; NB, necto-benthonic; P, pelagic.

Tab. 2. Results of PERMANOVA tests analysing the effect of LSC and MSC factors on fish assemblage (multivariate test), species richness and fish abundance (univariate tests). Results of pair-wise tests performed for the interaction factor "LSC x MSC" are also reported.

Source	Fish assemblage				Species richness			Abundance		
	df	MS	F	P	MS	F	P	MS	F	P
LSC	1	75,363	4.0051	0.002	102.78	50.627	0.001	3.14E+06	54.959	0.001
MSC	2	52,279	16.826	0.001	133.95	113.99	0.001	2.15E+06	25.179	0.001
LSC x MSC	2	18,817	6.0562	0.001	10.616	9.0341	0.001	2.14E+06	25.024	0.001
Res	426	3107			1.1751			1.82E+07		
8-legs platforms			*t*	P		*t*	P		*t*	P
Compl 0. Compl 1			3.8476	0.001		10.934	0.001		3.9496	0.001
Compl 0. Compl 2			5.2578	0.001		17.747	0.001		9.1615	0.001
Compl 1. Compl 2			2.754	0.001		5.2947	0.001		6.3641	0.001
4-legs platforms										
Compl 0. Compl 1			2.3831	0.001		2.8711	0.001		1.2443	0.226
Compl 0. Compl 2			3.8503	0.001		9.7555	0.001		0.31125	0.772
Compl 1. Compl 2			1.8512	0.009		3.9344	0.001		0.95222	0.349

df, degree of freedom; LSC, large scale complexity; MSC, medium scale complexity.

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result was observed at both investigated spatial scales. In particular, as far as medium spatial scale is concerned, a positive relationship was observed between increasing habitat complexity and mean species richness at both levels of large spatial complexity (4- and 8-legs platforms). The same pattern was detected for mean fish abundance at the most complex platforms, while at 4-legs platform, a clear pattern was not observed since the highest values were not associated with the most complex internal structures. In this less complex platform, internal structure, corresponding to different degree of medium spatial scale complexities, are usually closer to each other compared with those at 8-legs platforms. Then, fishes probably, could not be able to distinguish these different degrees of spatial complexities. Mean fish abundance and species richness resulted positively correlated with increasing complexities also at large spatial scale.

These results strengthen and confirm observations made in previous studies carried out on different man-made structures such as artificial reefs (Roberts and Ormond ,1987; Hixon and Beets, 1989; Chang *et al.,* 1977; Higo *et al.,* 1980; Buckley, 1982; Gorham and Alevizon, 1989; Bohnsack *et al.,* 1991; Charbonnel *et al.,* 2002*,* Gratwicke and Speight, 2005), fringing reef (Roberts and Ormond 1987), shipwrecks (Chandler *et al.,* 1985; Fagundes-Netto *et al.,* 2011; Consoli *et al.,* 2015) and extractive platforms (Love *et al.,* 2003, 2010, 2012; Love and York, 2006; Rilov and Benayahu, 1998, 2000, 2002; Rooker *et al.,* 1997; Consoli *et al.,* 2013). All these studies proved a positive relationship between fish species-richness/abundance and the increasing habitat complexity.

After all, it is well known that these artificial habitats promote the aggregation of fishes that would otherwise be dispersed across larger areas of the ocean, a result of peculiar interest in the Mediterranean basin, locally characterized by a very peculiar hydrodynamic system (Hastings *et al.,* 1976; Aabel *et al.,* 1977; Driessen, 1985; Gallaway *et al.,* 1981; Bohnsack and Sutherland, 1985; Love and Westphal, 1990; Bull and Kendall, 1994; Kasprzak, 1998; Minton and Heath, 1998; Jørgensen *et al.,* 2002; Løkkeborg *et al.,* 2002; Love *et al.,* 2003; Love and York, 2006; Andaloro *et al.,* 2011, 2012; Consoli *et al.,* 2007, 2013; Capodici *et al.,* 2018). In particular, as regard extractive platforms, as these structures extend throughout the entire water column, their effects are not confined to demersal fishes, but also involve pelagic species that congregate about them, attracted either by the solid reef-like nature of the supporting structures, or by the numerous smaller forage organisms in the area (Bombace *et al.,* 1999, Fabi *et al.,* 2002, Relini *et al.,* 1976, Stanley and Wilson, 1991). The reason is that fishes use these artificial structures, for shelter, feeding, spawning, and orientation (Kojima, 1956; Hunter and Mitchell, 1967; Gooding and Magnuson, 1967; Luckhurst and Luckhurst, 1978; Kakimoto, 1982; Ogawa, 1982; Steimle and Ogren, 1982; Yoshimuda, 1982; Kellison and Sedberry, 1998; Rilov and

