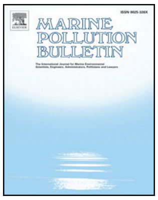
Marine Pollution Bulletin xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul



# Ecological assessment of a heavily human-stressed area in the Gulf of Milazzo, Central Mediterranean Sea: an integrated study of biological, physical and chemical indicators

Michela D'Alessandro [a,b,*], Valentina Esposito [a], Salvatore Giacobbe [b], Monia Renzi [c], Maria Cristina Mangano [d], Pietro Vivona [a], Pierpaolo Consoli [a], Gianfranco Scotti [a], Franco Andaloro [e], Teresa Romeo [a]

[a] ISPRA, Institute for Environmental Protection and Research, STS Palermo, Laboratory of Milazzo, Via dei Mille, 46–98057 Milazzo, Messina, Italy
[b] Department of Biological and Environmental Science, University of Messina, Viale Stagno d'Alcontres, 31–98166 S. Agata, Messina, Italy
[c] Bioscience Research Center, Via Aurelia Vecchia, 32–58015 Orbetello, Grosseto, Italy
[d] IAMC-CNR, Via del Mare 3, 91021 Capo Granitola, Campobello di Mazara, Sicily, Italy
[e] ISPRA, Institute for Environmental Protection and Research, STS Palermo, c/o Marbela Residence, via Salvatore Puglisi 9, 90143 Palermo, Italy

ARTICLE INFO

*Article history:*
Received 10 September 2015
Received in revised form 29 December 2015
Accepted 14 January 2016
Available online xxxx

*Keywords:*
Sediment pollution
Biotic index
Nonindigenous species
Ecological assessment
Central Mediterranean Sea

ABSTRACT

Marine environmental disturbance can be assessed directly from physical and chemical parameters, or indirectly by the study of indicator species. In this study, an integrated approach to monitor the Gulf of Milazzo, labeled as a highly contaminated site, is presented. A total of 83 samples were collected from hard and soft bottoms in 2010. In sum, 2739 specimens belonging to 246 taxa, two first records for the Tyrrhenian Sea (*Micronephthys stammeri* and *Nicomache lumbricalis*) and three nonindigenous species (*Brachidontes pharaonis*, *Crassostrea gigas* and *Notomastus aberans*) were recorded. Biodiversity and biotic indices and their relationship with sediment parameters and the level of pollutants were assessed to describe faunal assemblage and evaluate environmental quality. Pearson tests evidenced significant negative correlation between polychlorinated biphenyls (PCBs) and specific richness ($p < 0.10$). A comparison of the standard and recorded biotic values showed that M-AMBI seems to be the index more representative of ecological quality status (EcoQ) in the Gulf of Milazzo. No evident signs were highlighted on the complex.

## 1. Introduction

Coastal waters are sensitive habitats that support high levels of biodiversity and provide many marine raw materials and services (Costanza et al., 1998; de Groot et al., 2002; Beaumont et al., 2008). Excessive human use of marine ecosystems (Mason, 2002; Matthiessen and Law, 2002) has led to local different degrees of environmental disturbance such as loss of habitat, change of nutrient status and cycling, loss of food supplies, erosion, reduced sediment supply, change of sea level and consequent inundations, and increased exposures to natural disturbances (Lotze et al., 2005; Worm et al., 2006; McCauley et al., 2015).

Other focal threats to ecological health are represented by bioinvasions of nonindigenous species that, by different vectors such as marine traffic (hull fouling or ballast water), aquaculture and interoceanic canals, are able to colonize new locations, causing loss of biodiversity of autochthon species (Vitousek et al., 1996; Ojaveer et al., 2014; D'Alessandro et al., 2015). Nonindigenous species, because of lack of natural prey, tend to supply autochthon species, causing loss of biodiversity (Bax et al., 2003; Occhipinti-Ambrogi, 2007).

Environmental disturbance, caused by natural or human causes, can be assessed directly from physical and chemical parameters (Daskalakis and O'Connor, 1995) or indirectly by the study of indicators as macrozoobenthic species (Pearson and Rosenberg, 1987; Borja et al., 2000; Lindegarth and Hoskin, 2001). The latter method is found on the paradigm of Pearson and Rosenberg (1987), which showed that macrobenthic organisms change their community structure according to natural conditions and anthropogenic environmental impacts in three progressive steps: abundance increases, species diversity increases and dominant species change from pollution-tolerant to pollution-sensitive ones (Grigg, 1994; Pearson and Rosenberg, 1987; Otway, 1995; Borja et al., 2000). On the basis of this assumption, by the study of benthic community, it is possible to establish an ecological quality status (EcoQ) of studied areas (Borja et al., 2000; Cruz-Motta and Collins, 2004; Currie and Isaacs, 2005).

The implementation of the European Water Framework Directive 2000/60/EC and 2008/56/CE has developed several biotic indices based on the classification of species (or groups of species) in several ecological groups representing specific sensitivity levels to disturbance. In this study, the applicability of BOPA (benthic opportunistic polychaetes amphipods) index, AMBI (AZTI marine biotic index) and M-

---

* Corresponding author at: ISPRA, Institute for Environmental Protection and Research, STS Palermo, Laboratory of Milazzo, Via dei Mille, 46–98057 Milazzo, Messina, Italy.
*E-mail address:* mdalessandro@unime.it (M. D'Alessandro).

http://dx.doi.org/10.1016/j.marpolbul.2016.01.021

Please cite this article as: D'Alessandro, M., et al., Ecological assessment of a heavily human-stressed area in the Gulf of Milazzo, Central Mediterranean Sea: an integrated study of b..., Marine Pollution Bulletin (2016), http://dx.doi.org/10.1016/j.marpolbul.2016.01.021

AMBI (multivariate AMBI) for monitoring the impact of pollution on soft-bottom macrobenthic communities of the Gulf of Milazzo was tested. The first index is easier to use than the other two indices. However, it needs the maximum taxonomic effort. For using BOPA index, it is necessary to recognize amphipods, distinguishing the opportunistic genera of amphipods *Jassa* from others and a reduced list of opportunistic polychaetes. M-AMBI is a multimetric index based on benthic macroinvertebrates, which integrates AMBI values with values of diversity and richness. Aims of this study are to assess the ecological status of the highly polluted Milazzo shelf through a multidisciplinary study, including chemical, physical and biological features, to examine relationships between biotic and abiotic compounds (seafloor features and contaminant distribution) and investigate the presence of nonindigenous species.

## 2. Materials and methods

### 2.1. Study area and sampling activity

Sampling was carried out along the narrow continental shelf of the Gulf of Milazzo, north-eastern coast of Sicily, Central Mediterranean Sea (Fig. 1). The Gulf is exposed to high anthropogenic pressure because of the presence of an international harbor, oil refineries, thermal power plant and shipbuilding industry. According to a census on the marine traffic associated with refinery activities (ISPRA, 2009), it was estimated that approximately 3256 vessels (66% chemical/oil product tanker; 15.86% crude oil tanker; 12.56% LGT tanker and 5.48% oil product tanker) have transited between 2006 and 2010 through the Gulf of Milazzo. The area is also subject to marine traffic associated with fishing and tourism (recreational ships, cruise ships and hydrofoils daily to the Aeolian Islands). In 2005, the industrial area of Milazzo was included in the list of Contaminated Sites of National Interest (Directive 23 December 2005 n. 266, art. 1 com. 561, national law in Italian language). The study area is characterized by low water circulation, mainly driven by NW winds. The surface water circulation is defined by a branch of Modified Atlantic Water (MAW), which, flowing eastward, forms a near-coast anticyclonic gyre and generates an accumulation area in the northern part of the Gulf (Sitran et al., 2009). This area is also subject to the influence of three small rivers with irregular flows (Corriolo, Niceto, Muto and Saya Archi/Rio Cucugliata Streams).

Undisturbed soft-bottom samples were collected during the summer of 2010 by a 0.1-m$^2$ *van Veen* grab in 16 sampling sites, two of which, at a distance of about 10 km from the refinery, were chosen as control.

Sampling sites were located along two bathymetries, at depths of 20 and 50 m (Table 1). Four replicates were collected for each sampling site, for 64 samples, of which three were used for macrofaunal analysis and one for grain size and chemical analyses.

Sampling from hard bottom was carried out by scuba diving, scraping a surface of 400 cm$^2$ from three pillars of refinery, of which two were functional (P1 and P2) and one was disused (P3). Three samples were collected from each station at three different depths (0.5, 6.0 and 15.0 m), for a total of 35 samples (Table 1).

Benthic samples from soft and hard bottoms were sieved on board through a 0.5-mm mesh, and the retained material was fixed with 4% buffered formalin. After 48 h, the samples were transferred for a long-term storage to 70% ethanol.

### 2.2. Laboratory analyses

Grain size analysis was performed according to Buchanan and Kain (1971), the fraction above 63 μm was examined by American Society for Testing Materials (ASTM) series sieves with an interval of 1 Φ ($\Phi = -\log_2 Ø$, mm), while the fraction below 63 μm (silt and clay) was analyzed by column dispersion method. Sediment types were classified according to the ternary Wentworth scale (Wentworth, 1922).

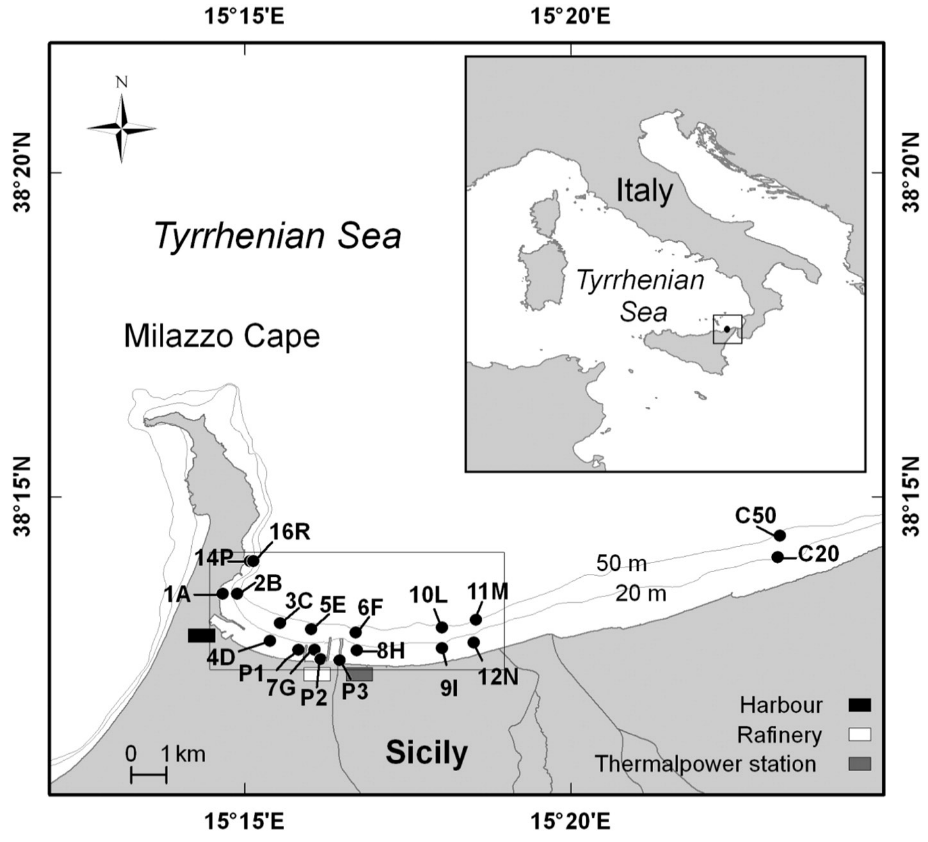


**Fig. 1.** Area of sampling, with sampling stations represented by black points and SIN zone by the selected area.

Please cite this article as: D'Alessandro, M., et al., Ecological assessment of a heavily human-stressed area in the Gulf of Milazzo, Central Mediterranean Sea: an integrated study of b..., Marine Pollution Bulletin (2016), http://dx.doi.org/10.1016/j.marpolbul.2016.01.021

**Table 1**
Coordinate of soft and hard sites of samplings.

| Latitude (°N) | Longitude (°E) | Site | Data sampling | Depth | Replicates | Sediment |
|---|---|---|---|---|---|---|
| 38 13 500 | 15 14 659 | 1A | 18/06/2010 | 20 | 3 | Soft |
| 38 13 500 | 15 14 884 | 2B | 18/06/2010 | 50 | 3 | Soft |
| 38 13 050 | 15 15 537 | 3C | 18/06/2010 | 50 | 3 | Soft |
| 38 12 775 | 15 15 387 | 4D | 18/06/2010 | 20 | 3 | Soft |
| 38 12 953 | 15 16 015 | 5E | 18/06/2010 | 50 | 3 | Soft |
| 38 12 900 | 15 16 700 | 6F | 19/06/2010 | 50 | 3 | Soft |
| 38 12 638 | 15 16 070 | 7G | 18/06/2010 | 20 | 3 | Soft |
| 38 12 630 | 15 16 720 | 8H | 19/06/2010 | 20 | 3 | Soft |
| 38 12 663 | 15 18 023 | 9I | 19/06/2010 | 20 | 3 | Soft |
| 38 12 974 | 15 18 023 | 10L | 19/06/2010 | 50 | 3 | Soft |
| 38 13 095 | 15 18 546 | 11M | 20/06/2010 | 50 | 3 | Soft |
| 38 12 750 | 15 18 512 | 12N | 20/06/2010 | 20 | 3 | Soft |
| 38 14 001 | 15 15 075 | 14P | 18/06/2010 | 20 | 3 | Soft |
| 38 14 000 | 15 15 130 | 16R | 18/06/2010 | 50 | 3 | Soft |
| 38 14 065 | 15 23 170 | W20 | 20/06/2010 | 20 | 3 | Soft |
| 38 14 393 | 15 23 200 | W50 | 20/06/2010 | 50 | 3 | Soft |
| 38 12 388 | 15 15 492 | Pillar1 | 13/09/2010 | 0.5, 6, 15 | 9 | Hard |
| 38 12 358 | 15 16 100 | Pillar2 | 28/09/2010 | 0.5, 6, 15 | 9 | Hard |
| 38 12 339 | 15 16 254 | Pillar2 | 14/09/2010 | 0.5, 6, 15 | 9 | Hard |

Chemical analyses were performed on lyophilized sediment samples. Trace elements (Al, Cd, Cr, Fe, Hg, Ni, Pb, Cu, Zn) were determined according to the United States Environmental Protection Agency (US EPA) methods (US EPA 3051A/2007; US EPA 6010C/2007; US-EPA Method 7010/2007; US-EPA Method 7473/2007). Limits of quantification of trace elements were 0.05 mg/kg dry weight (d.w.) for Al and 0.003 mg/kg d.w. for all other elements. Polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs) and hexachlorobenzene (HCB) were determined after extraction by the pressurized fluid extraction US-EPA 3545/A method (1996) using ASE 200 (Dionex®) instrument. Quantifications were performed as follows: *i*) PAHs were quantified by HPLC PDA/Fluorimeter (Waters); *ii*) PCBs were quantified by GC-FID/ECD (Clarus 200, PerkinElmer) according to the US-EPA method 8082A (2007); and *iii*) organochlorine pesticides and HCB were quantified by GC-FID/ECD (Clarus 200, PerkinElmer) according to the US-EPA method 8081B (2007). Results were expressed in mg/kg d.w. and were not recovery corrected. Limits of quantification of persistent organic pollutants were 0.001, 0.0001 and 0.0001 mg/kg d.w. for PAH single compounds, PCBs and OCPs, respectively.

