*Pol. J. Environ. Stud. Vol. 31, No. 5 (2022), 4539-4547*
DOI: *10.15244/pjoes/150384* ONLINE PUBLICATION DATE: 2022-08-08

*Original Research*

# The Cost of Pollution to Dam's Fisheries

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*Received: 6 April 2022*
*Accepted: 24 May 2022*

## Abstract

Cirata Dam is one of the dams in West Java, Indonesia, which has significant resources of endemic fish potential from adjacent rivers, as well as fish introduction from other regions or countries. Unfortunately, the production of fishing in these dams has decreased significantly every year due to unregulated fishing activities, water pollution caused by the feed from aquaculture activities, as well as domestic and industrial wastes discharged into the waters. This study analyzes the depletion of fish resources due to fishing and pollution at these sites. Methods used in this research are the bio-economic logistic standard and Gompertz model, to measure the impact of fishing on the dynamics of fish resources, and linear as well as non-linear regression to obtain the coefficient of pollution on production. The depletion of fish resources calculated by Anna model modification. The result shows that the depletion rate of Cirata's fish, varies in a year with an average depletion of 25% during the year of observation with standard model for analyzing fishing activities intervention alone. Combined with pollution, the rate of depletion is increased. The implication of the MSY or MEY management instruments is required to control the fish resources.

**Keywords**: fish depletion, capture fisheries, pollution, bio-economic model, dam

## Introduction

Fish resources in the dam are one of the potentials of incredible freshwater biodiversity which contributes ecologically, socially, and economically to the surrounding ecosystem. The fish resources in the dams are endemic and fish that are introduced from other regions and from abroad. The existence of fish resources in dams, both endemic and introductory, has a positive impact as the replacement for the fish resources which has lost due to the construction of the dam, hydraulic turbines or over spillways during downstream migration [1, 2]

Biologically, fish resources in dams have their intrinsic value and are proficient in balancing the ecosystem in the aquatic systems [3-5]. Furthermore, in the roles of freshwater ecosystems, fish become one of the types of biota that can dampen various ecosystem dynamics. The over exploitation of fish resources in the waters dams impacts not only on fisheries stock but also on other aquatic organisms, ecological

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processes, and even the whole ecosystems [6-8]. Thus, fish resources have a significant role in the aquatic ecosystems sustainability [9, 10]. Fish resources in the dam, as another terrestrial water, although often unrecorded and unreported [11, 12], significantly provide social contributions for protein supply [13, 14], food security [14-16], and the economy of the surrounding communities, especially from commercial fisheries [5, 17], and tourism [18, 19]. In some countries, dams fisheries provide significant contributions to local, national, and global economy.

Nevertheless, the main challenges in maintaining and enhancing dam fisheries and associated social and economic benefits are the inadequate management on the dam, fish habitat and environmental degradation, unconditioned fish introduction, the unregulated water use for fisheries activities (catch and cultivation), conflicts among locals and fishermen, lack of spatial rules, and insufficient institutional and political recognition [11, 17]. Furthermore, dam fisheries are also subject to various threats such as accelerated eutrophication [20, 21], overexploitation and overfishing [8, 12], invasive species [22, 23], toxic contamination [24, 25], and climate change [20, 26].

Degradation of water quality is a result of human activities around the dam, and it becomes the most occurring issue in managing fish resources, in addition to the unsustainable use of fish resources [27-29]. Dams or reservoirs are often used as domestic waste disposal sites as well as industrial waste discharged either directly or from streams leading to the dam. This problem also happens to the terrestrial waters in many developing countries, including Indonesia. Cirata Dam experiences water quality degradation due to pollution [17, 21, 30-32]. Fisheries in Cirata Dam is one of the resources of livelihood and food security of surrounding communities [5, 16, 17].

Pollution in Cirata Dam is mostly caused by the high sedimentation of Citarum upstream, uncontrolled fish farming activities using the floating net, and land use at the upstream [31, 33, 34], Degradation of water quality in line with unregulated exploitation has caused fish production in the region to decline yearly. For sustainable management, this study analyzes the impacts of economic activities (fishing) and non-economic activities (pollution), to the depletion of fishery resources in the dam.

