# Sediment Oxygen Demand of the Santubong River and Their Contributing Factors

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## Abstract

*Sediment oxygen demand (SOD) is the oxygen required for the biological and chemical processes occurring in the sediment. The concentration of dissolved oxygen in the Santubong River was reported to be low. However, sediment oxygen demand of the river has not been reported in literature. Therefore, the objective of this study was to measure the oxygen demand of the sediment in the Santubong River. Cores of sediment were collected from five selected sampling stations in three different trips during low tide. Oxygen depletion was measured every 10 minutes for 180 minutes in the laboratory. Results showed that SOD at 20 $^{o}$C ranged from 4.5 to 9.8 g $O_2/m^2$-day. It was found that SOD values were significantly higher near aquaculture sites. Furthermore, total organic carbon and total phosphorus of the sediment explained 96% of the total variation in $SOD_{20}$. The high oxygen demand of sediment potentially leads to low dissolved oxygen in the water column at the cage culture and aquaculture effluent discharge areas which is potentially detrimental to aquatic life.*

**Keywords**: *sediment oxygen demand, sediment phosphorus, total organic carbon, sediment pollution*

## 1. Introduction

Sediment of water bodies in the wetland is a sink for pollutants from anthropogenic sources especially particulate matters. Sediment oxygen demand is the rate of dissolved oxygen consumption by benthic ecosystem and in natural condition, waste materials derived from naturally occurring aquatic plants and animals and from detritus discharged into the water body by natural runoff has the ability to support the benthic ecosystem (Truax *et al.* 1995). However, inputs from anthropogenic sources could increase the oxygen demand as such inputs result in an increase in organic materials and nutrients such as nitrogen and phosphorus. The increase in nutrients leads to phytoplankton blooms and when the phytoplankton decays, aerobic bacteria consume oxygen in the decomposition process exerting an increased demand in dissolved oxygen in the water column.

The Santubong River located in Kuching Division of Sarawak is a tidal river important for aquaculture and it drains north into the South China Sea. Water quality studies of the Santubong River show that dissolved oxygen were frequently below the level that is healthy for aquatic organisms and biochemical oxygen demand, nitrogen and phosphorus were elevated near residential and aquacultural areas (Ling *et al.* 2010b). However, sediment oxygen demand for this river has not been investigated.

Sediment oxygen demands of the Serin River, a non-tidal stream and the Semariang Batu River, a tidal river, in Sarawak have been reported and it was found that the values were higher near residential, aquaculture and animal farming areas (Ling *et al.* 2009a; b). However, different rivers may show different oxygen demand due to factors such as dissolved oxygen concentration in the water column, mixing rate of the overlying water, presence of toxic chemicals, and changes in temperature (Utley *et al.* 2008). Therefore, the objectives of this study were to measure the oxygen demand of the sediment collected from different stations of the Santubong River and investigate its relationship with the characteristics of the sediment.

## 2. Materials and Methods

Sediment samples were collected at the Santubong River in Kuching, Sarawak, during low tide and the experiment was conducted in the laboratory. The five stations where surface sediment cores were collected are shown in Figure 1 and the descriptions of the stations are given in Table 1. Sediment was collected in cores from the same sampling stations three times between December 2008 and March 2009 to give a better representation of its oxygen demand and sediment characteristics. After collection, the cores were capped at the top and bottom and placed in an icebox while transported to the laboratory for immediate analysis. Sediment cores inner diameter and height were 5.1 cm and 12.7 cm respectively. For each station, three cores were collected. River water was also collected for the SOD study. Grab samples of surface sediment were also collected for analysis of its characteristics.

In the laboratory, sediment cores were equilibrated to room temperature before the study. The method of SOD analysis follows that of Ling *et al.* (2009a), modified from Truax *et al.* (1995). River water was transferred to the SOD chamber after which three cores of sediment were uncapped and were carefully placed in the chamber. The chamber was filled to the brim with river water. A dissolved oxygen meter (Adwa AD610) and a pump (HAQOS SP500) were placed in the chamber. The pump created water movement to simulate the condition in the river. Temperature of the water in the chamber was recorded. Then, the chamber was sealed until airtight using silicon sealant. A control chamber was setup whereby it was filled with river water but not sediment cores. The diameter and height of the chamber were 24.2 cm and 24.0 cm respectively.