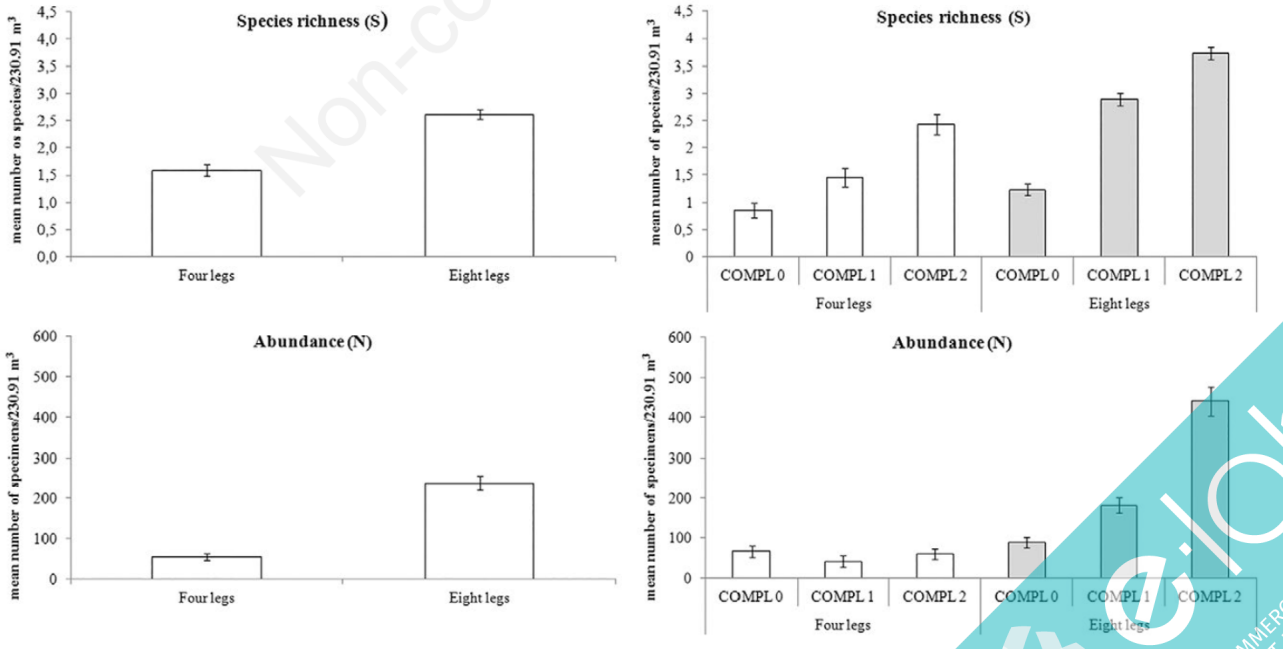


Fig. 3. Mean number of species and specimens for each combination of levels of factor MSC within each level of LSC. Bars represent standard errors.

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Benayahu, 1998; Caselle *et al.,* 2002; Castriota *et al.,* 2011; Fabi *et al.,* 2006; Leitão *et al.,* 2007). Indeed, extractive platforms can furnish shelter for protection from predation, additional food supply and spawning substrate, and can act as a visual attractant for organisms not strictly dependent on hard bottoms (Fabi *et al.,* 1998).

Then, according to these findings, a more complex structure is able to attract more fish species and specimens than a less complex one. In particular, what we observed is that most of the pelagic and demersal fishes were particularly abundant where cross beams and vertical beams cross each other. At these junctions, there is a greater available surface that species such as *C. chromis*, *A. anthias* and *B. boops* use like shelter in case of strong

Tab. 3. SIMPER of the fish taxa contributing most (%) to the dissimilarity, on large spatial scale, between 4-legs *vs* 8-legs platforms and, on medium scale, among internal structures with increasing complexity degrees (Compl 0, 1 and 2).

