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Water quality, fertility, fish culture carrying capacity of Riam Kanan Reservoir, South Kalimantan Province

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Abstract. Fish cultivation in Riam Kanan Resevoir has well developed based on the floating fish cage production development in the last few years. However, this development, if not controlled, will exceed the reservoir carrying capacity and can result problems in relation with degradation of water quality and its trophic status. This study was aimed at analyzing the water quality condition, the trophic status, and the fish cage culture carrying capacity in Riam Kanan reservoir. This study was carried out for 5 months, from May to September 2019. It applied field survey method to gather the water quality data. Water sample sites were pusposely selected as many as 7 stations, and water quality measurements were conducted 3 times at 2-month interval. There were 16 parameters measured, temperature, transparency, turbidity, TDS, TSS, pH, DO, TP, TN, NH_3-N, free NH_3, BOD, COD, NO_3, NO_2, and chlorophyll-*a*. Results revealed that water quality of Riam Kanan Reservoir was categorized as moderately polluted with mesotrophic fertility status. The capacity of total phosphorus load was 137.3 ton yr^{-1}. Riam Kanan Reservoir has recently an excessive load of TP as much as 89.3 ton yr^{-1} that is equivalent to excessive fish production of 5,030 ton yr^{-1}. The recommended fish culture production is 3,925 ton yr^{-1} or equivalent to 1,869 plots of floating fish cage.

Key words: water quality status, trophic status, fish production, floating fish cage.

Introduction. Riam Kanan Reservoir is the largest reservoir in South Kalimantan Province that has multifunctions, such as hydropower plant, irrigation, source of standard water, tourism object, water transportation media, fisheries, and aquaculture (RDBPW 1995; SCBR 2016a, 2016b, 2016c). Riam Kanan Reservoir is one of the fish culture center using the floating fish cage system. Fish culture production in this area contributes 40% of total floating fish cage production in Banjar Regency (SCBR 2019b).

In line with need development for human food, fish culture has developed fast including fish culture using the floating fish cage (FFC) system. Fish production from FFC system in Banjar Regency has significantly increased from 1,116 ton in 2006 to 11,364.8 ton in 2018 (SCBR 2007, 2019b).

The development of floating fish cage culture in Riam Kanan Reservoir has given positive impact to business opportunity and job opportunity for people around the reservoir (Soendjoto et al 2009; SCBR 2009). Floating fish cage culture business in Riam Kanan Reservoir is source of income for 425 fisheries households with revenue-cost (R/C) ratio of 1.12 meaning that the business is feasible (Nur et al 2020a, b). Besides positive impact, the FFC culture development is also potential to give negative impact on the aquatic environment since the waste produced will rise. FFC culture yields some wastes, such as uneaten feed, feces, and metabolites that are potential to contaminate the aquatic environment (Shakouri 2003; Yusuf et al 2011). Pollution can occur if the fish culture exceeds the carrying capacity of the aquatic environment. Problems of excessive carrying capacity also happen on Fangbian Reservoir, China, causing increase in total nitrogen (TN) and total phosphorus (TP) as much as 2.3 and 9.6 times, respectively, above the standard criteria so that they are considered as main contribution of the pollution and ecological problems in the reservoir (Zhou et al 2011). The excess of carrying capacity of fish culture also occurs in Cirata Reservoir and Jatiluhur Reservoir, West Java, and Maninjau Lake, West Sumatera, resulting in water quality decline, increased disease infection frequency, and massive mortality of the cultured fish (Pribadi 2005; Fakhrudin 2010; Lukman et al 2015; Astuti et al 2016).

