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A review on the changes in lake Naivasha fisheries: Causes, exploitation trends and conservation

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Abstract
Lake Naivasha is the second largest freshwater lake in Kenya, located in the floor of the Eastern arm of the Kenyan Great Rift Valley and supports a large biodiversity of macrophytes, aquatic birds and exotic fish species. Consequently, the lake is recognized for tourism, fishing, water provision, and has been designated as a Ramsar site. This paper followed the use of unpublished and published data as the key methodological design. The aim of this paper was to undertake a comprehensive review of the changes of Lake Naivasha fisheries by focusing on the causes, exploitation trends, and conservation measures. The limnological and fishery status of Lake Naivasha have received a significant attention due to the need for better management practices to sustain its ecological and economic values. The fishery of L. Naivasha has been dominated by different species with the current catch contribution consisting mainly of common carp, *Cyprinus carpio*, Nile tilapia, *Oreochromis niloticus*, blue-spotted tilapia, *O. leucostictus* and African catfish, *Clarias gariepinus.* The previous dwindling trends observed in Lake Naivasha fisheries has been attributed to factors such as catchment degradation, pollution, excessive water abstraction for flower farming and domestic use, introduction of invasive plant and animal species, changing water quality attributed to increasing anthropogenic and climate change. There has been immense amount of efforts put by private and public institutions to arrest this problems affecting the lake towards management and conservation. In order for sustainable utilization, and exploitation of the lake resources, there is urgent need to consider a holistic ecosystem management approach within the lake's catchment area.

Keywords: Lake Naivasha, fisheries, conservation, exploitation trends, conservation

Introduction
Lake Naivasha is the second largest freshwater lake in Kenya located in the floor of the Eastern arm of the Kenyan Great Rift Valley at an altitude of 1890 m above sea level [1] with a surface area of between 100 and 152km^2 that varies during dry and wet seasons [2]. The lake exhibits unique freshness maintained by underground seepage [3] and its conductivity fluctuates between 250-450 µS cm^{-1} [4, 5]. Lake Naivasha has a shallow bathymetry with a maximum depth of 21 m around the Crescent Island [6], and an average depth of approximately 6m, which corresponds to the maximum depth of the southern part of the lake [7]. Lake Naivasha is made up of three main portions: the main Lake, Oloidien and the Sonachi, which lies on a crater [8]. Sonachi has is located towards the southwestern side of the main lake and has alkaline characteristics because of its surface independence from the main lake to which it is connected through an underground drainage [3]. The topographic divide of Lake Naivasha catchment lies within the Intertropical Convergence Zone (ITCZ). The location in ITCZ contributes to bi-modal rainfall pattern; long rains are experienced between April and June [9], while short rains are experienced in the period October-November annually [8]. The lake is mainly recharged by two perennial rivers-River Malewa and Gilgil- accounting for inflow recharge rates of approximately up to 80% and 20% respectively [4, 10].
Because of its freshwater characteristics, the lake supports a large biodiversity of macrophytes, aquatic birds and exotic fish species [4, 11]. Consequently, the lake is recognized for tourism, fishing, water provision, and has been designated as a Ramsar site since 1995 [7, 12, 13].

Nevertheless, the limnological and fishery status of Lake Naivasha have received a global attention due to the need for better management practices to sustain its ecological and economic values [5, 11, 13, 14]. The lake and its catchment have experienced a multiple of complex ecological and environmental changes due to the ongoing urban development, intensive agricultural activities and argumentation of fisheries through exotic introductions [13, 14, 15]. For instance, population growth around the lake catchment has resulted into an increased demand for the overexploitation of scarce environmental resources, which result in lake degradation [16, 17]. Lake degradation is manifested by changes in hydrology, increased turbidity and eutrophication with the dominance of blue green algae and free floating macrophytes [12]. The free floating macrophytes such as *Eichhornia crassipes* and *Salvinia molesta* plays a crucial role in the distribution, abundance, diversity and composition of phytoplankton [8, 45]. Dense mats of macrophyte assemblages affect phytoplankton growth through shading which limits light availability for algae, they also smother algae through their allelopathic effects and competition for nutrients [9, 12, 13]. Sometimes, high levels of nutrient load into the lake results in overproduction and growth of algal blooms which deplete dissolved oxygen and increase the biological oxygen demand [8, 18]. It has been projected that water temperatures of lakes will increase following global warming which is likely to cause dynamics in lake physico-chemical parameters and cause changes in its biotic components overtime [19, 41]. The past historical trends also point that the interrelationships between different biotic components and fish will further be subjected to increased anthropogenic impacts [5, 43]. Therefore, this study reviews existing information on Lake Naivasha fisheries to assess exploitation trends, ecology, causes and conservation efforts of Lake Naivasha.

