Journal of the Marine Biological Association of the United Kingdom, 2015, 95(1), 17–24.
doi:10.1017/S0025315414000940

The effect of shipwrecks on associated fish assemblages in the central Mediterranean Sea

PIERPAOLO CONSOLI[1], ANDREA MARTINO[1], TERESA ROMEO[1], MAURO SINOPOLI[2], PATRIZIA PERZIA[2], SIMONEPIETRO CANESE[3], PIETRO VIVONA[2] AND FRANCO ANDALORO[2]

[1]Laboratory of Milazzo, ISPRA, Italian National Institute for Environmental Protection and Research, via dei Mille 44, 98057 Milazzo, ME, Italy, [2]ISPRA, Italian National Institute for Environmental Protection and Research, c/o Residence Marbela, via Salvatore Puglisi 9, 90143 Palermo, Italy, [3]ISPRA, Italian National Institute for Environmental Protection and Research, Via Vitaliano Brancati, 48, 00166 Roma, Italy

Understanding the role played by sunken vessels in Mediterranean marine ecosystems is acquiring increasing importance. The aim of this research was to study the fish communities associated with four shipwrecks, by means of underwater visual censuses performed by a remotely operated vehicle, and to test the differences in composition of fish assemblages between these shipwrecks and the adjacent soft bottoms, considered as control sites. Multivariate analysis on the total fish assemblage showed significant differences between wrecks and controls. Results also showed higher levels of species richness and abundance near all wrecks than at a short distance from them on soft bottoms, thus indicating that these sunken vessels, thanks to their higher habitat complexity, act as artificial reefs, attracting aggregations of fish species and leading to a greater diversification of the local fish assemblage. Nevertheless, shipwrecks, which are an ideal target for recreational fishermen, could contribute to the over-exploitation of some high-value fish species, such as Mycteroperca rubra, Dentex dentex *and* Diplodus *spp., attracted by the artificial hard substrate of the vessel-reefs. The recent European directives suggest an urgent need for a better understanding of the crucial role played by these potential sources of pollutants on marine environments and ecosystems. An ecosystem approach to study and monitor these pollutant sources is, therefore, mandatory for appropriate remediation and/or mitigation of the potential negative effects on a productive and healthy ocean.*

Keywords: fish diversity, remotely operated vehicle, underwater visual census, artificial habitat

Submitted 21 January 2014; accepted 17 June 2014; first published online 17 July 2014

INTRODUCTION

By the word 'wreck', we usually mean the remains of a craft, aircraft or any other object of conspicuous dimension which, due to various possible causes (from accidental collisions to acts of war or terrorism, or deliberate sinking), is partially or totally submerged by seawater.

In Resolution No. 1869, adopted in 2012, the Parliamentary Assembly of the Council of Europe underlined that 'shipwrecks are among the biggest sources of ocean pollution. The Mediterranean has 4% of the world's sunken vessels, high considering its size and the fragile marine environment of landlocked seas. Some 75% of sunken wrecks date back to the Second World War' (Parliamentary Assembly of the Council of Europe, 2012). These thousands of vessels, aircraft and other commercial and military devices located at the bottom of the Mediterranean Sea due to accidents, collisions, etc, are a cryptic source of pollution, since the uncontrolled leakage of toxic material and organic/inorganic pollutants can generate ecological damage, thus modifying the natural biological diversity, leading to unpredictable hazards and potentially dangerous effects on the marine ecosystem (Sprovieri *et al.*, 2013).

In spite of the potential hazards, sunken vessels are commonly deployed as artificial reefs (Arena *et al.*, 2007), because they help to enrich and diversify the local fish community. This is well known outside the Mediterranean Sea, where the use of decommissioned marine ships as artificial reefs for fisheries or conservation is a common practice in many coastal countries (Jensen *et al.*, 2000; Love *et al.*, 2006; Arena *et al.*, 2007) and increased fishing yields can be obtained almost immediately after the installation of these artificial structures (Seaman & Jensen, 2000). In the Mediterranean Basin, the Professional Diving Schools Association, with the support of the Malta Tourism Authority, has successfully promoted several wreck dive sites around the Maltese Islands by intentionally scuttling vessels at suitable locations. As a result, Malta has become one of the most popular wreck-dive destinations in Europe.

In the Mediterranean Sea, although the effects on fish diversity of other artificial structures, such as extractive platforms and artificial reefs, have been investigated (Fabi *et al.*, 2002a, b, 2004; Consoli *et al.*, 2007, 2013; Andaloro *et al.*, 2011, 2012; Scarcella *et al.*, 2011), no data on the role played by shipwrecks in Mediterranean marine ecosystems are available.

Corresponding author:
P. Consoli
Email: pierpaolo.consoli@isprambiente.it

Due to the high number of military ships abandoned on the seabed of the Mediterranean Basin due to accidents during the First and Second World Wars (Sprovieri *et al.*, 2013), it is pressing to increase our knowledge about the role played by these artificial structures in marine ecosystems; this becomes crucial and is assuming considerable importance on a world-wide scale for its implications on biodiversity and especially on fish diversity. Moreover, according to the 2012 Resolution of the Parliamentary Assembly of the Council of Europe, Member States of the Council of Europe should support research in order to improve the technology of remotely operated underwater vehicles (ROVs), with a view to reducing the cost of identifying and locating wrecks.

The main aim of this study was, therefore, to study the fish communities associated with four different shipwrecks by means of underwater visual censuses (UVCs) performed by a ROV, and to test the difference in the composition of the fish assemblage between these shipwrecks and adjacent soft bottoms.

