Marine Pollution Bulletin 109 (2016) 205–220

Contents lists available at ScienceDirect

Marine Pollution Bulletin

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

Effect of abalone farming on seawater movement and benthic foraminiferal assemblage of *Zostera marina* in the inner bay of Wando, South Korea

Yeon Gyu Lee [a,*], Yang Ho Choi [b], Da Un Jeong [a], Jung Sick Lee [c], Yong Wan Kim [d], Jung Jun Park [b], Jae Ung Choi [a]

[a] Faculty of Marine Technology, Chonnam National University, Yeosu 59626, South Korea
[b] South Sea Fisheries Research Institute, NIFS, Yeosu 59780, South Korea
[c] Department of Aqualife Medicine, Chonnam National University, Yeosu 59626, South Korea
[d] Center for Research Facilities, Chonnam National University, Yeosu 59626, South Korea

ARTICLE INFO

Article history:
Received 24 March 2016
Received in revised form 30 May 2016
Accepted 31 May 2016
Available online 7 June 2016

Keywords:
Abalone farming
Benthic foraminifera
Zostera marina
Wando

ABSTRACT

Tidal current survey as well as geochemical and benthic foraminiferal analyses of sediment cores were conducted in an abalone farm and a *Zostera* bed to understand the degree to which the abalone farm facilities installed along a channel in a shallow sea affect the benthic environment and ecology. In the abalone farm, *Ammonia beccarii-Pseudoparrella naraensis-Elphidium somaense-Rosalina globularis-Trochammina hadai* and *P. naraensis-E. somaense-A. beccarii-T. hadai* assemblages appeared owing to an increase in the total nitrogen content from the biodeposits. The *Zostera* bed consisted of *A. beccarii*-P. *naraensis-Buccella frigida-T. hadai* assemblage owing to the gradual expansion of a brackish shallow-water environment by the rapidly decreasing current speed, and it may have flourished. Moreover, the total sulfur, Zn, Cr, and Cu contents in the sediments decreased remarkably more than those of the pre-abalone farming did, caused by the vigorous activity of *Zostera marina* physiology.

1. Introduction

During the last few decades, coastal marine environments have faced various problems caused by urban growth and associated activities, such as the disposal of domestic, agricultural, and industrial wastes in addition to the effluents of aquaculture. These anthropogenic activities influence different segments of a particular ecosystem such as water, sediment, and organisms in particular (Vidovic et al., 2014). The effluents from cage cultures in aquaculture including fish, mussel, and abalone farms are composed of mainly uneaten food, and fecal and urinary products. These are released directly into the surrounding environment and result in many environmental problems such as eutrophication, growth retardation, and changes in the benthos communities (Guo and Li, 2003; Yucel-Gier et al., 2007; McKindsey et al., 2011; Kang et al., 2015; Lee et al., 2016). The extent of the environmental impact of aquaculture depends on the amount of nutrients and organic matter (OM) released as well as the hydrodynamic processes such as waves, current activity, and water residence time (Ackefors and Enell, 1994; Wu, 1995; Aure et al., 2007; Duarte et al., 2008; Stevens et al., 2008; Strohmeier et al., 2008).

Abalone, which is a common name for any group of small to very large edible sea snails or marine gastropod molluscs belonging to the family Haliotidae, are macroalgal herbivores feeding on the most prevalent types of algae found in a particular area (Geiger, 1991; Shepherd and Steinberg, 1992). Because natural abalone stocks have dwindled, aquaculture has become an important alternative to fisheries (Olin and Schlosser, 2008). The principal abalone farming regions are China, Taiwan, Japan, and Korea. In farming, the juveniles are grown to the market size by using a variety of implements and methods, such as long-line rafts, sea cages or barrels, land-based tanks, intertidal ponds, and stock enhancement (Lucas and Southgate, 2012). However, abalone farming has received relatively little attention, even though it creates a greater potential risk of contamination in marine sediments as compared to fish farms and many effluents discharged from the abalone farming activities in long-line rafts systems flow into the marine sediments (Kang et al., 2015).

