Article

The Strong Downwelling (Upwelling) Impact on Small Pelagic Fish Production During the 2016 (2019) Negative (Positive) Indian Ocean Dipole Events in the Eastern Indian Ocean off Java

Jonson Lumban-Gaol [1,*], Eko Siswanto [2], Nyoman Metah N. Natih [1], I Wayan Nurjaya [1], Mochamad Tri Hartanto [1], Erwin Maulana [1], Lucky Adrianto [3], Kedarnath Mahapatra [4], Herlambang Aulia Rachman [5], Takahiro Osawa [6], and Arik Permana [7]

[1] Department of Marine Science and Technology, Faculty of Fisheries and Marine Science, IPB University, Bogor 16680, Indonesia; jonsonlumban@apps.ipb.ac.id (J.L); natih1406@gmail.com (N.M.N.N); i.wayan.nurjaya@apps.ipb.ac.id (I.W.N); mochamadha@apps.ipb.ac.id (M.T.H); erwin.itk@gmail.com (E.M)
[2] Research and Development Center for Global Change Japan Agency for Marine-Earth Science and Technology 3173-25, Showa-machi, Kanazawa-ku, Yokohama, Kanagawa, 236-00015; ekosiswanto@jamstec.go.jp
[3] Department of Aquatic Resources Management Faculty of Fisheries and Marine Science, IPB University, Bogor 16680, Indonesia; lukyadrianto@ipb.ac.id
[4] School of Marine Science and Technology, Tokai University, 3-20-1 Orido, Shimizu, 424-8610, Japan; kedar@scc.u-tokai.ac.jp
[5] Postgraduate student of Marine Technology, Faculty of Fisheries and Marine Science, IPB University, Bogor 16680, Indonesia; herlambangauliarachman@gmail.com
[6] Center for Remote Sensing and Ocean Science (CReSOS), Udayana University, Post Graduate Building, Denpasar, Bali 80232, Indonesia; osawa320@gmail.com
[7] Marine Field Study, Faculty of Fisheries and Marine Science, IPB University, Palabuhanratu, Bogor 16680, Indonesia; : arik.ikan@gmail.com
* Correspondence: jonsonlumban@apps.ipb.ac.id

Abstract: Although researchers have investigated widely the impact of IOD phases on human lives, only a few have examined such impacts on fisheries. In this study, we analyzed the influence of negative (positive) of IOD on a chlorophyll a (Chl-a) concentration as an indicator of phytoplankton biomass and small pelagic fish production in the eastern Indian Ocean (EIO) off Java. We also conducted field surveys in the EIO off Palabuhanratu Bay at the peak (October) and the end (December) of the 2019 positive IOD phase. Our findings show that the Chl-a concentration had a strong and robust association with the 2016 (2019) negative (positive) IOD phases. The negative (positive) anomalous Chl-a concentration in the EIO off Java associated with the negative (positive) IOD phase induced strong downwelling (upwelling), leading to the preponderant decrease (increasing) of small pelagic fish production in the EIO off Java.

Keywords: chlorophyll-a; downwelling; IOD; small pelagic fish; upwelling.

1. Introduction

The Indian Ocean Dipole (IOD) is well-known as a dominant mode of interannual climate variability that develops from air-sea interactions in the Indian Ocean. With anomalously low sea surface temperatures (SST) associated with strong upwelling in the eastern Indian Ocean (EIO) off Java-Sumatra and high SST in the western Indian Ocean, it is known as the IOD positive phase (pIOD). Featuring opposite anomalies over a similar region is the IOD negative phase (nIOD) [1-3].

Researchers have investigated widely the impact of IOD phases on human lives and have found it to be considerably large particularly with respect to socioeconomics. For example, the IOD plays an important role in monsoon rainfall. The rainfall over East Africa (Indonesia) increases (decreases) during a pIOD phase [4]. High rainfall during the pIOD serves as a driving force in the resurgence of malaria in the East African highlands [5-6].

The impact of the IOD on the physical structure of the Indian Ocean is well known. The stronger-than-normal seasonal southeasterly winds along the Java-Sumatra coast during the pIOD phase have intensified coastal upwelling [7]. During the pIOD phase, the intense upwelling event occurs concurrently with a chlorophyll a (Chl-a) bloom off the South Java and Sumatra coast [8-10]. Meanwhile, during the 2016 nIOD, the downwelling event occurs concurrently with a Chl-a decrease along the coast of Sumatra and Java [11].

Although many researchers have tried to understand IOD impacts, only a few have examined such impacts on small pelagic fisheries. Generally, during the pIOD, fish production increase sharply in the EIO owing to increased upwelling [12-14], but nIOD phase impact on fish production is not well known in the EIO off Java.

According to mass media information, the quantity of small pelagic fishes landing in the fishing port tends to decrease during negative IOD phases from 2016 to 2017 and conversely tends to increase during the 2019 pIOD. The high fluctuation in the fishes landing during the IOD phases has influenced socio-economic activities. Usually, if the quantity of fishes landing decreases, the price of fish increases and the quantity of raw materials for the fishing industry reduce. However, the quantity of these raw materials increases during an increase in fishes landing.

The Dipole Mode Index (DMI) shows that 2016 and 2019 could be two of the most extreme nIOD and pIOD years ever, respectively [15-16], as shown in Figure 1. The negative and positive impacts of this phenomenon need to be investigated so as to enhance understanding of them with respect to small pelagic fisheries production and make predictions of future productions.