MATERIALS AND METHODS

Study area

The wrecks investigated are all located in the southern Tyrrhenian Sea (northern coast of Sicily; Figure 1). The data come from literature sources of the Italian Army Historical Office, as well as from Loran maps which provide information on submerged obstacles for marine traffic. The study was performed on four wrecks ('Arturo Volpe', 'Valfiorita', 'Enrico Costa' and 'Carboniera'), located on the continental platform in the province of Messina at depths between 50 and 100 m. Detailed information on the four investigated ships is shown in Table 1.

Data acquisition

First of all, the shipwrecks were identified during a pre-survey, by acoustic remote survey using a hull-mounted RESON SeaBat 8111 MultiBeam echosounder (MBES), operating at a frequency of 100 kHz and a nominal resolution of 3.7 cm. Data were acquired with 40% lateral overlap and processed to remove spikes due to navigation system problems and/or to the acquisition system by means of the PDS2000 Thales packet. The xyz data, detected by MBES, were processed in post-processing with the ArcGIS 9.2 ESRI software to map and characterize physically the four shipwrecks, information reported in Table 1.

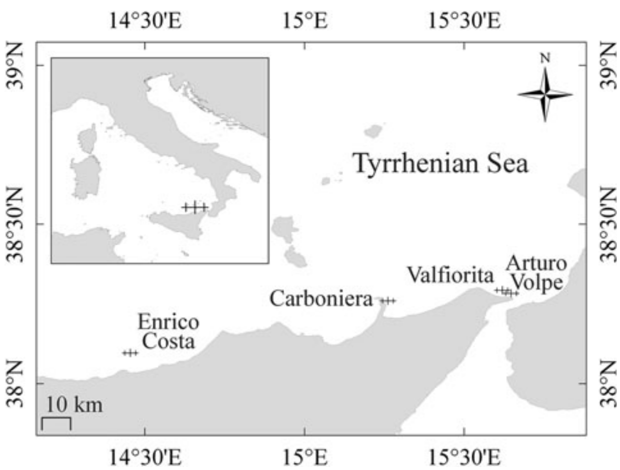

Fig. 1. Sampling area with the four investigated wrecks.

Once the four vessels had been found and mapped, data on associated fish assemblages were collected, during the June 2010 survey, by means of UVCs, performed by ROV 'Pollux'.

The ROV was equipped with a digital camera (Nikon D80, 10 megapixels), a strobe (Nikon SB 400), a high-definition video camera (Sony HDR-HC7), and three jaw grabbers. The ROV also hosted a depth sensor, a compass, and two parallel laser beams providing a 10 cm scale for measuring the frames and the specimen size, and it was equipped with an underwater acoustic tracking position system (Tracklink 1500 MA, Link Quest Inc.) providing detailed records of the transects along the seabed.

Underwater visual censuses were carried out on four wrecks and at the four control sites, one for each sunken vessel, randomly located on soft bottoms at a distance of 300 m from the respective wreck and at the same depth. The fish communities (fish species and their abundance) associated with the four investigated wrecks were surveyed by random transects, lasting 10 min each, conducted along the surfaces of the sunken hulls. Moving at an average speed of 6 m min^{-1}, the ROV performed a transect around each wreck, achieving an approximate total distance of 600 m in 10 min (covering an area of 1200 m^2 for each run, the visual field of the ROV being 2 m when moving at a distance of 1.5 m from the bottom). Four replicates were carried out at each wreck and four at each control site for a total of 32 observation units (total explored area = 38,400 m^2).

Fish abundance was estimated by counting single specimens up to a maximum of 10 individuals, and using abundance-classes (11–30, 31–50, 51–100, 101–200, 201–500, 500) for schools. This recording system leads to a similar degree of error over a wide range of abundances, ensuring homogeneity of variance after log-transformation of the data (Frontier, 1986; Guidetti *et al.*, 2003).

Remotely operated vehicle trials were recorded and stored on hard disks and four different researchers contributed to analysing both underwater and video data recordings, thus reducing any systematic error between methods. During the video analysis, the data were entered onto spreadsheets, with the following fields: Date; ID-Video; Wreck; Replicas of transects; Time; Depth; Temperature; horizontal and vertical Visibility; and Species.

Data analysis

The fish community was described by means of fish abundance (*N*), species richness (*S*) and frequency of occurrence (%O) data. A one-way permutational multivariate analysis of variance (PERMANOVA) (PERMANOVA; Anderson, 2001; McArdle & Anderson, 2001) was used to test for differences between fish assemblages with regard to the factor SITE (made up of 8 levels, 4 wrecks + 4 control sites). The analysis was designed to test the null hypothesis of no significant differences between wrecks/controls in terms of fish assemblages. The test was based on Gower distances calculated on log $(x + 1)$ transformed data, and each term in the analysis was tested using 4999 random permutations of appropriate units

https://doi.org/10.1017/S0025315414000940 Published online by Cambridge University Press

Table 1. Location and physical characterization of vessel-reefs and their control sites.