Quality control and quality assurance analyses were performed using methodological blanks and standard reference materials (estuarine sediment SRM 1646a, Toronto Harbor sediment EC-4 and polychlorinated biphenyls in marine sediments HS-1). Limits of quantification were determined according to the Association of Analytical Communities (Shrivastava and Gupta, 2011) as the sum of mean concentration of the blank ($n = 10$) and 10 times the standard deviation of the blank, while the limit of blank was determined as the sum of mean of the blank ($n = 10$) and 1.645 times the standard deviation of the blank. For macrofaunal analysis, the samples were carefully washed in the laboratory and then hand-sorted under a stereomicroscope equipped with a micro-camera AxioCam Vs40 v4.8.20.

### 2.3. Data analysis

#### 2.3.1. Biodiversity

The macrobenthic community was characterized by the following diversity indices for each sampling station: species richness (S), Shannon–Wiener diversity index (H′) (Shannon and Weaver, 1963) and Pielou's evenness index (J). AMBI and M-AMBI indices were calculated using AMBI index software (version 4.0, available at www.azti.es). Species that are absent in the AMBI list were classified according to the literature and authors' knowledge on their ecological distribution. BOPA index and relative environmental quality were determined according to Dauvin and Ruellet's (2007) revised formula. Variations of BOPA index, given the limits of the AMBI, to assess EcoQ were calculated according to Dauvin and Ruellet (2007).

### 2.4. Statistical analysis

#### 2.4.1. Soft-bottom community

Univariate analysis by Pearson's correlation coefficient was performed to assess potential correlations between grain size and contaminant and grain size and heavy metals. For testing the most pertinent biotic indices in the Gulf of Milazzo, correlations between biotic indices AMBI, M-AMI and BOPA and trace elements and organic contaminants were also assessed.

Multivariate analyses were performed to assess potential correlations between the abundances of macrobenthic taxa and environmental variables (persistent organic pollutants (POPs) and trace elements concentration). Spatial pattern of macrobenthic community composition was assessed by using the Bray–Curtis similarity index (Bray and Curtis, 1957) on the square-root-transformed abundance matrix. Then, for the abiotic data, a similarity profile based on permutation was tested using the SIMPROF routine to group stations with similar (i.e. branch with $p > 0.05$) contaminant data. Groupings generated using the SIMPROF procedure were validated with a dissimilarity matrix based on the Euclidean distance, which was used in an agglomerative hierarchical clustering (routine CLUSTER). Differences between cluster groups were tested using permutation analysis of variance (PERMANOVA). The similarity percentage procedure (SIMPER) was used to identify the taxa that are most responsible for similarities and dissimilarities within and between clusters. A principal coordinates analysis (PCoA) was also performed to describe the contaminant data that most accounted for variation among the group identified by the SIMPROF procedure. The BIOENV procedure (BEST routine) was then applied to test the correlations between biotic and abiotic data.

Moreover, the relationships between the biodiversity indices (S, N and H′) and contaminant concentrations were investigated using the Pearson correlation test.

Statistical analyses were performed using the PRIMER6 & PERMANOVA+ software packages (Clarke and Warwick, 2001; Anderson et al., 2008).

#### 2.4.2. Hard-bottom community

The biodiversity indices (S, J and H′) were also calculated to describe the hard-bottom community. Moreover, PERMANOVA was performed to assess potential differences between the benthic community of the used (pillars 1 and 2) and nonused (pillar 3) refinery pillars. Abundance data were square-root transformed and analyzed on the basis of Gower distance using 4999 permutations. SIMPER test was performed to determine the contribution of each benthic category to average dissimilarity between groups.

## 3. Results

### 3.1. The abiotic environment: sediments and contaminants

Sandy silt sediments mainly characterized the study area; sands prevailed at 20 m, whilst silt prevailed at a depth of 50 m (Table 2). The highest percentages of sands were found at a depth of 20 m in the easternmost and innermost sites, with a general trend of increasing in the eastward direction. The silt fraction showed the highest percentages in the central sites at a depth of 50 m. A high percentage of pebble was locally found in site 5E at 50-m depth, outside the industrial complex. Results of chemical analysis (Table 2) showed the highest levels of PAHs in 3C and control 20. HCB showed the highest value in site 5E, while ΣPCBs in 8H. The highest DDT values were found in all stations at a depth of 20 m and in control 50. In general, trace element concentrations increased with increasing depth and decreasing grain size, except for Pb, which showed a peak in 1A. Significant positive

Please cite this article as: D'Alessandro, M., et al., Ecological assessment of a heavily human-stressed area in the Gulf of Milazzo, Central Mediterranean Sea: an integrated study of b..., Marine Pollution Bulletin (2016), http://dx.doi.org/10.1016/j.marpolbul.2016.01.021

**Table 2**
Values of trace elements, organic contaminants (mg/kg d.w.) and grain size (% d.w.).

| Site | Σ16PAH | ΣHCB | ΣDDT | ΣPCB | Fe | Cu | Al | Zn | Cr | Hg | Ni | Pb | Cd | Grain size % | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | Silt | Pebble | Gravel | Sand | Clay |
| 1A | 60.37 | 7.51 | 16.79 | 46.43 | 22,620.4 | 27.85 | 37,668.0 | 62.2 | 93.54 | 0.151 | 60.61 | 66.56 | 0.579 | 49.75 | 0.56 | 1.03 | 45.70 | 2.96 |
| 2B | 70.96 | 1.88 | 7.00 | 69.16 | 26,213.5 | 32.95 | 46,070.8 | 73.3 | 92.87 | 0.139 | 59.18 | 18.15 | 0.813 | 52.03 | 4.95 | 4.11 | 36.88 | 2.03 |
| 3C | 109.85 | 6.14 | 5.23 | 24.86 | 25,775.9 | 31.69 | 46,083.1 | 63.1 | 107.68 | 0.087 | 75.77 | 9.65 | 1.018 | 57.70 | 12.58 | 3.35 | 24.58 | 1.80 |
| 4D | <0.01 | 1.87 | 7.72 | 37.66 | 25,145.7 | 15.10 | 32,956.1 | 70.4 | 89.13 | 0.018 | 62.77 | 8.25 | 0.466 | 7.54 | 0.04 | 0.03 | 91.80 | 0.59 |
| 5E | <0.01 | 0.53 | 1.88 | 25.24 | 22,729.2 | 19.81 | 35,102.1 | 56.1 | 82.41 | 0.069 | 53.77 | 9.17 | 0.460 | 21.03 | 36.33 | 15.45 | 25.53 | 1.67 |
| 6F | 9.59 | 0.92 | 0.75 | 2.73 | 26,575.8 | 38.91 | 50,325.7 | 71.6 | 115.72 | 0.048 | 179.77 | 8.75 | 0.533 | 78.47 | <0.01 | <0.01 | 18.78 | 2.75 |
| 7G | 11.70 | 7.44 | 8.61 | 29.67 | 24,170.9 | 18.24 | 34,321.1 | 56.3 | 83.72 | 0.040 | 53.96 | 6.43 | 0.572 | 19.99 | <0.01 | <0.01 | 78.34 | 1.67 |
| 8H | 14.82 | 3.46 | 18.17 | 93.19 | 23,082.0 | 23.21 | 35,044.7 | 52.2 | 81.30 | 0.026 | 62.15 | 7.30 | 0.492 | 35.41 | <0.01 | 0.01 | 63.58 | 0.99 |
| 9I | 30.56 | 4.68 | 1.16 | 18.97 | 22,257.9 | 12.23 | 32,191.5 | 48.1 | 72.76 | 0.020 | 49.77 | 6.90 | 0.349 | 25.45 | <0.01 | <0.01 | 72.09 | 2.46 |
| 10L | <0.01 | 8.35 | 3.62 | 19.95 | 24,828.9 | 31.10 | 42,685.2 | 61.9 | 98.50 | <0.001 | 121.00 | 8.00 | 0.500 | 87.96 | <0.01 | <0.01 | 10.56 | 1.48 |
| 11M | 66.43 | 3.62 | 2.36 | 16.35 | 25,706.8 | 28.60 | 48,710.5 | 65.2 | 97.74 | 0.051 | 63.18 | 9.37 | 0.597 | 82.50 | <0.01 | 0.04 | 15.24 | 2.22 |
| 12N | 74.91 | 3.49 | 9.64 | 17.93 | 21,471.5 | 9.14 | 29,339.6 | 44.8 | 61.82 | 0.040 | 38.70 | 6.12 | 0.491 | 10.33 | 0.48 | 0.41 | 87.58 | 1.20 |
| 14P | 5.18 | 1.09 | 9.87 | 19.60 | 13,569.6 | 5.18 | 18,900.7 | 20.7 | 44.46 | 0.028 | 24.06 | 11.51 | 0.718 | 8.87 | 2.21 | 33.13 | 54.14 | 1.65 |
| 16R | 1.05 | 4.64 | 1.89 | 27.43 | 16,326.4 | 12.00 | 26,208.6 | 32.9 | 48.52 | 0.055 | 36.08 | 12.46 | 0.437 | 21.84 | 17.61 | 13.61 | 44.67 | 2.27 |
| W20 | 116.26 | 8.73 | 4.79 | 19.90 | 16,427.0 | 2.97 | 20,693.6 | 34.7 | 47.24 | 0.007 | 25.89 | 3.40 | 0.297 | <0.01 | <0.01 | 0.05 | 99.95 | <0.01 |
| W50 | 39.04 | 5.40 | 11.91 | 20.53 | 19,955.8 | 12.70 | 30,920.0 | 45.2 | 56.16 | 0.017 | 45.53 | 7.13 | 0.380 | 51.76 | 0.03 | 0.06 | 45.84 | 2.31 |

correlations ($p < 0.05$) were found between silt fraction and Fe, Cu, Al, Zn, Cr, Hg, Ni, Pb and Cd and between clay and Cu, Al, Hg and ΣPCBs; significant negative correlations ($p < 0.05$) were found between gravel and HCB, Fe, Al, Cr and Zn and between sand and Cu, Al, Cr, Hg, Ni and Cd. In general, trace element concentrations decreased in the following order: Al > Fe > Ni > Cr > Zn > Pb > Cu > Cd > Hg > As (Table 2).

## 3.2. The biotic environment

### 3.2.1. Soft-bottom community

A total of 2739 specimens, belonging to 246 taxa were found. The highest number of taxa (Annex 1) was recorded among class of Polychaeta (44.72%), followed by Mollusca (28.45%), Crustacea (23.58%), Echinodermata (2.03%) and Sipuncula (0.12%). The most abundant species were the molluscs *Timoclea ovata* (*N*% = 19.39), *Lucinella divaricata* (*N*% = 8.58), *Abra alba* (*N*% = 3.36) and the nonindigenous polychaete *Notomastus aberans* (*N*% = 2.88). Average values of the diversity indices for all sampling stations are reported in Table 3. Control 20 station recorded the highest value of species richness (S = 83) and the Shannon–Wiener diversity index (H′ = 3.0), whilst station 2B, with 19 identified taxa, recorded the lowest corresponding values (H′ = 1.1). The highest number of specimens was recorded in station 12N. Values of AMBI index ranged between 0.621 (2B) and 2.11 (5E). The software calculated a degree of disturbance 'Slight' for all stations, except for 12N, 3C, 2B and control 20, which showed 'Undisturbed' degree. M-AMBI ranged between 0.498 (3C) and 0.949 (control 20). The EcoQ resulted 'Good' for each station, except for control 20 and 5E, which showed 'High'. BOPA index showed the lowest value (0.0126) in station 4D, whilst the highest value (0.1040) in 8H. The calculation of EcoQ according the formula of Dauvin and Ruellet (2007) assigned a 'Good' status except for stations 2B, 14P, 16R, control 20, control 50 and 12N, where the EcoQ resulted 'High' (Table 3). (See Table 4.)

