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Pumping bottom water to prevent Korean red tide damage caused by *Cochlodinium polykrikoides* Margalef

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Abstract

Cochlodinium polykrikoides Margalef produces annual massive blooms in Korean coastal waters which cause great damage to aquaculture and fisheries. Although various methods have been developed to remove the red tide of *C. polykrikoides*, release of yellow loess has been regarded as the most desirable technique for mitigation for over 10 years. Each August, strong irradiation generates water column stratification separating warm surface from colder bottom waters. Water from a distance of 0 (St. 1), 5 (St. 2), 10 (St. 3), and 15 m (St. 4) was pumped by running a pump for 0, 10, 30 and 90 min and characterized water temperature, salinity collected, suspended solids, Chl-*a*, and phytoplankton including *C. polykrikoides*. After running for 30 min, was temperature and salinity in surface water was similar to those of bottom water, and water column stratification completely reversed after 90 min. Likewise, suspended solids, Chl-*a*, and total phytoplankton cell density decreased after 30 min, but *C. polykrikoides* did not show strong removal because of low cell density during sampling. However, the number of *C. polykrikoides* was significantly diluted (80%) after 90 min. These results suggested that pumping device was as an environmentally-friendly method convenient to be install in fish cages and effective to remove *C. polykrikoides* stratified water column conditions.

Key words

Cochlodinium polykrikoides, Device, Phytoplankton, Red tide, Removal, Underwater

Introduction

The first outbreak of *Cochlodinium polykrikoides* Margalef occurred in 1995 and this dinoflagellate has since than annually recurred in the southern coastal waters of Korea during summer. When *Cochlodinium* red tide is introduced into finfish cage culture by water currents it results in spontaneous fish death (NFRDI, 2000). Initiation, propagation and termination of *Cochlodinium* red tide has been observed in the southern coastal waters but not in western and eastern coastal waters (NFRDI, 2010). Southern coastal waters contain highest production of aquaculture and thus are vulnerable to fish damage due to *Cochlodinium* red tide during summer. Loss of money in 1995 was highest (74 billion Won, NFRDI, 2000) and therefore the Korean government carries out intensive monitoring of red tides during summer. Although various methods and techniques have been developed in Korea, yellow loess has played an important role as a unique tool to remove *Cochlodinium* red tide (Sengco and Anderson, 2004; Lee *et al.*, 2009: Song *et al.*, 2010). However, numerous researchers have suggested that this may harm the organisms living at the bottom of the sea and change the environment, as well as, require significant amount of clay (Pierce *et al.*, 2004; Pan *et al.*, 2006).

To solve this urgent problem, cold bottom water with low density of *C. polykrikoides* was used to remove red tide from the surface instead of using of yellow loess. Kim *et al.* (2010) observed that *C. polykrikoides* had a very strong ability of vertical migration. In summer, strong irradiation by stratification with significant water can cause temperature differences between the surface and bottom waters in fish cage culture. It is thought that cold water temperature at the bottom may destroy all of *Cochlodinium* red tide immediately. Furthermore, as compared to loess application of bottom water is environmentally-friendly. Consequently, the present study was carried out to try a pump device for preventing red tide using bottom water in fish cage culture, and to observe fluctuation of environmental characteristics and composition of phytoplankton during pumping.

Materials and Methods

Study area : Initiation, propagation and termination of *Cochlodinium* blooms were observed in the southern coastal waters and not in the western and eastern coastal waters of Korea (Lee and Kim, 2007). Yeosu (127°50'39"E, 34°40'20"N), lies to the southwestern part of Korea, where first stage of red tide formation occured (Lee, 2006). This area covers only a narrow strip of sea (Lee, 2006) and thus appears to be the best region for trial of device for preventing red tide damage using deep water.

Pump specification : Specification of this device (EMTS, Inha University, Korea) is as follows: drain (20 cm, *h* 10 m) with suction valve at the bottom and extrusion valve in the upper in which is exhibited to height of 2 m from the surface in fish cage; motor with 3,600 rpm min^{-1} and stainless to prevent tarnish from salt water; a faint noise by running the motor; no problem to run for long periods due to seawater cooling system; easy operation due to attached timer and remote sensing; convenient construction , destruction and movement of inter-intra fish cage (Fig. 1).