Features	'Arturo Volpe'	'Valfiorita'	'Carboniera'	'Enrico Costa'
Ship				
Gross tonnage	1500	6200	–	4080
Type	Cargo ship	Cargo ship	Cargo ship	Cargo ship
Construction year	1950	1942	End 1800	1928
Length (m)	86	110	–	116
Width (m)	13	–	–	16
Height (m)	4.5	–	–	7.7
Shipwrek				
Year sunk	1973	1943	1945	1941
Distance from the coast (m)	500	1000	400	7000
Depth (m)	55–80	58–68	45	70
Length (m)	81	114	21	–
Width (m)	13	18	7	–
Height (m)	5	12	2.5	–
Coordinates of control areas	15°39′02″E 38°16′39″N	15°36′55″E 38°17′04″N	15°15′01″E 38°15′51″N	14°27′26″E 38°5′55″N

(Anderson & ter Braak, 2003). This permutation method is generally thought to be best suited because it provides the best statistical power and avoids the probability of Type I errors (Anderson & Legendre, 1999). Moreover, a one-way permutational univariate analysis of variance (permutational ANOVA) was performed in order to detect significant differences between the mean values of species richness and abundance recorded at each site. Unlike the multivariate analyses described above, we used the Euclidean distance in this univariate model. Data were transformed to log $(x + 1)$ in order to reduce the weighting of abundant categories and increase that of rarer ones.

Both univariate and multivariate analyses were employed using the software package PRIMER 6 with PERMANOVA + add-on (Anderson *et al.*, 2008). Whereas ANOVA/MANOVA assumes normal distributions, PERMANOVA works with any distance measurement that is appropriate to the data, and uses permutations to make it distribution-free. Thus, the same *F*-statistics were calculated, but *P*-values were obtained by permutation. Moreover, the similarity percentage procedure SIMPER (Clarke & Warwick, 2001) was used to identify the fish species contributing most to the differences between wrecks and control sites.

RESULTS

In Table 2, mean abundances, standard errors (SEs) and frequencies of occurrence for each species are shown for the four vessel-reefs and their respective natural sandy bottoms (control sites). Overall, 15 fish taxa belonging to 15 families were recorded in the study area; nine taxa were found on control sites and 13 on shipwrecks. Six species were common to both locations (shipwrecks and controls), six were exclusive to wrecks, whereas only two species were exclusively observed on the control sites. In particular, high-value species, such as *Mycteroperca rubra* and *Phycis phycis* were observed only on artificial structures (Table 2). Multivariate analysis (PERMANOVA) on the total fish assemblage showed significant differences for the factor WRECK (Table 3), indicating that fish assemblages changed between sampling sites. Pair-wise tests revealed that each wreck was significantly different from its control site ($P < 0.05$). SIMPER analysis pinpointed some fish taxa as the major contributors to these dissimilarities (Table 4). Indeed, high densities of *Anthias anthias* characterized the censuses carried out on vessel-reefs, thus helping to differentiate the fish communities on shipwrecks from those on nearby natural soft bottoms. As shown in Figure 2, the mean species richness and fish abundance were higher at the four artificial structures than at their natural control sites.

Permutational univariate ANOVAs on overall abundance and species richness, confirming the multivariate test result, showed significant differences for the factor SITE considered in the analyses (Tables 5 and 6). In spite of this, pair-wise tests showed significant differences in species richness only between the 'Carboniera' and its control site ($P < 0.05$; Table 5) whereas, as regards fish abundance, pair-wise tests confirmed significant differences in all comparisons.

DISCUSSION

There are thousands of sunken vessels (4% of the world's shipwrecks), at the bottom of the Mediterranean Sea (Parliamentary Assembly of the Council of Europe, 2012; Sprovieri *et al.*, 2013). As the environmental risks posed by these artificial structures are still unclear, studies focusing on their impact on biodiversity are crucial. Indeed, to our knowledge, in the Mediterranean Sea, the role played by shipwrecks in the marine ecosystem and, particularly, on fish assemblages, has not yet even been investigated.

This study was designed to fill this gap and, indeed, detected significant differences between fish communities living either close to or far from these artificial structures. Moreover, in accordance with other studies carried out on extractive platforms and artificial reefs in the Mediterranean Sea (Fabi *et al.*, 2002a, b, 2004; Scarcella *et al.*, 2011; Consoli *et al.*, 2013), our survey recorded higher levels of species richness and abundance near all wrecks than at a short distance from them (control areas), indicating that these sunken vessels act as artificial reefs (usually deployed for production or protection), attracting aggregations of fish species (tigmotrophic effect) and leading to an enrichment and a greater

https://doi.org/10.1017/S0025315414000940 Published online by Cambridge University Press

Table 2. Mean abundances, standard errors (SEs) and percentages of occurrence (%O) of fish species recorded at the four wrecks and their control sites.

Wreck	'Valfiorita'			'Valfiorita'-C			'Arturo Volpe'			'Arturo Volpe'-C			'Carboniera'			'Carboniera'-C			'Enrico Costa'			'Enrico Costa'-C		
Species	Mean	SE	%O	Mean	SE	%O	Mean	SE	%O	Mean	SE	%O	Mean	SE	%O	Mean	SE	%O	Mean	SE	%O	Mean	SE	%O
Anthias anthias	2300.00	734.84	100				1375.00	515.39	100				2250.00	629.15	100				1600.00	533.85	100			
Chromis chromis							125.00	125.00	25				1575.00	440.41	100									
Conger conger																			0.20	0.20	20			
Coris julis	1.80	1.80	20	0.75	0.48	50	0.75	0.48	50	2.00	1.08	75	2.00	0.71	75							1.00	0.41	50
Dentex dentex	7.00	7.00	20													0.50	0.29	50	5.20	4.95	40			
Diplodus puntazzo	1.60	1.17	40													0.50	0.50	25						
Diplodus vulgaris	1.00	0.55	60	0.75	0.75	25	1.25	0.48	75	0.75	0.48	50	6.50	4.72	50	0.75	0.75	25	4.60	3.87	60			
Gobius geniporus				1.50	0.65	75				0.25	0.25	25				0.25	0.25	25				0.25	0.25	50
Mycteroperca rubra	4.60	3.61	80																2.60	1.17	60			
Phycis phycis																			0.20	0.20	20			
Sardinella aurita	450.00	228.03	60																					
Scorpaena scrofa				0.25	0.25	25							0.25	0.25	25									
Serranus cabrilla				2.00	0.41	100	0.50	0.50	25				2.25	0.25	100									
Serranus hepatus																1.50	0.65	75				0.50	0.29	50
Spicara maena				1.50	0.96	50													8.00	8.00	20			

