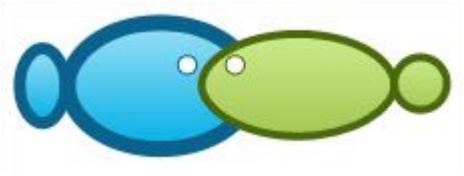

Assessment of the trophic status in Kendari Bay, Indonesia: a case study

[1,2]Asriyana, [1]Nur Irawati

[1] Department of Aquatic Resources Management, Faculty of Fisheries and Marine Sciences, Halu Oleo University, Kampus Bumi Tridharma Anduonohu, Kendari 93232, Southeast Sulawesi, Indonesia; [2] The Indonesian Ichthyological Society (IIS), Bogor, Indonesia. Corresponding author: Asriyana, yanasri76@yahoo.com

Abstract. Primary production, nutrient concentration, phytoplankton biomass, and chlorophyll-*a* (Chl-*a*) are important indicators used in trophic state assessment of a water body. Trophic status is defined as the total living biomass in a specific water body at a specific period of time. It is regularly used in the ecosystem classification of a water body based on its biotic production including this study. The assessment of the trophic status of Kendari Bay in Indonesia was carried out from August 2016 to June 2017. This present study was arguably the first assessment of the trophic status of Kendari Bay that used the trophic index (TRIX) method in combination with primary production. This study found that the spatial distributions of Chl-*a* and primary production were relatively homogenous across the bay ($p > 0.05$). In contrast, the temporal distribution of Chl-*a* temporally varied across the bay ($p > 0.05$) compared to a more homogenous temporal distribution of primary production. This study concludes that the spatial and temporal variations of the trophic level in Kendari Bay do not differ significantly. Thus, the bay can be categorized as oligotrophic waters (TRIX < 4 and PP < 1.5 gC m^{-3} d^{-1}) indicated by the low levels of primary production (0.01585 gC m^{-3} h^{-1}) and phytoplankton biomass (92.91 mg m^{-3}).
Key Words: trophic status, chlorophyll-*a*, production, oligotrophic, Kendari Bay.

Introduction. Kendari Bay is one of the important estuaries in Southeast Sulawesi, Indonesia. It is considered an economically important water body for the region and ecologically critical as a nursery area for the local fish species (Asriyana et al 2009). Currently, the bay has suffered a tremendous pollution pressure from the surrounding anthropogenic activities such high-density settlement effluent, brackishwater aquaculture, fish post-processings, and sand minings as well as agriculture farms along the banks of the four major rivers flowing in the bay (Asriyana 2011; Asriyana et al 2018). Such complex condition can cause an extreme shift in the ecology of the waters such as degradation of water quality and substantial changes in phytoplankton, zooplankton, benthic organisms, and fish community structures as had happened in other water bodies worldwide (Orpin et al 2004; Karakassis et al 2005; Jaureguizar & Milessi 2008). These changes will eventually affect the availability of food sources or known as trophic status for organisms in the bay. Trophic status is defined as the total living biomass in a specific water body at a specific period of time regularly used to classify the waters based on its biotic production (Knoppers et al 1991; Wasmund et al 2001; Ignatiades 2005). The total standing stock of phytoplankton is generally estimated as the total concentration of Chl-*a* and has been agreed by the science community as a valid representation of phytoplankton biomass (APHA 2005; Boyce et al 2010; Agirbas et al 2014). Trophic status information could be used to determine waters productivity in supporting the ecosystem food web, assess the maturity, provide a baseline data for monitoring and management policy as well as eutrophication modeling of the aquatic system (Knoppers et al 1991). The information could also be used to determine the total biomass at the lower hierarchy of food web in supporting higher trophic levels (Sibert et al 2006; Coat et al 2009; Asriyana 2011).

There were few studies that addressed the partial aspects of the trophic status of the Kendari bay such as phytoplankton diversity (Irawati 2011); fish diversity (Asriyana

et al 2009, 2011); fish foodweb (Asriyana & Syafei 2012; Asriyana & Irawati 2018; Asriyana et al 2018) and fish biological reproduction (Asriyana & La Sara 2013). Most of the specific research regarding the trophic status of water bodies were mostly conducted in freshwater systems (Molisani et al 2010; Trolle et al 2011; Siagian & Simarmata 2018). Other studies on trophic status were also carried in estuarine and marine systems (Primpas & Karydis 2011; van de Poll et al 2013; Agirbas et al 2014). However, the information regarding the trophic status of many important water bodies in Southeast Asia is relatively limited including Kendari Bay. This study was aimed to assess the trophic status of waters of Kendari Bay based on spatial and temporal variations. The information from this study was then used to estimate the total fish stock which Kendari Bay could support by considering the energy transfer efficiency between the trophic levels.

Material and Method

Study area and sampling procedures. A sampling campaign of every two months, from August 2016 to June 2017 was carried out at three sampling stations located in Kendari Bay, Southeast Sulawesi, Indonesia. The bay is located between latitudes of 3°57'59.37"-3°59'32.39"S and longitudes of 122°31'38.07"-122°35'55.93"E (Figure 1). The sampling stations were selected to represent the general flow of water mass in Kendari Bay (upstream and downstream). Station I was located at the upstream part of Kendari Bay which constantly receives freshwater inputs, organic materials, and sediment from four big rivers in Kendari (Mandonga, Kadia, Wanggu, and Kambu rivers). The sources of organic materials are from villages, fish ponds, and agricultural activities along the banks of the rivers whilst sediment sources are released from sand minings along Wanggu and Kambu rivers. The average water depth in this area was 5 m. Station II was located at the center of the bay with water depth ranging from 5 to 10 meter. Station III was located downstream, near the mouth of the bay, which is constantly influenced by seawater from the outside of Kendari Bay with water depth ranged between 5 and 8 m.