Exploitation Trends and Conservation

Illegal, Unreported and Unregulated (IUU) fishing is one of the major challenges facing the fisheries of Lake Naivasha. It involves the use of small mesh-size nets of less than 4`` that capture the juvenile fish reducing the lacustrine recruitment and increases bycatch, which makes it difficult to promote the recovery of the overexploited fish stocks [20]. There have been specific fisheries management strategies to deal with IUU fishing in Lake Naivasha. For instance, in the year 2001, a lake wide closure was imposed on Lake Naivasha fisheries following an annual five-month closure from the year 2003 onwards [14]. The county of Nakuru lifted the ban imposed by closed seasons after devolution of the fisheries sector in the year 2010, resulting to an increase in the number of fisher folk using all manner of legal fishing gears [21]. Consequently, the used of small sized seine nets and monofilament nets became widespread. Gill nets with the mesh size of less than 3.5 inches were used to capture small sized tilapia species such as *O. leucosticus* and *T. zilli* [22]. This reduced fish yields from the lake prompting the county fisheries department to reintroduce Nile tilapia, *Oreochromis niloticus* which was done purposely to argument the declining catches of *Cyprinus carpio* and native tilapiines [23]. The more recent trends point the *O. niloticus* outcompeted *C. carpio which* became a prevalent bycatch in the tilapia fishery, with only few fishers folk targeting large sized common carp [24].

Due to population growth and ecosystem degradation, the fishery of Lake Naivasha was quickly approaching a verge of collapse [12, 13]. Lake Naivasha is located adjacent to Naivasha town, whose population explosion grows at an alarming rate. The current population of the lake catchment is estimated at 200,000 and majority of these people reside in an urban setting [9, 12]. Unfortunately, the town lacks an elaborate sewerage treatment system to sequester large volumes of urban and municipal wastes [25]. Consequently, raw and poorly treated wastes are discharged directly into the lake and indirectly through overland flows into the lake. These wastes contain nutrients that enrich the lake waters causing eutrophication [12, 26]. According to Harper *et al*. [16], increased eutrophication of the lake has to proliferation and growth of algal blooms and recently has been attributed to growth of free floating macrophytes such as *Eichhonia crassipe*s and *Salivinia molesta*. The free floating macrophytes such as *Eichhornia crassipes* and *Salvinia molesta* plays a crucial role in the distribution, abundance, diversity and composition of phytoplankton [14, 27, 40]. Dense mats of macrophyte assemblages affect phytoplankton growth through shading which limits light availability for algae [28], and they also smother algae through their allelopathic effects and competition for nutrients [8, 9]. Sometimes, the wastes discharged into the lake contains high concentration of heavy metals such as copper, lead and mercury which bioaccumulate in the muscles of the fish and end up in higher organisms in the aquatic food chains fed directly to human population [29, 30, 44]. Through collaborative efforts by the Kenya marine and fisheries research institute (KMFRI) and the department of fisheries, periodic restocking of the lake has been conducted with the hope of reviving the lake's declining fisheries [17, 18]. However, continuous restocking and introductions of exotic species have caused complex interactions among the existing populations and changing environment and the lake is currently regarded as a natural "pond" because all the species in the lake are introduced [30]. The fish stocks have been unstable and changing over time. Initially, the common carp dominated lake catches but was succeeded by *O. niloticus* species which dominated the multi species fishery comprising of other species such as the African catfish [31], whereas absence of endemic species of Lake Naivasha indicates that the ecological and limnologic integrity of the lake have been compromised [32]. The increased turbidity inhibits the mating in tilapia thereby negatively impacting the lake recruitment of major fish stocks. The current lake degradation is mainly attributed to indiscriminate logging and clearing of forests for charcoal [33] and use of pesticides which contain synthetic chemicals such as organoflorides which are detrimental to aquatic biota including inhibiting reproduction in some fish and their dynamic effects under the changing climate scenarios remain largely unknown [34]. These chemicals are mainly discharged from floriculture farms in Lake Naivasha catchment [35]. The catchment has reported massive loss of C. *papyrus* wetlands surrounding the lake *from* ~ 1200 ha to currently less than 200 ha caused by frequent harvesting of these macrophytes [8, 12, 14]. Restoration of the lake ecosystem is meant to benefit the riparian communities who derive their livelihood directly from the lake [36]. However, there could be other pertinent challenges such as security, fisheries policy and inadequate infrastructural facilities for value addition and preservation of fish which are not directly contributing to change in lake fisheries but may affect exploitation trends and conservation of the available fish populations [37].

