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Statistical multi-metric based eutrophication index: Case of study at Batam Marine Reserve Park

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Abstract

Excessive human waste nutrients, which usually consist of nitrogenous and phosphate compounds, are known as the major environmental stresses in coastal waters. Therefore, monitoring of nutrients level is very important in marine reserve park. This study presents an application of multi-metric index in accessing the spatial and temporal level of a nutrient in surface water at Batam City Marine Reserve Park, Indonesia. Research had been done with seasonal and spatial zones on three major islands namely Petong, Abang, and Dedep. Water samples from each station were taken from the surface water. Phosphate, nitrate, nitrite, and ammonia, were analyzed in situ and chlorophyll was conducted in the laboratory by spectrophotometric method. Statistical multi-metric detected the average eutrophication index (EI) value between 0.2-0.7, which is mesotrophic to eutrophic. Petong and Abang zones were categorized as eutrophic, and Dadap was mesotrophic. Continuous nutrients contamination throughout seasonal may be derived from sedimentation and domestic run-off from human-populated islands in the middle and northern region. Therefore, ecosystem rehabilitation and mitigation of anthropogenic run-off are needed to optimise the conservation management. Moreover, Dadap zone as the area with the least anthropogenic pressures is potential to be the core of conservation area in Batam City marine reserve park.

Keywords: marine reserve, water quality, nutrients, eutrophication index

Introduction

Nitrogen and phosphate nutrients are the most common pollutant in coastal waters. Excessive human waste nutrient to coastal regions was reported from all around the world, not only in low environmental enforcement southern countries but also in several advanced northern countries (Amin *et al*. 2017; Wiegner *et al*. 2017). In Jakarta Bay - Indonesia, it was recorded that 40-174 tons.day^{-1} and 14-60 tons.day^{-1} of nitrogen and phosphate entered the bay from rivers through domesticated areas (van der Wulp *et al*., 2016). Nutrients enrichment has many coastal ecosystem consequences, as it may shift species in benthic and pelagic waters (Snickars *et al*., 2015). It may lead to coral degradation by bio-erosion in the benthic region and also phytoplankton blooming in pelagic waters (Schmoker *et al*., 2016; Chazottes *et al*., 2017).

The excessive proliferation of algae, particularly diatom bloom species, may cause a mass fish die-off in coastal waters (López-Cortés *et al*., 2015; Zhang *et al*., 2016). Moreover, the biomass of several bio-toxin producing algae that may increase in eutrophic waters (Hattenrath-Lehmann *et al*., 2015). This may lead to food safety concern of fisheries products, particularly marine sea mussel and other bivalve mollusks. Various bio-toxin compounds from algae in the group of shellfish poison, e.g. Paralytic Shellfish Poison (PSP), Amnesic Shellfish Poison (ASP) and Diarrheic Shellfish Poison (DSP), were reported to accumulate in bivalve organisms (McIntyre *et al*., 2013; McNamee *et al*., 2016; Michalski and Osek, 2016). Therefore, monitoring of nutrients is important in coastal management, particularly in marine reserve park, to conserve the sustainability of ecological ecosystem and ensure the food safety of coastal economic products.

However, it may difficult to evaluate the overall seawater quality from inspection of each nutrient variable. For example, if the phosphate level is above the limit but other nitrogen compounds are in normal value, the evaluation may become difficult. Therefore, there are several indexing methods to characterize the overall level of nutrients in the water environment, to evaluate the overall nutrients water quality. Among those methods, the statistical multi-metric index was found to be effective in discriminating the nutrient level in a particular water environment (Primpas *et al*., 2010). This method is based on the equation of five major variables

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concentration in water quality (NO_3, NO_2, NH_3, Chlorophyll-a and PO_4) with coefficient derived from statistical multivariate Principal Component Analysis (PCA). the statistical multi-metric index was found to have an agreement with the requirement of European Water Framework Directive (Kitsiou and Karydis, 2011). This study presents an application of multi-metric index in accessing the spatial and temporal level of a nutrient in surface water at Batam City Marine Reserve Park, Indonesia. Marine Reserve Park in Batam City region was established in 2007, however until now, zonation conservation system has not been implemented (Mailanti and Rani, 2017). Therefore, results of this study may serve as a baseline environmental study to support the conservation authority to establish the conservation zonation in this region.

