Effect of monsoon on ocean productivity in Aceh waters

A Auliati, Y Haditiar, R Wafdan, M Ikhwan, M Muhammad, Z Jalil, M A Chaliluddin, S Sugianto and S Rizal

1 Department of Marine Sciences, Faculty of Marine and Fisheries, Universitas Syiah Kuala, Banda Aceh, 23111, Indonesia
2 Graduate School of Mathematics and Applied Science, Universitas Syiah Kuala, Banda Aceh, 23111, Indonesia
3 Department of Physics, Faculty of Mathematics and Natural Science, Universitas Syiah Kuala, Banda Aceh, 23111, Indonesia
4 Department of Fisheries Resource Utilization, Faculty of Marine and Fisheries, Universitas Syiah Kuala, Banda Aceh, 23111, Indonesia
5 Department of Soil Sciences, Faculty of Agriculture, Universitas Syiah Kuala, Banda Aceh, 23111, Indonesia.
*Corresponding author: syamsul.rizal@unsyiah.net

Abstract. Monsoon in Aceh waters is dominated by the northeast and southwest monsoons. Based on previous research, the monsoon affects oceanography and general hydrodynamics in Aceh's waters and its surroundings. This study aimed to see the effect of the monsoon on the abundance of chlorophyll-a in Aceh waters. The data used in this study consisted of wind, sea surface temperature (SST), and chlorophyll-a data obtained from remote sensing observation data. Wind data is obtained from Metop-B ASCAT (Advanced SCATterometer). SST and chlorophyll-a were obtained from Aqua MODIS (Moderate Resolution Imaging Spectroradiometer) level 3 with resolution 4 x 4 km. The results obtained, in February, chlorophyll-a concentrations were higher in the range of 0.7 mg/m$^3$ - 1.4 mg/m$^3$, compared to August with lower concentrations ranging from 0.2 mg/m$^3$ - 0.5 mg/m$^3$. It is due to low temperatures in February. Seasonal changes affect the productivity content of chlorophyll-a in the waters.

1. Introduction

Aceh, one of the provinces in Indonesia, is located in the north of Sumatra. Geographical Aceh 01°58'37.2" - 06°04'33.6" N and 94°57'57.6" - 98°17'13.2" E. The eastern part of Aceh is bordered by the Andaman Sea and the Strait of Malacca, while the western part is bordered by the Indian Ocean [1] (Figure 1). On all three sides, Aceh is surrounded by waters, and it is necessary to review the level of fertility using chlorophyll-a data. Chlorophyll-a data in Aceh waters obtained from Aqua MODIS satellite images show varying results [2]. The presence of chlorophyll-a at a depth that is still translucent to sunlight (50m-70m). This depth is very influential in the potential productivity in waters [3-5]. Chlorophyll-a variation is influenced by two monsoons and SST. In the Northeast (NE) monsoons, the winds are strong, while in the Southwest (SW), the winds are weak [6]. The spatial structure of the wind monsoon regulates downwelling and upwelling processes [7]. This process is directly related to the distribution of chlorophyll-a in water [8]. So that when the upwelling process, the nutrients from the bottom are lifted upwards together with the exchange of water masses, which causes SST to decrease and salinity increases [9-11]. SST information is closely related to ocean stratification, such as the mixed
layer and the thermocline layer [12], where the mixed layer gets nutrients from the sea beneath it in the upwelling process [7]. Apart from this process, nutrients can also be lifted with internal waves [13-14].

Information about chlorophyll-a distribution needs to be studied to see the potential for productivity in waters [15]. Our study focuses on the ocean productivity of Aceh Waters in general view and its relationship with the monsoon.

2. Materials and Methods
The data used in this study consisted of wind data, sea surface temperature (SST), and chlorophyll-a. Wind stress from near real-time Metop-B ASCAT (Advanced SCATterometer) data. The data used has a monthly resolution and a spatial resolution of 0.25° (https://coastwatch.pfeg.noaa.gov/erddap/index.html). SST and chlorophyll-a from ocean color Aqua MODIS (Moderate Resolution Imaging Spectroradiometer) level 3 with a resolution of 4 km.

SST Aqua MODIS is a reproduction data of 11 µm spectral bands infrared radiometers on the sea surface layer, called the skin temperature. Skin temperature or thermal has a thickness of about 1 mm. Currently, SST MODIS uses the latest nonlinear algorithm from Walton et al. [16] and corrections of in situ and satellite measurements. SST MODIS has also been sorted by Quality Flagging and Cloud Classification (https://oceancolor.gsfc.nasa.gov/). Chlorophyll-a MODIS was obtained from the visible wave spectrum analysis of 440 - 670 nm with a standard algorithm [2]. This data has been well projected in the spatial and time domains. Before being analyzed, we chose Chlorophyll-a data with relatively good visibility (clear-sky conditions).

