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ZOOPLANKTON COMMUNITY GRAZING RATES IN A SMALL CRATER LAKE: LAKE KURIFTU, ETHIOPIA

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ABSTRACT: Lake Kuriftu is a small eutrophic lake exposed to human impacts such as irrigation, resorts and livestock watering. It was studied for zooplankton community grazing rates using different size classes and concentrations of both zooplankton and phytoplankton from July 2005 to April 2006. The food removal method or changes in chlorophyll-*a* concentration measured before and after grazing was used to quantify zooplankton grazing rates. Grazing rates ranging from 18.3% to 135.6% per day were recorded during the study period. Increasing zooplankton density at two to four times the ambient density was found to decrease grazing rates, indicating that grazing was at optimal level in the lake. Grazing rates were higher for larger zooplankton (>250 μm) than smaller ones (<250 μm). Phytoplankton with size of <10 μm were found to be more easily removed than microplankton (up to 63 μm). Increasing the natural food density decreased the rates while diluting the algal concentration by one-fourth increased grazing rates. The implications of the size and density manipulations on zooplankton grazing are discussed with regards to using different management options for algal control in Lake Kuriftu. It is concluded that regulation and control of external nutrient inputs into the lake should be given priority to prevent algal productivity in the lake since grazing by zooplankton does not control the common large and filamentous cyanobacteria in Lake Kuriftu.

Key words/phrases: Grazing, Lake Kuriftu, phytoplankton, size fractionation, zooplankton manipulation

INTRODUCTION

Globally, many lakes are becoming eutrophic and are suffering from blooms of toxic phytoplankton, which are responsible for animal and human health hazards, deterioration of water quality and several other problems (Vasconcelos, 1999). There has been great interest and intensive research for decades to understand what regulates the abundance of the phytoplankton and to control their proliferation. However, most of the earlier studies focused on chemical and engineering techniques and overlooked biological means (*e.g.*, Vanoni, 1975).

In recent years, biomanipulation, a series of manipulation of biota of lakes to facilitate biological interactions, has been conducted as a means of managing water quality through reduction of excessive algal biomass (Shapiro and Wright, 1984; Ventella *et al*., 2002). The success of this technique depends basically on the effectiveness of zooplankton grazing, which in turn depends on species composition, body size, biomass and feeding habit of zooplankton (*e.g*., Brooks and Dodson, 1965; Peters, 1984; Lampert, 1992; Kasprzak, 1995). The achievement in improvement of water quality through deliberate manipulation of zooplankton was reported by many researchers (*e.g*., Carpenter *et al*., 1985). However, implementing such management technique *in situ* requires detailed knowledge of trophic relationships between the zooplankton and phytoplankton species present in a particular water body. The role of zooplankton grazing in water clarity must be studied in a particular lake before implementing remedial actions by manipulating zooplankton. According to Hubble and Harper (2000), zooplankton grazing should be considered as biological regulation control although productivity of lakes is primarily dependent on nutrient levels.

It is evident that all zooplankton size classes and species do not graze equally and all phytoplankton are not equally removed by grazing (*e.g*., Haney, 1987; Carney and Elser, 1990). Thus, zooplankton grazing rates should be studied at manipulated size and density conditions of both phytoplankton and zooplankton

and with different species. The result of such studies is important to identify which part of size class, species composition, and density should be manipulated to achieve clear water phase.

A considerable number of studies have been conducted on zooplankton grazing under variable size, density and species of both zooplankton and phytoplankton in both temperate and tropical water bodies (Peters, 1984; Haney, 1987; Carney and Elser, 1990). However, few studies have been done in Ethiopian lakes on this aspect. Habte Jebessa (1994) estimated the zooplankton community grazing rate in three lakes and one reservoir of Ethiopia. The interaction between cladocerans and their response to fish predation was studied using enclosure experiment by Brook Lemma *et al*. (2001).

Lake Kuriftu is one of the Ethiopian crater lakes that are being impacted adversely by anthropogenic effects. The human population, livestock and the agricultural farms around the lake are utilizing the lake water. The runoff from the farms adds nutrients to the lake and detergents, which are being used by local people for washing, and bathing in the lake could also be other sources of nutrients. Such activities around the lake and unsustainable utilization of the lake water are threats, which will worsen the condition of the lake in the future given the closed nature, small size and proximity of the lake to human dwellings. Depletion of oxygen, reduction of biodiversity, increase in turbidity, increase in biomass of alien species and public health are some of the threats, which come from the enrichment of the lake and unwise utilization of the lake resource. Therefore, research focusing on the current condition of the quality of the lake water and the different management options to maintain good water quality should be undertaken. One aspect of such research is grazing by zooplankton. The objective of this work was to determine the magnitude of zooplankton community grazing rates under manipulated size and density of both zooplankton and phytoplankton with the aim of using the results for recommending management options for the lake.