Table 3. One-way permutational multivariate analysis of variance analysing the effect of factor wreck, on fish assemblage based on Bray–Curtis dissimilarities of log transformed data. The *P* values of pair-wise comparisons are also reported. $^{*}P < 0.05$; $^{**}P < 0.01$; $^{***}P < 0.001$.

Source of variation	df	MS	*F*	*P* (perm)
Site	7	730.550	8.085	0.001^{***}
Res	26	90.355		
Total	33			
Pairwise tests			*t*	*P* (perm)
'Valfiorita', 'Valfiorita'-C			3.484	0.009^{**}
'Carboniera', 'Carboniera'-C			5.477	0.036^{*}
'Arturo Volpe', 'Arturo Volpe'-C			2.455	0.02^{*}
'Enrico Costa', 'Enrico Costa'-C			2.434	0.006^{**}

diversification of the local fish assemblage. These effects were mainly due to a higher occurrence around the structures of reef-dwelling or partially reef-dwelling species, which were not present further from the wrecks on natural soft bottoms. In particular, as shown by SIMPER analysis, planktivorous species such as *Anthias anthias* and *Chromis chromis* were the dominant trophic group on vessel-reefs, thus contributing most to the dissimilarity between wreck and control areas. These results are comparable to previous studies carried out on oil platforms (Rilov & Benayahu, 2000) and on a shipwreck (Lindquist & Pietrafesa, 1989): in both cases, the authors reported planktivores to be the most numerous species.

The main mechanism invoked to explain the aggregation effect of these artificial structures is a higher habitat complexity in comparison to control sites located on natural soft bottoms. In fact, habitat complexity, defined as 'heterogeneity in the arrangement of physical structure in the habitat surveyed (Lassau & Hochuli, 2004), is one of the most important ecological factors in shaping structure and community dynamics, influencing fish abundance, diversity and species richness (Bell & Galzin, 1984; Roberts & Ormond, 1987; Jones, 1988; Bell *et al.*, 1991; Hixon & Beets, 1993; Warfe & Barmuta, 2004; Harvey *et al.*, 2005; Willis *et al.*, 2005). Indeed, a positive relationship has been reported for several natural environments between habitat complexity and community structure (i.e. both numbers of individuals and numbers of fish species; Luckhurst & Luckhurst, 1978; Roberts & Ormond, 1987; McClanahan, 1994; McCormick, 1994; Öhman & Rajasuriya, 1998; Gratwicke & Speight, 2005; Garcia Charton & Pérez Ruzafa, 2008). More complex habitats increase the amount of refuge available to prey species, thus reducing predation pressure (Hixon & Beets, 1993; Macpherson, 1994; Caley & St John, 1996; Almany, 2004a). Increases in available refuges due to enhanced substrate topography have also been shown to reduce competition for space (Hixon & Menge, 1991; Almany, 2004b) as well as adding to niche dimensionality (MacArthur & Levins, 1967), both of which potentially increase fish abundance and distribution. The same pattern regarding spatial complexity, fish abundance and species richness has also been reported by previous studies carried out on various man-made structures such as artificial reefs (Chang *et al.*, 1977; Higo *et al.*, 1980; Buckley, 1982; Roberts & Ormond, 1987; (Gorham & Alevizon, 1989; Hixon & Beets, 1989; Bohnsack *et al.*, 1991; Charbonnel *et al.*, 2002; Gratwicke & Speight, 2005), fringing reefs (Roberts & Ormond, 1987), shipwrecks (Chandler *et al.*,

https://doi.org/10.1017/S0025315414000940 Published online by Cambridge University Press

Table 4. SIMPER of the fish species contributing most (%) to the dissimilarity between wrecks and controls.

Species	**'Valfiorita' Av.Abund**	**'Valfiorita'-C Av.Abund**	**Contrib%**	**Cum.%**
Anthias anthias	7.51	0.00	44.07	44.07
Sardinella aurita	3.90	0.00	20.18	64.26
Serranus cabrilla	0.00	1.07	6.38	70.64
Mycteroperca rubra	1.10	0.00	5.51	76.15
Coris julis	0.46	0.45	4.63	80.78
Gobius geniporus	0.00	0.79	4.58	85.36
Spicara maena	0.00	0.68	3.79	89.14
Diplodus vulgaris	0.55	0.35	3.67	92.81
	'Arturo Volpe'	'Arturo Volpe'-C		
	Av.Abund	Av.Abund	Contrib%	Cum.%
Anthias anthias	6.96	0.00	72.24	72.24
Chromis chromis	1.55	0.00	10.02	82.25
Coris julis	0.45	0.90	7.95	90.20
	'Carboniera'	'Carboniera'-C		
	Av.Abund	Av.Abund	Contrib%	Cum.%
Anthias anthias	7.60	0.00	38.22	38.22
Chromis chromis	7.25	0.00	36.42	74.64
Serranus cabrilla	1.17	0.00	5.94	80.57
Diplodus vulgaris	1.25	0.35	5.83	86.41
Coris julis	0.97	0.00	4.94	91.34
	'Enrico Costa'	'Enrico Costa'-C		
	Av.Abund	Av.Abund	Contrib%	Cum.%
Anthias anthias	7.16	0.00	63.51	63.51
Mycteroperca rubra	0.99	0.00	7.89	71.40
Diplodus vulgaris	0.97	0.00	7.14	78.54
Coris julis	0.00	0.62	5.51	84.06
Dentex dentex	0.79	0.00	4.44	88.49
Spicara maena	0.74	0.00	3.92	92.41

