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Determination of trophic status and carrying capacity of floating net cages in Jatigede Reservoir

Penentuan status trofik dan daya dukung keramba jaring apung (KJA) di Waduk Jatigede

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ABSTRACT

Aquaculture activities with floating net cages are essential to increase fishery production. However, The fish cages in the Jatigede Reservoir are illegal because they are against local government regulations. However, the people affected by the dam's construction still maintain it for economic reasons. Therefore, it is necessary to conduct research to address these problems by determining the carrying capacity of aquaculture and evaluating the trophic status of the waters. Determination of the carrying capacity of fish farming in the Jatigede Reservoir was conducted using the Beveridge method by calculating the remaining phosphorus still available in the Jatigede Reservoir and evaluating the trophic state index based on three indicators: transparency, total phosphorus, and chlorophyll-a. The sampling was carried out by purposive sampling method. The calculation results show that the condition of the Jatigede Reservoir was eutrophic to hypertrophic with a trophic state index (TSI) value of 66-71. The results of calculating the carrying capacity of cage aquaculture using class three water quality standards. Indicate that Jatigede Reservoir waters can still increase fish production by 7,140.25 tons of fish/year, provided that fish replace the primary fish commodities cultivated.

Keywords: aquaculture, cage aquaculture, carrying capacity, eutrophication, Jatigede Reservoir

ABSTRAK

Kegiatan budidaya dengan keramba jaring apung (KJA) sangat penting untuk meningkatkan produksi perikanan. Keberadaan KJA di Waduk Jatigede merupakan kegiatan ilegal karena bertentangan dengan peraturan pemerintah setempat. Namun, masyarakat yang terkena dampak pembangunan waduk tetap mempertahankannya karena alasan ekonomi. Oleh karena itu, perlu dilakukan penelitian untuk mengatasi permasalahan tersebut dengan menentukan daya dukung perikanan budidaya dan mengevaluasi status trofik perairan. Penentuan daya dukung budidaya ikan di Waduk Jatigede dilakukan dengan menggunakan metode Beveridge dengan menghitung sisa fosfor yang masih tersedia di Waduk Jatigede dan mengevaluasi indeks status trofik berdasarkan tiga indikator yaitu transparansi, total fosfor, dan klorofil-a. Pengambilan sampel dilakukan dengan metode purposive sampling. Hasil perhitungan menunjukkan bahwa kondisi Waduk Jatigede adalah eutrofik hingga hipertrofik dengan nilai indeks kondisi trofik (TSI) 66-71. Hasil perhitungan daya dukung budidaya perikanan keramba dengan menggunakan baku mutu air kelas tiga. Perairan Waduk Jatigede masih dapat meningkatkan produksi ikan sebesar 7.140,25 ton ikan/tahun, dengan catatan ikan menggantikan komoditas ikan utama yang dibudidayakan.

Kata kunci: akuakultur, daya dukung, eutrofikasi, keramba jaring apung, Waduk Jatigede

INTRODUCTION

Aquaculture activities with a floating net cage system in the reservoir are one of the efforts to increase fisheries production by utilizing various potentials of the water. The development of the aquaculture business continues to increase along with the growing need for animal protein within the community (Béné *et al*., 2016). The economic benefits of the fish cultivation system motivate the community to continue building and developing floating net cages. However, fish cage activities pose one of the problems that existing in Jatigede Reservoir. Jatigede Reservoir is a reservoir located in Sumedang Regency, Jawa Barat Indonesia, with an area of 4112 Ha.

The construction of this reservoir aims for facilitate fishing, flood control, irrigation, and water supply (Herawati *et al*., 2018). Reservoir managers prohibit the existence of floating net cages in Jatigede Reservoir, which is supported by Sumedang Regency regional regulation No. 4/2018. However, the community around the reservoir has been utilizing the reservoir for fish cages to meet their daily economic needs. Fish cultivation in reservoirs causes pollution of organic matter from feed residue, and metabolic waste, leading to an increase in the concentration of organic matter, especially phosphorus and nitrogen (Neto & Ostrensky, 2015).

