VERTICAL - HORIZONTAL WATER QUALITY PROFILES OF BATUR LAKE, BANGLI DISTRICT, BALI SUPPORTING SUSTAINABLE LAKE MANAGEMENT

Sophia Sagala*)# and I Nyoman Radiarta**)

*) *Research and Development Institute for Mariculture, Gondol, Bali*
**) *Center for Aquaculture Research and Development, Jakarta*

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ABSTRACT

Batur Lake located in Bangli District is one of fisheries-basedregions in Bali with niletilapia as the main cultured species. Monitoring on environmental conditions of the lake was carried out to get the vertical and horizontal water quality profiles of the lake. Climatology condition of the area was also presented in the study. The study area were between 8º13' - 8º18' S and 115º22' - 115º26' E. Field survey was done with random and transect sampling points distribution. The water quality monitored in the lake essentially covers important parameters such as depth, transparency, temperature, pH, dissolved oxygen, salinity, nutrients (ammonia, nitrate, nitrite, and phosphate), sulfide, chlorophyll, and planktonic composition. Results of spatial analysis (vertically and horizontally) of water quality indicated that oxygen concentration up to 10 m deep is still appropriate for nile tilapia culture. Nutrient (phosphate, ammonia, nitrate, and nitrite) contents of the lake meet the standard levels set by Ministry of Environment of Indonesia, and were still suitable for aquaculture operation at depth 710 m. From climatology point of view, it is known that the extreme climate occurred in June-August resulting in water mass changes, thus, affecting aquaculture sustainability in the lake.

KEYWORDS: water quality, climatology condition, Batur Lake, sustainable lake management, aquaculture

INTRODUCTION

Batur Lake is an active caldera lake formed by volcanic process of Batur Mount. Located in 1,080 m above sea level, the lake has an area of 1,607 ha with coastal line of 21 km. Batur Lake has been exploited for aquaculture development using floating net cage for about 7 years, and the activity is mainly located along the coast of the lake. The main species cultured in the lake is nile tilapia, although carp and catfish are also possible to be cultured. Area for nile tilapia culture was about 6.2 ha in 2005 and increased up to 8.11 ha with total fish production of 189.15 in 2010 (Anonymous, 2010). As one of fisheries-based regions in Bali, Batur Lake is expected to contribute in enhancement of local and national fish production.

Aquaculture using floating net cages in either lakes or reservoirs may lead to environmental degradation. Exceeding carrying capacity, over feeding, and high stocking density

Corresponding author. Research and Development Institute for Mariculture, Jl. Br. Gondol, Kec. Gerokgak, Kab. Buleleng, Kotak Pos 140, Singaraja, Bali 81101, Indonesia. Tel.: +62 362 92278
E-mail address: sophia.sagala@hotmail.com

are some examples of improper management of floating cage fisheries contributing to high nutrient loadings, thereby, leading to water quality degradation. Poor water quality, thus, results in massive fish kill. The problems attributed to exceeding carrying capacity of the lakes/reservoirs were observed in Maninjau Lake and Cirata Reservoir as reported by previous studies (Sulastri *et al.*, 2001; Meutia *et al.*, 2002; Lukman & Hidayat, 2002). Therefore, frequent monitoring is necessary for sustainable aquaculture management and to support good aquaculture practice.

Geographical Information System (GIS) has widely used in aquaculture fields, for instance site selection, zoning, coastal mapping, and monitoring (Nath *et al.*, 2000; Windupranata, 2007; Radiarta *et al.*, 2008). Radiarta *et al.* (2005) showed that GIS was applicable in mapping floating net cages in Cirata Reservoir in order to support the reservoir management. The aim of the present study was to obtain vertical-horizontal profile of water quality of Batur Lake, Bangli District, Bali Province. GIS was applied in the analyses of the study. Spatial analyses of selected parameter profiles (temperature, pH, and dissolved oxygen) were also discussed. In addition, climate performance of Batur Lake for ten years was presented in the study.

MATERIALS AND METHODS

Study Area and Sampling Stations

The study area is located in Batur Lake as one of fisheries-based regions in Bangli District, between 8°13' - 8° 18' South and 115°22' - 115° 26' East (Figure 1). The lake is relatively calm, and has cove-like areas making the lake potential for floating net cages culture.

Distributions of sampling sites are given in Figure 1. Fourteen sampling stations were designed by simple random sampling (Morain, 1999). Information from related agencies was also used as justification to determine the sampling positions. Besides the random sampling, the sampling points were also designed to transect the lake. The sampling was conducted from 09:30 until 16:30 local time. Coordinates of each sampling point were determined using Global Positioning System (GPS).