## Materials and Method

This study uses primary and secondary data. Primary data were obtained by interviewing 300 out of 4,580 fishermen in Cirata Dam, which consisted of main fishing gears such as handline, gillnet, and cash net. This research used random sampling and direct field observation to obtain the data of cost per catch effort, catch per unit of fishing effort, length, and total fishing effort or trips, and fish commodity price. Physical, chemical, and biological water quality parameters were observed. Samples were taken from 10 specified points in Cirata Dam, namely dam inlet, middle, and outlet at different depths (from surface, 5 meters depth, and the bottom).

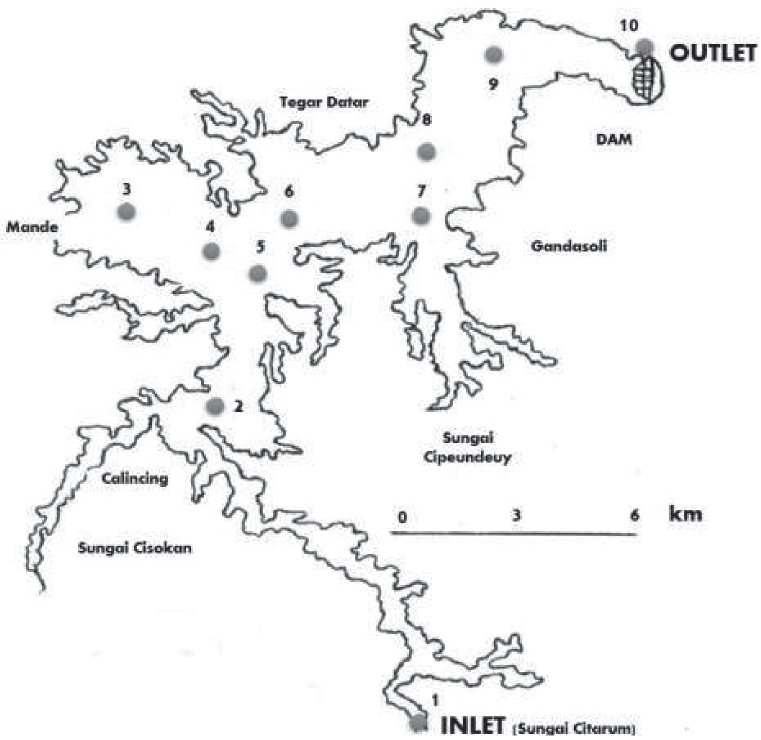


Fig. 1. Water Sampling Points Map.

Secondary data were obtained from several related institutions such as the Office of Marine and Fisheries of West Java Province, Livestock and Fishery Service of Cianjur Regency, Task Implementation Unit of Cirata Dam, Marine and Fisheries Office of Cianjur Regency, Regional Technical Implementation Unit (UPTD) of Cianjur Fishery, PT. Java Bali Power Station Management Agency Cirata Dam (BPWC), and related agencies to obtain time-series data of production and efforts as well as water quality parameters from 2011 to 2018 per quarter to find out changes in water quality yearly.

Fishing gears that operate in the research area are very diverse, so to measure with equivalent units, standardization efforts are performed on the tools using the techniques developed by King [35], as follows:

$$E_{jt} = j_{jt} D_{jt}$$
$$j_{jt} = \frac{u_{jt}}{u_{st}} \quad (1)$$

Where:
$E_{ij}$ = standardized effort of fishing gear j at time t
$D_{jt}$ = fishing days of fishing gear j at time t
$j_{jt}$ = fishing power offishing gear j at time t
$u_{jt}$ = catch per unit effort (CPUE) of fishing gear j at time t
$u_{st}$ = catch per unit effort (CPUE) standardized based gear

To construct the baseline bio-economic model, it is worth considering the specific functional form of biomass growth function as well as the harvest function. Let the Gompertz function represent the biomass growth function

$$F(x) = rxln(K/x) \quad (2)$$

Where r is intrinsic growth, K is the ability of the environmental carrying capacity, and q is the capability of power (catch capability coefficient). Meanwhile, the the harvest function is given by the following Cobb-Douglass type production function:

$$h = qxE \quad (3)$$

Where E is the level of efforts, so that with fishing taking place, the biomass function can be written:

$$F(x) = rxln\left(\frac{K}{x}\right) - qxE \quad (4)$$

The estimation of biological parameters involves non-linear techniques with algorithms from Clarke Yoshimoto and Pooley/CYP [36] with the equation as follow:

$$\frac{U_{t+1} - U_{t-1}}{2U_t} = \mathrm{rLn(qK) - rln(U_t) - q\,ln(E_t)} \quad (5)$$

Economic parameters are obtained from the primary data from interviews such as the number of catches, fish prices, cost per trip, and utilize time series data which include fish production and inputs used (efforts), output price per unit (fish price per ton per year), consumer price index, Gross Domestic Regional Product of West Java region, and other supporting data.

