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Short-term impact of bait digging on intertidal macrofauna of tidal mudflats around the Kneiss Islands (Gulf of Gabès, Tunisia)

Nawfel Mosbahi[1,a], Jean-Philippe Pezy[2], Jean-Claude Dauvin[2] and Lassad Neifar[1]

[1] Laboratoire de Biodiversité et Ecosystèmes Aquatiques, Faculté des Sciences de Sfax, Université de Sfax, BP 1171, 3038 Sfax, Tunisie
[2] UNICAEN, CNRS, UMR 6143 M2C, Laboratoire Morphodynamique Continentale et Côtière, 24 rue des Tilleuls, 14000 Caen, France

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Abstract – In the Gulf of Gabès (South-eastern Tunisia), polychaete bait digging is widely practiced for recreational and commercial fishing and is an economically significant activity. The present study aims to assess the short-term effects of intertidal bait digging on macrobenthic communities from the Kneiss Islands. Following a protocol with a control station (not impacted) and three impacted stations for polychaete collection, the study was conducted during March and April 2015 at spring tides. After digging, immediate significant decreases were observed in the abundance of total macrofauna as well in numerous families of polychaetes. Control of this activity should be proposed for the future to protect the biodiversity of this intertidal area of high heritage interest.

Keywords: Bait harvesting / Macrofauna diversity / Gulf of Gabès / Polychaetes

1 Introduction

Coastal areas in general are very productive and ecologically important. But they are also extremely sensitive (Afli et al. 2009), because they are exposed to several anthropogenic disturbances which can affect organisms at several biological scales (Halpern et al. 2008). In fact, coastal marine benthic communities are threatened by human activities, and the present rate of habitat degradation is alarming (Gray 1997; Snelgrove et al. 1997). Indeed, effective environmental management involves the assessment of resource exploitation in relation to environmental degradation (Ellis et al. 2000).

The Kneiss Islands, situated in the Gulf of Gabès, located in the southern Tunisia, represent the most important coastal wetlands in Mediterranean Sea, and make up a very important intertidal area exploited for clam harvesting and the collection of polychaete bait by the local population (Abdennadher et al. 2011; Mosbahi et al. (submitted)). Three polychaete families (Nereididae, Eunicidae and Arenicolidae) are commercially collected from natural populations, to be used as baits, by semi-professional bait harvesters, either by hand or with fishing gear, using rakes or stainless steel spatula for digging into the sand and tidal mudflats (El Barhoumi et al. 2013). Due to the biodiversity of its intertidal zone (Mosbahi et al. 2015), this gulf has long been recognized as one of the most important wintering areas for Palearctic waterbirds migrating via the Mediterranean (Van Dijk et al. 1986; Isenmann et al. 2005; Hamdi et al. 2008; Hamza et al. 2015).

Bait digging from intertidal and estuarine habitats is practiced worldwide, and supports the subsistence of many small fishing communities (Watson et al. 2007; Carvalho et al. 2013a, 2013b; http://www.ukmarinesac.org.uk/activities/bait-collection/bc18.htm). The very large intertidal sand and mudflat zone of Kneiss Islands is exploited for bait harvesting, mainly targeted on the species i.e. *Arenicola marina* (Linnaeus 1758), *Hediste diversicolor* (Müller 1776), *Marphysa sanguinea* (Montagu 1815) and *Perinereis cultrifera* (Grube 1840). Traditionally, bait digging in intertidal areas has been undertaken by hand or using rudimentary fishing gear for overturn the sediments. However, in some countries, traditional collection methods have been superseded by mechanized methods (Ferns et al. 2000). Still though, tidal flats used by waterbirds during the foraging activity and nesting period are also exploited by humans, especially for traditional clam harvesting.

The aim of this study is to assess, for the first time in Tunisia, the immediate impact of polychaete digging on the intertidal macrozoobenthic diversity (Number of taxa / Abundance) during the period March–April 2015.

