ECOTECHNOLOGY AND ECOSYSTEM BASED MANAGEMENT TOOLS AS ALTERATIVE SOLUTIONS TO REDUCE RISKS OF ECOSYSTEM DISASTER AND FISH KILLS IN LAKE MANINJAU

CYNTHIA HENNY
Research Center for Limnology-LIPI
Cibinong Science Center, Jl. Raya Bogor km 46, Cibinong 16911
email: cynthia@limnologi.lipi.go.id

ABSTRACT

Overexploited by floating cage fishery and extreme wether condition due to global climate change has caused ecosystem disater including massive fish kills, decrease in local/ endemic fish population and deteriorated water quality in Lake Maninjau. Decrease in water quality including eutrophication problems due to high input of organic matter and nutrient concentrations from the excess feeding of floating cage fishery (FCF) has led the ecosystem of Lake Maninjau are susceptible to climate change. The fact that Lake Maninjau is a tectono-vulcanic type of lake, the sulfide production can cause oxygen defisit in the lower water column and with the extreme weather this anoxic water column can be overturn to the surface and trigger even bigger disaster of fish kills. Fish kills disaster in Lake Maninjau has occured more often since 1997 up to 2014 and has caused more than thousands of tons fish dead and the farmer has lost billions of IDR (Indonesian rupiah) over the years. The catch of local fish production hasl also been decreasing. Although floating cage fishery is considered non-ecosystem based fishery for lake ecosystem, to get the cage fishery completely out from the lake is impossible because it is considered the main economy for the people. The complexity of the problems faced in Lake Maninjau requires a comprehensive management tools and inovative ecosystem based technology to reduce disaster risk and to advance climate change adaptation. Ecosystem based management tools proposed include determination of the numbers of FCF units according to lake carrying capacity and the placing, determination of the fish loadings in one cage using high nutritious efficient fish pellets, practice of lake resting (no fish loadings) during extreme weather months (e.g. December – February), and application of layered fish cage fishery. Development ecosystem based technology such as Attracting Fish Device Floating Wetland (AFDFW) to serve as nursery ground and habitat protection for local/endemic fish and to reduce nutrient and organic matter concentration in the lake to advance the climate change adaptation. In addition, develop an early warning system tools such as determining the key parameters in critical time (e.g. threshold dissolved oxygen concentration and water transparency) also help in disaster risk reduction. Fundamental requirement is that developed ecosystem based management tools can be incorporated into decision making in order to not only effective in reducing disaster risk in Lake Maninjau but also effective in maintaining the stability of lake ecosystem to advance climate chage adaptation and to enhance ecosystem services in lake.

Keywords: ecotechnology, ecoystem based management tools, water quality, floating cage fishery, lake

INTRODUCTION

Overexploited by floating cage fishery (FCF) and extreme wether condition due to global climate change has increased the risk of ecosystem disater including massive fish kills, decrease in local/ endemic fish population and deteriorated water quality in Lake Maninjau. Decrease in water quality including eutrophication problems due to high input of organic matter and nutrient concentrations from the excess feeding of floating cage fishery has led the ecosystem of Lake Maninjau are susceptible to climate change. The fact that Lake Maninjau is a tectono-vulcanic type of lake, the sulfides production can cause oxygen defisit in the lower water column and with the extreme weather this anoxic water column can be overturn to the surface and trigger even bigger disaster of fish kills where the phenomenon known to be called as ”tubo belerang” by the local people (Henny, 2009). When the phenomenon occurred the water surface was anoxic with 0 g/L dissolved oxygen (DO) and smelled like sulfur and very odorous like rotten egg. Fish kills disaster in Lake Maninjau has occured more often since 1997 up to 2014 and has caused more than thousands of tons fish dead and the farmer has lost billions of IDR (Indonesian rupiah) over the years. Compared to reservoirs which also have been overexploited by floating cage fishery, such as Cirata and Jatiluhur, the risk of fish kills disaster in Lake Maninaju is massive due to sulfides content in lake and its long retention time of 25 years (Henny, 2009; Fachrudin,2001).

