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PRIMARY PRODUCTIVITY OF JAKARTA BAY IN A CHANGING ENVIRONMENT: ANTHROPOGENIC AND CLIMATE CHANGE IMPACTS

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ABSTRACT

Jakarta Bay receives direct impact from the rapid development of infrastructure and land-based industries which contributed to the increase in pollution and nutrient, and at the same time facing climate change. This condition influenced growth of chlorophyll-*a* and primary production. To investigate changes of primary production in Jakarta Bay due to anthropogenic and climate change impacts, a field measurement, laboratory experiment and collection of several data sets have been conducted. The study showed that impact of anthropogenic, particularly sediment load from the land to primary production is important. The intensification of primary production occurs in the middle region of Jakarta Bay, while the chlorophyll-*a* concentration is high in the river mouth area. The anthropogenic impact is indicated by the land use change that has increased to 73% during the last ten years. The laboratory experiments by injecting CO_2 in the waters, as a global warming simulation, have shown a decrease in chlorophyll-*a* and primary production. Therefore, the combination of anthropogenic and climate change may have a double impact on the Jakarta Bay ecosystem.

Key words: Primary production, Jakarta Bay, anthropogenic, climate change, impact

INTRODUCTION

As a part of the Java Sea, the mass transport of water and material in Jakarta Bay are controlled by ocean dynamics which is generally influenced by monsoon system and tidal mixing. Wyrtki (1961) showed that there are two distinct seasons over the Indonesia seas: southeast monsoon and northwest monsoon. Associated with the East wind from Australia, southeast monsoon brings warm dried air during boreal summer (June-August). In contrast, the West wind from Asia or northwest monsoon brings warm moist air during the boreal winter (December-February). Thus,

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monsoon systems also control the dry season (northwest monsoon) and wet season (southeast monsoon) in Indonesian seas where the monsoon wind patterns also affect those of surface flow. In Jakarta bay, the distribution of nutrients is strongly affected by monsoon system along the year, but its spatial distribution is more pronounced, high near the coast and low at seaward (Ilahude 1995).

Although coastal waters is an area relatively small in global seas, but it plays an important role in biogeochemical cycles. Gattuso *et al.* (1998) reported that coastal water contributed 14-30% of primary productivity, 80% of organic matter decomposition, and 90% mineralized sediments. In the sea, half of the production of organic matter was provided by phytoplankton (Boyce *et al.* 2010). As many shelf seas in the world, ecosystems of the Java Sea are under pressure due to human activities in the coastal region. The Java Sea covers an area of 450 000 km^2 where some cities and industries are located along northern coast of Java Island. Talaue McManus (2000) reported that most of the pollution in the Java Sea is caused by domestic sewage, agricultural, industrial and waste as well as solid waste that goes to the coastal region. Rapid development of infrastructure and land-based industries also contributed to the pollution increase of the coast, for example: Jakarta Bay and its surrounding waters are influenced by human activities of the Jakarta Metropolitan Area (JMA) which contribute to the pollution of the Jakarta Bay (Suwandana *et al.* 2011).

Population in JMA has been increasing year by year, as reported by the Indonesian Statistics that the population has increased to 30.2 % from 7.6 million in 2007 to 9.8 million in 2012 (Provinsi DKI 2012). This has an implication to land use change of the coastal area and its vicinities, hence affected Jakarta Bay. Therefore, the population of JMA may have direct impact (exploitation and human settlements) and indirect impact (via watersheds) to Jakarta Bay.

Anthropogenic impact due to human activities has caused an increase in the concentration of nitrates and phosphates in Jakarta Bay, to 5 and 15 times, respectively, in the last three decades (Arifin 2005). In addition, the eutrophication condition in Jakarta Bay can be categorized as hyper-eutrophication, especially in estuarine waters or region near river mouth as reported by Damar (2003). On the other hand, the Java Sea ecosystem is facing climate change impact, particularly sea surface temperature (SST) rise and marine acidification. According to the IPCC'S predictions (Christensen *et al.* 2007), increase of SST in the Southeast Asia waters will be about 1.5 - 3.7°C during the last 21st century. Marine acidification is related with decline of pH as a result of absorbing atmospheric CO_2 by the global ocean. According to Orr *et al.* (2005) marine pH has decreased to 0.1 since post-industrial era. Regarding to the recent condition of Jakarta Bay and climate change issue, hence, this research aim was to investigate changes of primary production in Jakarta Bay due to anthropogenic and climate change impacts.