1985; Arena *et al.*, 2007; Fagundes-Netto *et al.*, 2011) and extractive platforms (Rooker *et al.*, 1997; Rilov & Benayahu, 1998, 2000, 2002; Love *et al.*, 2003, 2010, Love & York, 2006; Love & Nishimoto, 2012; Consoli *et al.*, 2013).

Greater species richness, as well as the several exclusive fish species (six) found at the four investigated vessel-reefs, suggests these artificial habitats are providing unique habitat characteristics, which may not be found on surrounding natural ones. In spite of this, it is important to underline that shipwrecks, which are an ideal target for recreational fishermen, could contribute to the over-exploitation of some high-value fish species, such as *Mycteroperca rubra*, *Dentex dentex* and *Diplodus* spp., attracted by the artificial hard substrate of the vessel-reefs.

The present study also helped to identify the strengths and weaknesses of the ROV as a tool for studying the fish community associated with sunken vessels. In fact, it is unlikely that the wreck areas contained only the 13 fish species observed; this would mean that the ROV probably did not allow for a complete description of the fish assemblage associated with these artificial structures. Similar conclusions were drawn by Andaloro *et al.* (2012) in other artificial habitats (extractive platforms) located in the Mediterranean Sea, by comparing UVCs performed using a ROV and by scientific SCUBA divers. According to these authors, the ROV is unable to identify crypto-benthic species due to their small size and to their tendency to hide in holes or crevices. This cryptic behaviour, which is also a well-known constraint for the UVC methodology performed by divers (Smith, 1988; Willis, 2001), makes these fish invisible to the camera, whose resolution and field of vision is clearly lower than the diver's eye. By contrast, according to Tessier *et al.* (2005) and Andaloro *et al.* (2012), the ROV is an appropriate method for censusing planktivorous fish, both from a qualitative and quantitative point of view, mostly in relation to their high abundance and low mobility.

Francour *et al.* (1999) highlight the less invasive nature of the ROV in comparison with the presence of SCUBA divers, the possibility of recording at dawn and dusk by means of highly sensitive cameras and, lastly, the ability to gather data for longer periods than a single dive. In spite of its limits, UVCs performed by ROV are the only way to explore depths where divers cannot operate.

Finally, the evidence of leakages and/or transfer of hazardous contaminants, from similar sunken vessels in the same area, to the sediments (Sprovieri *et al.*, 2013) suggests that there is an urgent need to better understand the crucial role played by this potential source of pollutants for the marine environments and ecosystem. Therefore, an ecosystem approach to study and monitor this pollutant source is

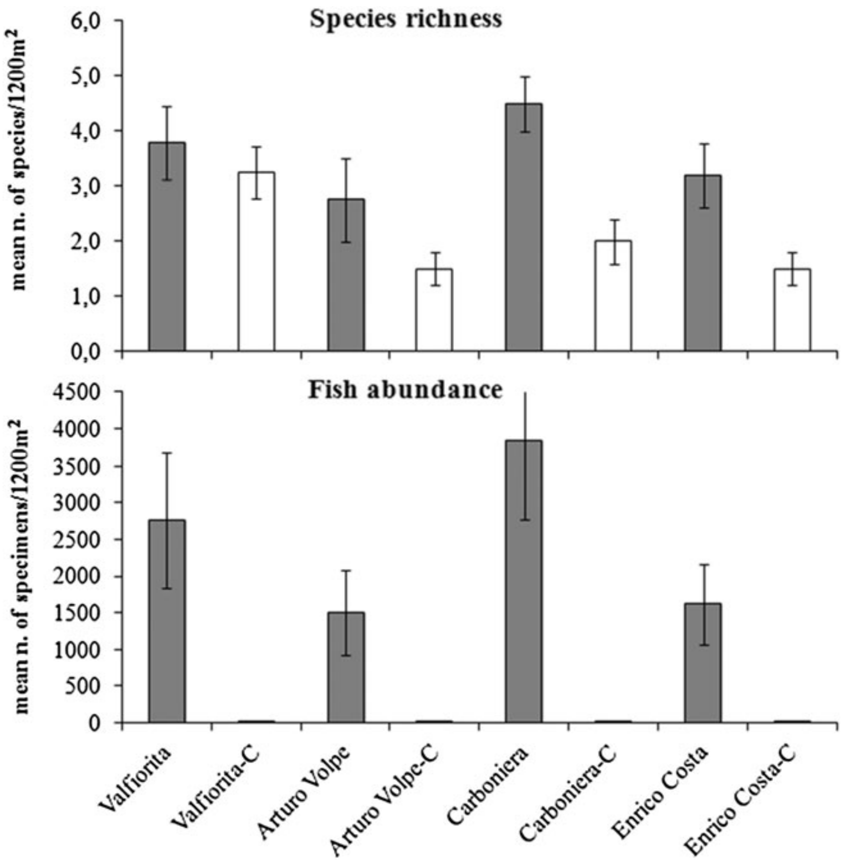

Fig. 2. Mean species richness and fish abundance (mean number of species/1200 m^2 $\pm$ standard error) for each wreck and its control.