2 Materials and methods

2.1 Sampling site

The intertidal area of the Kneiss Islands is located in the north-western part of the Gulf of Gabès (south-eastern

[a] Corresponding author: nawfelmosbahi@hotmail.fr

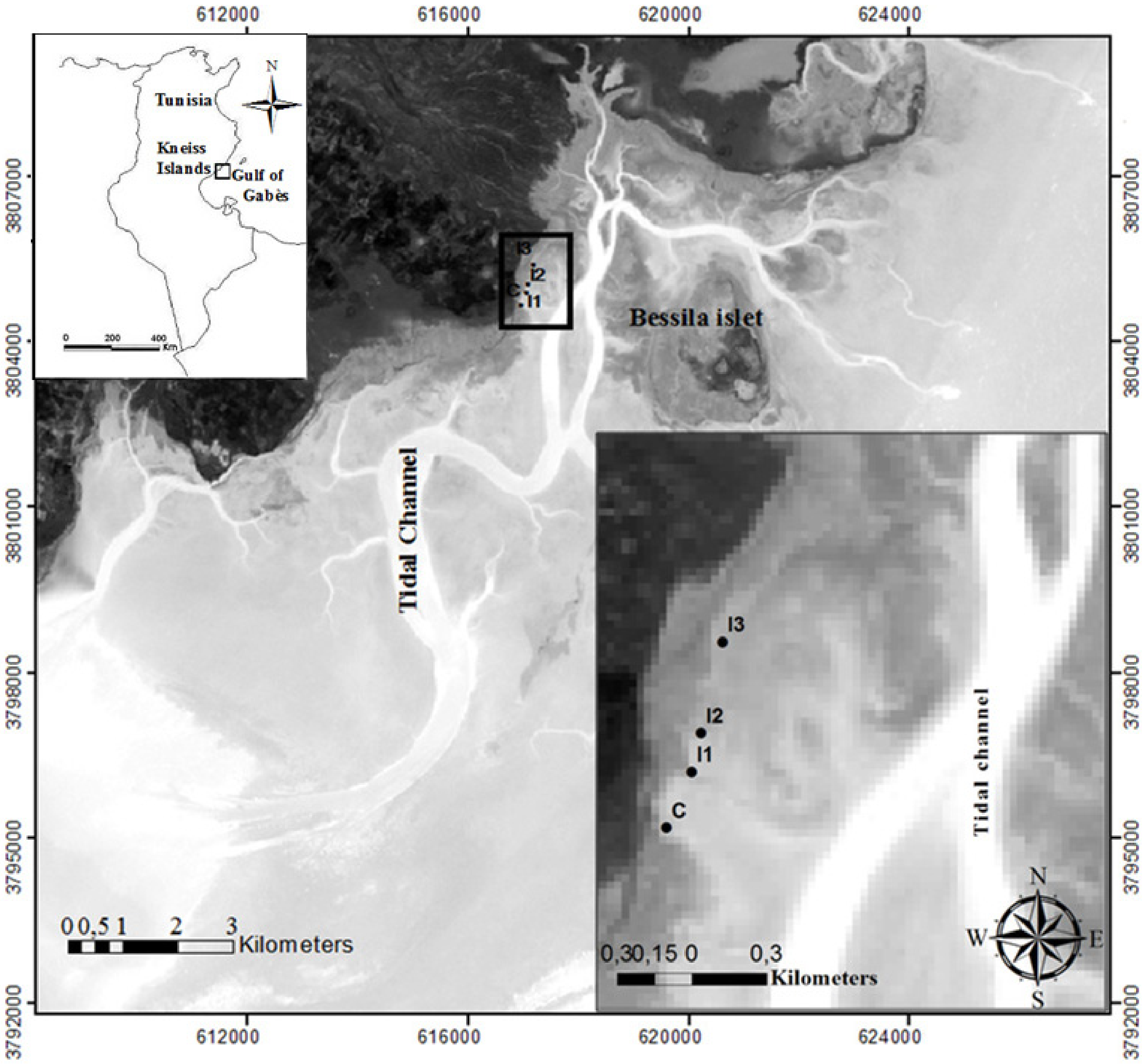

Fig. 1. Location of all sampling stations (I1, I2, I3 and C) in the intertidal zone of the Kneiss Islands (Gulf of Gabès, Tunisia) (Coordinates in WGS84).