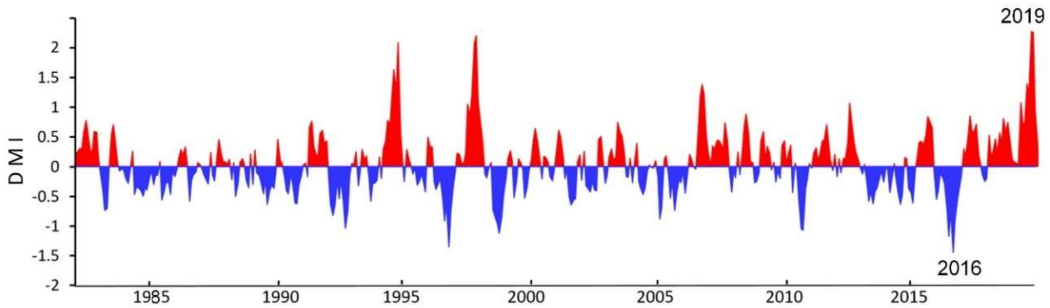

Figure 1. Dipole Mode Index shows that the 2016 dan 2019 negative and positive extreme IODs, respectively.

3. Materials and Methods

We conducted field surveys twice a year—at the peak of the pIOD (October 5, 2019) and the end of the pIOD (December 18, 2019) phase—and deployment and water sampling of the Conductivity Temperature Depth (CTD) sensors at five stations in the EIO off Palabuhanratu Bay (Figure 2). This bay is the largest in the EIO off West Java and is geographically located at 6.9° to 7.1° S and 106.3° to 106.5° E with a coastline of approximately 105 km. The bathymetric of Palabuhanratu Bay is steep with a depth of between 3 and 4 meters (coastal estuary waters) to more than 200 meters in the central part of the bay waters where it is a continental slope. Such topographic profile results in the phenomenon of the current along the coast (longshore current) in several locations of the bay waters. There was a depth of 200 meters at about 2 km. At another point, a rapid increase in depth supposedly forms a large puddle with a width of about 300 meters. The depths of more than 500 meters are in locations 6.5 km from the coast.

We analyzed the in-situ Chl-a concentrations from water samples at each station using a standard method (APHA, 23nd Edition, 10200-H, 2017) both at the peak and end of the pIOD. The monthly and daily means of Chl-a concentration and SST used in this study are from https://oceancolor.gsfc.nasa.gov/ and https://worldview.earthdata.nasa.gov/, respectively. The IOD

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 2 November 2020 doi:10.20944/preprints202011.0071.v1

mode index dataset we used in this study is from the Japan Agency for Marine-Earth Science and Technology (JAMSTEC) available at: http://www.jamstec.go.jp/frcgc/research/d1/iod/DATA/dmi_HadISST.txt. Also, we applied a Hovmöller diagram as a way of plotting Chl-a and SST data to highlight the variability of Chl-a and SST during the pIOD and nIOD for the 2004–2019 period, and power spectral density (PDS) analysis was applied to determine the energy dominant temporal variability of Chl-a concentration [17].

We conducted the fish-landing observation at the Palabuhanratu fishing port in October and December 2019. There we collected the monthly data of small catches of pelagic fishes to compare the difference in fish catches between the 2016 nIOD and 2019 nIOD phases. To compare the means of the catches between the nIOD and pIOD phases, we performed a paired t-test, and to evaluate the strength of time-lagged relationship between IOD and Chl-a as well as between Chl-a and small pelagic fish production, we performed a statistical cross-correlation analysis.