### 3.2.2. Hard-bottom community

A total of 670 specimens belonging to 84 taxa were found by scraping. Crustacean was the most represented (*N*% = 53.13), followed by molluscs (*N*% = 29.55) and polychaetes (*N*% = 17.31). The most abundant species was the Maeridae, *Elasmopus rapax* (*N*% = 29.55) (Annex 1). Two naturalized nonindigenous species, the Mytilidae, *Brachidontes pharaonis* (*N*% = 4.18) and the Ostreidae, *Crassostrea gigas* (*N*% = 0.75) were found (Annex 1). The highest values of species richness (S) and biodiversity index (H′) were recorded in P2, whilst P3 recorded the highest abundance of individuals (N).

## 3.3. Statistical analysis

### 3.3.1. Soft bottom

Concerning the relationships between macrobenthic abundances and contaminants, the similarity test based on SIMPROF analysis of contaminant data revealed three distinct groups (a, b and c) ($p < 0.01$) confirmed via hierarchical cluster analysis (Fig. 2). Their characterization is shown in Table 5.

The PCO1 axis (Fig. 2) accounted for 97.6% of the total observed variation and clearly separated the three groups. PCO2 axis gathered 2.4%

**Table 3**
Values of biodiversity (S, N, J′ and H′), biotic indices (AMBI, M-AMBI and BOPA) and corresponding disturbance/EcoQ values of soft-bottom sites.

| Site | S | N | J′ | H′ | AMBI | Disturbance | M-AMBI | EcoQ | BOPA | EcoQ |
|---|---|---|---|---|---|---|---|---|---|---|
| 1A | 58 | 37 | 0.9 | 2.9 | 1.634 | Slight | 0.83773 | Good | 0.0963 | High |
| 2B | 19 | 12 | 0.7 | 1.1 | 0.622 | Undisturbed | 0.64043 | Good | 0.0223 | Good |
| 3C | 35 | 23 | 0.9 | 2.3 | 1.143 | Undisturbed | 0.498 | Good | 0.0482 | High |
| 4D | 42 | 90 | 0.7 | 1.9 | 1.892 | Slight | 0.66255 | Good | 0.0126 | High |
| 5E | 73 | 67 | 0.9 | 3.0 | 1.228 | Slight | 0.88981 | High | 0.0532 | High |
| 6F | 56 | 52 | 0.9 | 2.9 | 2.011 | Slight | 0.78613 | Good | 0.0801 | High |
| 7G | 47 | 83 | 0.8 | 2.4 | 1.168 | Slight | 0.528472 | Good | 0.0748 | High |
| 8H | 32 | 39 | 0.9 | 2.2 | 1.792 | Slight | 0.65347 | Good | 0.1040 | High |
| 9I | 46 | 66 | 0.9 | 2.5 | 1.738 | Slight | 0.73971 | Good | 0.0643 | High |
| 10L | 56 | 60 | 0.9 | 2.7 | 1.739 | Slight | 0.80453 | Good | 0.0802 | High |
| 11M | 43 | 44 | 0.9 | 2.3 | 1.844 | Slight | 0.72903 | Good | 0.0687 | High |
| 12N | 53 | 162 | 0.6 | 2.0 | 0.487 | Undisturbed | 0.74471 | Good | 0.0214 | High |
| 14P | 57 | 38 | 0.9 | 2.9 | 1.353 | Slight | 0.84761 | Good | 0.0461 | Good |
| 16R | 30 | 18 | 0.9 | 2.1 | 1.296 | Slight | 0.67817 | Good | 0.0620 | Good |
| Control 20 | 83 | 100 | 0.9 | 3.0 | 1.199 | Undisturbed | 0.94976 | High | 0.0245 | Good |
| Control 50 | 29 | 22 | 0.9 | 2.1 | 1.235 | Slight | 0.67905 | Good | 0.0247 | Good |

Please cite this article as: D'Alessandro, M., et al., Ecological assessment of a heavily human-stressed area in the Gulf of Milazzo, Central Mediterranean Sea: an integrated study of b..., Marine Pollution Bulletin (2016), http://dx.doi.org/10.1016/j.marpolbul.2016.01.021

**Table 4**
Values of biodiversity (S, N, J′ and H′) of hard-bottom sites.

| Site | S | N | J′ | H′ |
|---|---|---|---|---|
| pillar1 (1–1) | 22 | 25.5 | 0.9350 | 2.306 |
| pillar1 (1–2) | 18 | 41.0 | 0.8615 | 2.204 |
| pillar1 (2–1) | 16 | 12.5 | 0.9705 | 1.756 |
| pillar1 (2–2) | 7 | 13.0 | 0.9479 | 1.845 |
| pillar1 (3–1) | 7 | 4.0 | 0.9732 | 1.213 |
| pillar1 (3–2) | 18 | 15.0 | 0.9321 | 2.110 |
| pillar2 (1–1) | 10 | 22.0 | 0.7513 | 1.398 |
| pillar2 (1–2) | 14 | 26.0 | 0.8047 | 1.6975 |
| pillar2 (2–1) | 22 | 13.5 | 0.9734 | 2.3125 |
| pillar2 (2–2) | 15 | 11.5 | 0.9300 | 1.5258 |
| pillar2 (3–1) | 7 | 5.0 | 0.9359 | 0.8385 |
| pillar2 (3–2) | 23 | 20.0 | 0.9419 | 2.3665 |
| pillar3 (1–1) | 22 | 47.5 | 0.8634 | 2.248 |
| pillar3 (1–2) | 20 | 29.0 | 0.8740 | 2.1245 |
| pillar3 (2–1) | 13 | 15.5 | 0.7984 | 1.4793 |
| pillar3 (2–2) | 22 | 26.0 | 0.8511 | 2.049 |
| pillar3 (3–1) | 8 | 5.5 | 0.9878 | 1.567 |
| pillar3 (3–2) | 9 | 9.0 | 0.8166 | 1.2822 |

of the total variation. The superimposed vectors showed three sets of contaminants, each associated with one of the group.

Group ‘a’ included almost all sampling stations located at a depth of 50 m (2B, 3C, 6F, 10L, 11M) and characterized by the highest concentration of trace elements and ΣPAHs (Fig. 2; Table 5). This group comprised 148 macrobenthic species, 34 of which were exclusively found in the sampling stations (Fig. 3). The most characteristic species of this group were *Arabella iricolor, Magelona minuta, Lumbrineris latreilli, N. aberans* and *Pseudoleiocapitella fauveli*. Group ‘b’ comprised almost all sampling stations located at a depth of 20 m (1A, 4D, 5E, 7G, 8H, 9I and 12N) and the control at 50 m depth (control 50), and recorded the highest concentrations of ΣDDT and ΣPCB (Fig. 3; Table 5) and the highest number of identified species (169), 46 of which were exclusive of this group. In this group, the following characteristic species were found: *T. ovata*, *A. alba*, *Micronephthys stammeri*, *Aricidea (Aricidea) pseudoarticulata* and *Cossura sp*. Finally, group ‘c’ included only three sampling stations (14P, 16R and control 20) characterized by the lowest value of contaminant concentrations, except for HCB, which recorded the highest value and the lowest number of macrobenthic species (122). The characteristic species of the group were *T. ovata, Aponuphis bilineata, L. divaricata, Goniada maculate* and *Scoloplos (Scoloplos) armiger*.

The BEST analysis, implemented through the BIOENV protocol, revealed no significant correlation between contaminant concentrations and spatial distribution of macrobenthic fauna within the sampling stations. Results of Pearson test evidenced a significant negative correlation between the concentration of ΣPCBs and specific richness ($p < 0.10$). No other significant correlation was found among contaminant concentrations and biodiversity indices.

### 3.3.2. Hard bottom

Results of PERMANOVA evidenced no significant differences between benthic communities of used and disused pillars.

## 4. Discussion

Because of the link between coastal cities and seas, coastlines have often been subjected to heavy anthropogenic pressure, causing pollution of water and sediments (Estacio et al., 1997; Adami et al., 2000; Fadeeva et al., 2003). Sediments represent one of the ultimate sinks for the discharge of heavy metals into the environment (Gibbs, 1977; Luoma and Bryan, 1981; Bettinetti et al., 2003). The background concentration of hazardous substances in sediments is an important factor for evaluating the degree of contamination. Pollutants are discharged into the environment by both anthropogenic activities and natural processes, such as weathering of rocks and volcanic activities, which play a significant role in enriching the reservoirs with heavy metals (Nriagu, 1989; Veena et al., 1997). Streams are also among the main source of environmental pollutants (Alexander et al., 2000; Alam and Pathak, 2010), which is also confirmed by our data. This study shows the presence of some hotspots of metals and contaminants near mouths, testifying their unnatural role of waste receptacle (Humborg et al., 1997). Another factor responsible for contaminant accumulation is grain size of the sediment, which, in the Gulf of Milazzo, is mostly represented by fine sediment (Pepe et al., 2010) that is mainly subject to absorption of pollutants and heavy metals (Salomons and Stigliani, 2012; Farkas et al., 2007). In particular, this study shows an increase of mud fraction

**Table 5**
Affinity group according to relationships between macrobenthic abundances and contaminants.

| | Affinity group | a | b | c |
|---|---|---|---|---|
| Trace elements | Al (mg/kg d.w.) | 46,775.06 | 33,442.89 | 21,934.30 |
| | Fe (mg/kg d.w.) | 25,820.18 | 22,679.18 | 15,441.00 |
| | Zn (mg/kg d.w.) | 67.02 | 54.41 | 29.43 |
| | Cr (mg/kg d.w.) | 102.50 | 77.61 | 46.74 |
| | Ni (mg/kg d.w.) | 99.78 | 53.41 | 28.68 |
| | Pb (mg/kg d.w.) | 10.78 | 14.73 | 9.12 |
| | Cu (mg/kg d.w.) | 32.65 | 17.29 | 6.72 |
| | Cd (mg/kg d.w.) | 0.69 | 0.47 | 0.48 |
| | Hg (mg/kg d.w.) | 0.08 | 0.05 | 0.03 |
| Persistent contaminants | Σ16PAH (mg/g d.w.) | 64.21 | 38.57 | 40.83 |
| | ΣHCB (mg/g d.w.) | 4.18 | 4.30 | 4.82 |
| | ΣDDT (mg/g d.w.) | 3.79 | 9.49 | 5.52 |
| | ΣPCB (mg/g d.w.) | 26.61 | 36.20 | 22.31 |
| Sediment characteristics | Pebble (%) | 3.51 | 4.68 | 6.61 |
| | Gravel (%) | 1.50 | 2.12 | 15.60 |
| | Sand (%) | 21.21 | 63.81 | 66.25 |
| | Silt (%) | 71.73 | 27.66 | 10.24 |
| | Clay (%) | 2.06 | 1.73 | 1.31 |
| | Median (Φ) | 5.28 | 3.10 | 1.52 |
| | Depth (m) | 50.00 | 27.50 | 30.00 |
| Biotic characteristics | Total species richness | 148 | 169 | 122 |
| | N. of exclusive species | 34 | 46 | 34 |
| | Most characteristic species (>40% similarity) | *Arabella iricolor*<br>*Magelona minuta*<br>*Lumbrineris latreilli*<br>*Notomastus aberans*<br>*Pseudoleiocapitella fauveli* | *Timoclea ovata*<br>*Abra alba*<br>*Micronephthys stammeri*<br>*Aricidea (Aricidea) pseudoarticulata*<br>*Cossura sp.* | *Timoclea ovata*<br>*Aponuphis bilineata*<br>*Lucinella divaricata*<br>*Goniada maculata*<br>*Scoloplos (Scoloplos) armiger* |

Please cite this article as: D'Alessandro, M., et al., Ecological assessment of a heavily human-stressed area in the Gulf of Milazzo, Central Mediterranean Sea: an integrated study of b..., Marine Pollution Bulletin (2016), http://dx.doi.org/10.1016/j.marpolbul.2016.01.021

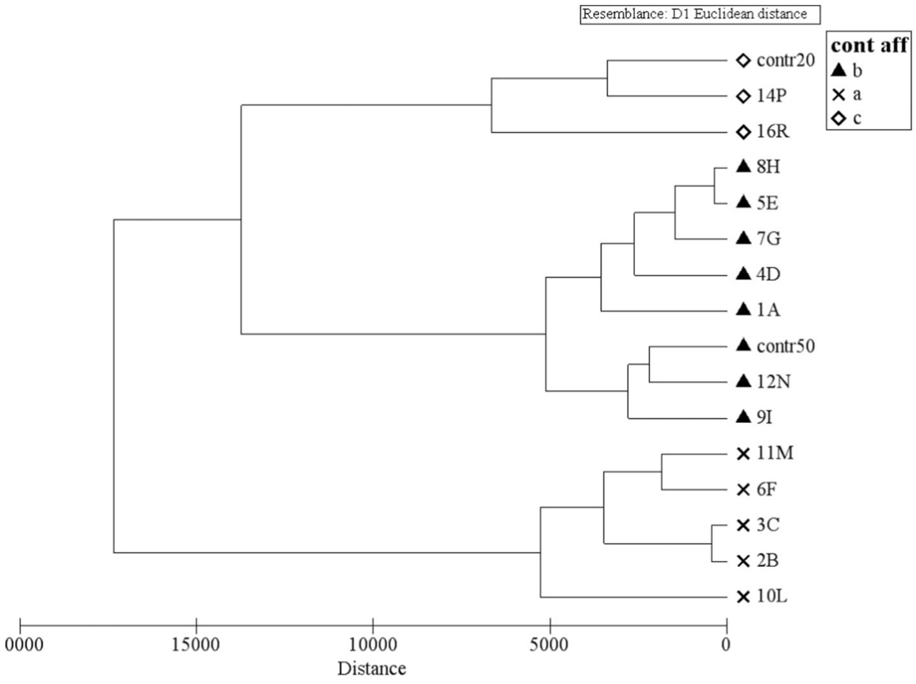


**Fig. 2.** Spatial distribution of three affinity groups along the study area.

westwards, reaching the maximum in front of the harbor and close to the crude oil refinery, which also represented the area in which some of the contaminant values are slighter higher than those in other sites. Nevertheless, values of trace metals and metals recorded in this study showed low levels of contamination according to regulations of reference (Annex 5 to Part IV of Legislative Decree no. 3 April 2006, n. 152; Annex A of DM 367/2003).