Water Quality Measurement

Water sampling was conducted in August 2011. The sampling was conducted at several stratified depths: 0 m, 3 m, and 10 m for all sampling points and 0 m, 3 m, 7 m, 10 m, 20 m, 30 m, 40 m, and 50 m for sampling points transecting the lake (B1, B2, B3, B4, B5, and B6)

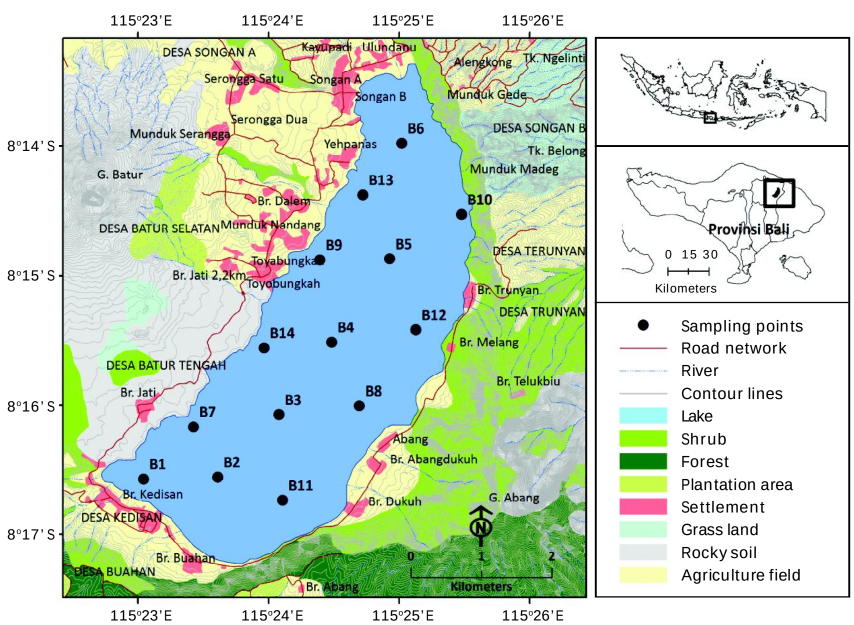

Figure 1. Study area in Batur Lake, Bangli District, Bali Province, and distribution of water quality sampling stations

(Figure 1). Water quality parameters, *i.e.* temperature, transparency, depth, pH, salinity, and dissolved oxygen were measured in situ at each sampling station using YSI 556. Other water quality parameters such as phosphate, nitrate, nitrite, ammonia, chlorophyll, and sulfide were measured at selected sampling stations (B4, B7, B8, B9, and B10). These parameters were then analyzed at the laboratory of Faculty of Fisheries and Marine Science, Bogor Agriculture University. All analysis methods are based on the procedure of standard methods (APHA, 2005).

Besides water quality data, climatology data as secondary data from the last 10 years (2000-2009) were also collected in order to observe the connection between these data. Moreover, it is also necessary to get insight on climatology profile of the area as climate changes could indirectly affect the limnology conditions of waters.

Planktonic Biomass

Planktonic population was collected by filtering 30 L of water in to 30 mL of plankton sample through 20 µm plankton net with 30 cm of diameter. Lugol was added into the sample for preservation. Identification was carried out under a microscope and the abundance was measured. Plankton analysis was carried out at the laboratory of Faculty of Fisheries and Marine Science, Bogor Agriculture University. Diversity, similarity, and dominancy indexes of plankton were determined using Shannon-Wiener and Simpson equations, respectively, to quantify the ecological indicator of water quality (Odum, 1993), and to determine the pollution level of waters. The pollution level criteria used in the study are based on Lee *et al*. (1978).

Data Analysis

Lake water quality data were analyzed spatially (horizontal and vertical) and descriptive. Data were analyzed spatially using Ocean Data View (ODV) (Schlitzer, 2011) and ArcGIS v.10 (*The Environmental System Research Institute (ESRI), USA*).

RESULTS AND DISCUSSIONS

In the growing aquaculture industry, particularly inland aquaculture using floating net cage system, good water quality is required for maintaining viable aquaculture production and economically sustainable aquaculture. The results of water quality measurements, particularly bathymetry, transparency, temperature, pH, salinity, and dissolved oxygen in the study area are given in Table 1. As mentioned earlier, these parameters were measured at all sampling stations with three stratified depths (0 m, 3 m, and 10 m). It is seen that depth of Batur Lake ranged from 20.1 to 73.4 m with transparency of 100 - 180 cm. The relatively low transparency is suggested due to plankton density (Suryono *et al*., 2008). Other possibilities explaining the low transparency could be ascribed to relatively high suspended particles and/or soluble colored organic compounds which were not analyzed in the study. It is suggested in future study to include suspended and dissolved solid parameter in the analysis. However, transparency in the present study is still feasible for tilapia culture in cages as tilapia, generally, can be cultured at 20 - 25 cm transparency (Hossain *et al*., 2007).

Surface water temperature at Batur Lake was 23.1ºC - 23.9ºC then decreased to 22.7ºC - 23.6ºC, and 22.5ºC - 22.8ºC, respectively, at 3 and 10 m deep. Temperature in the lake is relatively low which is normal for a lake located in highlands; however, the temperature is still acceptable for tilapia culture. Boyd (1998) reported that the optimum temperature range for tilapia (*Oreochromis mossambicus*) is 18ºC - 34ºC over which feeding occurs, but temperature range at 28ºC - 32ºC is best for the fastest growth. In addition, tilapia is a species easily cultured and could be reared in highland areas (ca. 1,000 m above mean sea level).