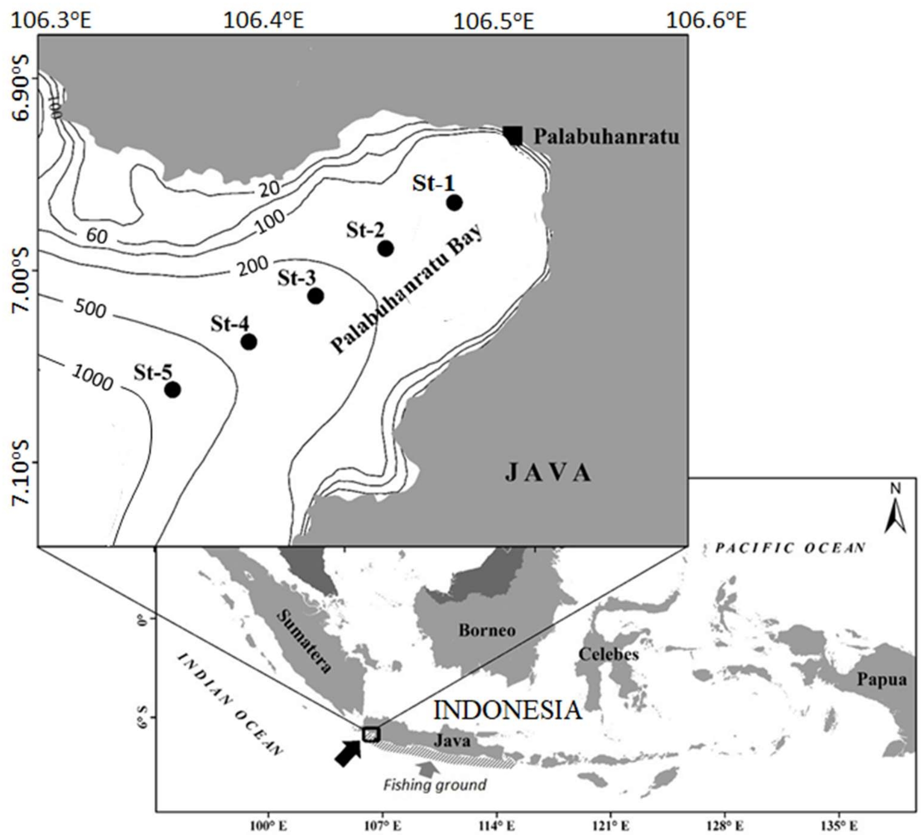

Figure 2. Water sampling stations at Palabuhanratu Bay, southern coast of West Java

3. Results

3.1. Temperature, Salinity, and Chl-a in Situ

The vertical profiles of temperature and salinity within Palabuhanratu Bay during the peak (October) and the end (December) of 2019 pIOD were significantly different (Figure 3). The mean of sea surface temperature (SST) was very low (23.35 ^{o}C) in the peak of pIOD phase. Meanwhile, at the end of pIOD phase, it was very high (29.15 ^{o}C), so there was a very high difference in the SSTs between the peak and the end of the pIOD phase, which is close to 6.00 ^{o}C. At a depth of 15 to 25 m, the temperature difference is higher compared to SST, which is around 7 ^{o}C. The thermocline layer rises to the shallower depth layer up to 80 m at the peak of the pIOD phase. The mean of surface salinity at the peak of the pIOD phase is 34.77 psu while at the end of the pIOD it is 33.41 psu. The difference in surface salinity between the peak and the end of the pIOD phase is quite high (1.36 psu). The vertical distribution of temperature and salinity shows an extreme upwelling during the 2019 pIOD.

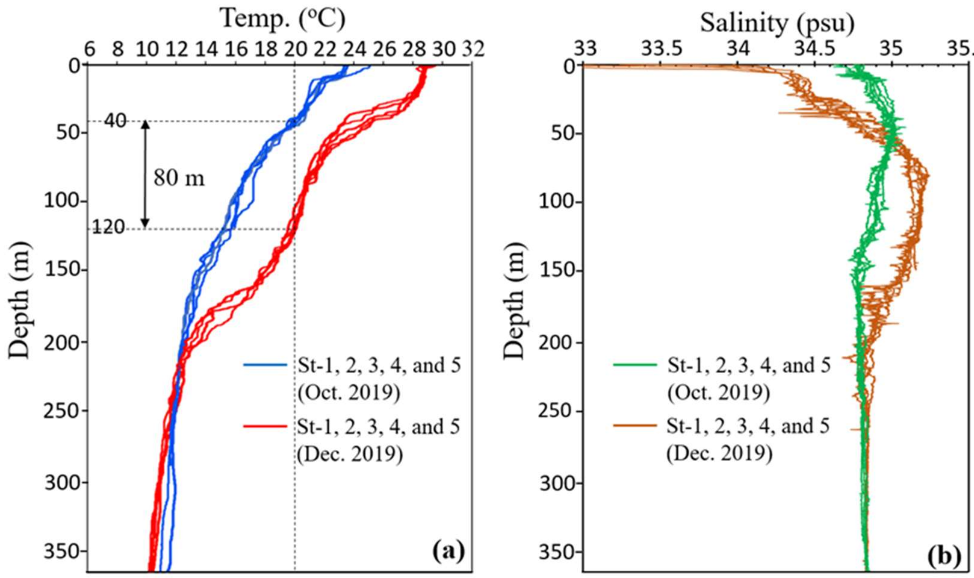

Figure 3. a) Temperature and (b) Salinity profile observed on October 5 (peak of pIOD) and on December 18 (end of pIOD), 2019, within the Palabuhanratu Bay

The mean of Chl-a concentration at the peak of the pIOD phase in Palabuhanratu Bay was 5.77 mg/m3 increased six times compared to the end of the pIOD phase (0.95 mg/m3) (Table 1). The high Chl-a concentration supports a physical process that showed a very strong upwelling in the study area during the 2019 pIOD phase.

Table 1. The Chl-a concentration at the peak and end of the 2019 pIOD phase

	Chl-*a* (mg/m^3)	
Stations	Peak of pIOD	End of pIOD
St-1	0.42	0.62
St-2	5.29	0.81
St-3	5.03	1.28
St-4	8.06	1.15
St-5	10.06	0.90
Mean	5.77	0.95

3.1. Temperature, Salinity, and Chl-a in Situ

We used a Hovmöller diagram as a way of plotting Chl-a and SST derived satellite data to highlight the variability of SST and Chl-a during the pIOD and nIOD phases for 2004–2019 (Figure 4b, c). Chl-a concentrations and SST allowed investigation of the most recent 2019 pIOD phase and 2016 nIOD phase. The intense 2019 pIOD phase was characterized by a strong Chl-a bloom and cooler surface temperatures in the EIO off Java. Meanwhile, the nIOD phase led to a low Chl-a and a high SST. PSD analysis shows the significant variance in Chl-a over the course of a one-year and more than 4 years period (Figure 5). The one-year period is a reference to the significant influence of the monsoon and more than 4 years which reflects the influence of the IOD phenomenon in the EIO. This finding is in accordance with a number of previous studies where we find Chl-a bloom to be positively associated with the pIOD phase [8, 11, 18).