Water quality in Lake Maninjau has been worsening over the years due to accumulation of pollutants such as nutrients and organic carbon compounds from the excess feeding and fish feces of the KJA. High organic carbon compound has increased to high sulfide production in the hypolimnion layer and lead to anoxic water column in the upper layer (Henny, 2009; Henny and Nomosatryo, 2012a). The implications of the production of hydrogen sulfide in the lake not only cause the oxygen depletion and loss of free iron in the water but also lead to the phosphate release from the sediment, which subsequently cause the accumulation of phosphate in water bodies and result in the lake eutrophication (Henny and Nomosatryo, 2012a). High nutrient concentrations were reported in several area of floating cage fishery which could trigger the eutrophication problem (Sulawesty et al, 2011). Severe eutrophication problem has been recorded after massive fish kills occurence in Lake Maninjau with indication of toxic algae blooms of mycrocystis (Sulastri et al., 2001). The trophic status of Lake Maninjau was varied over the years ranging from meso to eutrophic (Henny and Nomosaryo, 2012b).

The aim of this paper is to elucidate the main problems causing ecosystem disaster and the fish kills and to propose the possible environmentally sound remedies to reduce the risk of disasters in Lake Maninjau.

Main threats affecting ecosystem disaster in Lake Maninjau

The health of ecosystem of lake Maninjau decreasing from time to time observing from the water quality and the local fish production. Several previous research have shown increasing anoxic water layer above 10 meter depth due to accumulation of organic matter and increasing of hydrogen sulfide production (Henny, 2009), increasing nutrient as TN and TP and decreasing status tropic from meso to eutrophic (Henny and Nomosatryo, 2012b) and decreasing local fish production (Henny and Hamdani, 2013).

One of the main cause that has impact on decreasing of the ecosystem health of L. Maninjau is overexploitation of floating cage fishery (FCF). Growing FCF in L. Maninjau since 1990s and the number of cages exceeding the lake carrying capacity has lead to ecosystem disaster and fish kills problem. The number of fish cages increseas every year from less than 100 units to more than 10,000 units in 2008 up to recent time (Figure 1). The first fish kills disaster occurred in 1997 where the number of fish cage were about 3500 units (Syandri, 20000). The incidence was suspected to happen due the extreme weather combined with synergistic effect of elevated sulfide and oxygen deficit that was uplifted to the water surface. However, more fish kill incicence occurred after 2008, and the incidence happened more than once every year. The exceeding number of fish cages have been believed the cause of this incidence took place. The number of cages allowed based on the calcualtion of lake carrying capicity were only 6000 (Hartoto and Ridwansyah, 2001). Since 2005 the number of cages have been exceeding more than the numbers allowed.

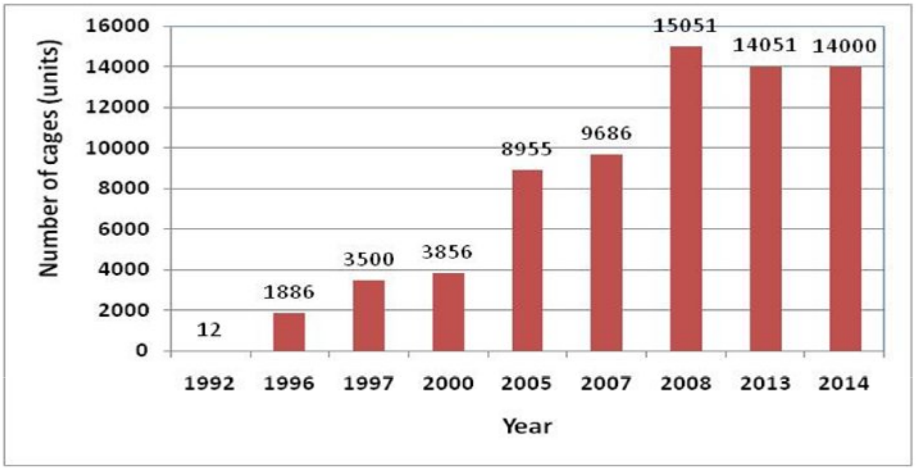

Figure 1. The develoment of number of fish cages in 12 year perios in Lake Maninjau (source: University of Muhammadiyah (for data in 1992 – 2008); Antara News (for data in 2014); Suara Pembaharuan (for data in 2014)

Organic and Toxic Sulfide Pollution

High inputs of organic waste from the excess feedings of floating cage fishery over the years has caused the acccumulation organic matters in the lake sediment. Concentration of organic content as COD in the water increased around 80% from 2006 to 2009. Indication of accumulation of organic matters in the lake sediments could be observed from the the accumulation of solids. Total and volatile solids in the sediment of L. Maninjau form 2006 to 2009 increased more than 70 % . C-organic concentration in lake sediment reached to 700 g/kg (Henny, 2009). The accumulation of solids in the sediment indicating that only small portions of solids were transported out of the lake, and the accumulation will increase even more now with the growing number of fish cages.