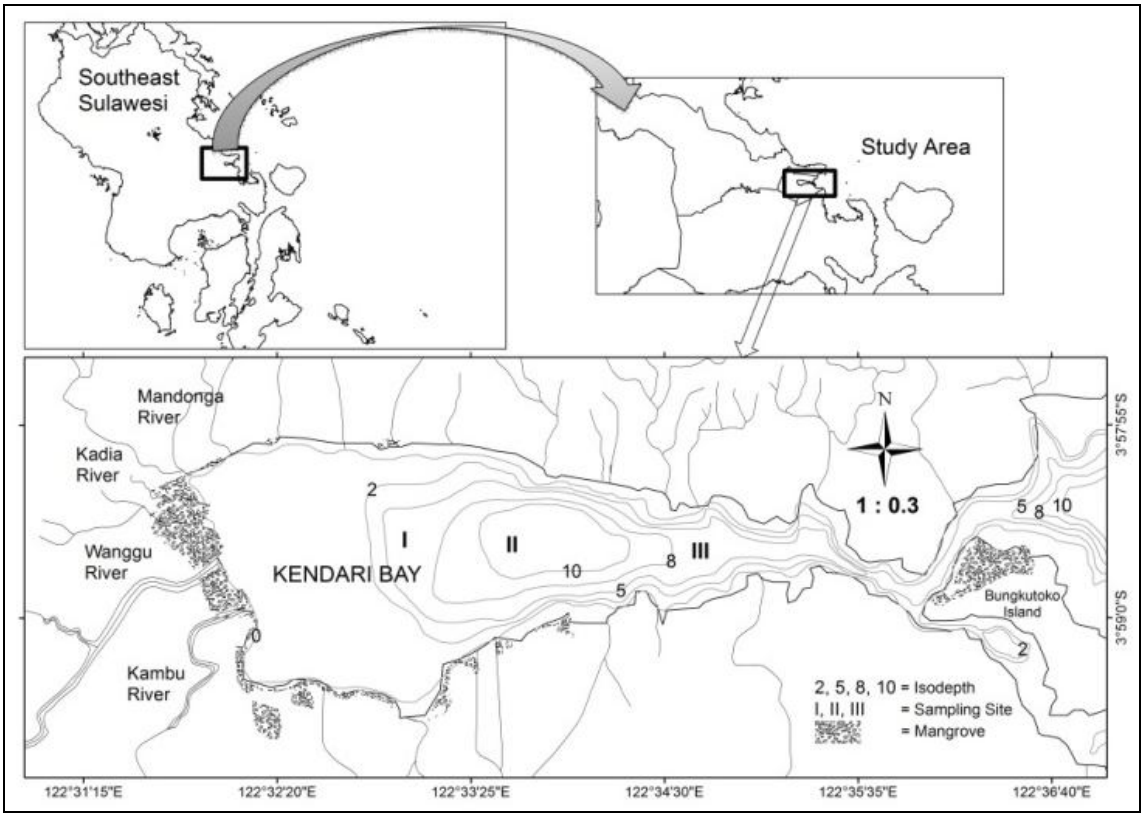

Figure 1. Location of Kendari Bay and sampling area.

Water samples were collected using a Kemmerer Water Sampler of 2 liters in volume to measure temperature, salinity, turbidity, dissolved inorganic nitrogen (DIN: nitrate, nitrite, and ammonium), dissolved inorganic phosphate (DIP: orthophosphate), and Chl-*a*. The water samples were collected at several depths i.e.: 0, 0.5, 2.5, and 4 meters. Temperature and salinity were measured in-situ using a Hg thermometer and hand refractometer, respectively. Turbidity was measured in the laboratory based on the nephelometric method (Strickland & Parsons 1972). Water samples were analyzed using a standard Spectrophotometer method to determine the DIN and DIP values (APHA 2005). Phytoplankton Chl-*a* concentration in water samples was analyzed using the spectrophotometer standard method (APHA 2005). Each water sample was filled into a dark bottle and placed in a coolbox. As much as 1 liter of each water sample was filtered using Millipore paper filter Whatman GF/C 42 µm using a vacuum pump. The paper filter holding the filtered phytoplankton was then wrapped with aluminum foil and stored in a freezer at 4ºC for the following procedure. The prepared phytoplankton samples were mixed with 5 mL of 90% acetone and ground until forming a smooth mixture. The process was repeated with the addition of 3.5 mL of 90% acetone and re-grinded until all paper filter dissolved in the mixture. The addition of 1.5 mL of 90% acetone was used to wash the grinding tools until no samples left. Each sample was then placed in a test tube and stored in the freezer at 4ºC for 1 hour for the next procedure. The prepared samples were placed into a centrifuge and spun at 500 rpm for 1 min.

The samples were then analyzed using a spectrophotometer at a wavelength range of 664 and 665 nm. Chl-*a* concentration was calculated using APHA standard equation (2005):

$$\text{Chlorophyll } a \text{ (mg m}^{-3}) = \frac{26.7\,(664_b - 665_a) \times V_1}{V_2 \cdot l}$$

where V_1 is the volume of extract (L), V_2 is the volume of sample (m^3), 664_b, 665_a are optical densities of 90% acetone extract before and after acidification, respectively, l is light path length of the width of the cuvette (cm), 26.7 is absorbance correction.

Phytoplankton primary production was measured in each sampling station using the light-dark oxygen bottle method followed by Winkler titration. In each sampling station, water samples were collected at different depths but still within the euphotic zone (Preisendorfer 1986) which were 0, 0.5, 2.5, dan 4 meters. The water samples were collected using a Kemmerer Water Sampler of 2 liters in volume and filled immediately into the light and dark bottles until full. Then initial dissolved oxygen (DO) concentration was determined using Winkler titration. Both of the bottles were then suspended in the water column at the same depth and location for 4 hours. Afterward, the bottle samples were recollected and measured their final DO concentrations. The phytoplankton primary productivition was calculated using Umaly & Cuvin (1988) equation:

$$PP_N = \frac{O_2 LB - O_2 IB \times 1000 \times 0.375}{(PQ)(t)}$$

where PP_N is net primary production (mg C m^{-3} t^{-1}), O_2 is dissolved oxygen (mg L^{-1}), LB is light-bottle, IB is initial-bottle; PQ is coefficient photosynthesis (1.2), t is incubation period (hour), 0.375 is the coefficient of conversion of oxygen to carbon (12/32), and 1000 is converted liter to m^3.

The trophic status of Kendari Bay was determined based on TRIX trophic criteria developed by Vollenweider et al (1998) and primary production classification by Pinckney et al (2001), Ignatiades (2005) and Agirbas et al (2014). The TRIX index is based on four variables directly related to productivity: chlorophyll *a* (Chl-*a* mg m^{-3}), oxygen as the absolute percentage deviation from oxygen saturation (DO, %), dissolved inorganic nitrogen (DIN, mg m^{-3}, and dissolved inorganic phosphate = orthophosphate (DIP, mg m^{-3}) (Ærtebjerg et al 2001; Rinaldi & Giovanardi 2011). In particular, DIN = N-NO_3 + N-NO_2 + N-NH_4 and DO = $|100 - O_x|$, where O_x is the oxygen saturation; Mi is the observed Chl, DO, DIN, and DIP values. TRIX formula is presented in equation and the reference values of the trophic index (TRIX) are shown in Table 1.

$$TRIX = \frac{1}{1.2}[\log(M_{chl}M_{DO}M_{DIN}M_{DIP}) + 1.5]$$

Table 1

Reference values of the trophic index (TRIX) developed from ARPAE Daphne Emilia-Romagna (Rinaldi & Giovanardi 2011; Fiori et al 2016)

Conditions	*TRIX units*	*Trophic state*	*Water quality conditions*
Oligotrophic	< 4	Elevated	Scarcely productive waters, good water transparency, absence of anomalous water colors, absence of oxygen undersaturation in the bottom waters.
	4-5	Good	Moderately productive waters, occasionally water turbidity, occasionally anomalous water colors, occasionally bottom waters hypoxia episodes.
	5-6	Mediocre	Very productive waters, low water transparency, frequently anomalous waters colors, hypoxia and occasionally anoxia episodes in the bottom layers, suffering of the benthic communities.
Eutrophic	> 6	Bad	Strongly productive waters, high water turbidity, diffuse and persistent anomaly in the water colors, diffuse and persistent hypoxia/anoxia episodes in the bottom waters, high mortality rate of benthic organisms, alteration of the benthic communities and strong decrease of the biodiversity.