MATERIALS AND METHOD

The field measurement of some water quality parameters at 21 stations and laboratory experiments had been carried out during the period of 9 - 14 July 2012. In addition, Landsat satellite data as well as secondary data had been collected and analyzed. Water samples parameters were taken including water quality, primary production and Chlorophyll-*a*. Water quality parameters measured were surface temperature, salinity, turbidity, using water quality checker at a depth of 0 - 10 m. Primary production and Chlorophyll-*a* water samples were collected using *Niskin* water sample at a depth of 1 - 2 m, and the transparency was measured using a secchi disk. Secondary data for nutrient concentrations analysis was obtained from Damar (2003). The field stations are shown in Fig. 1.

Laboratory experiments were set up in Untung Jawa Island, northern part of Jakarta Bay using seawater collected directly in real time from the sampling area to measure chlorophyll-*a* and primary production influenced by increasing temperature and CO_2 injection as treatments. Two different treatments have been performed to increase the seawater temperature 1^0C and 2^0C of the initial temperature (29^0-30^0 C) using Tube Lamps, while CO_2 gas was injected to seawater until 450 ppm and 560 ppm, respectively.

Gross Primary Production (GPP) and Net Primary Production (NPP) were measured based on dissolved oxygen in the light and dark bottles before and after incubation (3 hours incubation using halogen lamp) in field laboratory with ambient condition. Dissolved oxygen was measured based on modified Winkler method (Strickland & Parsons, 1972; APHA, 1980). Chlorophyll-a parameter was measured using fluorometric method.

In addition, the Landsat satellite data were downloaded from source : (http://earthexplorer.usgs.gov/) to analyze land use coverage change during 10 years (2002-2011 using color composite, total suspended solid (TSS) applying formula of Ambarwulan (2002) and Chlorophyll-*a* distributions in Jakarta Bay using an algorithm (Wouthuyzen 1991).

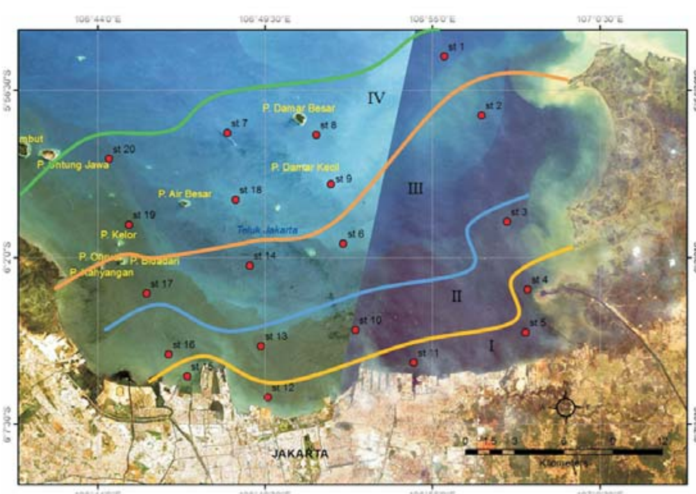


Figure 1. Sampling stations and its clustering in Jakarta Bay

RESULTS AND DISCUSSION

General Condition of Jakarta Bay Water

Jakarta Bay receives material and water discharges from several rivers that cover JAM and its surrounding area, such as Cisadane in the western part and Citarum in the eastern part. In addition, there are several rivers that drain in the central part of Jakarta Bay, such as: Muara Gembong, Cikarang, Marunda, Muara Angke, and Kamal. All rivers are responsible in carrying sediment in the bay and affect TSS and transparency of the water. Considering the sediment distribution regime, four clusters of sampling stations were based on their distance from the coast-line as shown in Table 1.

Table 1. Clustering of sampling stations

Cluster	Station	Description
1	15, 12, 11, 4, 5	Near estuary and coastline
2	16, 13, 10, 3	4- 5 Km from coastline
3	17, 14, 6, 2	8-10 Km from costline
4	19, 18, 9, 1, 8, 7, 20	>10 Km from coastline

Sea surface temperature depends on several factors such as precipitation, evaporation, wind speed, intensity of sunlight, and freshwater input from the river. In Jakarta Bay, distribution of the sea surface temperature horizontally decreased from near the coast to seaward (Fig. 2). The vertical distribution of sea temperature showed the same pattern as those of horizontal distribution (Fig. 3).

