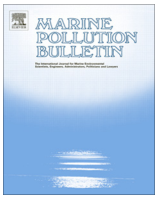
Marine Pollution Bulletin 90 (2015) 227–241

Contents lists available at ScienceDirect

Marine Pollution Bulletin

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



Distribution of trace metals and the benthic foraminiferal assemblage as a characterization of the environment in the north Minjiang River Estuary (Fujian, China)

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ARTICLE INFO

Article history:
Available online 17 November 2014

Keywords:
Benthic foraminifera
Trace metal pollution
Multivariate statistical analysis
Self-organizing map
Minjiang River Estuary

ABSTRACT

A study of the total benthic foraminifera was carried out in 173 surficial sediment samples collected from the north Minjiang River Estuary and two bays. Foraminiferal assemblages are dominated by *Ammonia tepida* and subordinately by *Elphidium advenum*. Trace metal analyses reveal that the study area is unpolluted to moderately polluted with As, Cr, Cu, Ni, Pb, and Zn. The metal distribution has an affinity with fine-grained sediment. Five metal groups are recognized based on their distribution patterns: (1) As, Cr, Cu, Ga, Ni, V, and Zn, (2) Hg, Pb, and Sb, (3) Ba and Zr, (4) Rb and Y, and (5) Sr. The species-environment relationship showed that the species composition is adversely influenced by Cr, Cu, Ga, Pb, Rb, Zn, and Zr, whereas sand may exert a positive influence on *Quinqueloculina*. This study supports the adaptability of using benthic foraminifera as bio-monitors of trace metal pollution in marginal marine environments.

1. Introduction

With industrialization and urban development in estuarine and coastal areas, pollution in these environments has been a problem for human health. The marine environments are continuously threatened by chemical contamination caused by the discharge of domestic and industrial waste, agricultural and fishing activities, spilling of oil, etc. River mouths occupy a transitional freshwater–seawater interface zone, and the hydrodynamic processes prevailing there efficiently trap fluvial particles because the physiochemical conditions change significantly through the mixing of fresh water and seawater (Anthony, 2009). This behavior limits suspended components transport to the open sea and makes estuarine sediments the ultimate destination of sediments-associated contaminants (Szefer et al., 1995; Ip et al., 2004).

Trace metals are considered one of the most serious pollutants in nature due to their toxicity, persistence and bioaccumulation problems (Tam and Wong, 2000). These chemicals have been long used for environmental monitoring, but they do not provide information on how the ecosystem has been affected (Selvin et al., 2008). The living organisms, including macro- and meio-fauna (seabirds, mammals, sponges, foraminifera, ostracoda, etc.), on the contrary, reveal the adverse effects by the accumulation of metals in their tissues (Bergin et al., 2006; Selvin et al., 2008). The utilization of foraminifera assemblages as bioindicators of pollution has some advantages: (1) They have a short life span and therefore respond rapidly to environmental changes; (2) they are abundant and diverse; (3) they are small, and their hard tests are well-preserved in sediments; (4) they are widely distributed and almost immobile, and their taxonomy and ecological distribution is well-known; (5) some opportunistic species exist in severely polluted areas where other eukaryote organisms disappear; they may benefit from certain types of pollutants (Schafer, 2000; Murray, 2006; Carnahan et al., 2008, 2009; Debenay and Fernandez, 2009). Besides, dead assemblage of foraminifera can reconstruct the history of the human impact on marine ecosystems (e.g., Elberling et al. (2003), Hayward et al. (2004). Ruiz et al. (2004), Scott et al. (2005), Irabien et al. (2008), Tsujimoto et al. (2008), Alve et al. (2009), Bergamin et al. (2009), Debenay and Fernandez (2009), Dolven et al. (2013)). For the past few decades, researchers developed the utilization of benthic foraminifera to monitor different types of chemical pollutant contamination (Alve, 1995; Armynot du Châtelet and Debenay, 2010; Frontalini and Coccioni, 2011), particular trace metal contamination (i.e., Ellison et al. (1986), Yanko et al. (1998), Elberling et al. (2003), Bergin et al. (2006), Ferraro et al. (2006), Carnahan et al. (2008), Frontalini and Coccioni (2008), Alve et al. (2009), Coccioni et al. (2009), Frontalini et al. (2010), Cosentino et al. (2013), Li et al.

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http://dx.doi.org/10.1016/j.marpolbul.2014.10.047
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(2013, 2014)). The fundamental aim is to increase understanding of how foraminifera interact with trace metals. The majority of the literatures focuses on the field-based studies on assemblage composition, abundance and diversity patterns, whereas a few examples analyze the response of special species to metal concentration on culture conditions (e.g., Saraswat et al. (2004), Le Cadre and Debenay (2006)).

The current research aims to (1) identify the distribution patterns of benthic foraminiferal assemblages in the north Minjiang River Estuary (MRE), (2) classify the trace metals by the SOM and PCA and compare them, (3) interpret the dynamics of trace metal distributions on the basis of sediment transport, and (4) examine the variance of the foraminiferal assemblage response to the environmental factors.