Tunisia) between latitudes 34°10'–34°30' N and longitudes 10°–10°30'E (Fig. 1). The tides are semidiurnal, attaining a range of 2.3 m during spring tides (Seurat 1924; Sammari et al. 2006). The mudflats of the Kneiss Islands are composed by muddy to sandy muddy sediments (Bali and Gueddari 2011), colonized by the seagrass *Zostera noltei* (Hornemann 1832), protected species listed in the IUCN Red List of threatened species in Mediterranean Sea, as characterizing a diversified habitat requiring monitoring and protection. Due to their biodiversity, the Kneiss Islands were declared as a nature reserve in 1993, then as a "Specially Protected Area of Mediterranean Importanc" (SPAM) in 2001, an "Important Bird Area" (IBA) in 2003 and a "RAMSAR site" in 2007.

2.2 Macrofauna sampling

Benthic macrofauna sampling was performed between March and April 2015, by collecting the top most 0.3 m of the sediment with a 0.0225 m^2 corer (core diameter of 0.15 m) with eight replicates per station. The sampling was carried out at three stations (i.e., I1, I2 and I3) in zones where the fishers collect four polychaete target species, i.e. *A. marina*, *H. diversicolor*, *M. sanguinea* and *P. cultrifera*, as well as at a control station (C) in an area where digging polychaetes is normally forbidden (Not impacted) (Fig. 1). Each station situated on a *Zostera noltei* meadow was located with a GPS and was visited during two sampling campaigns. The first campaign was on 6 March, coinciding with the beginning of the annual bait collection period denoted here as B (for *before*). The second campaign took place on 4 April (after a month of polychaete collection) denoted here as A (one month *after* bait digging started).

Samples were sieved through a 1-mm mesh, fixed with buffered formalin 10% and stained with Rose Bengal to facilitate the sorting. In the laboratory, the species were sorted and identified to species level (whenever possible) and preserved in 70% ethanol.

Table 1. Main characteristics of stations used in sampling campaign on 6 March 2015.

Stations	Coordinates		Grain size fraction (%)							Sediment type	Organic Matter (%)
	Longitude E	Latitude N	>2000	<2000	<1000	<500	<250	<125	<63		
I1	32.617067	38.04883	1.30	4.80	6.85	18.35	34.17	29.58	5.22	Fine Sand	2.54
I2	32.617105	38.05038	0.30	1.80	4.61	13.35	59.20	22.13	8.57	Fine Sand	2.42
I3	32.617192	38.05405	0.50	0.35	0.78	2.33	71.65	16.05	8.34	Fine Sand	2.18
C	32.616966	38.04658	0.02	0.02	0.05	4.84	78.17	12.97	3.93	Fine Sand	2.25

2.3 Sediment Analysis

For grain-size analysis, sediment from each sample was homogenized and wet-sieved through a 63 μm mesh to separate mud (including silt and clay) and sandy fractions (retained in the sieve). After being oven-dried to constant weight at 60 °C, sandy fractions were separated using a mechanical shaker (column of six sieves of mesh sizes 2, 1, 0.5, 0.25, 0.125 and 0.063 mm) for 10 min. All fractions (including the fines <63 μm) were then weighed and to determine the percentages. For the organic matter (OM) content, sediment samples were dried at 80 °C to constant weight and ground to a fine powder. OM content was determined in the powder samples by "loss on ignition" at 450 °C for 4 h (Table 1).

2.4 Statistical analyses

Multivariate and univariate techniques are utilized here to test hypotheses about changes in the structure and composition of macrobenthic assemblages due to polychaete digging. The taxonomic richness (number of taxa) and abundance are considered per replicate.

