Sustainable aquaculture in the Koto Panjang Reservoir, Indonesia

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Abstract. The Koto Panjang Reservoir is a fish cultivation area with floating net cage systems with carp (*Cyprinus carpio*) commodities and only concentrated in the dam site. The sustainability of this fish farming business is under threat from its own activities which can lead to a decrease in quality due to the entry of leftover feed and metabolic products of cultured fish into the waters, as well as the entry of organic and inorganic materials from other activities in the riverine and lacustrine zones. This study aimed to analyze the sustainability status of fish farming, the attributes of levers and the driving factors in the management of fish farming in this reservoir. The research method used consisted of survey methods, interviews, laboratory analysis and literature studies to collect primary and secondary data covering five sustainability dimensions, namely: ecological, economic, socio-cultural, technological and legal-institutional dimensions. The comprehensive analysis method of each dimension uses multidimensional scaling analysis (MDS), with the help of the Rapfish software. Prospective analysis is used to determine the components of the dominant factors in the management strategy of this fish farming. The status of fish farming was found in the moderately sustainable category, with an index value of 67.26. The results of the MDS analysis of the economic and technological dimensions showed a very sustainable status, with index values of 94.35 and 84.66, respectively. Meanwhile, the analysis results from the ecological and legal-institutional dimensions showed a quite sustainable status, with index values of 71.66 and 51.16, respectively, and the socio-cultural dimension had a sustainability index value of 34.46, which means less sustainable. The average value of stress, squared correlation (R2) and validation test obtained were 0.14, 0.94 and <5, respectively, which indicates that the results of this MDS analysis are acceptable and adequate as an estimator of the sustainability index value.

Key Words: *Cyprinus carpio,* multidimensional scaling, sustainability index, defining factor.

Introduction. The Koto Panjang Reservoir has long been a location for the cultivation of floating net cages and about 70% of the cage plots are concentrated around the dam site (Budijono et al 2021). The number of fish cages operating at this location reached 1,204 plots, the same as in 2019 (IEC 2019). During the period of 5 years (2016-2020), the cage plots increased by only 51 plots (4%) compared to the increase in 2009-2015 which reached 253 plots. However, the increase in the number of plots was not directly proportional to the increase in the concentration of nitrate, total nitrogen and total phosphate, including both suspended and dissolved organic matter which could cause a decrease in the water quality. It turns out that, in the riverine and lacustrine zones without cage activity, this water quality parameter is also already above the quality standard, so that contributions come from plantation, agricultural, residential and tourism activities (Budijono et al 2021), which also have the potential to reduce water quality around the location of the dam, which is the location for the cultivation of carp (*Cyprinus carpio*). However, the development and strengthening of the aquaculture industry does not reflect sustainable fisheries development, because it is located close to the dam so that it can threaten the electricity supply and economic activity of the community, which is most important than that borne by about 30 cage business owners and other problems develop. The same thing also happened in Jatiluhur Reservoir (Putri et al 2019). This means that the essence of sustainability has not yet become a concern for both cultivators and the local government. According to Sutardjo (2014) and WCED (1987), the meaning of sustainability is the harmony between the economy, society and environment to ensure the needs of present and future generations, which are expected to be capable of economic growth and equity that is balanced with the environmental conservation.

The concept of aquaculture sustainability, according to FAO (2010), is implemented in the ecosystem approach to aquaculture (EAA), that considers the balance between ecological, social, and economic aspects. In order to avoid problems that arise as a result of cage cultivation activities, it is necessary to pay attention to the five dimensions of sustainable development (ecological, economic, socio-cultural, institutional and technological) and such a research has not been carried out.

Material and Method

Description of the study sites. The present research was conducted from March 2020 to February 2021 and sampling was carried out every three months in June, September, December, and March. The sampling location in the Koto Panjang Reservoir was determined by purposive sampling from 10 stations, representing the upstream part of the river (upstream), puddles (reservoir) and downstream reservoir (downstream), consisting of Station 1: Tanjung Balit Village, Station 2: Tanjung Village, Station 3: Batang Mahat Village, Station 4: Koto Tuo Village, Station 5: Batu Besurat Village, Station 6: Bridge 1, Station 7: Bridge 2, Station 8: damsite reservoir, Station 9: dam footprint outlet and Station 10: Rantau Berangin bridge, shown in Figure 1.

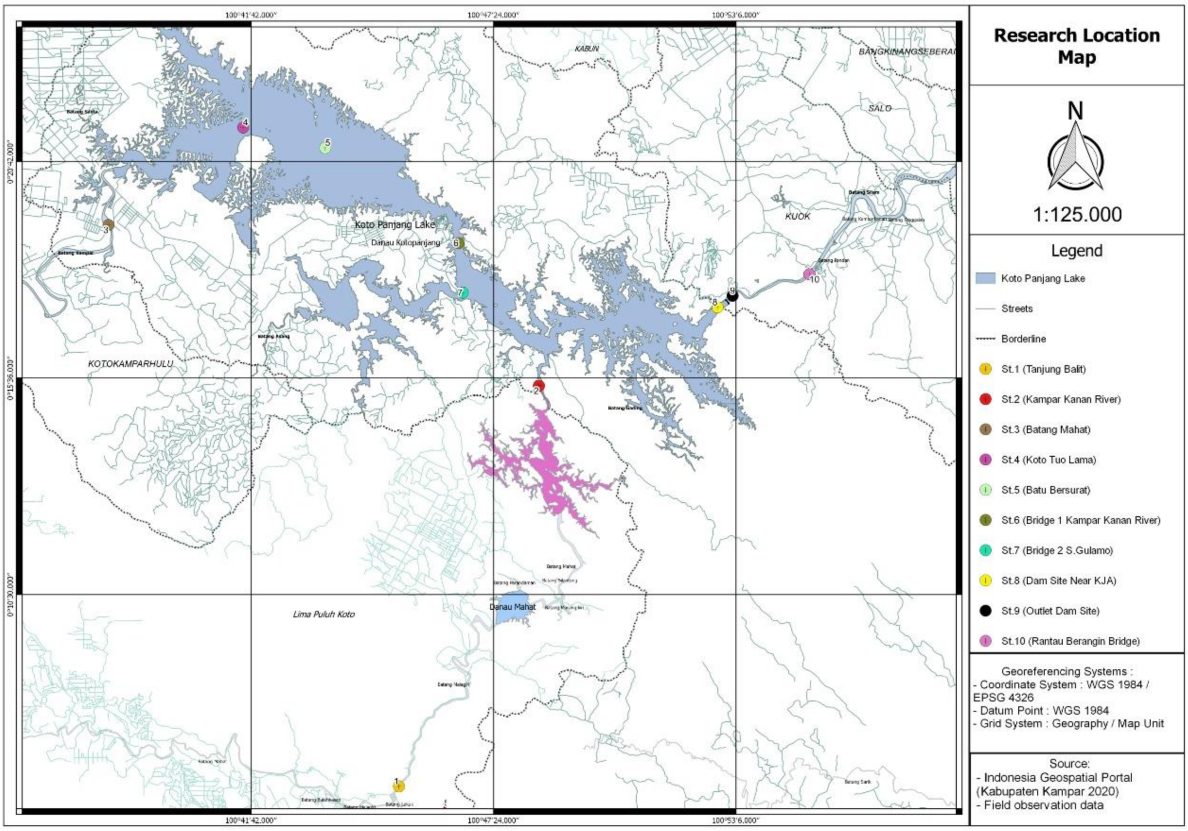


Figure 1. Sampling stations location in the Koto Panjang Reservoir, Riau Province, Indonesia.