Trophic status can be classified into three groups based on the value ranges of primary production i.e. : oligotrophic (PP < 1.5 g C m^{-3} d^{-1}); mesotrophic (1.5-3 g C m^{-3} d^{-1}); and eutrophic (> 3 g C m^{-3} d^{-1}) (Ignatiades 2005; Agirbas et al 2014).

Statistics. The differences in the distribution of chl-a, PP_N, TRIX, and other spatially and temporally related parameters during the study were statistically compared using Kruskal-Wallis test at 95% confidence level. The SPSS v.16 was used in the data statistical analysis.

Results

Hydrography. The measured temperature, salinity, DO, and turbidity are presented in Figure 2. The temperature variation in each sampling station was relatively uniform (isothermal) from the upper water column to 4 meter depth. Salinity was also uniform likewise (isohaline). One exception was in the months of February and April where the salinity was relatively lower with value ranges of 10.5-25.0 psu and 13.5-27.0 psu, respectively. Turbidity was relatively low during the research period from the upper water surface to the 4 meter depth except in station I where the turbidity reached 1.20-5.14 NTU and 0.90-10.25 NTU in the months of February and April, respectively.

Nutrients. The ratio of N:P in the waters of Kendari Bay was above 16:1 in all sampling stations except in Station II (0 and 0.5 m depth) and Station III (0-4 m depth) ($p < 0.05$, $\alpha = 5\%$, Table 2). Similarly, N:P ratio was also below 16:1 during the month of August, October, and February ($p < 0.05$, $\alpha = 5\%$, Table 3). DIN concentrations ranged between 0.61-3.02 mg L^{-1} (Station I), 0.44-0.69 mg L^{-1} (Station II), 0.48-0.59 mg L^{-1} (Station III). In general, the spatial distributions of DIN concentration were gradually decreasing toward the mouth of the bay. The highest DIN concentration was observed in April 2016 (2.36–2.79 mg L^{-1}). In contrast, the distribution of DIP concentration was increased toward the mouth of the bay (Station I = 0.02-0.08 mg L^{-1}, Station II = 0.01-0.05 mg L^{-1}, and Station III = 0.17-0.18 mg L^{-1}). The highest concentration of PO_4-P was observed in August (0.26-0.39 mg L^{-1}) (Table 3).

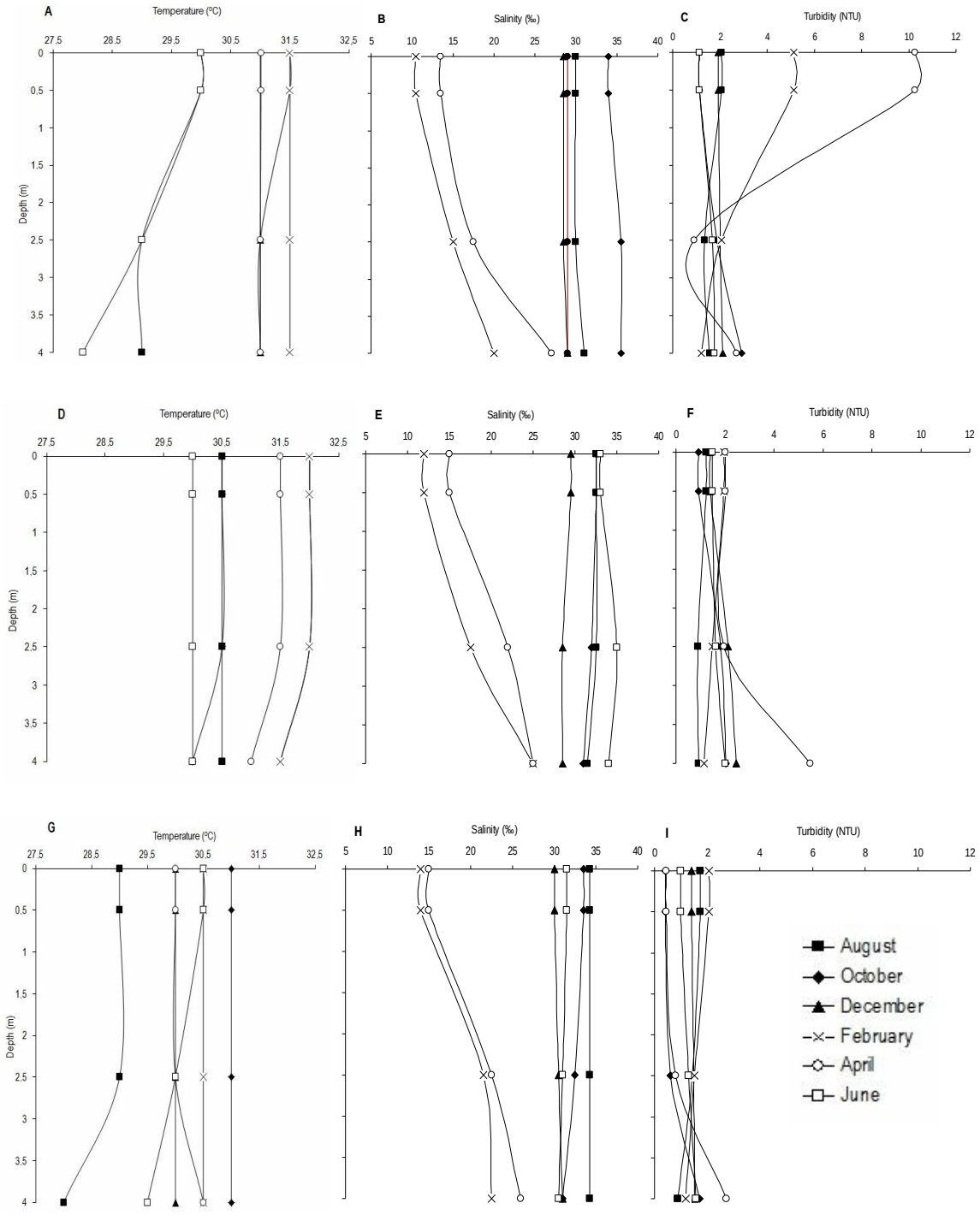

Figure 2. Vertical distribution of temperature (°C), salinity (psu), and turbidity (NTU) in Kendari Bay during the study period: (A, B, C) for Station I; (D, E, F) for Station II; and (G, H, I) for Station III.

