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Benthic foraminifera assemblages as elemental pollution bioindicator in marine sediments around fish farm (Vrgada Island, Central Adriatic, Croatia)

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ABSTRACT

Effects on sediments of fish farming activity near Vrgada Island was analysed through living and total foraminiferal assemblages and concentration of major, minor and trace elements from three sediment cores. Elemental concentrations of sediments are in accordance with carbonate characteristics of the surrounding area and show mostly natural element variations between sampling locations and throughout the cores, with no significant increases due to fish farming activity. Only phosphorus concentration shows elevate values below the fish cage, assigned to fish pellets. Foraminiferal communities are dominated by epifaunal and stress tolerant species, while diversity indices point to normal marine conditions. The type of substrate and phosphorus content in sediments principally influence foraminiferal community composition, while other elemental concentrations have no perceptible effect on the assemblages. Some foraminiferal species *Ammonia tepida*, *Ammonia beccarii*, *Elphidium crispum*, *Elphidium macellum* and genus *Haynesina* are confirmed to be tolerant to elevated nutrient (phosphorus) content, while *Ammonia parkinsoniana* shows sensitivity to pollution. Postmortem processes cause decrease of foraminiferal density and species richness with core depth. All results point to negligible influence of fish farming and relatively stable environmental conditions at all sampling locations.

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1. Introduction

In the last decades, coastal marine environments have become areas with different ecological problems caused by urban growth and associated activities like fish farming, disposals of domestic, agricultural and industrial wastes. These unnatural activities influence on different segments of particular ecosystem i.e. water, sediment and especially organisms.

Benthic foraminifera have been the target for the monitoring of human impact on marine environments from early 1960s (Zalesny, 1959; Reisig, 1960; Watkins, 1961). The utility of foraminifera for such studies arises from their short life cycles and high biodiversity (Murray, 1991), which makes them highly sensitive to environmental stress. Furthermore, their calcareous tests have high preservation potential thus making these microorganisms one of the most effective indicators of pollution in marine environments (Nigam et al., 2006). Due to their small size and principally high abundance even in small samples, foraminiferal assemblages present reliable statistical basis for environmental studies.

Since early 1960s, the number of pollution studies has increased significantly; foraminifera have been used worldwide in monitoring the impact of vast range of anthropogenic contamination sources, such as sewage disposals (Burone et al., 2006; Mojtahid et al., 2008; Teodoro et al., 2010), industrial wastes (Ellison et al., 1986; Alve, 1991; Coccioni, 2000; Ferraro et al., 2006; Coccioni et al., 2009; Popadić et al., 2013), agricultural wastes (Samir and El-Din, 2001), various harbor activities like painting, cleaning and outfall of motor-fuel (Debenay et al., 2001), oil spillages (Ernst et al., 2006), drill cutting disposals (Mojtahid et al., 2006) and aquaculture activities (Schafer et al., 1995; Scott et al., 1995; Angel et al., 2000; La Rosa et al., 2001; Kalantzi and Karakassis, 2006; Bouchet et al., 2007; Sutherland et al., 2007; Vidović et al., 2009).

Among several different pollutants, elevated element (heavy metal) concentrations were found to be important response for foraminiferal modifications. There were several studies in coastal environments that describe relations between element concentrations and variations of foraminiferal changes (Alve,

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1991, 1995; Yanko et al., 1998; Armoynot du Châtelet et al., 2004; Bergin et al., 2006; Burone et al., 2006; Ferraro et al., 2006; Frontalini and Coccioni, 2008; Coccioni et al., 2009; Frontalini et al., 2009; Rumolo et al., 2009; Caruso et al., 2011; Popadić et al., 2013). These investigations found that such kind of contaminations may result in pathological processes in the foraminiferal cells and play an important role in the development of test abnormalities, as well as changes in foraminiferal abundance, taxonomic composition, size variation and structural modification (Debenay et al., 2000; Coccioni et al., 2009). Although all mentioned studies investigate different cases of elemental pollution in coastal environments, aquaculture activities for this aspect are practically unstudied (Teodoro et al., 2010; Toefy and Gibbons, 2014). For these reason, presented study was important for understanding the role and extent of elemental concentration due to farming activities on foraminiferal assemblages within impacted areas.

Although the majority of papers document changes in assemblage composition on polluted sites, different test deformations and even local extinctions, there are several papers pointing to complexity of foraminiferal community dynamics in polluted environments and difficulties in separating natural faunal properties from pollution effects (Alve, 1995; Coccioni et al., 2009; Samir, 2000; Geslin et al., 2002).

