Problems and restoration of cascade Mahakam Lakes in the climate change perspective

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Abstract. Cascade Mahakam Lake (CML) have function as a flood retention area, a freshwater fishery center, and settlements. Problems in CML include damage to catchment areas, reduced biodiversity, fisheries productivity, and decreased water quality. Climate change is believed to have an impact on increasing pressure on the ecosystem and problems on the CML. This research aims to deals with the problems and needs of restoration from the perspective of climate change. Rainfall, water level, and water quality data were obtained from secondary data, while the problems of flooding, drought, declining fisheries productivity, and environmental health as a result of climate change are obtained from field observations and interviews with communities in CML. The results showed that annual rainfall in the CML area tended to increase, fluctuations in water level during floods and very high tide with uncertain cycles, conditions of flooding and drought were difficult to predict, and trend water quality declined. These conditions reduce the ability of the community in aquaculture and agriculture, flooding and drought adaptation, providing clean water and increasing weed. Restoration of CML areas ware urgently needed, include rehabilitation of catchment areas, increasing aquatic vegetation, reducing pollutant sources, maintaining biodiversity and increasing fisheries productivity. The implementation of Restoration CML faces obstacles such as had not yet been established management plans, lake boundaries, lack of information and monitoring of lake conditions, community empowerment, and disaster risk reduction activities.

1. Introduction

Cascade Mahakam Lake (CML) is located in the middle of Mahakam watershed, consisting of 3 large lakes, namely Lake Jempang (15,000 Ha), Lake Semayang (13,000 Ha), Lake Melintang (11,000 Ha) and 17 other small lakes which have size of 200 - 3,000 Ha. CML has important benefits so that it is designated as one of the Strategic Areas of East Kalimantan Province. This determination is also due to its critical condition which is included in the category of 15 national priority lakes. CML has a catchment area of 6,216,077.8 Ha or 80.7% of the Mahakam watershed, while the lake area is 102,000 Ha according to the proposed border.

As a flood-exposed lake, CML includes wetland ecosystems and is associated with swamp and river ecosystems [1]. The flood-exposure lake is a type of lake in which water that is very dynamic, with extreme seasonal changes in floodplain areas. High water level fluctuations cause seasonal cycles of flooding and drought in this region, which covering a very wide area. The increased volume of river
water level seasonally causes lateral overflow which results in the inundation of low areas in the wing of the river flow and forms exposure to bank flooding [2]. Nevertheless, a permanent core of water will be found throughout the year in a basin or river channel. In flood-exposed lakes, water entering the lake comes from the river flows from the catchment area, and also from the main river through the inlet and out through the river outlet. In the dry season, water in flood-exposed lakes will be limited in the river channel, the surrounding plains, and formed swamps. For measurement of inundation area, lake banks, and borders by taking into account the differences in height and inundation area during the rainy season and dry season, especially the nature of the flat land in the lake area. Morphology of CML consists of the form of a very wide plain, with almost all surfaces ± 90% covered by water (figure 1). The condition of the lake is very much influenced by the rivers, especially the Mahakam River. Mahakam River is a permanent river, where the river is watery every season. The Mahakam River flow pattern is meandering, which is found along the Mahakam River flow around the lake outlet.

![Morphology of Cascade Mahakam Lake.](image)

The CML area is used by the community for various types of interests. In the catchment area, these activities include agriculture, cultivation, oil palm plantations, forestry, mining, and settlements, while in the CML area the uses are not only for forest conservation but also settlements, fisheries, and agriculture. The absence of regulation on the utilization of resources and the CML management plan makes land use out of control and causing problems that threaten the existence of lakes. These problems include: the destruction of water catchment areas, siltation, the rapid growth of aquatic weeds, pollution, drought, flooding, damage and loss of aquatic vegetation, loss of fish stock, decreased biodiversity and increased poverty. Exploitation of lake areas as natural resources that are not accompanied by wisdom, raises a variety of major problems, such as damage to natural resources, loss of resources and the emergence of various wastes, which results in a decrease in the quality of the environment [2]. These problems are expected to continue to increase and will cause huge losses economically, environmentally and socially.

Climate change is believed have been happened [3], which is shown by an increase of air temperature, changes in rainfall patterns and rising of sea levels. The effect of climate change will increase pressures in inland water areas, including lakes [4]. Changes in rainfall as an input variable
component of the watershed will affect the river flow which will further affect the lake water level which generally gets input from the river [2]. The impact of climate change on lake ecosystems including the physical, chemical, biological and social characteristics of the lake [5]. Considering the important function of the CML region, it is necessary to restore the CML. Restoration of CML has to receive support from all parties through an integrated approach that is mutually agreed, based on the nature, characteristics, and functions of CML as a complex and integrated ecosystem. Restoration is defined as a return or an effort to repair and restore to its original state [6]. Returning conditions to their original state are difficult to do, because conditions have been changed by the demands of human life [7]. Therefore, understanding CML restoration is more directed to achieve the desired future conditions or to increase the carrying capacity of CML.