Research design. The research design was carried out using survey methods, literature studies, laboratory analysis and interviews. The collection of biophysical, economic, social, technological and institutional data was carried out by survey methods. Interviews were conducted to identify environmental issues that arise in aquaculture management;

to know the problems and opinions of stakeholders regarding the management of aquaculture, and to find out the opinion of experts or experts regarding the management of aquaculture in the Koto Panjang Reservoir.

Research scope. The scope of this research consisted of ecological, economic, socio-cultural, technological and legal-institutional aspects (Figure 2).

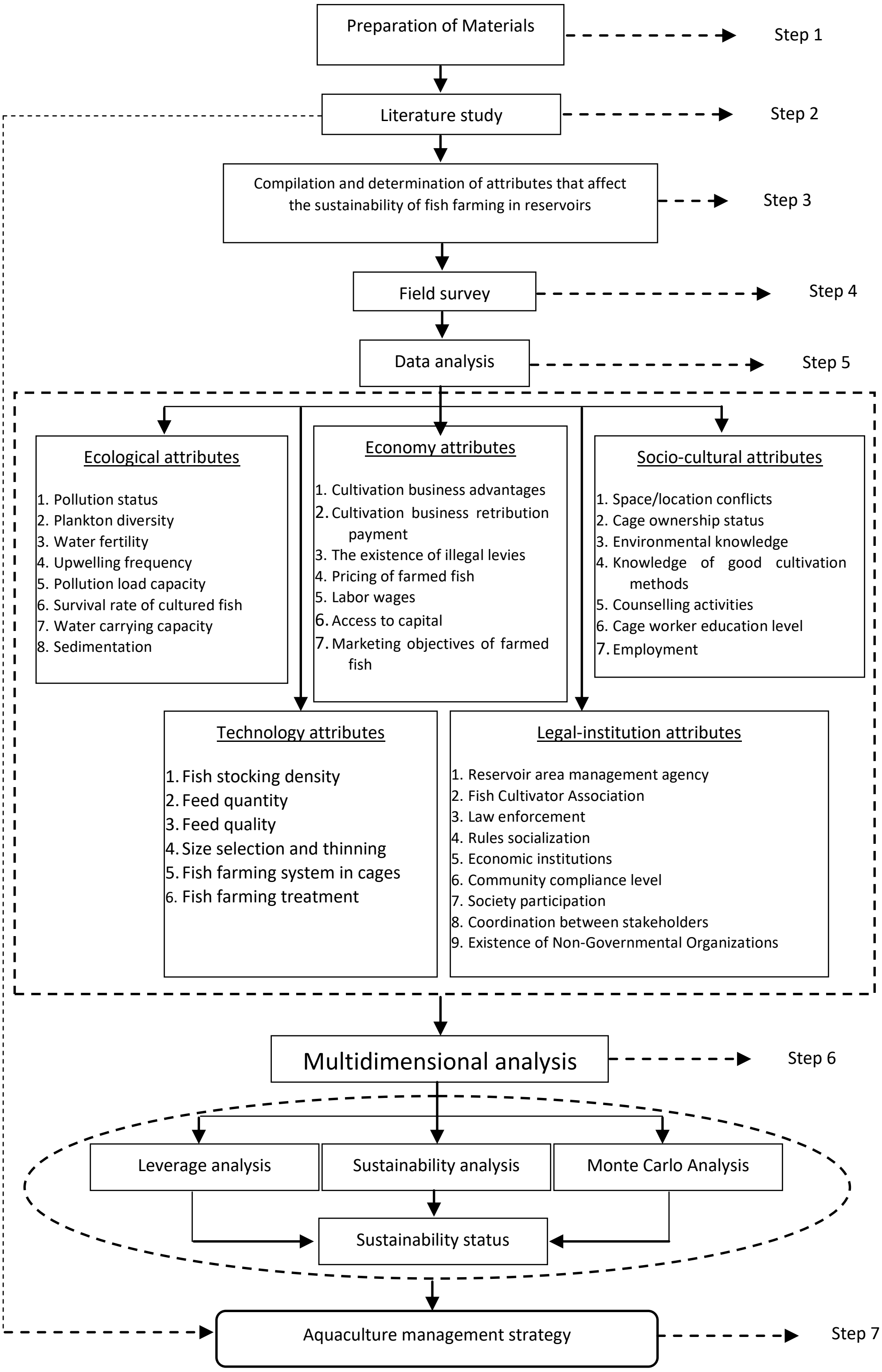


Figure 2. Research operational framework.

The stages of implementing this research, as described in Figure 2, consist of:
(1) a desk study is carried out by collecting various research results on reservoirs and the factors that influence them;
(2) preparation and determination of key (main) attributes in each ecological, economic, socio-cultural, technological, and legal-institutional dimension that affect the sustainability of fish farming management in this reservoir;
(3) conducting field surveys to collect data on biophysical, economic, socio-cultural, technological, and legal-institutional components;
(4) analyzing data on ecological, economic, socio-cultural, technological and legal-institutional dimensions, sustainability analysis and prospective analysis;
(5) determine the sustainability status of fish farming in reservoirs;
(6) develop alternative scenarios for fish farming management strategies based on the results of prospective analysis.

Data types and data collection methods. The types of data used in this research consist of primary data and secondary data. Primary data was collected from direct observation findings at 10 research stations and respondents through interviews, while secondary data was collected from literature in the form of results, research reports and technical reports from various government agencies and universities related to the Koto Panjang Reservoir. Details of the types and sources of data needed in this research are shown in Table 1.