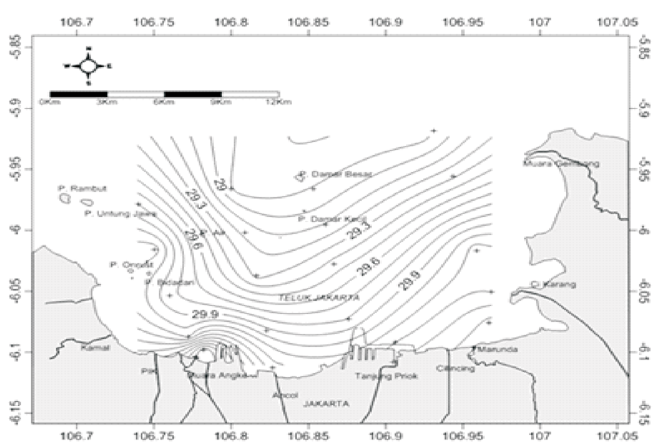


Figure 2. Horizontal distribution of sea surface temperature July 2012

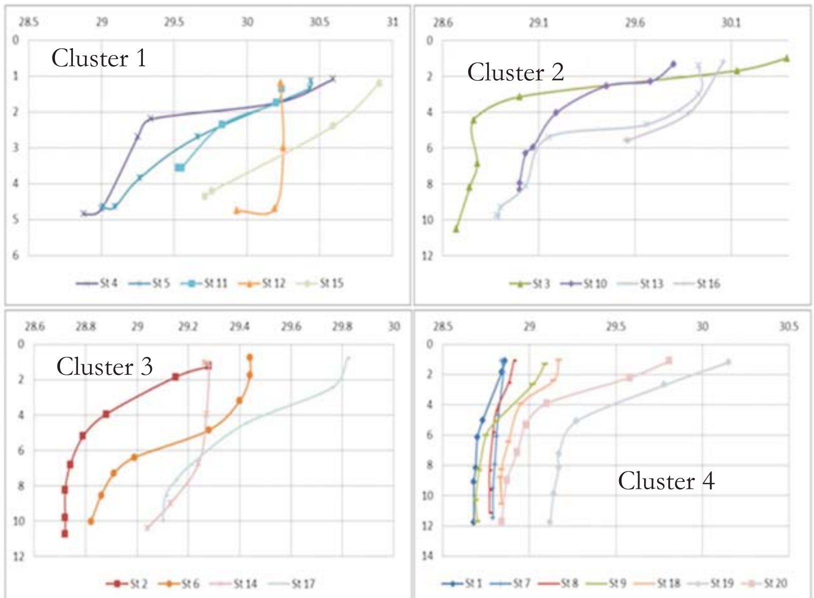


Figure 3. Vertical distribution of sea temperature of Jakarta Bay waters

The role of river discharges in Jakarta Bay was represented by sea surface salinity distribution. In Jakarta Bay, the river discharges were relatively low as shown in Figure 4 where the observed salinity distribution tended to decrease slightly from Cluster 4 to Cluster 1.This condition was actually influenced by level of rainfall during dry season (July 2012) at which the sampling period was carried out. In general, the sea surface salinity in Jakarta Bay is typical of coastal water varying between 30.4 to 32.1 psu.

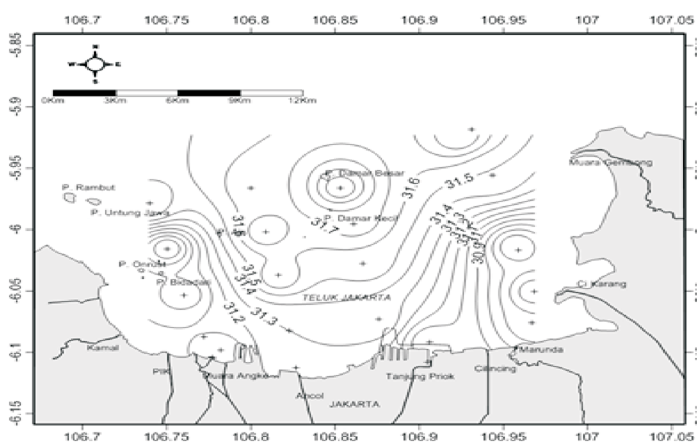


Figure 4. Sea surface salinity distribution in Jakarta Bay July 2012

The river discharges were relatively low, although the effect of human activities in the coastal region has affected the turbidity of Jakarta Bay, particularly in Custer 1 and Cluster 2 regions. Turbidity consisted of colloidal particles and suspended pollutants, such as: organic materials and inorganic waste from industry, households and aquaculture. Turbidity could be caused by the presence of organic materials produced by the waste industry. The turbidity in Jakarta Bay varied between 2.43 - 7.00 NTU (Fig. 5) and the high turbid water was located in St.15 (Muara Angke), St. 11 (Priok), and St. 3 and 4 (Cikarang). So, the turbidity was high at the coastline due to land runoff and gradually decreases seawards. Similar to the turbidity, total dissolved substance (TDS) distribution had the same pattern. The dissolved substance could be carbonate and bicarbonate, chloride, sulfate, phosphate, nitrate, calcium, magnesium, sodium, organic ions, and more ions. The TDS ranges between 31 - 32 g/l, where the highest concentration occurs in St. 15 (Muara Angke).