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 2 November 2020 doi:10.20944/preprints202011.0071.v1

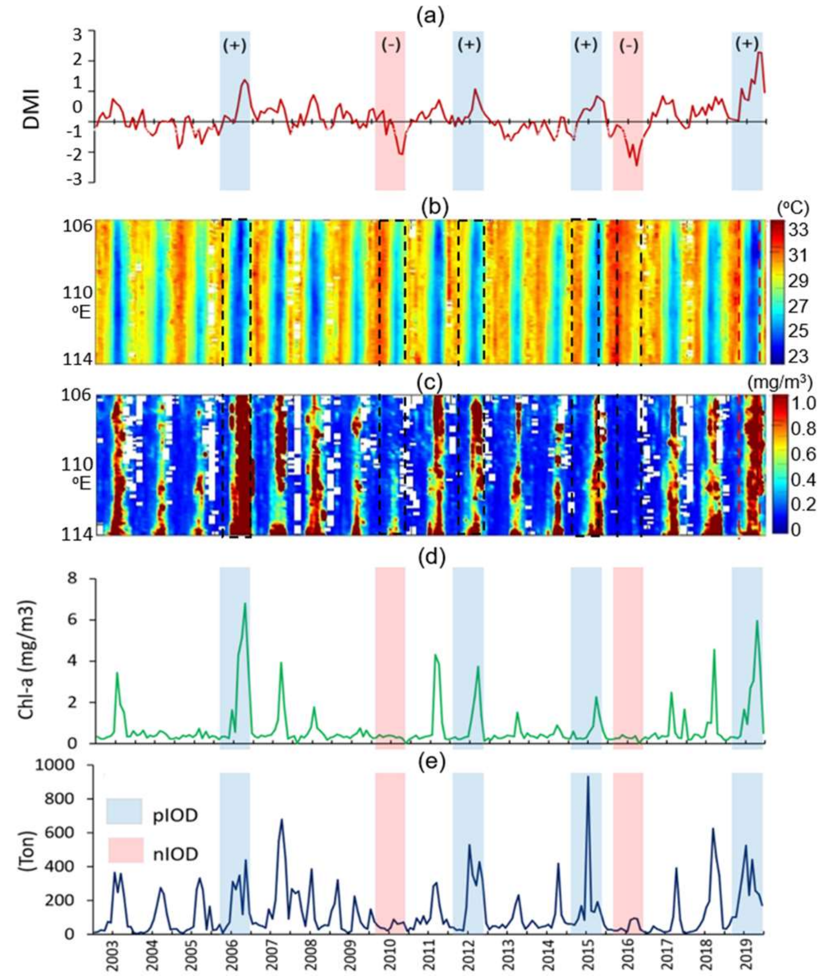

Figure 4. a) Temperature and (b) Salinity profile observed on October 5 (peak of pIOD) and on December 18 (end of pIOD), 2019, within the Palabuhanratu Bay

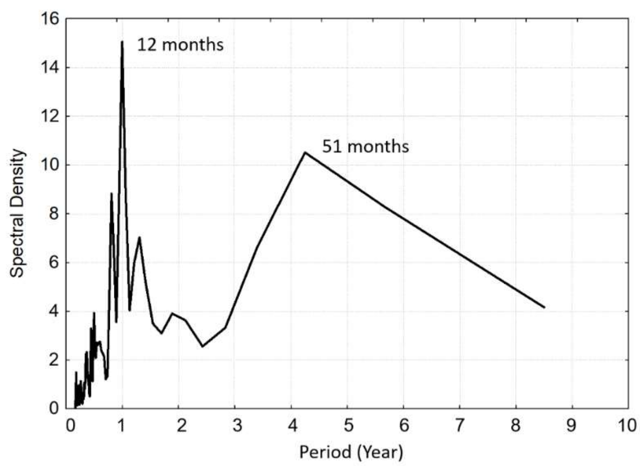

Figure 5. Power spectral density of the Chl-a concentration of the EIO off Java

The highest Chl-a during the pIOD phases can be explained by an extreme upwelling that is typically rich in nutrients. These nutrients "fertilize" surface waters and have high biological productivity in the EIO [8,18] The IOD has altered the trophodynamics of the small pelagic zone in the EIO owing to an increase in the phytoplankton abundance and biomass significantly.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 2 November 2020 doi:10.20944/preprints202011.0071.v1

The monthly time series of landings of small pelagic fishes are shown in Figure 4e. During the pIOD phase of 2006, 2012, 2015, and 2019, the increase in Chl-a concentration (Figure 4c, d) as a phytoplankton biomass indicator was followed by an increase in small pelagic production (Figure 4e). Conversely, during the nIOD phase of 2010 and 2016, the phytoplankton biomass was lower than normal, especially in summer 2010 and 2016, which was followed by a decrease in a production of small pelagic fishes.