The water quality parameters analyzed were BOD and COD, Total Nitrogen (Nitrite, Nitrate and Ammonia), and phosphate. The first two parameters have been suspected to exceed class III addressed to fishery belts based on Government Regulation Number 22 of 2021 on water quality standard. Other parameters observed are indicators of water fertility in the Cirata Dam that has undergone eutrophication. The selected parameters were based on the polluted parameters which were discharged from the domestic waste (BOD), industrial waste (COD) dam's aquaculture industries (BOD, Total Nitrogen), and agricultural waste (Total Nitrogen) from the surrounding area. The pollution load of each of the contaminant was obtained by using the Hufschmidt & Dixon [37], formula:

$$BL = Q \times C \quad (6)$$

In which:
BL = Pollutant from a river/ton/year
Q = River water debit/m/year
C = Concentration of pollutant from each water quality parameter.

The pollution load carried by each water quality parameter from the inlets rivers of Cirata Dam is converge (Citarum River, Cisokan River, and Cibalagung River are the main inlets of Cirata Dam). The pollution load was calculated only from pollutants entering from the land base through Cirata Dam inlets. The following then portrayed using Gompertz function for the Fishery-Pollution model, abide by Anna [38, 39], where pollution affects intrinsic growth, so the growth function of the fish becomes:

$$x = \left(rxln\left(\frac{K}{x}\right) - \gamma P\right) - qxE \quad (7)$$

where P is the pollution load and gamma ($\gamma$) is the constant coefficient. Estimation of biological parameters and also pollution parameters are done by transforming the equation as follows:

$$X_{t+1} - X_t = rx_t ln\left(\frac{K}{x_t}\right) - \gamma Pt - qx_t E_t \quad (8)$$

By introducing the catch per unit effort variable (CPUE) at t time as:

$$U_{t=}{}^{h_t}/_{E_t} \quad (9)$$

Using algebraic simplification, equation can now be modified as:

$$U_{t+1} - U_t = rU_t lnKq - rU_t lnU_t - q\gamma P_t - qU_tE_t \quad (10)$$

Furthermore, the parameters r, q, K, and gamma were estimated using Ordinary Least Square (OLS) from time-series CPUE data, the total pollution load from the analyzed parameters derived from 3 main rivers entering the dam inlet, and effort. For this analysis, we use data series quarterly from 2011 to 2018. The economic rent can be found by using the formula:

$$\pi = p_t(h_t)h_t - c_th_t \quad (11)$$

To calculate the economic loss due to pollution, using assumptions that the economic rent generated from the fishery without pollution variable is in the form of $\pi(h_t, E_t)$, while with pollution variable is defined as $\pi(h_t, E_t, P_t)$. The economic loss to the fishery due to pollution, then defined as the difference between these two ($L = \pi(h_t, E_t, P_t) - \pi(h_t, E_t)$) and L denotes economic loss.

The economic loss approximated by calculating the loss of surplus production using the equation:

$$PS = P_0h_{0-} \int_0^{h_0} \frac{2c}{\alpha + \sqrt{-\beta + \alpha^2}} \quad (12)$$

Parameter α and β are constant coefficient of yield effort curve, obtained by solving Gompertz growth function simultaneously. By applying time series data of catch and effort these parameters derived using OLS technique. Parameter P and c represent the price per kg of fish and cost per unit of effort, respectively. Parameter h represents average landing from the fishery under pollution scenario, while $h_0$ represents landing under the untainted scenario. Data for these landings were obtained from adjacent landing sites with and without polluted water.

The regression results reported in Table 2, which include one year lag of the dependent variable as one of the regressors, are the empirical representation of the theoretical model outlined in Equations (1) to (12). These theoretical equations are a district dynamic (difference equation) model with one period difference (one year). Therefore, the use of one year lag in the regression is dictated by the theoretical model.

