ENVIRONMENTAL CONDITON, FISH RESOURCES AND MANAGEMENT OF MANINJAU LAKE OF WEST SUMATERA

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ABSTRACT

A blooming of *Microcytis aeruginosa* occurred in Maninjau Lake in 2000. Mass fish killed happened frequently due to deterioration of water quality in this lake. This study is aimed to observe the current environmental condition, fishery resources status and the state of development process of co-management regime in Maninjau Lake. Water quality parameter such as temperature, conductivity, turbidity, pH and dissolved oxygen (DO) were measured *in situ* by using Horiba U-10 water checker. Total nitrogen, ammonia, nitrate, nitrite, total phosphorous, orthophosohate and chlorophyll-a parameter were analyzed using standard method. Phytoplankton was analyzed by Lackey Drop Microtransect. Fish samples were obtained from fishers' catch. Fisheries data were collected by enumerator, through Focus Group Discussion (FGD), and questioner list methods. Stakeholder analysis was conducted by focus group interview and discussion. In general, water quality parameters were suitable for the life of aquatic organisms except for DO and ammonia. These parameters indicated that the water quality of lake was still undergoing degradation process. Maninjau Lake is rich of nutrient as indicated by abundance of blue green algae. Bada fish (*Rasbora argyrotaenia)* is an important commodity and the fisheries significantly contributes to local people' income. Current fisheries problems indicate the urgency of the management and conservation efforts. Several stakeholder groups showed their interest in management. The increment of institutional sustainability concern was reflected by the emergence of local wisdom and the demand for participatory development and management.

KEYWORD : Water quality, fisheries resources, management, Maninjau Lake

INTRODUCTION

Lake Maninjau, a tecto-volcanic type lake, is an eutrophic lake where the massive blooming of *Microcytis aeruginosa* (blue green algae) occured in 2000 (Syandry, 2000). It seems that the current cage culture activities caused the increase of the organic material level then stimulated blue green algae growth. This culture system had been developed continuously since 1990 until 1997. During those periods, some environmental problems of Maninjau Lake have emerged as indicated by blooming microalgae and mass fish kill tragedy (Syandry, 2000).

Maninjau Lake has a natural purification phenomenon called *tubo belerang*. Tubo belerang happens through up-welling and down-welling process triggered by strong wind coming from Southern part. The wind then lifts up the water from hypolimnion and brings it to the epilimnion water column. Finally, the water is discharged to the outlet of the lake or Batang Antokan.

From 1983 Maninjau Lake supplies waters to Maninjau Hydroelectric Power Plant. Natural purification system was disturbed due to existence of power plant. The history of environmental problems and management measures has been studied by Hartoto (2009). One of the problems identified by the author is the destruction of social capital among the people living in the surrounding Maninjau Lake. Some efforts to resolve the problem of the lake have been initiated since 2001 such as by opening the weir, so the discharge also flows through its natural outlet to enable to control algae bloom (Sulastri, 2002a).

Fisheries activities are dominated by fish cage culture that is rapidly developed excessing the capacity limit. The carrying capacity of cage culture was estimated in this lake around 1,500 units (Hartoto & Ridwansyah,2001). However the number of cage culture reached to 9,825 units in 2006 and as the result, a mass fish killed happened in 2009. The fish killed tragedy might be due to deterioration of water quality, caused by the excessive number of cage. The water revealed clearer condition resulted by waters quality monitoring. The monitoring results showed that water quality changed gradually from 2005 to 2006. Moreover, the trophic state also changed from mesotrophic in 2005 to eutrophic condition in 2006 (Triyanto *et al*., 2006).

To reduce the number of floating cages, District Agam local government issued Local Regulation No

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22 in 2009. Ownership of cages was limited to having two units per person. In addition, the cages should be installed at 50 m from the lake shore (Peraturan Bupati Agam No 22, 2009). Hartoto (2009) indicated that inappropriate economic development regime which more emphasizes on capitalistic-neoliberalistic system also contributed significantly to environmental problems in Maninjau Lake. Therefore, a suitable participating management regime should be developed in this lake for fishery resources sustainability. This study aimed to elucidate the current environmental condition, fishery resources status and development process of co-management regime in Maninjau Lake, especially the foundation for stakeholder involvement.