Salinity of the lake ranged from 1.15-1.17 ppt. No significant salinity changes were found at different depth stratifications. Salinity has been shown to influence fish growth and survival (Boyd, 1990). Several studies and reviews on salinity tolerance of tilapias have been published (Watanabe & Kuo, 1985; Watanabe *et al*., 1985; Stickney, 1986; Likongwe *et al*., 1996). A study by Payne & Collinson (1983) showed that the upper estimate salinities giving unobstructed growth of *O. niloticus* ranged from 5 to 10 g/L, suggesting that the species was limited by salinity. Another study by Likongwe *et al*. (1996) suggested that a comparable high growth of *O. niloticus* might be achieved at the temperature range of 28ºC - 32ºC and the salinity range of 0 to 12 g/L. Based on these, the salinity of the lake still meets the salinity required for tilapia.

Table 1. Water quality data measured in situ in Batur Lake, Bangli, Bali Province (Total number of sampling stations is 14 stations (B1-B14))

Parameters	**Depth of water sampling (m)**	**Range**
Bathymetry (m)		20.10-73.40
Transparency (cm)		100-180
Temperature (°C)	0	23.14-23.87
	3	22.70-23.59
	10	22.46-22.81
Salinity	0	1.17
	3	1.15-1.17
	10	1.16-1.17
Dissolved oxygen (mg/L)	0	6.78-10.62
	3	5.01-8.75
	10	3.05-6.61
pH	0	6.14-7.34
	3	5.58-7.30
	10	5.54-7.29

Concentration of dissolved oxygen (Table 1) of Batur Lake up to 3 m deep was high and still within the value recommended for aquaculture operation (8 5 mg/L). Meanwhile, at 10 m deep, the concentration of dissolved oxygen was relatively low. The water pH in the site were 6.1-7.3 at the surface, 5.6-7.3 at 3 m deep, and 5.4-7.3 at 10 m deep. Though some sampling points had pH lower than 6.5, it can be said pH of the water generally is still suitable for tilapia culture as tilapia live in nature at pH of 6.0-8.5. In addition, pH of water ranged from 6.5 to 9.0 was still appropriate for finfish culture (Boyd & Tucker, 1998).

Spatial distributions of water temperature, dissolved oxygen, and pH at three different depths (0, 3, and 10 m) are shown in Figure 2. It can be seen that water temperature decreased with an increase of water depth. A similar pattern was also observed at spatial distribution of dissolved oxygen. Dissolved oxygen content at water surface was higher than those at 3 and 10 meters deep. More interestingly, southern waters of Batur Lake (starting from Banjar Dukuh, Abang Dukuh up to Toyabungkah; the positions refer to Figure 1) had higher surface dissolved oxygen content than the northern waters (Yeh Panas-Trunyan). The lowest dissolved oxygen concentration at 10 m deep was found at Songan (northern part of the lake). Different from those of water temperature and dissolved oxygen, pH spatial distribution did not show any significant relationship of pH concentration with the depth. A previous study by Suryono *et al*. (2008) showed that water pH in the surface was higher (8.26-8.70) than that in the deeper stratification (bottom surface) and the range was higher than the range observed in the present study. The lower pH values in the bottom could be correlated to the accumulated organic matter contents in the water.

Vertical profile for water temperature, dissolved oxygen, and pH at six selected stations are presented in Figure 3. Temperature profile showed that epilimnion layer was formed at a depth of 7 10 m (B1-B6), thermocline was at a depth of 10-30 m (B1, B3, B5, and B6), and hipolimnion layer was at depth of 8 30 m. The result is in a good agreement with a previous study (Suryono *et al*., 2008). The pattern is a common phenomenon for lakes. Meanwhile, from the vertical profile point of view (Figure 3, middle), the dissolved oxygen concentra-

