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INTEGRATED WATER MONITORING TO SUPPORT THE MANAGEMENT OF HEALTHY SEGARA ANAKAN ESTUARY
(Pemantauan Air Terpadu Untuk Mendukung Pengelolaan Kesehatan Sumber Mata Air Segara Anakan)

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Abstract

Estuaries provide vital nesting and feeding habitats for many aquatic plants and animals, therefore suitable methods are needed for monitoring the changes in estuarine waters to keep the health of coastal habitats. Limitations in understanding the relationship between discrete physicochemical measurements and cause of the alteration in the quality and functioning of an ecosystem, has lead to the integration of physicochemical and biological monitoring. In this work, spatial time series integrated monitoring of Southern part of Segara Anakan Estuary, Central Java, Indonesia, was carried out from August 2003 to May 2004. The parameters were measured at the lowest water depth. Dramatic changes in physicochemical parameters of salinity, total suspended solids, turbidity and biological parameters of phytoplankton diversity, density was observed during dry season (August-September 2003) and wet season (December 2003-March 2004), while the changes in parameters of organics (DO, BOD and COD) and nutrients (N-NH_3 N-NO and P) were not significant. The difference of freshwater influx into the estuary caused higher salinity in dry season (25 to 2 ppt) and faster water velocity in wet season (0,4 to 0,2 m/detik). The higher rainfall and faster water velocity in wet season caused more re-aeration via the water surface, therefore, photosynthetic production, measured as increase rate of DO in day time, could be assessed only in dry season. Limitation of phytoplankton ability to carry out photosynthesis in wet season, as observed by the decrease of the daytime CO consumption rate, were due to the drastic increase of turbidity (0,8 to 14,1 NTU) caused by total suspended solids transported with the freshwater influx. In other turn, this limitation caused the decrease of phytoplankton diversity and density. Considering that healthy estuaries are critical for the continued survival of many species of fish and other aquatic life, and phytoplankton forms the base of the aquatic food web, it is recommended to prevent excessive solids entrance into Segara Anakan estuary from the surrounding water catchments area.

Keywords: Integrated monitoring, estuary, phytoplankton

Abstrak

Estuari merupakan lingkungan alamiah yang mampu menyediakan habitat dan nutrien yang diperlukan bagi kehidupan berbagai tumbuhan dan hewan akuatik. Untuk menjaga agar sistem lingkungan tetap dalam keadaan yang ideal, sehingga dapat menjalankan fungsinya dengan baik, perlu dilakukan berbagai jenis pemantauan. Pengukuran fisikokimiawi saja tidak dapat menjelaskan perubahan kualitas dan fungsi suatu ekosistem, oleh karena itu, dalam penelitian ini dilakukan pemantauan terpadu antara pemantauan fisiko kimiawi dengan pemantauan biologik. Pemantauan terpadu yang terjadual dilakukan dibagian selatan Segara Anakan (Majingklak, *Gombol, Klaces dan Motean), Jawa Tengah, Indonesia, mulai Agustus 2003 sampai dengan Mei 2004. Parameter fisikokimiawi yang diukur adalah salinitas, total padatan tersuspensi, turbiditas, DO, BOD, COD, N-NH_3, N-NO and P, sedangkan parameter biologik yang diukur adalah diversitas dan densitas fitoplankton. Pengukuran dilakukan pada saat permukaan air terendah (surut). Perbedaan total curah hujan per bulan pada musim kering (Agustus-September 2003) dan musim hujan (Desember 2003-Maret 2004), sangat berpengaruh pada salinitas, total padatan tersuspensi, turbiditas, diversitas dan densitas fitoplankton. Perbedaan masukan air tawar kedalam estuari menyebabkan salinitas yang sangat tinggi, dari 25 ppt di musim kering turun menjadi 2 pp di musim hujan. Demikian pula dengan kecepatan alir yang meningkat dari 0.2 m/sekon di musim kering menjadi 0.4 m/sekon di musim hujan. Peningkatan kecepatan alir ini menyebabkan re-aerasi sehingga sebaran DO menjadi lebih besar. Hal ini menyulitkan pengukuran produktivitas fotosintetik yang diestimasikan melalui laju peningkatan DO pada saat matahari bersinar. Disamping itu, peningkatan aliran air tawar kedalam estuari juga membawa padatan tersuspensi, yang menyebabkan peningkatan turbiditas, dari 0.8 NTU di musim kering menjadi 14.1 NTU di musim hujan. Peningkatan turbiditas ini mengganggu fotosintesis fitoplankton, seperti terlihat pada penurunan laju konsumsi CO_2 yang diukur dari peningkatan pH pada saat matahari bersinar. Sebagai akibatnya, diversitas dan densitas fitoplankton menurun drastis di musim hujan. Meskipun demikian, tidak terlihat perbedaan signifikan pada DO, BOD, COD, N-NH_3, N-NO and P, yang diukur pada musim hujan dan musim kering.Mengingat bahwa kesehatan lingkungan estuari merupakan suatu keharusan untuk menunjang kelangsungan kehidupan berbagai spesies akuatik; dan fitoplankton merupakan dasar dari lingkaran nutrisi akuatik, perlu adanya usaha untuk menghalangi dan/atau mengurangi masuknya padatan tersuspensi yang berlebihan dari daerah tangkapan air disekitar Segara Anakan ke dalam estuari.*