Lake Naivasha Fisheries Status, Dynamism and Succession: Sustainable exploitation of Lake Naivasha fisheries is threatened by the changing water quality attributed to increasing anthropogenic influence on freshwater ecosystems and climate change [9, 12, 13]. The previous dwindling trends observed in Lake Naivasha fisheries has been attributed to factors such as catchment degradation, pollution, excessive water abstraction for flower farming and domestic use and introduction of invasive plant and animal species [4, 9, 26, 32, 46]. This has led to water level fluctuations (Fig. 1), increased turbidity and sedimentation due to activities within the riparian zone like floriculture and horticulture and consequently changes in macrophytes communities [16, 22, 26].

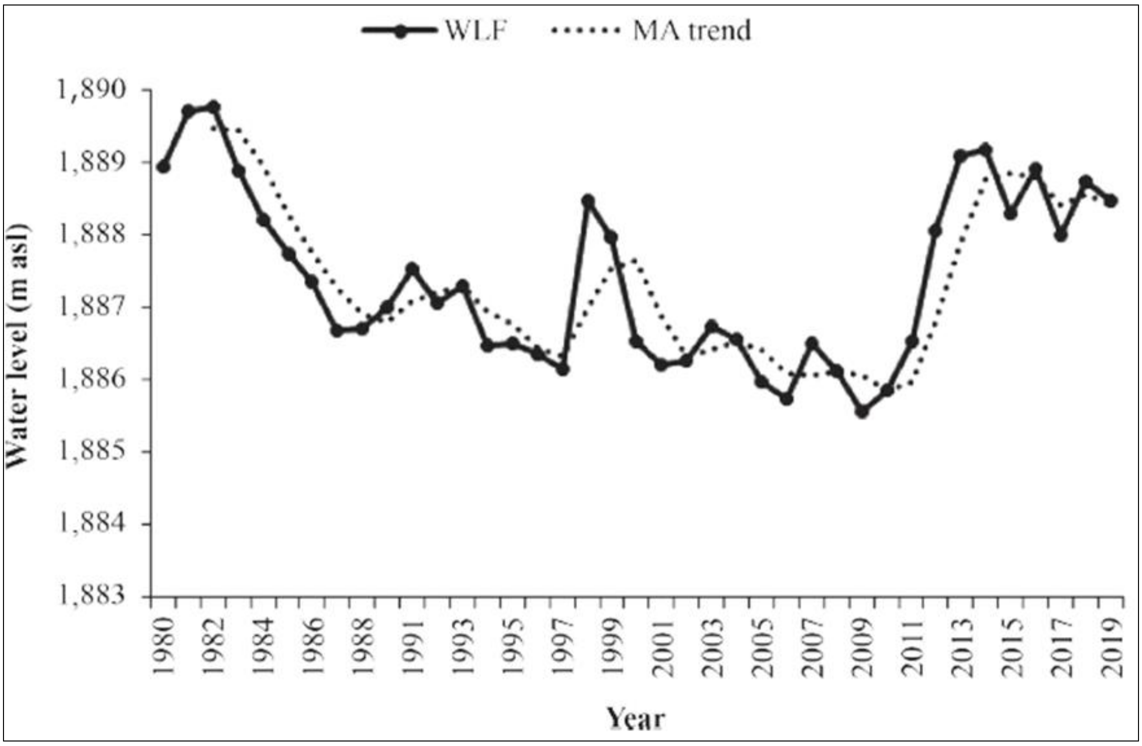

Fig 1: Lake Naivasha annual average water level fluctuations (WLF) (Morara *et al*. [13]