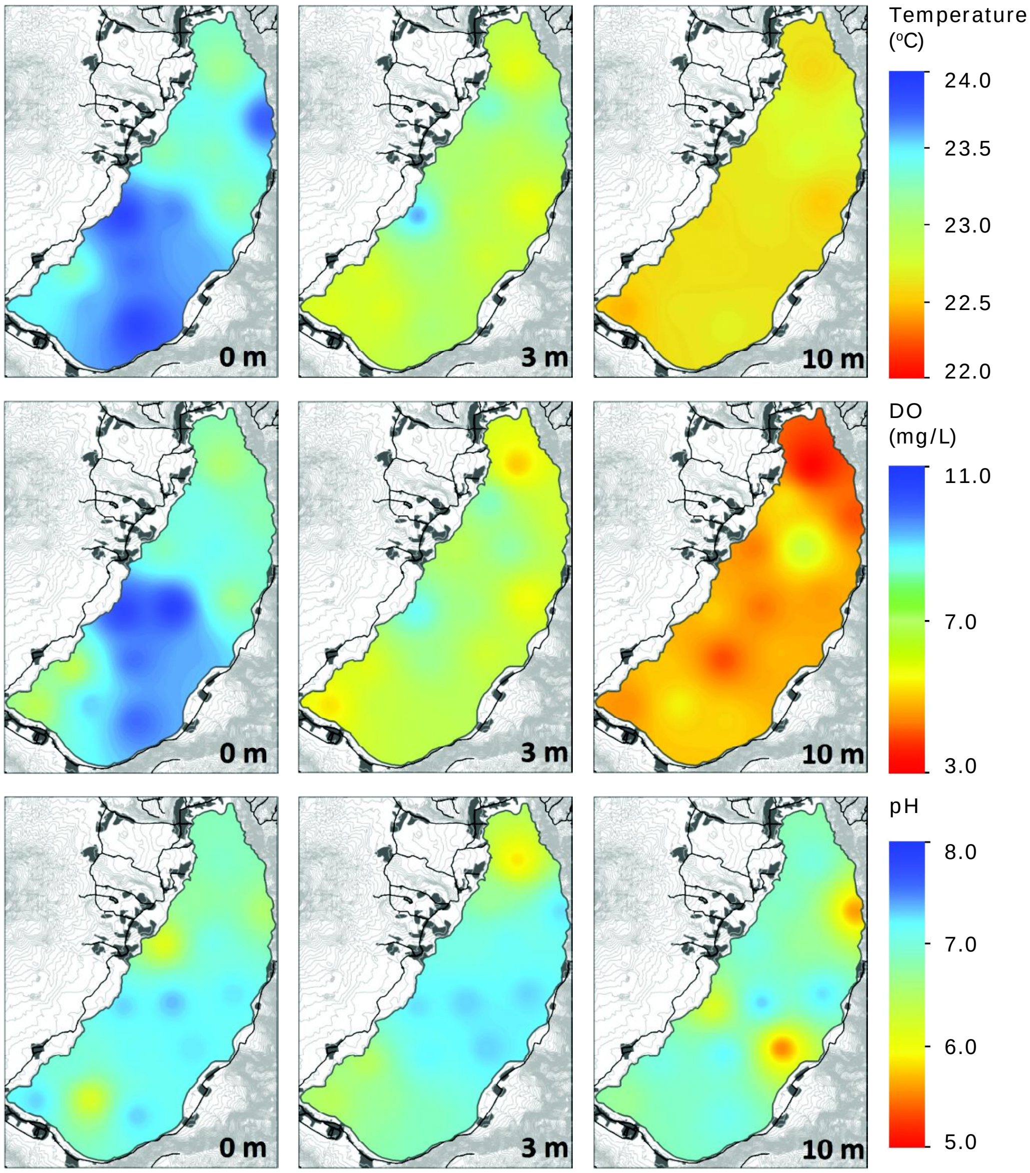

Figure 2. Spatial distributions of water temperature (top), dissolved oxygen (middle), and pH (bottom) at different depth stratifications (0 m, 3 m, and 10 m) in Batur Lake, Bangli, Bali Province

tion of the lake was > 4 mg/L up to a depth of 15 m. The concentration started decreasing at a depth of 20 m and a significant concentration decrease occurred at 30 m deep (DO= 2.81-1.73 mg/L). This observation is similar to the result obtained by Suryono *et al*. (2008). On the other hand, pH profile of the water gave no specific trend. pH concentration observed in the study was lower (5.5-7.3) than that observed in Suryono's study (8.1-8.7; Suryono *et al*., 2008). The discrepancy could be caused by sulfur compounds or more organic acids content in the water.

Cross section results of vertical profile of three important parameters for aquaculture are