Table 1

Date type and data source

Data type	*Data source*
Primary data	
Ecological data	
Water quality status (temperature, turbidity, TDS, TSS, pH, DO, BOD_5, COD, nitrate, NH_3, Total nitrogen, Total phosphate)	In situ and laboratory
Plankton diversity	In situ and laboratory
Water fertility	In situ and laboratory
Upwelling frequency	Respondent (stakeholders)
Pollution load capacity	In situ and laboratory
Survival rate of cultured fish	Respondent (stakeholders)
Water carrying capacity	In situ and laboratory
Sedimentation	Indonesian Electricity Company (IEC 2020)
Economic, social-cultural, technology and legal-institutional data	Respondent (stakeholders)
Secondary data	
Total population	Indonesian Central Statistics Agency (2020)
Regional minimum wage	Indonesian Central Statistics Agency (2020)

Respondents from community groups were determined based on criteria that represented several communities, including cultivators (cage owners and workers), fishermen, tourism and other communities related to fish farming activities. In-depth interviews were also conducted with informal sources (community leaders, fishermen, cultivators, tourism actors) and formal sources as key stakeholders and experts, such as the Departments of Fisheries, Agriculture, Plantations, Environment of Bappeda Kampar Regency, Department of Fisheries and Marine Affairs of Riau Province, universities and NGOs. The selected key respondents or experts have competence in the field of work related to the reservoir area, in particular in aquaculture. According to Marimin (2004), respondents should be selected according to their knowledge of the problem, in order to share information. Other considerations include the experience and reputability and credibility in the field and at the location being studied. Interviews with respondents used a closed questionnaire technique, based on a choice among the already available answers.

Data analysis. Each attribute in each dimension was given a score based on the scientific judgment of the scorer, with a range between 0–3 (Table 2) or depending on the state of each attribute, which is interpreted from bad to good. The aggregate score results, base on index values ranging from 0 to 100 for each attribute, were analyzed by multidimensional scaling (MDS), as in Table 3.

Table 2

Assessment of attributes on an ordinal scale (scoring)

Attribute	*Score*	*Evaluation*	
		Good	Bad
Ecology, economics, social culture, technology, legal-institutional	0;1;2;3	3	0

Table 3

Category for the sustainability status of aquaculture management (Fauzi & Anna 2005)

Index value	*Category*
0.00-25.00	Bad (not sustainable)
25.01-50.00	Inadequate (less sustainable)
50.01-75.00	Fair (fairly sustainable)
75.01-100.00	Good (highly sustainable)

The components of the determining factors (dominant factors) of the fish farming management strategy in the Koto Panjang Reservoir were obtained through a prospective analysis (Bourgeois & Jesus 2004; Hardjomidjodjo 2004).

Results

Sustainability status for the ecological dimension. The attributes that are estimated to have an influence on the sustainability of deep fish farming from the ecological dimension perspective are: (1) water conditions; (2) plankton diversity; (3) trophic level index (TLI); (4) the survival rate of caged fish; (5) sedimentation; (6) the capacity of the pollution load based on fish cage waste; (7) up-welling frequency; (8) the death of caged fish due to parasite/disease attack; and (9) water carrying capacity. The results of the sustainability analysis based on the ecological dimension resulted in a sustainability index of 72%, classified as quite sustainable (Figure 3a). This value illustrates that cage aquaculture activities experience low pressure from the ecological aspect. This is in accordance with field observations which revealed that the reservoir environment experienced a decrease in water quality in the lightly polluted category both at the upstream location, without any floating net cage fishing activities, and at the floating net cage activity location, even at the reservoir outlet. Odum (1996) stated that ecology is the study of the structure and function of an ecosystem or nature, and humans as part of it. Thus, the impacts caused by human activities will affect the structure and function of the ecosystem.

Based on the results of the MDS analysis (Figure 3a), the sustainability status of floating net cage aquaculture for the ecological dimension has a value of 72% with a fairly sustainable category and the position of the value of 72% is below the value 0 on the x and y axes. Statistically, this shows an indication of a decline even though the status is quite sustainable.

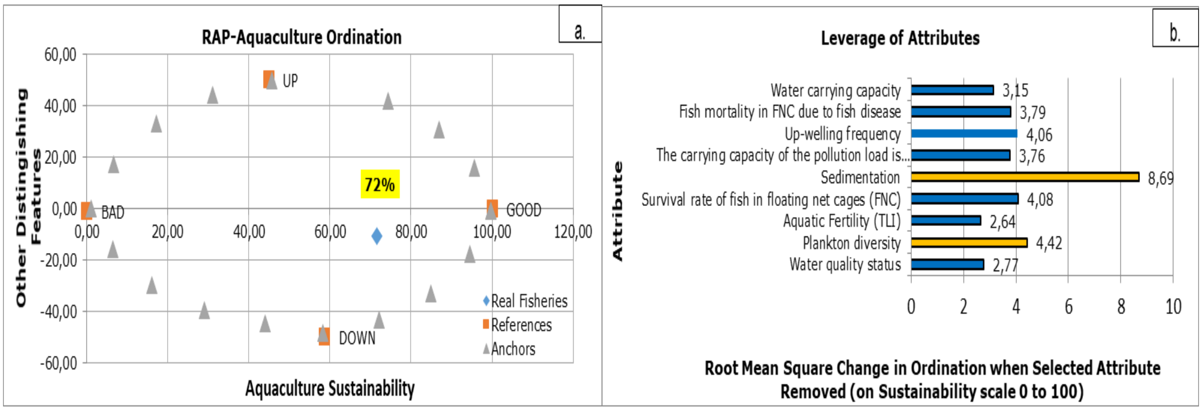


Figure 3. The value of the ecological dimension sustainability index and the influence of each attribute, based on the RMS value.

Based on the analysis of leverages (Figure 3b), there are two attributes that are sensitive to the sustainability index value of the ecological dimension which has a change in the value of the root mean square (RMS) which is represented by an elongated bar (yellow color), more than half the value scale on the x-axis, namely: (1) sedimentation (RMS=8.69) and (2) plankton diversity (RMS=4.42). This shows that if there is an intervention on sedimentation and plankton diversity, it will affect the value of the sustainability index. The RMS value indicates the magnitude of the influence of each attribute on the sensitivity of the sustainability status. According to Kavanagh & Pitcher (2004), the higher the RMS value, the greater the influence of these attributes on the sustainability sensitivity. Thus, these two attributes provide an interpretive direction suggesting that cage cultivation is strongly influenced by activities on land and floating net cages themselves.

Sustainability status for the economic dimension. The attributes that are estimated to have an influence on this economic dimension are: (1) marketing objectives for marine cages; (2) access to capital; (3) labor wages; (4) fluctuations in the price of cultured fish; (5) the existence of illegal levies; (6) payment of retribution for cage business; and (7) the profits of the cage cultivation business. Based on the MDS analysis of the sustainability of fish farming in cages from the economic dimension, a value of 93% is obtained, which is classified as very sustainable (75.01–100.00) (Figure 4a) and the position of this value is above the value of 0 on the x and y axes, which statistically indicates an increase with the status of very sustainable. This illustrates that the management of fish farming in cages is experiencing very little pressure from the economic aspect and it is very clear that it provides large economic benefits for cage owners so that they are able to encourage the economic growth of the local community. This advantage is driven by the cage system carp farming business which is still profitable, because the market is still able to absorb the production of cultivated fish, without generating any legal fees, thus increasing the income of the cage workers.