Table 2

The average and standard deviation of spatial distribution of nutrient during the study period

Station	Depth (m)	NH_3-N (mg L^{-1})	NO_3-N (mg L^{-1})	NO_2-N (mg L^{-1})	PO_4-P (mg L^{-1})	DIN (mg L^{-1})	N:P
I	0	0.35±0.18	2.27±4.60	0.01±0.02	0.02±0.04	2.63±2.60	131.50±1.81
	0.5	0.36±0.19	2.26±4.61	0.01±0.02	0.02±0.04	2.63±2.60	122.32±1.81
	2.5	0.32±0.17	2.69±6.04	0.01±0.02	0.08±0.17	3.02±3.43	39.85±2.31
	4.0	0.28±0.16	0.32±0.29	0.02±0.02	0.02±0.03	0.61±0.13	38.71±0.08
II	0	0.32±0.17	0.13±0.15	0.01±0.02	0.06±0.08	0.46±0.10	7.67±0.01
	0.5	0.31±0.19	0.12±0.17	0.01±0.02	0.05±0.08	0.44±0.09	8.82±0.01
	2.5	0.37±0.16	0.30±0.34	0.02±0.02	0.01±0.02	0.69±0.16	79.37±0.10
	4.0	0.28±0.16	0.18±0.27	0.02±0.03	0.02±0.03	0.47±0.12	20.10±0.06
III	0	0.38±0.31	0.08±0.13	0.01±0.02	0.19±0.31	0.47±0.15	2.47±0.11
	0.5	0.39±0.31	0.08±0.12	0.01±0.02	0.18±0.31	0.48±0.15	2.69±0.11
	2.5	0.35±0.30	0.15±0.18	0.01±0.02	0.17±0.30	0.51±0.14	3.01±0.11
	4.0	0.34±0.30	0.24±0.34	0.01±0.02	0.17±0.30	0.59±0.18	3.55±0.09

Kruskal-Wallis = $p < 0.05$ ($\alpha = 5\%$, df = n-1).

Table 3

The average and standard deviation of temporal distribution of nutrient during the study period

Month	NH_3-N (mg L^{-1})	NO_3-N (mg L^{-1})	NO_2-N (mg L^{-1})	PO_4-P (mg L^{-1})	DIN (mg L^{-1})	N:P
August	0.23±0.09	0.19±0.23	0.01±0.01	0.26±0.39	0.43±0.12	1.65±0.19
October	0.42±0.12	0.11±0.11	0.01±0.01	0.04±0.06	0.53±0.07	14.29±0.01
December	0.61±0.05	1.48±3.83	0.01±0.01	0.08±0.14	2.09±2.20	25.23±1.45
February	0.24±0.08	0.13±0.14	0.02±0.01	0.05±0.03	0.39±0.07	7.60±0.03
April	0.22±0.04	2.09±4.85	0.05±0.01	0.04±0.06	2.36±2.79	63.15±1.93
June	0.26±0.15	0.22±0.27	0.02±0.01	0.01±0.01	0.49±0.14	126.31±0.09

Kruskal-Wallis = $p < 0.05$ ($\alpha = 5\%$, df = n-1).

Primary production and chlorophyll-a. The vertical variation of the primary production in waters of Kendari Bay showed a significant difference ($p < 0.05$; $\alpha = 5\%$, Figure 3), whilst the spatial and temporal variations were relatively uniform ($p > 0.05$; $\alpha = 5\%$). The highest primary production was found in the depth of 2.5 m at each sampling station (Station I = 58.68 mg C m^{-3} h^{-1}; Station II = 40.62 mg C m^{-3} h^{-1}; Station III = 36.31 mg C m^{-3} h^{-1}). The spatial distribution of primary production in each sampling station is provided in Figure 3. In addition, the highest temporal primary production was found in February (24.98 mg C m^{-3} h^{-1}) and the lowest in August (9.65 mg C m^{-3} h^{-1}).

The Chl-*a* distribution in waters of Kendari Bay varied significantly according to the depth and time of measurement ($p < 0.05$, $\alpha = 5\%$, Figure 3). The highest Chl-*a* concentration was found in the depth of 2.5 m of each sampling station (Station I = 1.81 mg m^{-3}; Station II = 1.94 mg m^{-3}, and Station III = 2.65 mg m^{-3}). The highest concentration of Chl-*a* was found in February (2.28 mg m^{-3}) and the lowest in August (0.72 mg m^{-3}). However, the spatial distribution of Chl-*a* was relatively uniform in all sampling stations ($p > 0.05$, $\alpha = 5\%$, Figure 3).

