Brackish water pond management strategies based on salinity and pyrite distribution in the Mahakam Delta, East Kalimantan

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Abstract. Brackish water ponds in the Mahakam delta are located in the area that has acidic soil and is affected by the distribution of salinity. This study aims to analyze brackish water pond management strategies based on salinity and pyrite distribution. The location of this research was in the local farmers’ brackish water ponds in the Mahakam delta, East Kalimantan. Sampling collection was carried out on several brackish water ponds with different salinity, namely salinity of 0 – 10 ppt, 11 – 20 ppt, and 21 – 30 ppt. Each type of salinity was represented by 10 brackish water ponds. Samples were selected using a purposive sampling technique in which respondents consisted of farmers, academics, and the government. Data were analyzed using the Analytic Hierarchy Process and qualitative descriptive methods. The results indicated that the alternative pond management strategies employed in the Mahakam delta were brackish water pond management with salinity and pyrite management approaches (0.312), brackish water pond management with pyrite management approach (0.222), and brackish water pond biophysical management (0.155).

1. Introduction
The area of brackish water ponds in the Mahakam Delta is 60,288.52 ha or 55.69% of the total area of the Mahakam delta, namely 108,251.311 ha [1,2,3,4], there is a massive change in mangrove ecosystems mainly due to the conversion of mangrove forests into brackish water ponds. Brackish water ponds in the Mahakam Delta are generally brackish water ponds with the traditional system without management as in general in other regions. The productivity of brackish water ponds in the Mahakam delta is relatively low, namely only 41.48 - 47.86 kg/ha/year for giant tiger prawns with the average productivity of 45.19 kg/ha/year [5]. The productivity for milkfish ranges from 4.51 to 15.86 kg/ha/year while the productivity for crabs ranges from 2.07 to 15.42 kg/ha/year. Meanwhile, the productivity for spotted prawns ranges from 38.22 to 59.60 kg/ha/year. The productivity of brackish water ponds in the Mahakam delta is below the standard of the productivity of traditional brackish water pond (nationally), which is 600 - 1000 kg/ha, while in 2008, it was only 14.92 kg/ha/MT [6].
The average productivity in the last five years (2006 - 2010) is 30.3 kg/ha/year for giant tiger prawns, 163.6 kg/ha/year for milkfish and 19.3 kg/ha/year for spotted prawns [7]. Brackish water ponds in the Mahakam delta have salinity in the range of 0 - 30 ppt. They further stated that salinity distribution affects the level of brackish water pond productivity [5].

The traditional brackish water pond system is adopted by all brackish water pond farmers in this area because, until now, this system has proven to be a system that still survives in the business of growing shrimp and fish. The adopted traditional system is identical to the extensive system, namely the activity of increasing the production of brackish water ponds cultivation by expanding the area of cultivation. This system promotes the destruction of mangrove ecosystems because it involves the encroachment of mangrove forest ecosystems to be made as brackish water ponds to increase productivity. However, in reality, it is not followed by high brackish water pond productivity.

The local government of Kutai Kartanegara in 2014 and 2015 issued a policy to address the problem of declining brackish water pond productivity in the Mahakam delta through the brackish water pond revitalization program. Brackish water pond revitalization activities that had been carried out have a purpose to diversify the business of the farmers without making efforts to improve the brackish water ponds, especially the rehabilitation of brackish water ponds that were not productive. One of the efforts to increase the productivity of the brackish water ponds is by making improvements to the subgrade so that the pyrite content in the brackish water ponds is not exposed which can cause the subgrade to become toxic.