For the biological parameters, a Shapiro-Wilk normality test and a Bartlett's test for homogeneity of variance are performed prior to each ANOVA to check whether the assumptions of ANOVA are met and if data transformation is necessary. Then, ANOVAs are performed to assess the effect of bait digging on benthic abundance and taxonomic richness for both campaigns. A Tukey Honestly Significant Difference test is employed to determine differences before and after raking as well as between the three sediment types.

Then, a square root transformation is applied to the abundance matrix (data for each station are pooled prior to undertaking further analyses), before calculating the Bray-Curtis similarities using the statistical package PRIMER®. 6.0 (Clarke and Gorley 2006). A dendrogram is created, with group averages expressed in the cluster mode. Then, a non-parametric multi-dimensional scaling (MDS) ordination, using the Bray-Curtis similarity measure, is applied to the abundance matrix (after square root transformation), with the objective of examining the structure of the intertidal endofauna. The SIMilarity PERcentages (SIMPER) routine is applied to establish which species contribute most to the observed differences in the data. ANOSIM (ANalysis of SIMilarities) (Clarke 1993) is also carried out to test for significant differences in intertidal endofauna composition in response to raking (one-way analysis).

3 Results

Bait digging is a recent activity on the intertidal zone around the Kneiss Islands. However, with the aim of preserving the stock during the winter reproductive period, but rather in relation with the high productive period of clam *Ruditapes decussatus* (Linnaeus 1758), which is exploited mainly by the same fishers (Mosbahi et al. (submitted)); the fishing activity is relatively less intense from the beginning of December to the end of February (three months), and extends with full intensity from the 1st March to the 30th November. Around the Kneiss Islands, nearly 100 fishermen exercise this activity every day during the harvest period (270 days). Bait harvesters can dig about 100–150 worms/day for a fresh weight estimated at 0.3 kg; they sell their harvest directly after fishing to a wholesaler who sells the bait to Tunisian fishermen and for the export market. Thus, we estimate that about 8 tonnes are collected per year in the target zones of the Kneiss Islands.

3.1 Main characteristics of sediment and macrofauna

Sampled stations are colonized by *Zostera noltei* and the grain-size analyses show that the sediments at the four stations are mainly composed of fine sand. The organic matter content is closely similar for all stations (between 2.0 and 2.5%) (Table 1).

A total of 63 species were collected belonging to six zoological groups unequally distributed among the sampling stations. Annelid polychaetes are dominant (37% of total number of species), followed by crustaceans (27%), mainly amphipods, isopods, decapods and mysids, along with molluscs (27%), mainly bivalves and gastropods. The other three phyla (echinoderms, cnidarians, and tunicates) account for only 9% of the total number of species.

3.2 Short-term impact of bait digging on intertidal macrofauna

Before the polychaete bait collection period, the faunal composition was predominately composed of polychaetes (2033 ind. in the 32 replicates of 0.0225 m^2), with abundant representatives of the Nereididae, Arenicolidae and Cirratulidae, and also by molluscs (1614 ind.), dominated by Scrobiculariidae, Cerithiidae, Cardiidae and Potamididae.

After bait digging, the number of taxa (species richness) and abundance in the 0.0225 m^2 are decrease, for the abundance that is almost −50% (Tables 2 and 3), as well as the disappearance of some polychaetes, such as *Amphitritides gracilis* (Grube 1860), *Heteromastus filiformis* (Claparède 1864)

Table 2. Number of species (richness) and total benthic abundance for each station, Before and After bait digging. Mean values with the same superscript are not significantly different (Tukey's HSD test; $p > 0.05$) (I1, I2, and I3: Impacted stations; C: Control station).