This research aims to discuss the problems and strategies of CML restoration in the perspective of climate change. The problems examined include climate and hydrological conditions, catchment areas, water quality, water level fluctuations, and disaster vulnerability. The results of this study are expected to encourage the implementation of an integrated CML restoration.

2. Methods
Data on rainfall, water level, water quality, and land cover were obtained from secondary data, which were described and analyzed for trends (specifically rainfall data). While the identification of problems in the CML area used data triangulation techniques that combine secondary data, field observations and interviews with the community. The proposed CML restoration strategy was formulated based on the problems identified.

3. Results and Discussion
3.1. Conditions of Cascade Mahakam Lake
Land Cover in the CML areas covers two regencies namely West Kutai and Kutai Kartanegara Regency, while the catchment area covers four Regencies, namely Mahulu, West Kutai, Kutai Kartanegara, and East Kutai Regency. The area of land cover in the catchment area of 6,216,077.8 ha consists of secondary dryland forest (30.98%), primary dryland forest (25.76%), range brush (21.80%), plantation (8.22%), swamp (5.05%), bare land (1.25%), bog (1.28%) and the rest in the form of water bodies, settlements, mining, and agriculture (figure 2).

![Figure 2. CML land use map.](image-url)
3.1.1. Climatic conditions and rainfall

Based on the "Schmidt-Ferguson" climate classification, the type of climate in the CML region in the 1986-2016 period is included in the "Type B" category, which has the characteristics of wet areas with vegetation still in tropical rain forests. Monthly rainfall ranges from 103 mm to 273 mm, with the peak of rainfall twice, December-January and March-April, respectively. Annual rainfall in CML tends to increase (figure 3).

Rainfall trends in the Mahakam cascade lake region showed an increase from year to year, this made frequent and higher floods that occur in the CML. Besides that the duration of flooding in the lake also increased. Low rainfall such as in 1991, 1997, and 2009 recorded a long drought that resulted in the narrowing of the lake area and the loss of aquatic biota’s habitat in the Mahakam cascade lake. The longest dry season was occurred in 2009, when the dry season lasted almost six months. The duration of this drought resulted in changes in the lake's ecosystem, due to changes in the lake's environment [8].

![Figure 3](image-url)

Figure 3. (a) Monthly rainfall patterns for the period 1986-2016, and (b) annual rainfall period 1986-2016

3.1.2. Sub-watershed conditions in CML

The CML area has 6 direct-related sub-basins namely Kahala Sub-basin (93.295 Ha), Submerged Sub-Basin (62.727 Ha), Ohong Sub-Basin (40.453 Ha), Bongan Sub-basin (200.579 Ha, Perian Sub-Basin (74.795 Ha) and Tanjung Isui Sub-Basin (32.451 Ha). River widths range from 6.2-152 m, with river depths between 1.5-12 m and flow rates range from 17.15 - 122.56 m$^3$/s. The largest sediment loading in CML comes from the Mahakam River. Rebak Rinding has a TSS value of 89.4 mg / l and the Tanjung Betuq River has TSS value of 73.4 mg / l. Blimbing River which is connected to the Mahakam River tributary has a TSS value of 40.7 mg / l. When it compared to the Kahala River and the Enggelam River, the TSS values of the later rivers were smaller (2.8 mg /l and 8.1 mg /l), as well as the sediment content in Ohong River water had a relatively small value of 14.08 mg /l.

3.1.3. Water quality conditions

In general, the waters in CML are divided into three segments, namely acidic peat waters originating from the Kahala River and the Enggelam River, and waters affected by the Mahakam River, which
tend to be neutral and murky, and waters of Lake Jempang, which are influenced by the flow of rivers’ inlet. The waters tend to be neutral and relatively clear due to the relatively high density of aquatic plants. The water quality status for the Class 2 category generally was in accordance with the quality standard - medium polluted. The main contributors to pollution status are COD, BOD, phosphate concentration, and iron concentration. COD, BOD, and phosphate concentration are closely related to anthropogenic activity, especially settlements and wastes carried by the inlet flow from the Mahakam River. While Fe was considered to be influenced by the nature of the water which tends to be acidic and dissolves the metal elements from the surrounding rocks. This could be seen from the locations, Muara Enggelam and Mancong, where the status of the waters that were heavily polluted was densely populated. It should be noted that the status of the waters in this report was based on data measurement during the flood season, when the waste concentration from anthropogenic activities were diluted by surface water discharge. In the receding water conditions, the status of waste concentration of the three lakes, especially around densely populated settlements, are expected to decline. The results of this study also showed that the main source of pollutants in the waters of these three lakes was waste from domestic activities.