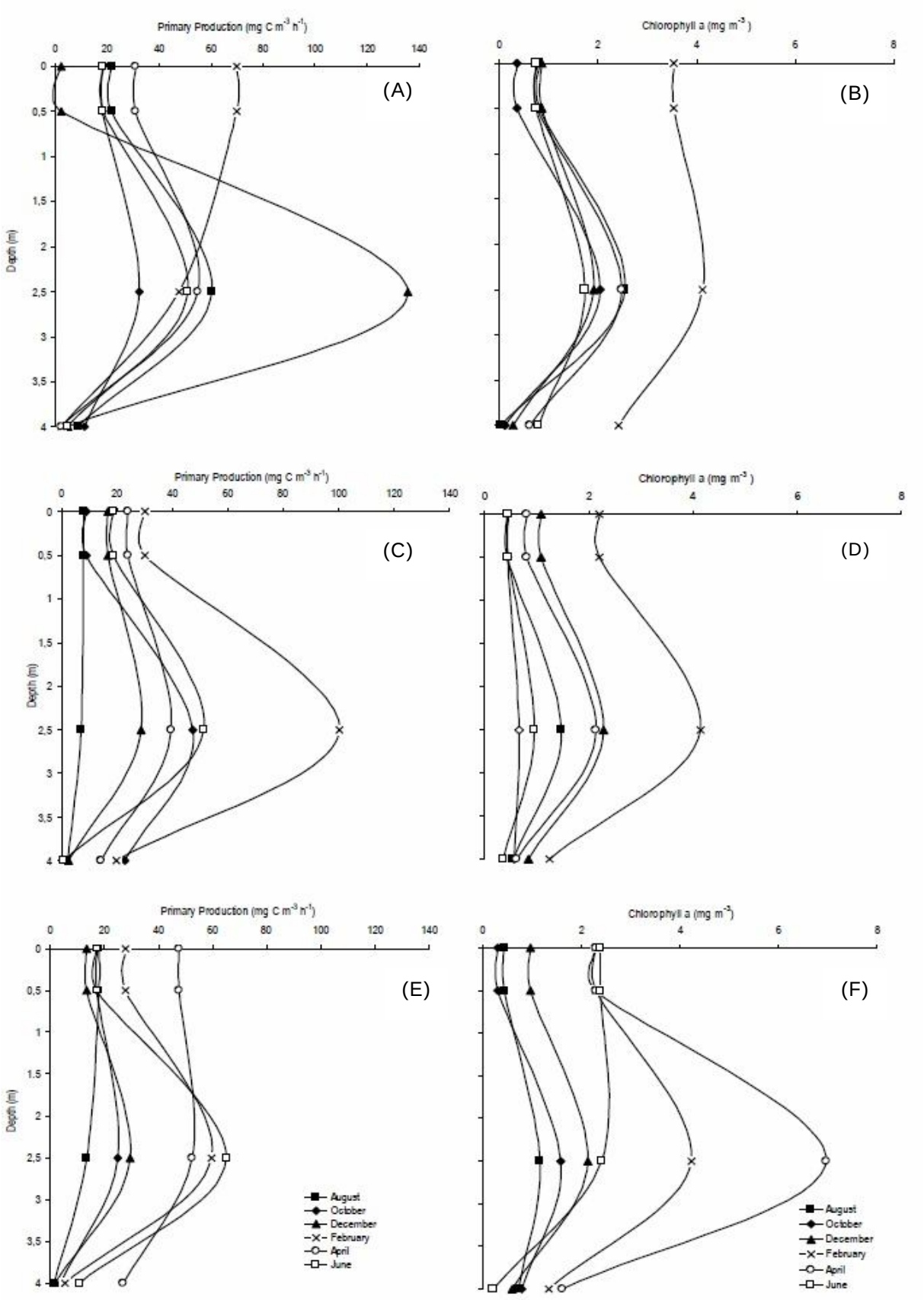

Figure 3. Vertical distribution of primary production and chlorophyll-*a* during the study period: (A, D) = station I; (B, E) = Station II; (C, F) = Station III.

Trophic status. The primary productivity of Kendari Bay was considered low with an estimated annual primary production of 27.89 g C m^{-2} y^{-1} and phytoplankton biomass of 367.594 mg y^{-1}. Based on the calculated TRIX and primary production values, the trophic status of Kendari Bay was spatially and temporally uniform and classified as elevated oligotrophic water ($p > 0.05$, $\alpha = 5\%$, Figure 4).

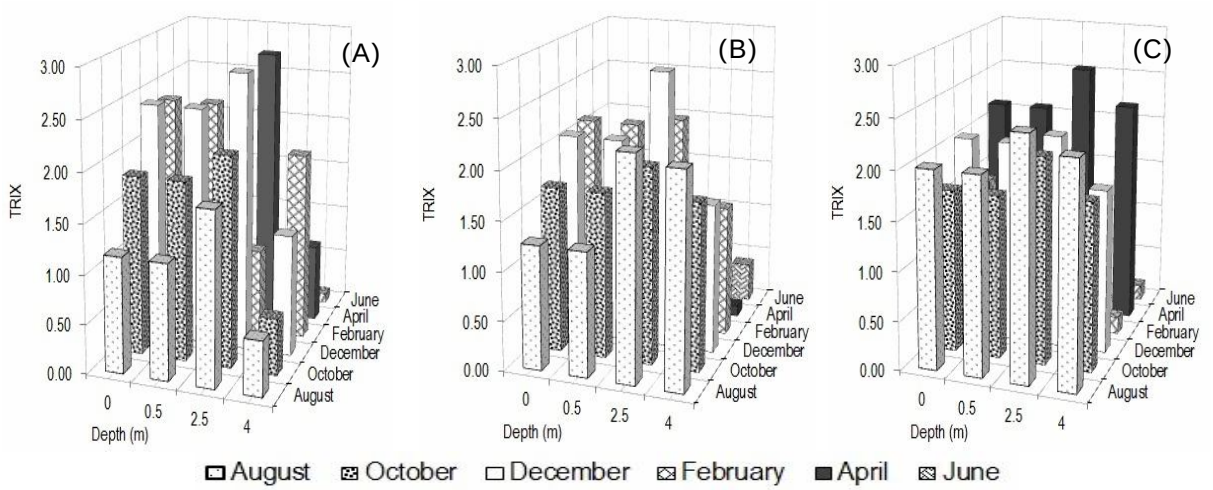

Figure 4. Comparison of TRIX values for each depth at each station during the study period: (A) = Station I; (B) = Station II; (C) = Station III.

Discussion

Primary production. The assessment of phytoplankton primary production is a prerequisite in the study of structure and function of an aquatic ecosystem (Gocke & Lenz 2004). It is estimated that phytoplankton contributes up to 50% of the primary production in marine waters (Falkowski et al 1998; Rost et al 2003). In waters of Kendari Bay, both primary production and Chl-*a* concentration have uniform spatial and temporal distributions where the highest was at 2.5 meters from the water surface. This finding indicates the tendency of phytoplankton to avoid the high intensity of sunlight at the water surface which can cause damage to its chloroplast. As a result, the primary production at the water surface was consistently lower. According to Lalli & Parsons (1997), the main controlling factor of phytoplankton primary production in waters is the sunlight intensity. In clear water, sunlight absorbance by phytoplankton is only 1.4% and can reach up to 40% in turbid water (Kishino 1994). However, when the positive linear relationship between sunlight intensity and primary production passes an optimum tipping point, the relationship between the two will be counterproductive (Herman & Platt 1986; Irawati 2011; Kartamihardja 2007). Furthermore, the relatively narrow variation of the measured water quality parameters such as temperature, salinity, turbidity, DIN and DIP might contribute to the uniform primary production of the bay. McNaughton & Wolf (1979) implied that a uniform horizontal distribution of photoautotroph organisms follows closely with the uniform characteristic of its environment. The average value of primary production in Kendari Bay was 15.85 mg C m^{-3} h^{-1} which was lower than that of Hurun Bay, Lampung, Indonesia (34.25 mg C m^{-3} h^{-1}) (Tambaru 2000); Maros coastlines, South Sulawesi, Indonesia (35.24 mg C m^{-3} h^{-1}) (Tambaru 2007). These differences can be attributed to the specific differences in the environmental condition of each location. Both Hurun Bay and Maros coastlines have better environmental physicochemical conditions to support higher phytoplankton production. In contrast, Kendari Bay has relatively high turbidity (0.42-10.25 NTU) which limits sunlight penetration into the water column and subsequently reduces the phytoplankton primary production. In addition, nutrient availability in the bay is considered low (DIN = 0.44±0.09 - 3.02±3.43 mg L^{-1}; PO_4-P = 0.01±0.01 - 0.19±0.31 mg L^{-1}) causing lower primary production. The ratio of N:P was generally greater than 16:1. However, it is still below the optimum value to support phytoplankton growth and population. The decrease of nitrate concentration down to 6

µM equivalent to 0.456 mg L^{-1} indicates that there is an accelerated absorption of nitrate by phytoplankton (Goes et al 2004). The optimal growth of phytoplankton requires nitrate availability in the range of 0.10-3.00 mg L^{-1}. An optimal PO_4-P concentration to support phytoplankton growth ranges between 0.06 and 5.51 mgL^{-1} (Bruno et al 1980). Such requirements reconfirm that phytoplankton primary production in Kendari Bay is limited to a certain level by N and P concentrations. If the N:P ratio is below 16, the N concentration will be the controlling factor whereas the ratio of N:P is greater than 16, then the P concentration will take over as a controlling factor. This relationship will have an effect on the biological conditions of an ecosystem in which a species might dominate the ecosystem of the water body and its food web (Lessard et al 2005). The fluctuations of N:P have been found in other water bodies including freshwater ecosystem (Cloern 2001; Justus 2005) and marine waters (Jennerjahn et al 2004; Lagus et al 2004; Yuliana 2012). In this study, there was evidence that phosphate controlled the primary production during the sampling period. Nitrogen constituents were regularly detected in the water samples while the dissolved phosphate constituents were absent. The absence of dissolved phosphate constituents and the occurrence of total phosphate indicate that all forms of phosphate were bounded in the suspended sediment (sediment particle and living organism) (Justus 2005).