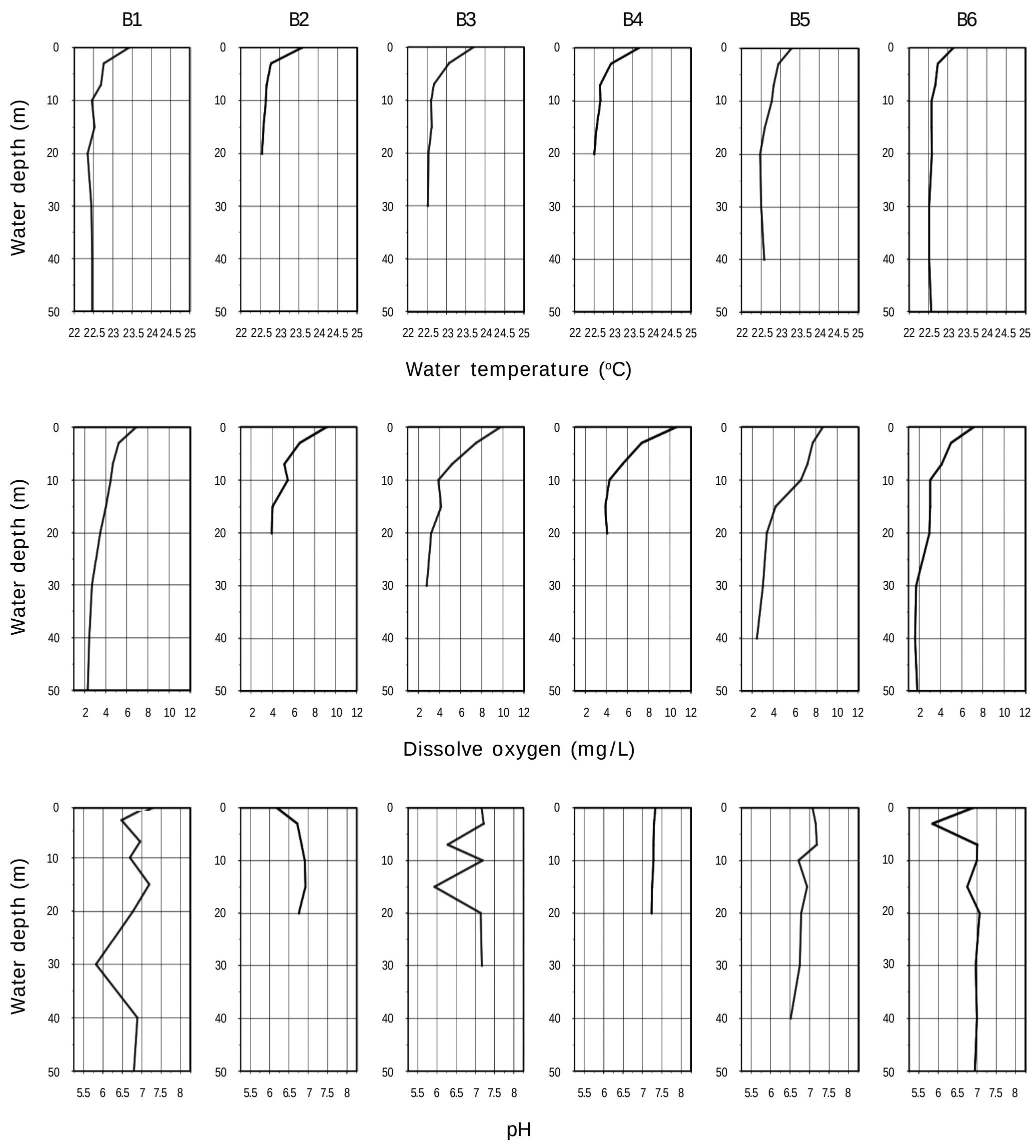

Figure 3. Vertical profile for water temperature (top), dissolved oxygen (middle), and pH (bottom) in six selected stations (B1-B6) in Batur Lake, Bangli

shown in Figure 4. Vertically, temperature of the southern water of the lake was relatively warmer than that of the northern part (Figure 4a). As mentioned previously, water temperature in Batur Lake is relatively low for aquaculture; however, the values are still feasible for tilapia culture (Hossain *et al*., 2007). A similar trend to temperature cross section profile was also observed in dissolved oxygen cross section profile (Figure 4b). The cross section profile also showed that the southern waters of the lake have relatively higher dissolved oxygen content compared to the northern waters. Cross section of vertical profile gave clearer overview than the vertical profile. It showed that high pH values (8 7) were more concentrated on the middle of the lake (Figure 4c).

Other water quality parameters observed in the present study were phosphate, ammo-

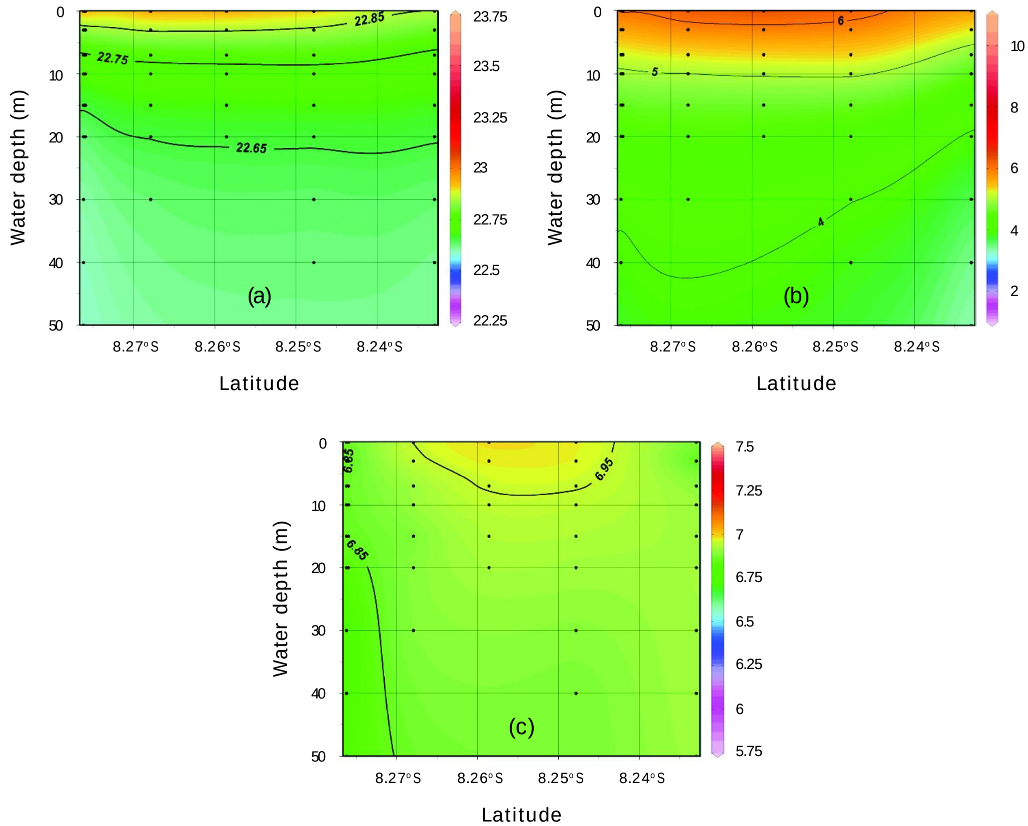

Figure 4. Cross section of vertical profile for water temperature (a), dissolved oxygen (b), and pH (c) in six selected sampling stations (B1-B6) of Batur Lake, Bangli, Bali Province (station location refers to Figure 1)

