

The outbreak of *Chochlodinium* sp.: the red tide maker in the coastal of Lampung Bay

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Abstract. Red tide is a common phenomenon and almost present every year in Lampung Bay. In 2012, the red tide in Lampung Bay showed a different characteristic compared to the previous ones. The research was conducted to analyze the characteristics of organisms causing the red tide and the factors affecting its occurrence. Assessments were done by identifying the dominant phytoplankton and observing the environmental condition using rapid assessment method. Seawater sampling was conducted in 15 stations in December 2012 to monitor the phytoplankton abundance, nutrient, and physical condition. The results showed that the organism dominating the phytoplankton population is *Cochlodinium* sp., comprising of 85.89% of the total phytoplankton suggesting it was the red tide organism in the Bay. The average abundance of this species in the stations was 2.0×10^4 cells/L. *Cochlodinium* sp. was present agglomerated and distributed along the west coast of the bay. The highest concentration of the organism was found around the tip of the bay. The outbreaks of *Cochlodinium* sp. were induced by the high concentration of nitrogen in the coastal water with N:P ratio of 35.5. Moreover, the physical condition of the coastal water strongly influenced the distribution and abundance of *Cochlodinium* sp. in the bay.

1. Introduction

Red tide phenomenon (harmful algal bloomings, HABs) commonly occurs in Lampung Bay. It is a phenomenon in which a few species of algae/phytoplankton accumulate rapidly in the water column, and the bloom takes on a red or brown color depending on the pigment-containing in the phytoplankton [1]. Algae blooms have occurred in Lampung Bay nearly every year since 2005. This bloom is caused by different species of microscopic algae/plankton. The most common species growing out of control, thus inducing red tides in the bay was *Noctiluca* sp. (2005-2010), while some other causative organisms were *Pyrodinium* sp. (2008), *Phaeocystis* sp. (2009) *Dynophysis* sp. (2010, 2011) *Trichodesmium* sp. (2002 – 2012), *Ceratium* sp. (2011), *Pseudonitzschia* sp. (2009 – 2012) [2].

In 2012 an outbreak of algae bloom showed different characteristic from that occurred in previous years. It turned the seawater red brownish and caused massive fish kills in a culture which mortality was characterized by redfish fin and gills. The outbreak lasted for a longer time than usual, starting in October 2012 until the beginning of March 2013 (Fisheries and Marine Affairs Service, Lampung



Province, personal communication). This outbreak resulted in adverse effects on the environmental conditions and may become a threat to mariculture activities in Lampung Bay.

In some other coastal regions, red tides with similar characteristics above were caused by the bloom of *Cochlodinium polykrikoides*. This species was the most common species of phytoplankton identified upon blooming in Korea coastal waters [3], Jepang [4] dan Chesapeake Bay [5]. This species was widely sp. read distributed from Atlantik, Europe and to Asia coastal waters. However, no *Cochlodinium* bloom was ever observed in Indonesia. Previous research had identified *C. fulvescens* phytoplankton in December 2003 in Lampung Hurun Bay which was an area for mariculture in floating net cages; however, this species was found not to induce red tides as that occurred in 2012 [6].

The present study was aimed to analyze the characteristics of organisms inducing red tides in Lampung Bay in December 2012. Additionally, identification of factors affecting the outbreaks of red tides in the bay was conducted as well.

2. Materials and method

2.1. Study location and sampling period

The present study and monitoring were conducted in Lampung Bay in December 2012. Automatic Weather Station (AWS), Tide Master, Acoustics Doppler Current Profiler (ADCP), and Temperature Logger is stationarily deployed to monitor the hydrodynamics characteristics [7-9]. Samples were collected from 15 selected stations, based on stratified sampling method (figure 1). The sampling stations were spread from the tip to the mouth of the bay and covering the red-tide area and the normal one. Sampling location with its geographical position was presented in table 1.