FFC culture is one of the organic pollution load sources in Riam Kanan Reservoir, while other sources come from domestic, animal husbandry, and agricultural activities (Brahmana & Achmad 2012). Increase in pollution load can be seen from number of fish culture production, number of human population, number of livestocks cultured, and the agricultural areas that tend to increase in the last several years. The statistics of 2006-2018 indicate that the fish culture production of Aranio district rises 114% yr^{-1}, far reaching the other pollution load sources, only less than 18% yr^{-1} (SCBR 2007, 2019b). It means that FFC culture is potential to contribute the largest organic pollution load to Riam Kanan Reservoir waters. Increased number of FFC culture is feared to be going to exceed the carrying capacity and cause future problems in relation with worsening water quality and aquatic trophic status if it is uncontrolled. Riam Kanan Reservoir is a multifunctional reservoir as source of standard water so that the quality needs to be maintained in order to meet the required quality standard criteria. This study aims to analyze the water quality status, the trophic status, and carrying capacity of the fish culture in Riam Kanan Reservoir.

Material and Method

Research locality and period. This study was carried out for 5 months, from May to September 2019 in Riam Kanan reservoir, Aranio district, Banjar regency, South Kalimantan province. Aranio district is located at 3°9’34”-3°17’58” S and 115°7’50”-115°5’13” E with an area of 1,166.35 km^2. This district is mostly in forest area, either public forest or national forest (SCBR 2019a, b).

Data collection. The study used field survey method on water quality. It covered 16 parameters, temperature, pH, dissolved oxygen (DO), transparency, turbidity, total density solid (TDS), total suspended solid (TSS), biological oxygen demand (BOD), chemical oxygen demand (COD), NH_3-N, free NH_3, nitrate (NO_3), nitrite (NO_2), total phosphorus (TP), total nitrogen (TN), and chlorophyll-*a*. Water quality observations were done 3 times at 2-month interval. Water sampling was purposively done at 7 stations, 3 stations on the inlet of downstream, one at the middle reservoir, 2 in the floating fish cage culture area, and another one near the outlet (Table 1 and Figure 1).

Table 1

Water sampling stations

Station	*Coordinate*		*Remarks*
	S	*E*	
St 1	03°31'09.6"	115°00'37.6"	Reservoir outlet
St 2	03°31'43.2"	115°01'48.8"	Floating cage fish culture
St 3	03°32'17.3"	115°02'50.6"	Floating cage fish culture
St 4	03°32'40.9"	115°05'07.7"	Middle reservoir
St 5	03°32'57.0"	115°05'51.9"	River mouth
St 6	03°30'49.7"	115°05'24.3"	River mouth
St 7	03°27'34.5"	115°06'51.2"	River mouth

Water sample was collected at 3 depth points, 0.5 m below the surface, midwater column, and 1 m above the bottom. Water sampling was done twice per observational period, at 13.00-17.00 pm to measure all water quality parameters and 01.00-06.00 am to record water temperature, pH, DO, and turbidity. Water quality measurements were done *in situ* and in laboratory. Water temperature, pH, DO, turbidity, and transparency were measured *in situ*, whereas other 11 components were measured in the laboratory.

For TDS, TSS, BOD, COD, NH_3-N, free NH_3, NO_3, NO_2, TP and TN measurements, as much as 2 L of water sample was collected, whereas for chlorophyll-*a* analysis, one-liter of water was taken. The water quality analytical method is presented in Table 2.