Stations	Taxonomic richness		Total benthic abundance	
	Before	**After**	**Before**	**After**
I1	35.5 ± 4.6^a	20.5 ± 4.0^b	168.4 ± 24.5^c	51.4 ± 8.7^d
I2	31.7 ± 4.4^a	20.6 ± 3.0^b	132.6 ± 22.9^c	48.7 ± 5.4^d
I3	32.6 ± 4.0^a	20.2 ± 1.7^b	156.0 ± 21.1^c	60.9 ± 9.5^d
C	38.1 ± 2.2^a	36.5 ± 3.0^a	169.5 ± 16.4^c	137.8 ± 7.9^c

Table 3. Density of individuals recorded at all the stations sampled during the two campaigns (March and April 2015).

Species	Total number of individuals (on area of 0.0225 m^2)			
	Impacted stations (I1, I2, I3)		Non-impacted station (C)	
	Before	After	Before	After
Actinia equina (Linnaeus 1758)	5	7	2	3
Alpheus inopinatus (Holthuis and Gottlieb 1958)	14	7	16	9
Amphipholis squamata (Delle Chiaje 1828)	11	9	7	9
Amphitritides gracilis (Grube 1860)	20	0	9	16
Anthura gracilis (Montagu 1808)	49	11	13	21
Aoridae	27	10	14	21
Arenicola marina (Linnaeus 1758)	131	45	61	1
Asterina pancerii (Gasco 1870)	10	6	3	2
Bulla striata Bruguière 1792	12	3	4	4
Carcinus aestuarii Nardo 1847	7	7	5	3
Cerastoderma glaucum (Bruguière 1789)	115	26	41	13
Cerithium scabridum Philippi 1848	333	100	122	55
Cerithium vulgatum Bruguière 1792	8	18	0	13
Chiton olivaceus Spengler 1797	46	36	15	17
Cirratulus cirratus (Müller 1776)	232	94	90	82
Cirriformia tentaculata (Montagu 1808)	32	17	8	6
Conus ventricosus Hwass in Bruguière 1792	2	4	2	4
Cyathura carinata (Krøyer 1847)	49	12	22	22
Cyclope neritea (Linnaeus 1758)	31	6	9	6
Cymadusa filosa Savigny 1816	21	9	25	12
Dexamine spiniventris (Costa 1853)	97	25	33	37
Dexamine spinosa (Montagu 1813)	27	12	23	17
Euclymene oerstedii (Claparède 1863)	219	116	94	85
Eulymene lumbricoides (Quatrefages 1866)	41	10	16	18
Gammarus insensibilis Stock 1966	40	14	26	29
Hediste diversicolor (O.F. Müller 1776)	182	45	88	29
Heteromastus filiformis (Claparède 1864)	39	0	6	9
Hexaplex trunculus (Linnaeus 1758)	14	2	3	20
Holothuria	5	0	3	5
Idotea balthica (Pallas 1772)	64	31	24	27
Idotea granulosa Rathke 1843	11	2	6	15
Leiochone leiopygos (Grube 1860)	17	8	6	7
Loripes lucinalis (Lamarck 1818)	42	22	8	17
Marphysa bellii (Audouin & Milne Edwards 1833)	22	18	8	16
Marphysa sanguinea (Montagu 1815)	20	11	6	2
Melinna palmata Grube 1870	50	37	43	44
Melita palmata (Montagu 1804)	80	24	46	45
Microdeutopus gryllotalpa Costa 1853	75	20	42	33
Monocorophium insidiosum (Crawford 1937)	200	26	83	28
Mysidae	91	12	34	9
Nassarius corniculum (Olivi 1792)	51	9	7	6

Table 3. Continued.

