BASELINE

When the levee breaks: effects of flood on offshore water contamination and benthic community in the Mediterranean (Ionian Sea)

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Abstract

In the last few years extreme weather events, including changes to storm frequency and intensity, have increased across all continents. In this note we assessed, for the first time in the Mediterranean Sea, the impact of a violent storm and consequent flood on offshore water contamination and benthic community along the Calabrian coast (Ionian Sea). Three sites (at 500, 1000, and 2000 m off the coast) were sampled along three parallel transects in 2013, 2014 (before), and 2015 (after the flood). After the flood, metals (especially Al, Cr_{VI}, Ni, Cu, Zn) in the water column increased in concentration. The flood affected the structure of the benthic community, causing a decrease of diversity, the dominance of few opportunistic species, and the decrease of M-AMBI values.

Keywords: Extreme weather event; Flood; Benthic community; Mediterranean Sea

For the near future, a considerable increase in the frequency and magnitude of weather extremes, such as storms, heatwaves, and severe floods has been predicted across all continents, together with an increase in global mean surface air temperature and alteration in rainfall patterns (IPCC, 2007; Coumou and Rahmstorf, 2012; Trenberth et al., 2015). The Mediterranean is one of the world's regions where projected future increases in greenhouse gases concentrations are most likely to cause significant changes in climate, with a high degree of consistency among different projections (Giorgi, 2006). The Mediterranean is particularly vulnerable to changes in the frequency and intensity of heat waves, wind storms, heavy precipitation, and droughts (Beniston et al., 2007), that can severely damage the natural environment and socio-economic sectors (IPCC, 2001).

Storms may cause dramatic changes to coastal assemblages, however studies on the impact of tropical storms on invertebrate assemblages are still scarce, mostly because of the unpredictable nature of such extreme events, and the consequent largely "opportunistic nature" of those studies (Harris et al., 2011). Storm effects were investigated on intertidal benthic communities (Jaramillo et al., 2012; Machado et al., 2016; Corte et al., 2017), shallow subtidal areas (Boesch et al., 1976; Reusch and Chapman, 1995; Lomovasky et al., 2011; Taghon et al., 2017), seagrass meadows (Fourqurean and Rutten, 2004), coral (Anticamara and Go, 2017; White et al., 2017) and algal assemblages (Smale and Vance, 2016), but effects on offshore, deeper-water benthic communities are still poorly studied (Posey et al., 1996; Teixidó et al., 2013; Sukumaran et al., 2016). If the benthic responses to storms are poorly studied in areas where storms typically develop (Nagelkerken and Munday, 2016), this is even more true for the Mediterranean, where studies on the effects of such extreme events on invertebrate assemblages are so far completely absent.

The Calabrian coast (southern Italy) is particularly fragile, mainly due to illegal construction over the past 60 years. There, 61.8% of properties are abusive (ISTAT, 2016), with inevitable consequences on the degradation of the landscape and environmental risk. From the afternoon of the 11th and until the afternoon of 12th August 2015, a strong rainstorm accompanied by whirlwinds affected the eastern Calabrian coast (Ionian Sea), particularly in the area of Corigliano-Rossano, a small coastal municipality. Precipitations triggered major geo-hydrological instability phenomena, especially flood of watercourses. The most severely affected area was Lido Sant'Angelo, a tourist resort, flooded by the creek Citrea escaped from its bed following the sudden collapse of part of the levee (Fig. 1). The flood caused serious damages to buildings, infrastructures, and automobiles.

Assessing possible effects of such extreme events on marine ecosystems is often hampered by incomplete knowledge of conditions before the event. The coastal area off Corigliano-Rossano was subject to a monitoring program since 2013. This program allowed to collect regular benthos and environmental data at 12 offshore sites, before and after the storm. In this study, for the first time for the Mediterranean region, we describe physical, chemical, and biological environmental effects caused by a storm.