Kata kunci: pemantauan terpadu, estuari, fitoplankton

INTRODUCTION

From environmental point of view, estuaries are important natural ecosystem where saltwater from the ocean and fresh water from rivers or streams are mixed. They provide two ecosystem services: water filtration and habitat protection. The waters from the surrounding watersheds are filtered through salt marshes and mangrove forests, bring in nutrients into the estuaries, and made them as some of the most fertile ecosystems for birds, fish, amphibians, insects, and other wildlife to live, feed, nest, and reproduce. However, in addition to nutrients, they filter out sediments and pollutants from rivers and streams before they flow into the oceans, providing cleaner waters for marine life. Estuaries are also stabilizing shorelines and protect coastal areas. Phytoplankton is more and more becoming a great biotic indicator of environmental alterations. As the autotrophic organisms, they convert light energy of solar photon into biological energy in the form of organic matter and serve as the first step in the system of energy transfer through aquatic food web in an estuary. Healthy estuaries are critical for the continued survival of many species of fish and other aquatic life, since the abundance of healthy animals in an estuary often depends on the amount of phytoplankton and primary productivity taking place.

The majority of phytoplankton photosynthesis in estuaries appears to be contributed by nanoplankton. Factors regulating phytoplankton photosynthesis are seasonal pattern, including light, temperature, nutrients, and physical transport processes. Nutrients, especially nitrogen and phosphorus, are the most essential for aquatic plants; therefore they are key indicators of water quality in estuaries.

Waters of poor quality affect most estuarine organisms. With the growing environmental problems in both the industrialized and the developing countries, suitable and proper methods are required for monitoring the environment and pollution levels. Lacking in understanding the relationship between discrete physicochemical measurements and cause for the corresponding alteration of the quality and function of an ecosystem, has lead to the need of integrated monitoring involving physicochemical and biological. Integrated physicochemical and biological monitoring is a cost effective strate-gy to have more comprehensive information, since biological monitoring makes use of the reactions of life at any level, from the sub-cellular dimension to the entire biocenosis, to the changing of environmental characteristics as described by the precise physicochemical measurements. Therefore, it can be used as the base of scientifically environmental risk management.

Segara Anakan, a tropical lagoonal estuary in Southern part of Java, is an extremely productive ecosystem that plays a critical role as a nursery ground and feeder for migratory, residential and occasonal visitors fish and shrimp of commercial importance, and supporting a rich fisheries resource within its boundaries. Therefore, this study was carried out in Segara Anakan

In this work, integrated monitoring was carried out to study the cause effect relationship of natural disturbances due to the tropical climatic changes to the alteration of productivity of Segara Anakan estuarine.

MATERIALS AND METHODS

Materials

Samples

Water samples were taken from the southern part of Segara Anakan Estuary during low tide at 4 sampling sites: Majingklak, Gombol, Klaces and Motean (Figure 1), in two weeks interval, starting from July 2003 up to May 2004. Phytoplankton was collected from the same sampling sites every 2 months, and sediments were collected quarterly

Samples Accountability

Water Samples:

Composited water from several points and depth were divided for BOD measurements, solids and nutrients. Each of them are labeled with water proof marker immediately after sample collection, and sealed in plastic name tag. BOD bottles were filled up, closed tightly, stored in ice chest and transported as soon as possible to the laboratory (maximum storage 6 hours). Water samples for solid, ammonium, nitrate, dissolved phosphates were kept in polyethylene bottles, stored in cool place and transported as soon as possible to the laboratory (maximum storage 48 hours). Water samples for COD were acidified with HNO_3 to pH<2 (maximum storage 48 hours).