Excess organic matter would trigger more microbial activity in the lake that can lead to oxygen deficit and elevated sulfides concentrations in lake. Organic matter degradation in the water and the sediments will consume the oxygen available. When the concentration of organic matter exceeds the concentarion of oxygen needed, the oxygen depletion will occur. When there is no oxygen the excess organic matter as organic carbon will be oxidized by coupled with reduction of sulfate, ferric iron, nitrate by other types of microorganism such as sulfate reducing bacteria (SRB), iron reducers and denitrifyers (Wetzel, 2001; Widdle, 1988). Lake

Maninjau is a caldera type of lake that the lake contains sulfate in its water and sediment. The implication of high organic matter inputs in the lake is increase in sulfide production and furthermore causing more anoxic waer column. Sulfide concentration at depth of 40 m reached level of 400 µg/L and the anoxic water column reached at depth of 20 m. However, in 2011 the anoxic layer of water column reached to < 10 m depth. (Henny, 2009; Henny dan Nomosatryo, 2012). Elevated hydrogen sulfide, one of sulfide species, with concentrations of > 2 µg/L is toxic to aquatic organisms (Weiner, 2000). Hydrogen sulfide concentration in lake Maninjau in water column of 20 – 40 m depth was 10 - 120 µg/L (Henny, 2009). This result indicated that in condition with no light during day time and limited oxygen production from the photosynthesis, the elevated sulfide could diffuse to the water surface causing oxygen depletion and subsequently leading to fish kills in fish cages. The extreme weather with heavy wind also has been suspected can cause mixing and consequently resulting in upwelling-downwelling process where the deeper water column conataining sulfide and anoxic will be uplifted to the water surface and lead to fish kill disaster in L. Maninjau (Apip et al*.,* 2003). This phenomenon has been called by the local people as ”tubo belerang”.

Impact of elevated sulfides concetration in lake depending on the hydrochemistry of lake can cause the loss of iron and internal phosphorus release from the sediment that can stimulate the internal eutrophication (Hines et al, 200; Wetzel, 2001; Smolders et al., 2006). Henny and Nomosatryo (2012 a) indicates that L. Maninjau constantly produce sulfides and release phosphorus from its sediment.

Nutrients pollution and eutrophication

The waste from excess feeding of FCF in a large amount is entering the lake directly that cause enrichment in nutrient and lead to water quality deterioration (Yee et al., 2012; Guo and Lie, 2003; Garg and Garg, 2002). The main source of nutrient input in Lake Maninjau has known from the FCF counted around 400 ton/year. Ninety five percents of nutrient waste load as nitrogen and phosphorus that enters the lake was from FCF and small percentage of waste from other sources such as domestic waste, agricultural run-off and detergent (Figure 2).

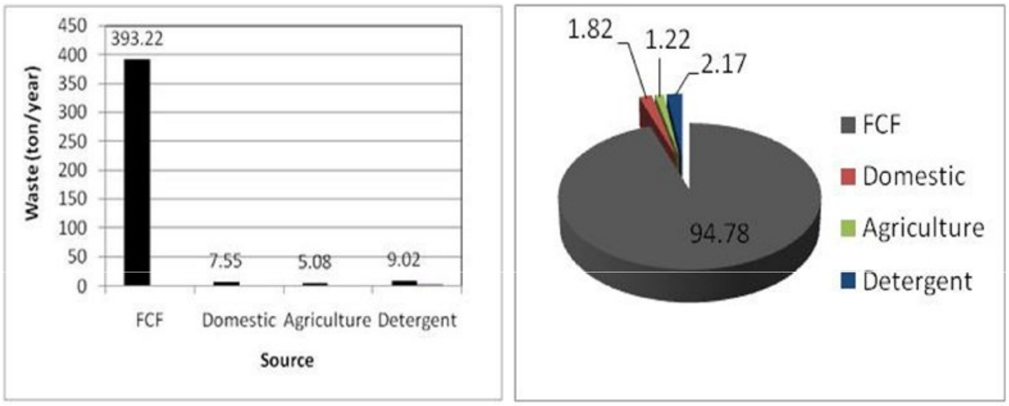

Figure 2. Total and percentage of nitrogen and phosphorus waste load to Lake Maninjau in 2006 (source: Research Institute of Muhammadiyah University)