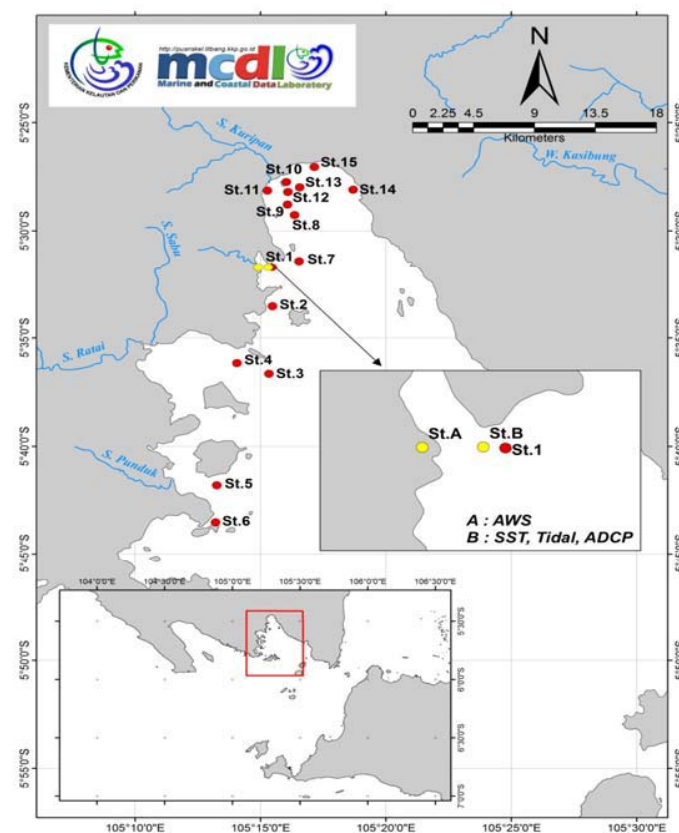


Figure 1. Sampling stations along the coastal area of Lampung Bay.

Table 1. Sampling location for red-tide monitoring in Lampung Bay.

No	Name of sampling location	Geographical position	
1	Kyoko (mouth of Hurun Bay)	05°31.704' LS	105°15.456' BT
2	Ringgung	05°33.529' LS	105°15.474' BT
3	Adjacent to Maitam Islands	05°36.661' LS	105°15.333' BT
4	Kelagian	05°36.170' LS	105°14.057' BT
5	Puhawang Island	05°41.800' LS	105°13.252' BT
6	Putus Cape	05°43.519' LS	105°13.208' BT
7	Kyoko (Mutiarra)	05°31.405' LS	105°16.5359' BT
8	Adjacent Lempasing Fishing Port	05°29.259' LS	105°16.353' BT
9	Floating Net Cages of Marine and Fisheries Service, Kota	05°28.773' LS	105°16.072' BT
10	Kota Karang Estuary	05°27.727' LS	105°16.026' BT
11	Keteguhan Embouchure	05°28.124' LS	105°15.269' BT
12	Pasaran Bay	05°28.192' LS	105°16.088' BT
13	Middle of the bay	05°27.976' LS	105°16.561' BT
14	Panjang Port	05°28.085' LS	105°18.691' BT
15	Sukaraja	05°27.027' LS	105°17.147' BT

2.2. Materials

Phytoplankton samples were collected using *Kemmerer Water Sampler* and then filtered through plankton net of bolting silk no. 25. Seawater filtration was conducted to concentrate the phytoplankton, particularly in the coastal area with no blooming. Filtered plankton samples were then fixed directly with Lugol solution and stored for later examination. Phytoplankton abundance was analyzed according to [10], and plankton was identified based on [11].

Physical parameters monitoring in the study were temperature, salinity, water current, and wind profile. Seawater temperature was measured using HOBO instrument, while the water current was measured using ADCP. Wind speed and direction were obtained from AWS instrument. Meanwhile, the chemical parameters measured were pH, dissolved oxygen, chlorophyll-a, nitrate (NO₃-N), nitrite (NO₂-N), orthophosphate (PO₄-P), and silica (Si). To determine the concentration of nutrients and chlorophyll, laboratory analysis using spectrophotometer was conducted.