Species	Total number of individuals (on area of 0.0225 m^2)			
	Impacted stations (I1, I2, I3)		Non-impacted station (C)	
	Before	After	Before	After
Nephtys hombergii Savigny in Lamarck 1818	14	10	6	8
Nereis caudata (Delle Chiaje 1822)	23	3	4	9
Nereis rava Ehlers 1864	6	4	5	2
Neverita josephinia Risso 1826	17	4	0	9
Nicomache sp.	7	4	3	7
Ophiactis virens (M. Sars 1857)	4	1	2	3
Orbinia cuvierii (Audouin & Milne Edwards 1833)	12	3	2	3
Ostreola stentina (Payraudeau 1826)	8	4	1	7
Perinereis cultifera (Grube 1840)	223	62	85	40
Pinctada radiata (Leach 1814)	45	14	16	14
Platynereis dumerilii (Audouin & Milne Edwards 1834)	25	8	27	21
Polydora ciliate (Johnston 1838)	22	18	10	12
Potamides conicus (Blainville 1829)	194	64	21	21
Pseudoprotella phasma (Montagu 1804)	11	6	1	12
Ruditapes decussatus (Linnaeus 1758)	51	14	14	20
Sabella pavonina Saint-joseph 1894	45	0	10	10
Scoloplos armiger (Müller 1776)	35	26	11	12
Scrobicularia plana (da Costa 1778)	306	155	51	55
Serpula vermicularis Linnaeus 1767	17	4	1	5
Solemya togata (Poli 1791)	19	0	6	0
Sphaeroma serratum (Fabricius 1787)	17	3	5	14
Tunicata sp.	13	10	2	1

and *Sabella pavonina* (Saint-Joseph 1894), along with the Holothuria (Table 3).

Table 2 reports the total number of individuals sampled in each replicate and at each station (mean ± SD) for both dates.

Firstly, all control station abundances are higher before and after one month of harvesting bait compared with the other stations (i.e. 169.5 ± 16.4 and 137.8 ± 7.9 recorded individuals per 0.0225 m^2). The species richness and abundances at the three impacted stations are higher before (B) versus after (A) bait digging. Thus, it appears that bait digging causes a decrease in the number of species and total benthic abundance in the intertidal zone of the Kneiss Islands (Table 3).

Before bait digging, no significant difference is observed between the four stations for the taxonomic richness (ANOVA, $F_{3.28} = 1.982$; $p = 0.472$) or for the abundance of the macrofauna (ANOVA, $F_{3.28} = 2.731$; $p = 0.177$) (Table 2). A strong effect on benthic abundance and taxonomic richness is observed one month after bait digging: the taxonomic richness decreases significantly at the three impacted station (ANOVA, $F_{7.56} = 85.75$; $p < 2e^{-16}$), and a similar decrease is observed in total benthic abundance (ANOVA, $F_{7.56} = 106.8$; $p < 2e^{-16}$). After bait digging, no decrease of taxonomic richness and benthic abundance is observed at the Control station, showing that the differences at the impacted stations (I1, I2 and I3) are due exclusively to bait digging (Table 2).

The dendrogram (Fig. 2A) shows the separation of the eight situations into two main groups: the first group (GI) corresponds to the four stations sampled before bait collection plus the control one month after the beginning of the bait digging period, and the second group (GII) gathers together the three stations impacted by bait digging. The MDS ordination (Fig. 2B) showed a remarkable spatial separation between Group I (five situations) and Group II (three impacted stations). SIMPER illustrates the biological significance of the clustering before and after bait digging (Fig. 2) by displaying the group similarity and identifying the species contributing most to the dissimilarity between groups. The main species contributing to the dissimilarity was given in Table 4. The ANOSIM shows that the two groups are statistically highly separated ($r = 1$, $p = 0.018$) (Table 4).

4 Discussion

The objective of this study is to assess the immediate impact of polychaetes bait collection on the surrounding intertidal benthic macrofauna from the tidal flats of the Kneiss Islands.

Bait digging for recreational and commercial fishing is widely practiced in many parts of the world and is an economically significant activity. Since polychaetes form part of the diets of several demersal species, they are commonly used as fresh bait by sports and professional fishermen (Olive 1993; Cunha et al. 2005).