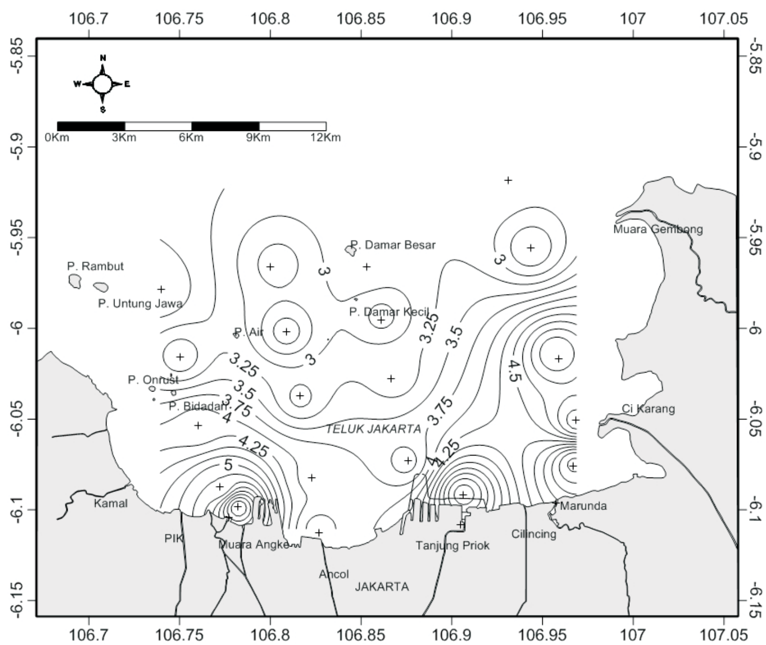


Figure 5. Turbidity distributions in Jakarta Bay based on field measurement on July 2012

The observed Secchi disk depth distribution in Jakarta Bay showed that Cluster 1 and Cluster 2 were lower than Cluster 3 and Cluster 4. It is emphasized that the transparency of Jakarta Bay close to the estuary and coastline were poor. The Secchi depth for each cluster was varied between 1.3 and 3.5 m (Cluster 1), 1.6 and 3 m (Cluster 2), 4 and 4.5 m (Cluster 3), 3 and 6.2 m (Cluster 4).

Chlorophyll-*a* is a necessary pigment of phytoplankton for photosynthesis. Phytoplankton serves as primary producers in the chain of life in the sea, so its existence is very important as the basis of life on the sea. The chlorophyll-*a* concentration in Jakarta Bay varied between 0.78-15.74 mg/l (Figure 6), while the annual chlorophyll-*a* concentration derived from the satellite data (2002-2012) varied from 1.09 mg/l to 6.07 mg/l and showed a stable trend , except in 2011-2012 the trend was increasing significantly close to the coastal area (cluster1,2) (fig. 7).

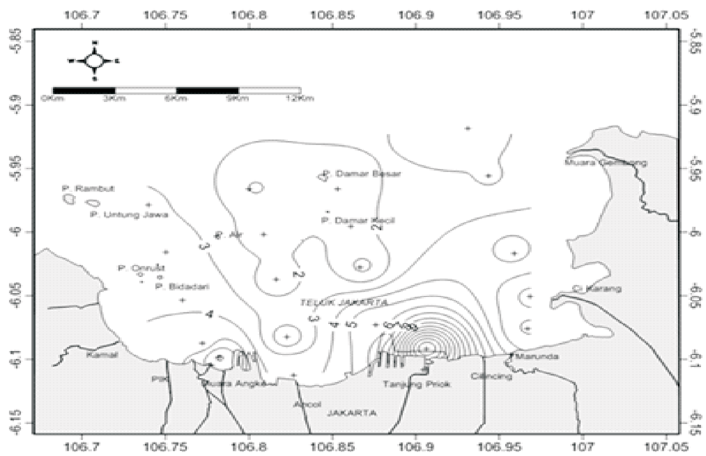
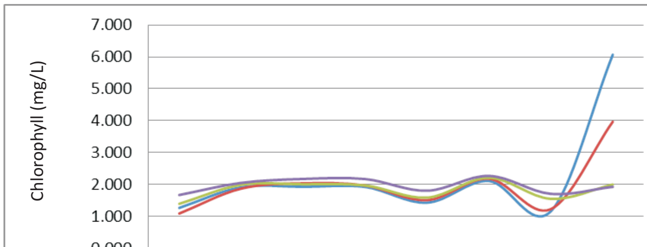