The negative impacts caused by fish cultivation include sedimentation, turnover, and eutrophication, which can reduce the quality of reservoir waters (Zaniboni-Filho *et al*., 2018). Due to the different views between the government and the local community, fish cultivation in the reservoir should be planned and designed to minimize the negative impact on water quality (David *et al*., 2015). The development of cage aquaculture in the reservoir is positive as long as it remains within the limits of its carrying capacity. Currently, there is no research examining the carrying capacity of aquaculture in Jatigede Reservoir. Ecological carrying capacity is a best practice for setting environmental limits for sustainable aquaculture production (Ross *et al*., 2013).

The conception of carrying capacity relies on balancing nitrogen and phosphorus nutrients, but phosphorus is often the cause. It happens because denitrification occurs in nitrogen compounds, while phosphorus accumulates directly in the sediment (Hamid *et al*., 2022). Excess phosphorus also impacts changes in the trophic status of waters, leading to eutrophication and negatively impacting cultured fish (Schindler *et al*., 2016). Measuring trophic status is also important to determine the level of eutrophication that can be tolerated in lentic ecosystems (Cunha *et al*., 2013). This study aims to determine the trophic status of waters and the carrying capacity of fisheries in Jatigede Reservoir so that it can be sustainable.

MATERIALS AND METHODS

Research area

The study was conducted in September 2022 at Jatigede Reservoir in Sumedang Regency, Jawa Barat, Indonesia. The researchers aimed to determine the trophic condition of the waters and the carrying capacity of the floating net cage aquaculture system using a purposive sampling method. The research location includes six stations based on reservoir zoning, namely riverine, transition, and lacustrine (Figure 1).

Procedure

Water quality measurements

Water quality measurement on surface water was carried out in situ and ex situ at six sampling sites (Table 1). Water quality parameters measured include physical parameters (transparency and temperature) and chemical parameters (DO, pH, chlorophyll-a, and total-P). The measured water quality parameters were compared with the reservoir water quality standard according to PP Number 22 of 2021 concerning the implementation of environmental protection and management according to lake water quality standards.

Data Analysis

Water trophic status

Trophic Status of Jatigede Reservoir was determined using TSI (Carlson, 1977). TSI method uses three water quality parameters: chlorophyll-a (Chl-a), transparency (SD), and total phosphorus (P-tot).

$$TSI_{SD} = 10 \times (6 - \frac{\ln SD}{\ln 2})$$

$$TSI_{Chl\text{-}a} = 10 \times (6 - \frac{2.04 - 0.86 \ln (Chl - a)}{\ln 2})$$

$$TSI_{Ptot} = 10 \times (6 - \frac{\ln 48 / Ptot}{\ln 2})$$

$$TSI = \frac{TSI\ (SD) + TSIChl - a) + TSI(Ptot)}{3})$$

Note:

SD = Transparency (m)
Chl-a = Chlorophyll-a (mg/m^3)
P_{tot} = Total phosphorus (mg/m^3)

Cage agriculture carrying capacity

The analysis of the carrying capacity of fish cultivation in floating net cages aquaculture (FNCA) is calculated based on Permen (2009) concerning the load capacity of lake and/or reservoir pollution loads. Calculations were carried out using the Beveridge (1984) method, which refers to the total-P waste load discharged into the aquatic environment. Carrying capacity calculation is as follows

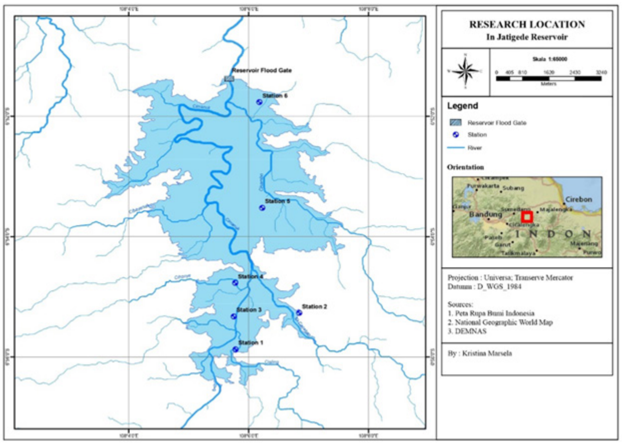

Figure 1. Research location map.