Table 5. Analysis of variance table for permutational univariate analyses of species richness based on Euclidean distance of log transformed data. The *P* values of pair-wise comparisons are also reported. $^{*}P < 0.05$; $^{**}P < 0.01$; $^{***}P < 0.001$; n.s., not significant.

Source of variation	df	MS	F	P (perm)
Site	7	0.359	4.247	0.007**
Res	26	0.084		
Total	33			
Pairwise tests			*t*	*P* (perm)
'Valfiorita', 'Valfiorita'-C			0.544	0.708 n.s.
'Carboniera', 'Carboniera'-C			3.773	0.028*
'Arturo Volpe', 'Arturo Volpe'-C			1.422	0.338 n.s.
'Enrico Costa', 'Enrico Costa'-C			2.681	0.082 n.s.

Table 6. Analysis of variance table for permutational univariate analyses of fish abundance based on Euclidean distance of log transformed data. The *P* values of pair-wise comparisons are also reported. $^{*}P < 0.05$; $^{**}P < 0.01$; $^{***}P < 0.001$.

Source of variation	df	MS	F	P (perm)
Site	**7**	**45.802**	**114.230**	**0.001*** **
Res	26	0.401		
Total	33			
Pairwise tests			*t*	*P* (perm)
'Valfiorita', 'Valfiorita'-C			14.441	0.009**
'Carboniera', 'Carboniera'-C			17.509	0.025*
'Arturo Volpe', 'Arturo Volpe'-C			10.506	0.028*
'Enrico Costa', 'Enrico Costa'-C			15.217	0.004**

mandatory for appropriate remediation and/or mitigation of the potential negative effects on a productive and healthy ocean (Sprovieri *et al.*, 2013).

ACKNOWLEDGEMENTS

We would like to thank the crew and researchers of RV 'Astrea' for their help during ROV operations. The authors would also like to thank Anthony Green for kindly reviewing the English of the manuscript.

FINANCIAL SUPPORT

This study has been conducted by ISPRA, within the project n.490 Relitti–SIA, financed by the Italian Ministry of the Environment, Land and Sea.

REFERENCES

Almany G.R. (2004a) Differential effects of habitat complexity, predators and competitors on abundance of juvenile and adult coral reef fishes. *Oecologia* 141, 105–113.

Almany G.R. (2004b) Does increased habitat complexity reduce predation and competition in coral reef fish assemblages? *Oikos* 106, 275–284.

Andaloro F., Castriota L., Ferraro M., Romeo T., Sarà G. and Consoli P. (2011) Evaluating fish assemblages associated with gas platforms:

evidence from visual census techniques and experimental fishing surveys. *Ciencias Marinas* 37, 1–9.

Andaloro F., Ferraro M., Mostarda E., Romeo T. and Consoli P. (2012) Assessing the suitability of a remotely operated vehicle (ROV) to study the fish community associated with offshore gas platforms in the Ionian Sea: a comparative analysis with underwater visual censuses (UVCs). *Helgoland Marine Research* 67, 241–250.

Anderson M.J. (2001) A new method for non-parametric multivariate analysis of variance. *Austral Ecology* 26, 32–46.

Anderson M.J., Gorley R.N. and Clarke K.R. (2008) *PERMANOVA+ for PRIMER: guide to software and statistical methods.* Plymouth: PRIMER-E.

Anderson M.J. and Legendre P. (1999) An empirical comparison of permutation methods for tests of partial regression coefficients in a linear model. *Journal of Statistical Computation and Simulation* 62, 271–303.

Anderson M.J. and ter Braak C.J.F. (2003) Permutation tests for multifactorial analysis of variance. *Journal of Statistical Computation and Simulation* 73, 85–113.

Arena P.T., Jordan L.K.B. and Spieler R.E. (2007) Fish assemblages on sunken vessels and natural reefs in southeast Florida, USA. *Hydrobiologia* 580, 157–171.

Bell J.D. and Galzin R. (1984) Influence of live coral cover on coral reef fish communities. *Marine Ecology Progress Series* 15, 265–274.

Bell S.S., McCoy E.D. and Mushinsky H.R. (1991) *Habitat structure: the physical arrangement of objects in space.* London: Chapman and Hall.

Bohnsack J.A., Johnson D.L. and Ambrose R.F. (1991) Ecology of artificial reef habitats and fishes. In Seaman W. Jr and Sprague L.M. (eds) *Artificial habitats for marine and freshwater fisheries.* San Diego, CA: Academic Press, pp. 61–107.

Buckley R.M. (1982) Marine habitat enhancement and urban recreational fishing in Washington. *Marine Fisheries Review* 44, 28–37.

Caley M.J. and St John J. (1996) Refuge availability structures assemblages of tropical reef fishes. *Journal of Animal Ecology* 65, 414–428.

Chandler C.R., Sanders R.M. Jr and Landry A.M. Jr (1985) Effects of three substrate variables on two artificial reef fish communities. *Bulletin of Marine Science* 37, 129–142.

Chang K., Lee S.C. and Shao K.T. (1977) Evaluation of artificial reef efficiency based on the studies of model reef fish community installed in northern Taiwan. *Bulletin Institute of the Zoology, Academia Sinica* 16, 23–36.