Concentration of total nitrogen (TN) in lake water varies with time but concentrations of total phosphorus in L. Maninjau tend to increase from time to time both in epilimion and hypolimnion layers. High phosphorus concentrations in the hypolimnion indicates constant internal P loadings from sediment release that can contribute to higher P concentration in the epilimnion layer. Annual trend of total phosphorus was followed by chlorphyll-a trend indicating the bloom of green algae population. The status trophic of Lake Maninjau changed from mesotrophic in 2007 to eutrophic since 2008 (Henny and Nomosatryo, 2012b). High nutrient in lake water also caused the bloom of blue green algae which known as toxic to fish. Population of blue green algae counted more tan 40 up to 60% in almost all areas especially near the FCF (Sulastri et al 2012). Both internal and external loading of phosphorus has prolonged Lake Maninjau in condition of eutrophic state and poor water quality. Although both nitrogen and phosphorus is increasing in L. Maninjau, usually phosphorus is a limiting factor that control blue green algae bloom. Schindler, et al (2008) indicated that in order to reduce eutrophication problem, the focus of management must be on decreasing inputs of phosphorus not nitrogen. Eutrophication problem is one of the complicated problems that require comprehensive solution.

Fish kills occurences

In the early period of no cage for fishery (FCF) before 1997, the lake has never experienced any fish kills although the occurrence of phenomenon of tubo belerang has been reported by the local people. When the phenomenon of tubo belerang occurred during this period the local fish were not totally affected, instead they were all in the water surface in intoxicating condition, making it easier for local people to catch the fish. The phenomenon of tubo belerang had been reported by local people to occur every 10 years due to extreem whether condition and when it happened it turned out to be blessing for the local people because they could get a big catch of local fish.

FCF had been intrduced in Lake Maninjau in 1992 and continuesly developed untill now. The hydropower installation in the lake made the water outlet was shut, meaning that the lake water only flowed out form the lake under the hydro turbine which was below 10 m, while the surface water was trapped in lake which caused the toxic algal blooms. The first massive fish kills took place in 1997 which was caused by decreasing water quality and was triggerred by the extreem weather condition. The lake condition was in eutrophic condition with indication of toxic algal blooms (Syandri, 2000). After the fish kills disaster, the activity of FCF had been downsized and some mangement strategies were made including opening the weir at the outlet near the hydropower (Sulastri et al, 2012). However, in 2006 the numbers of FCF increased to more than 10,000 units and the water quality of lake decreased again with the trophic status change from meso to eutrophic to meso trophic (Triyanto et al, 2006). Massive fish kills occurred again in 2009 with big economic lost (R.C. Limnology, 2009). Since then the fish kills occurred several times every years up to now. The number of fish kills and economic lost from 1997 to 2014 can be observed in Figure 1.

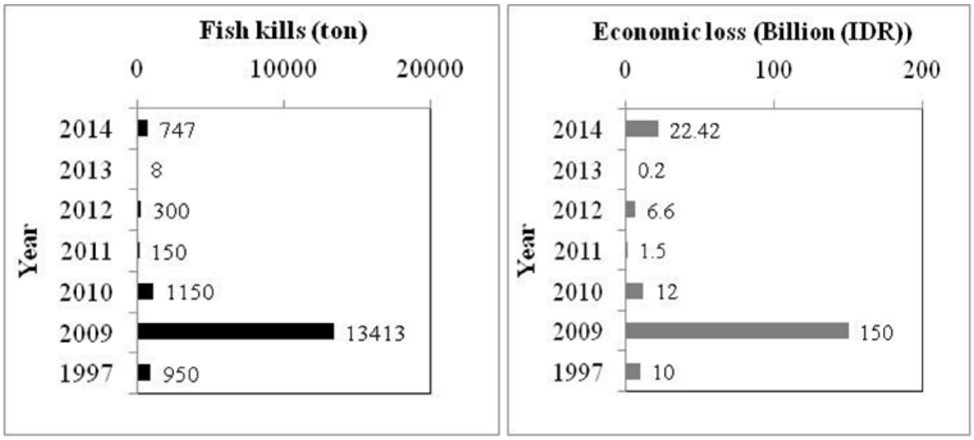

Figure 3. The number of fish kills and economic lost in lake Maninjau (sources: Syandri (2000), RCL (2009), Republika (2014))