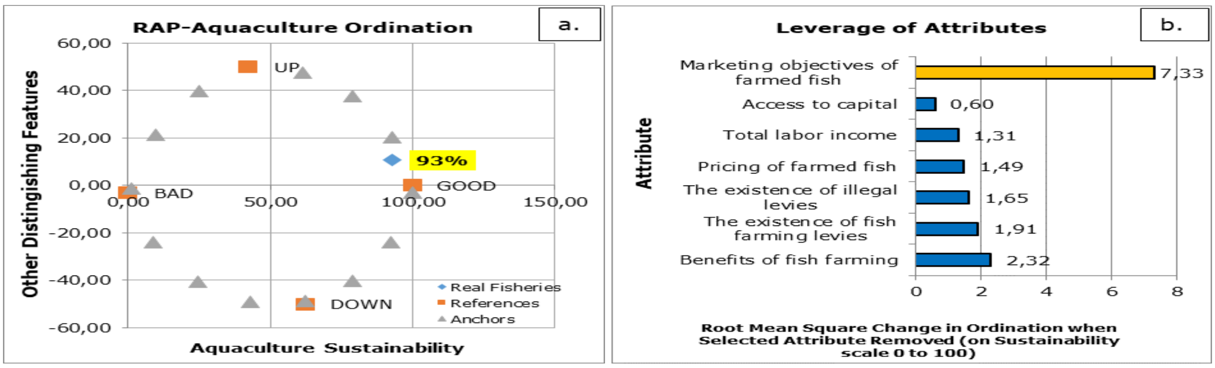
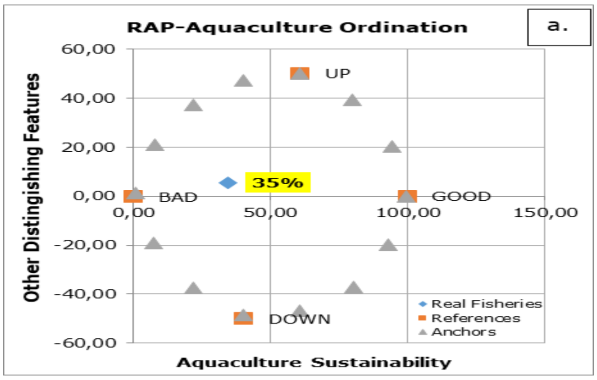


Figure 4. Value of the sustainability index of the economic dimension and the influence of each attribute, based on the RMS value.

Based on the analysis of leverages (Figure 4b), there is one attribute that is sensitive to the value of the sustainability index of the economic dimension which has a change in the value of the RMS, which is represented by a longitudinal bar (yellow color) of more than half the value scale on the x-axis: marketing of cultured fish (RMS=7.33). This states that the value of the sustainability index of the economic dimension is influenced if there is an intervention in the marketing objectives of aquaculture to absorb the fish production.

***Sustainability status for the socio-cultural dimension*.** The attributes that are estimated to have an influence on the social dimension are: (1) absorption of local labor; (2) education level of cage owners/workers; (3) outreach activities; (4) knowledge of good fish farming practices; (5) environmental knowledge; (6) cage ownership status; and (7) space/location conflicts. The results of the MDS of the socio-cultural dimension are shown in Figure 5a and the leverage analysis in Figure 5b.



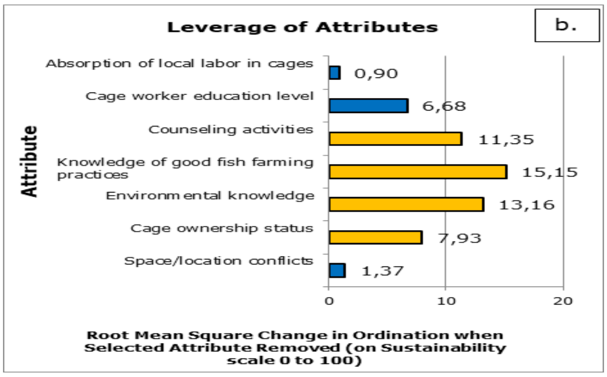


Figure 5. The value of the sustainability index of the social dimension and the influence of each attribute aspect, based on the RMS value.

The results of the MDS analysis (Figure 5a) on the sustainability of fish farming in cages from the socio-cultural dimension has a value of 35%, which is categorized as less sustainable (25.01–50.0). It is observed that the position of this 35% value is above the value of 0 on the x and y axes. Statistically, this shows an indication of improvement, even though the sustainability status is inadequate.

Based on the results of the analysis of leverage of the attributes (Figure 5b), showing the most sensitive attributes, that have an influence on the value of the sustainability index of the social dimension, three sensitive attributes were obtained, namely: (1) knowledge of good fish farming practices (RMS=15.15), (2) environmental knowledge (RMS=13.16) and (3) extension activities (RMS=11.35) (Figure 5b). The attributes: knowledge of good fish farming practices, environmental knowledge, extension activities and cage ownership status are classified as very sensitive. Good fish farming practices and increased environmental knowledge in the application of fish cultivation by fish farmers arise because of the awareness that the water area is fixed and limited, while cage aquaculture activities tend to increase. Therefore, extension activities are needed as a form of informal education to increase the applied knowledge of the cage owners/workers and of the community around the cage location. This is in accordance with what Hermawan (2005) stated that there is a positive relationship between the level of education and the environmentally sustainable behavior: a high level of education will provide a positive behavior towards the environment. Thus, these three attributes need serious attention to increase the sustainability of the social dimension.

Sustainability status for the technology dimension. The attributes that are estimated to have an influence on the technological dimension are: (1) feed quality, (2) feed quantity, (3) fish farming system in cages, (4) size selection and thinning, (5) fish stocking density and administration of drugs. The results of the MDS analysis on the sustainability of fish farming in cages from the perspective of the technology dimension are presented in Figure 6a.

Figure 6. The sustainability index value of the technology dimension and the influence of each attribute aspect, based on the RMS value.

Figure 6a shows that the sustainability of fish farming in cages in terms of technological dimensions has a value of 85% in the very sustainable category (75.01–100.00). The position value of 85% is above the value 0 on the x and y axes. Statistically, this is an indication of improvement with good sustainability status.

