Tropic Status Assessment in Segara Anakan Lagoon, Indonesia: Experience in Applying the Trophic Index Trix

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Abstract. Segara Anakan is a large lagoon, located along the southern coast on western part of Central Java, Indonesia. It has an important ecosystem role as a nursery ground, so that it is important to have further study of the primary productivity. The human activities around the area and natural factors sedimentation have changed the inrush input to the lagoon. Feared, it will influence the change in tropic status of the lagoon, and will cause the average degradation of the primary productivity value. The aim of the research is to explore the study of the primary productivity in Segara Anakan lagoon (SAL) with trophic status assessment. Index TRIX has been used for evaluating long-term trend and spatial trophic pattern in the lagoon with linear combination of the log of 4 state variables: chlorophyll-α, aD%O, macronutrient: Total Nitrogen (TN) and Total phosphat (TP). The main objective of this study is to estimating tropic status with spatio-temporal approach. The spatial approach is done on 7 stations (S) with representations: (S) natural factors and (S) the presence of anthropogenic activities. The temporal approach (time series) for a year refers to the monsoon wind pattern (west, transition I, east and transition II) season. The results of laboratory tests are discussed descriptively. Index TRIX assessment in SAL shows that point values, exceeding 6 TRIX units are typical of highly productive coastal waters, where the effects of eutrophication determine frequent episodes of anoxia in bottom waters and indicated by high Habs phytoplankton. The effects of highest rainfall at transition II season, anthropogenic pressure, aquatic hydrodynamics are thought to cause in the increasing of SAL macronutrients which trigger eutrophication of waters. Management and lagoon management strategies are required by the local government, stakeholders and communities to prevent the phenomenon of eutrophication of the lagoon.

Keywords: Segara Anakan Lagoon, Macronutrient, Tropic Status Assessment, Index TRIX
1. Introduction

Segara Anakan Lagoon (SAL) is geographically located at 7°35‘- 7°46‘ South Latitude and 108°45‘-109°01‘ East Longitude, Cilacap Regency, Central Java, Indonesia. SAL starts from a gulf with lagoon mouth facing eastward and Nusa Kambangan Island serves to be barrier which sets apart SAL from Indian Ocean. The shape of lagoon today has been changing through multiple stages of environmental change. SAL is a non-independent region, in which some factors influences its ecological changes [1;5]. SAL is influenced by high quantity of fresh water flow input as well as suspended sediment, mainly from Citanduy River [17]. According to Holtermann [20], Citanduy River contributes catchment area of 3,520 km² or supplies about 80% of water flow to SAL. The accumulation takes place mainly on the western part of lagoon, especially in rainy season, while the eastern part of lagoon is dominated by tidal hydrodynamics of Indian Ocean [17]. River flow continuously carries supply of organic materials which triggers bottom sediment consolidation process of coastal zone, as nutritional source to form physical sediment structure. This is discovered to be natural factor which influences SAL.

According to Dewi [8], most of SAL body water volume is replaced by mangrove forest, which is then converted for various anthropogenic activities which influence the lagoon ecology. Continuous water dynamics causes physical, chemical and microbiological complexity of the waters which triggers accumulated nutrients concentration in the lagoon. The productivity is higher since its content is higher than that of high seas [13].

Dsikowitzky [14], Kennish [22] and Jennerjahn [18], report that the sediment derived from land use for anthropogenic activities will contain macronutrients such as Nitrogen (N) and Phosphate (P) strongly bound to water molecules. This condition causes high concentration of sediment. SAL naturally faces various issues such as high sedimentation, population growth and degradation of mangrove forest size because of land conversion for various anthropogenic activities which cause excessive nutrients disposal (eutrophic) to the water. Such a condition makes it important to further study the “eutrophication phenomenon” on SAL.

According to Giovanardi and Vollenweider [16] and Seisdedo [29], the best way to determine a coastal zone’s trophic status category, including specific water like lagoon, is to employ TRIX Index. Eutrophication is described in trophic levels as TRIX value. TRIX index is employed to assess nutrients enrichment on a specific water condition like lagoon [29; 4]

Nutrients enrichment symptom or commonly known as eutrophication phenomenon is a trophic status category which may create negative impact of lagoon water degradation, mainly on phytoplankton biota as the bio-indicator of water fertility. Phytoplankton is able to show its tolerance to water instability, mainly during increase of macronutrients (N, P) as marked with a change in species dominance, community structure and biomass [23;7;25;32;9;37]

2. Material and method

Sampling for analyzing the trophic status assessment is done by in-situ at temporal period (time series) for a year in 2016, based on representation of monsoon. It is matched with what is stated by Nontji [26], that based on the data served by Meteorology and Oceanography, Indonesia waters is influenced by monsoon, consisting of:
**M1** : West Season : December – February
(rainy season, February).