Materials and Methods

This research was conducted in Batam City Marine Reserve Park, at position 103057'27 "- 104025'53" E, 0050'4,99"- 0025'41,99" N. Research had been done with seasonal (west monsoon February 2016, intermediate monsoon April 2016, and east monsoon season August 2016) and spatial zones on three major islands namely Petong, Abang and Dedep (Figure 1). Visual observation in the field showed that Petong waters consist of several marine aquacultures and guest house for tourists. Moreover, Abang waters (consist of several islands, for example, Abang Besar and Abang Kecil) is the most human-populated area in this region. Several small villages and fisherman marine aquacultures laid on the seashore of Abang Besar and Abang Kecil Islands. Meanwhile, Dedep waters (consist of 2 major islands, namely Dedep and Pangelep Island) was shown as the lowest human rural area in this region. Random sampling stations were selected at the spot of coral reef around those islands.

Nutrient analysis

Water samples from each station were taken from the surface water. Phosphate, nitrate, nitrite, and ammonia ions were analyzed in situ above sampling station by portable spectrophotometric (HACH DR-890). Preservation of seawater for chlorophyll analysis was made according to Murray *et al*. (1986) and quantitative determination was conducted in the laboratory by the spectrophotometric method according to Jeffrey and Humphrey (1975). The average values of all data were compared to the ASEAN water quality criteria for aquatic life protection (McPherson *et al*. 1999). Chlorophyll value threshold on ASEAN water quality criteria was predicted by Håkanson and Eklund (2010) equation.

Data processing

Prior to statistical analyses, all variables were normalized by log-transformation (1+x) calculation (Loayza-Muro *et al*. 2010). The difference in temporal and spatial results was accessed by statistical Kruskall-Wallis analysis. Moreover, multivariate Discriminant Analysis (DA) was employed according to Dinsdale and Harriott (2004) in order to find

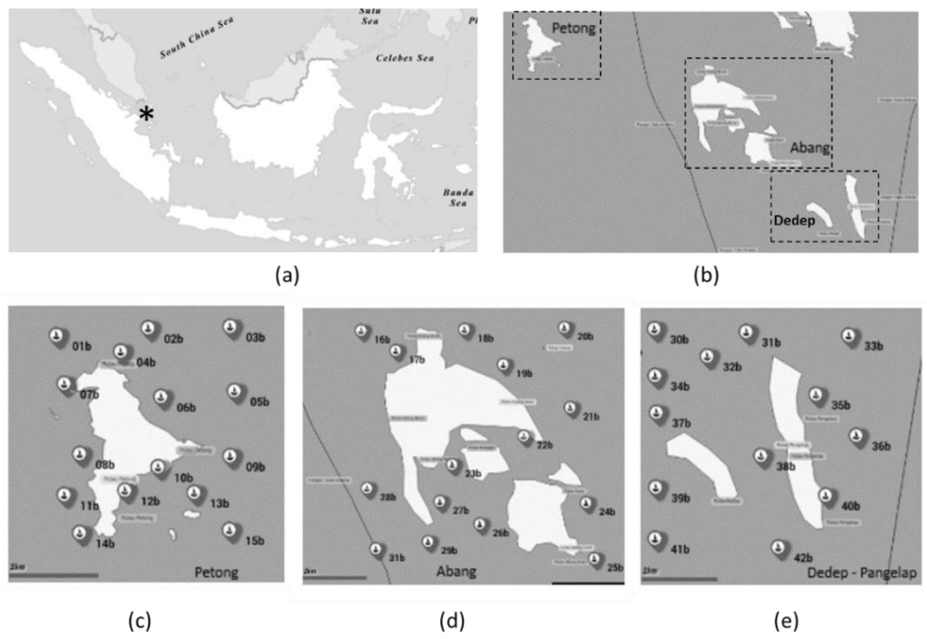


Figure 1. Map of sampling stations in western part of Indonesia (a), on the southern islands in Batam City marine reserve park (b), at Petong (c), Abang (d), and Dedep waters (e)

specific variables that discriminate the characteristics between a group of seasonal (east, intermediate, and west monsoon season) and spatial area (Petong, Abang, and Dadap stations).