Wind stress from near real-time Metop-B ASCAT (Advanced SCATterometer) results from 25 km (sufficient resolution: 50 km). Wind vector data is processed with CMOD.n geophysical model function and Hamming filter. As with SST and chlorophyll-a, wind data from ASCAT is stored in the netCDF version 3 format. Later the data is processed and read into a matrix and overlay geographically.

Figure 1. Topography of Aceh Waters
Data were spatial analyzed and visualized using GrADS software (Figure 2). Wind data shows how the main wind circulates in Aceh waters during the northeast and southwest monsoons. The northeast monsoon is represented by February, while the southwest monsoon is represented by August. SST and chlorophyll-a are used as indicators to determine the potential for upwelling in Aceh waters.

3. Results and Discussions

3.1. Wind
The distribution of wind in Aceh waters depends on the place and time. In February, the wind distribution blows faster from the East to the West towards the East Longitude (95°E - 98°E) and at North Latitude (5°N - 7°N) in the northern part of Aceh and the north of the strait (Figure 3). So that the Upwelling process occurred in the northern part of Aceh waters and north of the Malacca Strait. The northeast wind pushes the surface Ekman layer around the north of Aceh and the Malacca Strait towards the offshore (divergent). Meanwhile, the western part of the wind pattern is low at North Latitude (2°N - 5°N). August zonal wind stress exceeds 0.05 Pa from the West to the Northeast at East Longitude (95°E - 97°E) and North Latitude (5°N - 7°N) (Figure 4). It causes the water mass to converge. Meanwhile, those heading to the East at East Longitude (98°E - 99°E) and North Latitude (5°N - 7°N) are smaller than the zonal wind stress of 0.05 Pa. However, in the southwestern part, the wind direction is smaller than the zonal wind stress of 0.05 Pa in the East Longitude (95°E - 98°E) and North Latitude (2°N - 4°N).

3.2. Sea Surface Temperature
Based on Figure 5 and Figure 6, the difference in the distribution of temperature between February and August can be seen. The temperature distribution in February ranges from 29°C - 31°C. In the north and east, the temperature is lower, around 29°C, while in the western part, the temperature is higher, around 30°C - 31°C. The temperature in August is higher than in February, in the range of 29.5°C - 31°C. Spread over the high West, East, and South Sumatra. It is different in the north, which is lower around 29°C - 30°C. In August, the SST value is high, while in February, it is low. It is due to the high rainfall in February [17].

3.3. Chlorophyll-a
Figure 7 and Figure 8 show the temporal and spatial differences in the chlorophyll-a distribution in Aceh waters in February and August. In February, the distribution of high chlorophyll-a concentrations ranged from 0.7 mg/m^3 – 1.4 mg/m^3 in the northern part of Aceh and the north of the Strait. This value is due to the strong northeast winds in the northern part of Aceh and the north of the Strait and low sea surface temperatures [18-19]. It causes the Upwelling process to occur, which is reflected in the high chlorophyll-a in that section. Meanwhile, in Aceh's western part, chlorophyll-a concentrations were relatively high, ranging from 0.5 mg/m^3 - 3.0 mg/m^3. The northeast wind is relatively weak in the west of Aceh. It indicates that the possibility of wind-driven upwelling is not formed in this section. The
abundance of chlorophyll-a could be supported by parameters other than wind, such as general circulation and rainfall. In contrast to August, the chlorophyll-a concentration was lower, ranging from 0.2 mg/m$^3$ – 0.5 mg/m$^3$ due to high sea surface temperatures. Seasonal changes affect the chlorophyll-a productivity content in water [20-21].

The high chlorophyll-a concentrations in the eastern regions are caused by direct or indirect wide-scale changes in the surrounding aquatic environment [22]. Changes caused by the environment can affect the survival of phytoplankton [23-24]. Based on the SeaWiFS data analysis for August 2005 and
February 2006, Haridhi et al. [6] showed there are also indications that the western part of Aceh and other parts have different chlorophyll-a trends. Northeast winds influence increased chlorophyll-a in the eastern and northern parts of Aceh waters. Thus, this is relatively the same as the results of our analysis.

The concentration of chlorophyll-a in the bay area is higher than in the high seas, due to the entry of freshwater rich in nutrients into the waters, which are then used by phytoplankton to carry out photosynthesis, as seen in Figure 8 in areas near the coast, the concentration of chlorophyll-a is higher around 3.5 mg/m$^3$.