The analysis of fish catch resources depletion and depreciation were calculated using the formula developed by Anna [38], which is a modification of Amman and Duraipah models with the equation as follows:

$$\emptyset_{Dt} = \frac{1}{(1+e^{\frac{hs}{ht}})} \quad (13)$$

Where $ØD_t$ is a degradation coefficient during period t and h is the production on period t, $h_s$ is a sustainable production. The depreciation resulting from fishing activities is determined by the formulation developed by anna [38], as follows:

$$\emptyset_{\mathrm{Dt}} = \frac{1}{(1+e^{\frac{\pi s}{\pi t}})} \quad (14)$$

In this formula, $ØD_t$ denotes the depreciation during period t, $p_t$ is the economic rent on period t, and $p_s$ is the economic rent on a sustainable condition.

## Results and Discussion

Cirata Dam was built with the main purpose of a hydro-electric power plant besides its function as a water reservoir. The Cirata power plant has an installed capacity of 1428 Giga Watts (GWH) that is routed through the high-voltage transmission of 500 kilovolts to the Java-Bali power grid. If fully operated, this PLTA can distribute 1,008 MW of Java-Bali's total electricity and 23,000 MW at its peak.

This dam also has other economic values such as fisheries, aquaculture, and tourism. Even till this day, the dam is considered as one of the dams with the most significant aquaculture production and has become the center of freshwater fish cultivation in West Java, which is famous for the cultivation system of floating net cages. The number of floating net cages in Cirata has reached 70,000 units with an economic value of 241 billion Rupiah per year.

The dam has also become one of the non-economic potentials in the forms of externalities. The dam turned to be the location of waste disposal coming from Citarum river watershed, both from point sources of domestic waste and non-point sources of industrial waste. This problem would inevitably cause a severe decline in water quality in Cirata Dam [31, 34]. As a result, there is a decrease in the dam area (shallowing) that happens very rapidly every year.

Fish catch activities in these waters include the use of main fishing gears, which include handline, gillnet, and cash net. The production and catch per unit effort

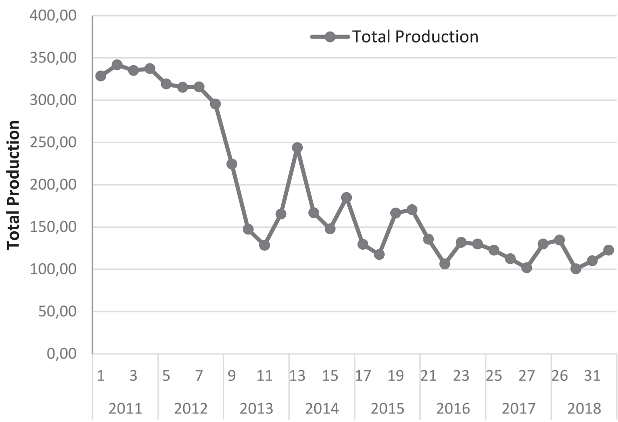


Fig. 2. Production per quarter of Cirata Fisheries.

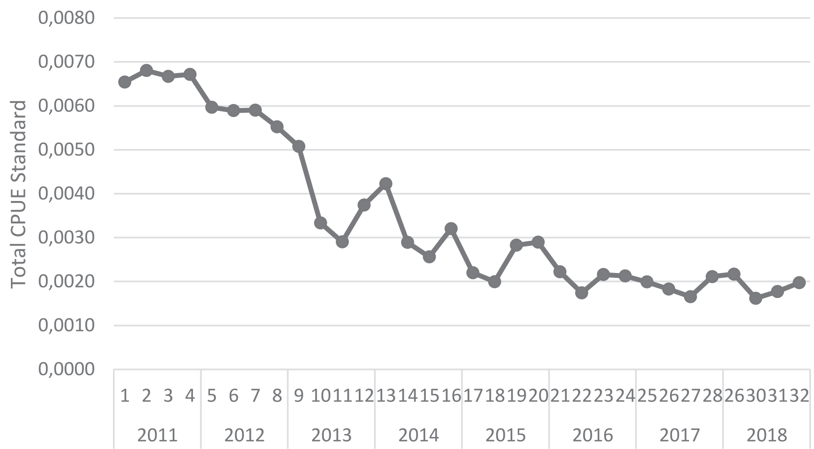


Fig. 3. Total Catch per Unit Effort Standardize.

of fish catch in this region decreased throughout the year as can be seen in Fig. 2 and 3.