2.3 Data analysis

The samples were taken into Sedgwick Rafter counting Cell (SRC) and identification of plankton was carried out, and counting was done according to the procedure outlined by [10]. The abundance of phytoplankton was estimated by counting their presence per focus of the microscopic field. The abundance of phytoplankton was expressed using the following formula:

$$N = \frac{n}{100} \times \frac{A}{B} \times \frac{C}{D} \times \frac{1}{E}$$

where,

- N = Total number of plankton (cells/L)
- n = Number of organisms per number of counting cells observed
- A = Volume of SRC (mm³).
- B = The area of counting cells observed (mm²)

- C = Volume of concentrated plankton sample (mL)
 D = Volume of 1-drop plankton sample underneath the cover glass (mL)
 E = Volume of total water filtered (L)

3. Results and discussion

3.1. Composition and abundance of phytoplankton

The results indicated the phytoplankton population in Lampung Bay in December 2012 composed of four classes which were Bacillariophyceae, Dinophyceae, and Cyanophyceae. Dinophyceae dominated the entire population in the coastal water, and it formed 92.88% of the total phytoplankton population. *Cochlodinium* sp. was the most dominant species of phytoplankton and it constituted 85.89% of the total phytoplankton abundance (figure 2), with the average abundance of 2.0×10^4 cells/L (table 2).

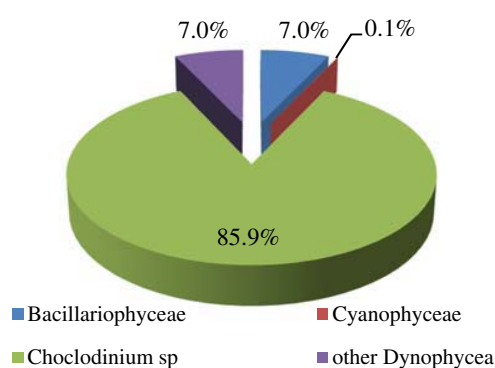


Figure 2. Phytoplankton abundance.

Table 2. The phytoplankton abundance in Lampung Bay.

Phytoplankton Classes	The range of abundance	The average abundance
Cyanophyceae	$0.0 \times 10^0 - 5.5 \times 10^2$	1.3×10^1
Bacillariophyceae	$3.0 \times 10^1 - 9.9 \times 10^3$	1.6×10^3
Dinophyceae	$1.1 \times 10^2 - 7.4 \times 10^5$	2.2×10^4
<i>Cochlodinium</i> sp.	$0.0 \times 10^0 - 7.4 \times 10^5$	2.0×10^4

Generally, in normal condition, no species *Cochlodinium* sp. was observed in Lampung Bay. The sudden occurrence of this dominant species in the bay suggested the blooming of this population. The average population abundance of the species was estimated at 2.4×10^4 cells/L. The value was indicated to be lower than the real population abundance because sample collection was conducted using a smaller mesh size of plankton net (60 μ m). However, the value is still in confirmation with the range value of abundance for *Cochlodinium* sp. blooms in Philippines, Malaysia, Korea, and Pakistan. *Cochlodinium* sp. bloom in Iligan Bay, South Philippine, was recorded as $3.1 \times 10^4 - 3.8 \times 10^4$ cells/L [12]. In Yeosu Korea, *Cochlodinium polikrikoides* bloom was found to occur $1 - 8.6 \times 10^4$ cells/L [3], whereas in Sabah Malaysia waters, average *Cochlodinium* sp. abundance could reach 6×10^6 cells/L [13]. Moreover, the occurrence of *Cochlodinium fulvescens* bloom in Pakistan was recorded at the abundance of $6 \times 10^2 - 9 \times 10^2$ cells/L [14]. [15] reported that *C. polykrikoides* abundance at a density of $10^3 - 10^4$ cells/L could lead to fish mortality, while the abundance of $>5 \times 10^4$ cells/L could kill all fish (100%) within a week.