Corigliano-Rossano area was monitored in late September 2013, 2014 and 2015. Along each of three transects (T1, T2, T3; Fig. 2) perpendicular to the coastline, three sites were sampled at different distance from the coast: 0.5 km at sites A (about 6 m depth), 1 km at sites B (about 12 m depth), and 2 km at sites C (about 18 m depth). In 2015, the transect T2 resulted to be the closest to Lido Sant'Angelo, the most heavily flooded area. At each site, 3 replicate samples were collected with a 0.1 m^3 Van Veen grab. Samples were sieved through a 1 mm mesh size sieve, fixed with 8% formalin, and brought to the laboratory, where all organisms were determined to the species level. Sediment samples were collected for grain size analysis. Water column parameters (temperature, dissolved oxygen, salinity, chlorophyll-a) were measured with a Seabird 19Plus V2 multiparametric probe. Water samples were collected with Niskin bottles for nutrient concentrations (ammonia, nitrates, phosphates, total nitrogen, total phosphorous, through a Seal Analytical QuAAtro39 AutoAnalyzer), and metal analysis (Al, As, Cd, Cr_{VI}, Cu, Hg, Ni, Pb, Se, V, Zn, through acid digestion and AE spectrometry with inductively coupled plasma).

For benthic fauna, richness (S), abundances (N), Pielou equitability (J'), Shannon diversity (H'_{loge}), AMBI (Borja et al., 2000) and M-AMBI (Muxika et al., 2007) indices were calculated for each sample. Reference values for M-AMBI were those reported by Italian legislation (Act 260/10): H_{log2}

= 4, S = 30, and AMBI = 0.5. To test if indices differed significantly among years, transects, and distance from the coast, Chi square test applied to Kruskal-Wallis (KW) ranks was ran (Kruskal and Wallis, 1952). Since significant differences were found only among years, the non-parametric pairwise Wilcox test with Bonferroni adjustment was used to find post hoc statistical differences, and mean values of indices were calculated for each year. The mean yearly percentage of species belonging to different ecological groups (EGs) according to the AMBI library was also calculated. Those analyses were performed using R version 3.5.0 (RDevelopmentCoreTeam, 2008). For the calculation of the AMBI and M-AMBI the free software (http://www.azti.es v.4) together with the guidelines from the authors (Borja and Muxika, 2005) was used. Bray-Curtis similarity coefficients were calculated on benthic log-transformed data, and a non-metric Multidimensional Scaling (nMDS) plot was drawn to represent differences in community structure. The ordination analysis was combined with cluster analysis to check the adequacy of the representation (Clarke and Warwick, 2001). In order to test if community structure varied significantly among years, transects, and distance from the coast, permutational multivariate analysis of variance (PERMANOVA) was carried out (Anderson et al., 2008). Species contributing mostly to the dissimilarity among groups were investigated using the Similarity percentage analysis (SIMPER) based on Bray-Curtis distance, calculated on log-transformed data. Distance-based redundancy analysis (dbRDA) was performed to find linear combinations of sedimentary and water column environmental data (predictor variables) which explain the greatest variation in the macrobenthic community structure. Only species with frequency higher than 5%, and a subset of 13 environmental variables, chosen to avoid problems related with the presence of too many zeros and collinearity, were considered. Those calculation were performed with PRIMER v6 + PERMANOVA software package (Clarke and Gorley, 2006; Anderson et al., 2008). A p-value <0.05 was chosen as threshold for significance.

Physical and chemical environmental characteristics are given in Table 1. After the flood, sediments showed higher proportions of sand. In the water column, metals (Al, Cr_{VI}, Ni, Cu, Zn) significantly increased in concentration after the flood (KW, $p<0.05$).

A total of 295 taxa (Appendix I) from 7,527 individuals were recorded during the study. Polychaetes dominated the community (145 taxa), followed by arthropods (58 taxa) and molluscs (57 taxa). Altogether they made up 88% of total taxa. From 2014 to 2015 arthropods showed a decrease of 64% in the number of taxa, polychaetes showed a decrease of 48%, while molluscs showed a decrease of only 10%. In 2013 and 2014 polychaetes were the most abundant group, followed by molluscs, and arthropods. Conversely in 2015 molluscs became the most abundant group, followed by polychaetes, and arthropods.