MATERIALS AND METHODS

The Maninjau Lake is pointed out as a research location related to a problem solving in fishery management of inland fisheries. This lake is a tecto-vulcanic lake, located at 462 m above sea level, with the surface area of 9737.50 ha with average depth of about 105.5 m and its maximum depth of 165 m (Fachrudin *et al*. 2002). Environmental data was collected at littoral zone of several sites in 2009. Littoral zone is the important area used for cage culture and fishing activities. The location and condition of the sites are presented in Fig. 1 and Table 1. Some data were also collected from secondary sources such as formal reports and scientific publications.

Water quality parameters such as temperature, conductivity, turbidity, pH and dissolved oxygen (DO) were measured *in situ* by using Horiba U-10 water checker. The samples were taken by Snatch Bottle sampler at the surface and Secchi depth layers.Water samples for analyzing nitrogen, ammonia, nitrate, total phosphorous, orthophosohate and chlorophyll-a parameter were preserved and analyzed in the laboratory according to Standard Method (Grinberg *et al*., 1992). Methods for nutrient and other parameters analysis are outlined in Table 2. To collect phytoplankton, 2 liters of water were filtered with plankton net (40 µm mesh size). These samples were then preserved in 1 % Lugol's solution. Phytoplankton species was identified according to Prescott (1951), Scott & Prescott (1961), Baker & Fabro (1999) and Gell *et al*., (1999).

Fish samples were obtained from fisher's catch, while fisheries data were collected through enumerator, Focus Group Discussion (FGD), and questioner list methods. Stakeholder analysis was conducted by focus group interview, focus group discussion and questioner list as proposed by FAO (2005).

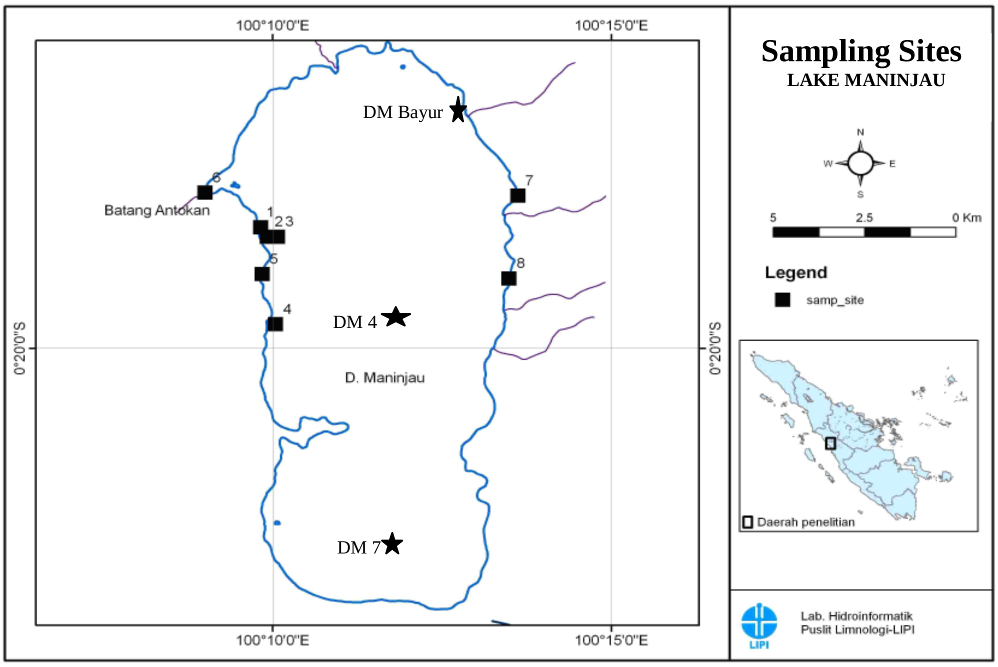

Figure ■ Sampling Sites.
Note: ■ Sampling sites for survey on 2009
★ Sampling sites for survey by Sunanisari (2009)

Table 1. Sampling Sites physical description

Station	Name of station	Sampling sites' physical description
1	Batu Anjing	Fishing area for bada fish (*Rasbora argyrotaenia*). Riparian condition is human settlement and sorounded by many trees.
2	Sawah Panjang	Fishing area for bada fish and no cage culture farming
3	The front of Sawah Panjang Site	100 m from Sawah Panjang Site, no cage culture farming
4	Sigiran	The area for cage culture farming and riparian is human setlement area
5	The proposed area for brush park fishery system ("Rasau")	Nearby of cage culture farming and human settlement area
6	Muko – Muko	A conservation area for bada fish, nearby of outlet of lake
7	The front of Limnological Station of Indonesian Institute of Sciences	Located quite far from cage culture activities. Riparian is an agricultural area
8	The front of Hotel Tan Dirih	Habitat of bada fish, nearby cage culture. The riparian condition is restaurants, human settlement, and small inlets of lake.
9	DM Bayur	Located on cage culture farming
10	DM 4	The middle part of lake.
11	DM 7	The deepest part of lake.