3.1.4. Sediment load conditions
Based on sediment loading from rivers entering the CML, sediment trapped was estimated to be 317,691.26 m$^3$ / year. This level of sedimentation has a considerable influence on the sustainability of the CML ecosystem. This level of sedimentation should be considered because CML has shallow depth. This condition causes CML during the dry season, only a river basin and dry land so that it will have an impact on the sustainability of the lake. The amount of sediment trapped in the lake varies greatly depends on the discharge conditions of the Pela River. The Pela River is affected indirectly by tides through the Mahakam River. The amount of sediment trapped in the lake is the rainfall conditions in the upper Mahakam River. Heavy rain that occurs in the upper Mahakam watershed cause more transported sediment, so that sediment concentration in the rivers that are directly connected to the Mahakam River increase (Rebak Rinding and Tanjung Betuq Rivers).

3.1.5. Water level fluctuation conditions
The CML has relatively shallow depths, but the water surface area is very large, so that rainfall has an important function on water level fluctuation. In addition to rainfall, rivers that enter the lake both directly from the Mahakam River and from the lake's catchment area also contribute to lake water level fluctuation. During the dry season, the condition of the lake water is generally only left in the river channels which also functions as a transportation route. But when the rainy season the water of the three lakes is very difficult to distinguish from the environment, all the surrounding land is inundated and can even blend with the Mahakam River.

Based on lake water level fluctuation data at high water level conditions in CML, is divided into five conditions, namely: extreme flooding (water level > 11 m), moderate flooding (9 m < water level <11 m), normal (6 m < water level <9 m), moderate ebb (4.5 m < water level <6 m), and extreme ebb (water level <4.5 m). Extreme flooding events are increasing, especially after 2000, almost every year there were extreme floods in a long time and in 2006 was occurred for 63 days. On the contrary, extreme ebb events were also increasingly frequent and over a long period of time, in 2006 extreme ebb occurred for 67 days. This extreme pattern of lake water level fluctuation has a negative impact on the function of lake, where flood disasters are likely to eliminate existing habitat resources, while the fast ebb time with longer dry periods is no longer in accordance with the life cycle order of aquatic biota. Increased water level fluctuations due to climate change will increase the hazard and risk of disaster [9].

Changes in water fluctuations are also considered as a factor of the structure of aquatic vegetation alteration in the lakes. Change Structure of vegetation is caused by changes in aquatic habitat due to the adjustment of conditions during water fluctuations [10].
3.1.6. Population conditions
The Administrative Border according to the CML management plan covers two districts, West Kutai and Kutai Kartanegara Regency, respectively. The two districts cover 8 subdistricts and 44 villages. The number of people living in CML and its surroundings is 60,681 peoples. Population in the Cascade Mahakam Lake region was growing for over the past three years. The growth was due to factors of migration from other regions of Kutai Kartanegara and West Kutai. The increase of migration flows is due to the opening of river and land transportation that connect between urban and hinterland of the two districts and several other cities in the regional scope. The livelihoods of people in CML are fishermen, farmers, oil palm plantation workers, miners, traders, and government employees.

3.2. Problems and restoration strategies of CML in the climate change perspective
Outline of the problem of CML from the perspective of climate change; First is the increase of critical land in the catchment area which shown by the expansion of secondary dry-land forests, range brush, and plantations. If rainfall increases, water runoff, and erosion on degraded land increase, so that accelerate silting process and decrease water quality. Second, changes in the amount and pattern of annual and monthly rainfall which causes water level fluctuations to change relatively quickly which increases the times of flood events. Third, rising temperatures and a long period of ebb conditions cause CML's vulnerability to drought and forest fires. These three problems have a continuing impact in the form of changes in water quality by increasing critical land, decomposition of peat areas and domestic waste. Fluctuations in water levels that were relatively fast and do not follow the usual cycle, which decrease of fisheries productivity, disrupt agricultural activities, community readiness in dealing with floods and droughts and raw water supply. In addition, this condition is also expected to reduce biodiversity in CML.

Climate change is believed to increase pressure on ecosystems of CML. Without restoration, this pressure can cause loss of lake existence. CML restoration is defined as an effort to restore CML conditions in accordance with the carrying capacity of the environment and its function as a flood retention area of the Mahakam watershed, a center for inshore fisheries and settlements, arranged in a CML management plan. CML restoration in the perspective of climate change is aimed to maintain and enhance the environmental capacity of CML and society facing climate change. Therefore CML restoration should contain mitigation and adaptation from the impacts of climate change as part of disaster risk reduction. Considering CML as an ecosystem, management must be carried out in an integrated manner including its water catchment area, border area and water body. The similarity of perception of policymakers and stakeholders according to the existence of CML can encourage the creation of harmony in the use of the lakes while preventing negative impacts on the lake ecosystem. Besides, this policy will direct development efforts in water bodies and around CML with an ecological approach so that the values and benefits of the lake can be optimized and sustainable.