Values of univariate (S, N, J' and H'_{loge}), AMBI and M-AMBI indices (Fig. 3) varied significantly before *vs* after the flood (KW, $p<0.05$). Richness (S) was significantly lower in 2015 compared with 2013 and 2014, while abundances (N) showed significantly higher values in 2015 compared with 2013 and 2014 (pairwise Wilcox test, $p<0.05$). Pielou (J') and Shannon diversity (H'_{loge}) showed significantly lower values in 2015 with respect to 2013 and 2014 (pairwise Wilcox test, $p<0.05$). AMBI values were significantly higher in 2015 compared with 2013, while M-AMBI was significantly lower in 2015 compared to 2013 and 2014 (pairwise Wilcox test, $p<0.05$). All those indices did not vary significantly between 2013 and 2014 (pairwise Wilcox test, $p>0.05$). The percentage of indifferent (EGII) and tolerant species (EGIII) was significantly lower in 2015 compared with 2014, while the percentage of opportunistic species of second (EGIV) and first order (EGV) was significantly higher in 2015 compared with 2013 and 2014 (KW and pairwise Wilcox test, $p<0.05$). All those percentages did not varied significantly from 2013 to 2014 (pairwise Wilcox test, $p>0.05$).

Our results showed that macrobenthic community structure and composition significantly differed among years (PERMANOVA, $p<0.05$), and transects (PERMANOVA, $p<0.05$), with an interaction between the two factors (PERMANOVA, $p<0.05$). Pairwise tests showed that significant differences occurred between 2015 and previous years. The nMDS (Fig. 4A) showed how sample points of 2015 clearly segregated from 2013 and 2014, despite some differences related to depth (PERMANOVA, $p<0.05$). The bivalves *Corbula gibba* and *Spisula subtruncata* altogether contribute to the 53.91% of dissimilarity between 2013 and 2015 and to the 53.55% between 2014 and 2015. The distance-based linear regression model dbRDA (Fig. 4B), explained a portion of the variability in macrobenthic community structure. The first two dbRDA coordinate axis explained 44.11% of the fitted variation and 27.75% of total variation. Percentage of sand and gravel in sediments, and content of metals (Al, Cr_{VI}, Cu, Ni, Zn) in the water, were the environmental parameters best correlated with community structure, with Zn concentration highly correlated with the change in macrobenthic community structure before and after the flood (2015 *vs* 2013 and 2014). This relationship however was unlikely to be causative. Most probably the correlation derived from the fact that both changes were the results of disturbance generated by the extreme weather event. In fact, storm effects appear to be driven mainly by marked increase of bivalves (mainly *Corbula gibba* and *Spisula subtruncata*) and large declines of arthropods, with the almost total disappearance of amphipods. The bivalves *C. gibba* and *S. subtruncata* are both favoured by high sediment resuspension. *C. gibba* has frequent “recruitment booms” in a community after a catastrophe, and becomes a short-term dominant species until the perished invertebrate species repopulate (Hrs-Brenko, 2006), while *S. subtruncata* is known to increase growth rate and improve efficiency of assimilation of the ingested algae and/or organic matter in presence of suspended bottom material (Møhlenberg and Kiørboe, 1981).

A clear drop in diversity and ecological indices was observed after the storm. The reduced diversity was mainly related a reduction in richness and an increase in abundances of opportunistic species. Major storm events have been associated with significant changes in faunal abundances also in other offshore systems (Posey et al., 1996). The observed decrease in the number of species, may have been caused by redistribution of sediments, burying fauna at some site and blowing off them from others (Corte et al., 2017). The decrease of species richness after the storm was more pronounced for arthropods, while mollusc richness was less affected. This differential response to storm disturbance have been observed also in intertidal systems (Corte et al., 2017) and could be explained with biological traits. Surface dwelling taxa are known to be affected mostly by movement of sediments, erosion, and deposition caused by storms and wave actions, while deeper borrowing guild are usually less affected (Tamaki, 1987; Posey et al., 1996). Other authors suggested that small-bodied individuals and those with low mobility are likely more susceptible to storms (Negrello Filho and Lana, 2013; Urabe et al., 2013).