Furthermore, Eutrophication Index (EI) was developed according to equation (1) that referred to Primpas *et al*. (2010). C is a concentration of each nutrient (ppm level). Moreover, a, b, c, d, and e, are coefficients from a first principal component of each nutrient in multivariate Principal Component Analysis (PCA). Classification of the index was made by comparison of EI calculation from three standard nutrients dataset from Ignatiades *et al*. (1992) that already characterized as eutrophic, mesotrophic, and oligotrophic type of water. Moreover, EI of the ASEAN water quality criteria for aquatic life protection from McPherson *et al*. (1999) was also calculated. All Statistical analyses were conducted with Past Statistical Software v3.08 (Hammer *et al*. 2001).

$$EI = aC_{PO4} + bC_{NO3} + cC_{NO2} + dC_{NH3} + eC_{chla}$$

Results and Discussion

Results of spatial and seasonal water analysis in Batam City Marine Reserve Park are shown in Figure 2. All nutrients were detected significantly different ($P<0.05$) among areas of study. Surface water of Abang and Petong sites were detected to contain more nutrients than Dedep sites. Meanwhile, ammonia content was the only variable that significantly different ($P<0.05$) in seasonal variables. Ammonia ion during west monsoon season was detected to be lower compared to intermediate and east monsoon season. Moreover, it was detected that the phosphate, nitrate, and ammonia nutrients in studied sites were above the ASEAN threshold for aquatic life protection (dash line in Figure 2). Furthermore, statistical DA detected the major variable that discriminates the spatial and seasonal nutrient level in Batam City marine reserve park (Figure 3). Nitrogen compounds (nitrate, nitrite, and ammonia) was found to discriminate at both spatial (94.02%) and seasonal (99.97%) variation.

Sedimentation rate might be responsible for the higher level of phosphate ions in Batam City marine reserve park. Deposition of sediment is suggested to increase the level of phosphate ions in coastal seawater (Bernini *et al*., 2010). Suspended particles were found as the major pollutant in Batam City waters, as high development rate and deforestation of mangrove area around the coastal region (Sachoemar and Purwanda, 2016). The needs of space for anthropogenic in human-populated islands are shown significantly increase the number of phosphate ions in Petong and Abang compared to Dedep waters. Meanwhile, higher phosphate ion was detected in west monsoon season. Rainy and rough seawater condition usually relate to the condition of

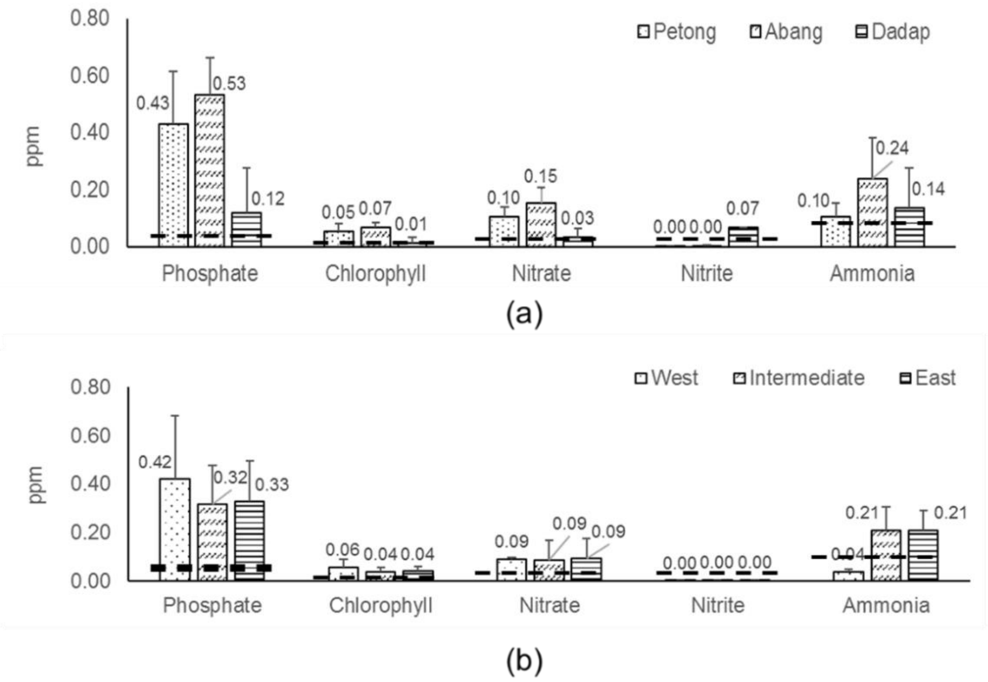
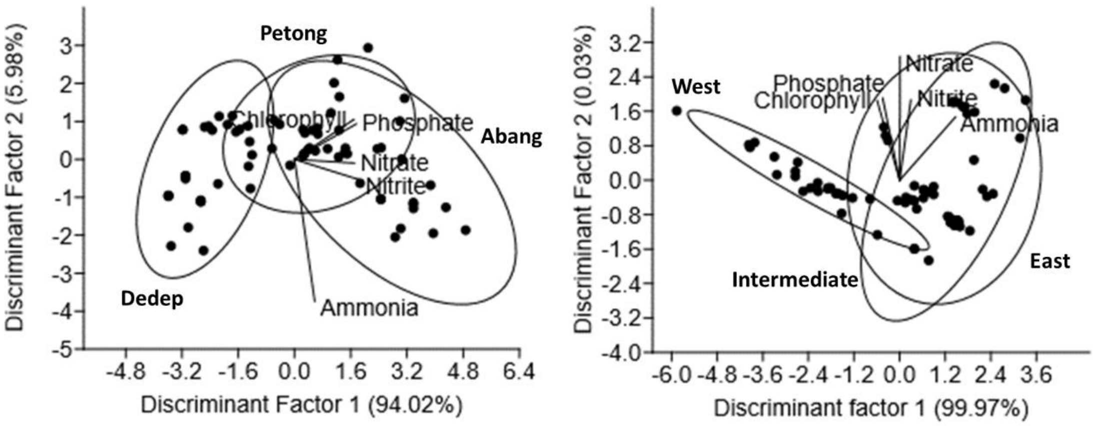