Table 2. Methods and instrument for water quality analysis in the laboratory

No.	Parameter	Method
1	Ammonia $N\text{-}NH_4$	Phenate Method
2	Nitrate ($N\text{-}NO_3$)	Brucine method
3	Nitrite ($N\text{-}NO_2$)	Sulphanilamide method
4	Total N (T-N)	Pre digested by peroxodisulphate and analysis by Brucine method
5	Total P (T-P)	Pre digested by peroxodisulphate and analysis by Ascorbic acid
6	$P\text{-}PO_4$	Ascorbic acid method
7	Alkalinity	Titrimetric
8	Suspended solid	Gravimetric
9	Chlrophyll-a	Colorometric
10.	Phytoplankton	Lackey Drop Microtransect

Source: Standard Methods (Grinberge *et al*., 1992)

RESULTS AND DISCUSSION

Environmental Condition

Water quality condition is presented in Appendix 1. In general water quality parameters are still suitable for the life of aquatic organisms except for DO and ammonia. Temperature and pH commonly found for tropical lake were also common in this lake and according to Goldman & Horne, (1983) and Harris, (1986), the pH ranges from 6 to 9.

Most of the DO concentration values were below the standard concentration of DO for fisheries as regulated by The Government Regulation of Republic of Indonesia (Peraturan Pemerintah No 20, 1990). The low concentration of DO in April may be related to the impact of organic material degradation originated from fish pellet residues or rotten fish resulted from mass fish kill occurred in February 2009.

Vertical distribution of DO in April at pelagic and littoral zone is presented in Figure 2. In pelagic zone (DM4 and DM7) high DO concentration was found in 0-10 m depth (3.71-6.79 mg/L) and low DO concentration (< 2 mg/L) in 20 m depth. In littoral zone or in the area of cage culture (DM Bayur) low DO concentration was found in 10 m depth (Sunanisari, 2009). The low DO concentration near by the upper column water could ascend to the surface waters and caused fish killed when the *tubo belerang* phenomenon occurred in Maninjau Lake. In 2005, low dissolved oxygen was found in 40 m depth while in 2007, low concentration of DO (<2 mg/L) moved to the upper column (20 m depth 2007) (Triyanto *el al*., 2005;2007). Based on DO concentration, water quality of this lake was under continuous degradation.

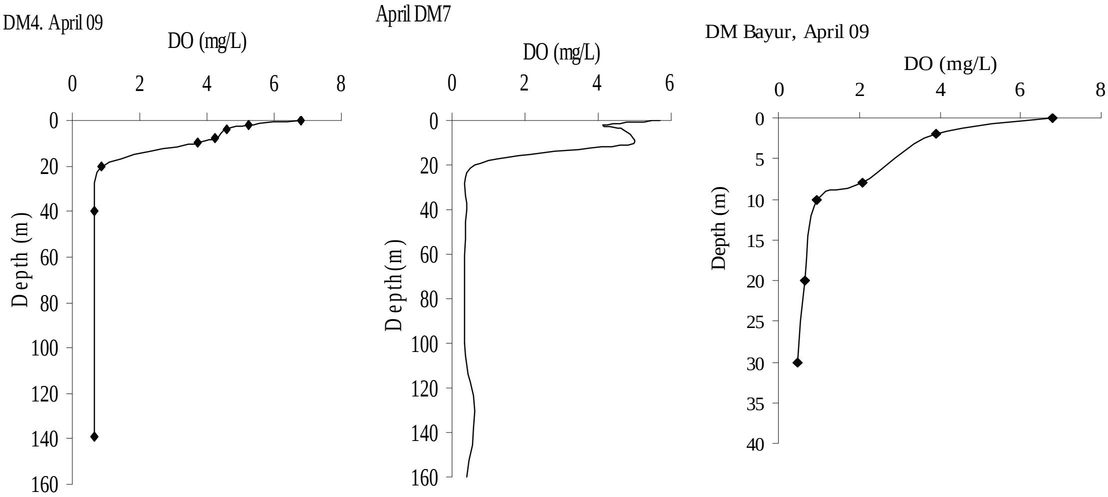

Figure 2. Vertical distribution of dissolved oxygen concentration at pelagic zone (DM4 and DM7) and littoral zone (DM Bayur) in April, 2009 (Sunanisari, 2009).