MATERIALS AND METHODS

Study area

Lake Kuriftu is located 47 km southeast of Addis Ababa in Bishoftu town at 8°47′ N and 39°00′ E at an altitude of 1860 masl. It is an artificial lake with an approximate maximum depth of 8 m. It was originally a dry crater depression later filled by diverting the river Belbela, a tributary of Mojo River, for irrigation practice in the area (Seifu Kebede *et al*., 2001). The Belbela river contributed large proportion of water to the lake. Precipitation and ground inflow play minimum role in water balance of the lake (Seifu Kebede, 1999). Recently many anthropogenic pressures on the lake have emerged, including irrigation, construction of resorts and livestock watering.

Plankton sampling

Zooplankton and phytoplankton samples were collected from the open water and littoral zone from July 2005 to April 2006 at three weeks intervals. Zooplankton samples were collected using a haul net (mesh size of 67 µm with 31 cm diameter) from 2 m (littoral site) and 6 m depth (open water). Phytoplankton samples were collected with a Ruttner sampler (0.0025 m^3 volume) from the same depth and sites.

Zooplankton community grazing rate calculation

Zooplankton community grazing rate was estimated using food removal method following Bamtstedt *et al.* (2000). The plankton were incubated in 1litre bottles *in situ* in controlled and treatment condition with two replications for each bottle. The duration of the incubation ranged from 4 to 24 hrs and was mostly done during the evening. Before and after each incubation period, the change in chlorophyll-*a* in the bottles was measured. Chlorophyll-*a* (µg/l) was calculated using the formula of Talling and Driver (1963).

A sample of 200 to 500 ml was filtered on a GF/C filter for chlorophyll-*a* analysis from each sample (initial and manipulated). The pigments were extracted with alkaline (basic) methanol.

$$\text{Chlorophyll-}a\ (\mu g/l) = \frac{13.9 \times (E665 - E750) \times Ve}{Vf \times PL}$$

where, E665 and E750 are extinction at 665 nm and 750 nm, respectively
Ve = Volume of extract in ml
Vf = Volume of sample filtered in the lake in litre
PL= Path length of the cuvette (1 cm)

The percentage of grazing rate per day (%G) was calculated following Marin *et al*. (1986).

Grazing coefficient (g) was determined using the exponential relation,

$$g = \ln\left(\frac{Ci}{Cz}\right)/t$$

where Ci is initial and Cz is final chlorophyll concentration in the bottle and t is time of incubation (in days).

$$\%G = g\left(\frac{V}{N}\right)X100$$

where V is volume of the container in ml and N is density of grazers (zooplankton number)

Enumeration and Identification of Zooplankton and Phytoplankton

Estimation of zooplankton abundance or density was done following Edmondson and Winberg (1971). A subsample of 25 ml (out of 1 litter sample) was taken for zooplankton counting using a wide–mouthed pipette and poured into a gridded petridish with 15 grids and counted under a WILD stereoscopic microscope (50 × magnification). Number of individuals per m^3 (N) was calculated as follows.

$$N = \frac{n \times SSF \times GF}{V}$$

where, n is actual count, SSF is sub-sample factor, GF is grid factor and V is volume of water filtered through the net which was determined using the formula ($V = \Pi r^2 h$) where r is the radius of the net mouth and h is the depth from which the sample was taken.

Zooplankton species were identified using keys from Defaye (1988) and Dussart and Fernando (1988).

Phytoplankton samples were counted using procedures given in Kobayashi *et al*. (1998) by allowing the subsamples to settle in 50 ml graduate cylinders for more than 24 hours. Excess water was removed by syringe to leave 5 ml of the sample. 1 ml of homogenized sub-sample was taken with a syringe for counting. Counting was done using a Sedgwick rafter and an inverted microscope (Nikkon) at magnification of 400x. Number of cell per ml was calculated after Hotzel and Croome (1999).

$$Co = \frac{N \times 1{,}000\ mm^3}{A \times D \times F \times 10}$$

where N is number of cells, A is area of field (mm^2), Depth of a field (1 mm) and F is number of fields counted and 1/10 is concentration factor.

Phytoplankton species were identified under a compound microscope (magnification of 1000x) using keys developed by Whitford and Schumacher (1973) and Komarek and Cenberg (2001).