Figure 2. Spatial (a) and temporal (b) nutrient concentration in selected region of Batam City Marine Reserve Park with dashed line (- - -) at each variable explains the threshold value for the ASEAN water quality criteria for aquatic life protection.



(a) (b)

Figure 3. Spatial (a) and temporal (b) discriminant analysis (DA) of nutrient concentration in selected region of Batam City Marine Reserve Park

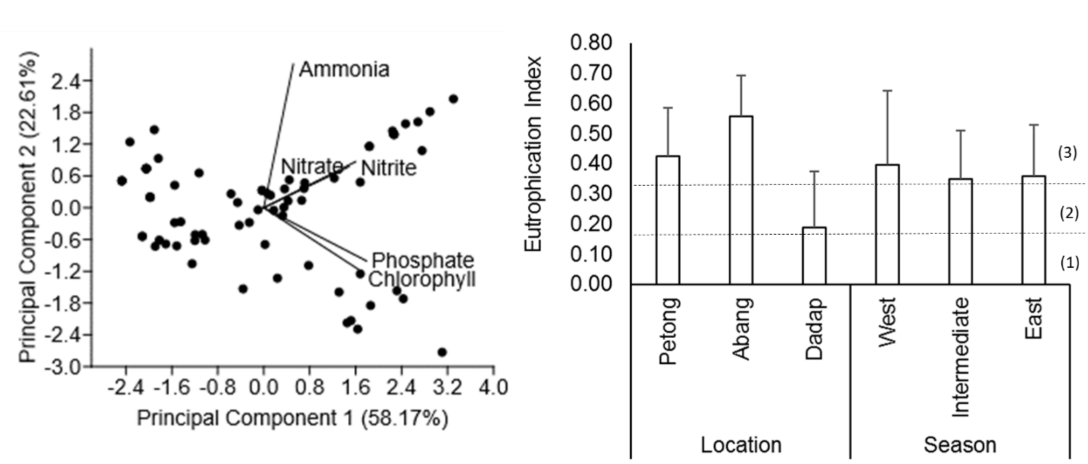
west monsoon season in the western Indonesian region. This condition may increase the sedimentation run-off and upwelling of phosphate ions from sediment.

The ratio of total nitrogen (TN) to total phosphate (TP) was calculated in the range of 0.47 to 1.16. A ratio below 9.0 is categorized as N deficiency water (Guildford and Hecky, 2000). Nitrogen is known as the limiting nutrient for eutrophication and algal reproduction in the coastal environment (Howarth and Marino, 2006; Osburn *et al*., 2016). As a consequence, higher content of nitrogen in coastal or estuary seawater may enhance the possibility of algal blooming. Seawater with high nitrogen content is known as a characteristic of the environment with anthropogenic pressures (Smith *et al*., 2003). Thus, the major source of nitrogen nutrients in Batam City marine reserve park may be derived from local domestic run-off. Areas with a higher human population (Abang and Petong) were detected to contain more nitrogen nutrients. Discriminant analysis showed that these ions were the major discriminant factor that explained the spatial difference between Petong, Abang, and Dedep stations. Further evidence was detected by the seasonal analysis. During east and intermediate monsoon season, the water flows from Batam City mainland to these islands and therefore, enhanced the level of nitrogen compounds in seawater. Meanwhile, current flows on the other way around during west monsoon season, and therefore, discriminant analysis was showed lower nitrogen compounds compared to the other seasons.