3.2. Morphology of *Cochlodinium* sp. cell

Visual observation during survey presented that during blooms, seawater turned into red-brownish. It was observed that upon water filtration through plankton net, the phytoplankton in the filtered water was sticking and coagulating each other leading to net clogging. Furthermore, when the filtered water was collected in a container, within less than 30 minutes, those phytoplanktons would coagulate and precipitate at the bottom of the container.

Based on morphological comparison results using microscopic imagery analysis, it was identified the bloom was caused by the high occurrence of the phytoplankton species closely related to *Cochlodinium* sp. [16] reported that *Cochlodinium* sp. had sub-spherical cells and made chains (consisting of 2-8 cells or more). The anterior part of the episode is conical, and the hypocone is sub-spherical forming epitheca. The cells have spiral cingulum, and the cell size ranged from 20 – 30 μm .

The observation also showed that the phytoplankton cells during bloom events in Lampung Bay had round shape, composing of two-to-four-cell chains and a single cell separated from the chains. The anterior of the cell is more rounded with a smaller diameter than the middle of the cell. The results of microscopic images with 400x enlargement showed that a circular line pattern in the middle of the cells was observed suggesting spiral cingulum commonly found in *Cochlodinium* sp. Morphological comparison suggested the cells had a closer shape to *C. fulvescens* cells than *C. polykrikoides* cells [17], however, with a smaller size. *Cochlodinium fulvescens* with the average length of 45.8 μm (37.5–57.5 μm) and 35.3 μm wide (30.0–42.5 μm) have been previously found in Hurun Bay of Lampung in December 2003. It was also observed that the size of *Cochlodinium* sp. cells in the present study was 7-10 μm . This size is much smaller than that of *Cochlodinium polykrikoides* commonly found in bloom events in Korea coastal waters [3] and Persia Bay [18]. Figure 3 presented the morphology of the cells during bloom events in Lampung Bay.

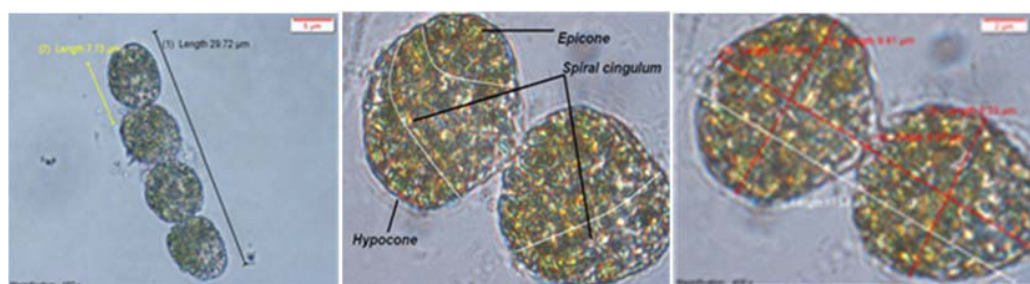


Figure 3. Morphology of phytoplankton forming red tides in Lampung Bay: (a) a four-cell chain, 38.65 μm long; (b) spiral cingulum encircling the cell (c) the cell size at 400x enlargement.

Morphological comparison among *Cochlodinium* sp. occurred in Lampung Bay, *C. fulvescens* [6, 17] and *C. polykrikoides* [6] is described below (table 3).

Table 3. Morphological comparison between *C. fulvescens*, *C. polykrikoides* and *Cochlodinium* sp.