Conductivity was commonly found in freshwater ecosystem and according to Boyd (1982) it ranged from 0.025 to 0.500 mS/cm. Water turbidity values showed a normal condition. Wood & Armitage (1997) reported that in the United State, the turbidity level for living aquatic organism range from 5 to 25 NTU. Alkalinity value ranged from 39.27 to 126.85 mg$CaCO_3$/L and the high values were found in July. Alkalinity is influenced by pH and as shown by the observation of pH.

Nitrite (N-NO_2) was less than 0.06 mg/L or below the standard concentration of nitrite for fisheries while almost in all observation sites, ammonia concentrations exceeded 0.02 mg/L or above the standard value for fisheries (Goverment Regulation No 20/1990). The distribution of ammonia is highly seasonal and spatially variable depending upon the level of productivity and the extent of pollution of organic mater (Wetzel, 2001). High concentration of ammonia in these observation sites could be influenced by riparian and littoral activities such as human settlement and aquaculture activities. The high concentration of nitrate was found in April that may be caused by runoff sources. Nitrate is usually not toxic in lake up to 1 mg/L (Goldman & Horne, 1983).

Most concentrations of total nitrogen (T-N) and total phosphorous (T-P) indicate that Lake Maninjau is rich in nutrient. According to Swedish Environmental Protection Agency (SEPA, 1991), the level of Total Nitrogen > 1.5 mg/L and Total Phosphor >0.05 mg/L indicate that an aquatic system is rich in nutrient. Concentration of orthophosphate (P-PO_4) was lower than nitrogen compound concentration. It was caused by the adsorption process between the reactive orthophosphate and sediment or particulate particles (Goldman & Horne, 1983).

In April TN/TP ratio was more than 12. It indicates that phosphorous is a limiting factor. In contrast, TN/TP ratio was less than 12 in July indicating nitrogen as limiting factor (Jorgensen, 1980). If nitrogen is the limiting factor for algae growth, then nitrogen fixing of blue green algae occurs frequently (Harris, 1986). This condition is supported by this observation, especially at Station 2, 4 and 8 where dominant micro algae was blue green algae (Cyanophyta) (Figure 3).

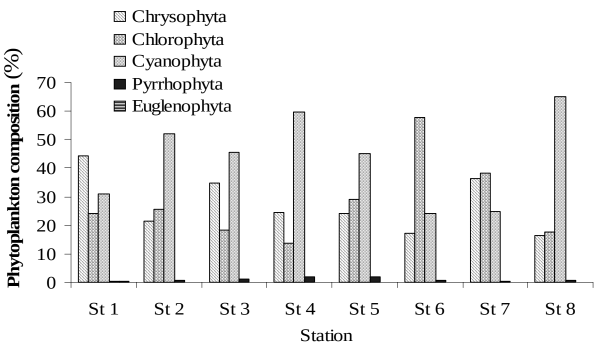

Figure 3. Phytoplankton composition of Maninjau Lake.

Chlorphyll-a concentration ranged from 1.241 to 9.533 mg/m^3. This level is similar to the concentration level observed in 2001 which ranged from 0.000 to 9.999 mg/m^3 (Sulastri, 2002b). During that time, the dominant blue green algae (Cyanophyta) was replaced by the green algae (Chlorophyta) and then changed to diatom (Chrysophyta) (Sulastri 2002a). Meanwhile, in this observation phytoplankton was dominated by blue green algae (Cyanophyta) (Figure 3). Increasing level of blue green algae or Cyanobacteria biomass is often coupled by the production and release of toxic material that may cause the animal and human poisoning (Roland *et al.*, 2005).