**M2** : Transition Season 1: March - May
(rainy to dry season, May).

**M3** : East Season: June - August
(dry season, July)

**M4** : Transition Season II: September-November
(dry to rainy season, Oktober).

**M5** : West Season : December – February
(rainy season, December).

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**Table. 1** The Sampling Characteristic by Spatial Approach of Phytoplanton in Segara Anakan Lagoon, District of Cilacap.

| Station | Characteristics                                                                 | Ordinate       |
|---------|---------------------------------------------------------------------------------|----------------|
| S1      | TPI and Majingkak Port                                                          | 108°48'02.4"BT 07°40'27.6"LS |
| S2      | The border of gate (west Plawangan) of SAL directly bordering with Hindia cean | 108°46'56.7"BT 07°41'59.0"LS |
| S3      | Gate of Cikonde dan Cimeneng river                                              | 108°49'47.9"BT 07°40'34.6"LS |
| S4      | The Area of Mangroves                                                           | 108°51'36.5"BT 07°41'44.9"LS |
| S5      | Kampung laut settlement                                                         | 108°52'14.0"BT 07°42'19.5"LS |
| S6      | Conservative tourism “Mina” “Ujung Alang, district of Kampung Laut             | 108°52'45.4"BT 07°42'55.4"LS |
| S7      | Cultivating place by using floating net                                        | 108°48'56.0"BT 07°41'01.0"LS |

Then, the influence of monsoon is used as the reference for time of sampling on the content of macronutrient with in-situ sampling as many as 7 stations having spatially different characteristic (Table. 1). The spatial evaluation impacts on natural factors (S) : 2, 3, 4, 6, and station with anthropogenic activities (S) : 1, 5, 7.

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**Figure. 1** The Sampling Characteristic by Spatial Approach in Segara Anakan Lagoon, District of Cilacap, Central Java, Indonesia.
Water trophic status value is determined using TRIX index referring to Giovanardi and Vollenweider (2004) with modification of nutrients concentration criteria to determine the trophic status using TN, which is based on the works of Vollenweider [33] dan Smith [33], who employ TN and TP criteria to determine trophic status. The measurement variables employed to calculate the TRIX index in this research are: N total, P total, % DO, and chlorophyll-a. Below is the calculation formula:

\[
TRIX = \frac{\left(\log_{10} \left(Chlo \times DO\% \times TN \times TP\right)\right) - (-k)}{m}
\]

TRIX : Index trophic status
TP : P total
TN : N total
%DO : Oxygen as absolute % deviation from saturation
Chlo-a : Chlorophyll-a concentration, a
coefficients : k = 1.5 dan m = 1.2

A 0-10 scoring scale is employed to determine the trophic status category of TRIX index. Higher TRIX index value indicates higher rate of water eutrophication. The TRIX index criteria refer to the work of Giovanardi and Vollenweider [16] with the range of category assessment as shown in (Table 2).

| Range          | Category       | Description                                      |
|----------------|----------------|--------------------------------------------------|
| TRIX ≤ 3       | Low            | On open sea zone                                 |
| 3.1 ≤ TRIX ≤ 4 | Medium         | TRIX value ≤ 4, on nearly productive coastal zone|
| 4.1 < TRIX ≤ 6 | High           | TRIX value 6 ≤, on highly productive coastal zone, to occasionally anoxia condition |
| 6.1 < TRIX ≤ 10| Very high/increasing |                                                 |

- Total Nitrogen (TN) macronutrient is measured using Micro Kjeldahl method; Total Phosphate (TP) with Spectrophotometry method [1].
- Dissolved Oxygen and temperature are measured using Water Quality Checker (Toa DKK-Japan Brand: Type WQC-22A), DO% value is obtained from the calculation of relationship between dissolved oxygen content in-situ, theoretical oxygen at the temperature with the pressure of 760 mmHg.
- Chlorophyll-a is measured using spectrophotometer method [21]
- Phytoplankton is vertically sampled using plankton-net 25 (100 liters), on the surface of lagoon water at a depth of 0.5 - 1 m [1]
• The sample is preserved using formalin up to 4% [26]. Calculation is performed 3 times at 20x field of vision. Phytoplankton is identified using: identifying Marine Phytoplankton, Tomas, C.R [31]. Phytoplankton abundance is calculated using Lackey Drop Microtransect Counting method [1].

3. Result and Discussion

SAL’s specific water trophic status category is determined using quantitative TRIX index measurement. In this research, the TRIX index may be employed with spatial and temporal approach to determine a zone’s trophic status.

Based on the quantitative calculation with spatio-temporal approach, SAL’s trophic status ranges from 5 – 8 (Table 3). According to Giovanardi and Vollenweider [16], quantitative TRIX index calculation scales from 0-10, in which higher value of TRIX index indicates higher rate of eutrophication of the water.