3.1. Comparison of Fish Catches During 2010 nIOD and 2019 pIOD Phases

Variations in catches of small pelagic fishes have been observed in association with neutral, 2016 nIOD and 2019 pIOD phases in the EIO off Palabuhanratu Bay. Almost all the kinds of small pelagic fish catches increased during 2019 (Figure 6a). We found that the total catch of small pelagic fishes during pIOD phases was twice as large compared to the neutral condition. Meanwhile, at the time of 2016 nIOD phase, the catch was five times smaller than that of the neutral condition (Figure 6b).

The mean of the catches of fishes landing in Palabuhanratu fishing port during the nIOD phase was 36.1 tons, and during the pIOD phase, it was 310.9 tons. By using a t-test paired to the sample of means comparing the t-stat, we obtained a value of 2.2499 against the two-tailed critical t of 2.447, which indicates that the calculated critical t value was greater than that at a 5% level of significance. Therefore, there is a significant difference between the means of catches of small pelagic fishes between the 2016 nIOD and 2019 nIOD phases; the catches during the 2019 pIOD phase were considerably high and contrarily very low during the 2016 nIOD phase.

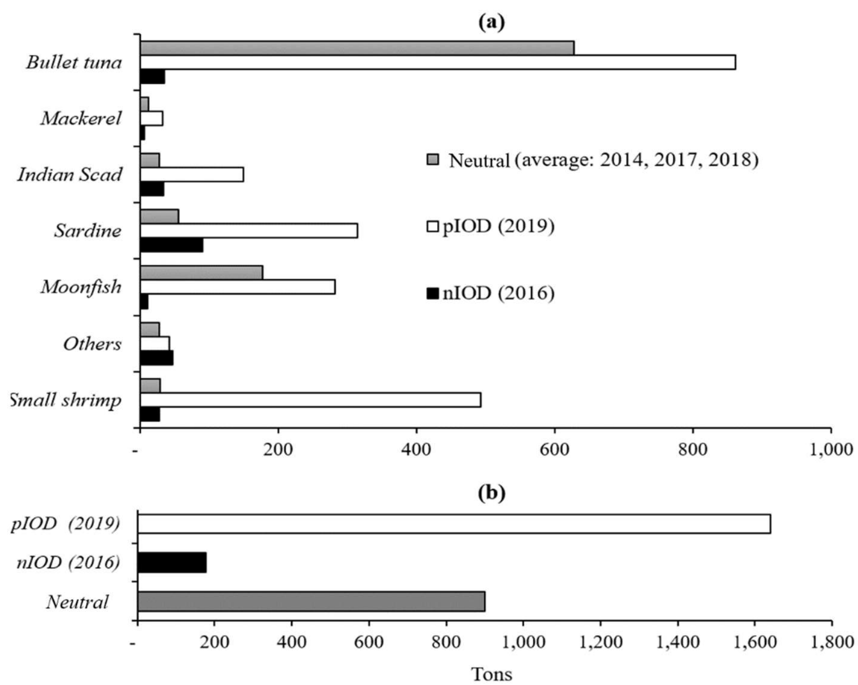

Figure 6. Catches of small pelagic fishes (a) by species, and (b) total in the Palabuhanratu Fishing Port during the neutral conditions (average of 2014, 2017, and 2018), 2016 nIOD and 2019 pIOD phases.

DMI and Chl-a concentration are positively correlated (Figure 7a). The maximum correlation has a time lag of zero, and the cross-correlation diagram is asymmetric: Correlations with positive time lag are dominant over correlations with a negative time lag. The positive correlation between DMI and Chl-a can be explained by the strong upwelling of nutrient-rich sub-thermocline water into the upper euphotic layer, resulting in an increase in phytoplankton growth rate.

The correlation between Chl-a and small pelagic fishes is significantly positive from zero up to the 2-month time lag (Figure 7b). This can be explained in the food web since plankton is the main

 doi:10.20944/preprints202011.0071.v1

food of small pelagic fishes. Particularly in upwelling regions, there are often a few small plankton-feeding pelagic fish species.

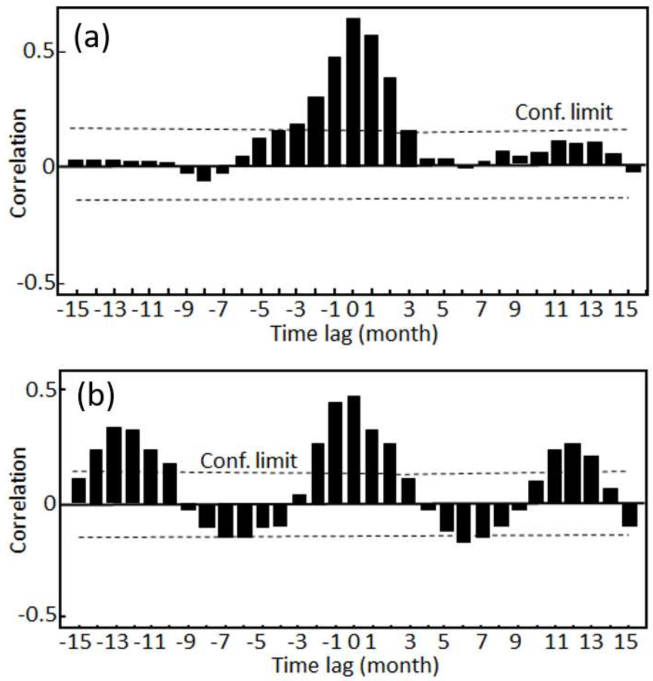

Figure 7. Time-lag cross-correlation coefficient between: (a) DMI and Chl-a, (b) Chl-a and small pelagic fishes landing in Palabuhanratu fishing port