Phytoplankton

Phytoplankton of 20 L water sample were filtered using plankton net (aperture 74m) and preserved with buffered formalin solution to 4%, stored in ice chest and transported as soon as possible to the laboratory.

Surface Sediment

Samples of sediment were collected up to 25 cm depth from the surface of the sediment using stainless steel tubes of 25 cm length i.d. 5 cm, closed and transported as soon as possible to the laboratory.

Climatic Condition

Climatic data such as rainfall, atmospheric temperature, relative humidity, and evaporation from July 2003 up to April 2004 were obtained from meteorological station of Cilacap

Water velocity

Surface water velocity was measured by float method using floats which is adequately submersed and not significantly influenced by wind

Analytical Methods

Water

pH and Salinity

pH was measured using TPS Conductivity-Salinity-pH-Temperature meter Model WP-81 equipped with pH and reference electrode. Calibration was done using primary pH standard solutions of KH_2PO_4 + Na_2HPO_4 (1:1)

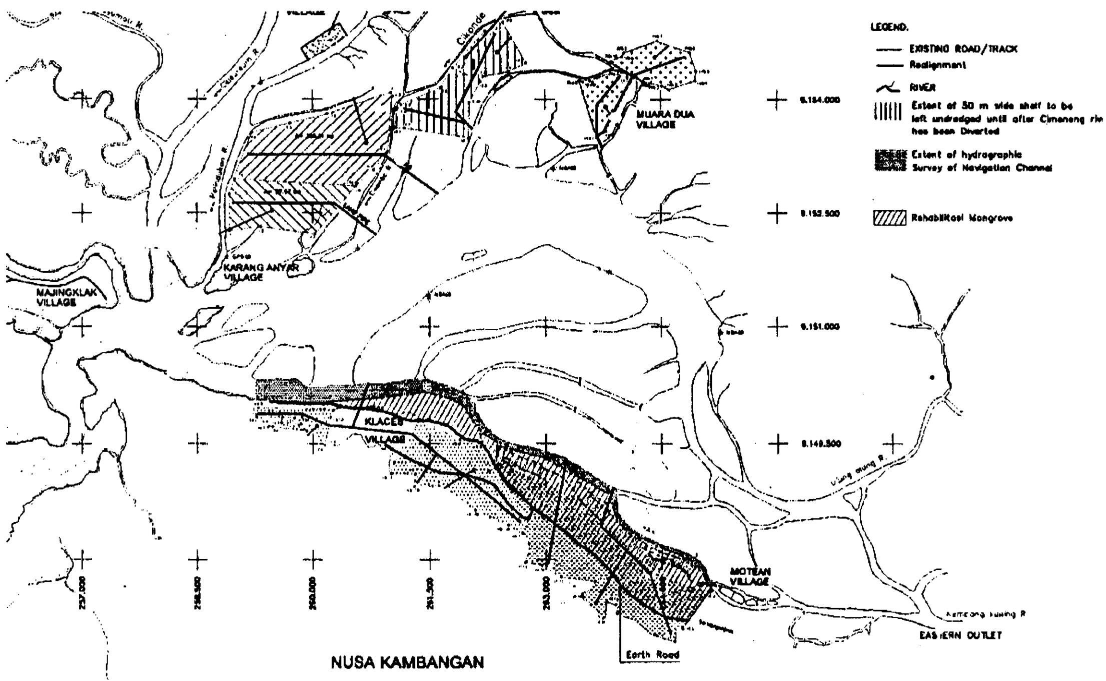

Figure 1. Sampling sites in southern part of Segara Anakan estuary

for pH 6.86, and (1:3.5) for pH 7.41.

Salinity was measured using the same instrument equipped with oxidation-reduction potential (ORP) and reference electrode, and cross checked in Gadjah Mada University (GMU) laboratory using Horiba Conductivity meter DS-8F (digital).

Dissolved Oxygen

Dissolved oxygen was measured using TPS Dissolved Oxygen-Temperature Meter Model WP-82 equipped with electrode ED1 Dissolved Oxygen Electrode and cross checked by iodometric (azide modification) methods (Standard Method for Examination of Water and Wastewater of APHA, AWWA, WEF) [1]

All other physicochemical determinations were carried out according Standard Method for Examination of Water and Wastewater of APHA, AWWA, WEF, (1992).