Figure 6. Chlorophyll-*a* distribution in Jakarta Bay based on field measurement on July 2012



	2002	2004	2005	2006	2008	2009	2011	2012
Cluster 1	1.267	1.915	1.926	1.925	1.430	2.110	1.161	6.070
Cluster 2	1.091	1.872	2.037	1.969	1.511	2.181	1.227	3.969
Cluster 3	1.396	1.990	2.005	1.971	1.588	2.211	1.551	1.999
Cluster 4	1.672	2.053	2.174	2.171	1.805	2.270	1.707	1.926

Figure 7. Annual Chlorophyll-*a* concentration derived from satellite data(2002-2012)

Increasing chlorophyll-*a* mainly occurred in the near river mouth of St. 11 (Tanjung Priok) and St. 15 (Muara Angke) due to runoff from the JMA. However, low primary production was observed surrounding the river mouth, whereas high production occurred in the centre of Jakarta Bay (Fig. 8). This could indicate that little support of the photosynthesis in the river mouth occurred and was probably due to the high turbidity.

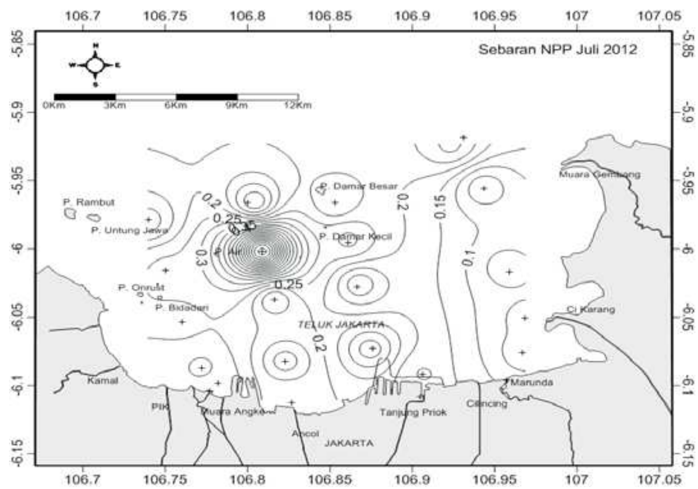


Figure 8. NPP distributions in Jakarta Bay based on field measurement on July 2012

Anthropogenic Impact

The studies of anthropogenic impact and primary productivity seas were analyzed based on the ratio of Chlorophyll-*a* and NPP. Chlorophyll-*a* as major component in phytoplankton is responsible for primary production activities. Increasing of Chlorophyll-a concentration in the waters resulted high primary productivities. Ratio of Chlorophyll-*a* and NPP has relation to an individual's capacity to produce phytoplankton primary productivity. The higher the ratio of Chlorophyll-*a* and NPP, the lower the capacity of phytoplankton result in the primary productivity. This indicated that abundance of Chlorophyll-*a* does not mean ability of primary productivity to increase in proportion to the amount of Chlorophyll-*a*. In this case, the impact of anthropogenic pollution, can affect capacity of Chlorophyll-a in generating primer productivity.

To analyze the impact of land use change on primary production in Jakarta Bay, Figure 9 shows ratio of chlorophyll-*a*/NPP. The high ratio means more chlorophyll-*a* to produce primary production or the high ratio the less efficiency in photosynthesis The ratio indicates the efficiency in photosynthesis processes by phytoplankton. The average value of ratio 79.83 in Cluster 1, 60.1 in Cluster 2, 38.05 in Cluster 3 and 20.39 in Cluster 4 . Thus, anthropogenic pressures were high in near river mouths or coastal region (Cluster 1) and gradually decrease to the seaward (Cluster 4).

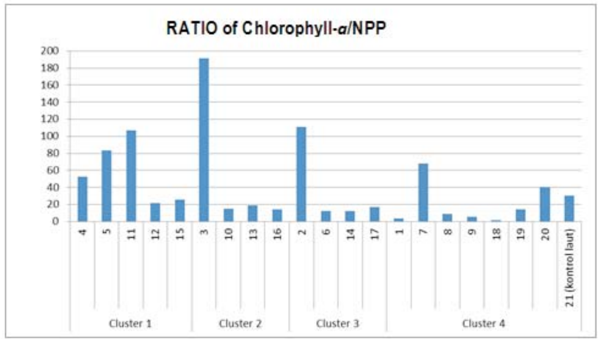


Figure 9. Distribution of ratio between chlorophyll-*a* and NPP in all stations

The analysis of the land cover change is only carried out by grouping of some particular class settlements, pond/swamp, rice field, and vegetation corresponding with the anthropogenic impacts of the waters. The maps of the land cover change during the last ten years are shown in Figure 10.