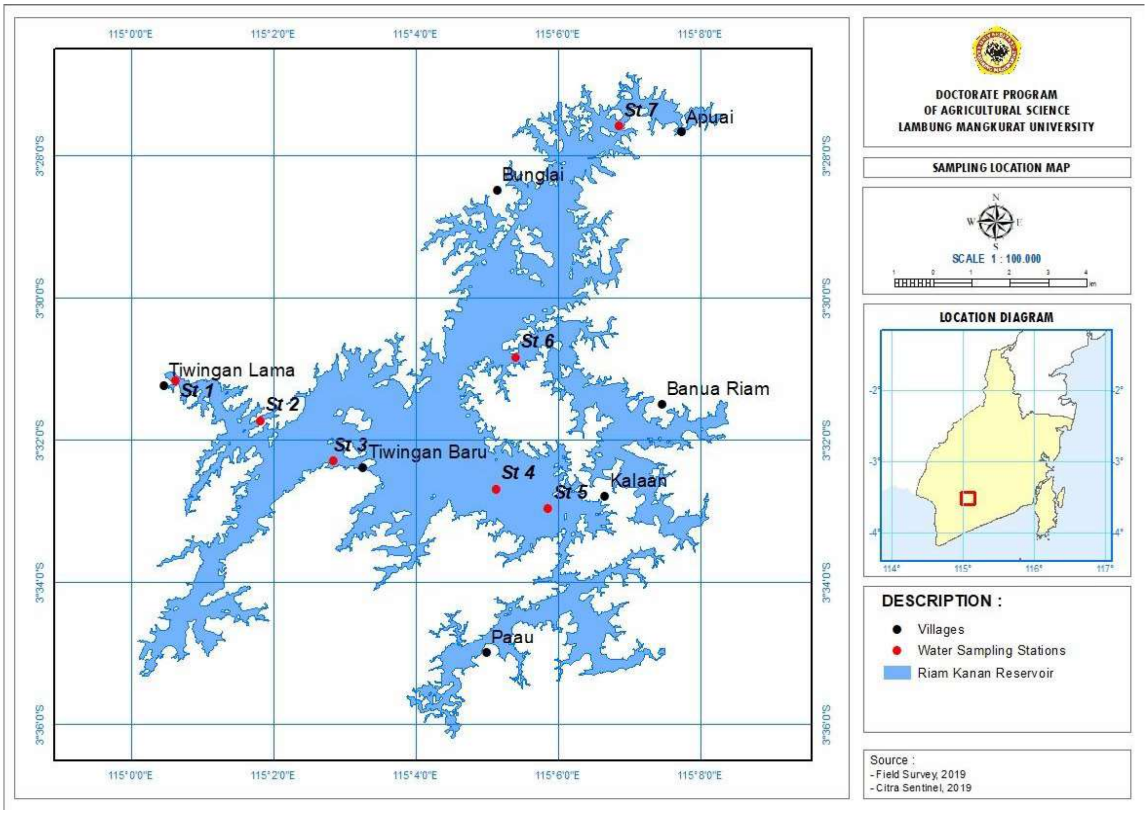

Figure 1. Sampling location map.

Table 2

Water quality parameter analytical method

Parameter	*Unit*	*Method*
Temperature	°C	In site, using thermometer
pH	-	In site, using pH meter
DO	mg L^{-1}	In site, using DO meter
Turbidity	NTU	In site, using turbidity meter
Transparency	cm	In site, using Secchi disk
TDS	mg	Gravimetry
TSS	mg L^{-1}	Gravimetry
BOD	mg L^{-1}	Titration
COD	mg L^{-1}	Titration
NH_3	mg L^{-1}	Spectrophotometry
Free NH_3	mg L^{-1}	Spectrophotometry
NO_3	mg L^{-1}	Spectrophotometry
NO_2	mg L^{-1}	Spectrophotometry
Total phosphorus	mg L^{-1}	Spectrophotometry
Total nitrogen	mg L^{-1}	Kjeldhal
Chlorophyll-*a*	mg L^{-1}	Spectrophotometry

Data analyses. Water quality data were analysed using Storet (Storage and Retrievel of Water Quality Data System) method, Carlson Trophic State Index (TSI), and carrying capacity approach.

Storet method was employed to determine the water quality status referred to the value system issued by the United States Environmental Protection Agency (US-EPA). Storet method is one of the methods recommended by the Government of Indonesia Republic to determine the water quality status through the decree of Living Environmental Minister numbered 115/2003 concerning the guide to water quality status determination. The Storet analysis steps are as follows:

1. Water quality data utilized time series data;
2. The water quality data were then compared with standard quality as class category;
3. If the measurements meet the standard water quality, it is scored 0;
4. If the measurements do not meet the standard quality, the score follows the requirements in Table 3;
5. Negative scores of all parameters were summed. The total value was compared with the criteria as listed in Table 4.