Morphological characters	<i>C. fulvescens</i>	<i>C. polykrikoides</i>	<i>Cochlodinium</i> sp.
Size	50 - 60 μm	20 - 30 μm	7 - 10 μm
Shape	Subspherical - ellipsoidal	Ellipsoidal	Subspherical
Sulcus	Branched	Shallow	Unclear
Cingulum	Encircle the cell twice	Encircle the cell twice	Encircle the cell twice

3.3 Distribution of *Cochlodinium* sp.

Cochlodinium sp. has a clumped distribution forming spots in particular spaces with different densities and coverage areas. This distribution type is typical for *Cochlodinium* bloom events [12,15,17]. It was

observed that *Cochlodinium* sp. was distributed in the western coast of Lampung Bay, starting from Sukaraja Beach to Putus Bay located in southern part of Lampung Bay (figure 4). No bloom event of *Cochlodinium* sp. was found in the eastern coast of Lampung Bay (Panjang Harbour-Kalianda).

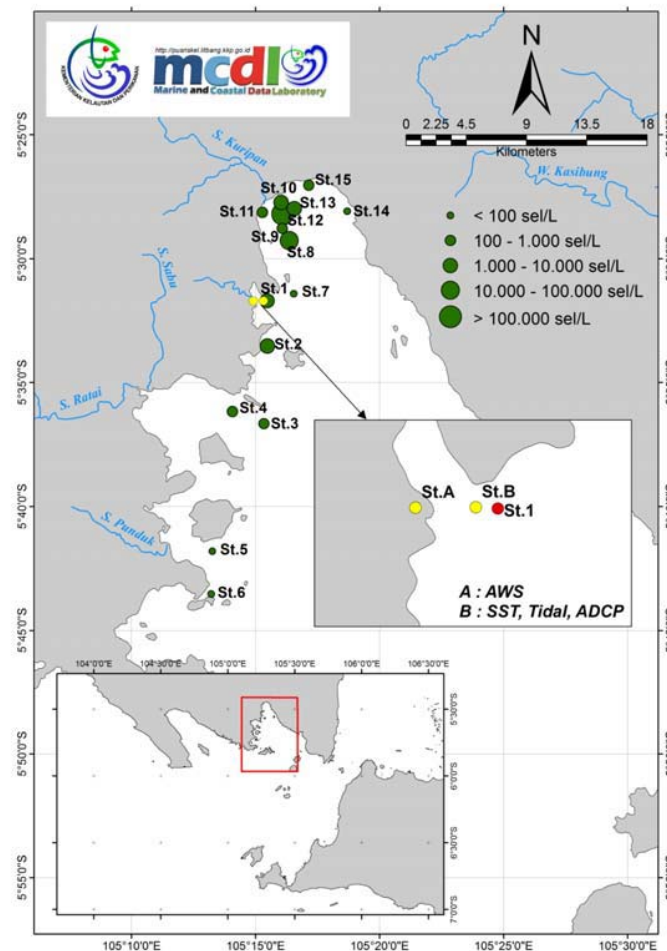


Figure 4. Spot distribution of phytoplankton bloom on 22 – 23 December 2012.

Furthermore, it is evident that *Choclodinium* sp. was highly abundant in the upper part of the bay, from Betung Bay to Ringgung Sub-district coastal areas. The highest abundance was found in Pasaran Bay (station 12) with the average abundance of around 1.1×10^5 cells/L. In this area, anthropogenic activities such as marine fish culture in floating net cages (Station 1, 2 and 9), sea pearl culture (station 7), and fish landing (station 8 and 15) were found. Moreover, an estuary was also located in the area. [19] reported that eutrophication resulted from water run-off from the river, nutrient-rich water arisen from aquaculture, heavy rainfall, and water stirring in mixing layer could lead to the bloom event of this phytoplankton.

Interestingly, the abundance of *Cochlodinium* sp. was lower in the southern and middle parts of the bay than the upper part. The abundance of *Cochlodinium* sp. in Ratai Bay particularly in ST 3 and 4 was 2.38×10^2 and 2.00×10^2 cells/L, respectively. Moreover, a much lower abundance of *Cochlodinium* sp. ($< 10^2$ cells/L) was observed in station 5 and 6 (a more southern area). The southern part of the bay is a more open connecting directly to Sunda Strait.