The variation of land use change in JMA concluded that settlement class has increased approximately 73% in the past 10 years. It implies that the anthropogenic contribution from residential waste (household and industry) has increased year by year. As the rice fields are likely to decrease, pond or swamp tends to remain unchanged. Meanwhile, vegetation cover increased due to the development of the green city program of Jakarta, which stated that every area should leave at least 30% of the open green area. The land cover change from 2002 to 2011 is shown in Figure 11.

The total suspended sediment concentration (TSS) extracted from satellite data during 2002-2011 in Jakarta Bay waters increased and showed higher concentration in the mouth of rivers (Cluster 1-2). TSS concentrations showed positive correlation with the turbidity. This similar pattern was also shown during the observation period and the concentration varied from 0.11 mg/l to> 135 mg/l. The spatial distribution of concentration of the TSS tends to develop year by year in the coast seaward. This is probably due to the increase of sediment load from land as a result of significant land cover change in JMA and surrounding cities.

In addition, Figure 12 shows ratio of compensation depth (dK) and attenuation depth (K). The compensation depth (dK) is a depth of water column where photosynthesis rate is the same as respiration rate. The compensation depth characterizes the occurrence of primary productivity capacity. Attenuation depth (K) is a maximum depth for sunlight intensity in water column, to allow photosynthesis processes. In turbid water such as Jakarta Bay, depth attenuation can be a limiting factor in photosynthesis process. Thus, ratio of compensation depth and attenuation depth characterize capacity of primary productivity. The higher ratio of dK and K, the greater capacity of primary production. The ratio of dK/K is generally high in Cluster 4 and low in Cluster 1. This is consistent with the high sediment load from land as shown previously in turbidity distribution (Fig. 5). Therefore, the land use change and sediment supply have influenced significantly to the primary production in Jakarta Bay.

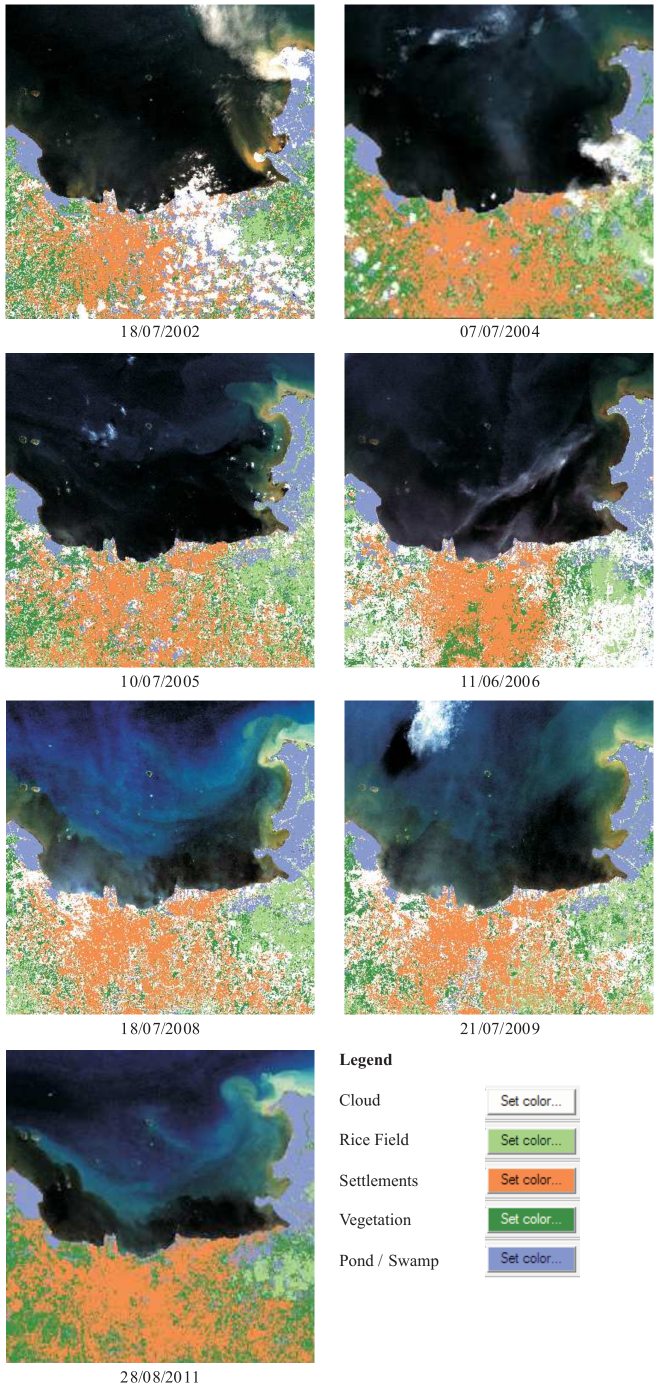


Figure 10. Land cover changes during the last ten years (2002-2011)