The category indicates that SAL’s trophic status is classified as high to very high/increasing. The category illustrates existing macronutrients enrichment in SAL water. This proves that the natural accumulated sedimentation factor and anthropogenic factor of SAL zone cause macronutrients accumulation which triggers eutrophication. Jennerjahn [17] state that the level of macronutrients of N and P in the water will influence phytoplankton’s chlorophyll-a and then influence its dominance and abundance. The dissolved oxygen (DO) parameter which supports the metabolism of water biota, including phytoplankton, and water fertility indicator has influence in N cycle to differentiate nitrification and de-nitrification processes.

Table 3. Results of Quantitative TRIX Index Calculation to Determine the Water Trophic Status of Segara Anakan Lagoon, Kabupaten Cilacap

| Spatial (Station) | Temporal (Season) | Spatial Average |
|-------------------|-------------------|------------------|
|                   | M1    | M2    | M3    | M4    | M5    |                  |
| S1                | 7.7   | 8.0   | 8.1   | 7.8   | 7.6   | 7.8              |
| S2                | 7.8   | 8.0   | 7.7   | 7.8   | 5.0   | 7.3              |
| S3                | 7.1   | 6.9   | 7.5   | 7.9   | 6.0   | 7.1              |
| S4                | 7.4   | 7.7   | 7.2   | 7.7   | 5.3   | 7.1              |
| S5                | 6.9   | 7.1   | 7.0   | 8.0   | 6.1   | 7.0              |
| S6                | 7.2   | 7.7   | 7.2   | 7.7   | 5.4   | 7.0              |
| S7                | 7.4   | 7.7   | 7.7   | 7.7   | 6.0   | 7.3              |
| Temporal Average  | 7.4   | 7.6   | 7.5   | 7.8   | 5.9   |                  |

• Processed from research’s primary data

The measurement variables of TRIX index calculation are: TN, TP, % DO, and chlorophyll-a. The variables describe the water’s fertility level. TN and TP describe the amount of water organism residue. Total Nitrogen (TN) is the nitrogen content in the body of water which is obtained from summation of organic nitrogen and inorganic nitrogen of: nitrate (NO<sub>3</sub>), nitrite (NO<sub>2</sub>), ammonium (NH<sub>4</sub>), nitrous oxide (N<sub>2</sub>O), di-molecular nitrogen (dissolved N<sub>2</sub>), dead organic materials (particulate), dead organic materials (dissolved), microbial biomass, animal
biomass and plant biomass [33]. TN fluctuation is influenced by the amount of organic and inorganic nitrogen of the water. Nitrogen as the most abundant element in the air may diffuse into body of water through stirring process. Excessive nitrogen content may trigger high level gas disease on aquatic organism, such as phytoplankton blooming [33].

Total phosphate (TP) in water is obtained from summation of organic phosphate (inside phytoplankton body and organic compound) and inorganic phosphate (orthophosphate, metaphosphate or polyphosphate). However, the inorganic phosphate resulted from dissolved degradation is only orthophosphate (PO4³⁻) which may be utilized by phytoplankton photosynthetic organism [25]. TP is the summation of all phosphate compounds which encourages formation of water eutrophication [24; 25].

The percentage of dissolved oxygen saturation content (% DO) is the representation of oxygen in water based on the calculation of relationship of dissolved oxygen content in-situ and theoretical oxygen at the pressure of 760 mmHg [6]. Vollenweider [33], explain that oxygen saturation content is % of dissolved oxygen content (DO) against theoretical oxygen at certain temperature. Phytoplankton chlorophyll-a parameter is used as the indicator of the amount of photosynthetic organism in body of water. Both factors of deviation of oxygen saturation content (% DO) and chlorophyll-a content in TRIX index illustrate lagoon’s productivity factor. This is consistent with the statement of Giovanardi and Vollenweider [16] that TRIX index is a multi-meter index which gives benefits in utilizing directly measurable and periodically collectible components of environmental variables.

**Determination of Trophic Status with TRIX Index Using Spatial Approach**

In spatial approach, the results of SAL’s trophic status calculation show that TRIX index value ranges from 7.0 – 7.8, which is classified as very high/ increasing category (Table 3). According to Giovanardi and Vollenweider et al. (2004), TRIX value of 6 ≤ indicates that the water condition is from very productive to anoxia condition. This anoxia condition, as marked with booming phytoplankton which potentially leads to HABs, allegedly, negatively influence the ecosystem.