Experimental design : The present study was carried out three times in August, 2009 and performed in the middle tide time to move water current of ebb and flood according to the tide in Yeosu. Running was carried out for 0, 10, 30 and 90 mins. Temperature and salinity were measured at the surface and bottom by YSI 6920. Samples of suspended solid and Chl-*a* was obtained from surface water through extrusion valve during running and analyzed according to standard methods of Ministry of Maritime Affairs and Fishery (MOMAF, 2002) as soon as possible. Suspended solid) analysis was as follows: samples were filtered by filter paper (GF/F: 0.7 m) and distinguished the weight of filter paper and control. For estimate on of Chl-*a*, samples were filtered by filter paper (0.45 m) and extracted in 90% acetone and measured in spectrophotometer (Perkin Elmer, LS50B). Stations were classified according to the distance of 0 m (St. 1), 5 m (St. 2), 10 m (St. 3) and 15 m (St. 4) from the device.

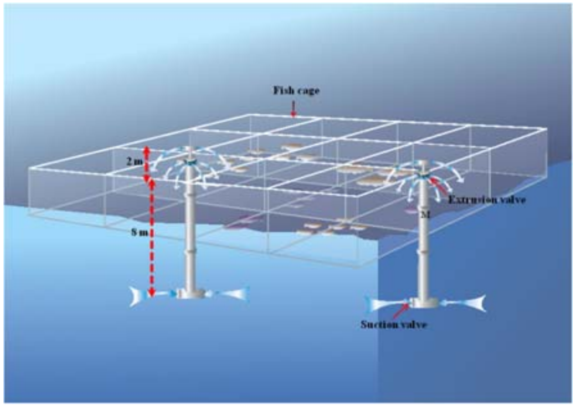

Fig. 1 : Underwater pumping arrangement for preventing red tide damage by *Cochlodinium polykrikoides* in fish cages. M is motor, run at a speed of 3,600 rpm m^{-1}.

Phytoplankton : Phytoplankton samples of a 1 l volume were obtained from the surface at different stations and running times and fixed with 3% Lugol's solution. Stained samples were kept in laboratory for at least 3 days and concentrated to a volume of 5 ml which was observed on Sedgwick-Rafter under light microscope (Olympus, BX50) for counting the number of total phytoplankton and identifying the composition of phytoplankton species level. Two groups of diatoms and dinoflagellates including Raphidophyceae were classified. To count *Cochlodinium polykrikoides*, samples (1 l) were concentrated with a volume of 1 ml using a sieve (10 μm) and directly counted them in the field under a Carl Zeiss microscope.

Results and Discussion

Fig. 2 shows fluctuation in water temperature and salinity at the surface and bottom according to different pump running times and different stations. When the device did not operate (0 min), all the stations had similar water temperature of 24.5°C at the surface and 21.5°C at the bottom. When the device operated for 10 min, no fluctuations in water temperature occured. After 30 min, temperature at the bottom increased approximately by 1ºC at all the stations, but surface temperature decreased. After 90 min, water temperature at the surface and bottom decreased by 1ºC as compared to 30 min after pumping, indicating complete reversal of the conditions at 0 and 10 min. In case of salinity, the bottom value was 2 psu higher (avg. 32.45-32.75 psu) than at the surface (avg. 29.49-29.77 psu) regardless of stations. After 10 min, salinity at the bottom decreased according to stations, with 31.88 psu (avg.) at station 1 to 31.08 psu (avg.) at station 4. Stations 1-3 had similar values of surface salinity (avg. 29.0-29.99 psu), but station 4 had higher salinity (avg. 31.02 psu) showing differences in salinity between surface and bottom. After 30 min, salinity at the surface and bottom had completely changed, indicating that surface increased more (avg. 31.11-31.19 psu) and bottom decreased (avg. 30.08-30.18 psu) as compared to at 0 min and 10 min. Even though the pumping operation extended up to 90 min as compared to 30 min, variability in salinity did not show that the surface and bottom waters were increased and decreased.

