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Removal of *Cochlodinium polykrikoides* by dredged sediment: A field study

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ABSTRACT

A 2-year field study was conducted in November 2006 at Haejin and September 2007 at Namhae, South Korea to exterminate harmful bloom, *Cochlodinium polykrikoides*, by sediment-based materials. Slaked lime, quicklime and an aluminum sludge were mixed with sediment for the Haejin field. Bentonite, zeolite and quicklime were mixed with sediment for the Namhae field. Before and after sediment spray, seawater samples were collected at three depths (surface, middle and bottom) at each site and the characteristics (pH, temperature and salinity) were monitored. All samples were fixed immediately with Lugol's solution for cell counting. The results showed no changes in pH, temperature and salinity of seawater after spraying of the materials but rapidly reduced seawater turbidity due to the settling of sediment particles. The *C. ploykrikoides* cell density decreased rapidly according with elapsed time after the spraying of all sediment-based materials. No significant differences in the percent removal efficiency were found across the sediment materials. However, this study clearly indicated that the removal efficiency of the *C. polykrikoides* depended on the initial cell density. The above results indicate that sediment could be effective for red tide control.

1. Introduction

Red tide, or harmful algal blooms (HABs) are natural phenomena that occur as plankton propagates in large numbers, resulting in a red coloration of the seawater. Red tide in seawater has been reported in Japan, Korea, and other countries, and frequently causes severe damage to fish farming (Onoue and Nozawa, 1989; Yuki and Yoshimatsu, 1989; Whyte et al., 2001). *Cochlodinium polykrikoides* is one of the most frequent harmful algal blooms responsible for fish kills (Jeong et al., 2003; Onoue and Nozawa, 1989; Yuki and Yoshimatsu, 1989), and it occurs annually in the coastal water of Korea, causing significant damage (Kim et al., 2007).

Until now, spraying of clay (Han and Kim, 2001; Anderson, 1997; Pan, 1998; Sengco et al., 2001; Sun et al., 2004), surface-changed modified clay, poly aluminum chloride-treated clay (Yu et al., 1999; Sengco et al., 2001), acid-treated clay (Maruyama et al., 1987), local soils (Pan et al., 2006; Zou et al., 2006) and algicidal or microbial enzymes (Fukami et al., 1991, 1992; Imai et al., 1993, 1995; Yoshinaga et al., 1995, 1997; Kim, 1998; Lovejoy et al., 1998) has been used to control harmful algal blooms. However, the above mechanisms are problematic due to the requirement of huge amounts of materials (Pierce et al., 2004; Sengco et al., 2001; Yu et al., 1994a,b, 1995), and the fact that they may significantly change the nature of the environment (Han and Kim, 2001; Pan et al., 2006) and they may harm the organisms living at the bottom of the sea (Bricelj and Malouf, 1984; Rhoads and Young, 1970). Marvin and Proctor (1967) and Shirota (1989) used flocculants in marine systems to control red tides, though the impact of their results was limited due to the rapid dilution of the flocculants and the high cost of application. Chemical agents, such as copper sulfate (Steidinger, 1983), hydrogen peroxide (Ryu et al., 1998), and triosyn (Koji et al., 1998), are effective in controlling blooms within a short period after application, but their use in aquatic ecosystems is potentially dangerous.

Coastal sediment has a similar geochemical composition to clay as both sediment and clay have small particle sizes and large surface areas. Moreover, large amounts of sediment dredged in the Busan new port site have been dumped over 70 years, exceeding

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Table 1
Characteristics of the coastal sediment used in this study.

Basic characteristics		Heavy metals ($mg\,kg^{-1}$)		Size distribution (%)	
Total solid (TS) (%)	32.1	Cd	0.15	<100 μm	92.1
Volatile solid (VS) (%)	7.7	Pb	1.6	100–200 μm	2.1
Total nitrogen (TN) ($mg\,kg^{-1}$)	1.5	Ni	1.1	200 μm–2 mm	3.7
Total phosphorus (TP) ($mg\,kg^{-1}$)	28.7	Cu and Cr	BDL	>2 mm	2.1
COD ($mg\,kg^{-1}$)	26,582	Zn	0.3		
Water content (%)	67.9	Fe	0.4		
		Mn	8.8		

BDL—below detection limit.

the computation range. Therefore, this preliminary study investigates the effects and practicability of using dredged sediment to remove *C. polykrikoides* algal blooms in the field. This process was carried out in November 2006 and September 2007 in coastal areas near Haejin and Namhae, respectively. Slaked lime, quicklime, aluminum sludge, bentonite and zeolite were mixed with the sediment and the *C. polykrikoides* removal efficiency was studied.