PCA showed two major components, with the first component (58.17%) related to chlorophyll, phosphate, nitrate, and nitrite, and the second component (22.61%) related to ammonia content (Figure 4a). Principal component constants that were used in the calculation of EI (Eutrophication Index) were all positive, with phosphate constant as the highest value (equation 2). Statistical multi-metric based eutrophication index detected that the almost all stations were categorized as eutrophic, only at Dadap region that was mesotrophic (Figure 4b).

$$EI = 0.910C_{PO4} + 0.753C_{NO3} + 0.814C_{NO2} + 0.262C_{NH3} + 0.884C_{chl\alpha}$$

The constant value of each variable to the first component in PCA imply the weight or relative correlation between variable and component (Brown and Froemke, 2012). Thus, the EI equation showed that phosphate ions level was the most contributed factor to EI and ammonia was the least. This equation is conditional, according to the case of environment that construct the way of eigenvectors and eigenvalues of each variable to the first and second principal components in the graph. For example, EI equation in Primpas *et al*. (2010) showed an evenness of nutrient variable constants to the first principal component (0.214–0.296). These were constructed as the variation of all nutrients were related to each other. Meanwhile, this study found unevenness of variable constants in EI equation, because the domination of phosphate ions variation compared to other variables in the seawater. In particular, the difference of phosphate concentration in Dadap region to other locations. Therefore, this method needs a standard set that already categorized, to stabilize the PCA results in EI equation development (Kitsiou and Karydis, 2011). Similar to Primpas *et al*. (2010) which found a validity between EI and their previous study, an agreement was also found between EI in this study and the threshold of the ASEAN water quality criteria for aquatic life protection.



(a) (b)

Figure 4. Principal Component Analysis (a) of nutrient variables and multi-metric based eutrophication index (b) of Batam City marine reserve park, where borderline (----) of (1) present the range of oligotrophic and the ASEAN water quality criteria for aquatic life protection, (2) mesotrophic water quality, and (3) eutrophic water quality

The results of this study found the eutrophic condition in all sites, except at Dadap stations. Nutrients contamination and sedimentation derived from domesticated islands in the middle and northern region (Abang and Petong area). This condition may shift the ecological ecosystem as the pressures were found continuously happen throughout seasons. Previous studies found a shift in macroalgae and coral reef diversity from the northern to the southern side in this region (Kadi, 2006; Raza'i, 2017). The concern of food safety on aquaculture, either fishes or mussels may also arise. The previous ecological study was found a statistical canonical correspondence between phosphate level and biotoxin producing algae abundance (Scholz *et al*. 2013). Therefore, mitigation of anthropogenic pressures on human-populated islands is the priority conservation management at Batam City marine reserve park. Moreover, the southern part of this area, Dadap region, is potential as the core of conservation area, as having the least impact of anthropogenic pressures in Batam City marine reserve park.

Conclusions

The finding of the eutrophic condition in almost all sites may imply that Batam City marine reserve park is under heavy pressured of human anthropogenic run-off. The pressure was found continuously happen throughout seasonal and as a consequence, degradation of marine life quality and concern of food safety of coastal economic products may arise. Ecosystem rehabilitation and mitigation of anthropogenic run-off, particularly from Petong and Abang islands are needed to optimize the conservation management at Batam City marine reserve park. Moreover, Dadap zone as the area with the least anthropogenic pressures is potential to be the core of conservation area in Batam City marine reserve park.

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References

Amin, M.N., Kroeze, C. & Strokal, M. 2017. Human waste: An underestimated source of nutrient pollution in coastal seas of Bangladesh, India and Pakistan. *Mar. Poll. Bull.* 118(1): 131-140. doi: 10.1016/j.marpolbul.2017.02.045

Bernini, E., da Silva, M.A., Carmo, T. & Cuzzuol, G.R. 2010. Spatial and temporal variation of the nutrients in the sediment and leaves of two Brazilian mangrove species and their role in the retention of environmental heavy metals. *Brazilian J Plant Physiol*. 22(3): 177-187.