Previous studies about the influence of storms on coastal soft-sediment ecosystems were mainly performed on intertidal or shallow subtidal areas, where macrobenthic communities were dominated by tolerant and opportunistic species, well adapted to natural fluctuations of environmental parameters. Studies in areas exposed to high energy waves have shown that storms may have stronger impacts on environmental features than on fauna (e.g. Negrello Filho and Lana, 2013, Harris et al., 2011). In more sheltered areas results are sometimes discordant: in Barnegat Bay (New Jersey, USA), a shallow back-barrier estuary, after the passage of Hurricane Sandy there were no differences in total abundance of invertebrates, species richness, species diversity, or the abundance of polychaetes, bivalves, or gastropods (Taghon et al., 2017), while on the intertidal flats of Aracá Bay (Southeast Brazil), storms accompanied by torrential rain, strong winds, and flood, the macrobenthic community exhibited decreasing richness, abundance, and biomass (Corte et al., 2017). Communities living in deeper soft bottom habitats, less adapted to changes, should be more vulnerable, but such communities have been assumed to experience lesser effects from storms because of diminished wave energy at depth (Posey et al., 1996). Our results showed that storms and floods can influence also offshore macrobenthic community structure in exposed areas, even few kilometres off the coast.

In the Mediterranean region, storm activity and intensity are predicted to change over the coming decades, thus ecological changes attributed to altered storm properties are to be expected in coastal communities. We showed, for the first time in the Mediterranean, that flood following a storm caused significant changes to offshore macrobenthic assemblages. Reduction in benthos density, diversity and ecological indices, and a concomitant increase in the dominance of the opportunistic species after the storm and flood, also in the relatively less exposed outer stations, was indicative of the extreme weather impact in the study area. Finally, the present note provides the first data ever recorded of diversity of benthic species of the offshore area in the eastern Calabrian coast, which could form the baseline for future ecological investigation.

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Table 1 Mean (±SD) values of environmental variables before (2013 and 2014) and after (2015) the flood. Temp = temperature, Chl = Chlorophyll, Sal = salinity, TN = total nitrogen, TP = total phosphorus (underlined: KW, $p<0.05$).

	2013	2014	2015		2013	2014	2015
Gravel (%)	34.1 ± 24.5	28.6 ± 33.0	20.6 ± 23.8	**Cu (µg/l)**	0.9 ± 0.6	< 0.1	10.7 ± 1.7
Sand (%)	56.1 ± 19.4	57.5 ± 31.0	72.5 ± 20.8	**Hg (µg/l)**	< 0.1	< 0.1	< 0.1
Silt (%)	9.5 ± 10.7	13.6 ± 9.3	4.5 ± 2.1	**Ni (µg/l)**	1.0 ± 0.5	< 1	7.7 ± 2.4
Clay (%)	0.3 ± 0.4	0.4 ± 0.3	2.4 ± 1.8	**Pb (µg/l)**	1.0 ± 0.9	2.3 ± 6.6	1.3 ± 2.9
Temp (°C)	15.4 ± 0.3	15.8 ± 0.9	16.0 ± 1.2	**Se (µg/l)**	< 1	< 1	< 1
O_2 (mg/L)	6.4 ± 0.3	6.9 ± 0.3	7.4 ± 0.3	**V (µg/l)**	< 1	1.7 ± 0.2	< 1
pH	8.4 ± 0.1	8.2 ± 0.0	8.2 ± 0.0	**Zn (µg/l)**	5.0 ± 2.7	3.9 ± 1.2	44.9 ± 8.3
Chl (µg/l)	0.5 ± 0.2	0.2 ± 0.2	0.1 ± 0.1	**NH_4 (µmol/l)**	0.09 ± 0.08	0.53 ± 0.21	0.09 ± 0.08
Sal (‰)	38.9 ± 0.1	38.6 ± 0.1	38.7 ± 0.1	**NO_2 (µmol/l)**	0.04 ± 0.03	0.02 ± 0.04	0.05 ± 0.02
Al (µg/l)	2.3 ± 3.7	4.6 ± 13.7	25.3 ± 11.7	**NO_3 (µmol/l)**	2.32 ± 1.38	0.46 ± 0.66	2.54 ± 1.29
As (µg/l)	2.1 ± 1.9	1.6 ± 0.1	< 0.1	**PO_4 (µmol/l)**	0.06 ± 0.01	0.04 ± 0.03	0.06 ± 0.02
Cd (µg/l)	< 0.1	0.2 ± 0.5	< 0.1	**TN (µmol/l)**	9.68 ± 1.97	7.01 ± 1.25	9.99 ± 1.87
CrVI (µg/l)	< 0.5	< 0.5	1.4 ± 2.9	**TP (µmol/l)**	0.08 ± 0.03	0.08 ± 0.03	0.08 ± 0.03

Figure legend

Fig. 1. Imagine of Lido Sant'Angelo (eastern Calabrian coast) on the morning of 12 August 2015 during the flood of the Citrea creek (from: www.corrieredellacalabria.it).