Fig. 3 shows variability in suspended solid, Chl-*a,* total cell number of phytoplankton, abundance of dinoflagellates and diatoms and number of *C. polykrikoides* according to operation times and stations. After 0 min, the average range of suspended solid was 98.13-111.06 mg l^{-1}, which did not greatly change even after 90 min. In contrast, the concentration of Chl-*a* at 30 min was five times less (avg. 3.50-3.84 g l^{-1} at 0 min and 10 min to 0.62-1.07 g l^{-1} at 30 min). Station 1 was more influenced than any other station. When operations were completed at 90 min, the

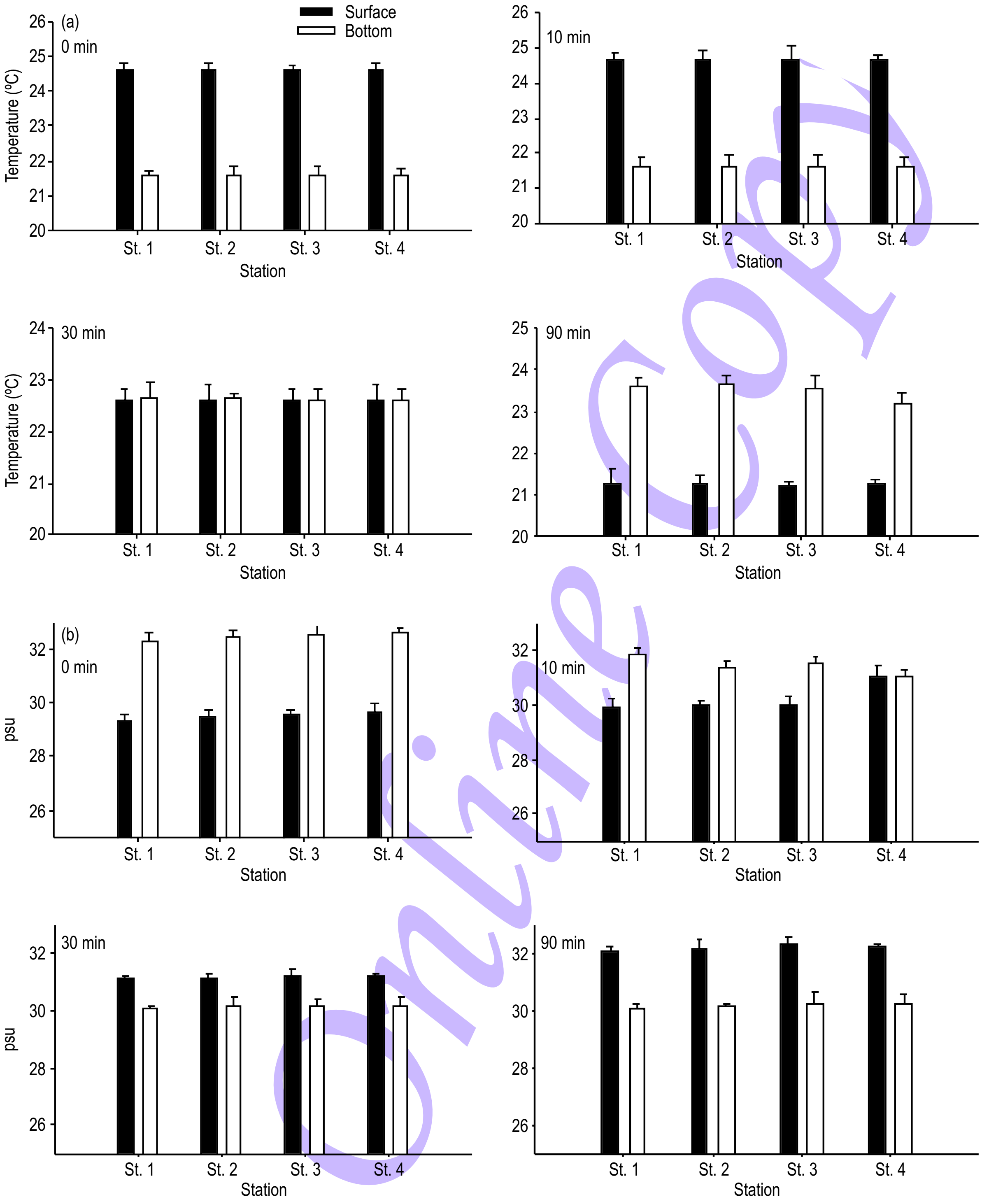

Fig. 2 : Fluctuation in water temperature (a) and salinity (b) at surface and bottom waters of different stations after running for 0, 10, 30 and 90 min. Water temperature and salinity surface and bottom water wad measured at 0 m (St. 1), 5 m (St. 2), 10 m (St. 3), 15 m (St. 4). Error bar means average standard error (*n* = 3)