Chlorophyll-a. Chl-*a* concentration has been referred to as the proxy value of the phytoplankton primary production (Damar 2003; Irawati 2011). Changes in Chl-*a* concentration can be attributed to the multiplication and growth of phytoplankton cells as part of its primary production processes. Similar to the primary production, the highest vertical distribution of Chl-*a* was found at the depth of 2.5 m. Herman & Platt (1986) and Irawati (2011) also reported similar findings that Chl-*a* concentration tended to be higher in 50% sunlight intensity compared to higher sunlight intensity. This result reconfirmed the findings of Fogg (1980) where the low concentration of Chl-*a* at the water surface was due to the inhibiting capacity of high sunlight intensity to photosynthesis.

The highest average of Chl-*a* concentration in waters of Kendari Bay was observed in February (2.28 mg m^{-3}) and the lowest in Agustus (0.72 mg m^{-3}). The month of February was within the wet season period in which a huge amount of fresh water from the rivers (7487 m^3 s^{-1}) filled into the bay (Iswandi 2003) carrying runoff sediments and organic materials. The decomposition of these run off materials will eventually create the final form of phosphate and nitrogen. Similar cases of the increase of phytoplankton in wet season were also reported by Damar (2003) in Jakarta Bay (13.2 µg Chl-*a* L^{-1} or equivalent to 13.2 mg m^{-3}); Lampung Bay (4.1 µg Chl-*a* L^{-1} or equivalent to 4.1 mg m^{-3}); and Semangka Bay, Indonesia (0.85 µg Chl-*a* L^{-1} or equivalent to 0.85 mg m^{-3}).

Trophic status. Kendari Bay has a lower concentration of phytoplankton biomass compared to other similar water bodies in Indonesia, for example Kayeli Bay estuary, Maluku (0.38-2.66 mg m^{-3} or equivalent to 25.46-178.35 mg Chl-*a* L^{-1} (multiplied by factor 67) (Pentury & Waas 2009)) and Pulau Pari Lagoon ((0.62-1.77 mg m^{-3} or equivalent to 41.67-118.59 mg m^{-3}; multiplied by factor 67) (Puspasari et al 2011)). Such a low concentration of phytoplankton biomass means that there will be limited biomass to support the upper trophic level. If the efficiency of energy transfer between trophic level is only 10% (Jennings et al 2003; Nontji 2006; Asriyana 2011), then the phytoplankton biomass of 367.594 mg y^{-1} in Kendari Bay can only support the biomass of second level trophic (zooplankton, benthic macro-invertebrate, and phytoplanktivora fish) as much as 36.759 mg y^{-1}. This second level trophic can only support the biomass of the third trophic level as much as 3.675 mg y^{-1}. This relationship means that the total energy within the food web in each trophic level is relatively low. This calculation does not include the dissipation of energy in form of entropy when the energy moves to the upper trophic level and organism metabolic processes such as respiration, swimming, feeding, growth, and reproduction (Asriyana 2011). The low biomass of phytoplankton in Kendari Bay can be attributed to the relatively high turbidity and the ratio of N and P as the limiting factors. As a result, the availability of food for the upper trophic level is also low which directly affect the population and diversity of the organisms within this level such

as zooplankton and fish (Mousseau et al 1998; Lanz et al 2009; Dutta et al 2016). The fish population in Kendari Bay is also considerably low depicted from the low average length and weight of fish caught in the bay (Asriyana et al 2011; Asriyana et al 2018; Asriyana & Irawati 2018). This indicates that: 1) the food availability (phytoplankton biomass) is relatively low (92.91 mg Chl-*a* m^{-3}), considering that most fish population in these waters is at $Trop_i$ = 2.08-2.34 (herbivore) (Asriyana 2011). As a result, fish juveniles using the area as nursery ground have a poor growth indicated by the low average of weight and length (Asriyana et al 2009; Asriyana 2011; Asriyana & Sjafei 2012); 2) only a small fraction of the total food energy in the waters of Kendari Bay is used for fish growth. Ideally, the food energy should be sufficient to be used by fish populations to grow, gain weight, and reproduce normally. However, most of the food energy has been used by the fish population in Kendari Bay to survive the unfavored environmental conditions such as high turbidity. Irawati (2011) reported that the suspended solids in the waters were considerably high ranging from 255 to 418 mg L^{-1}. Low sunlight penetration limits the growth and production of plankton despite the waters have a relatively high nutrient concentration. The effect of turbidity on reduced phytoplankton biomass was also observed by Domingues et al (2011) in Guadiana estuary waters. In another study, high turbidity suspended solids had impeded the growth of Arctic grayling, *Thymallus arcticus* (Birtwell 1999). If the concentration of suspended solids is more than 100 mg L^{-1}, fish feeding activity can be affected resulting in poor growth.

Conclusions. This study concludes that temperature, salinity, DO, and turbidity showed a general pattern commonly found in Kendari Bay. Based on the calculated TRIX and primary production values, the trophic status of Kendari Bay is classified as an elevated oligotrophic water. Therefore, the local government should initiate mitigation and revitalization plans to improve the trophic condition of Kendari Bay in order to ensure the long-term survival and sustainability of economically important fish stocks in Kendari Bay.

Acknowledgements. Special thanks to the students of the Faculty of Fisheries and Marine Sciences, Halu Oleo University for their assistance during sample collections. We are grateful to the Faculty of Fisheries and Marine Science, Halu Oleo University and the extension office of the Indonesian National Agency of Drug and Food Control in Kendari, Indonesia for providing access to the equipment and facilities in undertaking this study. Sincere gratitude to Hatim Albasri PhD who provided an informal peer-review to make this article more readable.

References

Agirbas E., Feyzioglu A. M., Kopuz U., 2014 Seasonal changes of phytoplankton chlorophyll *a*, primary production and their relation in the continental shelf area of the south eastern Black Sea. Turkish Journal of Fisheries and Aquatic Sciences 14:713-726.

[APHA] American Public Health Association, 2005 Standard methods for the examination of water and wastewater 21th edition. APHA, AWWA (American Waters Works Association) and WPCF (Water Pollution Control Federation), Washington, 1193 pp.

Ærtebjerg G., Carstensen J., Dahl K., Hansen J., Nygaard K., Rygg B., Sørensen K., Severinsen G., Casartelli S., Schrimpf W., Schiller C., Druon J. N., 2001 Eutrophication in Europe's coastal waters. European Environmental Agency, Copenhagen, DK, 115 pp.