Fig. 2. Study site and sampling stations.

Fig. 3. Mean (±SD) values of richness (S), abundances (N), Pielou (J’), Shannon diversity (H’), AMBI and M-AMBI indices before (2013 and 2014) and after (2015) the flood.

Fig. 4. (A) nMDS plot of sample’s centroid with Bray-Curtis similarity with superimposed hierarchical cluster at similarity level of 30% (green line). (B) dbRDA ordination plot illustrating the relationships between benthic community structure and the measured environmental variables (vectors overlay representing multiple partial correlations of those variables with the dbRDA axes). Data were log-transformed (Transects: T1-T3; stations: A-C).

Fig. 1

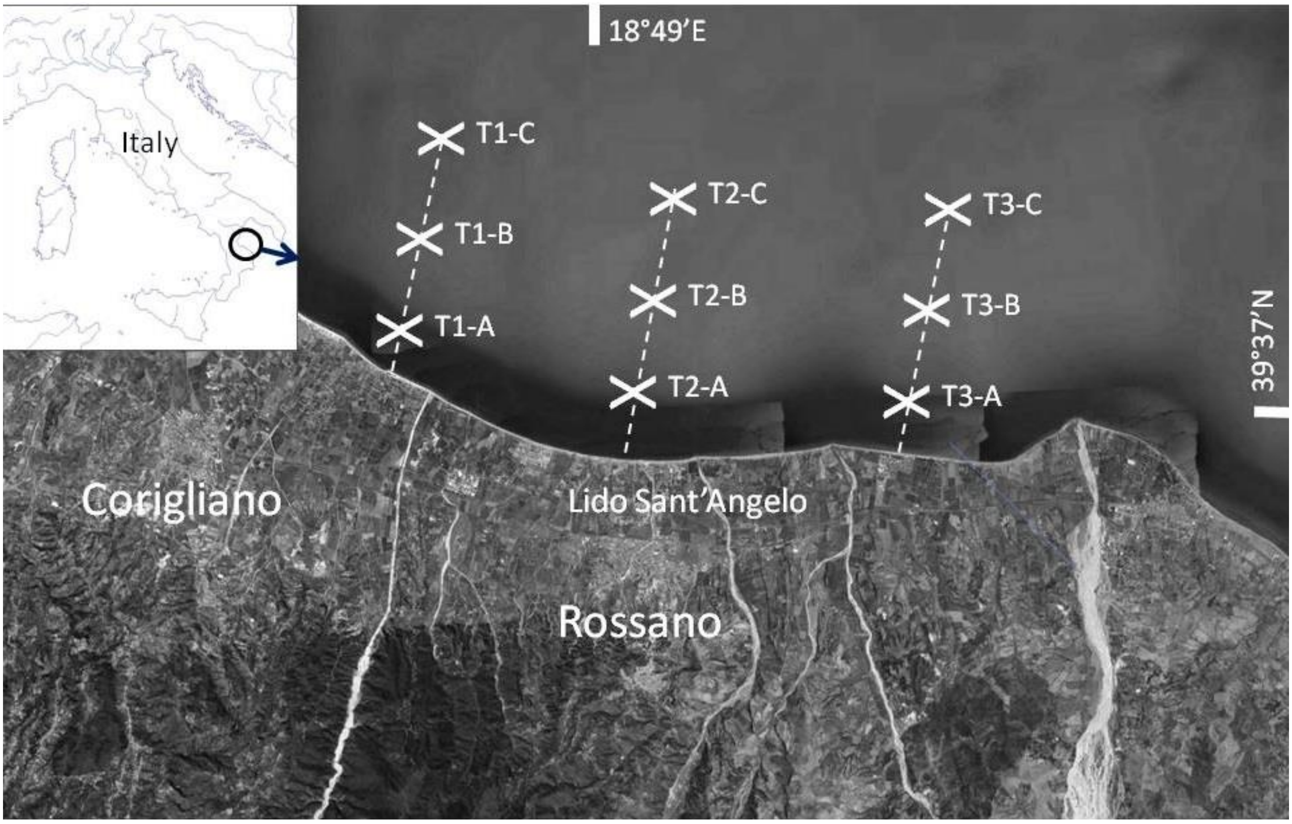
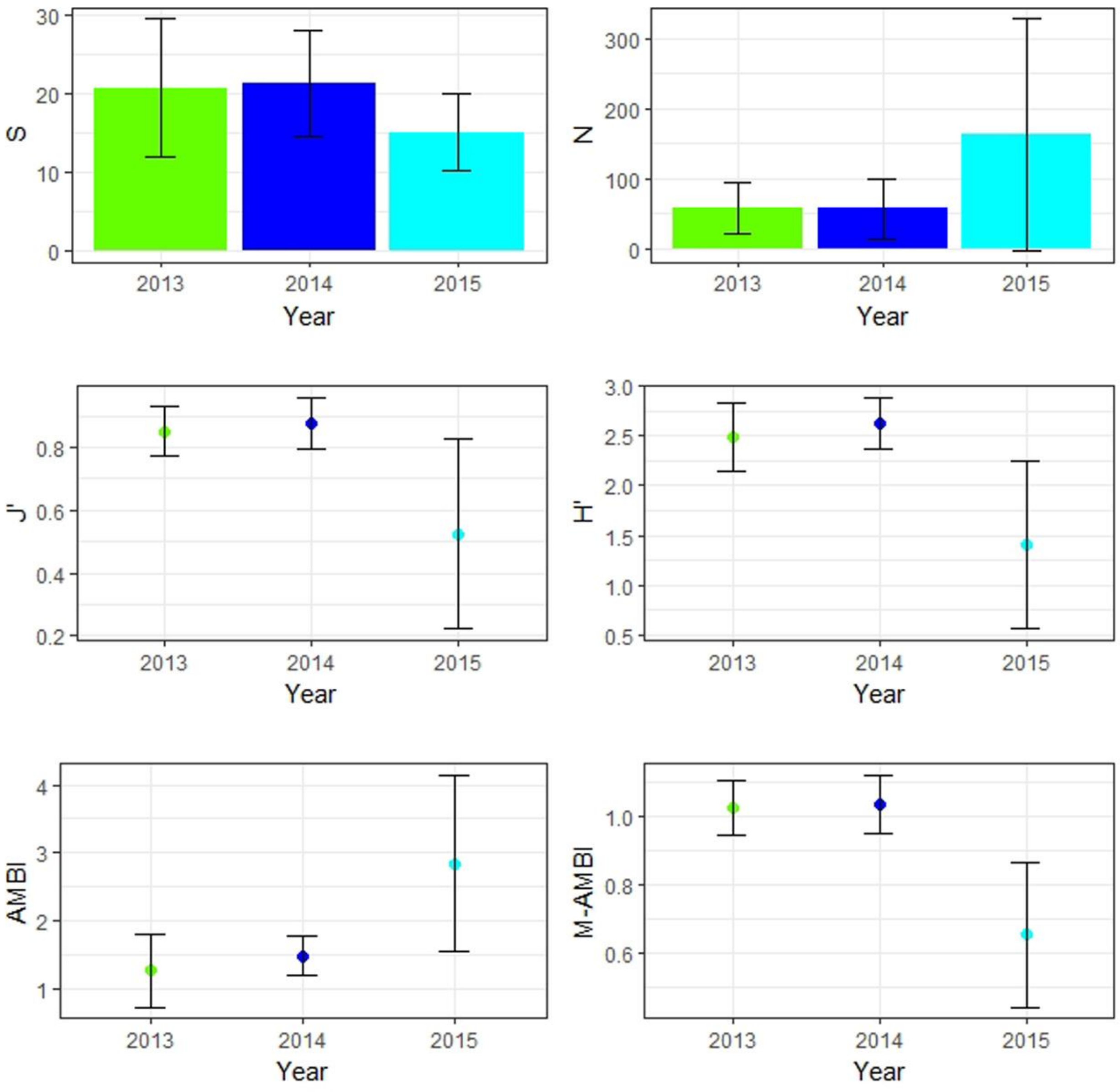