Human activities along the Gulf are responsible for the accumulation of pollutants in sediments and interstitial water within them. Several pollutants tend to accumulate in sediments and biota, because of their low water solubility and persistence, affecting the marine ecological health (Romeo et al., 2015). This is also confirmed by this study, which shows the highest negative effect of ΣPCBs on species richness of the invertebrates' community. In addition, the high concentration of anthropogenic activities in this study testifies that Milazzo values of pollution are lower than other areas of the Mediterranean Sea, such as Cogoleto (Bertolotto et al., 2003), Trieste (Notar et al., 2001), Napoli (Sprovieri et al., 2007) and Bagnoli (Romano et al., 2004). In general, the values of organic contaminants and trace elements found along the area of study showed no substantial difference between the heavily anthropized area and control site. The latter, in fact, even if placed at a higher distance from the heaviest human activities, appears to be influenced by small coastal activities such as fishing and agriculture. No difference was recorded also among the values of biodiversity between used and disused pillars.

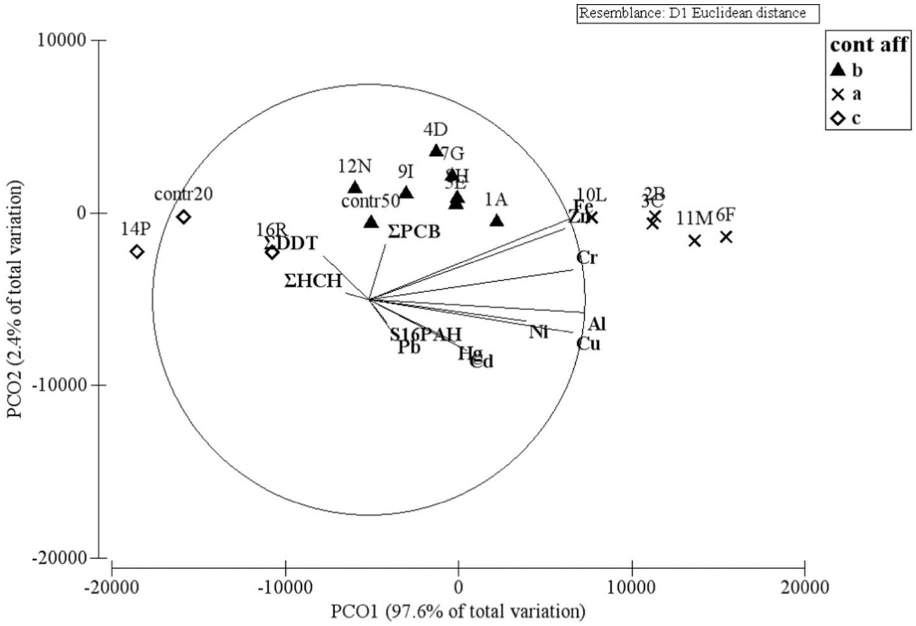


**Fig. 3.** Cluster analysis (A) and principal coordinates analysis (PCoA) based on the abundance community with the representation of affinity groups, superimposing the environmental factors (B) and species abundance (right-hand side of B).

Please cite this article as: D'Alessandro, M., et al., Ecological assessment of a heavily human-stressed area in the Gulf of Milazzo, Central Mediterranean Sea: an integrated study of b..., Marine Pollution Bulletin (2016), http://dx.doi.org/10.1016/j.marpolbul.2016.01.021

The structure of macrobenthos community-recognized indicator currently used for the assessment of EcoQ (Goodnight, 1973; Borja et al., 2000; Hilty and Merenlender, 2000; Klemm et al., 2002) seems to not underline evident signs of stress. This is also confirmed by statistical analysis, which subdivided the area of study into three groups, each characterized by species with different ecological values, testifying a well-structured community (Pearson and Rosenberg, 1987; Borja et al., 2000). Most abundant species found in soft-bottom samples (*T. ovata, L. divaricata*) are considered by Borja et al. (2000) as 'very sensitive organism' to organic enrichment, typical of under unpolluted status. However, the presence of three nonindigenous species (*N. aberans, B. paraonis* and *C. gigas*) and two first records of polychaetes (*M. stammeri* and *Nicomache lumbricalis*) testify the particular environmental status of harbors. These areas, in fact, play a role as hotspots for marine species invasions, because of both a direct link with human activities (shipping and tourism) and instability of these particular environments that facilitate the advantage of opportunistic and alien species (Occhipinti-Ambrogi et al., 2011; D'Alessandro et al., 2015). Although several studies reported a close relationship between benthic communities and level of pollutants (Simboura et al., 2000; Gray and Elliott, 2009; Martins et al., 2013a,b), such a relationship was not found in this study. This may be underlined as a generalized homogeneous environmental condition without an evident site of stress.

The indices of biodiversity calculated in the Gulf of Milazzo showed values higher than other Mediterranean harbors with similar human activities, such as Genoa Voltri, Portosole, Marina degli Aregai (Moreno et al., 2008), Trieste (Afli et al., 2009) and Taranto (Maiorano et al., 2011). In this study, the applicability of three most common indices used in coastal and estuarine waters: AMBI, M-AMBI and BOPA (Muxika et al., 2005; Dauvin and Ruellet, 2007; Borja et al., 2009) is examined. Calculation of biotic index showed elevated levels of EcoQ, which ranged between Slight–Undisturbed of AMBI and Good–High of M-AMBI and BOPA. These data confirm that the heavily anthropized marine invertebrates do no seem to be subjected to this type of pollution. By Pearson correlation between benthic indices versus trace elements and benthic indices versus organic contaminant, M-AMBI index seems to be the one with highest applicability to the environment of the Gulf of Milazzo. The correlation between pollutants and benthic community has also been affirmed by several studies that show sediments as contaminants that affect several levels of biological organization of benthos community (Luoma and Phillips, 1988; Shoults-Wilson et al., 2015; Signa et al., 2015).

## 5. Conclusions

The complexity of ecological systems influenced by human activities makes necessary the use of a multidisciplinary approach to accurately evaluate environmental status. Despite the presence of several human activities, our analysis testifies that the environment does not seem to show accentuate signs of stress. This study is the first of its kind to present a list of macro-invertebrate communities of the Gulf of Milazzo. This study is also recognized as the first multidisciplinary study conducted in the heavily human-stressed area of the Gulf of Milazzo. According to the results obtained, further studies are needed to reevaluate the limits of extension of the currently assigned SIN (site of national interest) zone of the Milazzo site, redimensioning the extension of the marine area, which seems to be the sector that is influenced lesser than the terrestrial and aerial environments by human activities.

## Appendix Annex 1. Faunistical list of species found in hard and soft bottoms

| | 7G | 5E | 3C | 4D | 2B | 1A | 16R | 14P | 6F | 8H | 10L | 9I | c50 | c20 | 11M | 12N | P1 | P2 | P3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Crustacea | | | | | | | | | | | | | | | | | | | |
| Leptocheliidae | | | | | | | | | | | | | | | | | | | |
| *Leptochelia savignyi* | | | | | | 3 | | 1 | | | | | | | | | | | |
| *Leptocheliidae* | | | | | | | | | | | | | | | | | 4 | 1 | 2 |
| Eriphiidae | | | | | | | | | | | | | | | | | | | |
| *Eualus pusiolus* | | | | | | | | | | | | | | | | | | | 1 |
| *Eualus occultus* | | | | | | | | | | | | | | | | | | 3 | |
| *Eualus cranchii* | | | | | | | | | | | | | | | | | 7 | 1 | 4 |
| Stenothoidae | | | | | | | | | | | | | | | | | | | |
| *Stenothoe elachista* | | | | | | | | | | | | | | | | | 16 | 10 | 15 |
| *Stenothoe eduardi* | | | | | | | | | | | | | | | | | | 1 | |
| *Stenothoe gallensis* | | | | | | | | | | | | | | | | | 2 | 2 | 3 |
| *Stenothoe tergestina* | | | | | | | | | | | | | | | | | 1 | | |
| *Stenothoe valida* | | | | | | | | | | | | | | | | | 3 | | 4 |
| *Stenothoe sp* | | | | | | | | | | | | | | | | | | | |
| Maeridae | | | | | | | | | | | | | | | | | | | |
| *Elasmopus affinis* | | | | | | | | | | | | | | | | | | | 2 |
| *Elasmopus brasiliensis* | | | | | | | | | | | | | | | | | 1 | | |
| *Elasmopus pectenicrus* | | | | | | | | | | | | | | | | | 2 | | |
| *Elasmopus rapax* | | | | | | | | | | | | | | | | | 29 | 8 | 33 |
| *Maerella tenuimana* | | | | | | | | | | | | | | | | | | 1 | |
| Ischyroceridae | | | | | | | | | | | | | | | | | | | |
| *Ericthonius punctatus* | | | | | | | | | | | | | | | | | 2 | 3 | 16 |
| *Jassa marmorata* | | | | | | | | | | | | | | | | | | 1 | |
| Apseudidae | | | | | | | | | | | | | | | | | | | |
| *Apseudes spinosus* | 3 | | | 1 | | | | | | | | 1 | | 1 | | | | | |
| *Apseudes latreillei* | | | | 9 | | 2 | | | | | | | | 1 | | | | | |
| Xantidae | | | | | | | | | | | | | | | | | | | |

(continued on next page)

Please cite this article as: D'Alessandro, M., et al., Ecological assessment of a heavily human-stressed area in the Gulf of Milazzo, Central Mediterranean Sea: an integrated study of b..., Marine Pollution Bulletin (2016), http://dx.doi.org/10.1016/j.marpolbul.2016.01.021

(*continued*)