Fish resources

Fish resources found in Maninjau Lake is presented in Table 3. Bada fish (*Rasbora argyrotaenia*) is an important commodity for capture fisheries in Maninjau Lake because its high market value especially as smoked fish product. The price of smoked bada reaches up to 140,000 IDR/kg (Dina, 2008), this indicates that the fish significantly contributes an important income to local people. Monthly production and the value of smoked bada are presented in Table 4. Smoked bada production depends on the fishers's catch and usually some of their catch is also consumed as fresh form to support local demand and fisher's family.

Table 3. Fish resources of Lake Maninjau (Triyanto, 2003)

Local Name	Scientific Name	Family	Common name
Barau	*Hampala macrolepidota*	Cyprinidae	Hampala barb
Garing	*Tor soro*	Cyprinidae	Barb
Asang	*Osteochilus haselti*	Cyprinidae	Hard lipped barb
Bada	*Rasbora argyrotaenia*	Cyprinidae	Silver Rasbora
Mas	*Cyprinus casio*	Cyprinidae	Common carp
Kalui	*Osphronemus goramy*	Osphronemidae	Giant gourami
Rinuak	*Psylopsis* sp.		
Mujair	*Oreochromis mossambicus*	Cichlidae	Mozambique Tilapia
Supareh	*Puntius* sp.	Cyprinidae	Barb
Nila	*Oreochromis niloticus*	Cichlidae	Nile tilapia
Gabus	*Ophiocephalus sp.*	Ophiocephalinidae	Snakeheads
Panjang / sidat	*Anguilla sp.*	Anguillidae	Shortfin eel
Puyu, betook	*Anabas testudineus*	Anabantidae	Climbing perch
Indosiar	*Oxyeleotris marmorata*	Eleotridae	Marbled goby
Baung	*Mystus sp.*	Bagridae	Redtail catfish
Pensi	*Corbicula*	Corbiculidae	Asian clam

a) Bada is caught by traditional gears such as gill net and trap named lukah. This fish lives in littoral zone; hence, it is easily caught by traditional gear. Besides the traditional gears, Bagan (a lift net) is also operated to catch this fish. This gear is considered as an unenvironmentally friendly fishing device that is presumed to disturb fish population balance in lake if the number of gear and mesh size of the gear is not controlled. Bagan was designed to catch small fish as found in Towuti Lake (Nasution, 2008). Important captured fishes in Maninjau are bada and rinuak. Both fishes are categorized as small fishes seizing 7 – 10 cm and 5 mm respectively.

b) Observation by local people indicated that the size of bada gets smaller by the years. The decrease of fish size may be caused by the overwhelming number of new fishers following the tragedy of fish killed in cage culture. Increasing number of small fish is supported by length frequency analysis conducted by Dina (2008). This study showed that the exploitation rate of bada was already higher than optimal exploitation. This situation indicates the urgency of the management and conservation efforts in Lake Maninjau

c) Rinuak (*Psylopis* sp) is an endemic species and important fisheries commodity in Maninjau Lake. Rinuak is small fish size of around 5 mm and supports local demand with the price of 25,000 IDR per kg in off season. Local people inform that, Rinuak was rarely found after fish killed occurred in Lake. In addition, Rinuak is an important fish to sustain the balance of food chain in Lake Maninjau. It is a prey for carnivorous fish such as Hampala barb and Redtail catfish (Yuniarti *et al,* 2010).

d) Hampala barb, redtail catfish, and hard lipped barb are always found in the local market although not plentiful compared to bada and rinuak. Meanwhile, Nile Tilapia which is a commodity from floating cage culture farming, sometimes also caught in the lake. Nile Tilapia is sold in local market and also outside of Maninjau area.

e) Marbled goby, another exotic species is currently found by the fishers in this lake. In the other part of Indonesia, marbled goby is a high value exported commodity. The existence of this fish it brought worries on local people about its potential impact of the fish to indigenous species. Study on the food habit revealed that the main food item of this species was zooplankton and mollusks (*Corbicula* & *Pomacea*) (Yuniarti *et al*., 2010). The study indicated that food webs in Maninjau Lake were still in balance indicated by the completeness of food web components. Therefore, there is no proof to support the local people concern about the negative impacts of this fish on the indigenous fish populations.

f) Asian clam (*Corbicula* sp.) is sold to support local demand such as restaurant and local households. According to local people, the production of this clam is also declining due to various reasons among of them is cage culture farming at littoral zone. Marbled goby is the predation of clam and shrimp therefore it may become a threat to the production of this clam. It is also suspected that disappearance of shrimp is related to the increasing number of marbled goby.