18°49'E
39°37'N
Italy
T1-C
T1-B
T1-A
T2-C
T2-B
T2-A
T3-C
T3-B
T3-A
Corigliano
Lido Sant'Angelo
Rossano

Fig. 2


S
30
20
10
0
2013
2014
2015
Year
N
300
200
100
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2013
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J'
0.8
0.6
0.4
0.2
2013
2014
2015
Year
H'
3.0
2.5
2.0
1.5
1.0
0.5
2013
2014
2015
Year
AMBI
4
3
2
1
2013
2014
2015
Year
M-AMBI
1.0
0.8
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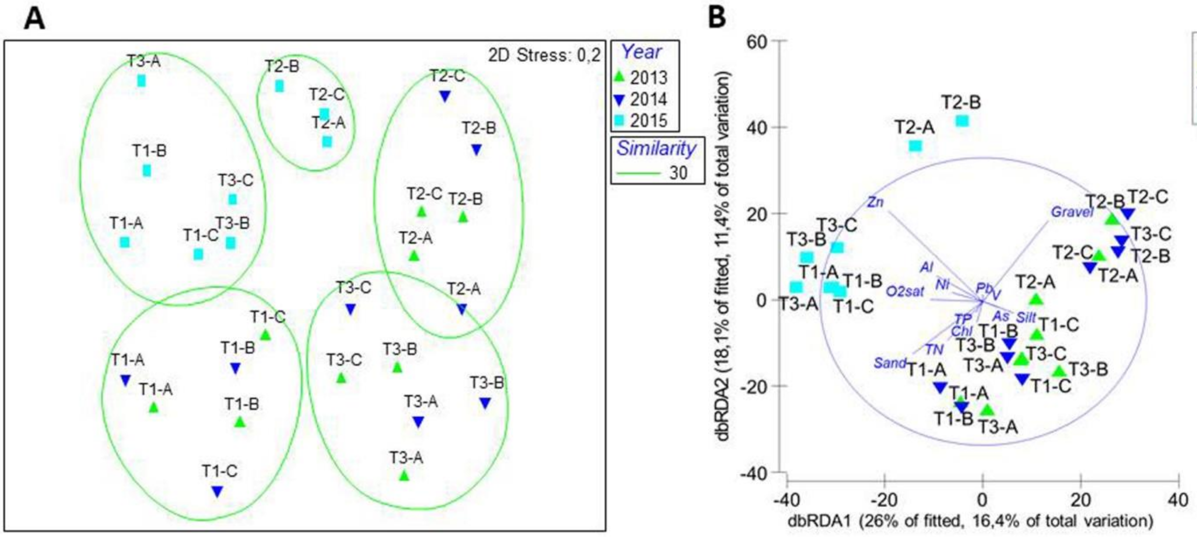
2013
2014
2015
Year

Fig. 3


A
2D Stress: 0,2
Year
2013
2014
2015
Similarity
30
T3-A
T2-B
T2-C
T2-A
T2-C
T2-B
T1-B
T3-C
T2-C
T2-B
T2-A
T1-A
T1-C
T3-B
T3-C
T2-A
T1-C
T1-A
T1-B
T1-A
T3-C
T3-B
T3-B
T1-B
T3-A
T3-A
T1-C
B
Year
2013
2014
2015
60
40
20
0
-20
-40
-40
-20
0
20
40
dbRDA2 (18,1% of fitted, 11,4% of total variation)
dbRDA1 (26% of fitted, 16,4% of total variation)
Zn
Gravel
Al
Ni
O2sat
Pb
V
TP
Chl
As
Silt
TN
Sand
T2-B
T2-A
T2-B
T2-C
T3-C
T3-B
T3-C
T2-C
T2-B
T2-A
T1-A
T1-B
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T3-A
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T1-C
T3-B
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T1-C
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T1-B
T3-A

Fig. 4