Table 3

Value system for water quality status determination

*No. samples**	*Value*	*Parameters*		
		Physical	*Chemical*	*Biological*
< 10	Maximum	-1	-2	-3
	Minimum	-1	-2	-3
	Mean	-3	-6	-9
≥ 10	Maximum	-2	-4	-6
	Minimum	-2	-4	-6
	Mean	-6	-12	-18

Notes: *) No. water quality parameters (Canter 1997 in Living Environment Minister's decree numbered 115/2003 concerning the guide to water quality status determination 2003).

Table 4

Water quality classification

Class	*Condition*	*Score*	*Remarks*
Class A	Very good	0	Meet the quality standard
Class B	Good	-1 s/d -10	Lightly polluted
Class C	Moderate	-11 s/d -30	Moderately polluted
Class D	Poor	≥ -31	Heavily polluted

Source: US-EPA in Living Environment Minister's decree numbered 115/2003 concerning the guide to water quality status determination 2003).

Carlson TSI method (Carlson 1977) was used to determine the aquatic trophic status. Some researchers have also utilized this method for the same purpose (Jarosiewicz et al 2011; Samudro et al 2012; El-Serehy et al 2018; Ghashghaie et al 2018). Water quality, such as water transparency, chlorophyll-*a*, and total phosphorus, was estimated as follows:

$$\text{TSI (SD)} = 60 - 14.41 \ln (\text{SD})$$

$$\text{TSI (CHL)} = 30.6 + 9.81 \ln (\text{CHL})$$

$$\text{TSI (TP)} = 4.15 + 14.42 \ln (\text{TP})$$

$$\text{TSI} = \frac{\text{TSI (SD)} + \text{TSI (CHL)} + \text{TSI (TP)}}{3}$$

where: TSI = Tropic State Index;
SD = Secchi disk (m);
CHL = Chlorophyll-*a* (μg L^{-1});
TP = total phophorus (μg L^{-1}).

The value of TSI analysis was then compared with the aquatic trophic criteria (Table 5) to determine the trophic status of the reservoir.

Table 5

Aquatic trophic status category based on TSI index

Trophic status	*TSI value*
Olygotrophic	0 - <30
Moderate mesotrophic	30 - <40
Mesotrophic	40 - <50
Acute mesotrophic	50 - <60
Eutrophic	60 - <70
Hypertrophic	70 - <80
Acute hypertrophic	80 - <100

Source: Ebrahimpour et al (2012) in Ghashghaie et al (2018); Yang et al (2012).

Carrying capacity analysis was employed to determine the capability of the water to support the FFC culture activities in relation with TP level given in the Living Environmental Minister's decree numbered 28/2009 concerning the carrying capacity for lake and or reservoir, 2009, using the following steps and formula (Table 6).

Table 6

Steps and reservoir carrying capacity calculations for fish culture

Parameters	*Formula*	*Remarks*
Mean depth (m), $\check{Z}$	$\check{Z} = 100\ x \frac{V}{A}$	V: reservoir water vol. (million m^3) A: area of reservoir waters (Ha)
Water replacement rate ($1yr^{-1}$), ρ	$\rho = \frac{Qo}{V}$	Qo: No. water outflow from the reservoir (million $m^3\ yr^{-1}$ in dry season)
TP load allocation of fish culture (mg P m^{-3}), $\Delta\ [P]_d$	$\Delta[P]_d = [P]_{STD} - [P]_i - [P]_{DAS}$	$[P]_{STD}$: max. TP according to BMA (mg P m^{-3}) $[P]_{DAS}$: allocation of TP other than fish culture (mg P m^{-3}) $[P]_i$: TP of monitoring activity (mg m^{-3})
Carrying capacity of TP of fish waste per unit area of the reservoir (gr P/m^{-3} yr^{-1}), L_{fish}	$L_{fish} = \frac{\Delta\,[P]_d \check{Z}\,\rho}{(1 - R_{fish})}$ $R_{fish} = X + [(1 - x)R]$ $R = \frac{1}{1 + 0{,}747\,\rho^{0507}}$	R_{ikan}: TP proportion into the sediment after the presence of FFC R: TP remains in the sediment X: TP proportion permanently stays in the bottom, 45-55%
No. carrying capacity of TP of fish wastes (gr P yr^{-1}), La_{fish}	$La_{fish} = L_{fish}\ x\ A$	
TP entering the reservoir through fish waste (kg P ton^{-1} of fish), P_{LP}	$P_{LP} = FCR\ X\ (P_{feed} - P_{fish})$	FCR: (ton feed ton^{-1} fish) P_{feed}: TP feed (kg P ton^{-1} feed) P_{fish}: TP fish (kg P ton^{-1} fish)
No. fish production (ton fish. yr^{-1}, LI	$LI = \frac{La_{fish}}{P_{LP}}$	