According to Ojuok *et al.* [27], increased fishing pressure and invasion of common carp, *Cyprinus carpio* are two main factors that have contributed to remarkable changes in the fisheries of L. Naivasha. For instance, the increase in common carp populations brought about detrimental effects on the ecology of L. Naivasha because this species displayed increased tolerance to environmental perturbations. This is attributed to its diversified feeding habits [14, 24]. The species dietary composition is based on a wide range of plant materials, such as seeds and detritus, insects, fish remains and fish eggs of different compositions [11]. Being a benthivore, common carp feeds on food materials attached to the bottom sediments thus this leads to uprooting of aquatic plants and resuspension of bottom sediments which causes increased turbidity resulting to reduced light penetration [24]. Unlike the most Tilapiine species such as *O. leucostictus* and *T. zillii* which are highly selective in the choice of substrate for building their spawning nests, common carp has no choice of substrate for eggs attachment [12, 13]. Turbidity affects primary productivity which provides a food base for planktivorous and herbivorous species such as *O. leucostictus and T. zillii* [29]. It also affects breeding in Black bass, *Micropterus salmoides* which make their nest at the muddy bottom [24, 30]. Species introductions have been made into L. Naivasha since 1925 with most introductions recording little ecological success in the new ecosystem [30]. The last endemic species *Aplocheilichthys antinorii* (Vinc.) was recorded in L. Naivasha in 1962 (Njiru *et al*., 2017). Prior to the introduction of *Cyprinus carpio* L. in 2002 [31], the only fish species present in the lake were *Oreochromis leucostictus* (Trewavas), *Tilapia zillii* (Gervais), *Micropterus salmoides* (largemouth bass), *Barbus amphigramma* and *Poecilia reticulate* [26, 28, 34, 36]. In an attempt to diversify the fishery of L. Naivasha, the red Lousiana swamp crayfish, *Procambarus clarkii*, a voracious omnivore was introduced into the lake in 1970s [16, 18, 23, 25]. Following its introduction, there was a reduction in submerged macrophytes, floating leaved water lily *Nymphaea nouchalli* and some aquatic invertebrate populations [27, 30, 32]. Fishing pressure added environmental stress on existing fish population resulting to dwindling trends in the available catches [9, 12, 13].

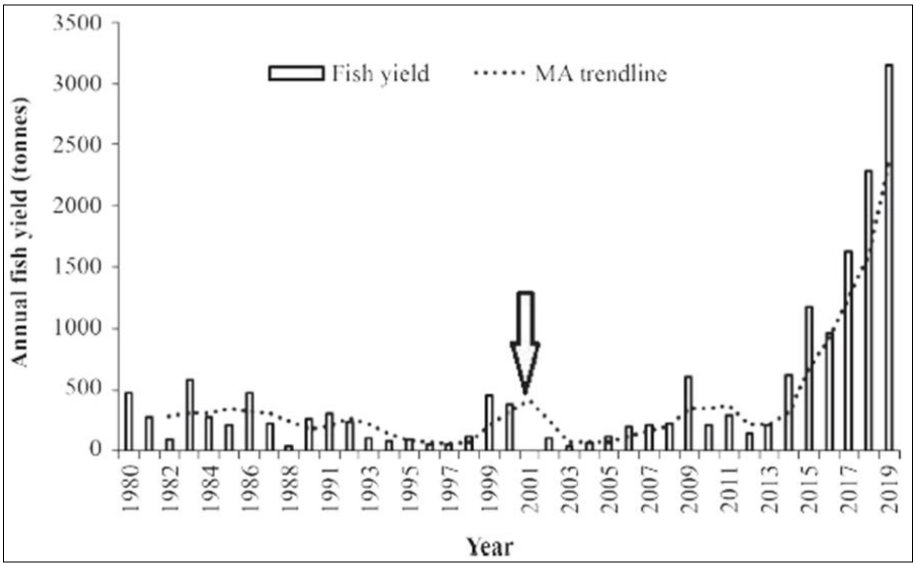

Fig 2: Lake Naivasha annual fish catch between 1980 and 2019 with a fishing ban imposed in the lake in 2000/2001 (Morara *et al*. [13])