Remedies to reduce the risks of ecosystem disaster in Lake Maninjau

There are several existing lake management tools and technology that can be adopted to reduce the risks of ecosystem disaster in Lake Maninja. Some even have been introduced to be evaluated however the lack of attention from the local authority and/or decision makers has contributed to even bigger disaster. One of the complex problems is no regulation issued on the number of FCF units allowed and placing the FCF in Lake Maninjau. The FCF has been growing over the years. Based on morphology of Lake Maninjau the water flows from the closed side with the steep depth like a dead zone to the other side at the only lake outflow and shallower area. Therefore the unit of FCF has to be placed properly near the area affected by flow or near the outlet area in order to flush out the excess fish pellets and waste from FCF to prevent the accumulation of waste. Placing and the number FCF units allowed should meet the lake carrying capacity. The number of cages allowed based on the calcualtion of lake carrying capicity were only 6000 (Hartoto and Ridwansyah, 2001).

Double layered floating cage fishery (FCF) had been introduced in Lake Maninjau to be evaluated in reducing the excess fish pellets from one layered FCF. The schematic diagram of double layered FCF can be seen on Figure 4. The top layered cage was filled with carps and the bottom layered cage was filled with tilaphia. Fish pellets were fed to the carps and the tilaphia only got the food from the excess pellets wasted from the top cage. The results indicated that double layered

FCF increased fish production by 6%. The excess feedings were reduced and less escaped to the bottom of the lake, however, the results did not quantify the reduction of the excess feedings. The double layered FCF seemed to be hard to be built and handled during harvest (Triyanto et al, 2005). Although it is a good alternative, people still do not want to try out.

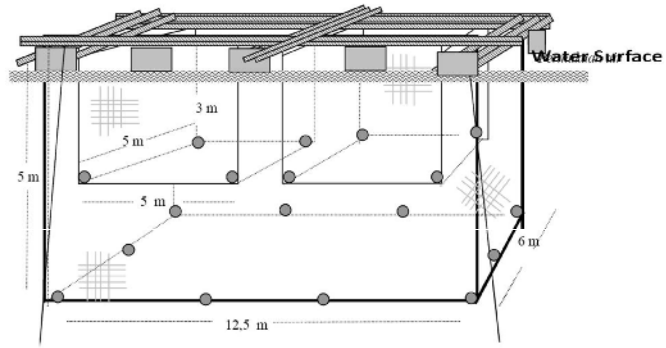

Figure 4. Schematic diagram of double layered FCF (Triyanto et al., 2005)

Wetland treatment can be used to reduce the pollutants that are discharged into the lake water. Surface, agricultural run-off and sewerage or domestic wastewater can be collected in the channel and can be treated by using constructed treatment wetlands (CTWs) in the lake catchment area before flowing into the lake. CTWs are engineered wastewater treatment systems that comprise combined biological, chemical and physical processes similar to processes in natural treatment wetlands. There are several types of CTWs include FWS (free water surface), VSSF (vertical subsurface flow) and HSSF (horizontal subsurface flow) and hybrid system combined two or more of those types of wetlands (Kadlec and Wallace, 2009). CTWs have been successfully used to treat wastewater by removing of pollutants such as organic compounds, suspended solids, pathogen, metals and nutrients (Kadlec and Wallace, 2009; Gikas et al, 2013). CTWs also have been used to treat domestic sewage, industrial wastewater and agricultural and storm run-off and even lake and river polluted water (Kadlec and Wallace, 2009; Mburu et al, 2013; Maine et al, 2007; He et al, 2006; Li et al , 2008). Zhang et al, 2014 have been reviewed the CTWs types used in developing countries and from their summary it has been indicated that hybrid systems composed of VSSF and HSSF have better performance in removing suspended solids, organic compounds, and nutrients with > 80% removal efficiency. Wetland systems in tropical area exposed to higher temperatures and direct sunlight throughout the year that gave high plant productivity are more efficient in removing the pollutants (Zhang et al, 2012).