For each replicate, regression of DO on time in minutes was conducted using PASW version 18.0. The slope was recorded and SOD at the temperature where oxygen depletion was measured was computed using the equation [1] modified from Ling *et al.* (2009a) and Doyle & Rounds (2003),

$$SOD_T = 1.44\frac{V}{A}[-(b_s - b_c)] \qquad [1]$$

where $SOD_T$ was the sediment oxygen demand at water temperature (°C), T, during the experiment (g $O_2/m^2$-d), V was the volume of the chamber (L), A was the surface area of the sediment ($m^2$), and $b_s$ and $b_c$ were the slopes of regression of dissolved oxygen concentration (mg $O_2$/L) on time (minutes) for the chamber with sediment and the control chamber respectively. Measured SOD rates were corrected to 20 °C using modified van't Hoff form equation [2] of the Arrhenius relationship (Bowie *et al.* 1985),

$$SOD_{20} = \frac{SOD_T}{1.065^{(T-20)}} \qquad [2]$$

where T was the water temperature (°C) at which the experiment was conducted**.**

Surface sediment collected was composited and analyzed in triplicates for particle size, total organic carbon (TOC) and total phosphorus (TP). Particle size analysis was conducted using the pipet method according to Gee and Bauder (1986). For TOC analysis, ashing method of Boyle (1995) was used. OM and TOC were computed using equations [3] and [4],

$$OM = \frac{W_{TS} - W_F}{W_{TS} - W_T} \times 100 \qquad [3]$$

where OM is the organic matter (%), $W_T$ was the tare weight of crucible (g), $W_{TS}$ was the tare weight of crucible and oven dried sediment (g) and $W_F$ was the weight of crucible and sediment after ashing (g).

$$TOC = 0.58 \times OM \qquad [4]$$

where TOC is total organic carbon (%) as shown in equation [4]. The sediment was analyzed for TP using the perchloric acid ($HClO_4$) digestion method (Jackson 1958).

TP in the digest was determined using ascorbic acid method and concentration determined using a spectrophotometer (Hach DR2010). For statistical analysis, two-way ANOVA was used to compare the results of SOD with station as factor and trip as block. For sediment characteristics, one-way ANOVA was used to compare the mean values among stations. Significant differences results from ANOVA were further investigated using Fisher's LSD (Least Significant Difference) pairwise comparisons. Multiple linear regression was conducted by using the Enter method. All analyses were conducted using PASW 18.0 software.

## *3. Results*

Sediment collected from different stations showed different characteristics. Sediment at station S1 sediment was sandy and it was the lowest in silt content as it was near the sea (Table 2). Sand content of sediment from stations S2 and S3 were higher than station S1 but lower than S4 and S5 and they were not significantly different (P=0.179). As for silt content, the trend was increasing as we move upstream in the order of S1<S2<S3<S4<S5. Clay content of station S2 was the highest followed by S4. S3 showed the lowest clay content, significantly lower than all the other stations except S1 (P=0.027). Station S1 showed the lowest TOC of 0.9% whereas station S2 had the highest TOC of 4.8%. Station S4 ranked the third highest in TOC and it was significantly higher than S3 (P=0.008). Stations S5 did not show any significant difference in TOC when compared with S3 and S4 (P=0.226, 0.075). TP in the sediment ranged from 86.6 mg/L to 266.2 mg/L as shown in Table 2. The highest mean value occurred at station S2. Stations S1, S3 and S4 did not show any significant difference in mean TP values (P=0.310). The lowest value was found at S5 and the mean value was significantly lower than all the other stations.

The study of oxygen depletion in the sealed chamber indicated that the rate of decrease of DO in the chamber with sediment cores was higher than the rate of decrease in the chamber without sediment, that is, the control chamber. For station S2, the sediment collected during the second trip showed decrease rate of 0.0150 mg/L-min when compared to 0.0098 mg/L-min for the control (Figure 2). For station S3, the sediment collected during the third trip showed decrease rate of 0.0077 mg/L-min when compared to 0.0054 mg/L-min for the control (Figure 3). This gives higher difference between sediment and control slopes for station S2 than station S3 and therefore, S2 had higher SOD than S3. Table 2 shows the mean SOD values at all the five stations. SOD was found to be the highest at S2 which was near the shrimp culture effluent discharge area. The second highest value was S4 which was near the cage culture area. Mean SOD values at the other three stations were not significantly different pairwise (P=0.445).