nia, nitrate, nitrite, sulfide, and chlorophyll. The results are given in Table 2. Phosphorous may occur in water as orthophosphate, polyphosphate, and organic phosphates. It is one of important nutrients required for aquatic organisms. However, excess concentration of this nutrient can lead to algal blooms, thereby monitoring on the phosphorous level has to be conducted. In the present study, only total phosphate and orthophosphate will be discussed. Concentration of total phosphate upon sampling period in the surface water, in depths of 3 m and 10 m ranged from 0.014-0.032 mg/L, 0.011-0.580 mg/L, and 0.017-0.061 mg/L, respectively. Phosphate values in the sampling points were low and within the acceptable value set by the government regulation, except the value at B9 in the depth of 3 m (0.58 mg/L). The higher phosphate concentration in the site could possibly be ascribed to excess and unused feed and wastes resulted from fish culture activities as the site is one of areas where floating net cages for fish culture are located. Meanwhile, the concentration of orthophosphate in the selected stations varied from 0 to 0.083 mg/L. The values were considerably low as orthophosphate would quickly be taken up by phytoplankton. In addition, orthophosphate also produced from bacterial decomposition is then rapidly re-assimilated by other phytoplankton cells (Boyd, 1998). At present, no standard value of orthophosphate is available recommended by Indonesian Government.

Nitrogen is of concern in aquaculture as at a certain point this nutrient may degrade the water quality. It enters into the aquaculture system through rainfall, in situ N_2 fixation, uneaten feeds, fish wastes, and diffusion from sediments. As inorganic combined compounds,

Table 2. Water chemical quality data collected from five selected sampling points in Batur Lake, Bangli, Bali Province

Parameters	**Sampling depth (m)**	**Stations**					**Range**	**Standard quality (Government Regulation, 2001)**
		B4	**B7**	**B8**	**B9**	**B10**		
pH	0	7.34	7	7.25	6.14	6.55	6.14-7.34	6-9
	3	7.3	6.49	7.3	7.06	7.27	6.49-7.30	
	10	7.29	7.03	5.54	7.02	5.61	5.54-7.29	
Total phosphate (mg/L)	0	0.032	0.028	0.014	0.014	0.015	0.014-0.032	0.2
	3	0.011	0.044	0.015	0.58	0.018	0.011-0.580	
	10	0.04	0.019	0.047	0.061	0.017	0.017-0.061	
Ortophosphate (mg/L)	0	0.003	0.012	0.008	0	0	0-0.012	-
	3	0.002	0.008	0.083	0	0	0-0.083	
	10	0	0.005	0.008	0.001	0	0-0.008	
Ammonia (NH_3-N) (mg/L)	0	0.011	0.026	0.001	0.023	0.052	0.001-0.052	7 0.02 as NH_3
	3	0.008	0.144	0,007	0.065	0,089	0.007-0,144	
	10	0.004	0.022	0.011	0.064	0.041	0.004-0.064	
Nitrate (NO_3-N) (mg/L)	0	0.28	0.345	0.218	0.26	0.303	0.218-0.345	10
	3	0.271	0.43	0.111	0.159	0.179	0.111-0.43	
	10	0.68	0.439	0.531	0.397	0.751	0.397-0.751	
Nitrite (NO_2-N) (mg/L)	0	0.003	0.014	0	0	0.008	0-0.014	0.06
	3	0	0.029	0.002	0.004	0.004	0-0.029	
	10	0.025	0.014	0.033	0.005	0	0-0.033	
Sulfide(H_2S) (mg/L)	0	0.001	0.001	0.001	0.001	0.001	0.001	0.002
	3	0.001	0.001	0.001	0.001	0.001	0.001	
	10	0.001	0.001	0.001	0	0.001	0-0.001	

nitrogen may present in water as ammonium ion (NH_4^+), un-ionized ammonia (NH_3), nitrite (NO_2), and nitrate (NO_3). The last three inorganic combined compounds will be discussed in the study. Ammonia is toxic to fish and aquatic organisms, even in very low concentrations.The ammonia-nitrogen (NH_3-N) concentration of the lake were 0001-0.052 mg/L, 0.007-0.144 mg/L, and 0.004-0.064 mg/L in the surface water, in depth of 3 m, and the depth of 10 m, respectively. To obtain the ammonia (NH_3) values of the water, ammonia-nitrogen was multiplied by the weight ratio of NH_3:N (17/14). The ammonia values, therefore, were 0.001-0.063 mg/L, 0.009-0.175 mg/L, and 0.005-0.078 mg/L, in the surface water, the depth of 3 m, and the depth of 10 m, respectively. It is clearly seen that the ammonia value in the surface water is lowest than those in the water depth of 3 m and 10 m. This value is within the standard NH_3 value (7 0.02 mg/L) which is attributed to diffusion between surface water and atmospheric air.