Pyrite content (FeS$_2$) in the brackish water ponds in the Mahakam delta has a high tendency. This is revealed in a study conducted [1], that pyrite content in brackish water ponds ranged from 1,125 - 1,834 ppm or 1,125 - 1,834 mg/kg. Furthermore, in general, the location of brackish water ponds had a higher pyrite content compared to the location in coastal waters. Stated that pyrite in brackish water pond soils is 6.15% ± 0.36 meaning that it is in a bad category [8]. The high pyrite content in the brackish water ponds in the Mahakam delta is caused by the type of soils in the Mahakam delta, namely acid sulfate soils. When acid sulfate soils are oxidized, it will cause the brackish water pond subgrade to become toxic. In addition to the high pyrite (FeS$_2$) content in the brackish water ponds in the Mahakam delta, the ponds are generally created in locations that have different salinity concentrations. By applying brackish water pond management using an ecological approach in the Mahakam delta, the ponds will be able to adapt to the conditions of high pyrite and salinity differences.

2. Material and methods

2.1. Location

The location of this research was in the local farmers’ brackish water ponds in the Mahakam delta, East Kalimantan. The brackish water ponds were selected based on differences in salinity, namely salinity of 0 – 10 °/oo, 11 – 20 °/oo, and 21 – 30 °/oo. Brackish water ponds with a size of 5 - 10 ha have better productivity compared to other brackish water ponds with different sizes [7]. The number of brackish water ponds in the location of the research was ± 300 plots. For sampling, only 10 % were selected from the total number of plots of brackish water ponds. Therefore, the number of samples was 30 plots. They were then divided based on the level of salinity. Each level of salinity was represented by 10 plots. The measured variables were salinity, the extents of the pond, and mangrove vegetation.
2.2. Data collection

Data were collected using questionnaires, focus group discussions, and direct interviews. Previously, the employed sampling method to select respondents was the purposive sampling method. Purposive sampling is the selection of samples based on specific considerations or goals. The population of this study was stakeholders, shareholders, and researchers that had a relation to the management of brackish water ponds in the Mahakam Delta [9].

The Analytic Hierarchy Process is a flexible model that provides an opportunity for individuals or groups to develop ideas and define problems by making assumptions and obtaining the desired solutions from the assumptions. The Analytic Hierarchy Process is a powerful process for overcoming complex political and socio-economic problems [10]. The use of the Analytic Hierarchy Process in this study was to determine the strategy of brackish water pond management in the Mahakam delta based on the pyrite (FeS$_2$) distribution and salinity gradient by considering the factors influencing the decision.

Furthermore, the steps that were taken were as follows.

- The first step was to set goals, namely to manage brackish water ponds in the Mahakam delta based on pyrite (FeS$_2$) distribution and salinity gradients.
- The second step was to determine aspects obtained from the results of discussions with key-persons who are competent in the management of brackish water ponds in the Mahakam delta based on the pyrite (FeS$_2$) distribution and salinity gradients.
- The third step was to determine alternatives. The step in determining alternatives was the same as the step in determining aspects. The alternative was also obtained from the results of discussions with key-persons (actors) who are competent in the management of brackish water ponds in the Mahakam delta based on the pyrite (FeS$_2$) distribution and salinity gradients.
- The fourth step was to distribute questionnaires to key-persons (respondents) who are competent in the management of brackish water ponds in the Mahakam delta based on the pyrite (FeS$_2$) distribution and salinity gradients which consisted of coastal communities, government, private sector, academics, and non-governmental organizations. The questionnaire of the Analytic Hierarchy Process was one of the research instruments to study the management of brackish water ponds in the Mahakam delta based on the pyrite (FeS$_2$) distribution and salinity gradients in which it was made based on existing data and results of the analysis. The selection of a brackish water pond management strategy in the Mahakam delta based on the pyrite (FeS$_2$) distribution and salinity gradients required expert judgment.
- The fifth step was to compile a matrix obtained from key-persons (respondents).
Brackish water ponds in the Mahakam delta are utilizing sediment areas. Therefore, the shape and size of the ponds are not the same as each other. The area of plots in the Mahakam delta ranges from 2 - 100 ha. The large area of this brackish water pond also causes differences in the distribution of salinity for each pond. Different salinity also affects the production and management methods of ponds in this region.