Brown, T.C. & Froemke, P. 2012. Nationwide assessment of nonpoint source threats to water quality. *BioScience*, 62(2): 136-146.

Chazottes, V., Hutchings, P. & Osorno, A. 2017. Impact of an experimental eutrophication on the processes of bioerosion on the reef: One Tree

Island, Great Barrier Reef, Australia. *Mar. Poll. Bull.* 118(1): 125-130.

Dinsdale E.A. & Harriott, V.J. 2004. Assessing anchor damage on coral reefs: a case study in selection of environmental indicators. *Environ. Manage.* 33(1): 126-139.

Guildford, S.J. & Hecky, R.E. 2000. Total nitrogen, total phosphorus and nutrient limitation in lakes and oceans: is there a common relationship? *Limnol. Oceanogr*. 45: 1213–1223.

Håkanson, L. & Eklund. J.M. 2010. Relationships between chlorophyll, salinity, phosphorus, and nitrogen in lakes and marine areas. *J. Coast. Res*. 26(3): 412-423.

Hammer, O., Harper, D.A.T. & Ryan, P.D. 2001. Past: Palaeontological statistics software package for education and data analysis. *Palaeontological Elec*. 4(1): 9pp.

Hattenrath-Lehmann, T.K., Smith, J.L., Wallace, R.B., Merlo, L.R., Koch, F., Mittelsdorf, H., Goleski, J.A., Anderson, D.M. & Gobler, C.J. 2015. The effects of elevated CO_2 on the growth and toxicity of field populations and cultures of the saxitoxin-producing dinoflagellate, Alexandrium fundyense. *Limnol. Oceanogr*. 60(1): 198-214.

Howarth, R.W. & Marino, R. 2006. Nitrogen as the limiting nutrient for eutrophication in coastal marine ecosystems: evolving views over three decades. *Limnol. Oceanogr.* 51: 364-376.

Ignatiades, L., Karydis, M. & Vounatsou, P. 1992. A possible method for evaluating oligotrophy and eutrophication based on nutrient concentration scales. *Mar. Poll. Bull.* 24(5): 238-243.

Jeffrey, S.T. & Humphrey. G.F. 1975. New spectrophotometric equations for determining chlorophylls a, b, c1 and c2 in higher plants, algae and natural phytoplankton. *Biochem. Physiol. Pflanz*. 167(2): 191-194.

Kadi, A. 2006. Community structure of macroalgae in Pengelap, Dedap, Abang Besar, and Abang Kecil at Riau islands. *Ilmu Kelautan*. 11(4): 234-240.

Kitsiou, D. & Karydis, M. 2011. Coastal marine eutrophication assessment: a review on data analysis. *Environ. Int*. 37(4): 778-801.

Loayza-Muro R.A., Elías-Letts, R., Marticorena-Ruíz, J.K., Palomino, E.J., Duivenvoorden, J.F., Kraak, M.H.S & Admiraal, W. 2010. Metal-induced shifts in benthic macroinvertebrate community composition in Andean high altitude streams. *Environ. Toxicol. Chem*. 29(12): 2761–2768.

López-Cortés, D.J., Núñez-Vázquez, E.J., Band-Schmidt, C.J., Gárate-Lizárraga, I., Hernández-Sandoval, F.E. & Bustillos-Guzmán, J.J. 2015. Mass fish die-off during a diatom bloom in the Bahía de La Paz, Gulf of California. *Hidrobiológica*. 25(1): 39-48.

Mailanti, R. & Rani, F., 2017. Implementation of Coral Reef Rehabilitation and Management Program-coral Triangle Initiative (Coremap-CTI) at local marine conservation in Batam island, Riau. *Indonesian Student J. Soc. Pol. Sci.* 4(2): 1-13.

McIntyre, L., Cassis, D. & Haigh, N. 2013. Formation of a volunteer harmful algal bloom network in British Columbia, Canada, following an outbreak of diarrhetic shellfish poisoning. *Marine drugs*, 11(11): 4144-4157.