Some clumps of *Cochlodinium* sp. with the average abundance of 7.51×10^2 cells/L were still found in the middle of the bay. Meanwhile, the abundance of *Cochlodinium* sp. was found to be lower (69 cells/L) in around Panjang Port (St. 14). This suggested that the distribution of *Cochlodinium* sp. abundance was significantly influenced by water stirring / distribution and tides.

3.4. Distribution of nutrients (nitrogen and phosphate)

Table 4 shows the dissolved nutrient conditions in Lampung Bay. It is evident that high concentrations of ammonia and nitrate were obtained indicating that the coastal water was in eutrophication. The results showed that the concentration of nitrate (NO_3) increased 4.5 fold compared to that in normal condition, and nitrite was 0.7 times lower than in the normal condition. Meanwhile, ammonia was significantly high during this bloom event, i.e., 6.5 times higher than that in the normal condition, whereas the concentration of nitrate obtained in the study was lower than that in the normal condition. Upon the bloom event, the concentration of phosphate in the water was lowest in seawater of the bay, i.e., 0.2 times lower than the common condition.

Table 4. Dissolved nutrient conditions in Lampung Bay.

Variable	Normal	Observation on 22 - 23 Dec 2012		
		Range	Average	Increment
NO_2	0.012	0.003 - 0.02	0.008	0.7
NO_3	0.036	0.032 - 0.413	0.162	4.5
NH_4	0.103	0.085 - 1.241	0.670	6.5
PO_4	0.119	0.080 - 0.075	0.024	0.2

According to nutrient data in the present study suggested that *Cochlodinium* sp. is a phytoplankton species that could grow well in seawater containing high N and low P. The present results showed that N/P ratio was 35.5, significantly higher than the normal N/P ratio [16]. In the Philippines, *Cochlodinium* bloom events occurred when N to P ratio was 14:1 [12]. Meanwhile, in Jejudo Korea, *Choclodinium polykrikoides* blooms occurred when the nitrogen content in seawater was higher than that in its normal condition [3].

High nitrogen content in seawater in the present study could be attributed to water run-off upon heavy rainfall occurred after a long dry season in early October 2012. Some outbreaks of *Choclodinium* sp. blooms could also be triggered by heavy rains happened before red tides, as the outbreaks found in Korea coastal areas [3] and Chesapeake Bay [5].

3.5. Conditions of physical oceanography

The results of temperature measurement using HOB0 showed that seawater temperature of Hurun Bay was relatively warm ($29.9\text{--}30.3^\circ\text{C}$) and had low T variability. Meanwhile, temperature data derived from World Ocean Database 2009 showed that the lowest seawater temperature was obtained in the season of December – February ranging from $28.25\text{--}28.50^\circ\text{C}$ [20]. Compared to the results indicated that the temperature condition in December 2012 was in anomaly which was higher than the seasonal temperature. This warm temperature with low variability obtained in the study is favorable for red-tide organisms. The water mixing in Lampung Bay is affected by the tidal phenomenon.