Studies related to brackish water ponds in the Mahakam delta have been conducted by several researchers. Examined the productivity of silvofishery brackish water ponds using polyculture systems in the Mahakam Delta [11]. Studied the cultivation of Polymesoda erosa (Solander, 1786) in brackish water ponds with mangroves and without mangroves in the Mahakam Delta [12]. Examined the presence of oxygen in silvofishery brackish water ponds in the Mahakam Delta [11]. Conducted a study on the pattern and strategy for post-harvest management of giant tiger prawns (Penaeus monodon F.) in brackish water ponds in the Mahakam Delta [13]. Conducted a study on the analysis of the compatibility of forestry cultivation area zoning in the Mahakam Delta, East Kalimantan [14], about mangrove ecosystems and sustainable livelihoods [15].

The study on salinity problems in acid sulfate soils in coastal areas was carried out [16]. The box model of freshwater, salinity, and soil nutrients in the Mahakam delta in which they specifically studied the transport mechanism of freshwater mass, salinity, and soil nutrients in the riverbank of the Mahakam River that interacts directly with seawater [17]. The vertical distribution of salinity in the Mahakam delta was found highly stratified. Observed the modeling of the salinity distribution and water movement time in the Mahakam Delta [18]. The results of the simulation indicated that salinity at the forefront of the Mahakam Delta directly adjacent to the Makassar Strait is 35 PSU. Furthermore, salinity in the middle of the delta was less than 20 PSU. Meanwhile, in the distance 15 km upstream, it significantly decreased to 5 PSU due to the flow of the Mahakam River. Brackish water ponds in the Mahakam delta generally apply the traditional brackish water ponds system by adopting the polyculture system [19].
This analysis was carried out with the help of Expert Choice 2000 software in which the results of the calculations can be seen in Appendix 3. The basis of new policies in natural resource management is by referring to the principles of effectiveness and efficiency for economic condition, equity, and sustainability[20]. The results of the analysis based on the criteria used for the success of the objectives indicated that the undertaken management plan must be effective and efficient. It is then followed by a management plan that is sustainable. Finally, the management plan must be equitable to all parties involved. This is as shown in Table 1 and Figure 2 as follows.

Table 1. Values of the priority of criteria

| No. | Aspects                                         | Weight | Priority |
|-----|------------------------------------------------|--------|----------|
| 1.  | Existing Brackish Water Pond Management         | 0.648  | 1        |
| 2.  | Biophysical Management                          | 0.230  | 2        |
| 3.  | Pyrite (FeS₂) and Salinity Management           | 0.079  | 3        |

Figure 3. Results of the calculation of aspects using Expert Choice 2000 software

Based on the results of the analysis above, the value of index inconsistency is 0.01 meaning that the results above have met the requirements proposed by Saaty. Therefore, the analysis can be continued. The next was determining priorities for the actors as shown in Table 2 below.

Table 2. Values of the priority of actors

| No. | Actors                     | Weight | Priority |
|-----|----------------------------|--------|----------|
| 1.  | Brackish Water Pond Farmers| 0.420  | 1        |
| 2.  | Government                 | 0.149  | 2        |
| 3.  | Higher Education Institutions| 0.079 | 3        |

The results of the analysis in Table 2 show that farmers have a very big role in the success of the management of brackish water ponds based on the pyrite distribution and salinity gradient, then followed by roles of government, and finally by roles of higher education institutions. Farmers have a big contribution to the management of brackish water ponds based on the pyrite distribution and
salinity gradient. This is because the farmer is actors involved directly in carrying out various activities in the management of brackish water ponds based on the pyrite distribution and salinity gradient. Furthermore, their activities will greatly affect the quality of the shrimp and the selling price of the shrimp so that it will have an indirect impact on the farmers’ income.