Table 4. Monthly production and value of smoked production of bada fish in 2009

Fishermen	April		May		June		July	
	Smoked Fish	Value	Smoked Fish	Value	Smoked Fish	Value	Smoked Fish	Value
	(Kg)	(IDR)	(Kg)	(IDR)	(Kg)	(IDR)	(Kg)	(IDR)
1	17.75	2.485.000	17.75	2.485.000	18.75	2.625.000	16.50	2.310.000
2	21.50	3.010.000	25.75	3.605.000	19.25	2.695.000	20.25	2.835.000
3	17.75	2.485.000	17.50	2.450.000	12.00	1.680.000	23.00	3.220.000
4	15.75	2.205.000	15.25	2.135.000	19.75	2.765.000	16.75	2.345.000
5	13.50	1.890.000	30.50	4.270.000	29.00	4.060.000	21.00	2.940.000
6	16.75	2.345.000	53.75	7.525.000	24.00	3.360.000	23.50	3.290.000
7	32.00	4.480.000	62.50	8.750.000	45.00	6.300.000	15.50	2.170.000
Average	19.3	2.700.000	31.90	4.460.000	23.96	2.730.000	19.50	2.730.000

Note: Value calculation: fishing activity in 25 days and the price 140,000 IDR

Most aquaculture areas are located at littoral zone where various organisms habit, for instances: mollusks, shrimp, and small fishes (Sulastri *et al*. 2010). Constructions of floating cage and other activities can destruct littoral habitat through the declining of water quality and losing of substrate and degradation of the habitats. Study by Yuniarti *et al*. (2010) indicated that insects were the main food item of most species, including carnivorous fish such as hampala barb, redtail catfish and marbled goby. However, it was shown by a study in other lakes (e.g. lake Ranau and Lake Bojongsari) conducted by Sulastri (2000) and Sulastri (1989) that these species mainly consumed fresh water shrimp (*Macrobrachium* spp.). The difference of the diets is probably related to the declining of shrimp species that may be caused by the destruction of the littoral zone of the lake.

Aquaculture activities in the lake are subject to local government regulation such as cage culture area should be 50 m from the shore (Bupati Agam Regulation No 22/2009)**.** However, other sources of problems in the littoral zone utilization in Maninjau Lake come from construction of restaurants, hotels and human settlement in littoral zone. These issues are extremely important issues to be awared. Therefore, a co-management regime must be developed to overcome such issues. This regime is a powerful tool to balance and share the benefits and obligations for all stakeholders. The importance of the participatory mangement has been underlined by Fisheries Law No 31/ 2004 (Bab2, Article 2)

Management of Maninjau Lake

Hartoto (2009) has identified that Maninjau Lake supports eleven social functions that should be managed harmoniously. Those social functions are aesthetic, education, culture, environmental health, spiritual, individual resilience, collective resilience, economic (fisheries, electricity, water supply, tourism industry) and recreation. The economic generation services especially cage culture fisheries drives various problems; for instances: algae bloom occurrence, fish kill, and social conflict in 2000 (Syandry, 2000).

Hartoto (2009) identified that the roots of the problems are the destruction of social capitals and the lack of the implementation of divine value system in daily life.

Co-management, defined as the sharing of management responsibility between local government and local user to manage a resource such as fisheries (FAO, 2005). In Indonesia, the success of co-management has been shown by *Panglima laut* (Aceh), *Awig-Awig* (Lombok), and Nila Jaya Group (Malahayu Reservoir, Brebes). Maninjau Lake should be counted as a candidate for the implementation of co-management system involving all stakeholders.

Co-management of natural resources needs a plan to be developed through participative planning process involving government and local community. Therefore, initiation of co-management process, identification of the roles, functions, capacities and barriers of involvement of each stakeholder is very important. Concerning that matter, a stakeholder analysis has been done to identify those criteria as shown in Appendix 2. In addition, a diagram showing the degree of interest and the role of identified stakeholders is presented in Figure 4.