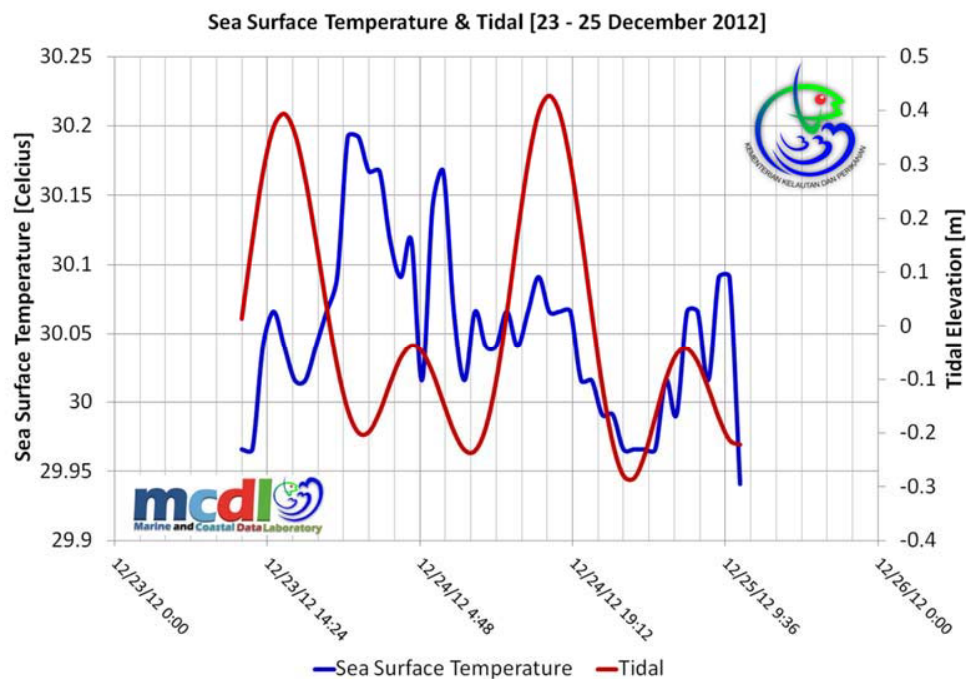


Figure 5. Water column temperature and tidal profile in Lampung Bay measured on 23 -25 December 2012.

The water mixing could be determined from vertical currents measured by ADCP in as shown in figure 6 [21]. Some outbreaks of *Choclodinium* sp. blooms in southern California coastal waters were initiated by the mixing of warm and cold water resulted from upwelling and freshwater run-off entering into the sea [22]. *Cochlodinium* sp. could grow well and rapidly in warm seawater [3]. In Korea coastal waters [3, 24] and Mexico coastal waters [17], the outbreaks of *Cochlodinium* blooms occurred in temperature of 29-30°C. Upwelling and downwelling upon monitoring occurred when no wind was present (figure 7). This suggested that wind was not the main factor inducing up and downwelling in the bay, tides were, instead [25]. During the high tide, water current moved into the bay, whereas during the low tide, the current would move out from the bay [26].

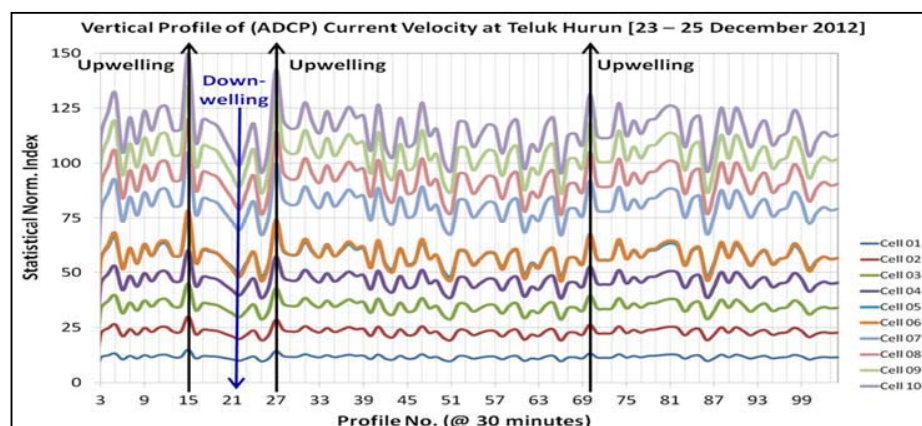


Figure 6. Vertical Velocity Profile Measured using ADCP at Teluk Hurun (23 – 25 December 2012).