Figure 4. Graph of results of the sensitivity analysis (performance model) of the choice of brackish water pond management strategy based on pyrite distribution and salinity gradient

Figure 5. Graph of results of the sensitivity analysis (dynamic model) of the choice of brackish water pond management strategy based on pyrite distribution and salinity gradient

The government as a policymaker should be able to implement various programs and policies that are in line with the management of brackish water ponds based on the pyrite distribution and salinity gradient. The higher education institutions have a role to educate the public so that the knowledge of the public can increase and they do not only get hereditary knowledge or knowledge from seeing other
communities. To make the management of brackish water ponds based on the pyrite distribution and salinity gradient to be better, coordination and harmonious cooperation are highly necessary from all of the stakeholders mentioned previously. Therefore, a policy can be obtained for the management of brackish water ponds based on the pyrite distribution and salinity gradient which is effective, efficient, sustainable, and equitable.

The analysis of sensitivity was also carried out using Expert Choice 2000 Software to determine inconsistencies in post-harvest management strategies as shown in the following figures.

The results of sensitivity analysis using Expert Choice 2000 software indicate that the value of inconsistency ratio is also 0.03 meaning that the results of the analysis to determine the choice of brackish water pond management strategies based on pyrite distribution and salinity gradient with the Analytic Hierarchy Process have met the requirements set by [10] in which the results of this calculation can be more clearly seen in the figure below.

![Figure 6. Calculation of inconsistency ratio value and priority of brackish water pond management strategies based on pyrite distribution and overall salinity](image)

### Table 3. The values of priority of the main alternatives based on grouping

| No. | Alternatives                                                                 | Weight | Priority |
|-----|------------------------------------------------------------------------------|--------|----------|
| 1.  | Change the existing brackish water pond management with a pyrite management approach. | 0.312  | 1        |
| 2.  | Make a standard procedure specifically about the brackish water pond management with a pyrite management approach. | 0.222  | 2        |
| 3.  | Conduct the biophysical management on brackish water ponds.                   | 0.155  | 3        |
| 4.  | Maintain the condition of brackish water pond biophysics naturally that supports the development of cultivation. | 0.108  | 4        |
| 5.  | Socialize procedures for reducing pyrite content in brackish water pond soils. | 0.074  | 5        |
| 6.  | Socialize pyrite and salinity in the brackish water pond management.          | 0.051  | 6        |
| 7.  | Conduct studies on the existence of pyrite and the distribution of salinity to create specific regulations for pyrite management involving all stakeholders. | 0.035  | 7        |
| 8.  | Review the management of brackish water ponds that have been carried out so far. | 0.025  | 8        |
| 9.  | Prohibit the use of hazardous substances in brackish water pond management.    | 0.18   | 9        |
The next stage was to conduct the Analytical Hierarchy Process using Expert Choice 2000 software on strategy options that had been grouped to determine the main alternatives in the management of brackish water ponds based on the pyrite distribution and salinity gradient. The result of the analysis indicates that the inconsistency value is 0.05. This value is still below the requirements proposed by Saaty (0.1) so that the result of the analysis is considered consistent and can be accepted. The values of priority of the main alternatives based on grouping are presented in the table below.

4. Conclusions
The results provided alternatives for the management of brackish water ponds in the Mahakam delta, namely the salinity and pyrite management approach (0.312), pyrite management approach (0.222), and biophysical management approach (0.155).

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**Acknowledgements**

Researchers would like to thank the Ministry of Research, Technology, and Higher Education that had provided the Domestic Education Assistance Scholarship (Ind. *Beasiswa Bantuan Pendidikan Dalam Negeri* (BPDN)), the Doctoral Program in Coastal Resources Management, Diponegoro University, and Mulawarman University. We also would like to thank our assistants who have helped a lot during this study, i.e. Fauzan, Asrin, Wira, Nurdin, Alfa, Ismail, Marisi, and Wafi.