Asriyana, 2011 [Trophic interaction of fish community as base of fish resources management in Kendari Bay waters, Southeast Sulawesi]. PhD thesis, IPB Graduate School, Bogor, 106 pp. [in Indonesian]

Asriyana, Syafei L. S., 2012 [Ontogenic shift on food content of ornate threadfin bream, *Nemipterus hexodon* (family Nemipteridae) in Kendari Bay]. Jurnal Iktiologi Indonesia 12(1):49-57. [in Indonesian]

Asriyana, La Sara, 2013 [Reproductive biology aspects of Indian oil sardine in Kendari Bay, Southeast Sulawesi]. Jurnal Iktiologi Indonesia 13(1):1-12. [in Indonesian]
Asriyana, Irawati N., 2018 [Food and feeding strategy of sunrise goatfish *Upeneus sulphureus*, Cuvier (1829] in Kendari Bay, Southeast Sulawesi]. Jurnal Iktiologi Indonesia 18(1):23-39. [in Indonesian]
Asriyana, Rahardjo M. F., Sukimin S., Lumban Batu D. T. F., Kartamihardja E. S., 2009 [Fish diversity in Kendari Bay, Southeast Sulawesi]. Jurnal Iktiologi Indonesia 9(2):97-112. [in Indonesian]
Asriyana, Rahardjo M. F., Lumban Batu D. T. F., Kartamihardja E. S., 2011 [Species composition and size of ponyfish, Family Leiognathidae in Kendari Bay, Southeast Sulawesi]. Jurnal Iktiologi Indonesia 11(1):11-19. [in Indonesian]
Asriyana, Irawati N., Indrayani, 2018 Trophic ecology of twoblotch ponyfish *Nuchequula blochii* in Kendari Bay, Southeast Sulawesi, Indonesia. AACL Bioflux 11(1):66-82.
Birtwell I. K., 1999 The effect of sediment on fish and their habitat. Canadian Stock Assesment Secretariat, Research Document 99/139, 34 pp.
Boyce D. G., Lewis M. R., Worm B., 2010 Global phytoplankton decline over the past century. Nature 466(7306):591-596.
Bruno S. F., Staker R. D., Sharma G. M., 1980 Dynamics of phytoplankton productivity in the Peconic Bay Estuary, Long Island. Estuarine and Coastal Marine Science 10: 247-263.
Cloern J. E., 2001 Our evolving conceptual model of the coastal eutrophication problem. Marine Ecology Progress Series 210:223-253.
Coat S., Monti D., Bouchon C., Lepoint G., 2009 Trophic relationships in a tropical stream food web assessed by stable isotope analysis. Freshwater Biology 54(5):1028-1041.
Damar A., 2003 Effects of enrichment on nutrient dynamics, phytoplankton dynamics and productivity in Indonesian tropical waters: a comparison between Jakarta Bay, Lampung Bay, and Semangka Bay. PhD thesis, der Mathematisch-Naturwissenschaftlichen Fakultät der Christian-Albrechts-Universität zu Kiel, 249 pp.
Domingues R. B., Anselmo T. P., Barbosa A. B., Sommer U., Galvão H. M., 2011 Light as a driver of phytoplankton growth and production in the freshwater tidal zone of a turbid estuary. Estuarine, Coastal and Shelf Science 91(4):526-535.
Dutta S., Chanda A., Akhand A., Hazra S., 2016 Correlation of phytoplankton biomass (chlorophyll-*a*) and nutrients with the catch per unit effort in the PFZ forecast areas of northern Bay of Bengal during simultaneous validation of winter fishing season. Turkish Journal of Fisheries and Aquatic Sciences 16(4):767-777.
Falkowski P. G., Barber R. T., Smetacek V., 1998 Biogeochemical controls and feedbacks on ocean primary production. Science 281(5374):200-206.
Fiori E., Zavatarelli M., Pinardi N., Mazziotti C., Ferrari C. R., 2016 Observed and simulated trophic index (TRIX) values for the Adriatic Sea basin. Natural Hazards and Earth System Sciences 16:2043-2054.
Fogg C. E., 1980 Phytoplanktonic primary production. In: Fundamentals of aquatic ecosystems. Barnes R. S. K., Mann K. H. (eds), Blackwell Scientific Publication, Oxford, pp. 24-45.
Gocke K., Lenz J., 2004 A new “turbulence incubator” for measuring primary production in non-stratified waters. Journal of Plankton Research 26(3):357-369.
Goes J. I., Sasaoka K., Gomes H. D. R., Saitoh S. I., Saino T., 2004 A comparison of the seasonality and interannual variability of phytoplankton biomass and production in the western and eastern gyres of the Subarctic Pacific using multisensor satellite data. Journal of Oceanography 60:75-91.
Herman A. W., Platt T., 1986 Primary production profiles in the ocean: estimation from a chlorophyll/light model. Oceanologica Acta 9(1):31-40.
Ignatiades L., 2005 Scaling the trophic status of the Aegean Sea, eastern Mediterranean. Journal of Sea Research 54(1):51-57.
Irawati N., 2011 [Relationship between phytoplankton primary productivity and nutrient availability on different levels of clarity in waters off Kendari Bay, Southeast Sulawesi]. MSc thesis, IPB Graduate School, Bogor, 106 pp. [in Indonesian]

