Marine Pollution Bulletin 109 (2016) 393–401

Contents lists available at ScienceDirect

Marine Pollution Bulletin

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

Effects of sedimentary sulfide on community structure, population dynamics, and colonization depth of macrozoobenthos in organic-rich estuarine sediments

Gen Kanaya [a,b,*], Tadayasu Uehara [c], Eisuke Kikuchi [a,d]

[a] Biological Institute, Graduate School of Science, Tohoku University, Aramaki-Aoba, Aoba-ku, Sendai 980-8578, Japan
[b] National Institute for Environmental Studies, 16-2 Onogawa, Tsukuba 305-8506, Japan
[c] Emeritus Professor, Tohoku Gakuin University, Japan
[d] EEC, Miyagi University of Education, 149 Aramaki-Aoba, Sendai 980-0845, Japan

ARTICLE INFO

Article history:
Received 4 February 2016
Received in revised form 16 May 2016
Accepted 18 May 2016
Available online 24 May 2016

Keywords:
Brackish lagoon
Community structure
Sulfide
Macrozoobenthos
Sediment
Recolonization

ABSTRACT

An annual field survey and in situ recolonization experiment revealed the effects of sedimentary sulfide (H_2S) on macrozoobenthos in a eutrophic brackish lagoon. Species diversity was much lower throughout the year in muddy opportunist-dominant sulfidic areas. Mass mortality occurred during warmer months under elevated H_2S levels. An enclosure experiment demonstrated that sedimentary H_2S modified community composition, size structure, and colonization depth of macrozoobenthos. Species-specific responses to each sediment type (sand, sulfidic mud, and mud with H_2S removed) resulted in changes in the established community structure. Dominant polychaetes (*Hediste* spp., *Pseudopolydora* spp., and *Capitella teleta*) occurred predominantly in a thin surface layer in the presence of H_2S. On the other hand, organic-rich mud facilitated settlement of polychaete larvae if it does not contain H_2S. These results demonstrate that sediment characteristics, including H_2S level and organic content, were key structuring factors for the macrozoobenthic assemblage in organically polluted estuarine sediments.

1. Introduction

Degradation of marine and estuarine ecosystems constitutes a major global environmental problem (Diaz and Rosenberg 2008). Environmental deterioration under ongoing eutrophication seriously affects benthic communities, leading to changes in species diversity, population dynamics, and the spatial distribution of macrozoobenthos (e.g., Llansó 1992; Nilsson and Rosenberg 2000; Como and Magni 2009; Sturdivant et al. 2013; Kanaya et al. 2015a). These changes induce loss of ecosystem functioning in soft-bottom communities along a broader spatial scale (e.g., Altieri and Witman 2006; Diaz and Rosenberg 2008; Sturdivant et al. 2013).

Main lethal effects on the benthic invertebrates associated with organic enrichment are low dissolved oxygen (DO) concentrations, leading to the accumulation of the toxic by-products of anaerobic metabolism (e.g. hydrogen sulfide and ammonia) in the reduced sediments (Gray et al. 2002). The accumulation of sedimentary H_2S, concurrent with hypoxic bottom water, often causes the mass mortality of organisms on the seafloor ("dead zone", see Diaz and Rosenberg 2008). Even at low concentrations, H_2S is highly toxic to aquatic invertebrates, as it inhibits aerobic respiration (Vismann 1991). Exposure to sulfide accelerates the mortality of macrozoobenthos under hypoxic conditions (Gamenick et al. 1996; Vaquer-Sunyer and Duarte 2010; Kozuki et al. 2012), as aquatic invertebrates need oxygen to detoxify H_2S (see Vismann 1991). Hence, the accumulation of H_2S associated with hypoxia can have serious negative effects on the benthic community in organically polluted estuaries.

As eutrophication proceeds, sediment turns anoxic, and anaerobic metabolism prevails (Hargrave et al. 2008). Generally, microbial sulfate reduction prevails in the anaerobic sediment layer of marine sediments (Hargrave et al. 2008), resulting in the release of dissolved sulfides ($H_2S + HS^- + S^{2-}$). Sulfide does not accumulate in a free dissolved form in sediment, as it quickly reacts with metals, such as iron, and precipitates as insoluble sulfide (Heijs et al. 1999). However, under excess organic loading, sulfide production exceeds the buffering capacity of iron in the sediment (Heijs et al. 1999), which leads to the accumulation of free H_2S (Marvin-DiPasquale and Capone 1998).

Gamo Lagoon (38.257°N, 141.014°E) is a shallow eutrophic lagoon located on the northern side of the Nanakita River estuary, Sendai Bay, Japan. Organic-rich mud containing high levels of H_2S was distributed in the northern subtidal portion of this lagoon (Kanaya and Kikuchi 2004; Kanaya et al. 2015b). In our previous study, we investigated the effects of sedimentary H_2S on the macrozoobenthic community structure in an in situ recolonization experiment using sediment with

* Corresponding author at: National Institute for Environmental Studies, 16-2 Onogawa, Tsukuba 305-8506, Japan.
E-mail address: gen@nies.go.jp (G. Kanaya).

http://dx.doi.org/10.1016/j.marpolbul.2016.05.043
0025-326X/

controlled H_2S contents (Kanaya 2014). However, the H_2S-induced alterations in population structure and the colonization depth of the macrozoobenthos were not fully examined.