McNamee, S.E., Medlin, L.K., Kegel, J., McCoy, G.R., Raine, R., Barra, L., Ruggiero, M.V., Kooistra, W.H., Montresor, M., Hagstrom, J. & Blanco, E.P., 2016. Distribution, occurrence and biotoxin composition of the main shellfish toxin producing microalgae within European waters: A comparison of methods of analysis. *Harmful Algae*, 55: 112-120.

McPherson, C.A., Chapman, P.M., Vigers, G.A. & Ong, K.S. 1999. ASEAN Marine Water Quality Criteria: Contextual Framework, Principles, Methodology and Criteria for 18 Parameters. ASEAN Marine Environmental Quality Criteria - Working Group (AMEQCWG), ASEAN-Canada Cooperative Programme on Marine Science - Phase II (CPMS-II). EVS Environment Consultants, North Vancouver and Department of Fisheries, Malaysia. 568 pp.

Michalski, M. & Osek, J. 2016. Contamination of raw bivalve molluscs available in Poland between 2009 and 2013 with marine biotoxins. *J. Vet. Res.*, 60(4): 447-451.

Murray, A.P., Gibbs, C.F., Longmore, A.R. & Flett, D.J., 1986. Determination of chlorophyll in marine waters: intercomparison of a rapid HPLC method with full HPLC, spectrophotometric and fluorometric methods. *Mar. Chem.,* 19(3): 211-227.

Osburn, C.L., Handsel, L.T., Peierls, B.L. & Paerl, H.W. 2016. Predicting Sources of Dissolved Organic Nitrogen to an Estuary from an Agro-Urban Coastal Watershed. *Environ. Sci. Technol.,* 50(16): 8473-8484.

Primpas, I., Tsirtsis, G., Karydis, M. & Kokkoris, G. D. 2010. Principal component analysis: Development of a multivariate index for assessing eutrophication according to the European water framework directive. *Ecological Indicators*, 10(2): 178-183.

Raza'i, T.S. 2017. Ecological appropriateness analysis of marine aquaculture in Abang Island waters, Batam City. *Indonesian J. Intek Aquaculture*, 1(1): 87-96.

Sachoemar, S.I. & Purwanda, A. 2016. Modelling of pollutant dispersion dynamics in Nguan Strait, Batam. *Indonesian J. Environ. Technol.,* 10(1): 90-103.

Schmoker, C., Russo, F., Drillet, G., Trottet, A., Mahjoub, M.S., Hsiao, S.H., Larsen, O., Tun, K. & Calbet, A., 2016. Effects of eutrophication on the planktonic food web dynamics of marine coastal ecosystems: The case study of two tropical inlets. *Mar. Environ. Res.*, 119: 176-188.

Scholz, B., Jónasson, B., Ólafsson, H.G., Davidson, K., Einarsson, H. & Magnússon, K.P. 2013. Development of a monitoring programme for the occurrence of phytoplankton derived toxins in blue mussels (*Mytilus edulis*) in northern Icelandic coastal waters-Report for VSS 2011-2012.

Smith, S.V., Swaney, D.P., Talaue-McManus, L., Bartley, J.D., Sandhei, P.T., McLaughlin, C.J., Dupra, V.C., Crossland, C.J., Buddemeier, R.W., Maxwell, B.A. & Wulff, F. 2003. Humans, hydrology, and the distribution of inorganic nutrient loading to the ocean. *BioScience*. 53(3): 235–245.

Snickars, M., Weigel, B. & Bonsdorff, E., 2015. Impact of eutrophication and climate change on fish and zoobenthos in coastal waters of the Baltic Sea. *Mar. Biol.*, 162(1): 141-151.

van der Wulp, S.A., Damar, A., Ladwig, N. & Hesse, K.J. 2016. Numerical simulations of River discharges, Nutrient flux and nutrient dispersal in Jakarta Bay, Indonesia. *Mar. Poll. Bull.*, 110(2): 675-685.

Wiegner, T.N., Edens, C.J., Abaya, L.M., Carlson, K.M., Lyon-Colbert, A., and Molloy, S.L. 2017. Spatial and temporal microbial pollution patterns in a tropical estuary during high and low river flow conditions. *Mar. Poll. Bull.*, 114(2): 952-961.

Zhang, Y., Shi, K., Liu, J., Deng, J., Qin, B., Zhu, G. & Zhou, Y. 2016. Meteorological and hydrological conditions driving the formation and disappearance of black blooms, an ecological disaster phenomenon of eutrophication and algal blooms. *Sci. Total Environ.,* 569: 1517-1529.