The object of this study is to define the intensity and spatial extent of the effects on foraminiferal assemblages in sediments near Vrgada Island affected due to fish farming activity. In order to accomplish the accurate interpretation of faunal changes within investigated sediment samples, the following aims were set: (1) to analyze standard biological properties of the foraminiferal community (abundance of species, changes in faunal composition and species dominance, biodiversity indices) in comparison with relevant physical and geochemical properties of the sediment (grain size characteristics, elemental concentrations), (2) to observe changes in listed biological, geochemical and sedimentological parameters horizontally – throughout the fish farm area toward the reference station, (3) to observe already mentioned changes vertically – along sediment cores, with a view to document (relative) time succession of environmental and faunal changes, and (4) to examine the suitability of using benthic foraminifera as bioindicators of environmental changes assignable to the effects of fish farming.

2. Study area

The studied fish farm is situated SE of Vrgada Island in the Murter Sea, Central Adriatic (Fig. 1a). Farming area is located around 4 nautical miles from the mainland, coastline between Zadar and Šibenik, and is surrounded by five islands (Vrgada, Murvenjak, Mali and Veliki Školjić and Oblik) (Fig. 1c) that provide protection from the strongest wind and waves. The total area under aquaculture at the time of sampling covered about 10,000 m^2 with water depth between 25 and 30 m. The water circulation within aquaculture area is mainly influenced by the predominant direction of Adriatic water current (SE-NW) and daily tides. Geologically, the surrounding hinterland consists mainly of carbonates (limestone, dolomites) from Cretaceous to Eocene age (Fig. 1b) (Mužimić, 1966).

The fish farm was set up in 1998 and operated till 2011. It produced about 550 tons of sea bass (*Dicentrarchus labrax*) and sea bream (*Sparus aurata*) annualy. Fish was breeded exclusively for the Italian market. Farm consisted of three systems of about 12–16 polyetilene–polypropilene cages. Diameters of cages were between 12 and 22 m, depending on the fish size and age. Fish production ran throughout the whole year, with new generation being settled between April and July and catched of during the whole summer. The amount of productivity was due to the highest breeding of fishes obviously higher during the summer, while during the winter the amount of farming productivity inflow was evidently reduced. Fishes were fed by hand with extracted pellets of different sizes and from different producers. The average composition of used pellets were: 44% proteins, 19% fat, 9% ash, 10% moisture, 1.0–1.4% phosphor and 7.5 mg/kg cooper.

Sediment samples were collected at three selected locations within the aquaculture area with different amounts of impact due to fish farming activity. The first location (FV1) was positioned directly below the cage, the second one (FV2) at the edge of the cage system and the reference station (FV3) for about 30 m away of the farming area (Fig. 1c). The water depth between the locations varied from 20.4 m at the sampling location FV1, 24 m at the location FV2 and 26.5 m at the reference location FV3.

3. Materials and methods

3.1. Sampling

Sediment samples were collected with scuba diving using plastic corers. The penetration depth of sediment corers was between 9 and 16 cm, depending on sediment consolidation. After sampling, sediment corers were immediately stored in a cool box and later frozen. In the laboratory, sediment was prepared for further analyses.

3.2. Granulometrical analyses

Grain size analyses of sediment samples were carried out using dry sieving method. Sediment samples were sieved through the eight ASTM standard stainless sieves which separated sediment into eight size fractions from very fine gravel (>5 mm) to mud (<0.063 mm). After 15 min of sieving in electrical shaker, separate sediment fraction was weighted and the results were calculated using statistical program Gradistat (Blott and Pye, 2001).

3.3. Geochemical analyses

For multi-elemental analyses, sediment corers were sliced in 2–4 cm and cool-dried (lyophilized) for at least 72 h until a constant weight has been reached. Dried sediment were homogenized and crushed to a fine powder by grinding in an agate mortar. Powdered samples were packed into plastic vessels.

Elemental composition of sediment samples were analysed using mobile Handheld Thermo Scientific Niton XL3t-GOLDD 900S-He energy-dispersive X-ray fluorescence (EDXRF) analyser. This is a non-destructive method. For about 3 g of powdered samples were put into stainless capsules and with hand-held press containing stainless hammer were pressed into pills. In the process of measurement two separate modules were used: 'Mining' module for major elements and 'Soil' module for trace elements. In case of 'Mining' module was used, helium (He) gas was pumped into the analyser, which enables better detection of light elements (Mg, Si, Al, S, P). The time of measurement on each sample was 120 s with 'Mining' module and 180 s with 'Soil' module. The accuracy and precision of the analyses were checked against the reference standards and duplicates of measured samples and were found to be within ±10%. Six international reference standard (NIST-1633a: coal fly ash, NIST-2780: waste, mine, NIST-1d: limestone, NIST-88b: dolomitic limestone, NIST-2709a: San Joaquin soil, W-2: diabase) were measured and were compared with defined international reference values.

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