Biological oxygen demand (BOD 5 days) was determined based on the difference of DO initial and DO after 5 days incubation at 20C. *Chemical oxygen demand* was determined using open reflux method, *Ammonia* (N-NH_4) was determined spectrophotometrically by Nessler method after alkaline distillation. *Nitrate* (N-NO_3) was determined spectrophotometrically by Cadmium reduction method. *Soluble Phosphates* (P-PO_4) was determined spectrophotometrically by Vanadomolybophosphoric acid method.

Total suspended solid (TSS) was determined by filtration to have particles between 5-60m, *Turbidity* was determined by Nephelometric method. Compared to a series of formazin solution giving a range of 0 – 40 nephelometric turbidity unit, NTU.

Sediment

Ammonia was determined by titration after alkaline distillation. Nitrate (N-NO_3) was determined spectrophotometrically by Cadmium reduction method after KCl 2M extraction. Total PO_4 was determined as orthophosphate by Vanadomolyb-ophosphoric acid method after dry-digestion at 450C and followed by HNO_3 1:1 solvation.

Phytoplankton density and diversity

Phytoplankton identifications and counting was done using a microscope equipped with a whipple micrometer (Standard Method for Examination of Water and Wastewater of APHA, AWWA, WEF, 1992).

Data Evaluation

All statistical evaluations were based on 95% confidence limit.

RESULTS AND DISCUSSIONS

Segara Anakan aquatic system was shown to be a potential plankton producer, the density were ranging from 1500 – 6000 individual/L at 1980 (White *et al,* 1989) and 11400 at dry season of 1994 (Noegrohati and Narsito, 1995). However, due to climatological influence of dry season and wet season, estuarine water quality exhibit complex temporal as well as spatial variability in salinity, nutrient and light penetration, which may altered the ecosystem health. Since phytoplankton is an important bioindicator of healthy aquatic ecosystem [4], the effect will be quantified as the density and diversity of phytoplankton.

Climatological Effect on the Environmental Dynamics of the Southern part of Segara Anakan Estuary

An estuary is a partially enclosed body of water, where saltwater from the ocean mixes with fresh water from rivers or streams. The characteristics of each estuary depend upon the local climate, freshwater input, tidal patterns, and currents, while the daily tides are a major influence on many of these dynamic environments. For that reason, all measurements were carried out at low tide.

In tropical area, the ecosystem is not subjected to regular seasonal light and temperature pulses, but more to the dry and wet condition. The total rainfall in Cilacap area as recorded by Cilacap meteorological station is presented in figure 2. It showed that the rainfall was started at October, and the heaviest rain was between November and December, afterwards, it was starting to diminish.

The response to the rainfall was rapid, as shown by the increase of water velocity, which was starting at October 2003, and increasing up to November. The average of water velocity at dry season (July-September) was 0.2 m/s, and at wet season (December-March) was 0.4 m/s (figure 3).

This changing in velocity will increase the volume of freshwater inflow into Segara Anakan, causing the decrease of salinity (figure 4), which also started at October up to November 2003. The average salinity at dry season was 25 ppt, while in wet season was 2 ppt

Only a few plants and animals can tolerate such wide changes of salinities. In this study, it was observed that the composition of plankton species, quantified as plankton diversity index was drastically reduced at wet season (figure 5). From this data, it can be concluded that phytoplankton in Segara Anakan are stenohaline organisms.

Similar plankton diversity index was obtained in the previous measurements, July 1994 (dry season at low tide) and the present study at July 2003, i.e. 0.71 (Noegrohati and Narsito, 1995) and 0.78 respectively.

Spatial Time Series of Integrated Monitoring in Southern part of Segara Anakan Estuary

From the obtained data ad A, it was clear that there was a big difference in environmental dynamics between dry and rainy or wet season. Therefore, the focus in this part of the study was the difference of water physicochemical characteristics which support or limiting the phytoplankton photosynthesis and its endpoint of related effect to phytoplankton.

Monitoring was carried out at 2 weeks interval, from August to September 2003 for dry season, and from December 2003 to March 2004 for wet season, at Majingklak, Gombol, Klaces and Motean.

