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Offshore platforms: Comparison of five benthic indicators for assessing the macrozoobenthic stress levels

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ABSTRACT

Within the European Water Framework Directive, many studies have been conducted to evaluate the sensitivity/robustness of a variety of indices in relation to natural or anthropogenic disturbance events. However, these indices have rarely been applied to verify the impacts of disturbances in offshore environments, though the Marine Strategy Framework Directive recommends their use for assessing benthic community conditions and functionality. The aim of this paper was to determine which biotic indicator performed the best for detecting the impacts of offshore structures on benthic populations in the Adriatic Sea. The impacts of four rigs were investigated six months after their installation, and the H′, AMBI, m-AMBI, BENTIX, and BOPA indices were assessed. Although these five indices delivered some contradictory results because of the differences in their structure and discrepancies in their assignment of species sensitivity, the BENTIX, H′ and BOPA indices appear to evaluate stress levels better than the AMBI and m-AMBI indices, which tend to provide results that are slightly overly optimistic.

1. Introduction

Italian production of oil and gas comprises approximately 3% of the total European output, and almost half of the gas production in the Mediterranean basin is acquired from offshore reserves in the Adriatic continental shelf (OGP, 2005). More than 110 offshore gas platforms have been deployed since the 1960s in the northern and central parts of this basin (Maggi et al., 2007), representing the highest concentration of fossil fuel extraction platforms in the Mediterranean area. These platforms are installed in a wide variety of environments, with different depths (from 20 to 80 m) and different types of sediments (from mud to sand). These environments may be influenced by the inflows of several rivers, including the Po River, which represents the main freshwater input into the northern Adriatic Sea (Cattaneo et al., 2003; Grilli et al., 2005; Marini et al., 2008). This high environmental variability, together with the high amount of drilling activity, makes the development of general models that assess the impacts caused by offshore platforms difficult.

Several studies have been conducted to assess the effects of offshore platforms on soft-bottom benthic communities (Wolfson et al., 1979; Frascari et al., 1991, 1992; Montagna and Harper, 1996; Love et al., 1999; Page et al., 1999; Spagnolo et al., 2002, 2006, 2009; Stachowitsch et al., 2002; Currie and Isaacs, 2005; Fabi et al., 2005, 2007; Terlizzi et al., 2008; Trabucco et al., 2008; Manoukian et al., 2010; Gomiero et al., 2011b). All these studies were based on univariate and/or multivariate indices (i.e., density, richness, diversity, and/or similarity patterns).

Only recently, and in very few cases, have some biotic indices, which are generally applied to assess the Environmental Quality Status (EQS) of estuarine and coastal waters, been tested or adopted to evaluate the stress level induced by offshore activities (Borja et al., 2003a; Muxica et al., 2005; Andrade and Renaud, 2011; Gomiero et al. 2013; Rygg and Norling, 2013). Within the context of the European Water Framework Directive (WFD), the use of these biotic indices of benthic stress levels has been proposed for evaluations of the impacts of natural and anthropogenically induced disturbances (e.g., Labrune et al., 2006; Salas et al., 2006; Dauvin and Ruellet, 2007; Munari and Mistri, 2008; Borja et al., 2009; Pinto et al., 2009; Kröncke and Reiss, 2010; de-la-Ossa-Carretero et al., 2012; Deter et al., 2012; Karakassis et al., 2013; Nikolić et al., 2013; Rombouts et al., 2013; Van Hoey et al., 2013). The aim of this proposal was to standardize the use of benthic communities to assess marine habitat quality.

Therefore, it is important to test the application of biotic indices on a wide range of impacts, including offshore gas and oil activities, as such information is required for specific management decisions

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(OSPAR, 2009). It is important to note that open sea areas, where offshore structures are usually placed, are only considered within the Marine Strategy Framework Directive (MSFD; 2008/56/EC). The WFD and the MSFD are based on different approaches (see Borja et al., 2010); while the assessment of EQS is based upon five biological quality levels in the case of the WFD, only two levels (good and not good) are used in the case of the MSFD. However, Borja et al. (2010) have hypothesized that some of the parameters and assessment tools applied for the WFD, such as some of the indices for soft-sediment macroinvertebrates, are also potentially applicable in the case of larger oceanic regions. Examples of the uses of various methods, tools, indicators and targets that are implemented in the WFD (such as the AMBI index; Borja et al., 2000) within the MSFD are reported in HELCOM (2006, 2010) and Borja et al. (2011).

The classification of soft-bottom benthic species into previously defined ecological groups and data on the respective proportions of these different groups within benthic communities is a requirement for some biotic indices (e.g., AMBI, BENTIX; Borja et al., 2000; Simboura and Zenetos, 2002). For these reasons, a large amount of work is required to correctly identify and classify the different taxa. Other indices, such as BOPA (Dauvin and Ruellet, 2007), are based on a limited number of taxonomic groups and are, therefore, easier to use.