Station 1 (6°55'52,59''S 108°5'46,97''E), its riverine zone and gets input water from Cimanuk and Cialing River Flow; Station 2 (6°54'46,1''S 108°5'46,4''E), its transition zone. There is captured fish activity and gets input water from Cacaban River flow; Station 3 (6°55'16,02''S 108°6'50,69''E), is a transition zone and gets input water from Cimanuk, Cimuja and Cijajaway river zone; Station 4 (6°55'19,54''S 108°5'45,07''E), its transition zone. There is aquaculture activity and it gets input water from Cihonje, Cimuja and Cacaban river flow; Station 5 (6°53'31,06''S 108°6'13,52''E), its lacustrine zone. There is aquaculture activity and gets input water from Cinambo River flow; Station 6 (6°51'45,96''S 108°6'10,9''E), Its lacustrine zone and reservoir outlet. Theres no human activity.

Table 1. The formula of carrying capacity calculation (Beveridge, 1984).

Variable of Calculation	Formula
Water Volume of Reservoir (V) (m^3)	-
Surface Area (A) (Ha)	-
Depth average of the reservoir (Z) (m)	V/A
Amount discharge water out of the reservoir (m^3/year) (Qo)	-
Rate of reservoir water change (per year)	Qo/V
Total phosphorus pollution load (P)	$\triangle [P] = [P]_f - [P]_i$
Total-P maximum accordance with water quality standard $[P]_f$ (mg/m^3)	-
Total-P of monitoring result in reservoir [P]i (mg/m^3)	-
Total-P left in sediment (R)	$1/(1 + 0.747\ \rho^{0,507})$
Total-P dissolves in sediment after cages is present (R_{fish})	$R_{fish} = x + [(1-x)R]$
Total-P permanently entered sediment, 45-55% (x)	-
Total-P fish waste capacity per unit of reservoir area (grP/m^2/year) (L_{fish})	$L_{fish} = \triangle [P]\ \check{z}\rho / (1-R_{fish})$
Total capacity of Total-P fish waste in reservoir waters (grP/year) (L_a)	$La = L_{fish}$ x A
Total-P entering the reservoir from fish waste (kg P/ton fish)	$P_{LP} = FCR \times P_{feed} - P_{fish}$
Feed Conversion Ration (FCR) (ton feed/ton fish)	
Total-P in the feed (P_{feed})(Kg P/ton feed)	-
Total-P in fish ($P_{fish)}$ (Kg P/ton fish)	-
Maximum total production of cahe culture (L_I) (tons of fish/year)	$L_I = La/P_{LP}$
Maximum total feed of cage culture ($L_{P)}$ (ton of feed/year)	$L_P = L_I \times FCR$

RESULTS AND DISCUSSION

Water quality measured

A healthy aquatic habitat can be determined by its water quality, which is impacted by the environment. Table 2 shows the value of water quality parameters measured and compares them with the water quality standards according to Government Regulation 21 of 2022 Class two. The water temperature in the Jatigede Reservoir ranges from 26^{o}C–29^{o}C, which falls within the optimum range for fish growth, that is 25^{o}C–32^{o}C (Ridho, 2021). Solar radiation, air temperature and weather at the location are factors that affect the difference in water temperature (Yang *et al.*, 2020).

The water temperature at station one is low, as well as at other stations, which is associated with a low light transparency ratio of 0.19 m. When sampling, the water at station one appears brown. Water transparency is a physical parameter that describes the intensity of sunlight entering the water body (Saputra *et al.*, 2018). Station one has the lowest water transparency value of 0.19 m, while the highest light transparency value of 1.1 is found at station three. The difference in water transparency is caused by turbidity, water colour and depth (Çako *et al.*, 2013).

Following the conditions at station one, namely shallow waters and brownish colour. The light transparency measurement result exceeds the class two quality standard for lake water according to Government regulation No. 22 of 2021, which is 4 m and indicates eutrophic waters (Permen, 2009). The pH measurements show a range of 7.9-8.4, which still meets the quality standards of Government Regulation 21 of 22 Class two, which indicates a suitable pH value for living organisms. Dissolved oxygen measured during the study showed a range of 4-5.3 mg/L, which is still good for the life of aquatic organisms, as it meets the quality standards of Government Regulation 21 of 22 Class two.