| | 7G | 5E | 3C | 4D | 2B | 1A | 16R | 14P | 6F | 8H | 10L | 9I | c50 | c20 | 11M | 12N | P1 | P2 | P3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Paractaea monodi* | | | | | | | | | | | | | | | | | 2 | | 1 |
| Paguridae | | | | | | | | | | | | | | | | | | | |
| *Pagurus bernhardus* | | | | | | | | | | | | | | | | | 5 | 3 | 5 |
| Galatheidae | | | | | | | | | | | | | | | | | | | |
| *Galathea strigosa* | | | | | | | | | | | | | | | | | 1 | 1 | |
| Anthuridae | | | | | | | | | | | | | | | | | | | |
| *Anthura gracilis* | 4 | | | 1 | | | | | | | | | | 3 | | 7 | | | 1 |
| *Isopoda sp.* | | | | | | | | | | | | | | | | | | 1 | |
| Pilumnidae | | | | | | | | | | | | | | | | | | | |
| *Pilumnus hirtellus* | | | | | | | | | | | | | | | | | 10 | 3 | 26 |
| *Pilumnus villosissimus* | | | | | | | | | | | | | | | | | 1 | | |
| Epialtidae | | | | | | | | | | | | | | | | | | | |
| *Acanthonyx lunulatus* | | | | | | | | | | | | | | | | | 6 | | 1 |
| Grapsidae | | | | | | | | | | | | | | | | | | | |
| *Pachygrapsus marmoratus* | | | | | | | | | | | | | | | | | 1 | | |
| Gnathiidae | | | | | | | | | | | | | | | | | | | |
| *Gnathia phallonajopsis* | | | | | | | | | 4 | | 3 | | | | | | | | |
| *Gnathia dentata* | | | | | | | | | | | 1 | | | | 11 | | | | |
| Cirolanidae | | | | | | | | | | | | | | | | | | | |
| *Cirolanidae* | | | | | | | 1 | | | | | | | | | | | | |
| *Eurydice pulchra* | | | | | 1 | | | | | | | | | | | | | | |
| Mysidacea | | | | | | | | | | | | | | | | | | | |
| *Mysidacea* | | | | | | | | | | | | | | 2 | | | | 1 | |
| Dyastilidae | | | | | | | | | | | | | | | | | | | |
| *Diastylis* | | 4 | | | | | | | | | | | | | | | | | |
| *Diastylis rugosa* | | 1 | | | | | | | | | | | | | | | | | |
| *Dyastilidae* | | | | 3 | | | | | | | | | | | | | | | |
| Bodotridae | | | | | | | | | | | | | | | | | | | |
| *Bodotridae* | | 1 | | | | | | | | | | | | | | | | | |
| *Iphinoe sp* | 3 | 2 | | | | 1 | | | | | 1 | | | | 2 | | | | |
| *Cumacea* | | | 1 | | | | | | 1 | | 3 | | | 7 | | | | | |
| Corophiidae | | | | | | | | | | | | | | | | | | | |
| *Corophium aculeatum* | | | | | | | | | 2 | | | | | 3 | | | | | |
| *Apocorophium acutum* | | | | | | | | | | | | | | | | | | | 3 |
| *Ampithoe ramondi* | | | | | | | | | | | | | | | | | | | 1 |
| *Corophium rotundirostre* | | | | | | | | | | | 1 | | | | 2 | | | | |
| Atylidae | | | | | | | | | | | | | | | | | | | |
| *Nototropis guttatus* | | | | | | | | | | | | | | | | | | 1 | 1 |
| Gammaridae | | | | | | | | | | | | | | | | | | | |
| *Cheirocratus sundevalli* | | | | | | | 1 | | | | | | | | | | | | |
| Leucothoidae | | | | | | | | | | | | | | | | | | | |
| *Leucothoe serraticarpa* | 1 | | | | | | | | | | 1 | 1 | | 1 | | 1 | | | |
| Leucothoidae | | | | | | | | | | | | | | | | | | | |
| *Leucothoe spinicarpa* | | | | | | | | | | | | | | | | | 1 | 1 | 6 |
| *Leucothoe venetiarum* | | | | | | | | | | | | | | | | | | 1 | |
| *Leucothoe oboa* | | 1 | | | | | | | | | | | | | 1 | | | | |
| Ampeliscidae | | | | | | | | | | | | | | | | | | | |
| *Ampelisca typica* | | | | | | | | | | | | | | | | 1 | | | |
| *Ampelisca multispinosa* | | 1 | | | | | | | | | | | | | | | | | |
| *Ampelisca tenuicornis* | 1 | | | | | | | | 1 | | 2 | | | 2 | 5 | | | | |
| *Ampelisca pseudosarsi* | | | | | | | | | | | | | 2 | 1 | | | | | |
| *Ampelisca sarsi* | | | | | | | | | | | 2 | | | 2 | | | | | |
| *Ampelisca brevicornis* | | | | | | | | | | | | | | 4 | | | | | |
| *Ampelisca sp* | 1 | | | | | | | | | | | | | | | | | | |
| Aoridae | | | | | | | | | | | | | | | | | | | |
| *Leptocheirus pectinatus* | 1 | | | | | | 3 | | | | 5 | | | | 1 | | | | |
| *Leptocheirus mariae* | | | 1 | | | 1 | | | | | | 1 | | | 4 | 1 | | | |
| *Aora gracilis* | | | | | | | | 1 | | | | | | | | | | | |
| *Lembos spiniventris* | | | | 1 | | 2 | | | | | | | | 2 | | | | | |
| Lysianassidae | | | | | | | | | | | | | | | | | | | |
| *Pardia punctata* | | | | | | | 1 | 1 | | | | | | 1 | | | | | |
| *Lepidecreum longicorne* | | | | | | | | | | | | | | 1 | | | | | |
| *Hippomedon massiliensis* | | 1 | | | | | | | | | | | | 2 | | | | | |
| Phoxocephalidae | | | | | | | | | | | | | | | | | | | |
| *Phoxocephalidae* | | | 2 | | 2 | 1 | | | 10 | | 12 | | | | 5 | | | | |
| Oedicerotidae | | | | | | | | | | | | | | | | | | | |
| *Perioculodes longimanus* | | | 1 | | | | | | | | 6 | | | 14 | | | | | |
| *Synchelidium haplocheles* | | | | | | | 1 | | | | | | | | | | | | |
| Haustoriidae | | | | | | | | | | | | | | | | | | | |
| *Urothoe pulchella* | | | | | | | | | | | | | | 7 | | | | | |
| *Urothoe grimaldii* | | | | | | | | | | | | | | 2 | | | | | |
| Pontoporeiidae | | | | | | | | | | | | | | | | | | | |
| *Bathyporeia phaiophthalma* | | | | | | | | | | | | | | 3 | | | | | |
| Caprellidae | | | | | | | | | | | | | | | | | | | |
| *Phtisica marina* | | | | | | | | | | | | | | 1 | | | | | |

Please cite this article as: D'Alessandro, M., et al., Ecological assessment of a heavily human-stressed area in the Gulf of Milazzo, Central Mediterranean Sea: an integrated study of b..., Marine Pollution Bulletin (2016), http://dx.doi.org/10.1016/j.marpolbul.2016.01.021

(*continued*)

| | 7G | 5E | 3C | 4D | 2B | 1A | 16R | 14P | 6F | 8H | 10L | 9I | c50 | c20 | 11M | 12N | P1 | P2 | P3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Pseudoprotella phasma* | | | | | | | | | | | | | | | | | 1 | | 1 |
| *Caprellidae* | | | | | | | | | | | | | | | | | | 1 | 1 |
| Photidae | | | | | | | | | | | | | | | | | | | |
| *Photis longicauda* | 3 | | | | | | | | | | | 1 | | 22 | 1 | | | | |
| *Photis longipes* | | | | 2 | | | | | | | | | | 8 | | | | | |
| Crangonidae | | | | | | | | | | | | | | | | | | | |
| *Philocheras trispinosus* | | | | | | | | | | | | | | 1 | | | | | |
| Processidae | | | | | | | | | | | | | | | | | | | |
| *Processa edulis* | | | | | | 1 | | | | | 1 | 1 | 1 | | | | 1 | | |
| Penaeidae | | | | | | | | | | | | | | | | | | | |
| *Parapenaeus longirostris* | | | 1 | | | | | | | | | | | | | | | | |
| Alpheidae | | | | | | | | | | | | | | | | | | | |
| *Alpheus glaber* | | | | | | | | | 1 | | 1 | | | | | | 15 | | 12 |
| *Alpheus macrocheles* | | | | | | | | | | | | | | | | | 2 | 6 | 6 |
| *Athanas nitescens* | | | | | | | | | | | | | | | | | 2 | 5 | 3 |
| *Synalpheus gambarelloides* | | | | | | | | | | | | | | | | | 2 | | 2 |
| *Eriphia verrucosa* | | | | | | | | | | | | | | | | | 2 | 1 | 4 |
| Goneplacidae | | | | | | | | | | | | | | | | | | | |
| *Goneplax rhomboides* | | | 1 | 12 | | | | | | | 3 | | | | 1 | | | | |
| Polybiidae | | | | | | | | | | | | | | | | | | | |
| *Liocarcinus maculatus* | | | | | | | | | | | | | | | | 1 | | | |
| Inachidae | | | | | | | | | | | | | | | | | | | |
| *Achaeus gracilis* | | | | | | 1 | | | | | | | | | | | | | |
| Callianassidae | | | | | | | | | | | | | | | | | | | |
| *Callinassa sp.* | | | | | | | | | | | | | | 1 | | | | | |
| *Callianassa truncata* | | | | 12 | | | | | | | | | | 2 | | | | | |
| Upogebiidae | | | | | | | | | | | | | | | | | | | |
| *Upogebia tipica* | | | | | | | | | 2 | | | | | | | | | | |
| Paguridea | | | | | | | | | | | | | | | | | | | |
| *Anapagurus petiti* | | 1 | | | | | 2 | | | | | | | 1 | 1 | | | | |
| Diogenidae | | | | | | | | | | | | | | | | | | | |
| *Clibanarius erythropus* | | | | | | | 2 | 2 | | | | | | | | | | | |
| Stomatopoda | | | | | | | | | | | 1 | | | | | | | | |
| Copepoda | | | | | | | | | 1 | | | | | 1 | | | | | |
| Ostracoda | | | | | | | | | | | | | | 2 | | | | | |
| Amphiuridae | | | | | | | | | | | | | | | | | | | |
| Echinodermata | | | | | | | | | | | | | | | | | | | |
| *Amphiura chiajei* | 1 | 2 | | | 2 | 1 | | 1 | 2 | | | | 1 | | 1 | 1 | | | |
| *Amphiura filiformis* | | 2 | 1 | | | | | | 2 | | 1 | 3 | 3 | 1 | 1 | | | | |
| Ophiuridae | | | | | | | | | | | | | | | | | | | |
| *Ophiura ophiura* | | | | | | 1 | | 1 | | | | | | | 1 | | | | |
| Astropectinidae | | | | | | | | | | | | | | | | | | | |
| *Astropecten irregularis* | | | | | | 1 | | | | | | | | 1 | | | | | |
| Synaptidae | | | | | | | | | | | | | | | | | | | |
| *Labidoplax digitata* | | | 1 | | | | | | | | 6 | | | 1 | | 1 | | | |
| Caecidae | | | | | | | | | | | | | | | | | | | |
| *Caecum trachea* | 1 | | | | | | | | | | | | | | | | | | |
| Chamidae | | | | | | | | | | | | | | | | | | | |
| *Chama gryphoides* | | | | | | | | | | | | | | | | | 2 | 3 | 5 |
| Haminoeidae | | | | | | | | | | | | | | | | | | | |
| *Atys rochii* | 1 | | | | | | | | | | | | | | | | | | |
| Calyptraeidae | | | | | | | | | | | | | | | | | | | |
| *Caliptraea chinensis* | | 1 | | | | | | | | | | | | | | | | | |
| Iravadiidae | | | | | | | | | | | | | | | | | | | |
| *Hyala vitrea* | | | | | | | | | | | | | | | 1 | | | | |
| Naticidae | | | | | | | | | | | | | | | | | | | |
| *Tectonatica sagraiana* | | 1 | | | | | | | | 1 | | 1 | | | | | | | |
| *Euspira pulchella* | 1 | | | | | | | 1 | | | | | | | | | | | |
| Eulimidae | | | | | | | | | | | | | | | | | | | |
| *Nanobalcis nana* | | | | | | 1 | | | | | | | | | | | | | |
| Mangeliidae | | | | | | | | | | | | | | | | | | | |
| *Bela nebulosa* | 1 | | | | | | | | | | | | | | | | | | |
| Skeneinae | | | | | | | | | | | | | | | | | | | |
| *Dikoleps nitens* | | | | | | | | | | | | | | 1 | | | | | |
| Nassariidae | | | | | | | | | | | | | | | | | | | |
| *Nassarius mutabilis* | | | | | | | | | | | | | | 1 | | | | | |
| Rissoidae | | | | | | | | | | | | | | | | | | | |
| *Peringiella elegans* | | | | | | | | | | | 6 | 1 | | | | | | | |
| Haminoeidae | | | | | | | | | | | | | | | | | | | |
| *Weinkauffia turgidula* | | | | | | | | 1 | | | | | | | | 1 | | | |
| Pyramidellidae | | | | | | | | | | | | | | | | | | | |
| *Odostomia conoidea* | | | | | | | | | | | | | | | | 1 | | | |
| *Eulimella turris* | 2 | | | | | | | | | | | | | | 3 | | | | |
| *Chrysallida flexuosa* | | | | | | | | 1 | | | | | | | | | | | |

(*continued on next page*)

Please cite this article as: D'Alessandro, M., et al., Ecological assessment of a heavily human-stressed area in the Gulf of Milazzo, Central Mediterranean Sea: an integrated study of b..., Marine Pollution Bulletin (2016), http://dx.doi.org/10.1016/j.marpolbul.2016.01.021

(*continued*)