The restoration strategy proposed in CML is formulated as follows: First, the policy strategy. Cascade Mahakam lake has a management plan in the form of a CML rescue document and a CML management plan book that had been signed by the East Kalimantan Governor. So that the management plan has strong legality, the policy strategy adopted is to establish a CML management plan through a Regional Regulation or at least a Governor Regulation. Second, the coordination and institutional strategy. This strategy outlines that CML management is carried out coordinatively given the multifunctional use of the lake. The division of roles of the parties is arranged transparently based on the agreement according to their main tasks and functions. It is proposed that there is a CML management body or at least a working group whose tasks and functions are described in a Regional Regulation in the CML Management Plan. Third, the determination boundaries of lake and CML. To minimize pressure on water bodies and lake boundaries, delineation and its boundary arrangements need to be determined through zoning utilization. Considering that the number of people living in water bodies and the CML border is quite
large, the community must understand and live in harmony with the zonation that has been determined so that environmental damage can be minimized.

**Fourth**, rehabilitation of critical land in the catchment area. Critical land in the catchment area must be rehabilitated through land and forest rehabilitation activities. Funding sources such as RSF (reforestation-sharing funds) and rehabilitation obligations for holders of FAUP (forest area use permit) must be optimized.

**Fifth**, water quality management. This strategy is aimed at the management of the Mahakam River and its sub-basin that enter the CML, as well as the management of waste. Water quality monitoring activities are carried out regularly with integrated monitoring points and involving the participation of the business community and the community. The construction of wastewater management installations in each village must be realized so that pollution sources from settlements can be reduced.

**Sixth**, maintenance of the river channel. The CML area is also used by the community for transportation, therefore maintenance of river channels and shallow lakes must be done routinely.

**Seventh**, restoring reservoir and fisheries productivity. This strategy was chosen so that the abundance of fish species and numbers in CML could be recovered, through dredging, revegetation activities, protection of spawning zones and control of fishing that is not environmentally friendly.

**Eighth**, weed control. This strategy was chosen in addition to protecting the river channel from weeds, also reducing siltation and mitigating emissions from rot weeds. Weeds can be used as compost, fish feed, handicraft materials, aquaculture materials, and so on.

**Ninth**, risk reduction from flood and drought. This strategy is carried out so that people are prepared to face the risk of catastrophic floods and droughts, especially in anticipation of floods and droughts, adjusting livelihoods to water level conditions, and the need for evacuation houses and land and forest fire prevention.

**Tenth**, development of agricultural potential. This strategy utilizes water conditions at the ebb and is used for agricultural land while adjusting water levels. This activity is in the form of organic rice farming.

**Eleventh**, restoration of the abundance of endemic fauna. It is necessary to establish and regulate zoning for endemic fauna protection such as bekantan, bondol eagles, stork barrels, beavers and so on which are still commonly found in CML. This activity will also support lake ecotourism which is being developed by the government and the community through tourism-conscious village groups.

**Twelfth**, lake information system improvement and community participation. Dynamic lake conditions must always be collected and informed to the community through environmental education, so that community awareness and participation in lake management can be built and improved.

The twelve proposed CML restoration strategies are believed to be carried out and strengthen the carrying capacity of lakes in the face of climate change. Reduced erosion-sedimentation due to the recovery of the catchment area, the restoration of vegetation in the waters, reduced pressure on the borders of lakes and water bodies, well-managed water quality and waste control require hard work and joint work of all parties. The use of multifunctional CML is a challenge in itself, so CML management must always pay attention to the ecological nature and sustainability of lake ecosystems.

### 4. Conclusions

Problems in CML are; first is the increase of critical land in the catchment area, which are indicated by the expansion of secondary dryland forests, range-brush, and plantations. Second, changes in the amount and pattern of annual and monthly rainfall cause water level fluctuations change's relatively quickly, which increases the frequency of the highest water level and duration of flood events. Third, rising temperatures and long periods of ebb conditions have led to vulnerable of the CML to drought and forest-fire.

The restoration strategies at CML are; policy, coordination and institutional strategies, determination of water body and lake borders, rehabilitation of critical land in catchments, water quality management, river channel maintenance, restoration of fisheries reservoirs and productivity, weed control, disaster risk reduction flooding and drought, development of agricultural potential,
restoration of endemic fauna abundance and improvement of lake information systems and community participation.

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