Seagrasses, which are marine flowering plants found in the littoral zone of the tropical and temperate seas, are known as "ecosystem engineers." Their advantages include (1) enhancing biodiversity (Boström and Bonsdorff, 1997; Ellison et al., 2005; Bos et al., 2007), (2) providing oxygenated habitats and food for both epifaunal and infaunal species (Bouma et al., 2009), and (3) reducing the current velocity, thereby enhancing the entrapment of suspended sediments and organic matter (Fonseca and Fisher, 1986; Ganthy et al., 2013). Seagrass beds are important in the primary production, nutrient cycling, sediment and

* Corresponding author.
E-mail addresses: lyg6342@jnu.ac.kr (Y.G. Lee), plumechoi@korea.kr (Y.H. Choi), daun@jnu.ac.kr (D.U. Jeong), ljs@jnu.ac.kr (J.S. Lee), marrytime@jnu.ac.kr (Y.W. Kim), pjj515@korea.kr (J.J. Park), jaeung.c@gmail.com (J.U. Choi).

http://dx.doi.org/10.1016/j.marpolbul.2016.05.081
0025-326X/

nutrient trapping, and sediment stabilization, and their structural complexity is critical for the animals inhabiting them (Orth et al., 2006). Meiofauna is more abundant and diverse in vegetated sediments than in adjacent bare sediments (Guerrini et al., 1998; Fisher and Sheaves, 2003). Seagrass beds most often grow in highly reduced sediments with high concentrations of potentially toxic compounds such as reduced manganese, iron, and sulfur (Terrados et al., 1999; Hemminga and Duarte, 2000). They also play a major role in the biogeochemistry of vegetated sediments (Plus et al., 2001; Ouisse et al., 2010), especially in the nitrogen and phosphorus recycling within the sediments (Deborde et al., 2008; Delgard et al., 2013; Cesbron et al., 2016).

Since the early 1960s, benthic foraminifera have been used as a tool for monitoring the human impact on marine environments, (Zalesny, 1959; Resig, 1960; Watkins, 1961) because their short life cycles and high biodiversity make them highly sensitive to environmental stress (Murray, 1991). Among the different studies on anthropogenic contamination sources, most have focused on organic pollution caused by biodeposits discharged from aquaculture, which is enhanced by organic matter inputs usually related to the farming of fish (Schafer et al., 1995; Scott et al., 1995; Angel et al., 2000; La Rosa et al., 2001; Kalantzi and Karakassis, 2006; Sutherland et al., 2007; Vidovic et al., 2009, 2014; Ellis et al., 2014; Thornberg et al., 2014), and to a lesser extent, shellfish (Bouchet et al., 2007; Grenfell et al., 2007; Tarasova and Preobrazhenskaya, 2007; Lee et al., 2016). Thus, little is known on the effects of such contamination on the benthic foraminiferal assemblages that inhabit seagrass and seagrass ecology.

The commercial-scale production of abalone (*Haliotis discus hannai*) in Korea began in the 2000s. As of 2011, abalone production reached about 7000 t. The abalone production system in Korea is divided into two stages: seed production and rearing (Park and Kim, 2013). Seed production begins generally in the middle of April in about 500 small-scale hatcheries. Juvenile abalone are transferred to sea cages 2.4 m × 2.4 m × 2.5 m in width, length, and depth, respectively, for culturing through November and December. Nearly all abalone farmers in Korea use this method. These abalone cages are distributed mostly along shallow coastal areas with seagrass or seaweed beds (Kang et al., 2015). The objective of this study is to define the effect of abalone farm facilities on seawater movement and that of biodeposits discharged from abalone farms on the benthic foraminiferal assemblages that inhabit seagrass and the environmental habitat of seagrass. This research has conducted a seasonal hydrographic and anchor mooring survey, and sediment core collection at an abalone farm area and a *Zostera* bed.

2. Study area

Wando is located off the southwest coasts of Korea at a shallow water depth of ~50 m and a tidal range of ~3.5 m (KHOA, 2010; Fig. 1). In summer, the water temperature, salinity, and dissolved oxygen are 15.19 °C–24.97 °C, 32.41–34.04 psu, and 7.40–9.14 mg/L, respectively (Oh et al., 2008). The area southwest of Nohwado, which is located to the southwest of Wando, is a littoral zone in a tidal flat along a 12-m-deep channel flowing northwest–southeast between Bogildo and Nohwado (Fig. 1-A). The abalone farm facilities have many cages distributed along the channel in an area of approximately 25–50 m in width × 7.5 km in length. The *Zostera* bed is located in an inner area of the shallow sea on a subtidal flat, about 1–2 m deep, in Jalpori and is almost separated from the channel by hydro-geomorphology (Fig. 1-B).