Moreover, volatilization of ammonia during periods of high pH could be another reason of lower ammonia concentration in the surface water (Boyd, 1990). Meanwhile relatively high ammonia contents in 3 m and 10 m is possibly caused by relatively low pH values. More interestingly, excess ammonia values in 3 m water depth were observed at B7 (0.175 mg/L), B9 (0.079 mg/L), and B10 (0.108 mg/L), respectively, referring to Jati, Toyobungkah, and Songan, where floating net cage culture with water depth of 3 m are located. The high ammonia values in the sites could be resulted from excretion, waste products or death, and decay of organic matters. Lawson (1995) pointed out that freshwater species can tolerate ammonia level up to 0.05 mg/L. An extensive review by Meade (1985) noted that maximum safe concentration of ammonia was unknown; however, it was concluded that the permissible value commonly accepted by the fish culturist was > 0.012 mg/L. Meanwhile, according to Boyd (1998), the acceptable ammonia concentration range in aquaculture pond were < 0.1 mg/L. It is suggested, water monitoring in the sites should be done in the future to know whether or not the high ammonia concentration will decrease. Nevertheless, it can be said that the water of Batur Lake in general is still appropriate for aquatic biota.

The concentration of nitrite in the selected sampling points of Batur Lake upon sampling period varied from 0 - 0.033 mg/L. The highest nitrite concentration was observed in the water depth of 10 m. Those values were still within the standard value (0.06 mg/L) set by the government. High concentrations of nitrite are commonly not found as nitrite is converted to nitrate as quickly as it is produced. Of all inorganic combined, nitrate is the least toxic compound. From Table 2, nitrate concentration of the stations ranged from 0.218-0.345 mg/L, 0.111-0.430 mg/L, and 0.397-0.751 mg/L, respectively, in the surface water and the water depths of 3 m, and 10 m. The nitrate valuein the water depth of 10 m is relatively higher than those in the water depth of 3 m and the surface water; meanwhile the value in the surface water is comparable to the value in the 3 m depth. The nitrate values in the stations interestingly are within the recommended value by the government (10 mg/L).

As mentioned previously, Batur Lake is a sulfur rich lake of where the sulfur compounds are resulted from volcanic activity. Sulfur compounds in natural waters may present in organic and inorganic sulfur. Sulfur species presented in the study was sulfide (H_2S). Table 2 shows that levels of H_2S content in the waters of selected sampling stations were 0-0.001 mg/L and still meet the standard level recommended by government regulation (PP No. 82/2001). More interestingly, the H_2S level in the surface water was comparable to that in the water depth of 3 m and 10 m. This can be ascribed to relatively high dissolved oxygen in the water column of the selected stations (3.9-10.6 mg/L) that could oxidize sulfide to elemental sulfur back to sulfate. The oxidation of sulfide could also be done by sulfur oxidizing bacteria. Another reason is the water column contains more sulfate as it is the predominant form of dissolved sulfur in the epilimnion layer in which the dissolved oxygen level is high (aerobic environment). A similar result in which comparable H_2S levels in the water of Maninjau Lake at depth of 7 20 m were observed (Heny, 2009). Sulfide or sulfate also depends on pH. Table 2 shows pH values in the lake were 5.54-7.34, suggesting that sulfur compounds commonly found are sulfate and H_2S as reported by Jorgensen *in* Sugiarti *et al*. (2011). Heny (2009) pointed out that elevated H_2S level >2 µg/L in the water was considered as a chronic hazard to aquatic animals.

Table 3. Planktonic biomass of surface water in five selected sampling stations of Batur Lake, Bangli, Bali Province

Biological parameters	Station				
	B4	B7	B8	B9	B10
Planktonic biomass					
Abundance (cell/m^3)	57,245,886	48,425,924	71,029,837	53,997,944	48,006,172
Diversity index (H')	2.12	1.96	2.17	2.16	2.14
Similarity index (E)	0.66	0.59	0.66	0.65	0.62
Dominance index (C)	0.18	0.22	0.17	0.17	0.16
Chlorophyll (µg/L)	16.36	60.54	40.99	61.49	9.91

Biological Water Quality of Batur Lake

There were 25 - 32 genera and four classes in B4, B7, B8, B9, and B10 sampling station with plankton abundance of 57,245,886 cell/m^3; 48,425,924 cell/m^3; 71,029,837 cell/m^3; 53,997,944 cell/m^3; and 48,006,172 cell/m^3; respectively (Table 3). The plankton abundance in the lake is high leading to relatively low transparency (Tabel 1). Plankton diversity index was 2.12, 1.96, 2.17, 2.16, and 2.14 (not polluted) with similarity index of 0.66, 0.59, 0.66, 0.65, and 0.62 in the five selected sampling stations (B4, B7 - B10), respectively (Table 3) indicating high uniformity. According to Soegianto in Soedarti *et al*. (2006) diversity index can be used to determine water quality since only plankton having high tolerance can thrive in polluted ecosystem because no or low competitor resulting in algal bloom such as blooming of *Microcystis* spp. occurred in Jatiluhur Reservoir (Sachlan, 1982). Plankton community having low or no pollution has high diversity although diversity index does not correlate with water purity (Wu, 1984). Decreasing diversity of phytoplankton species indicates threats to the structure and function of plankton community (Chang *et al*., 2008). Though can be used as water quality indicator, diversity index does not stand alone to determine environmental quality (Soedarti *et al.*, 2006).