4. Conclusions
The highest chlorophyll-a distribution occurred in February, ranging from 0.7 mg/m$^3$ – 1.4 mg/m$^3$ with an almost even distribution in each region. The lowest distribution occurs in August, ranging from 0.2 mg/m$^3$ – 0.5 mg/m$^3$ with an uneven distribution. The difference in the distribution of chlorophyll-a in water is influenced by wind and temperature. The overall temperature in Aceh waters ranges between 29°C - 31°C, while the sea surface temperature in Indonesia ranges from 26.0°C - 31.5°C, indicating that Aceh waters are classified as moderate waters. The higher the surface temperature, the lower the amount of chlorophyll-a in water. The relatively cold temperature (below 29°C) is an ideal habitat for chlorophyll-a to grow. In addition, cold temperatures cause seawater stratification to become weak, so that a strong northeast wind implies a more significant divergence process, further upwelling is formed. However, based on previous research, high upwelling and chlorophyll-a do not directly increase the number of catches but require a time lag of several months. Also, the northeast wind's relatively weak influence in the western part of Aceh differentiates the catchment conditions from the eastern and northern parts of Aceh, which are close to the Malacca Strait. In the next research, we recommend that run-off and rainfall be used to analyze chlorophyll-a productivity and fish catches in Aceh waters.

Acknowledgments
Authors would like to express gratitude to the Ministry of Education and Culture of Indonesia for financial assistance in term ‘Penelitian Terapan Unggulan Perguruan Tinggi (PTUPT)’, under contract number: 19/UN11.2.1/PT.01.03/DPRM/2020. We also thank Universitas Syiah Kuala through facility support at Ocean Modelling Laboratory during the research.
References

[1] Zuraida R, Troa R A, Hendriza M, Gustiantini L and Triarso E 2017 Bulletin of the Marine Geology 32 67.
[2] Hu C, Lee Z and Franz B A 2012 J. Geophys. Res. 117 C01011.
[3] Conkright M E and Gregg W W 2003 Int. J. Remote Sensing 24 969.
[4] Owens N J P, Burkhill P H, Mantoura R F C, Woodward E M S, Bellan I E, Aiken J and Howland R J M 1993 Deep Sea Res. Part II Top. Stud. Oceanogr. 40 697.
[5] Wiggert J D, Murtugudde R G and Christian J R 2006 Deep Sea Res. Part II Top. Stud. Oceanogr. 53 644.
[6] Haridhi H A, Nanda M, Haditiar Y and S. Rizal 2018 Ocean Coast. Manag. 154 46.
[7] Ardila D, Haditiar Y, Ilkhanw M, Wafdan R, Muhammad M, Sugianto S and Rizal S 2019 2019 IOP Conf. Ser.: Earth Environ. Sci. 348 012063.
[8] Ke Z, Tan Y, Ma Y, Huang L and Wang S 2014 Cont. Shelf Res. 82 119.
[9] McCreaity J P, Kohler K E, Hood R R and Olson D B 1996 Prog. Oceanogr. 37 193.
[10] Drushka K, Sprintall J, Gille S T and Brodjongegoro I 2010 J. Phys. Oceanogr. 40 1965.
[11] Rao R R, Kumar M S G, Ravichandran M, Rao A R, Gopalakrishna V V and Thadathil P 2010 Deep Sea Res. Part I Oceanogr. Res. Pap. 57 1.
[12] Irmasyithah N, Haditiar Y, Ilkhwan M, Wafdan R, Setiawan I and Rizal S 2019 IOP Conf. Ser.: Earth Environ. Sci. 348 012064.
[13] Rizal S, Wafdan R, Haditiar Y, Ramli M and Halfiani V 2020 J. Eng. Sci. Technol. 15(2) 1056-1078.
[14] Rizal S, Iskandar T, Muhammad M, Haditiar Y, Ilhamsyah Y, Setiawan I and Sofyan H 2019 J. Eng. Sci. Technol. 14(5) 2836-2846.
[15] Resplandy L, Vialard J, Lévy M, Aumont O and Dandonneau Y 2009 J. Geophys. Res. 114 C07024.
[16] Walton C C, Pichel W G, Sapper J F and May D A 1998 J. Geophys. Res. 103 27999-28012.
[17] Rizal S, Damm P, Wahid M A, Sundermann J, Ilhamsyah Y, Iskandar T and Muhammad 2012 American Journal of Environmental Science 8 479.
[18] Chen G, Han W, Li Y, McPhaden Y J, Chen J, Wang W and Wang D 2017 J. Phys. Oceanogr. 47 979.
[19] Wurtsbaugh W A and Newman D 1988 Nature 333 846.
[20] Reddy P R C, Salvekar P S and Nayak S 2008 IEEE Geoscience and Remote Sensing Letters 5 588.
[21] Maneesha K, Sarma V V S S, Reddy N P C, Sadhuram Y, Murty T V R, Sarma V V and Kumar M D 2011 J. Earth Syst Sci 120 773.
[22] Chen G, Han W, Li Y, and Wang D 2016 J. Phys. Oceanogr. 46 789.
[23] Yasuda T, Yukuami R, Ohshima S 2014 Mar. Ecol. Prog. Ser. 501 239.
[24] Yasuda T, Kawabe R, Takahashi T, Murata H, Kurita Y, Nakatsuka N and Arai N 2010 J. Exp. Mar. Bio. Ecol. 385 50.