The reduction of catch production (Fig. 2) and also the number of catch per unit effort (Fig. 3) are caused by the quality of water habitats from various pollutants. It is also because of the tendency of free, unregulated fishing behavior become the cause of overfishing both economically and biologically, as reported by several studies [5, 17, 30, 40].

It can be calculated that the highest pollution load comes from COD. This pollutant comes from domestic waste and industrial waste sources around the main river that goes into the dam, such as textile, food, and other industries. Based on Fig 4., the trend of total pollution load is increasing from year to year. However, the total load from aquaculture, such as the floating net cage industry, is excluded. Cirata Dam is estimated to produce 145,334,000 kg of organic waste containing 6,611,787 kg of nitrate and 1,041,417 kg of phosphate. Decomposition of the organic waste reducing the concentration of dissolved oxygen and producing other gases that may endanger the lives of other organisms, including fish. Too much nutrient can also cause eutrophication and lead to excessive growth of phytoplankton (blooming).

The analysis of the Gompertz model for the baseline and pollution model resulted in statistic performances as shown in Table 1.

As shown in the Table 1, the biological parameter values from the baseline and pollution conditions experienced significant changes, all parameters experienced decreased in value, the value of intrinsic growth parameters on the polluted condition shows a negative, which means there is a decrease in growth rate, according to Brown [41], there is a decline in Zebrafish population due to pollution and climate

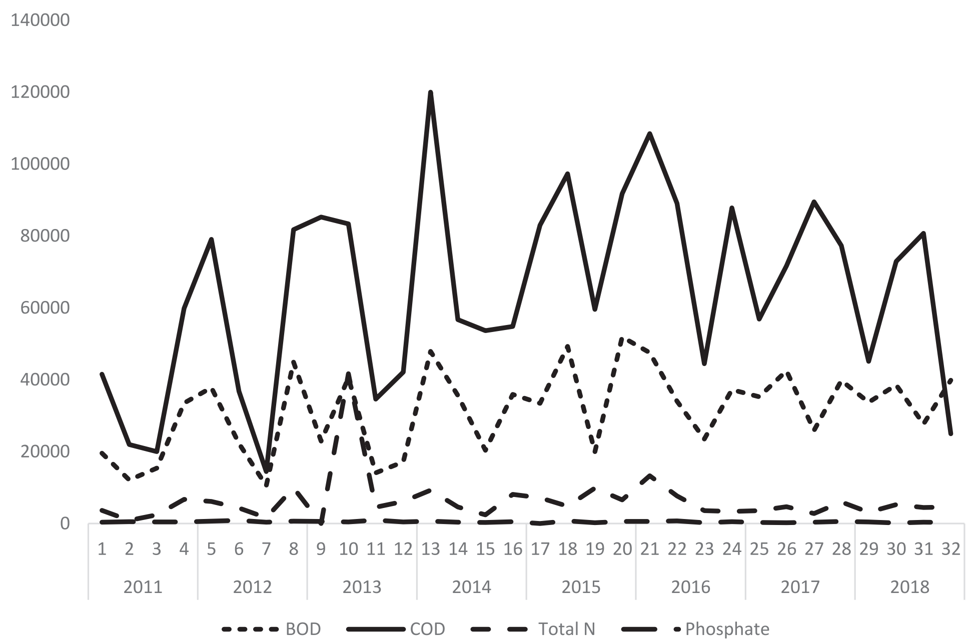


Fig. 4. Pollution Load at Cirata Dam per quarterly.

Table 1. Statistic Models Performance.

| Variable | Model | | | |
|---|---|---|---|---|
| | Without Pollution | | With Pollution | |
| | Coefficient | P Value | Coefficient | P Value |
| Constant | -0.571 | 0.169 | 0.0027 | |
| Et | | | 3.1319 | 0.160 |
| LnEt | 0.814 | 0.000 | | |
| Et+E(t+1) | -5E-06 | 0.279 | | |
| EtLnEt | | | 0.63102 | 0.171 |
| UtEt | | | 0.00000 | 0.512 |
| P | | | -0.00001 | 0.375 |
| R2 | 85.78% | | 0.13800 | |
| Adj R2 | 84.76% | | 1.06% | |
| F Statistik | 84.44 | | 1.083456483 | |
| Prob F Stat | 0 | | 0.384315744 | |
| Durbin Watson | - | | - | |
| Formulation | LnU(t+1)= - 0,571 + 0,815LnUt - 0,0000005 Et+E(t+1) | | U(t+1)-Ut = 0,0027 + 3,13 Ut + 0,631 UtLnUt-0,0000000 P -0,00001 Ut Et | |

change. In the other words, pollution can affect the fish population. The values of biological parameters obtained, are shown in Table 2.