Spatial Physical Monitoring of Water Characteristics

The water physical characteristics monitored are temperature and solids. Water temperature is an important indicator of habitat quality for many estuarine species and how much oxygen can be dissolved into the water. Solids entering the estuary from rivers or runoff can easily change the physical, chemical and biological conditions in an estuary. Periods of excessive rainfall affect the amount of fresh water and the concentration of dissolved and suspended materials in the water. As sediments and other suspended solids increase in the water, the amount of light that can pass through the water decreases. Therefore the solids parameters observed are total suspended solids and turbidity. Turbidity affects organisms that are directly dependent on light, like aquatic plants, because it limits their ability to carry out photosynthesis

The data presented in figure 6, showed the significant difference between dry season and wet season of TSS (10.15±1.57 to 66.22±43.07 mg/L) and turbidity (0.81±0.17 to 27.49±26.94 NTU). It is clearly showed that highest input of suspended is from Citanduy river as indicated by high TSS and turbidity observed in Majingklak..

Similar levels were observed in Brantas estuary between January 2003 to April 2004 using "MERMAID"-system (abbreviation for: marine environmental remote-controlled monitoring and integrated detection) which had been developed for marine applications (Martin, 2006).

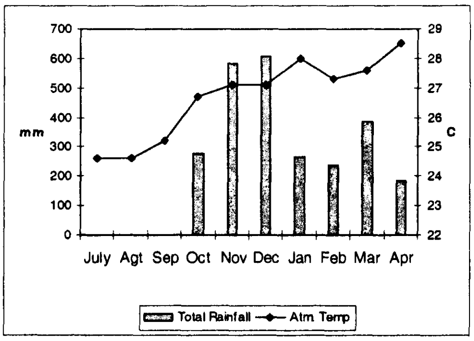

Figure 2. Total rainfall and mean atmosferic temperature

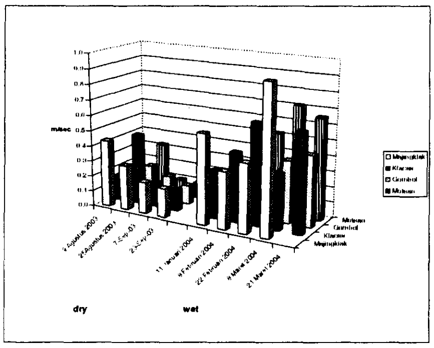

Figure 3. Water velocity during dry season (August-Sept 2003) and wet season (January-March 2004)

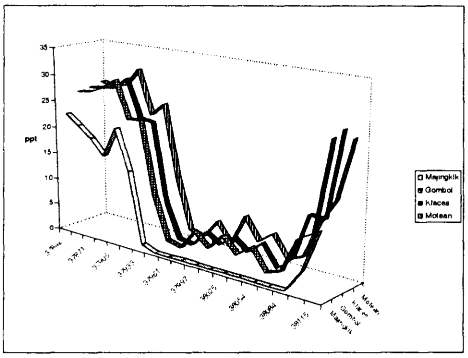

Figure 4. Salinity August 2003 - May 2004

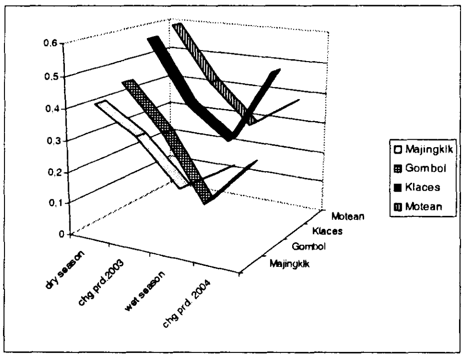

Figure 5. Plankton diversity index from August 2003 to April 2004

Spatial Chemical Monitoring of Water Characteristics

Oxygen enters the water through two natural processes: diffusion from the atmosphere and photosynthesis by aquatic plants. Photosynthetic organisms such as phytoplankton oxygenate the waters in their immediate vicinity and remove carbon dioxide from the water. Dissolved oxygen is critical for the survival of animals and plants that live in the water, the more oxygen there is in the water, the healthier the ecosystem is. Since CO_2 becomes carbonic acid when it dissolves in water, removal of CO_2 by photosynthesis activities, resulting in a higher pH. Therefore DO and pH are important indicator of healthy environment. No significant difference between the pH at the observed area at dry season 7.35±0.13 and wet season 7.10±0.14.