Dominance index (C) was 0.16 - 0.22 in the selected sampling stations indicating low partial dominance suggesting no specific dominance species is found in the lake. Dianthani (2003) reported that dominance index of planktonic community in the water of Muara Badak were 0.1045 - 0.4811. The values showed no species dominance and therefore, there were no plankton species to control the waters. Dominance index is closely related to diversity index. If dominance index is high, diversity index will be low and vice versa. Plankton diversity will decrease whenever a community is dominated by one or several species meaning that a species will be replaced by another species having faster reproduction rate (Odum, 1993).

Table 3 also shows the chlorophyll concentration at the surface water of Batur Lake. It is clearly seen that the highest chlorophyll concentration was observed in B7, B8, and B9, suggesting that the areas were highly productive in terms of relatively high phytoplankton availability. Meanwhile, the other areas (B4 and B10) are less productive as low concentrations of chlorophyll were found.

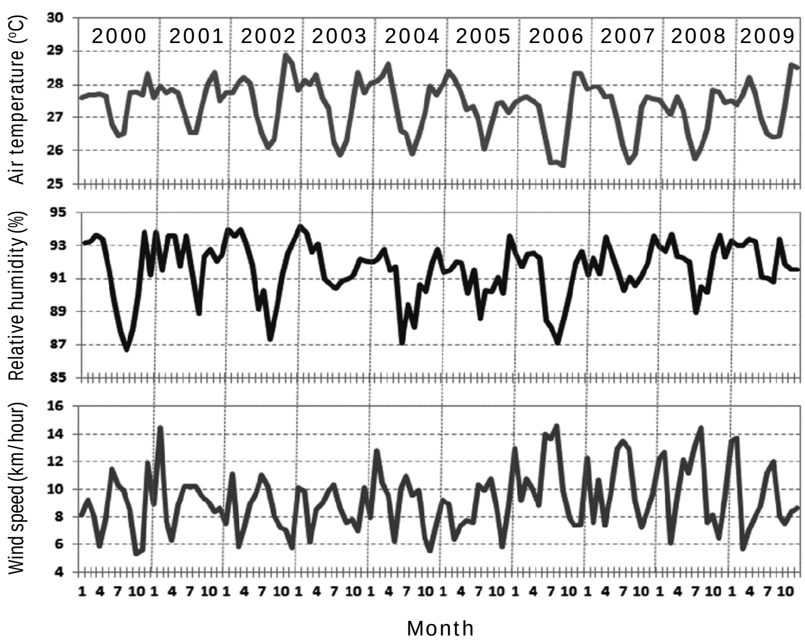

Figure 5. Condition of air temperature (°C), relative humidity (%), and wind speed (km/hour) from 2000 - 2009 in Eastern Bali

Climatology Performance of Batur Lake

Climate aspect is also of importance in lake management as climate indirectly affects the water limnological condition like upwelling, surface water current, wave, and surface temperature. The climate performance (temperature, relative humidity, and wind speed) of Eastern Bali representing the climate in the lake is presented as shown in Figure 5. The maximum air temperature occurred in October-November each year (Figure 5, top) and the minimum air temperature happened in July.

Rainfall condition of the lake in the present study was approached from the relative humidity data. It is found that the highest rainfall shown by high relative humidity occurred in December until February, while the lowest was in July-September. Figure 5 also shows that high wind speed occurred at low relative humidity. An extreme condition of these three climate factors could lead to poor water quality. Strong wind, for example, could lead to odorous and anoxic water in the lake as a result of vertical mixing of the water mass causing elevated sulfide and organic matters deposited at the bottom of the lake to reach the surface. When the phenomenon occurred, it was then often followed by a mass fish kill. The phenomenon is commonly occurred in a caldera lake containing hydrogen sulfide like Batur Lake. A similar phenomenon was also observed in Lake Maninjau (Heny, 2009) and in a crater lake in Italy (Caliro *et al*., 2008). An extreme condition usually occurred in June-August could influence adversely sustainable aquaculture in the lake as the water turnover due to climate change could deteriorate the lake water. More importantly, it is necessary to control the fish farming management such as the carrying capacity, stocking density, and feed composition which could promote high organic deposits possibly altering high reduced H_2S production in the lake water.

CONCLUSIONS

It can be summarized that Batur Lake as a fisheries-based region still has appropriate water quality for tilapia culture. Both vertical and horizontal spatial results indicated that temperature, pH, and dissolved oxygen profiles of the lake are feasible for environment and aquaculture up to 7 10 m deep. Nutrient (phosphate, ammonia, nitrate, and nitrite) contents of the lake meet the standard levels set by Ministry of Environment of Indonesia. Low sulfide concentration was also found at depth up to 10 m. From biological parameter, water column with 0-3 m deep is the most productive for its high chlorophyll concentration and planktonic abundance. From climatology point of view, it is known that the extreme climate occurred in June - August resulting in water mass changes, thus, affecting aquaculture sustainability in the lake.

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