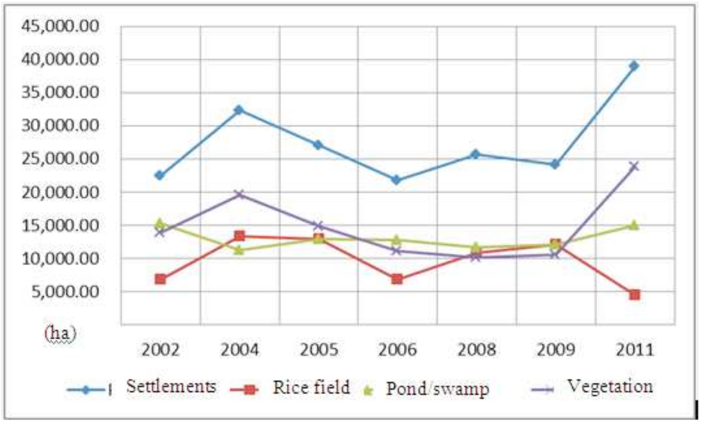


Figure 11. Land cover change from 2002 to 2011

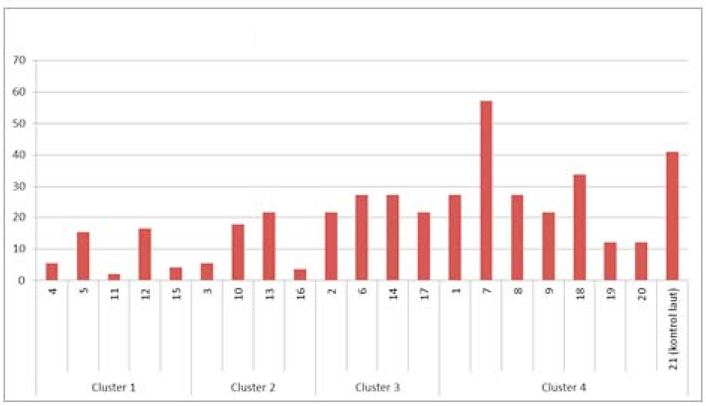


Figure 12. Ratio between compensation depth(dK) and attenuation depth (K) in all stations.

Climate change impact

The annual average of minimum surface air temperature in Jakarta bay have increased during 2002-2011 (Fig. 13). The lowest and the highest of minimum surface air temperature occurred in 2008 and 2011 were 25.33^{0}C and 25.76^{0}C, respectively. At the same period, the maximum surface air temperature tended to decrease, where the highest and the lowest occurred in 2002 and 2008, respectively. Those surface air temperatures could be used as a primary measurement of climate change in Jakarta bay and its surrounding areas (Hansen *et al.* 2010).

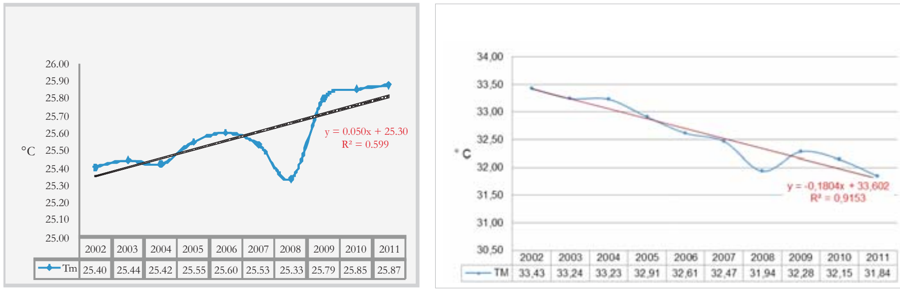


Figure 13. Annual average of minimum (left) and maximum (right) of surface air temperature in Jakarta bay during 2002-2011 (source : BMKG, Jakarta, 2012)

The laboratory experiments as simulation of the effects of climate change was set up streamlined in nature, where the created conditions are closed systems. However, to achieve conditions similar to the process in nature, the location of the experiment was placed close to the environmental conditions with a relatively recent natural changes.

In general, the experiment concluded that there has been a decline in chlorophyll-a and primary productivity (NPP) with increasing temperature 1^0C and 2^0 C and CO_2 gas injection (450 and 560 ppm) into the water sample, after the incubation process. In contrast, Hashioka and Yamanaka (2007) reported that chlorophyll-*a* and NPP in the sub-tropical and temperate waters will be increasing under global warming scenario, based on numerical modeling. This contradiction may suggest that marine ecosystem in tropical region has different response with those in sub-tropical and temperate regions. The summary of laboratory experiments related with climate change scenarios is presented in Table 2.