Charbonnel E., Serre C., Ruitton S., Harmelin J.G. and Jensen A. (2002) Effects of increased habitat complexity on fish assemblages associated with large artificial reef units (French Mediterranean coast). *ICES Journal of Marine Science* 59, 208–213.

Clarke K.R. and Warwick R.M. (2001) *Change in marine communities: an approach to statistical analysis and interpretation.* 2nd edition. Plymouth: PRIMER-E, 172 pp.

Consoli P., Azzurro E., Sarà G., Ferraro M. and Andaloro F. (2007) Fish diversity associated to gas platforms: evaluation of two underwater visual census. *Ciencias Marinas* 33, 121–132.

Consoli P., Romeo T., Ferraro M., Sarà G. and Andaloro F. (2013) Factors affecting fish assemblages associated with gas platforms in the Mediterranean Sea. *Journal of Sea Research* 77, 45–52.

Fabi G., Grati F., Lucchetti A. and Trovarelli L. (2002a) Evolution of the fish assemblage around a gas platform in the northern Adriatic Sea. *ICES Journal of Marine Science* 59, 309–315.

Fabi G., Grati F., Puletti M. and Scarcella G. (2004) Effects on fish community induced by installation of two gas platforms in the Adriatic Sea. *Marine Ecology Progress Series* 273, 187–194.

Fabi G., Luccarini F., Panfili M., Solustri C. and Spagnolo A. (2002b) Effects of an artificial reef on the surrounding soft-bottom community (central Adriatic Sea). *ICES Journal of Marine Science* 59, 343–349.

Fagundes-Netto E.B., Gaelzer L.R., Coutinho R. and Zalmon I.R. (2011) Influence of a shipwreck on a nearshore-reef fish assemblages off the coast of Rio de Janeiro, Brazil. *Latin American Journal of Aquatic Research* 39, 103–116.

Francour P., Liret C. and Harvey E. (1999) Comparison of fish abundance estimates made by remote underwater video and visual census. *Il Naturalista Siciliano* 23, 155–168.

Frontier S. (1986) La méthode des cotations d'abondance appliquée aux pêcheries artisanales. In Frontier S. (ed.) *Evaluation et optimisation des plans d'échantillonnage en écologie littorale*. Piren, ATP 9-82-65. Paris: Centre National de la Recherche Scientifique, pp. 262–285.

Garcia Charton J.A. and Pérez Ruzafa A. (2008) Correlation between habitat structure and a rocky reef fish assemblage in the Southwest Mediterranean. *Marine Ecology* 19, 111–128.

Gorham J.C. and Alevizon W.S. (1989) Habitat complexity and the abundance of juvenile fishes residing on small scale artificial reefs. *Bulletin of Marine Science* 44, 662–665.

Gratwicke B. and Speight M.R. (2005) The relationship between fish species richness, abundance and habitat complexity in a range of shallow tropical marine habitats. *Journal of Fish Biology* 66, 650–667.

Guidetti P., Terlizzi A., Fraschetti S. and Boero F. (2003) Changes in Mediterranean rocky-reef fish assemblages exposed to sewage pollution. *Marine Ecology Progress Series* 253, 269–278.

Harvey B.C., White J.L. and Nakamoto R.J. (2005) Habitat specific biomass, survival, and growth of rainbow trout (*Oncorhynchus mykiss*) during summer in a small coastal stream. *Canadian Journal of Fisheries Aquatic Sciences* 62, 650–658.

Higo N., Hashi H., Takahama I., Tabata S., Nagashima M., Sakono S., Kasmimizutara T. and Yamasaki T. (1980) On the fish gathering effect of the artificial reefs ascertained by the diving observation. VII. At the sea off Maskurazak City. *Memoirs of the Faculty of Fisheries, Kagoshima University* 29, 51–63.

Hixon M.A. and Beets J.P. (1989) Shelter characteristics and Caribbean fish assemblages: experiments with artificial reefs. *Bulletin of Marine Science* 44, 666–680.

Hixon M.A. and Beets J.P. (1993) Predation, prey refuges, and the structure of coral-reef fish assemblages. *Ecology Monographs* 63, 77–101.

Hixon M.A. and Menge B.A. (1991) Species diversity: prey refuges modify the interactive effects of predation and competition. *Theoretical Population Biology* 39, 178–200.

Jensen A.C., Collins K.J. and Lockwood A.P.M. (2000) *Artificial reefs in European seas.* Dordrecht: Kluwer Academic Publishers.

Jones G.P. (1988) Experimental evaluation of the effects of habitat structure and competitive interactions on the juveniles of two coral reef fishes. *Journal of Experimental Marine Biology and Ecology* 123, 115–126.

Lassau S.A. and Hochuli D.F. (2004) Effects of habitat complexity on ant assemblages. *Ecography* 27, 157–164.

Lindquist D.G. and Pietrafesa L.J. (1989) Current vortices and fish aggregations: the current field and associated fishes around a tugboat wreck in Onslow Bay, North Carolina. *Bulletin of Marine Science* 44, 533–544.

Love M.S. and Nishimoto M.M. (2012) *Completion of fish assemblage surveys around manmade structures and natural reefs off California.* Marine Science Institute, University of California, Santa Barbara, California. BOEM OCS Study 2012-020.

https://doi.org/10.1017/S0025315414000940 Published online by Cambridge University Press

Love M.S., Nishimoto M.M. and Schroeder D.M. (2010) *Fish assemblages associated with platforms and natural reefs in areas where data are non-existent or limited.* Marine Science Institute, University of California, Santa Barbara, California. BOEMRE OCS Study 2010-012.