Iswandi R. M., 2003 [Analysis of Kendari Bay sedimentation impact on the community activity and its prevention strategies]. PhD thesis, IPB Graduated School, Bogor, 173 pp. [in Indonesian]
Jaureguizar A. J., Milessi A. C., 2008 Assessing the sources of the fishing down marine food web process in the Argentinean-Uruguayan common fishing zone. Scientia Marina 72(1):25-36.
Jennerjahn T. C., Ittekkot V., Klöpper S., Adi S., Nugroho S. P., Sudiana N., Yusmal A., Prihartanto P., Gaye-Haake B., 2004 Biogeochemistry of a tropical river affected by human activities in its catchment: Brantas River estuary and coastal waters of Madura Strait, Java, Indonesia. Estuarine, Coastal and Shelf Science 60(3):503-514.
Jennings S., Kaiser M. J., Reynolds J. D., 2003 Marine fisheries ecology. Blackwell Publishing, New York, 417 pp.
Justus B. G., 2005 Water-quality, phytoplankton, and trophic-status characteristics of Big Base and Little Base lakes, Little Rock Air Force Base, Arkansas, 2003-2004. Scientific Investigations Report 2005-5068, U.S. Geological Survey, Reston, Virginia, 37 pp.
Karakassis I., Pitta P., Krom M. D., 2005 The contribution of fish farming to the nutrient loading of the Mediterranean. Scientia Marina 69(2):313-321.
Kartamihardja E. S., 2007 [Size spectra of plankton biomass and its potential utilization for fish community at limnetic zone of the Ir. H. Djuan da reservoir, West Java]. PhD thesis, IPB Graduated School, Bogor, 137 pp. [in Indonesian]
Kishino M., 1994 Interrelationships between light and phytoplankton in the sea. In: Ocean optics. Spinrad R. W., Carder K. L., Perry M. J. (eds), Oxford University Press, New York, pp. 73-102.
Knoppers B., Kjerfve B., Carmouze J. P., 1991 Trophic state and water turn-over time in six choked coastal lagoons in Brazil. Biogeochemistry 14:149-166.
Lagus A., Suomela J., Weithoff G., Heikkilä K., Helminen H., Sipura J., 2004 Species-specific differences in phytoplankton responses to N and P enrichments and the N:P ratio in the Archipelago Sea, Northern Baltic Sea. Journal of Plankton Research 26 (7):779-798.
Lalli C. M., Parsons T. R., 1997 Biological oceanography: an introduction. 2nd edition, Butterworth-Heinemann, Oxford, 314 pp.
Lanz E., Nevarez-Martinez M., Lopez-Martinez J., Dworak J. A., 2009 Small pelagic fish catches in the Gulf of California associated with sea surface temperature and chlorophyll. CalCOFI Report 50:134-146.
Lessard E. J., Merico A., Tyrrell T., 2005 Nitrate: phosphate ratios and *Emiliania huxleyi* blooms. Limnology and Oceanography 50(3):1020-1024.
McNaughton S. J., Wolf L. L., 1979 General ecology. Holt, Rinehart and Wilson, New York, 702 pp.
Molisani M. M., Barroso H. S., Becker H., Moreira M. O. P., Hijo C. A. G., do Monte T. M., Vasconcellos G. H., 2010 Trophic state, phytoplankton assemblages and limnological diagnosis of the Castanhão Reservoir, CE, Brazil. Acta Limnologica Brasiliensia 22(1):1-12.
Mousseau L., Fortier L., Legendre L., 1998 Annual production of fish larvae and their prey in relation to size-fractionated primary production (Scotian Shelf, NW Atlantic). ICES Journal of Marine Science 55(1):44-57.
Nontji A., 2006 [There is no life on earth without the presence of plankton]. LIPI, Oceanographic Research Center, Jakarta, 248 pp. [in Indonesian]
Orpin A. R., Ridd P. V., Thomas S., Anthony K. R., Marshall P., Oliver J., 2004 Natural turbidity variability and weather forecasts in risk management of anthropogenic sediment discharge near sensitive environments. Marine Pollution Bulletin 49:602-612.
Pentury R., Waas H. J. D., 2009 [Estimation of chlorophyll-*a* concentration in Kayely Bay, Buru Island by using remote sensing]. Jurnal Triton 5(2):60-66. [in Indonesian]

Pinckney J. L., Paerl H. W., Tester P., Richardson T. L., 2001 The role of nutrient loading and eutrophication in estuarine ecology. Environmental Health Perspectives 109(5):699-706.
Preisendorfer R. W., 1986 Secchi disk science: visual optics of natural waters. Limnology and Oceanography 31:909-926.
Primpas I., Karydis M., 2011 Scaling the trophic index (TRIX) in oligotrophic marine environments. Environmental Monitoring and Assessment 178(1-4):257-269.
Puspasari R., Damar A., Kamal M. M., Lumbanbatu D. T. F., Wiadnyana N. N., 2011 [Size fractionation of phytoplankton biomass and lagoon waters condition of Seribu Islands Pari Island]. Jurnal Segara 7(2):80-87. [in Indonesian]
Rinaldi A., Giovanardi F., 2011 The contribution of Richard A. Vollenweider toward understanding eutrophication of the coastal Adriatic Sea. Aquatic Ecosystem Health and Management 14:200-203.
Rost B., Riebesell U., Burkhardt S., Sültemeyer D., 2003 Carbon acquisition of bloom-forming marine phytoplankton. Limnology and Oceanography 48:55-67.
Siagian M., Simarmata A. H., 2018 Trophic status of the lacustrine zone around the dam site of Koto Panjang Reservoir, Riau Province, Indonesia. AACL Bioflux 11(1):1-9.
Sibert J., Hampton J., Kleiber P., Maunder M., 2006 Biomass, size, and trophic status of top predators in the Pacific Ocean. Science 314:1773-1776.
Strickland J. D. H., Parsons T. R., 1972 A practical hand book of seawater analysis. 2nd edition, Fisheries Research Board of Canada Bulletin, No. 167, 310 pp.
Tambaru R., 2000 [The influence of light intensity at incubation time to phytoplankton primary productivity in Teluk Hurun]. MSc thesis, IPB Graduated School, Bogor, 95 pp. [in Indonesian]
Tambaru R., 2007 [The dynamics of phytoplankton communities in relation to coastal waters productivity of Maros, South Sulawesi]. PhD thesis, IPB Graduated School, Bogor, 169 pp. [in Indonesian]
Trolle D., Hamilton D. P., Pilditch C. A., Duggan I. C., Jeppesen E., 2011 Predicting the effects of climate change on trophic status of three morphologically varying lakes: implications for lake restoration and management. Environmental Modelling and Software 26(4):354-370.
Umaly R. C., Cuvin L. A., 1988 Limnology: laboratory and field guide physicochemical factors, biological factors. National Book Store Publ., Manila, 322 pp.
Van de Poll W. H., Kulk G., Timmermans K. R., Brussaard C. P. D., van der Woerd H. J., Kehoe M. J., Mojica K. D. A., Visser R. J. W., Rozema P. D., Buma A. G. J., 2013 Phytoplankton chlorophyll *a* biomass, composition, and productivity along a temperature and stratification gradient in the northeast Atlantic Ocean. Biogeosciences 10:4227-4240.
Vollenweider R. A., Giovanardi F., Montanari G., Rinaldi A., 1998 Characterization of the trophic conditions of marine coastal waters, with special reference to the NW Adriatic Sea: proposal for a trophic scale, turbidity and generalized water quality index. Environmetrics 9:329-357.
Wasmund N., Andrushaitis A., Łysiak-Pastuszak E., Müller-Karulis B., Nausch G., Neumann T., Ojaveer H., Olenina I., Postel L., Witek Z., 2001 Trophic status of the south-eastern Baltic Sea: a comparison of coastal and open areas. Estuarine, Coastal and Shelf Science 53:849-864.
Yuliana, 2012 [Implications of changes in nutrient availability for phytoplankton rapid growth (blooming) at Jakarta Bay waters]. PhD thesis, IPB Graduated School, Bogor, 178 pp. [in Indonesian]

Received: 23 January 2019 Accepted: 29 March 2019 Published online: 30 April 2019.
Authors:
Asriyana, Department of Aquatic Resources Management, Faculty of Fisheries and Marine Sciences, Halu Oleo University, Kampus Bumi Tridharma Anduonohu, Kendari 93232, Southeast Sulawesi, Indonesia, e-mail: yanasri76@yahoo.com
Nur Irawati, Department of Aquatic Resources Management, Faculty of Fisheries and Marine Sciences, Halu Oleo University, Kampus Bumi Tridharma Anduonohu, Kendari 93232, Southeast Sulawesi, Indonesia, e-mail: nur_irawati78@yahoo.com

How to cite this article:
Asriyana, Irawati N., 2019 Assessment of the trophic status in Kendari Bay, Indonesia: a case study. AACL Bioflux 12(2):650-663.