Each index has advantages and disadvantages based on its ecological classification of species and its ability to distinguish ecological status. Moreover, it is difficult to define the correct boundaries for ecological status classes. In Italy, for example, the intercalibration exercise is still evolving; a national method is under development, and, at present, a mutual agreement upon the class boundaries has not been reached (Simboura and Argyrou, 2010).

Due to the differences in the performances of various indices, Borja and Muxica (2003), Borja et al. (2003b), Teixeira et al. (2007) and Kröncke and Reiss (2010) have suggested including several indices in assessment schemes to ensure that the level of natural variability can be detected and considered. Moreover, the application of more than one index makes up for the defects of any single index when used alone (Teixeira et al., 2007).

Following these suggestions, the goal of this paper was to examine and compare the effectiveness of five indices used to detect the stress levels of the benthic communities living near four offshore gas platforms installed across a wide area of the Adriatic Sea. It is noteworthy that the four rigs, as well as other offshore platforms, were subjected to an extensive monitoring program aimed at evaluating the effects of installing platforms on various components of the marine environment (i.e., water columns, sediments, benthic communities, fish assemblages, ecotoxicological responses). Some of the results from these studies have been published in Spagnolo et al. (2002, 2006, 2009), Fabi et al. (2004, 2005, 2007, 2011), De Biasi et al. (2006, 2007), La Mesa et al. (2010), Manoukian et al. (2010), Gomiero et al. (2011a, 2011b, 2013), and Scarcella et al. (2011).

2. Material and methods

2.1. Study sites

The study was carried out at four 4-leg rigs installed in the northern Adriatic Sea; the rigs are arranged along a hypothetical line of approximately 180 km (Fig. 1).

Rig A (hereafter indicated by pA) is located on a sandy bottom (depth: 60 m), 60 km offshore of Pesaro. The drilling operations were completed in October 2010.

Rig B (hereafter referred to as pB) is installed on sandy bottom, 57 km offshore of Ancona at a depth of 82 m. Its positioning was completed in July 2010.

Rig C (hereafter indicated by pC) is located 57 km offshore of Ancona on a silty-sand bottom (depth: 74 m). The drilling operations were completed in July 2000.

Finally, rig D (hereafter referred to as pD) is located on a silty-sand seabed at a depth of 69 m, 56 km off Pesaro. The drilling operations were completed in June 1999.

2.2. Sampling

All four areas were sampled 6 months after the end of the installation of the rigs. The sampling design followed the 'gradient design' approach, which is particularly useful when a stressor or disturbance attenuates with distance from the point source of the impact (Ellis and Schneider, 1997). Therefore, four sampling sites (approximately 20 m apart) were randomly selected for monitoring at 5 m, 30 m, 60 m, 120 m, and 1000 m from each structure (Manoukian et al., 2010). For the evaluation of the effectiveness of the five selected indices, only the four sites close to the platform at a distance of 5 m ("P"), the four sites located 120 m from the rig ("120 m") and the four sites located 1000 m ("K") from the rig were considered. These sites were sampled for physical and chemical analyses using a box-corer. Sediments were analyzed for their grain particle size and organic matter content (OM). The concentrations of the essential metals copper (Cu) and chromium (Cr) and the non-essential metals mercury (Hg) and nickel (Ni; Depledge and Rainbow, 1990; Ahsanullah and Williams, 1991) were also measured.

A Van-Veen grab (capacity = 13 L; width = 0.095 m^2) was used for the benthic community sampling. Six samples were collected from each site, sieved on board through a 0.5 mm mesh and preserved in 5% buffered formalin. In the laboratory, the macrofauna samples were sorted using a stereomicroscope and a binocular microscope, identified and classified to the species level using standard nomenclature when possible, quantified, and weighed.

2.3. Data analysis

To examine the differences among the four areas both in terms of environmental features and macrozoobenthic communities, multivariate analyses were performed. The differences in environmental variables (Cu, Hg, Cr, and Ni, percentage of sand, silt, clay and OM) among areas were investigated by performing a one-way permutation analysis of variance (PERMANOVA) with rig was a fixed factor. The PERMANOVA was applied using a Euclidean distance matrix of previously normalized environmental variables. The percentage data were arcsine square root transformed prior to performing analyses ($y' = \sin^1[\sqrt{y}]$).

Similarly, the differences among the macrofauna assemblages sampled at the four areas were also evaluated by performing PERMANOVA, but, in this case, a Bray–Curtis similarity matrix of the square root transformed data was used in the analysis. This method allowed for testing of the general multivariate hypothesis of differences in the composition and/or relative abundances of organisms of different species in samples from different groups (Anderson, 2001; McArdle and Anderson, 2001). Moreover, a multivariate multiple permutations test (SIMPER, Similarity Percentages, PRIMER®; Clarke, 1993) was used to determine which species were responsible for the differences among the four areas in terms of community dissimilarity. The multivariate analyses were performed using the PRIMER® software.

The mean density (N; n. ind. 0.095 m^{-2}) and total richness (S) for each area were also calculated.

2.4. Stress level assessment

The stress level assessment was performed by calculating the Shannon–Wiener diversity index (H' $\log_2$; Shannon and Weaver,