From the data shown in Table 5 and Figure 4, it appeared that the stakeholder groups having high interest on the resources (fishers and other fisheries entrepreneurs) tend to have lower role in the management of the lake. Meanwhile, formal institutions; for instances, local planning agency and local institutions: have the higher role in the management process although they have low interest on the resources. Furthermore, it is clearly shown in Figure 5 that cage culture farmers are the main players on the management of the lake. Importantly, the natural resources division of Agam District Gov. possesses the lowest role and interest in the management system. It indicates that there is no strong power of this institution to make and enforce the regulation related to sustainability of natural resources. Hence, sustainability of natural resources seems to be the less priority or is almost neglected by the stakeholders

Fishers appear to have lower role in the management despite they are one of the main users of the lake resources. The main reason of their low role is their low capacity (capitals, power, etc.) to be involved in the past management regime (Appendix 2). Therefore, in the co-management system, the role of this group should be enhanced, because they have the indigenous knowledge regarding the resources. Possession of indigenous knowledge is an imperative capital to elevate the success of co-management in a certain area. Similar reason can be applied to explain the other fisheries entrepreneurs, low role, their limitation of capital and knowledge also prevents them from being actively involved in the management process.

It has been largely known that local institutions (e.g. local planning agencies and sub-district government) have difficulties to enforce regulation in this area. However, the involvement of *Kerapatan Adat Nagari* and their ability to create networking with various stakeholders are powerful to develop their role in the management system.

In spite of their limitation involvement in the management system, cage culture farmers are the most capitally powerful groups among stakeholders; therefore, they have higher role than other resource users. However, their less knowledge about the natural system and they being legitimate to enforce the rules to other resource users, their role is less than formal institution. Thus, this group is proposed as one of the main groups that should be involved more actively in the co-management system. It is unfortunate that other stakeholders such as hotel and restaurant owners are not included in this research. Their participation is imperatively important in the next research.

Indicators of success were also obtained from this stakeholder survey. The results are shown in Table 5. Surprisingly, most of the mentioned indicators belong to the ecological sustainability indicators of Charles (2001). According to this author, there are four categories indicating the success of co-management implementation, namely ecological sustainability, community sustainability, institutional sustainability, and socio-economic sustainability indicators

Moreover, institutional sustainability indicators were also recognized by the respondents such as the emerging of local wisdom and the demand for participative development. These results are quite encouraging because respondents seemed to be aware of the environmental condition, in addition to the economic concern. Overall, it can be concluded that the respondents are also alarmed by the deterioration of the lake environment. This awareness is a very important factor that should be maintained for the establishment of co-management in Maninjau Lake area.

Table 5. Indicators of the success of Maninjau Lake management

No.	Identified Indicator	Categories
1	Sustainability	Ecological, socio-economic, institutional, and community
2	Benefit provision for local people	Socio-economic
3	Benefit provision for local government	Socio-economic
4	Clean and clear water and environment	Ecological
5	Survival of floating cage culture and other businesses	Socio-economic
6	Emerging of local people' awareness to the environmental	Ecological and community
7	Solving all problems	Institutional
8	Emerging of people' responsibility	Ecological and community
9	Reduction of floating cages	Ecological
10	Participative development	Institutional
11	Disappearance of water odor	Ecological
12	Well functioning ecosystem	Ecological
13	Lake resilience as before the existing of floating cage	Ecological
14	Development and application of local wisdom	Institutional

Figure 4. Degree of role and interest of some stakeholders in Lake Maninjau.

CONCLUSION

In general some water quality parameters are still suitable for the life of aquatic organisms except DO and ammonia indicating that the water quality of lake was under continuous degradation. Maninjau Lake is rich in nutrient concentration as indicated by abundance of blue green algae. The lake contains important fish resources to support the local people' life, and Bada fish (*Rasbora argyrotaenia*) is an important commodity and significantly contributes to local people' income.

Arising fisheries issues in this lake call for management and conservation action. There were some stakeholder groups that have different degree on interest and role of management. Institutional sustainability indicators were also recognized by the respondents such as the emergence of local wisdom and the demand for participative development in management.

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Appendix 1. Water quality condition and concentration of nitrogen and phosphorous compound of Maninjau Lake.