concentration of Chl-*a* at station 1 (avg. 0.55 g l^{-1}) was approximately same as that at stations 2-4 (avg. 0.58-0.60 g l^{-1}). Without pumping, total phytoplankton ranged from an average of 315 to 546 cell ml^{-1} values which were similar to 10 min. Stations 3 and 4 had lower numbers of phytoplankton than stations 1 and 2. After 30 min, total phytoplankton decreased significantly twice as much as at 0 and 10 min, in particular at stations 1 and 2 it decreased more than at stations 3 and 4. After 90 min, cell number was about 110 cells ml^{-1} regardless of stations. However, the composition of diatoms and dinoflagellates did not vary regardless of running times and stations, with percentage of diatoms ranging from 90.5 to 93.2 and dinoflagellates 5.8 to 9.3.

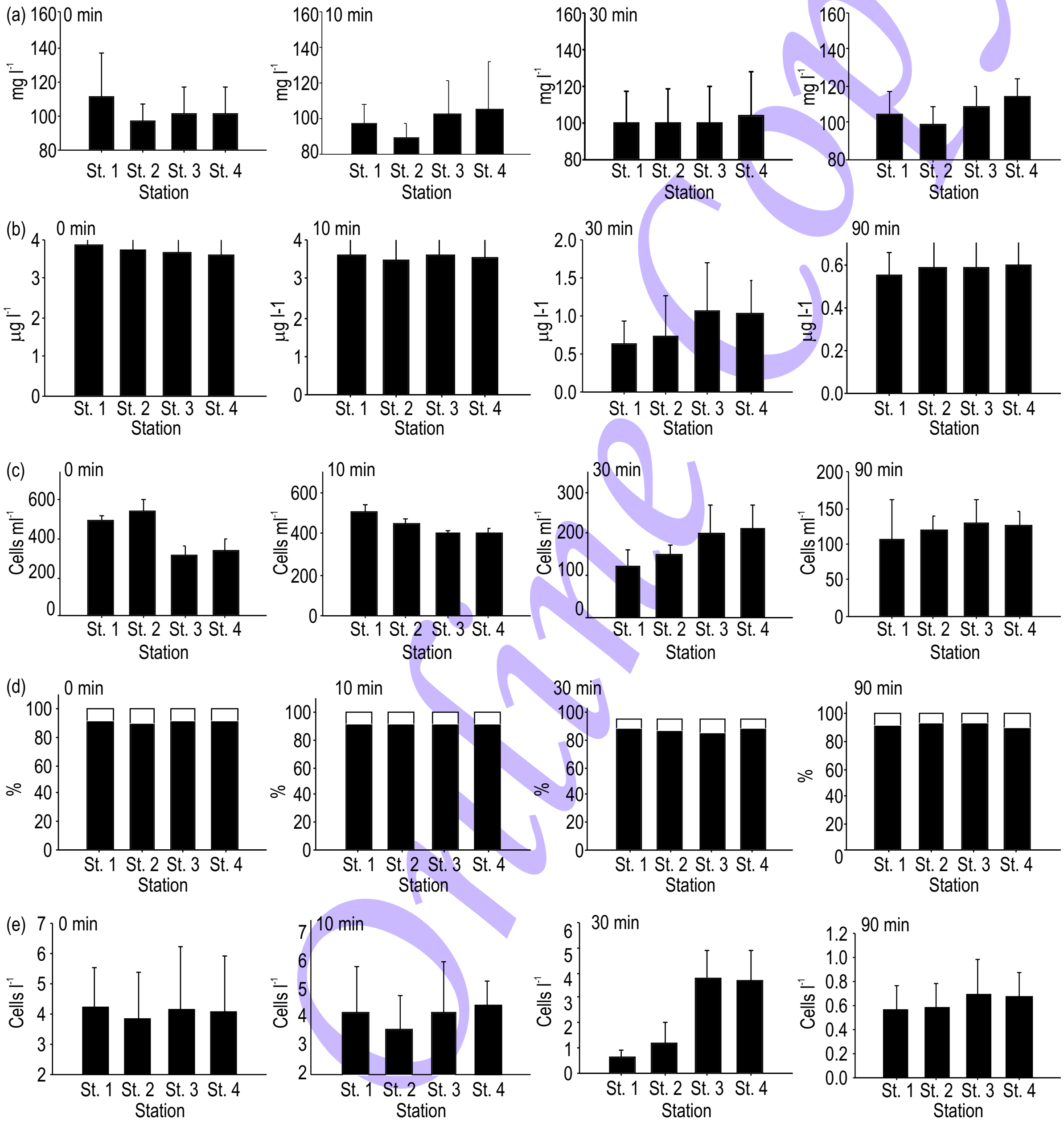

Fig. 3 : Fluctuation in suspended solids (a), Chl-*a* (b), number of total phytoplankton (c) % phytoplankton composition (d) and number of *Cochlodinium polykrikoides* cells (e) at different stations after 0, 10, 30 and 90 min pumping. All water parameters including phytoplankton were obtained from surface water. Phytoplankton composition was divided into two groups: dinoflagellates (white) and diatoms (black) from Fig. 3 (d). Error bar means average standard error ($n = 3$)

For *C. polykrikoides*, the number of cells greatly decreased at stations 1 and 2 after 30 min, with initial cell numbers ranging from 3.5 to 4.3 cells ml^{-1} at 0 and 10 min and *Cochlodinium* cell number at 30 min 0.6 and 1.2 cells ml^{-1} for stations 1 and 2. Stations 3 and 4 did not greatly change even after 30 min but after 90 min the number of cells was a similar value regardless of stations.

The current results show that pumping of deep water greatly contributes in changing water parameters including phytoplankton. In particular, operation after 30 min began to move bottom waters to the surface regardless of stations. Surface and bottom waters were completely reversed in fish cages after 90 min using a motor power of 3,600 rpm min^{-1}, but 30 min from our current results is also beginning to decrease the number of total phytoplankton and the amount of Chl-*a*. However, *C. polykrikoides* in the present study showed little influence under 30 min, but only within 5 m (station 1 and 2) from the motor pump at full operation for 90 min did see a strong decrease even at stations 3 and 4.