The organics parameters observed are those related to the availability of oxygen in water, which are DO, BOD and COD (figure 7). Even though there was re-aeration in wet season due to faster mixing with freshwater influx from land and rain, and lower salinity which increases the oxygen solubilization in water, no significant increase of DO in wet season was observed. They were 8.67±0.28 mg/L in Dry season and 8.12±0.45 mg/L in wet season. These data are still in the same range as observed in 1994, which was 5.0-8.3 mg/L (Noegrohati and Narsito, 1995)

A trend of higher BOD was observed in wet season, indicated an "out-flushing" of organic pollutant from reservoirs upstream. Beside that, COD was lower than in dry season, indicated that the water environments are in a more oxidative state. The possible causes for these conditions were faster water velocity and re-aeration during wet season.

Phytoplankton assimilates inorganic dissolved nutrient and transform it into the organic matrix of their cells. Essential elements for structural algae are C, N and P. According to Redfield, these elements are taken up on the long term in generally a constant ratio of 106:16:1 by atom, but it can be ranging between 120:20:1 and 90:5:1. Therefore the autotrophic nutrients parameters observed are $N\text{-}NH_3$, $N\text{-}NO_3$ and $P\text{-}PO_4$. The data are presented in figure 8. No significant difference between their level in dry and wet season were observed, also the N:P ratio, which are 1.2±0.9 in dry season and 1.3±0.2 in wet season, indicated that there is no nutrient limitations in phytoplankton uptake and productivity.

Spatial chemical monitoring of Sediment Characteristics

Nitrogen and phosphorus naturally enter estuarine waters when freshwater runoff passes over geologic formations rich in phosphate or nitrate, or when decomposing organic matter waste get flushed into rivers and streams.

For that reason, sediment could be considered as the source of the dissolved N and P. Indeed, the $N\text{-}NO_3$ and $P\text{-}PO_4$ were significantly higher in wet season, 296±107 mg/L to 5381±496 mg/L and 36±4 mg/L to 1160±825 mg/L respectively; On the contrary, ammonia was lower in wet season, 228±80 to 0.8±0.3. This is possibly caused by more oxidized state environment as shown by lower COD. Even though there were significant differences between dry and wet season within all autotrophic nutrient in sediment, the solubilization remain constant.

Spatial biological monitoring

Phytoplanktons are more and more becoming a great biotic indicator of environmental alterations. Despite the similar temperature, organics, and dissolved nutrients monitored in dry season and wet season, the quantification of photosynthetic productivity end point as plankton density showed drastic changes (Figure 9). Highest plankton density was achieved in dry season, and decreased drastically up to wet season and increasing again at the end of the study.

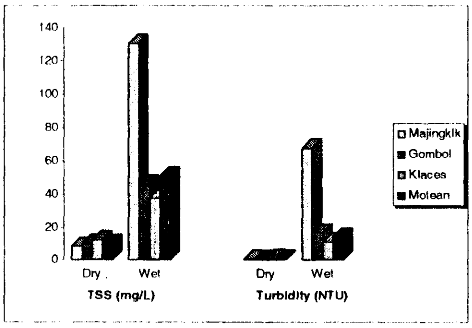

Figure 6. Total suspended solids and turbidity of dry season and wet season

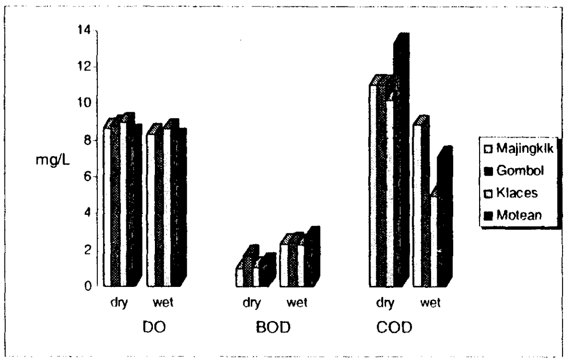

Figure 7. The organics parameters of dry season and wet season

Similar trend was observed in Brantas estuary between January 2003 and April 2004 (Scroeder et al, 2004).

Compared to the plankton density measured at July 1994 [3], which was 11394, the present data of July 2003, was 24932, indicating that there were no significant alteration in the plankton community within the last 9 years.

Since the cause of limitation in photosynthetic productivity seems to be suspended solids and turbidity, it is necessary to compare the primary productivity and consumption of phytoplankton photo-synthesis between dry and wet season.