The impact of baseline and pollution condition to sustainable yield and yield effort curve can be seen in Fig. 5. It is evident that following a decline of pollution state's biological parameters values, there are also declining sustainable yield values in the pollution compared to baseline. While the yield effort curve of pollution state is shrinking compared to baseline, declining sustainable yield and shrinking of yield effort curve can also be seen from Anna's study results [38, 39], for capture fisheries in polluted Jakarta Bay.

The calculation of fishery rent indicates a decrease from the baseline condition to the pollution condition. Furthermore, by using the average discount during observation time of data from Bank Indonesia, that is 6.79, the present value from fishery economic rent in Cirata Dam can be calculated. The result of the present value analysis shows that pollution significantly decreases the present value of economic rent that should be generated from fish catch in Cirata Dam. From the table, it appears that total loss presents the value of the economic rent due to pollution per quarter averaged to 4.6 Billion Rupiah or 340.7 thousand USD. Losses due to pollution are also calculated using the calculation of surplus production, the average loss of producer surplus per quarter amounted to 488,29 million Rupiahs.

Total net benefits under the baseline and pollution scenarios, From the loss of rent and producer surplus, total economic loss value in fish catch resulted from pollution is approximately 19.2 billion from 2011 to 2016 or an average of 3.2 billion rupiahs per year or 237 thousand USD per year, This value is a significant loss, considering that fisheries in this region are on a traditional scale that relies on an average income of only 6,000 to 23,000 rupiah per trip. The depletion rate calculations show significant differences between the baseline and pollution conditions, whereas at baseline, the average rate of depletion is 31% per quarter while in the polluted condition are at 33% per quarter, While the depreciation value obtained from polluted condition

Table 2. Biological Parameterization of Baseline and Pollution Model.

| Parameters | Without Pollution (CYP) | With Pollution |
|---|---|---|
| Intrinsic Growth ( r ) | 0.204929 | 0.631022 |
| Carrying Capacity (K) | 4.360 | 940 |
| Catchability Coefficient (q) | 0.000011 | 0.000007 |
| Pollution (γ) | - | 0.0002922 |

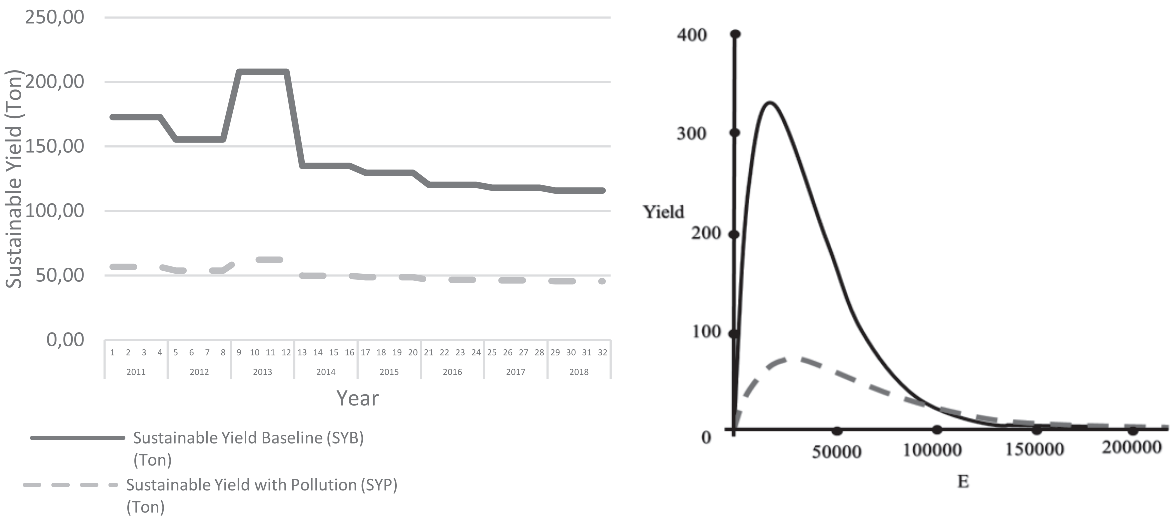


Fig. 5. Comparison of Sustainable Yield Baseline and Pollution Scenario.