The seagrass is composed of eelgrass growing on the southern coast of Korea and includes *Z. marina*, *Zostera asiatica*, *Zostera caulescens*, *Zostera caespitosa*, and *Zostera japonica* (Shin and Choi, 1998; Ok et al., 2013). *Z. marina* is mostly distributed at the shallow bay, tidal flats, and subtidal zones in Korea (Ok et al., 2013).

The basement rocks around Wando are composed of Cretaceous rhyolite, rhyolitic tuff, and biotite granite (KIGAM, 2002).

3. Materials and methods

3.1. Tidal current survey

To investigate the tidal current in the study area, seasonal hydrographic surveys were conducted by using a direct-reading current meter (Z-Pulse, Aanderaa, Norway) and a mooring current meter (Seaguard RCM, Aanderaa, Norway) at nine stations (stations 1–9) (Fig. 1). In addition, the Eulerian time series datasets of hydrodynamic conditions were collected continuously at sampling intervals of 10 min. Data collected from 3 × 3 lattice images of nine stations were converted to 18 × 18 lattice images of optimal interpolation data by using the kriging method (Cressie, 1991).

3.2. Sediment core sampling

A core sample 76 mm in diameter and 32 cm in length was collected from station 5 and from station 8 (Fig. 1). These cores were analyzed for grain size, trace metals, geochemical characteristics, ^{210}Pb radioactivity, and benthic foraminiferal assemblages. Stations 5 and 8 are located in the central part of the abalone farm and *Zostera* bed, respectively.

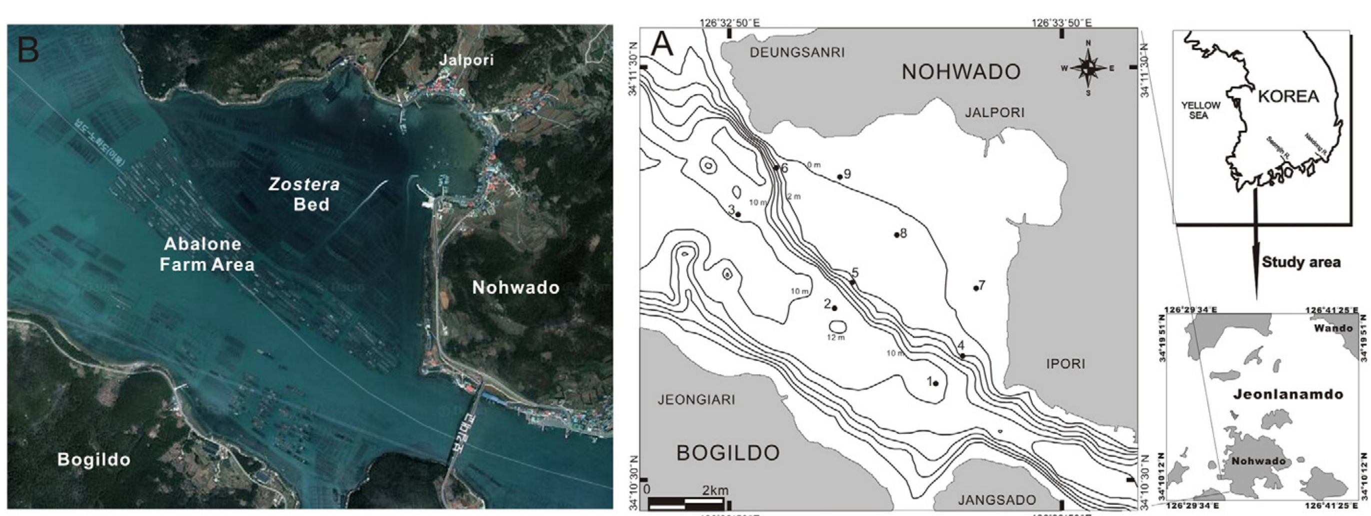

Fig. 1. Sample locations of sediment cores 5 and 8, locations (1–9) of seasonal hydrographic survey, and bathymetric map of Jalpori located on the southwest coast of Nohwado, Wando, South Korea.