Based on the analysis of leverage (Figure 6b), one attribute is sensitive to the value of the sustainability index of the technology dimension, namely, fish farming systems in cages (RMS=15.34). The results of field observations show that the cage cultivation system is still semi-intensive with the use of low stocking densities of fish and submerged type of commercial feed (pellets), without any additional technological input during fish rearing. An additional technological input for the restoration of water quality, which is considered environmentally friendly, has been introduced as SMART floating net cage technology. It can reduce the input of organic pollutants from wasted feed and fish excretion (Astuti et al 2009) and the nutrients contained can be utilized by plants. Also, it is able to reduce ammonia which can be toxic to currently cultivated fish. However, this SMART floating net cage does not need to be implemented by fish farmers in the Koto Panjang Reservoir because it will increase the cost of net bags and other costs. Therefore, efforts are needed to maintain this semi-intensive cultivation system, which is a sensitive attribute of the sustainability index of the technological dimension.

Sustainability status for the legal-institutional dimension. The attributes that are estimated to have an influence on the legal and institutional dimensions are: (1) the existence of a community self-sufficiency institution, (2) coordination between stakeholders, (3) the community participation, (4) the level of community compliance, (5) economic institutions, (6) socialization of rules, (7) law enforcement, (8) association of cage cultivators and (9) the management agency supervision of the production location and quantity. Based on the MDS analysis of the institutional dimension's sustainability index, the resulting value of 51% is categorized as moderately sustainable (Figure 7a). Based on Figure 7a, the position of the 51% value is below the value 0 on the x and y axes. This shows a statistical indication, although the status is moderately sustainable.

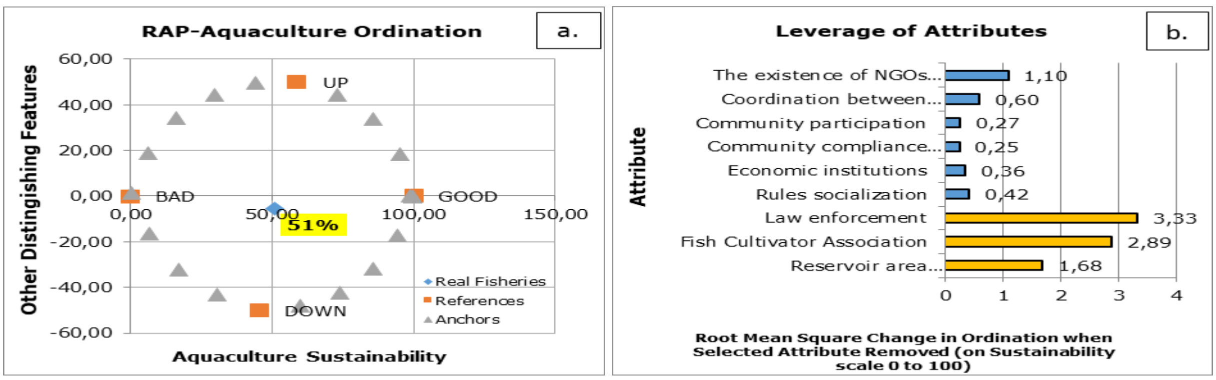


Figure 7. Sustainability index value for legal-institutional dimensions and the influence of each attribute aspect, based on the RMS value.

The leverage analysis on Rap-aquaculture (Figure 7b) indicated the three most influential attributes on the institutional dimension of the sustainability of fish farming in cages, namely: (1) law enforcement (RMS=3.33), (2) fish cultivators association (RMS=2.89) and (3) reservoir area management agency (RMS=1.68). These three attributes resulting from the observations and interviews, although not found at the floating net cage location, need to be considered in order to improve the institutional dimension of the sustainability status of the cage cultivation. It is important to consider the government's policy in order to establish reservoir management institutions, based on transparent mechanisms for the parties' roles regulation, since the farmer groups alone cannot manage the conservation of natural resources.

Sustainability status from a multidimensional perspective. The results of the MDS analysis show that there are two dimensions with a sustainability index value between 75 and 100 (very sustainable), namely: the economic dimension (93%) and the technological dimension (85%). Meanwhile, there are two dimensions that are considered quite sustainable, namely the ecological dimension (72%) and the legal-institutional dimension (51%). On the other hand, the socio-cultural dimension has a sustainability index of only 35%. This data implies that the management of aquaculture in the Koto Panjang Reservoir remains oriented to the socio-cultural and legal-institutional dimensions, and maintains the ecological, economic and technological dimensions. The results of the MDS analysis are illustrated in the form of a kite diagram (Figure 8).

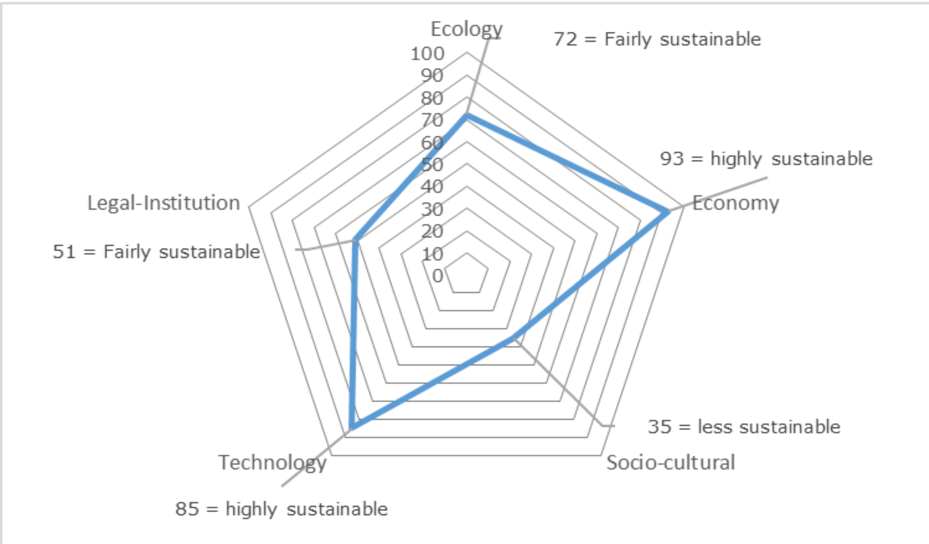


Figure 8. Fly-chart analysis of the sustainability index of the aquaculture floating net cages.

Stress value, coefficient of determination and error effect. The stress value of the Rap-KJA ordinance analysis from each dimension is analyzed to measure the accuracy of the configuration of a point that reflects the original data. Meanwhile, the explanatory ability and the contribution of each attribute to the sustainability of the system under study is determined based on the value of the coefficient of determination (R^2) of each analyzed dimension. On the other hand, a Monte Carlo analysis was performed to evaluate the effect of the attributes' assessment errors, the effect of score variation, the stability of the iterative MDS analysis process and the errors in the data input process or caused by missing data. Stress values, coefficient of determination and Monte Carlo analysis of each dimension are presented in Table 4.