Simple linear regression of the mean values of $SOD_{20}$ on TOC values and TP values are shown in figures 4 and 5. They show the strong relationships between $SOD_{20}$ and TOC and between $SOD_{20}$ and TP. Multiple regression showed that the regression was significant (P=0.04) and TP and TOC were both determinants of $SOD_{20}$ with beta values of 0.594 and 0.465, *t* statistic values of 2.970 and 2.324 respectively and adjusted $R^2$ of 0.92. TP and TOC explained 96% of the total variation in $SOD_{20}$. The estimated model is given in equation [5],

$$SOD_{20} = 0.772 + 0.02\, TP + 0.737\, TOC \qquad [5]$$

## *4. Discussion*

Sediment at station S1 showed the lowest TOC because it is situated near the sea and thus the soil was sandy with second lowest clay content. Even though station S2 sediment had less clay than station S4, it had the highest TOC, TP and SOD as it was located near the shrimp aquaculture farm effluent discharge area. At station S2, other than receiving the organic materials released during regular water exchange and harvesting pond water, it also receive the sludge during harvesting as it is a common practice to remove all the sludge from the bottom of the shrimp ponds after harvesting by flushing in order to prevent high oxygen demand sludge remaining in the pond which may lead to low dissolved oxygen and high mortality rate of the next batch of stocked shrimp. The high SOD was due to the high oxygen required by the microorganisms in breaking down the uneaten feed, shrimp waste, dead plant and animals that settled to the bottom sediment. According to Garcia and Brune (1991), at stocking rate of 4.5-10.5 animal/$m^2$, benthic oxygen demand was 32.8-39.2 $gO_2/m^2$-d. It is a common practice for shrimp ponds to be stocked 30-35 animals/$m^2$ which would mean that benthic oxygen demand is even higher. Studies of shrimp pond nutrient budget indicated that shrimp could only assimilate 10-13% phosphorus of the total inputs in *Peneaus monodon* ponds (Thakur and Lin 2003). As a result, the unassimilated phosphorus was discharged into the surrounding environment. Xia *et al.* (2004) reported that sediment accumulated 74.4% of the total phosphorus input for *Penaeus vannanm* ponds.

Ling *et al.* (2010a) reported that during harvesting of the shrimps, pond effluent was high in total suspended solids, biochemical oxygen demand, inorganic nitrogen and reactive phosphorus. SOD of the Semariang Batu River was also reported to be the highest near shrimp culture effluent discharge area (Ling *et al.* 2009a). The second highest TOC and SOD were found at S4 and the second highest TP was found at station S3. Both S3 and S4 were near aquaculture sites. TOC from S3 and S4 were most likely due to aquaculture feed and fish waste as not all the feed given to the fish were consumed and fish waste were deposited nearby. According to a study of SOD in the Serin River, the station downstream of fish culture showed elevated SOD value of 10.4 g $O_2/m^2$-d (Ling *et al.* 2009b) which is slightly higher than the value at S3 and S4 in the present study. This could be due to the difference between fish pond and cage culture as extra feed in cage culture is immediately dispersed by the current resulting in lower concentration. The elevated TOC value from station S5 was likely due to the organic materials brought by the tide water and river flow from the residential areas upstream. Even though station S1 is sandy, TP values were elevated likely due to residential discharge as a village was located there. Wastewater from residential areas has been reported to be high in organic matter as shown in the high $BOD_5$ and rich in nutrients such as nitrogen and phosphorus (Ling *et al.* 2010c).

The values of $SOD_{20}$ obtained in the present study were in the range reported by Ling *et al.* (2009a) for the Semariang Batu River (0.8-21.4 $gO_2/m^2$-d) and values from two stations were in the range reported by Ling *et al.* (2009b) for the Serin River (5.6-14.2 $gO_2/m^2$-d). The range in the present study is also in the range reported by Todd *et al.* (2007) for Georgia Coastal Plain (0.9-15.8 $gO_2/m^2$-d). However, the values are lower than those of a tropical reservoir in Singapore (1.4 to 3.3 $gO_2/m^2$-d) (Gin and Gopalakrishnan, 2010); Tolo Harbour, a large eutrophic land-locked estuarine embayment in Hong Kong (0.9 $gO_2/m^2$-d) (Chau 2002) and Upper New Meadows River and Quohog Bay Estuarine Areas, Maine (0.8 to 3.0 $gO_2/m^2$-d) (Bridges 2009). The difference in rates may be due to factors such as DO concentration in the water column, temperature, mixing rate of the overlying water and the presence of toxic chemicals (Utley *et al.* 2008).

## 5. Conclusions

This study shows that TOC, TP and $SOD_{20}$ values were affected by land use and activities in the river. The station near shrimp culture discharge showed the highest TOC, TP and $SOD_{20}$. The stations with fish cage aquaculture showed elevated TOC, TP and $SOD_{20}$ and human settlement contributed to elevated TP even though the sediment was sandy. Since TOC and TP were determinants of SOD, it is recommended that organic materials be removed and phosphorus recovered from aquaculture and residential wastewater.