2. Study area

The Minjiang River is the largest river in Fujian Province, flowing into the East China Sea in East Fujian (Fig. 1a). The drainage basin of the Minjiang River system covers an area of approximately 6.1 × 10^4 km^2. The current study focuses on the north section of the MRE and two partly enclosed bays: Sansha Bay and Luoyuan Bay (Fig. 1b). Sansha Bay appears as a stretched rightward-curving area. This bay is surrounded by mountains, presenting a sinuous shoreline. In the southeast, there is only one narrow outlet to the East China Sea. The fresh water inflow to the bay is mainly discharged into the northern inlet by two small rivers, the Huotongxi and the Saijiang. This bay is divided into three sub-bays: Sansha-ao, Shadouwan, and Dongwuyang (Fig. 1c). Luoyuan Bay is fallen gourd-shaped. It connects with the East China Sea by a narrow outlet lying to the northeast. A small stream called the Qibuxi carries fresh water into the bay, which has no other important source of fresh water inflow. The submarine topographic features of the two bays are mainly affected by the tidal current (Chen et al., 1994). Broad mudflats deposit along the shoreline, and a tidal ridge system forms within the inner and outer bays. The MRE is formed by the outflow of the Minjiang River. Near the river mouth, the outflow is blocked by Langqi Island and subsequently divides into two branches. A submerged delta develops at the front of the river mouth with water depths shallower than 15 m, and its east boundary reaches to the Matsu Islands (Chen et al., 1998).

The hydrography of the study area is more thoroughly described by Fu and Hu (1989), Chen et al. (1994) and Chen et al. (1998) but can be summarized as follows. In the study area, the strongest winds blow from the southeast, which lead to an ordinary northeast direction wave. Semidiurnal tides predominate the two bays from the perspective of the tidal coefficient (between 0.1 and 0.2). Generally, tidal energy is higher in the flooding phase and descends when the tide is ebbing. In the Sansha Bay, the surface residual current flows toward the north in summer and toward the southeast in winter, but the direction of the bottom residual current reverses in the summer and winter. In the Luoyuan Bay, the coastal residual current converges at the surface and then down to the subsurface or near the sea bed surface, where it diffuses outward. The formation of the MRE is impacted by the tidal current, river runoff, and waves, while the tidal and river current dominates the region. The surface residual current flows from land to sea, while the bottom residual current flows in the opposite direction.

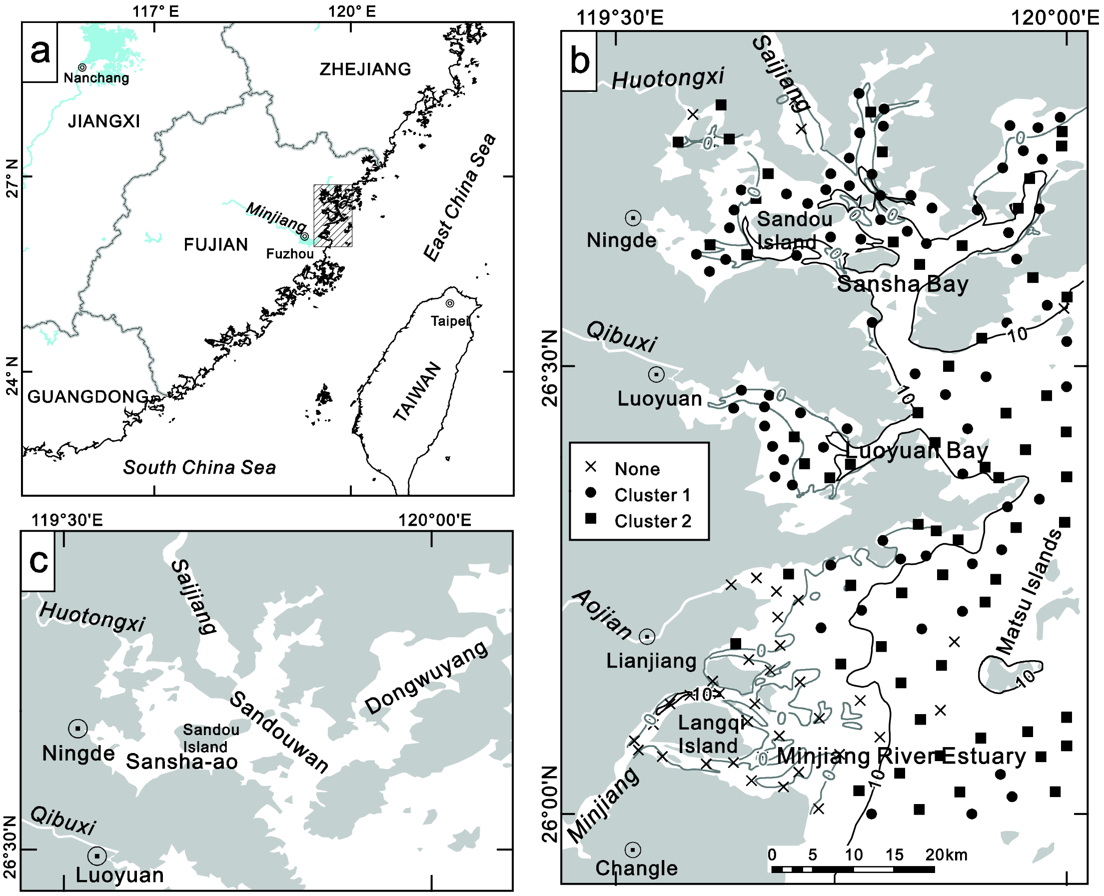

Fig. 1. Maps displaying the study area (a), sampling locations (b), and the Sansha Bay (c). Site coordinates are included in Appendix A. Samples are classified on the basis of Q-mode cluster analysis.