4-legs vs 8-legs **Average dissimilarity=83.26**			
Taxa	**8-legs** **Av. abund.**	**4-legs** **Av. abund.**	**Contribution %**
Boops boops	5.24	2.84	29.94
Anthias anthias	6.1	0	24.29
Chromis chromis	3.26	1.29	15.28
Spicara flexuosa	1.55	1.7	12.07
Thalassoma pavo	1.24	0.53	6.57
Oblada melanura	0.52	0.19	4.9

Compl 0 - Compl 1 **Average dissimilarity=86.06**			
Taxa	**Compl 0** **Av. abund.**	**Compl 1** **Av. abund.**	**Contribution %**
Boops boops	3.2	3.91	28.1
Anthias anthias	1.14	4.1	23.82
Chromis chromis	0.65	2.25	17.02
Spicara flexuosa	1.26	1.36	10.11
Thalassoma pavo	0.01	0.93	9.39
Oblada melanura	0.98	0.06	5.74

Compl 0 - Compl 2 **Average dissimilarity=87.07**			
Taxa	**Compl 0** **Av. abund.**	**Compl 2** **Av. abund.**	**Contribution %**
Anthias anthias	1.14	6.96	24.31
Boops boops	3.2	6.21	23.41
Chromis chromis	0.65	4.9	21.04
Thalassoma pavo	0.01	2.07	11.68
Spicara flexuosa	1.26	2.19	8.49
Oblada melanura	0.98	0.19	4.93

Compl 1 - Compl 2 **Average dissimilarity=68.01**			
Taxa	**Compl 1** **Av. abund.**	**Compl 2** **Av. abund.**	**Contribution %**
Boops boops	3.91	6.21	25.96
Anthias anthias	4.1	6.96	25.08
Chromis chromis	2.25	4.9	20.63
Thalassoma pavo	0.93	2.07	10.91
Spicara flexuosa	1.36	2.19	9.32

Av. abund., average abundance.

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currents. *C. chromis* and *A. anthias* also use junctions as refuges where to lay eggs: obviously in these places they can better defence the nest from the aggregation of *Thalassoma pavo* specimens, which frequently attacked and destroyed the benthic nests of these two species.

Moreover, at medium spatial scale, more complex structures provide shelter from predation and current for juvenile and adult fishes: in fact, in case of strong water current many fish species were observed to take refuge on the undercurrent side of these more complex structures.

Once an industrial decision is made to cease oil and gas production, managers must decide what to do with the structure, a process known as decommissioning and over which a huge debate is animating both scientific communities, stakeholder and common opinion from scientific literature to media (Jørgensen *et al.,* 2002; Love *et al.,* 2003; Schroeder *et al.,* 2004; Mangano and Sarà, 2017; Lucifredi, 2018). The process of decommissioning can be addressed in many ways, from the leaving most part of the structures in place to complete removal. Oil and gas platforms have finite economic lives and in the next few decades, several platforms in Mediterranean Sea will be decommissioned being nearing the end of their economic lives. Management decisions regarding the decommissioning of oil and gas platforms will be based on both biological and socioeconomic knowledge baseline (Mangano and Sarà, 2018), which are essential in evaluating the efficacy of any potential rigs-to-reef program.

CONCLUSIONS

The present results could bear strong implications for the environmental management of decommissioned platforms in this basin because the possibility of knowing the attractive potential of an extractive platform could be an important issue in the decommissioning process aiding legislators and resource managers. Moreover, further comparative, long-term and at larger spatial scale, studies should be funded in other Mediterranean gas/oil platforms, in order to investigate specific cases and propose to maintain a platform rather than another at the end of its life and then lunch a rig-to-reef program enhancing fishery production. Apart from the international recommendation on decommissioning options, (*i.e.* once the topside is removed total removal, partial removal, leave in place; OSPAR 1982, Hamzah 2003) and some case studies from the North Seas in a European context (*e.g.* the Indefatigable – Inde – Field Platforms Decommissioning Project), no specific regulation on decommissioning are prescribed in Italy (Legislative Decree no 257/2016). Under the light of the existing literature (Mangano and Sarà, 2017) future multi-criteria analysis for decommissioning options selection might take into account looking for potential alternative use (*e.g.* energy production), scientific (*e.g.* artificial reef monitoring) commercial (*e.g.* aquaculture, tourism and recreation) and multipurpose (all the above).

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