A fishery closure was imposed in L. Naivasha in 2001 (Fig. 2) to promote the recovery of commercially important species such as Black bass and *Tilapia zillii* [4, 7]. The average catch composition of the Lake Naivasha using gill net fishery surveys conducted between the 1987 – 2000 showed that *O. leucostictus* was the dominant species up re-opening of the fishery in 2002 [12, 24]. Later, *Cyprinus carpio* successfully invaded and established its population in the lake accounting for approximately 90% of the total fish landings from the lake [24, 28, 36]. In 2013, *C. carpio* accounted for ~ 95% of the total catches in fish landings [10]. This could be due to water level fluctuations as a result of change in climatic conditions and increased anthropogenic activities in the lake and the surrounding catchment [10, 12]. The most recent exotic introduction is that of Nile tilapia, *Oreochromis niloticus* was introduced around 1967 but the fish species later disappeared by 1971 [10, 14, 21] (Table 1). The species was later reintroduced into the lake in the year 2011 by the Government through the department of Fisheries during the Economic Stimulus Program [14, 23].

Table 1: Chronological introductions and status of fish species of Lake Naivasha, Kenya (Njiru *et al*. [14])

English name	Scientific name	Introduction date	Current status
Black lamprey	*Aploactinchelys antinori* (Vinciguerra, 1883)	Last reported in 1962	Endemic; Probably extinct by *M. salmoides* predation
Straight fin barb	*Enteromius paludinosus* (Peters, 1852), Synonym *Barbus paludinosus*	Came through in-flowing rivers since 1982	Currently occasionally caught
Guppy	*Poecilia reticulata* (Peters, 1859)	Date unknown	Recorded since 1982; Currently occasionally caught
Black bass	*Micropterus salmoides* (Lacépède, 1802)	1929 as sport fish; re-introduced in 1949/1951	Found today
Sabaki tilapia	*Oreochromis spilurus niger* (Günther, 1894)	1959	Last caught in 1971
Redbelly	*Coptodon zillii* (Gervais, 1848), previously known as *Tilapia zillii*	1955	Found today
Blue-spotted tilapia	*Oreochromis leucostictus* (Trewavas, 1933)	1959 unintentionally with *T. zillii*	Found today
Blue-spotted tilapia/ Sabaki tilapia hybrid	*O. leucostictus* × *O. niger* hybrid	Plentiful in 1960s	Last caught in 1972; lost the back crossing with *O. leucostictus*
Nile tilapia	*Oreochromis niloticus L.*	1967; Vanished by 1971, probably due to predation by bass	Re-introduced in 2011; Currently present
Mosquito fish	*Gambusia* sp.	Date unknown	Present since 1977
Rainbow trout	*Oncorhynchus mykiss* (Walbaum, 1792)	Date unknown; Came through River Malewa from fish farms	Occasionally caught
Common carp	*Cyprinus carpio* L., sub species mirror carp *C. carpio specularis* and leather carp *C. carpio coiaceus*	Date unknown; Entered through in-flowing rivers from fish farms	Found today
African catfish	*Clarias gariepinus* (Burchell, 1822)	Accidental introduction; escaped from fish farms into in-flowing rivers	First recorded in 2012; Currently present
Louisiana crayfish	*Procambarus clarkii* (Girard, 1852)	Introduced in 1950s to provide food for bass	Currently present

During the 1950's and 1960's, *T. zilli* and *O. leucostictus* were the two species that showed dismal performance after the introductions and did not adapt to the environment to establish lucrative fisheries [11, 13, 14, 28]. It was later established that common carp interferes with the breeding grounds of *O. niloticus* and *M. salimoides* because of their tendency to disturb bottom sediments and refugia during feeding [24, 29]. Recent studies revealed that changes in water quality led to fish kills in the lake which was recorded in February 2010 [21]. Majority of the fish killed were common carp followed by *Micropterus salmoides* and lastly *Oreochromis niloticus*. These fish kills altered the fisheries of the lake leading to low fish catches [10, 21]. Currently, Lake Naivasha fisheries are based on some riverine cyprinid of Longfin barb, *Barbus amphigramma* and four main introduced fish species of Black bass (*Miropterus salmoides*), common carp (*Cyprinus carpio*), *Tilapia zilli* and Nile tilapia (*Oreochromis niloticus*) [2, 6, 21, 28]. Although no direct predation of adult fish by the carp has been documented, its omnivorous behavior leads to consumption of juveniles and eggs of other species in the lake [21, 30]. Such behavior may upset establishment and recruitment of the affected species [28, 33]. Nonetheless, the greatest impact on Lake Naivasha fishery may stem from anthropogenic impacts and management strategies instituted [2, 13, 14, 20].