The highest dissolved oxygen concentration is 5.3 mg/L at station one, and the lowest is at stations two and three, which is 4 mg/L. Station one has the lower water temperature which is 26^{o}C than the measurement results at other stations. This station also has the highest dissolved oxygen content compared to other stations, namely 5.3 mg/L. At the same time, the lowest dissolved oxygen concentration is found at stations two and three, namely 4 mg/L. An increase in temperature causes the concentration of water DO to be low and the BOD content to increase, thus reducing oxygen availability for aquatic organisms (Verma & Singh, 2013).

Phosphorus content at all stations exceeds the established quality standards, ranging from 0.047 to 0.161 mg/L. The highest total phosphorus content is at station two, 0.161 mg/L. This station is a water area representing the riverine zone that receives input water from the Cacaban River and has agricultural activities. Anthropogenic activities in the watershed, such as agriculture and households, increase the nutrient load in the waters, stimulating the eutrophication process in the reservoir (Ji *et al.*, 2021). Meanwhile, the lowest phosphorus content at Station four is 0.047 mg/L.

This station is a water area representing the Cihonje River's transition zone and is used as a floating net cage area. Fish farming activities contribute phosphorus load to water from feed residue and metabolism, contributing around 30% (Simanjuntak & Muhammad, 2018). Although fish farming activities at station four can contribute phosphorus loads to the waters, the phosphorus concentration at station four is lower than at the other stations. Compared with chlorophyll-a data at station four, the amount is the highest compared to other stations.

Phosphorus is a macronutrient that is utilized by phytoplankton for their growth (Fitzsimons *et al.*, 2020). Based on the data comparison between phosphorus and chlorophyll-a, that phosphorus at station four is low because it is utilized by phytoplankton for growth. The chlorophyll-a concentration of the measurement results ranged from 11-116 mg/m^3, showing that only station one is still in accordance with the water quality standard for class two. High phosphorus content in waters could lead to eutrophication, a high phytoplankton biomass production, which leads to a decrease in dissolved oxygen level at night, endangering aquatic organisms and reducing the use value of a water body (BoQiang *et al.*, 2013).

Trophic state index of Jatigede Reservoir

The trophic state index (TSI) is used to determine the trophic status of the water, allowing monitoring water quality. TSI serves as the basis for determining the trophic status using algal biomass (Carlson, 1977), which is estimated by measuring three parameters: chlorophyll-a, Secchi depth, and total P. TSI value measurement results are presented in Figure 2. There are differences in trophic status values at each station, with TSI value ranging from 66-71. This value indicates that the reservoir waters are heavily eutrophic to hypertrophic.

The trophic status of the waters was categorized based on (Carlson, 1977), where a TSI value of 0-40 indicates oligotrophic, 41-50 mesotrophic, 51-70 eutrophic, and >71 hypereutrophic. The TSI value has changed from previous observation by Putrandy *et al*. (2021), showing that it range from 55.94 to 59, indicating mild eutrophic waters. An increased TSI value indicates decreased reservoir health (Sharma *et al*., 2010). The beginning of the inundation of Jatigede Reservoir has a moderate eutrophic fertility status (Warsa, 2016).

The reservoir was built on a plantation and residential land. Regarding new reservoirs, which are usually built by submerging large tracts of untreated land, with internal dissolved pollutant sources and external pollutant input sources, they are prone to eutrophication mainly due to low biodiversity and poor self-purification capacity. Eutrophication is the enrichment of nutrients, mainly by nitrogen and phosphorus, which are limiting factor for algae growth (Mhlanga *et al*., 2013). Both internal and external activities of the reservoir play a role in the eutrophication process. Rivers dammed for reservoir construction provide nutrient input loads to water bodies from fertilizer runoff from agricultural, domestic and industrial activities (Sulastri *et al*., 2016).