During the summer of 2009, massive blooms of *C. polykrikoides* did not occur in the southern coastal waters including the sampling site and in eastern and western waters in Korea where *Gonyaulax polygramma* Stein accured instead (NFRDI, 2010). Sampling sites showed diatoms as dominant above 80% (Fig. 3). *C. polykrikoides* during sampling exhibited a low cell density (below 10 cells ml^{-1}) which might be directly associated with lower removal as compared to total phytoplankton and Chl-*a* under 30 min. When environmental conditions for growth in *C. polykrikoides* are favorable, chain-forming instead of solitary cells can increase the velocity of swimming speed to enhance vertical migration (Kim *et al*., 2010; Smayda, 2010; Sohn *et al*., 2011; Bok *et al*., 2013), resulting in few cells at depth. Pumping of deep water during red tides may significantly dilute and decrease the number of *C. polykrikoides*. By above 50% removal is required to even running at 30 min based on total cell number of phytoplankton and variation of Chl-*a* (Fig. 3).

Fish cages in Korea mostly occur in shallow coastal waters where strong sunshine and wind during summer play an important role in separation between cold and warm waters, but stratification is easily destructed by tides. Unique water characteristics between surface and bottom water is not required to decrease the number of *C. polykrikoides* in surface water as this species can also occur at the bottom water. Because *C. polykrikoides* is sensitive to water temperature and appears at lower cell density in cold water (Lee *et al*., 2007; Glober *et al*., 2008; Lee *et al*., 2010; Jiang et al., 2011; Lee *et al*., 2013), a strong separation between surface and bottom water allows for a high chance of lower cell density at bottom water as compared when no stratification of water column occurs.

Suspended soled stimulates photosynthesis in phytoplankton; with dinoflagellates more sensitive than diatoms that are well adapted to coastal waters rich in suspended solid (Oh *et al*., 2008). *C. polykrikoides* exhibits good growth in clean water (Oh *et al*., 2008). In the present study, a large change in suspended solid was observed after pump running times (Fig. 3) but did not act as a factor to fluctuate the amount of Chl-*a* and number of total phytoplankton including *C. polykrikoides*. Major removal was achieved from continuous supply in deep water.

Consequently, the pumping device in the present study used cold bottom water in stratified water generated by strong irradiation in summer may protect fish cage against red tide in *C. polykrikoides*. Furthermore, in August, when water temperature is warm, it is necessary for fish cages to experience good environmental conditions for faster growth and health of fish. Use of deep water may also play an important role in good water characteristics for fish cages during summer.

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