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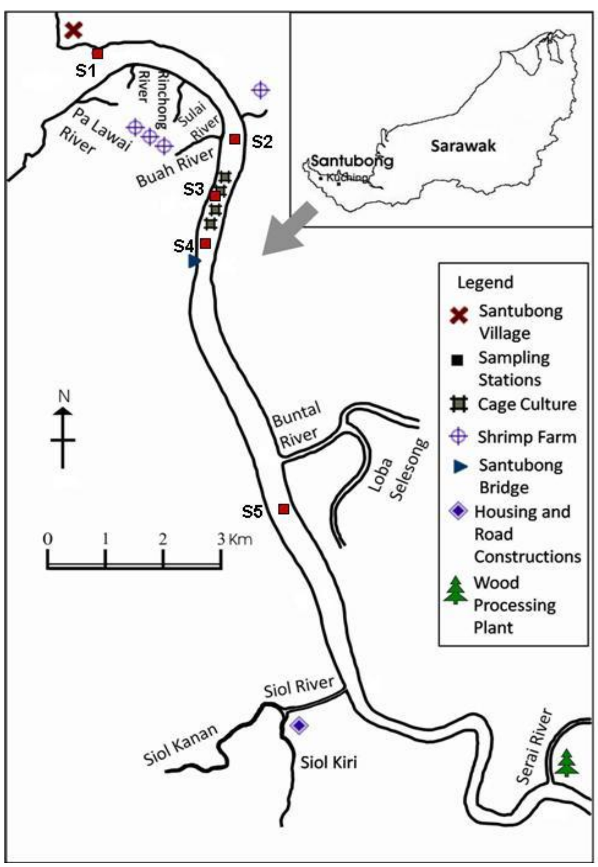


**Figure 1: Location of the five sampling stations in the Santubong River**

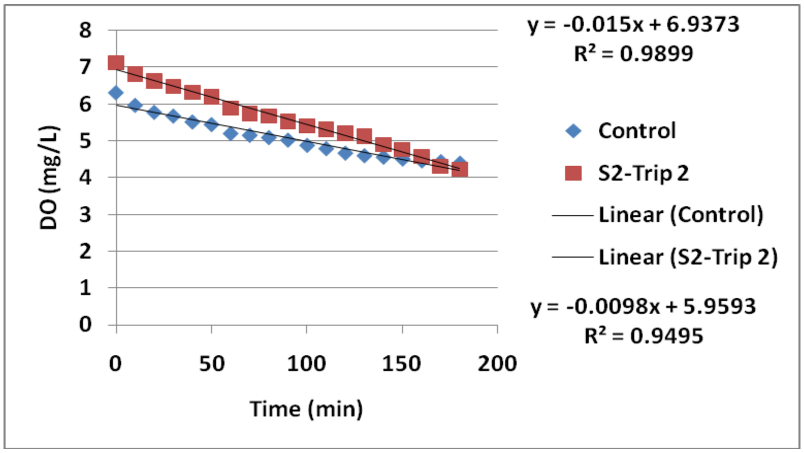


**Figure 2: Oxygen depletions at 24 °C for the chamber with sediment collected at station S2 during the second trip (S2-Trip 2) and without sediment (Control) and regressions of dissolved oxygen concentration on time**

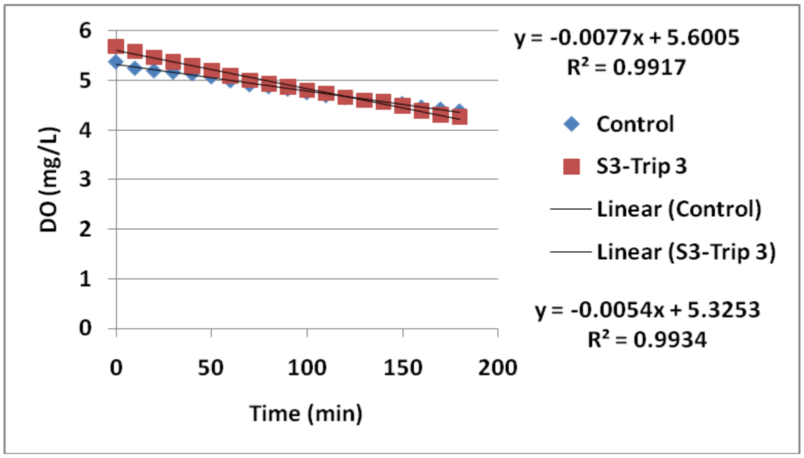


**Figure 3: Oxygen depletions at 22 °C for the chamber with sediment collected at station S3 during the third trip (S3-Trip 3) and without sediment (Control) and regressions of dissolved oxygen concentration on time**