Constructed treatment wetlands usually either use of free-floating aquatic plants, or sediment-rooted emergent wetland plants. Another type of treatment wetlands, floating treatment wetlands (FTWs), are innovative treatment concept that employ rooted, emergent plants growing as a floating mat on the surface of the water rather than rooted in the sediments. FTWs offer great promise small lake/ponds and rainfall-driven storm water treatment applications because they are not so much affected by fluctuations in water levels that may submerse and adversely stress bottom-rooted plants (Zhang et al 2012; Auckland Regional Council, 2006). FTWs not only have been used to improve water quality and to enhance habitat but also to improve the aesthetic on the lake/ponds in urban landscape. FTWs have been used to improve water quality of hyperuetrophic urban lake by reducing nutrient and solids concentration nearly 50 % and therefore improve the trophic status of the lake (DeBusk, 2005). FTWs have been use to treat storm water, agriculture and municipal waste water (Auckland Regional Council, 2006; Stewart, 2008). Beside having capability in reducing the pollutants, FTWs can also function as Attracting Fish Device Floating Wetland (AFDFW) to serve as nursery ground and habitat protection for local/endemic fish in the lake to advance the climate change adaptation.

Lake Maninjau has been in eutrophic condition since 2008, along with sulfides containing water just below chemocline the lake condition can face oxygen deficit at night, when all organisms including blooming algae will quickly use all oxygen. The anoxic water will reach to the surface with lake mixing and cause the fish kills. By reducing the nutrients in the lake water FTWs can reduce risk of eutrophication and mintain oxygen level in the lake water during critical time in the evening and hence bsy reduce the risk of fish kill. (FTWs) can be installed in the shallow area of lake water intercepting channel inflow or near the FCF area where the wave is not too big. FTWs have been evaluated in reducing nutrients and suspended solids in an urban lake in Jakarta megacity (Henny et al, 2014). Figure 5 shows schematic of FTWs and FTWs application in an urban lake.

CTWs and FTWs can also serve as wild life habitat. Over all the CTWs and FTWs are considered as an innovative eco-technology that can serve as water treatment and improve aquatic and wildlife habitat and at the same time provide the aesthetic the lake shoreline landscape.

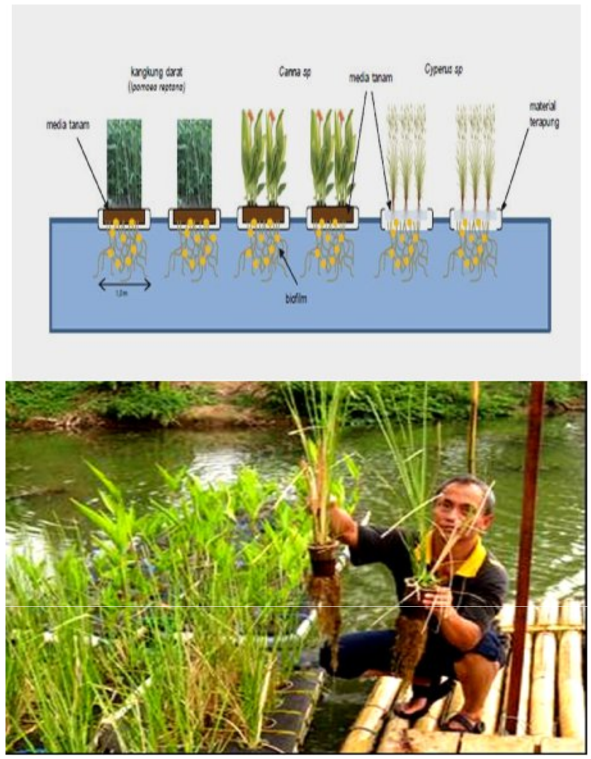

Figure 5 . Schematic diagram of floating treatment wetland (FTW) (courtesy: Sunaryani, 2014); FTW application on an urban lake (Henny, 2014).

Early warning system system tools such as determining the key parameters in critical time (e.g. threshold dissolved oxygen concentration and water transparency) should be developed to help in disaster risk reduction. Fakhrudin et al (2012) has preliminarily studied online monitoring system in Lake Maninjau for temperature and pH parameters but not yet dissolved oxygen. The system is currently still under construction and corrected.

Successful lake management to reduce the risk of natural disaster including massive fish kill requires that developed ecosystem based management tools should be incorporated into decision making. The users as social functions in Lake Maninjau should be able to comply with the legal basis. There are eleven potential conflict of social functions that should be included in the management role (Hartoto, 2009). Sulastri et al (2012) found that co management among the local institution (government), the local people authority and the 11 social functions by enhancing the role of these social functions and increasing the public awareness can support the successful management. The major indicators of successful lake management in Maninjau included ecological sustainability, community sustainability, institutional sustainability, and socio-economic sustainability.