Table 3 shows that the average stress value of all dimensions is 0.14, while the average value of R^2 is 0.94. In MDS, the stress value is said to be good if it is less than 0.25 (Malhotra 2006). The goodness of fit value in MDS is better when the stress value is close to zero. Kavanagh (2001) stated that the maximum tolerable stress value is 20%. Thus, the model is accepted with a stress value of 14%.

Table 4

Stress value, coefficient of determination (R^2) and Monte Carlo analysis

Dimension	*Sustainability index (MDS)*	*Stress*	*Coefficient of determination (R²)*	*Monte Carlo analysis (MC)*	*Difference MDS–MC*
Ecology	72	0.14	0.95	70	2
Economy	93	0.13	0.95	91	2
Socio-cultural	35	0.15	0.92	37	2
Technology	85	0.15	0.92	81	4
Legal-institutional	51	0.14	0.95	51	0

The goodness of fit test results also reveal that a model for estimating the sustainability index can be used, where the resulting quadratic correlation value (R^2) is equal to 0.94 or close to 1. An R^2 value close to 1 means that the existing data is mapped perfectly. This value indicates that the retained model is explanatory in a proportion of 9%and the remaining 6 percent is explained by other unconsidered factors. Kavanagh (2001) argues that a value of the squared correlation (R^2) greater than 80 percent indicates that the model for estimating the sustainability index is good and adequate to be used.

Each of the 10 sensitive attributes of the leverage analysis was used to determine the driving variables in the prospective analysis. From the results of the prospective analysis, it was found that 5 attributes are spread out in quadrant 1 and 4 attributes are in quadrant 3, as shown in Figure 9. Thus, the distribution tends to cluster in quadrant-I and quadrant-III. According to Bourgeois (2002), this type of distribution shows that the system built is stable because it shows a strong relationship, where the driving/determinant variable strongly regulates the dependent variable. Thus, the 5 determinants of the sustainability of cage cultivation in this reservoir are: (1) reservoir area management agency, (2) fish cultivator associations (3) law enforcement, (4) cage cultivation system and (5) extension activities, because they are located in quadrant 1. Attributes in quadrant 1 have a strong influence and dependencies between attributes are low, while the other 4 attributes (knowledge of good fish farming methods, diversity of plankton, sedimentation and marketing of cultured fish), located in quadrant 3, are output variables with a low influence and a strong mutual dependency.

Discussion

Sustainability status for the ecological dimension. In the ecological dimension, attributes like plankton diversity and sedimentation have a high sensitivity due to the erosion potential, as a result of changes in the catchment area. Sedimentation was monitored at the Batang Mahat Lama, Sungai Gulamo, Koto Tuo and Dam Site locations with an erosion potential of 402.8 tons ha^{-1} $year^{-1}$ (IEC 2020) and classified as heavy, based on the classification of the erosion hazard level (Ministry of Forestry of the Republic of Indonesia 1998). Around the Koto Panjang reservoir area, there are agricultural areas of about 32,296 ha, plantations (oil palm and rubber) covering about 11,548.57 ha, and residential land covering an area of about 1,243.11 ha (Nurdin et al 2017). This conversion of forest functions reduces its natural ability to prevent erosion and sedimentation so that the runoff contains a lot of soil material that is transported to low areas or to the waters. The exponentially decreasing forest vegetation canopy increases the magnitude of erosion and runoff. At the edge of the reservoir, land erosion directly enters the waters causing turbidity, as found in the reservoir transition zone, due to organic and inorganic materials carried by the rivers that supply the reservoir water source, especially the Kampar River and Batang Mahat River. The increased material on the surface of the water will reduce the diversity of plankton because sunlight is blocked by suspended material. The reservoir ecosystem and its landscape are one unit, just like a lake. Lake ecosystems and landscapes are inseparable parts (Haryani 2013), so that lake waters are influenced by activities in the lake catchment area (Kumurur 2001; Suhardi 2005). Therefore, an increased priority will be assigned to the sensitive attributes, while still considering the insensitive attributes, which will improve the sustainability status of fish farming from the ecological dimension perspective. The value of the sustainability status of the corresponding dimensions in Jatiluhur and Cirata Reservoirs is lower, with values of around 49.97% (Putri et al 2019) and 22.29% (Widiyati & Bengen 2012), respectively.

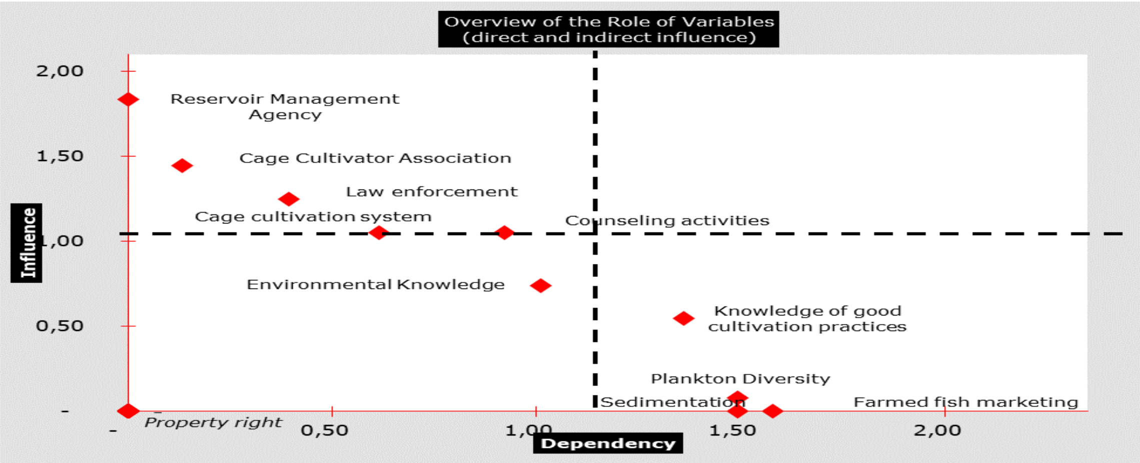


Figure 8. Effects and dependencies of the leverage factors, based on the sustainability analysis in floating cage cultivation fisheries, in Koto Panjang Reservoir.

Sustainability status for the economic dimension. In the economic dimension, the sensitivity value contained in 1 attribute, namely: the marketing objectives for the caged fish. The scope of marketing for caged fish is national, covering the Provinces of West Sumatra (City of Payakumbuh and Solok), North Sumatra and Jambi as well as the Provinces of Riau itself (Bangkinang and Pekanbaru). This attribute is very important to be managed for the absorption of the carp production per day, ranging from 10-15 tons in two harvest cycles per year. The profits earned by the cage owners are not reduced by the prescribed retribution fees and illegal levies, except for the garbage fee (per cage plot per month) mutual agreement of USD 0.34. This has a positive impact on the wages of cage workers, which is above the district/city minimum wage in Riau Province (USD 203.45 in 2020) and has caused other multiplier effects, such as opening up business fields and increasing the local community income. However, this sensitive attribute remains a priority that is managed while maintaining other attributes to anticipate the increase in carp production revenues (in the context of the Covid-19 pandemic) which is conditioned by the increasing purchasing power of the people. In the current research, the sustainability status for the economic dimension is higher than in Jatiluhur and Cirata Reservoirs with their index values of 54.13% (Putri et al 2019) and 51.32% (Widiyati & Bengen 2012), respectively.