Table 2. The increased influence of temperature and CO_2 towards primary productivity and chlorophyll-*a*

Type of Experiment	GPP (mgC/m³/day)	Respiration (mgC/m³/day)	NPP (mgC/m³/day)	Chlorophyll-*a* (mg/m³)
Control before incubation				1.916
Control after incubation	2.634	3.088	0.061	2.394
Temperature 1 °C after incubation	2.593	3.108	0.003	1.373
Temperature 2 °C after incubation	2.557	3.065	0.003	1.075
Injection CO_2: 450 ppm	2.441	3.086	-0.131	1.391
Injection CO_2: 560 ppm	2.392	3.257	-0.323	1.073

Note :GPP = Gross Primary Productivity/Photosynthesis
NPP = Net Primary Productivity

In order to evaluate the dominant parameters that affect NPP in Jakarta Bay, principal component analysis (PCA) has been performed. Selected parameters for PCA are nutrients (nitrite, nitrate, ammonium and phosphate) and chlorophyll-*a* as shown in Figure 14. In this analysis, nutrient concentrations was obtained from Damar (2003) where the chlorophyll-*a* is based on the present study.

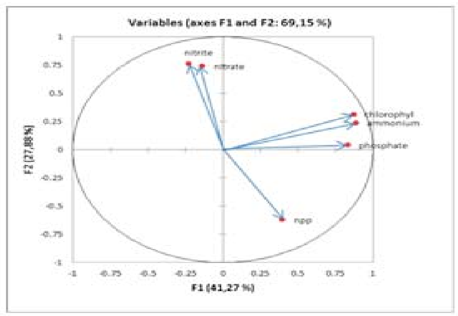


Figure 14. PCA of Chlorophyll-*a*, ammonium, phosphate and NPP

PCA results showed that chlorophyll-*a*, ammonium, phosphate and NPP have positive correlation. In this case, chlorophyll-*a* and ammonium are closely associated. This linkage suggests that ammonium influence significantly on phytoplankton growth (chlorophyll-*a* concentrations) in Jakarta Bay. Ammonium is a kind of nutrient nitrogen species, which generally come from sources of organic nitrogen remineralization processes in form of particles, as well as dissolved. In addition, ammonium sources are also coming from industrial activities. Nitrogen species such as nitrate and nitrite are generally derived from agriculture due to the use of chemical fertilizers.

According to data from the Environmental Status Report of the JMA (BPLHD Jakarta 2011), the ammonium supply in Jakarta Bay is mainly by rivers where the high contribution is Muara Cakung and Muara Sunter, particularly during ebb tide (Fig. 15). Both river mouths are located at Tanjung Priok, an international marine port of JMA.

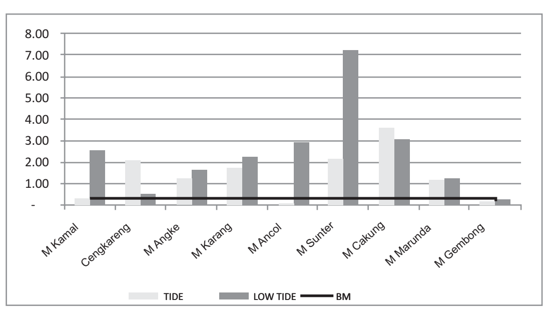


Figure 15. Ammonia concentration on the tide and low tide in estuary of Jakarta Bay

Assessment of anthropogenic impacts and climate change on primary production in Jakarta Bay, indicated that the role of human activities in Jakarta is more dominant, especially in the waters close to coastal or estuarine river. For example, the efficiency in photosynthesis is controlled by sediment load, not only containing clay and sand, but also organic particles or contaminants that enter through the rivers. This condition influences the change of water quality, resource supply , habitat availability and climate (Lotze *et al*. 2002). The impact of climate change in this case was significant and may have a double impact in combination with the anthropogenic change.

CONCLUSIONS

The anthropogenic impact was clearly shown by less efficiency in primary production in Jakarta Bay, particularly close to the river mouths or coastline due to sediment load from Jakarta Metropolitan Area. The anthropogenic impact was mainly influenced by domestic waste and land use change that had increased to 73% during the last ten years. The climate change impacts based on laboratory experiments by simulation of increasing temperature and $C0_2$ gas have shown a decrease in chlorophyll-*a* and primary production. Therefore, the anthropogenic and climate change may have a double impact to the Jakarta Bay ecosystem.

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