4. Discussion

Researchers have documented coastal upwelling off Java since the earliest oceanographic studies [19]. The coastal upwelling in the EIO off Java has a strong seasonal cycle [18-22]. These previous studies showed that the difference in SST between the Southeast monsoon (upwelling) and Northwest monsoon (downwelling) was only around 2 ^{o}C and thermocline rose up to 40 m in the Palabuhanratu Bay [23]. The differences in the mean of SST, thermocline depth, and salinity between the peak and end of the 2019 pIOD phase are 6 ^{o}C, 80 m, and 1.36 psu, respectively, indicating very strong coastal and open-ocean upwelling during the 2019 pIOD phase.

On the basis of Chl-a data derived by satellite (Figure 8) and field observations (Table 1), we describe the response of phytoplankton to the strong upwelling events in the EIO off Java from July to October 2019. By the Chl-a in-situ measurements, we have confirmed the significant (5 times) increase in Chl-a concentration during the 2019 pIOD phase (Table 1). Previous studies have shown the positive anomalies of Chl-a concentration derived from satellites in EIO off Java during 1997 and 2006 pIOD phases [9, 18]. The upwelling during pIOD phases associated with all these zones is evidenced by its high Chl-a concentrations [13]. In agreement with the results of Susanto and Mara [18] and Iskandar [8], we found increases in Chl-a concentration in the EIO during the 2019 pIOD phase. In contrast, in the 2016 nIOD phase, there was a downwelling that caused a very low Chl-a concentration (Figure 8a).

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 2 November 2020 doi:10.20944/preprints202011.0071.v1

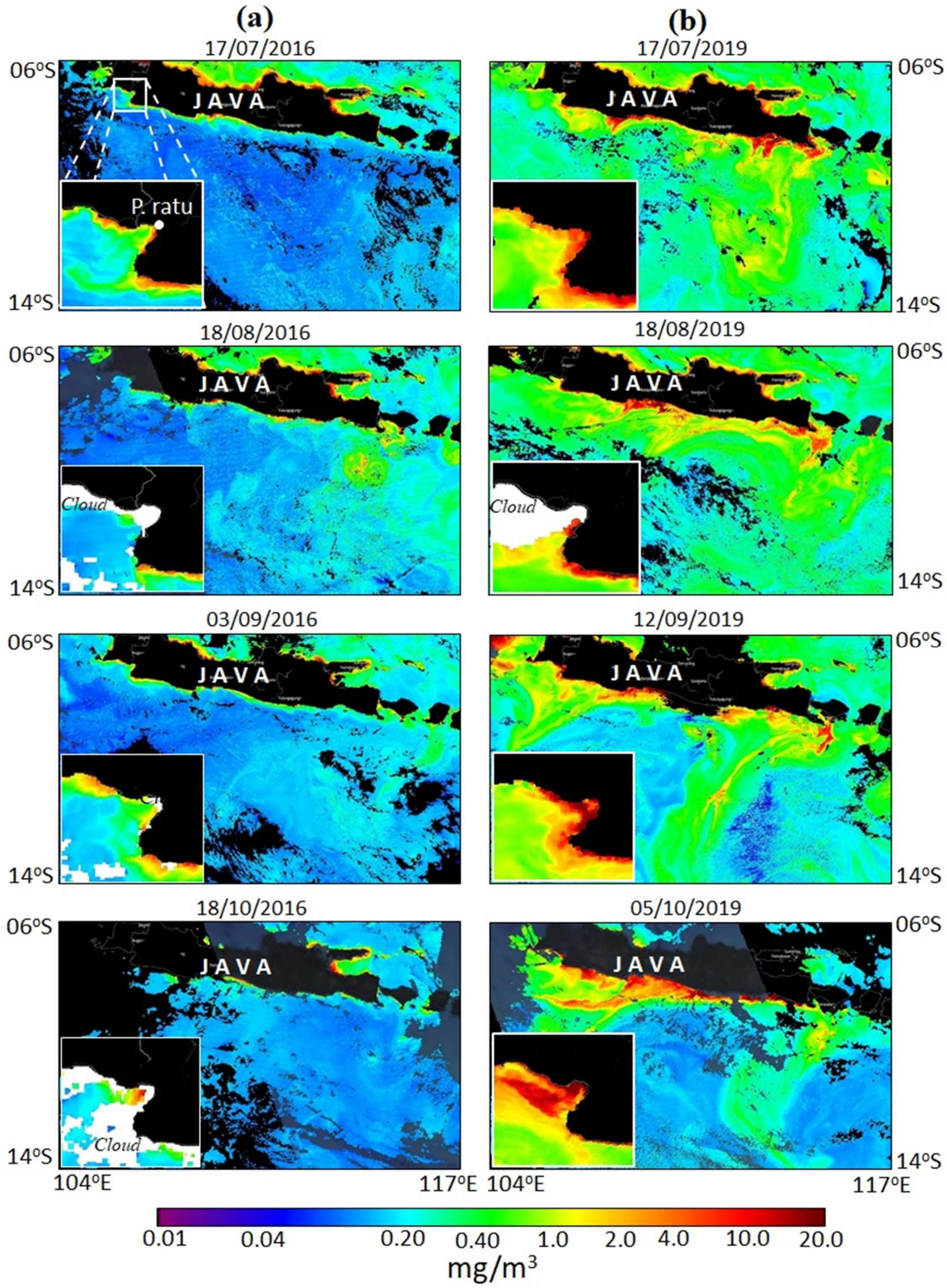

Figure 8. Distributions of daily Chl-a concentration (July–October) in the EIO off Java and Palabuhanratu Bay during: (a) 2016 nIOD phase and (b) 2019 pIOD phase.