In this study, the effects of the H_2S accumulation in the sediment were tested in Gamo Lagoon through a combination of annual field monitoring and a recolonization experiment using sediment-filled enclosures with controlled H_2S levels. A novel iron addition method was used to precipitate free H_2S as insoluble FeS (see Kanaya 2014). Specifically, we aimed to determine (1) the effects of environmental variables, including sediment H_2S level, on the population dynamics and assemblage structure of macrozoobenthos in the eutrophic lagoon; and (2) the effects of sediment characteristics (e.g., H_2S, grain size, and organic contents) on the habitat and depth choice and post-settlement survival of macrozoobenthos.

2. Materials and methods

2.1. Study area

Gamo Lagoon (mean water depth: 0.8 m; area: 0.13 km^2) is located on the northern side of the Nanakita River estuary in Sendai Bay, northeastern Japan (Fig. 1). The lagoon is separated from the river by a stone levee with three water gates. Tides are semi-diurnal with a 0.5 m range, and salinity fluctuates from near 10 to >30 (Kurihara et al. 1997). The inner stagnant area is highly eutrophic with a maximum chlorophyll *a* concentration > 100 μg L^{-1} (Kikuchi et al. 1992). The water in the lagoon often becomes anoxic at night during the summer and fall (Kurihara et al. 1997). Sediment in the inner portion is sulfidic and muddy (silt-clay > 50%), whereas it is sandier and oxidized near the

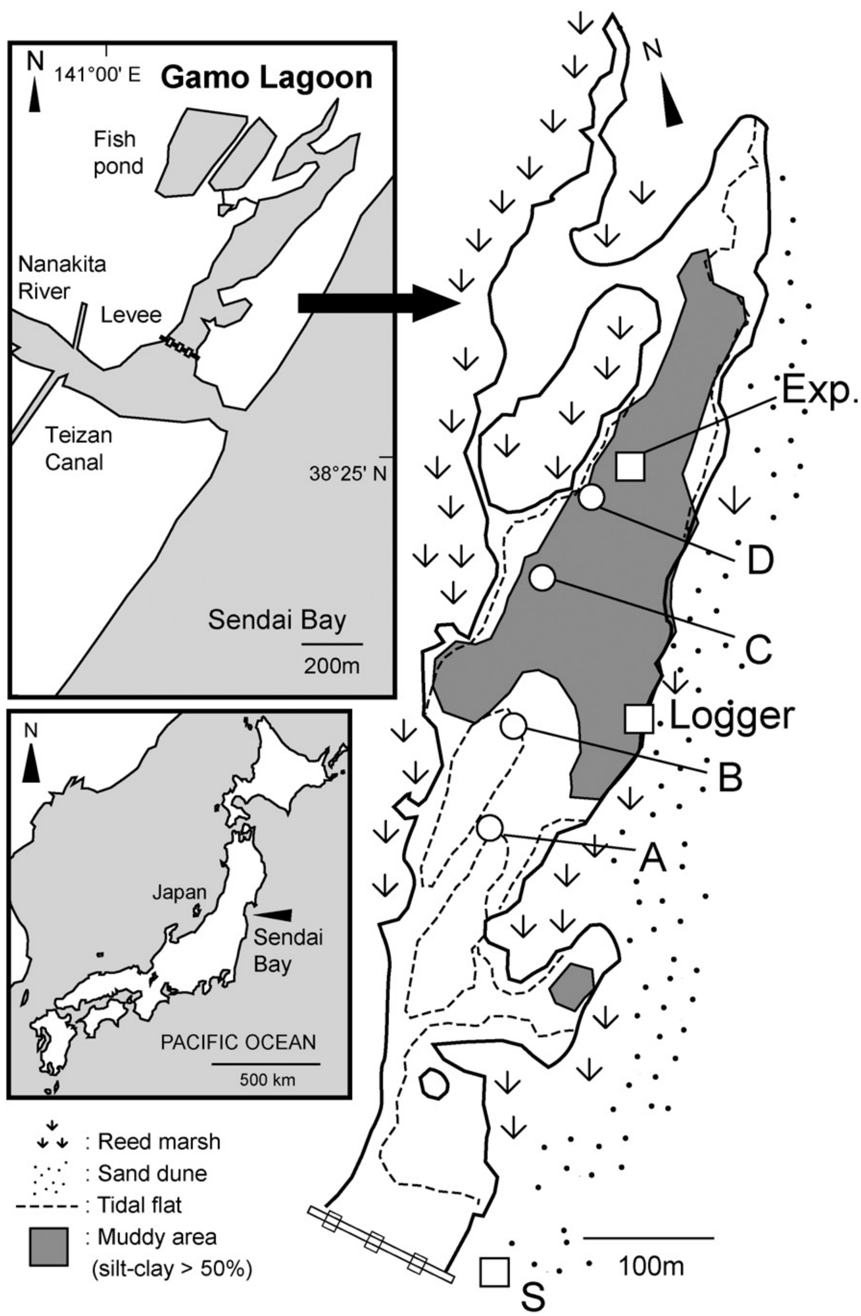

Fig. 1. Map of the study site. Stations for annual monitoring (St. A–D) and enclosure experiment (St. Exp.) are shown. Salinity was logged at St. Logger, and azoic sand for the experiment was collected at the sand bar (St. S). Broken line indicates water level during spring low tides. Grayed area indicates muddy sediment (data from Kanaya et al. 2015b).