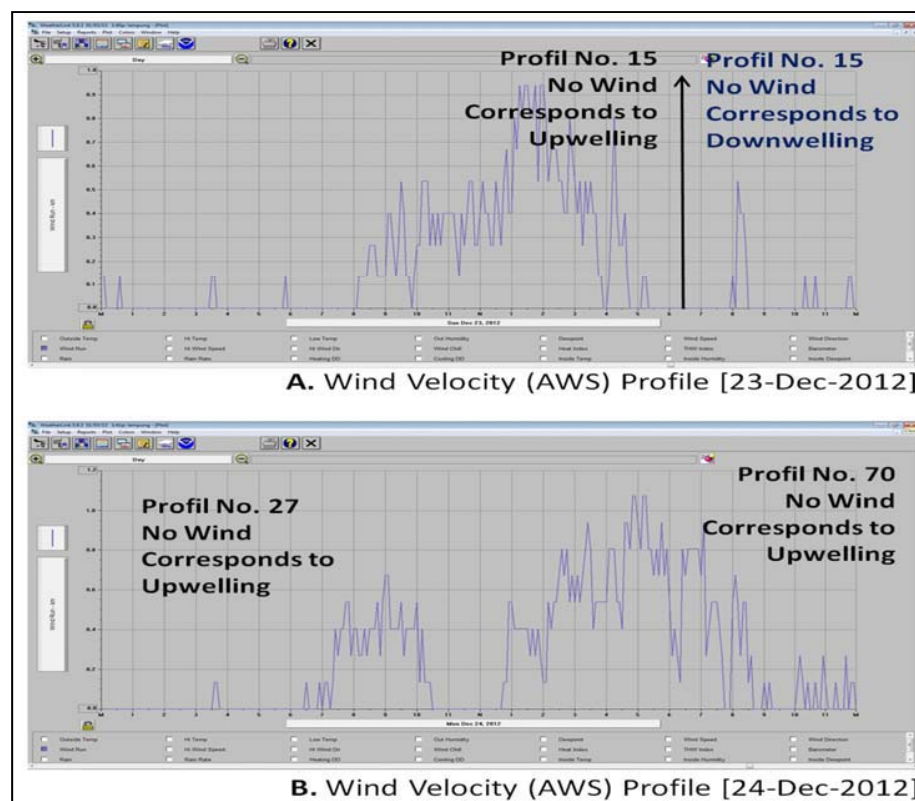


Figure 7. Wind profile in 23 (A) and 24 December 2012 (B).

Sea current movement driven by tides in Lampung Bay affected the *Cochlodinium* sp. distribution [27]. Tidal currents are moving into and out from the bay likely resulted in the water mass circulating within the gulf/bay [28]. The circulating water mass accumulated the water mass more in western coast areas of the bay where many small islands such as Puhawang, Kelagian, Maitem, Tegal islands were located. On the other hand, water mass running along the eastern coast areas was not obstructed by any islands or any neighboring corals, leading to no water mass accumulation in the area [29]. This indicated that the water mass accumulation in the western coast areas of the bay influenced the *Cochlodinium* sp. distribution, providing clumped propagation found only in the western bay.

4. Conclusions

The outbreak of *Choclodinium* sp. blooms in Lampung Bay was induced by the high content of dissolved N resulted from land intrusion and also organic decomposition from the sea bottom arising to the surface due to upwelling. Moreover, the bloom event was also triggered by the anomaly temperature in December 2012, in which the sea surface temperature was warmer than the usual. Water mass circulation resulted in *Cochlodinium* sp. distribution more concentrated in the west coast areas of Lampung Bay.

Acknowledgments

The surveys were conducted in 2012 funded by APBN DIPA TA. 2012 for the Indonesian Ministry of Marine Affairs and Fisheries. Further analysis of algae is undertaken during 2014 -2015 in The Research Institute for Fish Recovery & Resources Conservation. Discussions and hydrodynamics data analysis has been done in the Marine and Coastal Data Laboratory (MCDL), at Marine Research Center. This publication is funded by APBN DIPA TA 2017 for the Fisheries Research Center. Sp.ecial thanks go to Army and Tussadiah (MCDL) for making the beautiful maps (Fig. 1 & Fig. 3).

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