The identification results find HABs phytoplankton in all research stations. The average % of HABs relative abundance is 22.28%. Nine genera are found (20 species of HABs). Four toxic genera may cause health problems to human: *Nitzschia, Oscillatoria, Anabaena* and *Protoperidinium*. Meanwhile, the other five genera are not toxic, but may damage water ecosystem by preventing fish gills from functioning, with their sharp morphology and numerous chains, and even some of them may cause lack of oxygen in water (anoxia): *Chaetoceros, Coscinodiscus, Rhizosolenia, Thalassiosira, Thalassiotrix*. HABs phytoplankton species will be observed in semi-closed system like lagoon [7].

The results are in consistent with the statement of Livingston [23] and Dewi [10] that existing enrichment of macronutrient elements of N and P (eutrophic) or high or increasing trophic status category may stimulate rapid growth of phytoplankton blooming. Phytoplankton blooming may occur on productive phytoplankton or toxic phytoplankton which potentially leads to Harmful Algae Blooms (HABs) [11; 19].

The measurable research station (S1) spatially has the highest TRIX value. (S1) is allegedly supported by the anthropogenic activities of port and fish auction house (TPI), and is fresh water flow mouth of rivers which come into SAL zone and is right on the turn of Citanduy.
River heading to Hindia Ocean. It is consistent with the statement of Ayuningsih [13], that TN content gets higher as it is closer to coastal area and the highest content is found on estuary.

**Determination of Trophic Status with TRIX Index Using Temporal Approach**

In temporal approach, SAL’s trophic status shows that TRIX index value ranges from 5.9 – 7.8 (Table 3), which is classified as high to very high or increasing category. TRIX index calculation indicates that (M4) dry to rainy season in October is a season with the highest trophic status level of 7.8. This value is supported by the data of BMKG of Cilacap Regency, Indonesia which shows that the rainfall in (M4) is at its peak of 958 mm. This range is a season with the highest rainfall throughout the 1 year of research period (Figure 2). The analysis results also show that high rainfall will be followed by % of reactive abundance (KR) of phytoplankton which potentially leads to HABs and vice versa (Figure 3). This is shown with the fact that the highest (KR) of HABs phytoplankton is 31.84 % of total phytoplankton obtained throughout the season (M4).

![Average Rainfall (mm) in Cilacap Regency during Research Period](image)

**Figure 2.** Average Rainfall (mm) in Cilacap Regency during Research Period

- Source: BMKG of Cilacap Regency, processed as necessary

There is a decrease of TRIX value from 7.8 to 5.9 in the subsequent period (M5). This occurs along with decreasing rainfall. Based on the analysis of BMKG, Cilacap Regency, Indonesia, the rainfall decreases from (M4) to (M5), from 958 mm to 483 mm (Figure 2). Low TRIX value (M5) is allegedly because of the movement of west monsoon, a condition that the wind flows eastward, marking the rainy season, but the rainfall is not higher than that of (M4). According to Dyer, K.R. [15] relatively calm water condition in which rainfall decreases and fresh water flows from rivers into lagoon supports flushing time mechanism which causes macronutrients to move toward the lagoon mouth (west Pelawangan) toward the sea (Indian Ocean). This condition causes reduction of macronutrients in (M5).
Figure 3. Relative Abundance (KR) of Phytoplankton which potentially leads to HABs during the Research Period on Segara Anakan Lagoon Zone, Cilacap Regency

- Processed from research’s primary data

Noted: (M1) West season (February, rainy season); (M2) Transition season I (rainy to dry season); (M3) East season (dry season); (M4) Transition season II (dry to rainy season); (M5) West season (December, rainy season).

These research results are consistent with the research of Yuan, [34], that Hongkong Coastal water has lower nutrients content in west season than that of other seasons. Dewi [12], further explain that any shift to rainy or dry season will influence macronutrients content (N, P), chlorophyll-a and dissolved oxygen, mainly on euphotic area. The decrease of rainfall is along with decrease of trophic status value, which illustrates that SAL’s trophic status is influenced by rainfall and the rate of accumulated macronutrients both for the natural factor of sediment accumulation from the rivers and the disposal of macronutrients from anthropogenic activities [18].

Conclusion

The rate of rainfall will influence the fluctuation of macronutrients of N and P, concentration of chlorophyll-a and the (%) of relative abundance of phytoplankton which potentially leads to HABs. The rainfall pattern controls nutrients fluctuation, which significantly influences the fluctuation of N and P as the limiting factor which further influences the distribution and quantity of chlorophyll-a. The water is enriched (eutrophication) because of organic materials weathering, land waste disposal and shift of seasons. Eutrophication may occur in tropical region such as Indonesia in rainy season. Consequently, Local Government, relevant parties and the community need a strategy to manage the lagoon in order to preserve the stability of SAL ecology, mainly related to land use conversion and anthropogenic activities to minimize eutrophication phenomenon.
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