| | 7G | 5E | 3C | 4D | 2B | 1A | 16R | 14P | 6F | 8H | 10L | 9I | c50 | c20 | 11M | 12N | P1 | P2 | P3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Turbonilla acuta* | 1 | | | | | | | | | | | | | | | | | | |
| Retusidae | | | | | | | | | | | | | | | | | | | |
| *Retusa mammillata* | | | | 1 | | | | | | | 1 | 1 | | | | 1 | | | |
| *Cylichnina nitidula* | | | | | | | | | | | | | | | | 1 | | | |
| *Retusa leptoeneilema* | 3 | | | | | | | | | | | | | | | | | | |
| Cylichnidae | | | | | | | | | | | | | | | | | | | |
| *Cylichna crossei* | | | | | | | | | | | | | | 1 | | | | | |
| Ringiculidae | | | | | | | | | | | | | | | | | | | |
| *Ringicula conformis* | | | | | | | | | | | | | | | | 1 | | | |
| Philinidae | | | | | | | | | | | | | | | | | | | |
| *Philine scabra* | | | | | | | | | | | 1 | | | | | | | | |
| *Philine aperta* | 7 | 2 | | | | | | | | | | 2 | | 1 | | 1 | | | |
| Spondylidae | | | | | | | | | | | | | | | | | | | |
| *Spondylus gaederopus* | | | | | | | | | | | | | | | | | 2 | 1 | |
| Cerithiidae | | | | | | | | | | | | | | | | | | | |
| *Bittium latreillii* | | | | | | | | | | | | | | | | | | 9 | 11 |
| Littorinidae | | | | | | | | | | | | | | | | | | | |
| *Littoraria intermedia* | | | | | | | | | | | | | | | | | | 1 | |
| Patellidae | | | | | | | | | | | | | | | | | | | |
| *Patella caerulea* | | | | | | | | | | | | | | | | | | 7 | |
| Ostreidae | | | | | | | | | | | | | | | | | | | |
| *Crassostrea gigas* | | | | | | | | | | | | | | | | | 5 | | |
| *Ostrea edulis* | | | | | | | | | | | | | | | | | 9 | 1 | 2 |
| Noetiidae | | | | | | | | | | | | | | | | | | | |
| *Striarca lactea* | | | | | | | | | | | | | | | | | 4 | 2 | 3 |
| Mytilidae | | | | | | | | | | | | | | | | | | | |
| *Brachidontes pharaonis* | | | | | | | | | | | | | | | | | 13 | 8 | 1 |
| *Gregariella semigranata* | | | | | | | | | | | | | | | | | 1 | | |
| *Modiolus barbatus* | | | | | | | | | | | | | | | | | 1 | | |
| *Musculus costulatus* | | | | | | | | | | | | | | | | | 2 | 10 | 7 |
| *Mytilaster solidus* | | | | | | | | | | | | | | | | | | 17 | |
| *Mytilus galloprovincialis* | | | | | | | | | | | | | | | | | | 1 | |
| Arcidae | | | | | | | | | | | | | | | | | | | |
| *Arca noae* | | | | | | | | | | | | | | | | | 11 | 1 | 5 |
| *Arca tetragona* | | | | | | | | | | | | | | | | | | 4 | 1 |
| *Barbatia barbata* | | | | | | | | | | | | | | | | | | | 1 |
| Gastrochaenidae | | | | | | | | | | | | | | | | | | | |
| *Rocellaria dubia* | | | | | | | | | | | | | | | | | | | 1 |
| Nuculidae | | | | | | | | | | | | | | | | | | | |
| *Nucula nitidosa* | 1 | | | | | | | | | 1 | | | 1 | 2 | | | | | |
| *Nucula sulcata* | | | 1 | | | | | | | | | | | | | | | | |
| *Nucula sp.* | | | | | | | | | 1 | | | | | | | | | | |
| *Ennucula aegeensis* | | | | | | | | | | | | | | 1 | | | | | |
| *Nuculana fragilis* | | | | | | | | | | | | | 1 | | | | | | |
| *Nuculana pella* | | 3 | | 1 | 2 | | | | 1 | | | | | | | 6 | | | |
| Anomiidae | | | | | | | | | | | | | | | | | | | |
| *Anomia ephippium* | | | | | | | | | | | | | | | 1 | | 3 | 1 | 1 |
| Lucinidae | | | | | | | | | | | | | | | | | | | |
| *Anodontia fragilis* | | | | | | 1 | | 1 | | | | 1 | | | | 1 | | | |
| *Ctena decussata* | | | | | | | | 2 | | | | | | | | | | | |
| *Lucinella divaricata* | 44 | | | | 13 | 6 | 1 | 5 | | 2 | | 21 | 4 | 1 | 3 | 135 | | | |
| Thyasiridae | | | | | | | | | | | | | | | | | | | |
| *Thyasira biplicata* | | | 1 | | | | | | | | | | | | | | | | |
| *Thyasira alleni* | 1 | | 1 | 1 | | | | | | 1 | 6 | 14 | 5 | | 13 | 2 | | | |
| *Leptaxinus subovatus* | | | | | | | | | 1 | | | | | | | | | | |
| Carditidae | | | | | | | | | | | | | | | | | | | |
| *Glande aculeata* | | | | | | | | 1 | | | | | | | | | | | |
| Pharidae | | | | | | | | | | | | | | | | | | | |
| *Sinupharus africanus* | | 1 | | | | | | 2 | | | | | | 1 | | | | | |
| Montacutidae | | | | | | | | | | | | | | | | | | | |
| *Epilepton clarkiae* | | | | 1 | | | | | | | | | | | | | | | |
| *Kutiella bidentata* | | | | | | | | | | | | 2 | | 3 | 1 | 2 | | | |
| Astartidae | | | | | | | | | | | | | | | | | | | |
| *Astarte sulcata* | | | | | | | 1 | | | | | | | | | | | | |
| *Digitaria digitaria* | | | | | | | | | | | | | | 2 | | | | | |
| Cardiidae | | | | | | | | | | | | | | | | | | | |
| *Acanthocardia paucicostata* | | | 1 | | | | | | | | | 1 | | 4 | | | | | |
| *Laevicardium crassum* | | | | | | 1 | | | | | | | | | | | | | |
| *Parvicardium minimum* | | 1 | | | | | | | | | | | | | | | | | |
| *Plagiocardium papillosum* | | 2 | | | | | | | | | | | | | | 1 | | | |
| Mactridae | | | | | | | | | | | | | | | | | | | |
| *Spisula subtruncata* | 24 | 1 | | 3 | | | | | | | | | | 5 | | 2 | | | |
| Lottiidae | | | | | | | | | | | | | | | | | | | |
| *Tectura virginea* | | | | | | | | | | | | | | | | 1 | | | |
| Tellinidae | | | | | | | | | | | | | | | | | | | |

Please cite this article as: D'Alessandro, M., et al., Ecological assessment of a heavily human-stressed area in the Gulf of Milazzo, Central Mediterranean Sea: an integrated study of b..., Marine Pollution Bulletin (2016), http://dx.doi.org/10.1016/j.marpolbul.2016.01.021

(*continued*)

| | 7G | 5E | 3C | 4D | 2B | 1A | 16R | 14P | 6F | 8H | 10L | 9I | c50 | c20 | 11M | 12N | P1 | P2 | P3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Tellina distorta* | 21 | | | 6 | | | | | | | | 10 | | 17 | | 7 | | | |
| Limidae | | | | | | | | | | | | | | | | | | | |
| *Limatula Gwyni* | | | | | | | 1 | | | | | | | | | | | | |
| Psammobiidae | | | | | | | | | | | | | | | | | | | |
| *Gari fervensin* | 1 | | | 1 | | | | | | | | 3 | | | | 4 | | | |
| Semelidae | | | | | | | | | | | | | | | | | | | |
| *Scrobicularia cottardi* | | | | 37 | | | | | | | | | | | | | | | |
| *Abra alba* | 12 | 2 | | 40 | | 1 | | 2 | 2 | 2 | 1 | 11 | | 3 | 6 | 10 | | | |
| *Abra nitida* | | | | 1 | | | | | | | 3 | | 1 | | | | | | |
| *Abra prismatica* | | | | 1 | | | | | | | | 3 | | 3 | 2 | | | | |
| *Azorinus chamasolen* | | | | | | | | | | | | | | | | 1 | | | |
| Veneridae | | | | | | | | | | | | | | | | | | | |
| *Cardites antiquata* | | | | | | | | 1 | | | | | | | | | | | |
| *Gouldia minima* | 2 | | | | | 2 | | 1 | | | | | | | | | | | |
| *Dosinia lupinus* | 2 | | | | | | | | | | | | | | | 2 | | | |
| *Petricola lajonkairii* | 2 | | | | | | | | | | | | | | | | | | |
| *Pitar rudis* | | | | | | | | | | | | | | 3 | | | | | |
| *Callista chione* | | | | | | | | | | | | | | 2 | | | | | |
| *Timoclea ovata* | 31 | 53 | 19 | 77 | | 9 | 16 | 7 | 16 | | 2 | 28 | 17 | 48 | 10 | 198 | | | |
| *Chamelae gallina* | | | | | | | | 1 | | | | | | | | | | | |
| Corbulidae | | | | | | | | | | | | | | | | | | | |
| *Corbula gibba* | 7 | 2 | | 2 | | | | | 2 | | | 8 | | 2 | 1 | 10 | | | |
| Hiatellidae | | | | | | | | | | | | | | | | | | | |
| *Hiatella rugosa* | | | | | | 1 | | | | | | | | | | | | | |
| *Hiatella arctica* | | | | | | | | | | | | | | | | | | 6 | |
| Thraciidae | | | | | | | | | | | | | | | | | | | |
| *Thracia papyracea* | 4 | 1 | | | | | | | | | | 3 | | | | | | | |
| Cuspidariidae | | | | | | | | | | | | | | | | | | | |
| *Cuspidaria rostrata* | | | | | | | | | | | 1 | | | | | | | | |
| *Cardiomya costellata* | | 2 | | | | | | | | | | | | | | | | | |
| Ungulinidae | | | | | | | | | | | | | | | | | | | |
| *Diplodonta intermedia* | | 1 | | | | | | | | | | | | | | | | | |
| Polychaeta | | | | | | | | | | | | | | | | | | | |
| Ampharetidae | | | | | | | | | | | | | | | | | | | |
| *Ampharete grubei* | | 2 | | | | | | 2 | | | | | | 1 | 1 | 2 | 1 | | 1 |
| *Melinna palmata* | | | | | | | | 1 | | | | | | | | | | | |
| Capitellidae | | | | | | | | | | | | | | | | | | | |
| *Capitellidae sp.* | | | | | | | | | | | | | | 2 | | | | | |
| *Capitella capitata* | | 1 | | | | | | 3 | | | | | | | | | | | |
| *Capitomastus minimus* | 3 | 1 | | | | | | | | | | | | | | | | | |
| *Dasybranchus gajolae* | | | | | 1 | | | | | | | | | | | | 1 | | |
| *Heteromastus filiformis* | 2 | 1 | | | | | | | 4 | | 1 | | | | 6 | | | | |
| *Mastobranchus trinchesii* | | | | | | | 1 | 1 | | | | | | | | | | | |
| *Notomastus aberans* | 8 | 2 | 1 | 4 | | 2 | 1 | | | 26 | 2 | 15 | 1 | 1 | | 16 | | | |
| *Notomastus latericeus* | | 2 | | | | 1 | | | | 1 | | | | | | 2 | | | |
| *Notomastus sp* | | | | | | | | 1 | | | | | | | | | | 1 | 1 |
| *Notomastus sp.* | | | | | | | | | | 5 | | 5 | | 4 | | 4 | | | |
| *Peresiella sp.* | | | | | | 1 | | | | | | | | | | | | | |
| *Pseudoleiocapitella fauveli* | | 2 | 1 | | | 6 | 1 | 1 | 3 | 1 | 2 | | | 1 | 1 | | | | |
| Cossuridae | | | | | | | | | | | | | | | | | | | |
| *Cossura* | | 4 | 3 | | 1 | 1 | 1 | 1 | 3 | | 2 | 7 | 1 | | 1 | | | | |
| Aphroditidae | | | | | | | | | | | | | | | | | | | |
| *Aphroditidae sp.* | | | | | | | | | | | | | | | | | | 1 | |
| Ophelidae | | | | | | | | | | | | | | | | | | | |
| *Polyophthalmus pictus* | | | | | | | | | | | | | | | | | | | 1 |
| Phyllodocidae | | | | | | | | | | | | | | | | | | | |
| *Phyllodoce lineata* | | | | | | | | | | | | | | | | | 0 | 1 | 2 |
| Chrysopetalidae | | | | | | | | | | | | | | | | | | | |
| *Chrysopetalum debile* | | | | | | | | 1 | | | | | | | | | | | |
| Polinoe | | | | | | | | | | | | | | | | | | | |
| *Harmothoë fraserthomsoni* | | | | | | | | | | | | | | | | | 1 | | |
| *Polinoidae* | | | | | | | | | | | | | | | | | | 1 | |
| Dorvilleidae | | | | | | | | | | | | | | | | | | | |
| *Dorvilleidae* | | | | | | | | | | | 1 | | | | | | | | |
| Eunicidae | | | | | | | | | | | | | | | | | | | |
| *Eunicidae sp.* | | | | | | 2 | 2 | | | | | | | | | | | | |
| *Eunice vittata* | 2 | 3 | | | | 3 | 1 | | | | | 1 | | | | 1 | | | |
| *Marphysa bellii* | 3 | | | 2 | 1 | | 1 | 1 | | 1 | | 2 | | | | 4 | | | |
| *Palola siciliensis* | | | | | | | | | | | | | | | | | 3 | 1 | |
| *Nematonereis unicornis* | | | 1 | | 1 | 3 | | 2 | | | | | | 1 | | | | | |
| Flabelligeridae | | | | | | | | | | | | | | | | | | | |
| *Armandia cirrhosa* | | 4 | 2 | | | | | | 2 | | 3 | | | | | | | | |
| *Flabelligera sp.* | | 3 | | 1 | | 1 | | | | | | | | | 1 | | | | |
| *Pherusa plumosa* | | | | | | 1 | | | | | | | | | | | | | |

(*continued on next page*)

Please cite this article as: D'Alessandro, M., et al., Ecological assessment of a heavily human-stressed area in the Gulf of Milazzo, Central Mediterranean Sea: an integrated study of b..., Marine Pollution Bulletin (2016), http://dx.doi.org/10.1016/j.marpolbul.2016.01.021