Sustainability status for the socio-cultural dimension. 3 attributes of this dimension have a high sensitivity, namely: knowledge of good fish farming practices, environmental knowledge and extension activities. The sensitivity of the cage owner status is categorized as high, but it is considered not to affect the sustainability of this dimension because the operating cages are owned by individuals from the community. According to Putri et al (2019), ownership status can improve the social status in the community. Practical knowledge of good fish farming methods, as resulting from observations and interviews, comes from a long experience (about 19 years) in cultivating fish, supported by an adequate level of education. The owners or workers still do not have a good practice certificate in aquaculture, from the Fisheries Service of Kampar Regency, which could be a negotiation argument in global trade and a guarantee of the quality of the carp produced. In addition, the environmental awareness needs to be addressed, although in the last 3 years handling of the waste generated from cage activities was improved. This garbage is taken every day by garbage boats, but the garbage collected on the edge of the reservoir land is destroyed by burning and not coordinated with the local cleaning service. These two attributes can be managed by carrying out the intensity of extension activities, that have never been accepted by fish farmers, carried on especially by the related agencies, universities and others. On the other hand, the sustainability status for the socio-cultural dimension of the research is lower than, in Jatiluhur Reservoir (53.13%, according to Putri et al 2019) and in Cirata Reservoir (57.37%, according to Widiyati & Bengen 2012).

Sustainability status for the technology dimension. The technological dimension is categorized as highly sustainable and has one attribute that is sensitive to the sustainability index of this dimension, namely: fish farming systems. The cultivation system applied is semi-intensive using commercial pellets of sinking type and stocking density according to the cage capacity (60-70 fish m^{-3}), without additional technological input such as providing aeration to increase dissolved oxygen into the cage plot. This system is supported by the use of superior carp fry (rajadanu variety), resistant to diseases and having a low FCR (food conversion ratio). Cultivators also do size selection and thinning, without giving drugs. According to Putri et al (2019), the selection of sizes is carried out so that there is no competition for the size of the fish cultivated, while thinning aims to provide sufficient space for fish to grow more optimally and to quickly identify the grade of fish. With 30% protein content, the feed used is classified as good quality. Sukadi (2016) and Ardi (2013) recommend food with 24-30% protein, given at satiation. This method causes the amount of feed needed to be relatively higher and has a great opportunity to increase the amount of uneaten feed into the water, which is also a concern, in addition to the attributes that have a high sensitivity value. The application of SMART KJA (water management system cage with recirculation and plants) is not yet necessary, although it is able to reduce $P\text{-}PO_4$ with 6.3–84.8%, $N\text{-}NO_3$ with 4.1–77.7% and organic matter with 8.8–90.7%, after passing through aquaponic plants (Astuti & Krismono 2018) provided that the current cultivation system is maintained in 1204 cage plots. The value of sustainability status for the technological dimension of this research is higher than in Jatiluhur and Cirata Reservoirs: 57.53% (Putri et al 2019) and 49.79% (Widiyati & Bengen 2012), respectively.

Sustainability status for the legal-institutional dimension. There are 3 sensitive attributes of the legal-institutional dimension, namely: law enforcement, farmer associations and reservoir area management bodies. Reservoirs and lakes are commonly used as locations for fish cultivation according to Law no. 45/2009 on fisheries, where in article 7 it is stated that inland public waters such as rivers, lakes, reservoirs and swamps under the sovereignty of the Republic of Indonesia can be used for fish cultivation, with due regard to their carrying capacity and sustainability. The fact is that on the contrary, fish farming business often exceeds the carrying capacity of the environment and is only economically oriented, ignoring the ecological sustainability and social interests. As has been stated in the background, in this reservoir the increase in the number of cage plots was relatively low between 2016–2020, but most of them are concentrated around dams, which can threaten the sustainability of the reservoir's function as a provider of electricity. This is due to the absence of a spatial plan for the use of the reservoir, which is approved by the local government to provide formal legality in the utilization and management of this reservoir. The attribute "association of cage cultivators", which include groups of fish cultivators and breeders as well as fishermen, needs to be considered because the communication that is built and the coordination between them can support the sustainability of fish farming activities, before legal regulations can be provided by formal institutions like a management authority of the reservoir area. Therefore, these 3 attributes need to be considered while still considering other attributes in this dimension. The sustainability status for the legal-institutional dimension of this research is higher than in the Cirata Reservoir, with a value of 40.16% (Widiyati & Bengen 2012), but slightly lower than in the Jatiluhur Reservoir, with a value of 52.14% (Putri et al 2019).

From the above review, it results that improving the sustainability status of fish farming in this reservoir, in terms of socio-cultural criteria, requires considering sensitive attributes. It is very urgent for the government to establish a policy for the reservoirs exploitation, followed by the formation of a reservoir management agency regulating the stakeholders' roles and responsibilities. This sustainable aquaculture management strategy in the reservoir focuses on the increase of the socio-cultural understanding and awareness of the farmers through tripartite legal-institutional mediation on the zoning or relocation of the floating net cage (FNC), followed by the water quality improvement infrastructure development, while maintaining a semi-intensive FNC aquaculture system providing economic added value.

Sustainability status is seen from a multi-dimensional perspective. The multidimensional sustainability status in the Koto Panjang Reservoir is better than several reservoirs in Indonesia, including the Jatiluhur Reservoir Purwakarta and the Cirata Reservoir West Java, with values of 51.33% (Putri et al 2019) and 44.19% (Widiyati & Bengen 2012), respectively. The data from the MDS analysis implies that the management of fish farming in the Koto Panjang reservoir remains oriented towards the social, legal, institutional and ecological dimensions, while maintaining the ecological and economic dimensions. No significant difference was found between the sustainability index values in MDS and Monte Carlo analysis, a simulation method for evaluating the effects arising from random errors in statistical analyzes performed on all dimensions (Kavanagh & Pitcher 2004). This analysis is also a clue to the error caused by the assessment in each attribute and the multidimensional variation of the assessment due to differences of opinion and repeated data analysis (Fauzi & Anna 2005).