A much more successful management strategy requires combination in lake-actions and implementation of management tools. The management should not only effective in reducing the natural disaster including disaster of fish kill but also in maintaining the stability of lake ecosystem to advance climate chage adaptation and to enhance ecosystem services in lake.

REFERENCES

Antara News. Selasa 12 Agustus 2014. Lagi, 400 ton ikan Danau Maninjau Mati.

Apip, M.Fakhrudin, Sulastri, L. Subehi and I. Ridwansyah. 2003. Telaah Unsur Iklim dalam Proses Fisika Perairan Danau Maninjau. *Limnotek*, 10(1), 1-10.

Auckland Regional Council, 2006. Application of Floating Wetlands for Enhanced Stormwater Treatment: A Review. Technical Publication.

DeBusk, T.A., R. Baird, D. Haselow and T. Goffineta. 2005. Evaluation of a floating wetland for improving water quality in an urban lake. In: Proceedings of 8th Biennial Conference on Stormwater Research and Watershed Management, pp.175 –

184.

Fachrudin, M. 2001. Kajian ekohidrologi sebagai dasar untuk pengelolaan Danau Maninjau Sumatera barat. Puslit Limnologi LIPI.

Fachrudin, M., I. A. Satya, T. Chrismada, A. Hamid. A. Foni, T. Endra dan Kodarsyah. 2012. Pengembangan sistem monitoring online dan peringatan dini bencana lingkungan: Studi Kasus Maninjau. Prosiding Seminar Nasional Limnologi VI Tahun 2012.49-64

Hartoto, D.I. & I. Ridwansyah. 2001. Penghitungan daya dukung danau atau waduk untuk pengembangan budidaya ikan dalam karamba. Contoh kasus Danau Maninjau. 13 pp.

Hartoto, D.I. 2009. Rejuvenation of local Ecological Wisdom for the development of fisheries co-management in Lake Maninjau. Paper was presented in The Workshop on "Lembaga Adat di Indonesia: Apakah mereka memiliki peran dalam Pengelolaan Sumberdaya Perikanan dan Wilayah Pesisir", Lombok, Indonesia 2-5 Agustus 2009, International Collective In Support of Fishworkers. 36 pp.

Henny, C. and S. Nomosatryo. 2012a. Dinamika Sulfida di Danau Maninjau: Implikasi terhadap Pelepasan Fosfat di Lapisan Hipolimnion. *LIMNOTEK* , 102-112.

Henny, C., and S. Nomosatryo. 2012b. Nutrient Dynamicsin Lake Maninjau: Implication of fish cage fishery. The Tenth International Symposium on South East Asia Water Environment. November 7 – 11. Hanoi Vietnam.

Henny, C. 2009. Dynamics of Biogeochemistry of Sulfur in Lake Maninjau. *LIMNOTEK VII(2)* , 34-35.

Henny, C and A. Hamdani. 2013. Evaluation of decreasing in local fish population related to water quality in Lake Maninjau. Puslit Limologi. LIPI.

Henny, C. 2014. Effect of floating treatment wetlands on reduction of polutant in an urban lake. Laporan Teknis. Puslit Limnlogi. LIPI.

Hines, M. E., P. T. Visscher, dan R. Devereux, 2002, Sulfur Cycling, In: C. J. hurst, R. L. Crawford, G. R. Knudsen, M. J. McInerney, L. D. Stetzenbach (ed), Manual of Environmental Microbiology, ASM Press, Washington, pp 1138.

Kadlec, R.H. and Wallace, S.D. 2009. Treatment Wetlands. United States of America: CRC Press.

Mburu, N., S.M. Tebitendwa, D.P.I. Rousseau , J.J.A. van Bruggen, P.N.L. Lens. 2013. Performance evaluation of horizontal subsurface flow-constructed wetlands for the treatment of domestic wastewater in troics. J. Environ. Eng. 139, 358 - 367.

Maine, M. A., N. Sune, H. Haddad, G. Sanchez . 2007. Temporal and Spatial variation of phosphate distribution in the sediment of free water surface constructed wetland. Sci. Total Environ, 380, 75 - 83.