2. Materials and methods

2.1. General

The bulk of coastal sediment was collected from the Busan port construction site in November 2006. The physico-chemical characteristics of the sediment are shown in Table 1. The water content of the sediment was about 68%, and the organic matter was 26,600 mg COD kg^{-1}. Small sediment particles, less than 100 μm in diameter, formed over 92% of the sediment. This indicates that the size of the sediment particles was fairly even compared to the yellow loess that was used for red tide control in Korea (Kim, 2000a,b; Kim and Yun, 2002). The heavy metal contents in the sediment were less than the Korean standard guidelines for soil contamination concern.

A 2-year field study was conducted in November 2006 and September 2007 at red tide warning forced areas near Haejin and Namhae to evaluate the effect of sediment on controlling red tide. The sediment and the mixtures were moved to a coastal sea near Haejin, Cheonnam province in Korea, where the red tide organisms, *C. polykrikoides*, appeared in high densities. During the experiment, the density of the red tide organisms and the seawater temperature were 2700 cells ml^{-1} and 25–28 °C. Four sites (H1, H2, H3 and H4) for Haejin field and three sites (N1, N2 and N3) for Namhae field were selected. The distance between the sites was approximately 0.5 km and each field surface area covered 20 m × 40 m (800 m^2). Slaked lime [$Ca(OH)_2$], quicklime (CaO) and an aluminum sludge were mixed with sediment for Haejin field, while bentonite, zeolite and quicklime were mixed with sediment for Namhae field. The proportions of these additives to the sediment are given below. The suspensions were sprayed on the surface of the sea using a pump. In both the fields, the water current was weak because that area was surrounded by other islands and the experiment was performed around the slack tide. The boat's position was maintained over the slowly moving plume for about 10–60 min without using a motor and then receded gradually from the plume. When the boat seemed way off the plume completely, the position was resumed by carefully controlling the boat's speed using a motor. The area sprayed with cell-removing material could be distinguished by the sediment plume. After spraying, the seawater samples were taken from the surface, middle and deep layers using a Van Dorn water sampler before and after 10, 30 and 60 min of spray. The depths of the sampling sites varied (details given in Tables 2 and 3).

2.2. Material preparation for the Haejin field

For each site, 34 kg of sediment (dry basic) were dissolved with 600 l of seawater in the field. Since this was sprayed over an 800 m^2 experimental area, this corresponds to a concentration of 42 g sediment m^{-2}. The dissolved sediment was further treated with slaked lime, quicklime and aluminum sludge for sites H2, H3 and H4, respectively. The untreated dissolved sediment was used for site H1. The additive contents in the mixtures were 3%, 2% and 3% dry weight for slaked lime, quick lime and sludge, respectively.

2.3. Material preparation for the Namhae field

Mixing of sediment with the seawater was difficult in the Haejin field due to high sediment density. For this purpose, in this study, 19 kg of sediment (dry basic) were dissolved with 90 l of seawater in the laboratory before moving to the field. Three kinds

Table 2
Changes in the temperature, pH and salinity of seawater caused by spraying of sediment-based materials in the Haejin field.

Depth	Time (min)	Sediment (H1)			Sediment + slaked lime (H2)			Sediment + quick lime (H3)			Sediment + sludge (H4)		
		Temp. (°C)	pH	Salinity (o/oo)	Temp. (°C)	pH	Salinity (o/oo)	Temp. (°C)	pH	Salinity (o/oo)	Temp. (°C)	pH	Salinity (o/oo)
Surface (0 m)	0	27.0	8.1	30.0	26.6	8.4	30.3	26.7	8.4	30.4	26.6	8.4	30.6
	10	27.0	8.1	30.0	26.7	8.4	30.3	26.6	8.4	30.6	26.4	8.4	30.6
	30	27.0	8.3	30.2	26.8	8.4	30.5	26.9	8.3	30.4	26.3	8.4	30.6
	60	26.9	8.4	30.4	26.3	8.5	30.6	26.3	8.4	30.6	26.2	8.4	30.5
Middle (3 m)	0	26.2	8.3	30.0	26	8.4	30.3	26.4	8.4	30.4	26.4	8.3	30.5
	10	26.2	8.3	30.0	26.3	8.4	30.4	26.5	8.3	30.5	26	8.3	30.5
	30	26.3	8.3	30.1	26.2	8.4	30.6	26.3	8.3	30.5	25.9	8.3	30.5
	60	26.2	8.3	30.5	25.9	8.4	30.5	25.6	8.3	30.5	25.4	8.3	30.5
Bottom (6 m)	0	25.7	8.3	30.1	25.6	8.3	30.3	25.8	8.3	30.4	26.5	8.3	30.6
	10	25.7	8.3	30.1	25.6	8.3	30.3	26.4	8.3	30.5	25.9	8.3	30.5
	30	25.5	8.3	30.2	25.7	8.3	30.5	25.5	8.3	30.5	25.8	8.3	30.5
	60	25.0	8.3	30.5	25.4	8.3	30.6	25.4	8.3	30.6	25	8.3	30.6