The influence of domestic waste is also evident from the conditions found in the field, which much garbage is carried from the Cimanuk River basin. Internal influences that cause eutrophication in the reservoir come from agricultural activities and cage aquaculture. Agricultural intensity has a clear impact on physicochemical parameters as well as the contribution of sediment and nutrient waterways (Atwell & Bouldin, 2022). Farmers around the reservoir use NPK fertilizer as much as 10 kg for every 0.7 ha of land. Phosphate fertilizer absorbed by plants ranges from 10-15%, and the rest accumulates in the soil.

Phosphorus runoff from agricultural land due to rainfall into the waters is 5.07% (Li *et al*., 2021). Meanwhile, in fish farming activities, the

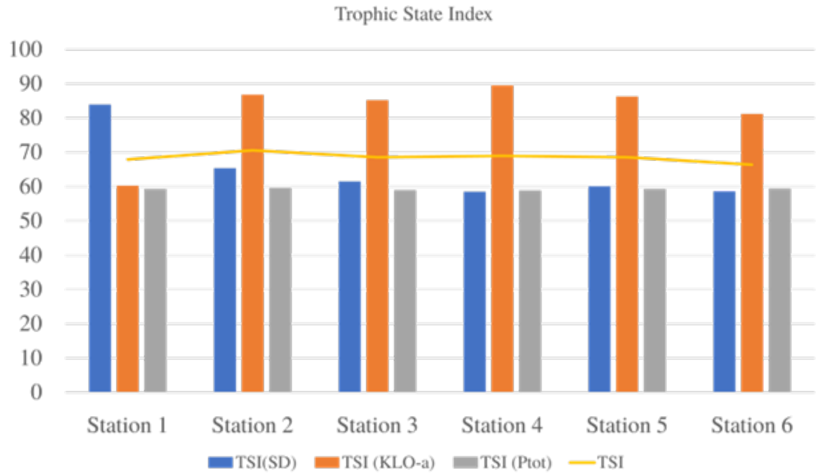

Figure 2. Trophic state index of Jatigede Reservoir.

Table 2. Water quality parameters.

No	Water Quality Parameters	Water Quality Standard (PP No. 22 of 2021, Class 2)	Station					
			I	II	III	IV	V	VI
	Physic							
1	Temperature (^{o}C)		26	29	29	29	29	29
2	Brightness (m)	4	0.19	0.69	0.9	1.11	0.99	1.1
	Chemistry							
3	pH	6-9	8.01	8.03	7.9	8.4	8.27	8.4
4	DO (mg/L)	4	5.3	5.1	4	4	4.1	4.6
5	Total-P (mg/L)	0.03	0.092	0.161	0.053	0.047	0.09	0.106
6	Chlorophyll -a (mg/m^3)	50	11	93	82	116	89	59

average use of feed is 11.7 tons for one cultivation cycle and the total fish production per year is 14,932.8 tons of fish/year. Fish farming activities contribute to phosphorus load in the water from feed residue and metabolism, accounting for around 30% (Simanjuntak & Muhammad, 2018). The reservoir water status is related to the quantity and quality of fish farming waste, such as phosphorus, nitrogen and other biological nutrients (Neto *et al*., 2017).

Eutrophication causes water quality degradation and reduces lake carrying capacity resulting in a loss of ecosystem services such as water supply, recreation, and fishing activities (Sulastri *et al*., 2016). It also causes fish mortality, unpleasant odors and unsightly conditions (Shrivastava, 2021). According to the facts in the field during the research in Jatigede Reservoir. The water is murky and has an unpleasant odor, causing fish diseases, and fish deaths occur. Based on the results of interviews in the field, fish mortality during the cultivation cycle it is stated that for every 100 kg of fish, there was 10 kg of dead fish.

Cage aquaculture carrying capacity

The community around the dam has been using the reservoir for carp cultivation using the fish cages system as the main commodity since 2017. The community has developed cage aquaculture with various sizes of plots in one unit used to raise two types of fish: carp in the first layer and tilapia in the second layer. The unit of cage aquaculture used by the community in Jatigede Reservoir consists of various sizes. One unit with four plots, each plot has a size of 7×7 m called a layered net. One unit with two plots, each plot with a size 7×14 m is called a dolos net and one unit without any dividers is called a drawstring net with a size of 14×14 m.