Source: Machbub (2010); Living Environmental Minister's decree numbered 28/2009 concerning carrying capacity of lake/reservoir water pollution load (2009).

Results and Discussion. Water quality analysis indicated that 5 of 16 parameters analyzed did not meet the standard water quality criteria, pH, DO, TP, BOD, and COD (Table 7). Water pH and DO did not meet the standard quality requirements at the minimum criterion, TP at the maximum criterion, BOD at the maximum and mean criteria, and COD at the minimum, maximum, and mean.

Table 7

Water quality measurements

Parameter	Unit	Standard water quality*	Measurements		
			Minimum	Maximum	Mean
Temperature	^{o}C	Dev 3	27.32	30.22	28.51
Transparency	m	-	0.77	2.00	1.31
Turbidity	NTU	-	4.39	18.35	7.14
TDS	mg L^{-1}	1000	60.00	98.00	76.48
TSS	mg L^{-1}	50	nd	27.00	2.86
pH		6-9	5.07**	6.78	6.02
DO	mg L^{-1}	6	3.77**	7.17	6.06
Total phosphorus	mg L^{-1}	0.2	0.002	0.434**	0.050
Total nitrogen	mg L^{-1}	-	0.666	9.862	2.140
NH_3-N	mg L^{-1}	0.5	nd	0.17	0.02
Free NH_3	mg L^{-1}	-	nd	0.08	0,01
BOD	mg L^{-1}	2	1.40	32.80**	8.50**
COD	mg L^{-1}	10	18.10**	224.00**	69.10**
NO_3	mg L^{-1}	10	nd	0,.92	0.263
NO_2	mg L^{-1}	0.06	nd	0.02	0.005
Chl-a	µg L^{-1}	-	0.1392	7.50	0.974

Notes: * = class-one water quality standard based on Governent's regulation of south Kalimantan No. 5/2007; ** = does not meet the quality standard requirements; - = not regulated; nd = not detected.

Based on the measurements in the study stations, water pH, BOD, and COD did not fulfill the water quality standard, in which DO did not meet the standard quality in station 1, 2, 3, 4, 6, and 7, while TP did not meet the standard requirements in stations 1, 2, and 5 (Table 8).

Table 8

Storet index-based water quality status

Station	Parameters that do not meet the standard water quality	Index	Status
1	pH, DO, TP, BOD, COD	-32	Heavily polluted
2	pH, DO, TP, BOD, COD	-38	Heavily polluted
3	pH, DO, BOD, COD	-24	Moderately polluted
4	pH, DO, BOD, COD	-22	Moderately polluted
5	pH, TP, BOD, COD	-30	Moderately polluted
6	pH, DO, BOD, COD	-28	Moderately polluted
7	pH, DO, BOD, COD	-24	Moderately polluted
Riam Kanan Reservoir	pH, DO, TP, BOD, COD	-24	Moderately polluted

Storet analysis revealed that the water quality status of Riam Kanan was categorized as moderately polluted with mean index of -24. With station, the water quality status of stations 1 and 2 was in heavily polluted category with index value of -32 and -38, respectively, whereas stations 3, 4, 5, 6, and 7 were categorized as moderately polluted with index range of -22 to -30.