The strength of the 2019 pIOD phase modulates the upwelling, thereby influencing biological productivity and fish catches across the EIO off Java. The total catch of small pelagic fishes that landed at the Palabuhanratu Fishery Port during the 2019 pIOD phase was five times greater than that of the 2016 nIOD phase.

Based on the field observations between October and December 2019, the number of small pelagic fishes landings increased sharply; we also found many juvenile fishes. This is due to coastal transport of the upwelled water and nutrients during the 2019 pIOD phase, injecting plankton-rich waters into key fish spawning areas located south of Java [24].

Along the coast of the EIO off south Java, the small pelagic fishes play an important role in the economics of the fishers. The fluctuation in prices of small pelagic fishes is considerable owing to the uncertainty of production. When fishes were more plentiful during the 2019 pIOD phase but market demand was stable, prices dropped. However, during the 2016 nIOD phase, when the fish catches declined, prices rose. Besides the uncertainty of fish production, the perishable nature of fish also affects the price thereof [25, 26]

The IOD-related fish price variability can be maintained by regulating the fishing fleets or the distribution of fish catches because we know well that during the pIOD (nIOD) phases, the production of small pelagic fishes was very high (low) because of the variability of Chl-a concentrations as primary production in the waters. The IOD phases can be predicted a few months earlier so that fish catches that are plentiful during the pIOD phase can be distributed to other regions to prevent disequilibrium in market demand and supply. Likewise, during the nIOD phase, fish supplies from other regions can be prepared. During pIOD phases, fishing operations can also be reduced and juvenile-sized fishing prohibited. If the market demand and supply are in equilibrium, the fish price will be stable because the fish supply is highly elastic [26].

5. Conclusions

During the interannual cycle of the 2019 pIOD phase, there was particularly strong coastal upwelling as seen from the six-fold difference in both temperature and Chl-a concentration between the peak and end of the pIOD in the Palabuhanratu Bay. Contrastively, during the 2016 nIOD phase, there was a strong downwelling. During pIOD (nIOD) phases, the Chl-a concentration became abnormally high (low) over the EIO off Java coastal waters through the increasing intensity of upwelling (downwelling). Chl-a bloom (decline) during the strong coastal upwelling (downwelling) subsequently increases (decreases) the abundance of small pelagic fishes in EIO off Java's coastal waters.

Variation in Chl-*a* concentrations due to IOD events significantly affects the small pelagic fish resources in the EIO off Java's coastal waters. Therefore, the information or predictions of both pIOD and nIOD phases can be used as a basis for fishing management to increase fishermen's income and reduce risks associated with IOD phases.

Author Contributions: Conceptualization, J.L., L.A. and E.S.; methodology, J.L., N.M.N.N. and I.W.N.; validation, M.T.H. and E.M.; formal analysis, J.L., T.O. and I.W.N.; data curation, N.M.N.N. and A.P.; writing—original draft preparation, J.L.; writing—review and editing, K.M., E.S., N.M.N.N. and I.W.N.; visualization, J.L. and H.A.R.; project administration, H.A.R. All authors have read and agreed to the published version of the manuscript.

Acknowledgments: The authors thank the anonymous reviewers for their valuable and constructive comments. This study was supported by a grant (CAF2017-RR02-CMY-Siswanto) from the Asia-Pacific Network for Global Change Research (APN). I thank the NASA Ocean Color Project (https://oceancolor.gsfc.nasa.gov/ and https://worldview.earthdata.nasa.gov/) for processing and distributing the datasets. Thanks are also due to "PPS Palabuhanratu" for providing Fishery Statistic data (2003–2019).

Conflicts of Interest: Conflicts of Interest: The authors declare no conflict of interest.

References

1. Saji, N.H.; Goswami, B.N.; Vinayachandran, P.N.; Yamagata, T. A dipole mode in the tropical Indian Ocean. *Nature.* **1999**, 401, 360–363.
2. Saji, N.H.; Yamagata, T. Structure of SST and surface wind variability during Indian Ocean dipole mode events: COADS observations. *J. Clim*. 2003, 16, 2735–2751.
3. Saji, N.H. The Indian Ocean Dipole. *In* Oxford Research Encyclopedia of Climate Science. **2018**, Oxford University Press.
4. Ashok, K.; Guan, Z.; Yamagata, T. Impact of the Indian Ocean dipole on the relationship between the Indian monsoon rainfall and ENSO. *Geophys. Res. Lett*. **2001**, 28, 4499–4502.