Love M.S., Schroeder D.M., Lenarz W., MacCall A., Bull A.S. and Thorsteinson L. (2006) Potential use of offshore marine structures in rebuilding an overfished rockfish species, bocaccio (*Sebastes paucispinis*). *Fishery Bulletin* 104, 383–390.

Love M.S., Schroeder D.M. and Nishimoto M.M. (2003) *The ecological role of oil and gas production platforms and natural outcrops on fishes in southern and central California: a synthesis of information.* US Department of the Interior, US Geological Survey, Biological Resources Division, Seattle, Washington, 98104, OCS Study MMS 2003–032.

Love M.S. and York A. (2006) The role of bottom crossbeam complexity in influencing the fish assemblages at California oil and gas platforms. *Fishery Bulletin* 104, 542–549.

Luckhurst B.E. and Luckhurst K. (1978) Analysis of the influence of the substrate variables on coral reef fish communities. *Marine Biology* 49, 317–323.

MacArthur R.H. and Levins R. (1967) The limiting similarity, convergence and divergence of coexisting species. *American Naturalist* 101, 377–385.

Macpherson E. (1994) Substrate utilization in a Mediterranean littoral fish community. *Marine Ecology Progress Series* 114, 211–218.

McArdle B.H. and Anderson M.J. (2001) Fitting multivariate models to community data: a comment on distance-based redundancy analysis. *Ecology* 82, 290–297.

McClanahan T.R. (1994) Kenyan coral reef lagoon: effects of fishing, substrate complexity, and sea urchins. *Coral Reefs* 13, 231–241.

McCormick M.I. (1994) Comparison of field methods for measuring surface topography and their associations with a tropical reef fish community. *Marine Ecology Progress Series* 112, 87–96.

Öhman M.C. and Rajasuriya A. (1998) Relationships between habitat structure and fish communities on coral and sandstone reefs. *Environmental Biology of Fishes* 53, 19–31.

Parliamentary Assembly of the Council of Europe (2012) The environmental impact of sunken shipwrecks. Resolution 1869.

Rilov G. and Benayahu Y. (1998) Vertical artificial structures as an alternative habitat for coral reef fishes in disturbed environments. *Marine Environmental Research* 45, 431–451.

Rilov G. and Benayahu Y. (2000) Fish assemblage on natural *vs.* vertical artificial reefs: the rehabilitation perspective. *Marine Biology* 36, 931–942.

Rilov G. and Benayahu Y. (2002) Rehabilitation of coral reef-fish communities: the importance of artificial-reef relief to recruitment rates. *Bulletin of Marine Science* 70, 185–197.

Roberts C.M. and Ormond R.F.G. (1987) Habitat complexity and coral reef fish diversity and abundance on Red Sea fringing reefs. *Marine Ecology Progress Series* 41, 1–8.

Rooker J.R., Dokken Q.R., Pattengill C.V. and Holt G.J. (1997) Fish assemblages on artificial and natural reefs in the Flower Garden Banks National Marine Sanctuary, USA. *Coral Reefs* 16, 83–92.

Scarcella G., Grati F. and Fabi G. (2011) Temporal and spatial variation of the fish assemblage around a gas platform in the Northern Adriatic Sea, Italy. *Turkish Journal of Fisheries and Aquatic Sciences* 11, 433–444.

Seaman W. and Jensen A.C. (2000) Purposes and practices of artificial reef evaluation. In Seaman W. (ed.) *Artificial reef evaluation: with application to natural marine habitats.* Boca Raton, FL: CRC Press, pp. 1–20.

Smith M.P.L. (1988) Effects of observer swimming speed on sample counts of temperate rocky reef fish assemblages. *Marine Ecology Progress Series* 43, 223–231.

Sprovieri M., Barra M., Del Core M., Di Martino G., Giaramita L., Gherardi S., Innangi S., Oliveri E., Passaro S., Romeo T., Rumolo P., Manta D.S., Tamburrino S., Tonielli R., Traina A., Tranchida G., Vallefuoco M., Mazzola S. and Andaloro F. (2013) Marine pollution from shipwrecks at the sea bottom: a case study from the Mediterranean Basin. In Hughes T. B. (ed.) *Mediterranean Sea: ecosystems, economic importance and environmental threats.* New York: Nova Publishers, pp. 35–64.

Tessier E., Chabanet P., Pothin K., Soria M. and Lasserre G. (2005) Visual census of tropical fish aggregations on artificial reefs: slate *versus* video recording techniques. *Journal of Experimental Marine Biology and Ecology* 315, 17–30.

Warfe D.M. and Barmuta L.A. (2004) Habitat structural complexity mediates the foraging success of multiple predator species. *Oecologia* 141, 171–178.

Willis S.C., Winemiller K.O. and Lopez-Fernandez H. (2005) Habitat structural complexity and morphological diversity of fish assemblages in a neotropical floodplain river. *Oecologia* 142, 284–295.

and

Willis T.J. (2001) Visual census methods underestimate density and diversity of cryptic reef fishes. *Journal of Fish Biology* 59, 1401–1408.

Correspondence should be addressed to:
P. Consoli
Laboratory of Milazzo, ISPRA, Italian National Institute for Environmental Protection and Research, via dei Mille 44 98057 Milazzo, ME, Italy
email: pierpaolo.consoli@isprambiente.it

https://doi.org/10.1017/S0025315414000940 Published online by Cambridge University Press