He, L.S., H.I. Liu, B.D. Xi, Y.B. Zhu. 2006. Effects of recirculation in vertical flow constructed wetland on treatment efficiency of livestock wastewater. Water Sci. Technol. 54 (11 - 12) ,137 - 146.

Li, L.. Y. Li, d.K. Biswas, Y. Nian, G. Jiang. 2008. Potential of constructed wetlands in treating the eutrophic water: evidence from Taihu Lake of China Bioresource Technol. 99, 173 - 179.

Garg, J. and H. K. Garg. (2002). Nutrient loading and its consequences in a lake ecosystem. *Tropical Ecology*., 43(2), 355-358.

Guo, Longgen and Zhongjie Li. (2003).Effects of nitrogen and phosphorus from fish cage-culture on the communities of a shallow lake in middle Yangtze River basin of China. *Aquaculture*, 226 (2003) 201 – 212.

Gikas, P., E. Ranieri, G. Tchobanoglous. 2013. Removal of iron, chromium and lead from wastewater by horizontal subsurface flow constructed wetlands. J. Chem. Technol. Biotechnol. 88 (10), 1906-1912.

Republika. Selasa 30 Desember 2014. Kerugian akibat ikan mati di Maninjau capai Rp. 22 miliar.

Stewart, F.M., T. Mulholland, A. B. Cunningham, B.G. Kania and M. T. Osterlund. 2008. Floating islands as an alternative to constructed wetlands for treatment of excess nutrients from agricultural and municipal wastes – results of laboratory-scale tests. Land Contamination & Reclamation, 16 (1), 25 – 33.

Smolders, A.R., L.P.M. Lamers, Lucassen ECHET, Van Der Velde, J.G.M. Roelofs. 2006. Internal eutrophication: How it works and what to do about it. A Review. *Chem Ecol*., 22, 93-111.

Suara Pembaharuan. Rabu 26 Maret 2014. Kematian missal ikan Danau Maninjau karena jumlah KJA membengkak.

Sulastri, D. I. Hartoto and I. Yuniarti. (2012). mEnvironmental Condition, Fish Resources and Management of Maninjau Lake of West Sumatera. *Ind. Fish Res. J. 18 (1)* .

Sulawesty, F., Sutrisno, A. Hamdani and Triyanto. (2011). Kondisi Kualitas Air Beberapa daerah Pemeliharaan Ikan Karamba Karing Apung di Danau Maninjau. *LIMNOTEK 18 (1)* , 38-47.

Syandry, H. 2000. Dampak Karamba Jaring Apung Terhadap Kualitas Air Danau Maninjau, *Presented in Panel Press Club (PPC)*, Padang. 13 pp.

Triyanto, Lukman and A. A. Meutia. (2005). Introduksi Keramba Jaring Apung Berlapis sebagai Alternatif Sistem Pemeliharaan Ikan dan Keramba Ramah Lingkungan di Danau Maninjau Sumatera Barat. *LIMNOTEK XII (2)* , 61-67.

Wetzel, R. G., 2001, Limnology: River and Lake Ecology, Academic Press, San Diego. 1006p.

Weiner, E. R., 2000, Applications of Environmental Chemistry: A practical Guide for

Environmental Professionals, CRC Press LLC, Boca Raton, pp 276

Widdel, F., 1988, Microbiology and Ecology of Sulfate- and Sulfur-Reducing

Bacteria, In A. J. B. Zehnder (ed.),_Biology of Anaerobic Microorganisms. John Wiley & Sons, New York.469-586.

Yee, L.T., D.D. Paka, L. Nyanti, N. Ismail, J.J. J. Emang. (2012). Water quality at Batang Ai Hydroelectric Reservoir (Sarawak, Malaysia) and implications for aquaculture . *International Journal of Applied Science and Technology,* 2(6),23-30.

Zhang, D. Q., K.B.S.N. Jinadasa, R. M. Gersberg, Y.F. Liu, W. Jern Ng., and S. K. Tan. 2014. Application of constructed wetlands for wastewater treatment in developing countries – A review of recent developments (2000 – 2013). J. Environ. Manage. 141: 116-131.

Zhang, D. Q., S.K. Tan, R. M. Gersberg, Y.F. Liu, J. F. Zhu, S. Sadreddin. 2012. Nutrient removal in tropical subsurface flow constructed wetlands under batch and continuous flow conditions. J. Environ. Manage. 96, 1 – 6.