(*continued*)

| | 7G | 5E | 3C | 4D | 2B | 1A | 16R | 14P | 6F | 8H | 10L | 9I | c50 | c20 | 11M | 12N | P1 | P2 | P3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Glyceridae | | | | | | | | | | | | | | | | | | | |
| *Glycera alba* | | 3 | | 1 | 2 | 1 | | | 9 | | 1 | 1 | | | 4 | | | | |
| *Glycera capitata* | | 1 | | | | | | | | | 2 | | | | | | | | |
| *Glycera fallax* | | 3 | 3 | | | | | | | | | | | | | | | | |
| *Glycera lapidum* | | 1 | | | | 1 | 2 | | | | | | 2 | | 1 | | | | |
| *Glycera tesselata* | | | | | | | | | | | | | 1 | | | | | | |
| *Glycera tridactyla* | | 1 | | 2 | | | | 2 | 3 | | | | 1 | | 3 | | 1 | | 1 |
| *Glycera unicornis* | | 1 | | | | 1 | | | 1 | 3 | | | 1 | | 1 | | | | |
| Goniadidae | | | | | | | | | | | | | | | | | | | |
| *Goniada maculata* | 3 | | | | 1 | | | | | 12 | 1 | | 1 | 3 | | 7 | | | |
| *Goniadidae sp* | | | | | | | | 1 | | | | 1 | | | | 2 | | | |
| Hesionidae | | | | | | | | | | | | | | | | | | | |
| *Kefersteinia cirrata* | | 1 | | | | | | 3 | 1 | | | | | | | | | | |
| Lumbrineridae | | | | | | | | | | | | | | | | | | | |
| *Abyssoninoe bidentate* | | | | | | 1 | | | | | | | 2 | | 1 | | | | |
| *Abyssoninoe hibernica* | 3 | 1 | | | | 2 | | | 1 | 6 | 2 | 2 | 2 | | | 2 | | | |
| *Gallardoneris iberica* | | 1 | | 4 | | 2 | | 6 | 3 | 1 | | 1 | | 4 | 1 | 4 | | | |
| *Lumbrineris funchanlensis* | | | | | | 2 | | | | | | | | 2 | | | | | |
| *Lumbrineris geldiayi* | | 4 | | 2 | 1 | | | 5 | 3 | 2 | 13 | 3 | 4 | | | | | | |
| *Lumbrineris latreilli* | | 2 | 2 | 8 | | 4 | 1 | 4 | 1 | 8 | 8 | | | | | | | | |
| *Lumbrineris luciliae* | | 2 | | 1 | | | | 1 | | | 1 | | | | | | | | |
| *Lumbrineris lusitanica* | | 1 | | 3 | | | | | | 3 | | | | | | 2 | | | |
| *Lumbrineriopsis paradoxa* | | | | | | | | 1 | | | | | | | | | | | |
| *Lumbrineris impatiens* | | | | | | | | | | | | | | 7 | | | | | |
| *Scoletoma emandibulata mabiti* | 1 | | | | | | | | | | | | | | | | | | |
| Magelonidae | | | | | | | | | | | | | | | | | | | |
| *Magelona minuta* | | 2 | 4 | | 1 | 3 | | 3 | 12 | 4 | 15 | 1 | | 1 | | 2 | | | |
| *Praxillella gracilis* | | | | | 1 | | | | 3 | | 1 | | | | | | | | |
| Maldanidae | | | | | | | | | | | | | | | | | | | |
| *Maldane sarsi* | | | | | 1 | 2 | | | 1 | | 1 | | | | | | | | |
| *Maldanidae sp* | 1 | 1 | 1 | | | 1 | 2 | | | | | | | 1 | | | | | |
| *Nicomache lumbricalis* | | | 1 | | | 1 | | 4 | 2 | 1 | | | | 1 | | 1 | | | |
| Nereididae | | | | | | | | | | | | | | | | | | | |
| *Nereididae sp.* | | 1 | | | | | | 1 | | 1 | | | 1 | | | 1 | 1 | 1 | |
| Nereididae | | | | | | | | | | | | | | | | | | | |
| *Ceratonereis (Composetia) costae* | | | | | | | | | | | | | | | | | 8 | 3 | 4 |
| *Pseudonereis sp.* | | | | | | | | 1 | | | | | | | | | | | |
| *Websterinereis glauca* | | | | | | | | | | 1 | | | | | | | | | |
| Nephtyidae | | | | | | | | | | | | | | | | | | | |
| *Micronephthys stammeri* | 3 | | 1 | 4 | | 3 | 3 | 8 | 1 | | | 7 | | 9 | | 6 | | | |
| *Nephtys hombergii* | | | | 2 | | 1 | | | | 2 | | 1 | | 1 | | | | | |
| *Nepthys sp.* | | | | | | 1 | | | | | | | 1 | | | | | | |
| Oenonidae | | | | | | | | | | | | | | | | | | | |
| *Arabella iricolor* | | 6 | 4 | 1 | | 7 | | | 2 | 7 | 4 | 2 | | 3 | 1 | | | | |
| Onuphidae | | | | | | | | | | | | | | | | | | | |
| *Aponuphis bilineata* | 3 | 1 | | 3 | | | 1 | 2 | 2 | 2 | | 3 | 3 | 4 | | 6 | | | |
| *Hyalinoecia brementi* | | | 2 | | 1 | | | 1 | | | | | 1 | | | 1 | | | |
| *Hyalinoecia fauveli* | | | | | | 3 | | | 2 | | | | | | | | | | |
| *Hyalinoecia sp.* | | 2 | | | | | | | | | | | | | | | | | |
| *Onuphidae spp.* | | | | | 1 | | | 1 | | | | | | | | | | | |
| Orbiniidae | | | | | | | | | | | | | | | | | | | |
| *Scoloplos (Scoloplos) armiger* | 4 | | | 6 | | 1 | | | | 8 | 2 | 3 | 1 | 16 | | 2 | | | |
| *Schroederella laubieri* | | | | | | | | 8 | | | | | | 2 | | 1 | | | |
| Paralacydoniidae | | | | | | | | | | | | | | | | | | | |
| *Paralacydonia paradoxa* | | 4 | 4 | | | | | | 1 | | 1 | 1 | 2 | | | | | | |
| Paraonidae | | | | | | | | | | | | | | | | | | | |
| *Aricidea capensis bansei* | | 1 | | 1 | | | | | 1 | | | | | | | | | | |
| *Aricidea (Aricidea) pseudoarticulata* | 2 | | | 3 | | 2 | 1 | | 3 | 8 | 1 | 4 | 2 | 1 | 9 | 9 | | | |
| *Aricidea cerrutii* | | | | | | | | | | | | | | 6 | | | | | |
| *Cirrophorus branchiatus* | 1 | | 1 | | | | | | 1 | 1 | | | | | | | | | |
| *Cirrophorus furcatus* | | | | | | | | | 1 | | | | | | | | | | |
| *Levinsenia gracilis* | | | | | | | | | | | | | | 1 | | | | | |
| *Levinsenia oculata* | | 3 | | 1 | | 4 | | | | 2 | | 11 | | 1 | | 4 | | | |
| *Paraonis fulgens* | 1 | 1 | | | | 1 | | | | | 2 | | | 1 | | | | | |
| *Paraonis lyra* | | | | | | | | 3 | 2 | | | | | | | | | | |
| *Paraonis paucibranchiata* | | 2 | | | | | | | | | | | | | | | | | |
| *Pharaonis sp.* | | | | | | | 1 | | 1 | | | | | | | | | | |
| Pilargidae | | | | | | | | | | | | | | | | | | | |
| *Ancystrosyllis* | | | | | | | | 1 | | | | | | | | | | | |
| *Pilargidae sp.* | | | | | | | | | | | | | | | | | 2 | | |
| Poecilochaetidae | | | | | | | | | | | | | | | | | | | |
| *Poecilochaetidae sp.* | | | | | | | | | 1 | | | | | | | | | | |
| *Poecilochaetus serpens* | | | | | | 1 | | 2 | 1 | | | 1 | | | | | | | |
| Phyllodocidae | | | | | | | | | | | | | | | | | | | |
| *Eteone* | | 3 | 1 | | | | | | 1 | | | | | | | | | | |

Please cite this article as: D'Alessandro, M., et al., Ecological assessment of a heavily human-stressed area in the Gulf of Milazzo, Central Mediterranean Sea: an integrated study of b..., Marine Pollution Bulletin (2016), http://dx.doi.org/10.1016/j.marpolbul.2016.01.021

(*continued*)

| | 7G | 5E | 3C | 4D | 2B | 1A | 16R | 14P | 6F | 8H | 10L | 9I | c50 | c20 | 11M | 12N | P1 | P2 | P3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Phyllodoce lineata* | | | | | | 1 | 1 | | 3 | | | 1 | | | | | | | |
| Polynoidae | | | | | | | | | | | | | | | | | | | |
| *Lepidonotus clava* | | | | | | | | | | 1 | | | | | | | | | |
| *Lepidonotus squamatus* | | | 1 | | | | | | | | | | | | | | | | |
| *Harmothoë* | | | | | | | | | | | | | | 1 | | | | | |
| *Harmothoë fraserthomsoni* | | | | | | | | | | | | | | | | 1 | | | |
| *Polynoë* | | 3 | | | | | | | 1 | | 2 | | | | | | | | |
| Sabellinae | | | | | | | | | | | | | | | | | | | |
| *Amphiglena mediterranea* | | | | | | | | | | | | | | 1 | | | | | |
| *Branchiomma* | | | | | | | | 1 | | | | | | 3 | | | | | 1 |
| *Bispira fabricii* | | 2 | | | | | | 1 | | | | | | | 1 | | | | |
| *Sabella sp.* | | 1 | | | | | | 1 | 1 | | | | | | | | | | |
| Serpulidae | | | | | | | | | | | | | | | | | | | |
| *Serpulidae* | | | | | | | | | | | 3 | | | | | | 6 | | 10 |
| *Filograna* | | | | | | | | | | | | | | | | | 4 | 1 | 2 |
| *Hydroides pseudouncinatus* | | | | | | | | | | | | | | | | | | 1 | |
| *Vermiliopsis striaticeps* | | | | | | | | | | | | | | | | | 1 | 6 | 11 |
| Sigalionidae | | | | | | | | | | | | | | | | | | | |
| *Sigalion* | | | | | | | | 1 | | | | | | 1 | | | | | |
| *Sigalion mathildae* | | | | | | | 1 | | | | 1 | | | 6 | | | 1 | 1 | |
| Spionidae | | | | | | | | | | | | | | | | | | | |
| *Laonice cirrata* | | 1 | | | | | 1 | | | | | | | | | | | | |
| *Laonice sp.* | | | | | | | | | | 1 | | | | | | | | | |
| *Malacoceros fuliginosus* | | 2 | | | | | | | | | | | | | | | | | |
| *Microspio mecznikowianus* | 2 | | | | | | | | | | | | | | | | | | |
| *Polydora sp.* | | | | 3 | | 1 | | 1 | 1 | | 1 | 3 | 2 | 2 | | | | | |
| *Prionospio fallax* | | 1 | 1 | | | | 1 | | 8 | | | | | | | | | | |
| *Prionospio ehlersi* | | | 1 | | | | | | 1 | | | | | | | | | | |
| *Prionospio malmgreni* | | 4 | 1 | | | 1 | | | 14 | | 15 | 2 | | 3 | 9 | | | | |
| *Prionospio sp.* | 1 | | 1 | | | 1 | | | 3 | | | | | | | | | | |
| *Prionospio steenstrupi* | | | | | | | | | | | 5 | | | | 6 | | | | |
| *Spio sp.* | | 2 | | | | 2 | | | | 2 | | | | | | | | | |
| *Spio filicornis* | | | | 3 | | | | | | | 5 | | | 6 | | 2 | | | |
| *Spionidae sp.* | | 1 | 1 | 2 | | | | 1 | 1 | 1 | | 2 | | | | | | | |
| Sternaspidae | | | | | | | | | | | | | | | | | | | |
| *Sternaspis scutata* | | | | | | | | | | | 1 | | | | | | | | |
| Syllidae | | | | | | | | | | | | | | | | | | | |
| *Syllis gracilis* | | 1 | | | 1 | 1 | 1 | 1 | | | 1 | | | | | | | | |
| *Syllis hyalina* | | | | | | | | | | | | | | | | | 7 | 10 | 7 |
| *Syllis sp.* | | | | | | | | | | | | | | | | | | 13 | 1 |
| Terebellidae | | | | | | | | | | | | | | | | | | | |
| *Amphitritides gracilis* | | | | | | 1 | | | | | | | | | | | | 2 | |
| *Terebellidae* | | 1 | | | | | | 1 | | | | | | | | 1 | | | |
| Sipunculidae | | | | | | | | | | | | | | | | | | | |
| Phascolosomatidae | | | | | | | | | | | | | | | | | | | |
| *Onchnesoma steenstrupii* | | 19 | | | | | | | 2 | | 9 | | 1 | 1 | 4 | 1 | | | |
| *Phascolion (Phascolion) strombus* | | | | | | | | | | | | | | | 1 | | | | |
| *Sipuncula sp.* | | 1 | | | 2 | | | | | | | | | | 2 | | | | |

## References

Adami, G., Barbieri, P., Piselli, S., Predonzani, S., Reisenhofer, E., 2000. Detecting and characterizing sources of persistent organic pollutants (PAHs and PCBs) in surface sediments of an industrialized area (harbour of Trieste, northern Adriatic Sea). J. Environ. Monit. 2 (3), 261–265.

Afli, A., Boufahja, F., Sadraoui, S., Ben Mustapha, K., Aissa, P., Mrabet, R., 2009. Functional organization of the benthic macrofauna in the Bizerte lagoon (SW Mediterranean Sea), semi-enclosed area subject to strong environmental/anthropogenic variations. Cah. Biol. Mar. 50 (2), 105.

Alam, M., Pathak, J.K., 2010. Rapid assessment of water quality index of Ramganga river, western Uttar Pradesh (India) using a computer programme. Nat. Sci. 8 (11), 1–8.

Alexander, R.B., Smith, R.A., Schwarz, G.E., 2000. Effect of stream channel size on the delivery of nitrogen to the Gulf of Mexico. Nature 403 (6771), 758–761.

Anderson, M.J., Gorley, R.N., Clarke, K.R., 2008. PERMANOVA+ For PRIMER: Guide to Software and Statistical Methods. PRIMER-E, Plymouth.

Bax, N., Williamson, A., Aguero, M., Gonzalez, E., Geeves, W., 2003. Marine invasive alien species: a threat to global biodiversity. Mar. Policy 27 (4), 313–323.

Beaumont, N.J., Austen, M.C., Mangi, S.C., Townsend, M., 2008. Economic valuation for the conservation of marine biodiversity. Mar. Pollut. Bull. 56 (3), 386–396.

Bertolotto, R.M., Tortarolo, B., Frignani, M., Bellucci, L.G., Albanese, S., Cuneo, C., 2003, May. Heavy metals in coastal sediments of the Ligurian sea off Vado Ligure. Journal de Physique IV (Proceedings) vol. 107. EDP Sciences, pp. 159–162.

Bettinetti, R., Giarei, C., Provini, A., 2003. Chemical analysis and sediment toxicity bioassays to assess the contamination of the River Lambro (Northern Italy). Arch. Environ. Contam. Toxicol. 45 (1), 0072–0078.

Borja, A., Franco, J., Pérez, V., 2000. A marine biotic index to establish the ecological quality of soft-bottom benthos within European estuarine and coastal environments. Mar. Pollut. Bull. 40 (12), 1100–1114.