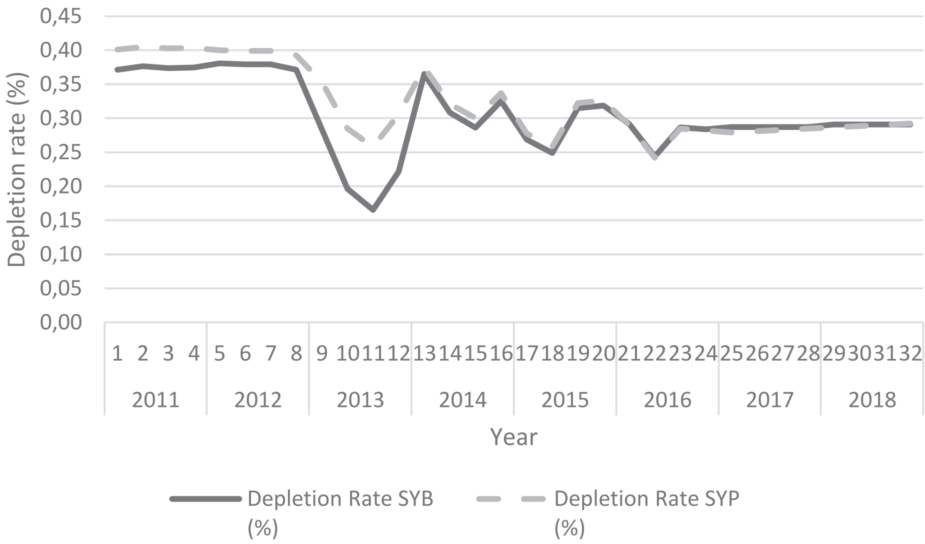


Fig. 6. Depletion Rate in the Baseline and Pollution Condition.

compared to the baseline condition shows 412.94 million rupiah per quarter under baseline condition and 568 million rupiah per quarter under pollution due to differences between actual and sustainable fishing conditions.

## Conclusions

There are not many studies discussing the impact of dam water pollution as well as the cost of the damage experienced by dam fisheries. The dam pollution is the excess of various economic and non-economic activities in the dam such as aquaculture as well as household, industrial and agricultural waste. This research shows that there is an impact of the pollution of dam waters from various activities surrounding the dam on fisheries production and at the same time the loss of economic value from fisheries. From the results of the study, it can be concluded that pollution gives effect to fisheries sustainable yield in Cirata Dam. In this case, there is a decrease in the value of biological parameters such as intrinsic growth (r), carrying capacity (K), and the catch capability coefficient (q). In line with the declining value of these biological parameters, pollution can also decline the curve of yield effort chart resulting in its sustainable yield to become significantly lower, the decrease in sustainable yields on polluted condition compared to the baseline condition (only influenced by fish catch activities), followed by the decline in rents that should be obtained from fish catch. Furthermore, the producer surplus is also corrected significantly. The total economic loss due to the pollution per year is up to 3,2 billion Rupiah.

This study recommends the need for a more integrated management of dam and fishery resources.

Stricter rules are needed to prohibit industrial and domestic waste disposal into rivers entering dam waters, the spatial planning that prioritizes forest conservation to avoid sedimentation, and limits on fishery inputs for both aquaculture and fish catch by recalculating the appropriate input and output quantities, under the environmental carrying capacity, and also follows the rules of sustainable fish catch instruments management with sustainable yield and optimal yield management regime. It is necessary to socialize and empower the community around the dam, to be able to conduct co-management of sustainable use of the dam, because community-based management of the common property resources such as the dam is highly efficient.

## Acknowledgments

This research was financially supported by Directorate General of Higher education, Ministry of Research, Technology and Higher Education Indonesia for funding this research through PTUPT 2017 Scheme.

## Conflict of Interest

The authors declare no conflict of interest

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