Reservoirs have a limited ability to tolerate pollution loads, including from fish farming activities. The development of fish farming must be based on the carrying capacity of the reservoir, which is the ability of the waters to support fish life (Gunkel *et al*., 2015). Determination of carrying capacity is done by calculating the phosphorus load entering the water body (Beveridge, 1984), as well as based on the hydrological, morphological and water regimen characteristics specific to each water body (Lukman, 2011). The hydrological and morphological data of the reservoir are in Table 3.

The construction of the Jatigede Reservoir is intended for irrigation, water supply, flood regulation, recreation, and capture fisheries. The objective of the Jatigede Reservoir construction requires a second-class water quality standard, but the monitoring (primary and secondary data) of total phosphorus have exceeded the quality standard, i.e., 73.7 mg/m^3. This value was obtained from calculating the average phosphorus monitoring during August 2020-February 2021, with average value of 30 mg/m^3 (Putrandy *et al*., 2021), February and April 2021 with an average value of 99.62 mg/m^3 (Junianti *et al*., 2021), as well as direct observation in September 2022 the total P content 91.5 mg/m^3. This value has exceeded the reservoir quality standard for classes one and two i.e. 10 mg/m^3 and 30 mg/m^3, respectively, so no remaining phosphorus can be used to support fish cultivation.

However, if there is a change in the use of the reservoir, i.e. it is not used for clean water supply, and recreation and aquaculture activities are allowed, the carrying capacity of the reservoir can be calculated based on class three water designation. Class three is water designation can be used for freshwater fish cultivators, livestock, water to irrigate plants, and other designations that require the same water quality as that use. The standard for class three lake water quality for fisheries is 100 mg/m^3. So the total P-load allocation for fish farming in the Jatigede Reservoir is 26.3 mg/m^3.

Total-P dissolved into the sediment after the

Table 3. Hydrology and morphology data of Jatigede Reservoir.

Reservoir Characteristics	Symbol	Value
Water surface area	A	3952 m^2
Volume of the reservoir (10^6)	V	796.3 m^3
Average depth	Z	20.15 m
Number of discharge waters reservoir out (10^6)	Q_o	2.251,98 m^3/year
Rate of water change in the reservoir (per year)	ρ	2.83

presence of cage aquaculture was 0.44, with an x value determined by Pulatsü (2003) as 0.5. The total P-total capacity of fish waste per unit area of the Jatigede Reservoir is 5,366.02 mg/m^2, so the total charge of phosphate pollution in the reservoir is 212,065.31 kg/year. The FCR value of fish cultured in reservoirs is 1.6. The phosphorus content in the feed used for maintenance is 20 kg/ton of feed, while the phosphorus content in the body of the rearing fish is 2.3 kg/ton of fish.

The total phosphorus content that enters the water from fish waste is 29.7 kg/ton of fish. Based on the calculation results, the maximum capacity of the Jatigede Reservoir to support fish cultivation activities using the cage system is 7,140.25 tons of fish/year. The calculated values indicate a possible ecologically sustainable level of aquaculture production (Mhlanga *et al*., 2013). In order not to provide excessively polluting materials into the waters (Syandri *et al*., 2016).

At the time of the research in Jatigede Reservoir, there were already 816 units of cage aquaculture with a total annual fish production of 16,564.8 tons/year. Based on the calculation results, the fish production capacity that can be added to be cultivated in Jatigede Reservoir after the existence of cage aquaculture is 7,140.25 tons of fish/year. These calculations indicate that Jatigede Reservoir can still add fish production to it if it uses class three water quality standards, provided that it replaces the main commodity fish cultivated, such as tilapia. Tilapia has a high level of tolerance to changes in water quality (Indriati & Hafiludin, 2022).

CONCLUSION

Based on the results of the research that has been carried out show that the Jatigede Reservoir waters have a trophic status of eutrophic to hypertrophic waters with a TSI value of 66-71. The results of calculating cage aquaculture carrying capacity using class three water quality standards. Jatigede Reservoir waters can still increase fish production by 7,140.25 tons of fish/year, provided that fish replace the primary fish commodities cultivated.

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