Conclusions. The current status of the fish farming sustainability in Koto Panjang Reservoir was evaluated based on 5 dimensions, being categorized as moderately sustainable, with an index value of 67. The economic and technological dimensions were very sustainable, the ecological and legal-institutional dimensions were moderately sustainable and the social dimension was less sustainable. Based on their sensitivity, 10 attributes that affect the sustainability index of fish farming were identified, namely: 2 attributes from the ecological dimension (sedimentation and plankton diversity), 1 attribute from the economic dimension (the marketing objectives of caged products), 3 attributes of the socio-cultural dimension (knowledge of good fish farming practices, environmental knowledge, extension activities), 1 attribute of the technological dimension (fish farming system) and 3 attributes from the legal-institutional dimension (law enforcement, association of marine cage cultivators, reservoir management agency). Five of the ten attributes determine the sustainable management of fish farming in this reservoir from a prospective analysis with a higher priority, namely: reservoir area management agency, fish cultivator associations, law enforcement, fish farming systems and extension activities. The study concludes on the necessity of improving the socio-cultural dimension which has a lower sustainability index, followed by the ecological and legal-institutional dimensions, while maintaining the attributes of cultivation system (in the technological dimension) and of marketing objectives for cage production (in the economic dimension).

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References

Ardi I., 2013 [Aquaculture with floating net cage system in order to maintain the environmental sustainability of Cirata reservoir waters]. Media Akuakultur 8(1):23–29. [In Indonesian].

Astuti L. P., Warsa A., Satria H., 2009 [Water quality and abundance of plankton in Sentani Lake, Jayapura Regency]. Gadjah Mada University Fisheries Journal 11(1):66–77. [In Indonesian].
Astuti L. P., Krismono K., 2018 [Management of water quality through the application of fish cultivation in "SMART" floating net cages]. Journal of Indonesian Fisheries 10(2):87–97. [In Indonesian].
Bourgeois R., 2002 Expert meeting methodology for prospective analysis. CIRAD Amis Ecopol, Muenchen, 114 p.
Bourgeois R., Jesus F., 2004 Participatory prospective analysis, exploring and anticipating challenges with stakeholders: center of alleviation of poverty through secondary crops development in Asia and the pacific and French agricultural research center for international development. Monograph 46(1):1-29.
Budijono, Tang U. M., Putra R. M., Nofrizal, 2021 Dynamic of water fertility in Koto Panjang Reservoir, Riau Province, Indonesia. Aquaculture, Aquarium, Conservation & Legislation 14(2):965–975.
Fauzi A., Anna S., 2005 [Fishery and marine resource modeling]. PT Gramedia Pustaka Utama, Jakarta, 343 p. [In Indonesian].
Hardjomidjodjo H., 2004 [Prospective analysis workshop guide]. Department of Agricultural Industrial Technology, Faculty of Agricultural Technology, Bogor Agricultural University, Bogor, 115 p. [In Indonesian].
Haryani G. S., 2013 [The condition of lakes in Indonesia and their management strategy]. Proceedings of the MLI I Cibinong Annual Scientific Meeting, 19 p. [In Indonesian].
Hermawan Y., 2005 [Relationship between education level and perception with environmental care behavior]. Bumi Lestari Journal of Environment 5(2):1-16. [In Indonesian].
Kavanagh P., 2001 Rapid Appraisal of Fisheries (RAPFISH) project. Fisheries Center University of British Columbia, Vancouver, 80 p.
Kavanagh P., Pitcher T. J., 2004 Implementing microsoft excel software for Rapfish: a technique for the rapid appraisal of fisheries status. Fisheries Centre Research Reports 12(2):1-80.
Kumurur V. A., 2001 [Land use conditions in the area around Moat Lake, Bolaang Mongondow Regency, North Sulawesi]. Ekoton 1(1):1-10. [In Indonesian].
Marimin, 2004 [Multiple criteria decision making techniques and applications]. Grasindo, Jakarta, Indonesia, 197 p. [In Indonesian].
Malhotra N. K., 2006 [Marketing research: An applied orientation]. Prentice Hall, Upper Saddle River, NJ, 912 p.
Nurdin, Bahri S., Zulkarnain, Sukendi, 2017 [Analysis of land cover index of Koto Panjang hydroelectric reservoir area using Geographical Information System (GIS) Applications]. 3rd National Seminar on Infrastructure Development Strategy (SPI-3) Padang Institute of Technology, pp. 219-227. [In Indonesian].
Odum E. P., 1996 Fundamental of ecology. Gajah Mada University Press, Yogyakarta, Indonesia, 697 p.
Putri M. A., Affandi R., Setyobudiandi I., Yulianto G., 2019 [Sustainability status of floating net cage aquaculture in Jatiluhur Reservoir, Purwakarta Regency]. Journal of Natural Resources and Environmental Management 9(3):771-786. [In Indonesian].
Suhardi, 2005 [Changes in land cover and its effect on water reserves in the Dusun Besar Lake Catchment Area]. Indonesian Journal of Agricultural Sciences 7(1):8-16. [In Indonesian].
Sutardjo S. C., 2014 [Development policy of marine and fisheries]. Indonesian Fisheries Policy Journal 6(1):37-42. [In Indonesian].
Sukadi M. F., 2016 [Water resistance and release of nitrogen & phosphorus to media water from various freshwater fish feeds]. Jurnal Riset Akuakultur 5(1):1–12. [In Indonesian].

Widiyati A., Bengen D. G., 2012 [A study of sustainability aspects in the management of floating net cage aquaculture in Cirata Reservoir, West Java]. Aquaculture Research Journal 7(1):121-129. [In Indonesian].
*** Indonesian Electricity Company (IEC), 2019 [Monitoring of the Environmental Management Plan (RKL) - Environmental Monitoring Plan (RPL) of PLTA Koto Panjang]. PT PLN (Persero) North Sumatra Power Generation Unit (UIK Sumbagut) Pekanbaru Power Generation Control Implementing Unit. [In Indonesian].
*** Indonesian Electricity Company (IEC), 2020 [Monitoring of the Environmental Management Plan (RKL) - Environmental Monitoring Plan (RPL) of PLTA Koto Panjang]. PT PLN (Persero) North Sumatra Power Generation Unit (UIK Sumbagut) Pekanbaru Power Generation Control Implementing Unit. [In Indonesian].
*** Indonesian Central Statistics Agency (ICSA), 2020 [Number of households in agriculture and fisheries]. [In Indonesian].
*** Republic of Indonesia, 2009 [Law of the Republic of Indonesia Number 45 of 2009 concerning Fisheries. [In Indonesian].
*** Ministry of Forestry of the Republic of Indonesia, 1998 [Guidelines for the preparation of field engineering plans for land rehabilitation and soil conservation for watersheds]. Directorate General of Reforestation and Land Rehabilitation, Jakarta, Indonesia. [In Indonesian].
*** World Commission on Environment and Development (WCED), 1987 Our common future. Oxford University Press, Oxford.

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