Stasiun	pH	Conductivity	Turbidity	DO	Tempe-rature	Alkalininity	Kloro-phyll-a	$N\text{-}NO_2$	$N\text{-}NO_3$	$N\text{-}NH_4$	TN	$P\text{-}PO_4$	TP	TN:TP
		mS/cm	NTU	mg/L	^oC	mg/L	mg/m^3	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	
April														
St1	8.3	0.112	1.1	4.3	28.2	78.54	6.775	0.001	0.3545	0.127	1.639	0.009	0.052	31.76
St2	8.7	0.113	1.15	3.1	28.6	78.54	9.553	0.001	0.2855	0.114	1.47	0.004	0.026	56.96
St3	8.5	0.114	1.5	2.4	28.7	72.93	5.936	0.001	0.3014	0.094	1.487	0.008	0.051	28.98
St4	8.3	0.113	1	2.3	28.5	39.27	3.412	0.001	0.1324	0.051	0.736	0.006	0.027	27.36
St5	8.4	0.114	1.2	2.3	29.3	76.67	4.253	0.004	0.3033	0.113	2.099	0.007	0.039	53.35
July														
St1	8.3	0.094	2.7	4.4	28.5	107.42	2.02	0.017	0.204	0.152	0.698	0.019	0.059	11.83
St2	8.7	0.096	5.85	6.2	28.9	119.18	5.107	0.006	<0.05	0.136	0.72	0.011	0.065	11.16
St3	9.2	0.097	7.85	7.1	29.4	126.85	6.831	0.005	<0.05	0.163	0.537	0.007	0.038	14.14
St4	9.2	0.096	9.5	6.9	29.3	123.78	9.233	0.005	<0.05	0.138	0.459	0.007	0.041	11.18
St5	9.1	0.097	4.35	6.8	29.9	110.48	5.879	0.004	0.1033	0.124	0.943	0.012	0.028	33.66
St6	8.2	0.096	4.7	5.3	29.6	110.48	1.241	0.007	0.1859	0.309	0.849	0.035	0.051	16.64
St7	8.0	0.096	1.4	4.8	27.4	118.67	-	-	0.0554	0.113	0.45	0.011	0.043	-
St8	8.4	0.129	13.4	6.5	31.4	123.78	1.529	0.007	<0.05	0.149	0.45	0.021	0.056	8.041

Appendix 2. Roles, Capacities, and Barriers of Involvement of Several Stakeholders of Maninjau Lake

Stakeholder	Potential interest/ Management roles	Capacities/Skills	Barriers to involve in management
Fishers group	➢ Fishing, maintaining fishing area from illegal fishing and control the water quality	➢ Fishing with gill net, traditional gears, determining fishing area and fishing time.	➢ Lack of capital and knowledge on pollution ➢ Pollution, habitat destruction and un-predictable fish catch.
Cage culture farming group	➢ Operating cage culture ➢ Cleaning lake waters from garbage of aquaculture ➢ Giving attention in conservation of lake.	➢ Making floating cage ➢ Identifying aquaculture area.. ➢ Breeding of Nile Tilapia and Carp	➢ Lack of capital and knowledge on water quality monitoring and aquaculture ➢ Un predictable *tubo belerang* and storm phenomenon causing fish killed ➢ Sometimes in balance income.
Fish trader, post harvest processor and business people on fisheries product.	➢ Marketing, processing fish product ➢ Securing the economic value of fish product.	➢ Marketing network ➢ Possessing smoked fish ➢ Good link with fishers and cage culture farmers	➢ Still using traditional method causing the product under expected quality ➢ Limited marketing
Local institution (Camat, Wali Nagari, Kerapatan Adat Nagari, Badan musyawarahs)	➢ Maintaining lake water from the destruction and pollution. ➢ Motivating the increment of economical activities for community through dissemination of local government regulation ➢ Participating in arrangement and monitoring the implementation of Lake management plan ➢ Determination and protection aquaculture area ➢ Protecting and resolving the right of people and " Nagari' (village) if there is conflict of interest ➢ Involving all fishers to cooperate in the management of Lake	➢ Having a local knowledge ➢ Having good relationship and strong positive networking to the nephew of cage culture farmers and to the community around the lake ➢ Disseminating and coordinating the regulation related to utilization and management activity.	➢ Deterioration of cultural system in the past management regime (ORBA) ➢ Lack of communities' knowledge and awareness about sustainability of lake. ➢ Rising of individualistic and apathy attitude in the community. ➢ Lack of good cooperation in all components around the lake. ➢ Lack of integrity on the wise of local ecological knowledge. ➢ The community is not ready yet to change the business pattern in increasing the economic and gives more priority on beneficial value from cage aquaculture activity ➢ Trust crisis to the community figures ➢ Synchronization between local government, institution and local community in resolving of management problem of lake has not been realized. ➢ The community has limited information about research result of Lake Maninjau