Borja, A., Muxika, I., Rodríguez, J.G., 2009. Risposte paradigmatici delle comunità bentoniche marine a diverse pressioni antropiche, con M-AMBI, nell'ambito della direttiva quadro europea sull'acqua. Ecol. Mar. 30 (2), 214–227.

Bray, R.J., Curtis, J.T., 1957. An ordination of the upland forest communities of southern Wisconsin. Ecol. Monogr. 27, 325–349.

Buchanan, J.B., Kain, J.M., 1971. Measurement of the Physical and Chemical Environment. Methods for the Study of Marine Benthos. p. 16.

Clarke, K.R., Warwick, R.M., 2001. An approach to statistical analysis and interpretation. Chang. Mar. Communities 2.

Costanza, R., d'Arge, R., De Groot, R., Farber, S., Grasso, M., Hannon, B., ... Van Den Belt, M., 1998. The value of the world's ecosystem services and natural capital. Ecol. Econ. 1 (25), 3–15.

Cruz-Motta, J.J., Collins, J., 2004. Impacts of dredged material disposal on a tropical soft-bottom benthic assemblage. Mar. Pollut. Bull. 48 (3), 270–280.

Currie, D.R., Isaacs, L.R., 2005. Impact of exploratory offshore drilling on benthic communities in the Minerva gas field, Port Campbell, Australia. Mar. Environ. Res. 59 (3), 217–233.

D'Alessandro, M., Castriota, L., Consoli, P., Romeo, T., Andaloro, F., 2015. *Pseudonereis anomala* (Polychaeta, Nereididae) expands its range westward: first Italian record in Augusta and Siracusa harbours. Mar. Biodivers. 1-5.

Daskalakis, K.D., O'Connor, T.P., 1995. Distribution of chemical concentrations in US coastal and estuarine sediment. Mar. Environ. Res. 40 (4), 381–398.

Dauvin, J.C., Ruellet, T., 2007. Polychaete/amphipod ratio revisited. Mar. Pollut. Bull. 55 (1), 215–224.

Please cite this article as: D'Alessandro, M., et al., Ecological assessment of a heavily human-stressed area in the Gulf of Milazzo, Central Mediterranean Sea: an integrated study of b..., Marine Pollution Bulletin (2016), http://dx.doi.org/10.1016/j.marpolbul.2016.01.021

De Groot, R.S., Wilson, M.A., Boumans, R.M., 2002. A typology for the classification, description and valuation of ecosystem functions, goods and services. Ecol. Econ. 41 (3), 393–408.

Estacio, F.J., García-Adiego, E.M., Fa, D.A., García-Gómez, J.C., Daza, J.L., Hortas, F., Gómez-Ariza, J.L., 1997. Ecological analysis in a polluted area of Algeciras Bay (Southern Spain): external 'versus' internal outfalls and environmental implications. Mar. Pollut. Bull. 34 (10), 780–793.

Fadeeva, N.P., Bezverbnaja, I.P., Tazaki, K., Watanabe, H., Fadeev, V.I., 2003. Composition and structure of marine benthic community regarding conditions of chronic harbour pollution. Ocean Polar Res. 25 (1), 21–30.

Farkas, A., Erratico, C., Vigano, L., 2007. Assessment of the environmental significance of heavy metal pollution in surficial sediments of the River Po. Chemosphere 68 (4), 761–768.

Gibbs, R.J., 1977. Transport phases of transition metals in the Amazon and Yukon Rivers. Geol. Soc. Am. Bull. 88 (6), 829–843.

Goodnight, C.J., 1973. The use of aquatic macroinvertebrates as indicators of stream pollution. Trans. Am. Microsc. Soc. 1-13.

Gray, J.S., Elliott, M., 2009. Ecology of Marine Sediments: From Science to Management. Oxford University Press.

Grigg, R.W., 1994. Community structure, succession and development of coral reefs in Hawaii. A Natural History of the Hawaiian Islands: Selected Readings II, p. 196.

Hilty, J., Merenlender, A., 2000. Faunal indicator taxa selection for monitoring ecosystem health. Biol. Conserv. 92 (2), 185–197.

Humborg, C., Ittekkot, V., Cociasu, A., Bodungen, B.V., 1997. Effect of Danube River dam on Black Sea biogeochemistry and ecosystem structure. Nature 386 (6623), 385–388.

ISPRA, 2009. Piano di caratterizzazione ambientale dell'area marino costiera prospiciente il sito di bonifica di interesse nazionale area industriale di Milazzo. CII-Pr-SI-MI-01.23.

Klemm, D.J., Blocksom, K.A., Thoeny, W.T., Fulk, F.A., Herlihy, A.T., Kaufmann, P.R., Cormier, S.M., 2002. Methods development and use of macroinvertebrates as indicators of ecological conditions for streams in the Mid-Atlantic Highlands region. Environ. Monit. Assess. 78 (2), 169–212.

Lindegarth, M., Hoskin, M., 2001. Patterns of distribution of macro-fauna in different types of estuarine, soft sediment habitats adjacent to urban and non-urban areas. Estuar. Coast. Shelf Sci. 52 (2), 237–247.

Lotze, H.K., Reise, K., Worm, B., van Beusekom, J., Busch, M., Ehlers, A., ... Wolff, W.J., 2005. Human transformations of the Wadden Sea ecosystem through time: a synthesis. Helgol. Mar. Res. 59 (1), 84–95.

Luoma, S.N., Bryan, G.W., 1981. A statistical assessment of the form of trace metals in oxidized estuarine sediments employing chemical extractants. Sci. Total Environ. 17 (2), 165–196.

Luoma, S.N., Phillips, D.J.H., 1988. Distribution, variability, and impacts of trace elements in San Francisco Bay. Mar. Pollut. Bull. 19 (9), 413–425.

Maiorano, P., Mastrototaro, F., Beqiraj, S., Costantino, G., Kashta, L., Gherardi, M., ... Tursi, A., 2011. Bioecological study of the benthic communities on the soft bottom of the Vlora Gulf (Albania). J. Coast. Res. 95-105.

Martins, R., Quintino, V., Rodrigues, A.M., 2013a. Diversity and spatial distribution patterns of the soft-bottom macrofauna communities on the Portuguese continental shelf. J. Sea Res. 83, 173–186.

Martins, R., Sampaio, L., Quintino, V., Rodrigues, A.M., 2013b. Soft-bottom Portuguese continental shelf polychaetes: diversity and distribution. J. Mar. Syst. 123-124, 41–54.

Mason, C.F., 2002. Biology of Freshwater Pollution. Pearson Education.

Matthiessen, P., Law, R.J., 2002. Contaminants and their effects on estuarine and coastal organisms in the United Kingdom in the late twentieth century. Environ. Pollut. 120, 739–757.

McCauley, D.J., Pinsky, M.L., Palumbi, S.R., Estes, J.A., Joyce, F.H., Warner, R.R., 2015. Marine defaunation: animal loss in the global ocean. Science 347 (6219), 1255641.

Moreno, M., Vezzulli, L., Marin, V., Laconi, P., Albertelli, G., Fabiano, M., 2008. The use of meiofauna diversity as an indicator of pollution in harbours. ICES J. Mar. Sci.: J. Conseil. 65 (8), 1428–1435.

Muxika, I., Borja, A., Bonne, W., 2005. The suitability of the marine biotic index (AMBI) to new impact sources along European coasts. Ecol. Indic. 5 (1), 19–31.

Notar, M., Leskovsek, H., Faganeli, J., 2001. Composition, distribution and sources of Polycyclic aromatic hydrocarbons in sediments of the Gulf of Trieste, northern Adriatic Sea. Mar. Pollut. Bull. 42, 36–44.

Nriagu, J.O., 1989. A global assessment of natural sources of atmospheric trace metals. Nature 338 (6210), 47–49.

Occhipinti-Ambrogi, A., 2007. Global change and marine communities: alien species and climate change. Mar. Pollut. Bull. 55 (7), 342–352.

Occhipinti-Ambrogi, A., Marchini, A., Cantone, G., Castelli, A., Chimenz, C., Cormaci, M., ... Piraino, S., 2011. Alien species along the Italian coasts: an overview. Biol. Invasions 13 (1), 215–237.

Ojaveer, H., Galil, B.S., Minchin, D., Olenin, S., Amorim, A., Canning-Clode, J., ... Zenetos, A., 2014. Ten recommendations for advancing the assessment and management of non-indigenous species in marine ecosystems. Mar. Policy 44, 160–165.

Otway, N.M., 1995. Assessing impacts of deepwater sewage disposal: a case study from New South Wales, Australia. Mar. Pollut. Bull. 31 (4), 347–354.

Pearson, T.H., Rosenberg, R., 1987. Feast and famine: structuring factors in marine benthic communities. Symposium of the British Ecological Society.

Pepe, F., Scopelliti, G., Di Leonardo, R., Ferruzza, G., 2010. Granulometry, mineralogy and trace elements of marine sedimentsfrom the Gulf of Milazzo (NE Sicily): evaluation of anthropogenic impact. Ital. J. Geosci. 129, 385–394.

Romano, E., Ausili, A., Zharova, N., Magno, M.C., Pavoni, B., Gabellini, M., 2004. Marine sediment contamination of an industrial site at Port of Bagnoli, Gulf of Naples, Southern Italy. Mar. Pollut. Bull. 49 (5–6), 487–495.

Romeo, T., D'Alessandro, M., Esposito, V., Scotti, G., Berto, D., Formalewicz, M., Noventa, S., Giuliani, S., Macchia, S., Sartori, D., Mazzola, A., Andaloro, F., Giacobbe, S., Deidun, A., Renzi, M., 2015. Environmental quality assessment of Grand Harbour (Valletta, Maltese Islands): a case study of a busy harbour in the Central Mediterranean Sea. Environ. Monit. Assess. http://dx.doi.org/10.1007/s10661- 015-4950-3.

Salomons, W., Stigliani, W. (Eds.), 2012. Biogeodynamics of Pollutants in Soils and Sediments: Risk Assessment of Delayed and Non-linear Responses. Springer Science & Business Media.

Shannon, C. E., & Weaver, W. (1963). University of Illinois Press. Urbana, IL.

Shoults-Wilson, W.A., Elsayed, N., Leckrone, K., Unrine, J., 2015. Zebra mussels (Dreissena polymorpha) as a biomonitor of trace elements along the southern shoreline of Lake Michigan. Environ. Toxicol. Chem. 34 (2), 412–419.

Shrivastava, A., Gupta, V.B., 2011. Methods for the determination of limit of detection and limit of quantitation of the analytical methods. Chronicles Young Sci. 2 (1), 21–25.

Signa, G., Mazzola, A., Costa, V., Vizzini, S., 2015. Bottom-up control of macrobenthic communities in a guanotrophic coastal system. PLoS One 10 (2), e0117544.

Simboura, N., Nicolaidou, A., Thessalou-Legaki, M., 2000. Polychaete communities of Greece: an ecological overview. Mar. Ecol. 21 (2), 129–144.

Sitran, R., Bergamasco, A., Decembrini, F., Guglielmo, L., 2009. Microzooplankton (tintinnid ciliates) diversity: coastal community structure and driving mechanisms in the southern Tyrrhenian Sea (Western Mediterranean). J. Plankton Res. 31 (2), 153–170.

Sprovieri, M., Feo, M.L., Prevedello, L., Salvagio, Manta D., Sammartino, S., Tamburrino, S., Marsella, E., 2007. Heavy metals, polycyclic aromatic hydrocarbons and polychlorinated biphenyls in surface sediments of the Naples harbour (Southern Italy). Chemosphere 67, 998–1009.

US EPA, 2007a. Method 3051A. Microwave Assisted Acid Digestion of Sediments, Sludges, Soils, and Oils (Washington, DC).

US EPA, 2007b. Method 6010C. Inductively Coupled Plasma-Atomic Emission Spectrometry (Washington, DC).

US EPA, 2007c. Method 7010. Graphite Furnace Atomic Absorption Spectrophotometry (Washington, DC).

US EPA, 2007d. Method 7473 "Mercury in Solids and Solutions by Thermal Decomposition, Amalgamation, and Atomic Absorption Spectrophotometry" (Washington, DC).

US EPA method 3545 revision B, 1996. Pressurized Fluid Extraction (PFE). Office of Water, Washington, D.C., USA.

US EPA method 8081B revision 2, 2007a. Organochlorine Pesticides by Gas Chromatography. Office of Water, Washington, D.C., USA.

US EPA method 8082A revision 1, 2007b. Polychlorinated Biphenyls (PCBs) by Gas Chromatography. Office of Water, Washington, D.C., USA.

Veena, K.B., Radhakrishnan, C.K., Chacko, J., 1997. Heavy metal induced biochemical effects in an estuarine teleost. Indian J. Mar. Sci. 26 (1), 74–78.

Vitousek, P.M., D'Antonio, C.M., Loope, L.L., Westbrooks, R., 1996. Biological invasions as global environmental change. Am. Sci. 84 (5), 468–478.

Wentworth, C.K., 1922. A scale of grade and class terms for clastic sediments. J. Geol. 377–392.

Worm, B., Barbier, E.B., Beaumont, N., Duffy, J.E., Folke, C., Halpern, B.S., ... Watson, R., 2006. Impacts of biodiversity loss on ocean ecosystem services. Science 314 (5800), 787–790.

Please cite this article as: D'Alessandro, M., et al., Ecological assessment of a heavily human-stressed area in the Gulf of Milazzo, Central Mediterranean Sea: an integrated study of b..., Marine Pollution Bulletin (2016), http://dx.doi.org/10.1016/j.marpolbul.2016.01.021