5. Hashizume, M.; Chaves, L.F.; Minakawa, N. Indian Ocean Dipole drives malaria resurgence in East African highlands. *Sci. Rep*. **2012**, 2, 1–6.
6. Chaves, L.F.; Satake, A.; Hashizume, M.; Minakawa, N. Indian Ocean dipole and rainfall drive a Moran effect in East Africa malaria transmission. *J. Infect. Dis*. **2012**, 205, 1885–1891.
7. Vinayachandran, P.N.; Iizuka, S.; Yamagata, T. Indian Ocean dipole mode events in an ocean general circulation model. *Deep Sea Res. Part II Top. Stud. Oceanogr*. **2002**, 49, 1573–1596.
8. Iskandar, I.; Rao, S.A.; Tozuka, T. Chlorophyll-a bloom along the southern coasts of Java and Sumatra during 2006. *Int. J. Remote Sens*. **2009**, 30, 663–671.
9. Sari, Q.W.; Utari, P.A.; Setiabudidaya, D.; Yustian, I.; Siswanto, E.; Iskandar, I. Surface chlorophyll-a variations in the Southeastern Tropical Indian Ocean during various types of the positive Indian Ocean Dipole events. *Int. J. Remote Sens*. **2020**, 41, 171-184.
10. Mashita, M.; Lumban-Gaol, J. Variability of sea surface temperature (SST) and chlorophyll-a (Chl-a) Concentrations in the Eastern Indian Ocean during the Period 2002-2017. *Int. J. Remote Sens & Earth Sci.* **2019**, 16, 55-62.
11. Iskandar, I.; Lestari, D.O.; Utari, P.A.; Khakim, M.Y.N.; Poerwono, P.; Setiabudidaya, D. Evolution and impact of the 2016 negative Indian Ocean Dipole. *In J. Phys. Conf. Ser*. **2018**, 985, 012017.
12. Sartimbul, A.; Nakata, H.; Rohadi, E.; Yusuf, B.; Kadarisman, H.P. Variations in chlorophyll-a concentration and the impact on *Sardinella lemuru* catches in Bali Strait, Indonesia. *Prog. Oceanogr*. **2010**, 87,168-174.
13. Lumban-Gaol, J.; Leben, R.R.; Vignudelli, S.; Mahapatra, K.; Okada, Y.; Nababan, B.; Mei-Ling, M.; Amri, K.; Arhatin, R.E.; Syahdan, M. Variability of satellite-derived sea surface height anomaly, and its relationship with Bigeye tuna (*Thunnus obesus*) catch in the Eastern Indian Ocean. *Eur. J. Remote Sens*. **2015**, 48, 465–477.
14. Syamsuddin, M.; Saitoh, S.I.; Hirawake, T.; Syamsudin, F.; Zainuddin, M. Interannual variation of bigeye tuna (*Thunnus obesus*) hotspots in the eastern Indian Ocean off Java. *Int. J. Remote Sens*. **2016,** 37, 2087-2100.
15. Lu, B.; Ren, H.L. What caused the extreme Indian Ocean Dipole event in 2019? *Geophys. Res. Lett*. 2020, p. e2020GL087768.
16. Lu, B.; Ren, H.L.; Scaife, A.A.; Wu, J.; Dunstone, N.; Smith, D.; Wan, J.; Eade, R.; MacLachlan, C.; Gordon, M. An extreme negative Indian Ocean Dipole event in 2016: dynamics and predictability. *Clim. Dyn*. **2018**, 51, 89–100.
17. Thomson, R.E.; Emery, W.J. Data analysis methods in physical oceanography. 1st ed.; Elsevier Inc.: New York, USA, **1998**; pp. 371–511.
18. Susanto, R.; Marra, J.O.H.N. Chlorophyll a variability. *Oceanogr*. **2005**, 18, 124-127.
19. Wyrtki, K. The upwelling in the region between Java and Australia during the south-east monsoon. *Mar. Freshw. Res*. **1962**, 13, 217–225.
20. Kuswardani, R.T.D.; Qiao, F. Influence of the Indonesian Throughflow on the upwelling off the east coast of South Java. *Chin. sci. bull*. **2014**, 59, 4516–4523.
21. Varela, R.: Santos, F.; Gómez-Gesteira, M.; Álvarez, I.; Costoya, X.; Días, J.M. Influence of coastal upwelling on SST trends along the south coast of Java. *PloS one.* **2016**, 11, e0162122.
22. Siswanto, E.; Horii, T.; Iskandar, I.; Gaol, J.L.; Setiawan, R.Y.; Susanto, R.D. Impacts of climate changes on the phytoplankton biomass of the Indonesian Maritime Continent. *J Mar Syst.* **2020**. p. 103451.
23. Matsuyama, M.; Senjyu, T.; Natih, N.M.N. Oceanographic conditions in Pelabuhanratu Bay, West Java. *La mer*. **1996**, 34, 283–291.
24. Matsuura, H.; Sugimoto, T.; Nakai, M.; Tsuji, S. Oceanographic conditions near the spawning ground of southern bluefin tuna; northeastern Indian Ocean. *J. Oceanogr.* **1997**, 53, 421–434.
25. Dahl, R.E.; Oglend, A. Fish price volatility. *Mar. Resour. Econ*. **2014**, 29, 305–322.
26. Sathiadhas, R.; Narayanakumar, R. Price policy and fish marketing system in India. *J. Biol. Educ.* **1994**, 11, 225–241.