Two human activities have become well developed over the last decades on the intertidal zone around the Kneiss Islands, clam harvesting (Mosbahi et al. (submitted)) and bait digging. These human activities have many effects on the intertidal macrobenthic fauna, which is an essential element in the food

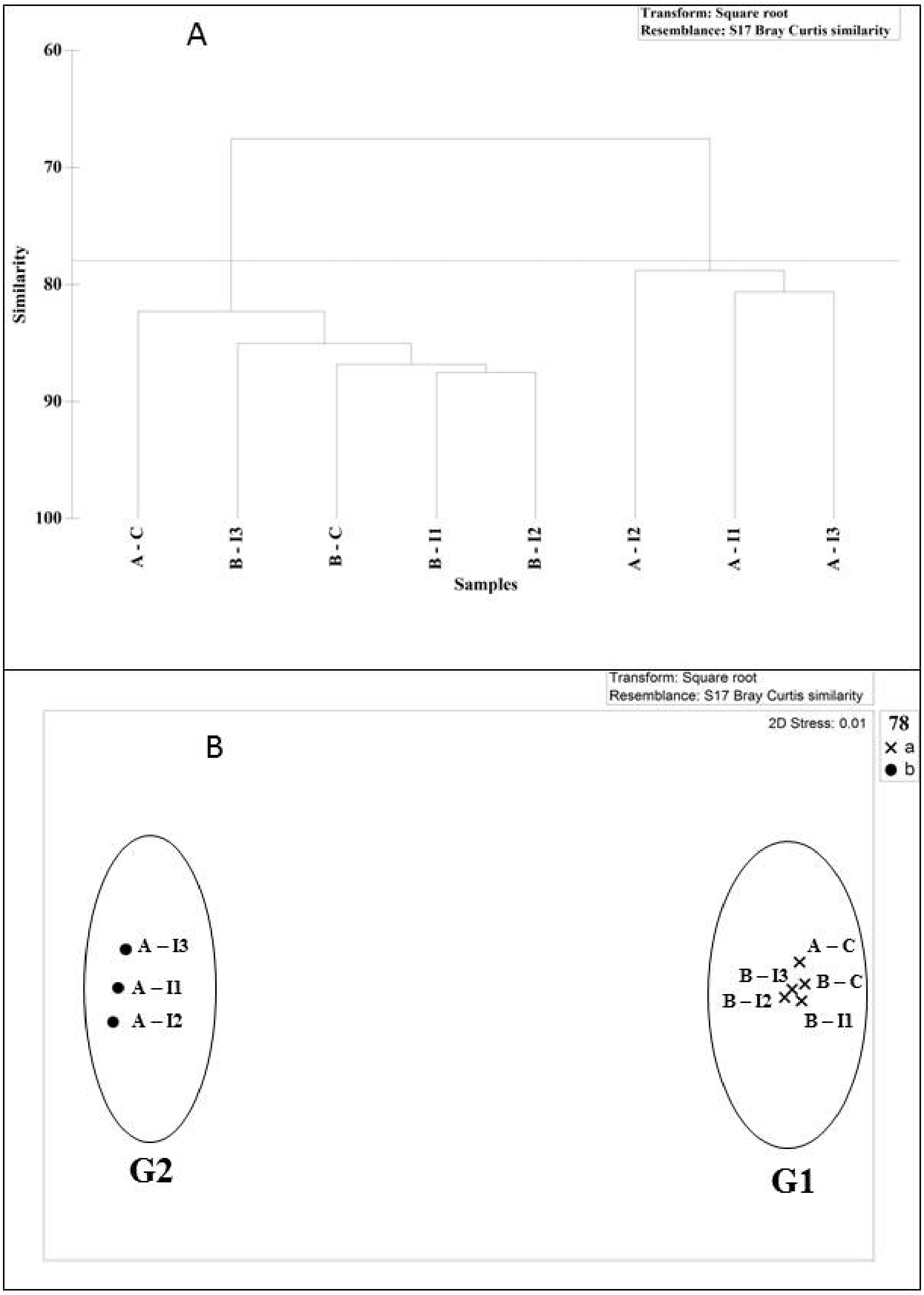

Fig. 2. (A) dendrogram and (B) two-dimensional MDS ordination/clustering of community data into two groups (G1 and G2) for each impacted station (I1, I2 and I3) and Control station (C). Sample prefixes B: Before digging; A: After digging.