The primary productivity was measured as the rate of oxygen production at day time, while

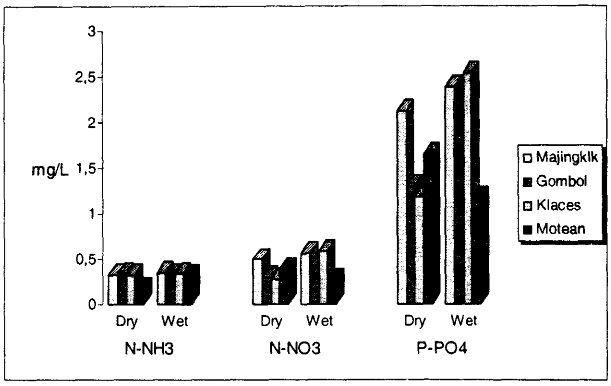

Figure 8. The autotrophic nutrients parameters of dry season and wet season

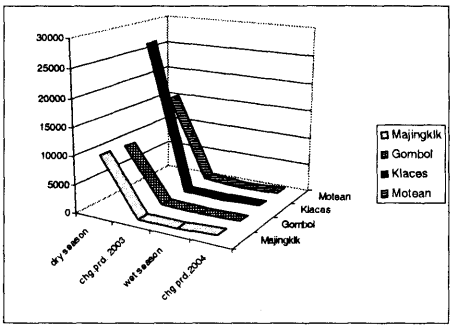

Figure 9. Plankton density from August 2003 to Aril 2004

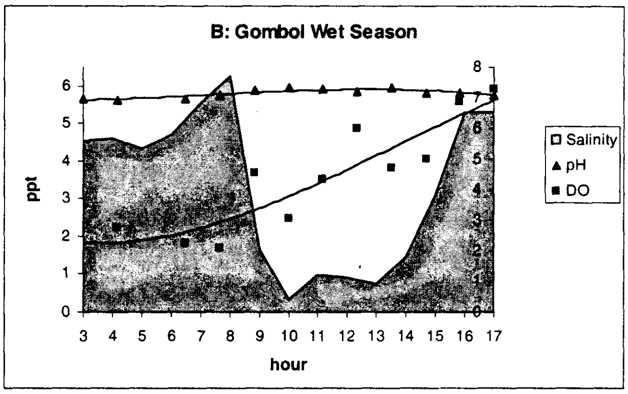

Figure 10. Daily productivity patterns of estuarine communities in dry season (A) and wet season (B). also shown the effect of rainfall between 8 and 16 at B.

rate of CO_2 uptake can be measured at day time as the increase rate of pH. Figure 10 showed the daily productivity patterns of estuarine communities, measured as diel changes of DO and pH at dry season and wet season, thus at different diurnal salinity.

Even though the density of phytoplankton was drastically decreased at wet season, no significant difference was observed between the rate of oxygen production at dry season (0.3±0.2) and wet season (0.3±0.2). The rate of oxygen production obtained in wet season is doubtful due to re-aeration from rain water and higher mixing rate of oxygen in the surface as shown in figure 10.b.

A trend of decreasing CO_2 consumption rate at wet season was observed as lower increase rate of pH, i.e. 0.07±0.02 in wet season and 0.11±0.03 in dry season.

From these time series of integrated monitoring studies, mindful the estuarine dynamic environment, a linkage can be drawn between the significantly higher physical parameter of suspended solids and turbidity, photosynthesis limitations, decreasing CO_2 consumption, and the drastic decrease of plankton diversity index and plankton density during wet season, indicate an unhealthy estuarine environment. Similar linkage and end point was observed in Brantas estuary (Scroeder et al, 2004).

Considering that Segara Anakan estuary provide critical habitat for commercially important species of fish and other aquatic life, healthy estuary is critical for the continued survival of fishing industry, therefore proper risk management should be carried out. Since the cause of these alterations is solids entrance into Segara Anakan estuary from Citanduy river, as observed in this study from figure 6 at Majingklak, prevention of excessive solid entrance should be done in Citanduy river.

CONCLUSION

The important climatological influences were drastic changes in salinity, water velocity, and turbidity. These changes caused the decrease of plankton diversity index in wet season.

Spatial Time Series of Integrated Monitoring showed that there is no limitation in oxygen demand and nutrient uptake of the estuarine community, however, drastic decrease in plankton density was observed in wet season.

The cause of drastic decrease of plankton diversity index and plankton density during wet season was excessive suspended solids and turbidity, which decreases the amount of light that can pass through the water, and limits the photosynthetic activity as shown by decreasing CO_2 consumption.

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