Conservation and Management Efforts

Over the past years, there has been key strategic management and conservation efforts that have been proposed and implement by public and private institutions in order to maintain the limnological integrity of Lake Naivasha [13, 14, 20]. Research has shown that the limnological integrity of the lake has been achieved through institutional mechanism such as the Lake Naivasha Riparian Association and Imarisha [14, 20]. Other management and conservation efforts have also been realized by the efforts of beach management units and legislative policies such as the Fisheries Management and Development Act [2, 13]. The Lake Naivasha Riparian Association (LNRA) is a Non-Governmental Organization (NGO) in charge of the riparian land around the lake and is under the guidance of a committee. The mandate of the committee is to ensure that the resources in the lake are utilized sustainably, including the fisheries. The LNRA played a significant role of making the lake be designated as a Ramsar site in 1995 and has subsequently developed Lake Naivasha Management Plan [38]. Despite having an elaborate plan on how to manage the lake, the organization has not achieved their goals. The major undoing of the organization is using Codes of Conduct that are voluntary and are not attached to the law. Based on this narrative, many users fail to comply with the rules. For the goals to be attained, the by-laws and penalties should be developed by the members [4, 11, 25]. At the same time, Imarisha is a program involving the Public-Private Partnership (PPP) that work to solve the destruction around Lake Naivasha Basin, protect the investments, safeguard sustainability, and advance the livelihoods of the community. The goal of the organization is to attain "wise use" of the lake resources and those in its riparian zone [11, 25, 39]. Several projects have been initiated under the program including landing sites for Beach Management Units (BMUs) and Imarisha Naivasha Water Stewardship Project (INWaSP). Reforestation is one of the strategies being used in the project to prevent soil erosion and nutrients load to the lake. The fisheries department in Kenya is managed with a top-down approach with the central government taking the main role and stakeholders doing the minor initiatives [2, 13, 14]. A participatory management approach that is integrated with law enforcement is the best method to manage Lake Naivasha Fisheries. Basing on this the Kenyan Government has involved the community by forming the Beach Management Units (BMUs). BMUs were formed in 2001 when the Lake Naivasha fisheries was on the verge of collapsing [20, 39, 42]. Through their involvement, there was an improvement in the number of fishes that were caught in the lake. For instance in 2001 the average catch for a boat was 44kg by unlimited number in fish catches. The number rose to 310 kg after a period of 4 years. The success was short lived because there was a return to the usual norm of using illegal gears while undertaking their activities [14, 18, 21]. Also, the political class felt that the closure could hinder them from attaining their votes leading to a lift to fishing ban in 2013. Despite of all this, co-management experience can be regarded as a learning process and improvements made on the programs. The programs need to be revisited and critical lessons picked from the initiative [20]. According to Nunan [17], the structures and systems in co-management are responsive and flexible but they need more technical, financial, and adaptive support. She also argues that co-management being a process it can yield better results because of its dynamic nature.

Conclusion

Sustainable exploitation of Lake Naivasha fisheries is threatened by the changing water quality attributed to increasing anthropogenic influence on freshwater ecosystems and climate change. Poaching, pollution from horticultural farms and unregulated water abstraction still continues to affect the fisheries of the lake. However, despite all these odds, L. Naivasha fishery has continued to thrive and increase in the lake with an increased dominance of *C. carpio* and *O. niloticus*. The questions is: Will the increased dominance of *C. carpio*, be the boon to the fishers of Lake Naivasha or the bane to the other fishery consisting of *O. leucostictus*, *T. zillii* and *M. salmoides*? Unfortunately, only time will tell. In Lake Naivasha, the stakeholders are being involved through the Fisheries Department though the gains have been minimal. Furthermore, management ought to align fishing effort control and stock enhancement with the changing lake level conditions. There is also an urgent need to explore environmental planning and management as a strategy for solving environmental problems, enhancing participatory natural resources management and utilization as far as the fishery of the lake is concerned.

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