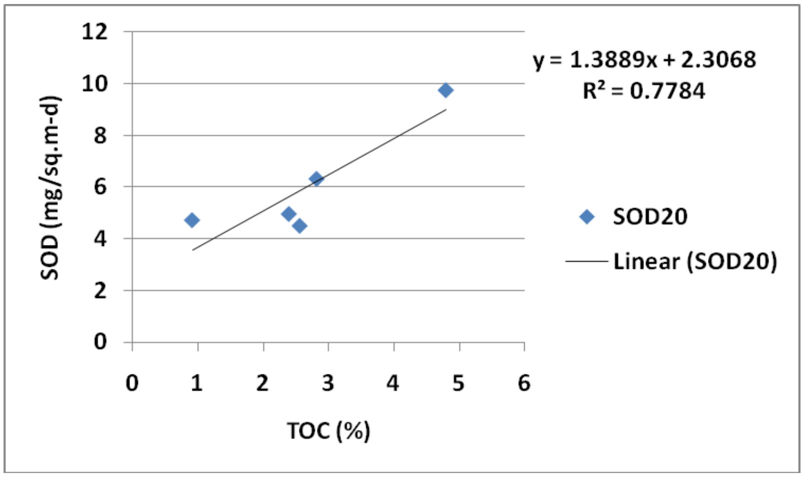


**Figure 4: Relationship between sediment oxygen demand at 20°C ($SOD_{20}$) and total organic carbon in the sediment (TP).**

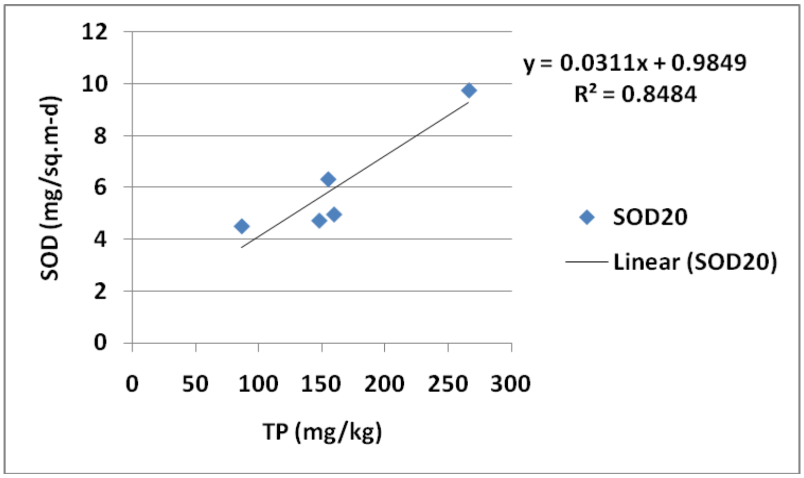


**Figure 5: Relationship between sediment oxygen demand at 20°C ($SOD_{20}$) and total phosphorus in the sediment (TP).**

**Table 1: Descriptions of the five sampling stations in the Santubong River**

| Station | Description |
|---|---|
| S1 | Near Residential Area (Santubong Village) |
| S2 | Near shrimp farm |
| S3 | Near cage culture |
| S4 | Near cage culture |
| S5 | Upstream station |

**Table 2: Means and standard deviations of sediment total organic carbon (TOC), total phosphorus (TP) and oxygen demand of the five stations in the Santubong River.**

| Station | Sand (%) | Silt (%) | Clay (%) | TOC (%) | TP (mg/kg) | $SOD_{20}$ (mg $O_2$/$m^2$-d) |
|---|---|---|---|---|---|---|
| S1 | 85.4±1.5a | 5.0± 1.7a | 9.6 ±0.3ac | 0.91±0.11a | 147.9±7.5a | 4.7±0.7a |
| S2 | 23.4±1.5b | 62.5±2.1b | 14.1±0.6b | 4.80±0.23b | 266.2±8.2b | 9.8±0.7b |
| S3 | 25.1±2.4b | 67.6±1.4c | 7.3 ±1.5a | 2.40±0.22c | 159.6±20.1a | 5.0±0.4a |
| S4 | 7.6±0.1c | 77.9±3.6d | 14.5±3.7b | 2.82±0.05d | 154.9±5.7a | 6.3±1.3c |
| S5 | 7.9±0.2c | 80.8±1.2d | 11.3±1.3bc | 2.56±0.10cd | 86.6±18.2c | 4.5±1.3a |

*Means in the same column with the same letters are not significantly different at 5% level