Zooplankton density change study

The ambient zooplankton density was manipulated by concentrating it at 1x, 2x and 4x, following Cyr and Pace (1992), and incubating each with natural phytoplankton assemblage separately. 1x concentrated means ambient density or filtering a known volume of natural lake water once; 2x and 4x samples were prepared in the same way by concentrating nets twice and four times, respectively.

Size fractionation study

Zooplankton was fractionated into two classes with 250μm sieve. Phytoplankton size was differentiated into three size classes (<l0 μm, <20 μm and <63 μm) using Nitex mesh with pore size of 10, 20 and 63 μm, respectively, and were incubated separately in three different bottles after adding grazers to each bottle.

Food density change study

Food density was manipulated by concentrating the natural algal density at 1x, 2x and 4x. Three types of bottles were prepared for each. For the first bottle, a known volume of lake water was filtered once and added to the bottle, and then zooplankters were added. The same was done for the remaining bottles by doubling and quadrupling the amount of filtered water and adding zooplankton by filtering the same volume of water as the first sample. The effect of reduction of algal density in grazing rate was done by diluting the lake water, by filtering with GF/F paper, at different ratios as ½, ¼, and ⅛, and mixed with unfiltered water at these ratios. For example, for 1/2x, half of the sample (500 ml) was filtered with GF/F paper and mixed with unfiltered, 500 ml, of lake water and incubated.

Index and statistical analysis

Regression analysis was done to determine the impact of grazing rate on biomass of phytoplankton in the lake (Minitab 1.4 Version). Carlson's trophic state index was used to categorize the productive status of the lake with the following formula (Carlson, 1977).

Chlorophyll-*a* TSI (TSIC) = 9.81 × [ln (Chlorophyll-*a* average)] + 30.6

RESULTS AND DISCUSSION

The zooplankton and phytoplankton species encountered in the experiment are given in Tables 1 and 2.

Table 1. Zooplankton taxa identified in Lake Kuriftu during the study time.

Cyclopodia	Rotifera	Cladocera
Thermocyclops consimilis ++	*Brachionus bidentata*	*Diaphanosoma excisum*
*Mesocyclops aequatorialis*r	*B. caudatus*	*Moina micrura*
	B. fulcatus	*Ceriodaphnia sp*
	B. calcyflorus	
	*Filinia sp.*r	
	*Polyarthra sp.*r	
	*Asplanchna sp.*r	
	Keratella cochlearis r	
	K. tropica r	

++ Dominant species; r Rarely occurred

Table 2. Phytoplankton species identified in Lake Kuriftu.

Phytoplankton group	Species name
Cyanophyceae (Cyanobacteria)	*Cylindrospermopsis africana* ++
	C. Curvispora ++
	Planktolyngbya sp+
	Microcystis aeuroginesa
	Anabaena circinalis+
	Psuedoanabaena sp
	Raphidiopsis sp+
Chlorophyceae (Green algae)	*Pediastrum simplex*
	P. duplex
	Scenedesmus armatus
	Chlamydomonas reticula
	Phacotus lenticularis
Bacillariophyceae (Diatoms)	*Thalassiosira sp*
	Navicula cryptocephale
	Nitzschia vernicularis
	N. rostellate
Dinophyceae (Dinoflagellates)	*Peridinium sp*r
Cryptophyceae (Cryptophyta)	*Cryptomonas obvata*
Euglenophyceae (Euglinophyta)	*Phacus longicauda*r
	Lepocincilis sp.

++ most dominant, + dominant, rrare occurrence

The mean zooplankton community-grazing rate at natural (ambient) density in Lake Kuriftu was 59.3%, which is lower when compared to values reported for many lakes, both in tropical and temperate lakes (*e.g.*, Jarvis, 1986; Cyr and Pace, 1992; Habte Jebessa, 1994). The low grazing rate in Lake Kuriftu can be attributed to the species composition of the zooplankton and phytoplankton community and its trophic status since grazing is dependent mainly on these factors (*e.g.*, Carney and Elser, 1990).

The Cyclopoid copepod, *Thermocyclops consimilis* dominated the zooplankton community in Lake Kuriftu (Table 1), followed by rotifers. No Calanoids were encountered during the study period. Grazing rate is expected to be lower in the systems where zooplankton communities are dominated by cyclopod copepods than cladocerans due to their feeding habit (Cyr and Pace, 1992). Most recent works have shown that *Thermocyclops* are not efficient grazers but predators of smaller cladocerans and chironomids (*e.g.*, Gophen, 1995; Feutchmayr *et al*., 2004). Stronger top-down effects on phytoplankton biomass is observed in systems dominated by cladocerans and calanoids (*e.g.*, Lampert, 1988; Carney and Elser, 1990; Habte Jebessa, 1994), which are more efficient grazers than others. Particularly, calanoids increase grazing rates regardless of the trophic status of the lake since they have the ability to feed raptorially and utilize longer phytoplankton filaments (James and Forsyth, 1990).