Table 4. MDS formed groups, with indication each group similarities (%) and the most representative species (%) contributing for the similarity within the group, determined with SIMPER analysis.

Group	I	II
Group mean similarity	84.54	79.43
Main species (after each species the % of contribution for the similarity within the group)	*Dexamine spiniventris* – 29.75 *Monocorophium insidiosum* – 27.07 *Hediste diversicolor* – 23.67 *Scrobicularia plana* – 20.27 *Perinereis cultrifera* – 16.60 *Cerithium scabridum* – 12.74 *Cirratulus cirratus* – 8.67 *Euclymene oerstedi* – 4.33	*Potamides conicus* – 28.93 *Perinereis cultrifera* – 25.05 *Cerithium scabridum* – 21.01 *Cirratulus cirratus* – 16.61 *Euclymene oerstedi* – 11.78 *Scrobicularia plana* – 6.01

chain in marine ecosystems (Turpie et al. 2002; Gray and Elliot 2009; Henninger and Froneman 2011).

The fauna is mainly composed of polychaetes (number of taxa and abundance of individuals), the more abundant families being the Nereididae, Arenicolidae (fishing target species) and the Cirratulidae. Bait digging does not lead to marked sediment changes (percentage of grain-size classes and organic matter content remain constant one month after the beginning of bait digging); nevertheless, the number of taxa and abundance of individuals are affected. For both periods, the abundances estimated at the control stations are significantly higher than those estimated at the three stations before and after bait collection, with some polychaetes, *Heteromastus filiformis* (Capitellidae), *Amphitritides gracilis* (Terebellidae) and *Sabella pavonina* (Sabellidae) disappearing after one month of bait digging. This indicates that the intertidal macrozoobenthic biodiversity at the impacted stations is affected by the type of destructive gear or possibly by trampling (Rossi et al. 2007; Navon and Dauvin 2013).

The decrease in abundance and diversity of intertidal macrofauna after bait digging has been commonly observed, and is thought to be due to direct and indirect mortality (destruction of tubes, exposure to predators and habitat destruction including seagrass reduction) (Brown and Wilson 1997; Cowie et al. 2000; Munari et al. 2006; Carvalho et al. 2013a, 2013b). Usually, the abundance of tubicolous polychaetes decreases after impact, under the effects of fishing gear and human trampling which eliminate the most vulnerable organisms and modify the habitat structure. Therefore, these organisms respond negatively to human activities (invertebrate harvesting or bottom trawling), since they are highly vulnerable and considerably reduced in abundance, and sometimes entirely eliminated by fishing activities, being extremely fragile and particularly susceptible to damage (Kaiser and Spencer 1994; Wassenberg et al. 2002; De Juan et al. 2007).

Macrobenthic assemblages may respond differently to the same intensity, frequency or nature of disturbance, depending on their biological traits; organisms resistant to disturbance can be considered as better indicators than opportunistic species, since the former tend to adapt easily and respond weakly to disturbance (Carvalho et al. 2013a, 2013b; Frid 2003; De Juan et al. 2007). The existence of less diverse assemblages with a consequent reduction of ecological functions may magnify the effects of bait digging, as mortality due to fishing has been shown to be related to animal size, animal type, position in sediment, the existence of external protective structures and body design (Jennings et al. 2001; De Juan et al. 2007).

This preliminary study constitutes the first ecological impact of bait digging on the intertidal macrobenthic communities in the foreshore of the Gulf of Gabès; it can be considered as a baseline for further studies on the impact of traditional human activities on the benthic communities from the Gulf of Gabès. For the moment, there is no data on the impact of this activity on the target species stocks.

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