The recommended water quality standard based on the regulations of South Kalimantan Governor numbered 05/2007 concerning river water designation and standard 2007 was 6-9 for water pH and minimum 6 mg L^{-1} for DO. In pH of 4-5, fish do not reproduce, and most fish species die at pH below 4.0 and above 11 (Lawson 1995). Suitable DO ranges from 5 to 15 mg L^{-1} (Boyd & Tucker 1998). DO is critical for tropical cultured fish if it is less than 4 mg L^{-1} (Mallasen et al 2012).

Water fertility analysis showed that Riam Kanan Reservoir belonged to mesotrophic with mean TSI of 46.58 (Table 9). The tropic status varied with station from mesotrophic to acute mesotrophic with the lowest TSI in station 4, 41.62, and the highest in station 2, 50.18.

Table 9

Trophic status analysis

Station	*May*	*July*	*September*	*Mean*	*Tropis status*
1	48.70	40.26	49.53	46.16	Mesotrophic
2	48.93	49.39	52.20	50.18	Acute mesotrophic
3	46.32	43.33	51.69	47.11	Mesotrophic
4	41.34	40.70	42.81	41.62	Mesotrophic
5	44.43	47.54	45.65	45.87	Mesotrophic
6	47.73	47.29	42.45	45.82	Mesotrophic
7	49.46	46.05	52.32	49.28	Mesotrophic
Mean	46.70	44.94	48.09	46.58	Mesotrophic

High BOD, COD, and TP indicate that Riam Kanan Reservoir water has been polluted by organic matters. The organic matters entering the reservoir particularly came from domestic activities, such as animal husbandary, agriculture, and floating fish cage culture. The highest mean BOD, COD, and TP was recorded in station 2, 14.83 mg L^{-1}, 110.07 mg L^{-1}, and 0.1573 mg L^{-1}, respectively. Station 2 is the floating fish cage culture activity with the highest density, 5.96 plots Ha^{-1} (Nur et al 2020b). Montanhini Neto & Ostrensky (2015) stated that percent of fish feed nutrients released into the floating fish cage culture environment consisted of 78% organic matter, 65% N and 72% P. High BOD, COD, and TP in the floating fish cage culture area indicate that fish culture activities play jmportant role in raising the three water quality parameters.

The trophic status of Riam Kanan Reservoir in the present study is higher than that in previous study indicating that the trophic status changes from olygotrophic to mesotrophic status (Brahmana & Achmad 2012). Increased water fertility could result from addition of organic matters into the reservoir from the floating fish cage culture.

Furthermore, with observational period, the trophic status was categorized as mesotrophic with the lowest mean TSI in July and the highest in September, 44.94 and 48.09, respectively. In May and July, the trophic status in all stations belonged to mesotrophic category, whereas in September it varied from mesotrophic to mesotrophic acute. Variations in TSI value could be related with the water volume of the reservoir. In July, water volume of the reservoir was higher than that in May, so that organic matter concentration dilution, including TP and chlorophyll-a, whereas in September, water volume and input declined so that the wastes in the reservoir were accummulated and its concentration rose.

The capacity of TP load, 137.3 ton yr^{-1}, and the existing TP load existing, 226.6 ton yr^{-1} demonstrated that Riam Kanan Reservoir has got excessive load of TP, 89.3 ton yr^{-1}, that is equivalent to excessive fish production of the floating fish cage, 5,030 ton yr^{-1} or excessive floating net units as many as 2,394 plots. The fish culture poduction in Riam Kanan Reservoir was estimated as 8,955 ton yr^{-1}. The carrying capacity of fish production is the difference between total production and the total excess production, 3,925 tons yr^{-1} or equivalent to 1,869 units of floating fish cage (Table 10).

Although Riam Kanan Reservoir has had water quality degradation into moderately polluted, this condition is still better than several large lakes or reservoirs in Indonesia that are in heavily polluted condition with eutrophic or hypertrophic fertility status, such as Cirata Reservoir and Jatiluhur Reservoir in West Java (Jubaedah et al 2014; Komarawidjaja et al 2005; Hamzah et al 2017), Koto Panjang Reservoir in Riau (Hasibuan et al 2017), and Maninjau Lake in West Sumatera (Syandri et al 2017, 2020).

Table 10

Fish culture carrying capacity analysis

Parameters	Value	Unit	Source
Morphometry			
Volume	621.7	million m^3	UL PLTA/D Gunung Bamega (2019)
Area	54.4	million m^2	UL PLTA/D Gunung Bamega (2019)
Mean depth	11.42	m	Data analysis
Water outflow	1.157.2	million m^3 yr^{-1}	UL PLTA/D Gunung Bamega (2019)
Water replacement rate	1.86	times yr^{-1}	Data analysis
The capacity of water pollution load from total phosphorus			
Standard TP (mesotrophic)	30.00	mg P m^{-3}	MLE (2009)
TP monitoring data	49.52	mg P m^{-3}	Data analysis
Allocation of TP load	-19.52	mg P m^{-3}	Data analysis
TP load capacity	137.3	ton P yr^{-1}	Data analysis
Existing TP load	226.6	ton P yr^{-1}	Data analysis
Excess of TP load	89.3	ton P yr^{-1}	Data analysis
Carrying capacity based on number of fish production			
FCR	1.85		Survey data of 2019
TP of feed	13	kg P ton^{-1} feed	Widyastuti et al (2009)
TP of fish	3.4	kg P ton^{-1} fish	Montanhini Neto & Ostrensky (2015)
TP of fish wastes	17.76	kg P ton^{-1} fish	Data analysis
Existing FFC production	8.955	ton fish yr^{-1}	Data analysis
Excess of FFC production	5.030	ton fish yr^{-1}	Data analysis
FFC production as carrying capacity	3.925	ton fish yr^{-1}	Data analysis
Carrying capacity based on number of FFC			
No. existing FFC units	4.263	plot	Nur et al (2020b)
No. FFC unit excess	2.394	plot	Data analysis
No. FFC units as carrying capacity	1.869	plot	Data analysis

Based on the potential analysis of TP pollution in this study, it was found that 70% of TP pollution load in Riam Kanan Reservoir was caused by the floating fish cage culture activity (Table 11). Water quality decline is in general caused by uncontrolled floating fish cage culture development that exceed its carrying capacity (Komarawidjaja et al 2005; Pribadi 2005; Machbub 2010; Sutjinurani & Suharyanto 2016; Hamzah et al 2017; Hasibuan et al 2017; Syandri et al 2020), so that this finding reconfirms the previous studyhe cause of the degradation of water quality condition.

Table 11

Potency of water pollution load from total phosphorus in Riam Kanan reservoir

Source	*TP load (ton yr^{-1})*	*%*
Human population	3.06	1.35
Agriculture	3.13	1.38
Animal husbandary	39.75	17.54
Other source	21.62	9.54
Fish culture	159.04	70.19
Total	226.59	100.00

Conclusions. Water quality status of Riam Kanan Reservoir was categorized as moderately polluted with Storet index of -24. The water quality parameters that did not fulfil the quality standard were pH, DO, TP, BOD, and COD. The trophic status of Riam Kanan Reservoir belonged to mesotrophic category with mean TSI of 46.58. The use of Riam Kanan Reservoir for fish culture has exceeded the aquatic carrying capacity with mesotrophic status. To overcome the water quality degradation and increased fertility, it is necessary to reduce the number of floating fish cage as much as 56% of the recent condition. Since this study was carried out in dry season, April-September, other measurements need to be done in rainy season, October-March, in order to obtain core complete condition of the reservoir water.

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