Lake Kuriftu is categorized as eutrophic, with a Carlson trophic state index value of 69.1, and is also a turbid lake. Like other turbid eutrophic lakes, phytoplankton community of the lake is dominated by blue greens (Table 2), which have competitive dominance over other phytoplankton in the system because of their physiological adaptations and poor utilization by grazers (Paerl, 1988). Porter and Orcutt (1980) and Lampert (1987) have shown that three general characteristics of blue greens, manageability, nutritional inadequacy and toxicity, tend to limit their exploitation by zooplankton. In addition, these algae interfere with filtration processes of grazers (Jarvis, 1986; De Bernardi and Guissani, 1990). Because of such factors, grazing is lower in eutrophic lakes unlike mesotrophic ones where relatively edible and nutritious algae dominate (Benndorf *et al*., 2002). These facts partially explain the lower grazing rate of zooplankton in Lake Kuriftu.

Increasing the ambient zooplankton density decreased the grazing rates (Fig. 1). This result is in contrast to the trend observed in all studied lakes in the work of Habte Jebessa (1994), except Bishoftu Lake, but is similar to results of most works elsewhere (*e.g.*, Sommer *et al*., 2001). Crowding of zooplankton above a certain density reduces the grazing rate of both copepods and cladocerans by reducing space, interfering with the filtering apparati and creating over competition on available edible algae and has effect on

physical and chemical factors (Hayward and Gallup, 1976). The implication of this result is that the existing zooplankton density has little impact in reducing algal density in Lake Kuriftu, and increasing grazers' density (*e.g.*, by reducing planktivorous fish) will have no importance in controlling phytoplankton biomass.

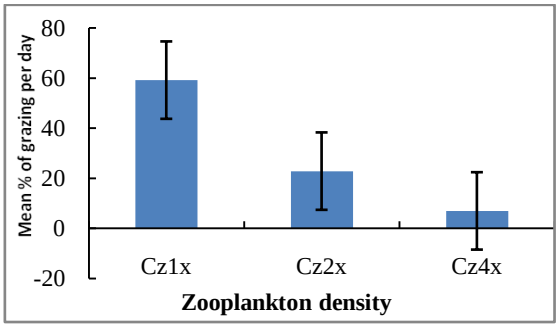

Figure 1. Effect of zooplankton density change on grazing rates (mean of 33 incubations), bars show standard error.

Higher grazing rate (125.5%) was obtained for the phytoplankton group <10 µm size. Grazing rates on this size group of phytoplankton was above 100% in October, November, January and February. Lowest mean grazing rates (33.9%) was recorded for larger microplankton (<63 µm). The mean grazing rate trend showed inverse relationship with size of phytoplankton (Fig. 2). This result implies that the presence of larger algae can reduce grazing ability of the existing zooplankton community, and grazing by zooplankton community seems to have little impact in controlling larger phytoplankton in this lake.

Our result is in agreement with the "size-efficiency" hypothesis (Brooks and Dodson, 1965).

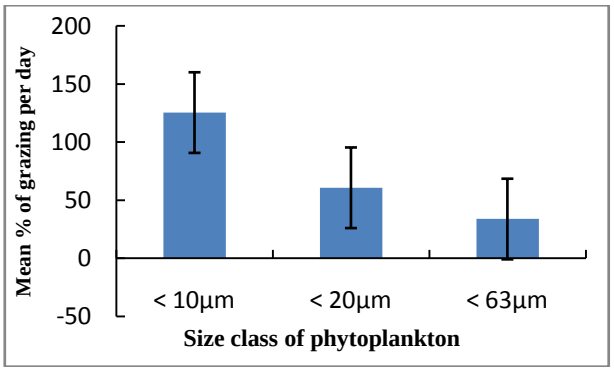

Figure 2. Result for phytoplankton size fraction study (mean of 18 incubations), bars show standard error.

According to the hypothesis, since all zooplankton size groups compete for smaller-sized food (1–15 µm) and because of their ease of edibility, grazing on this phytoplankton class is most intensive. According to Gliwicz (1977), zooplankton grazing rate decreases with an increase in algal size. Zooplanktons have a lower and upper limit to ingest edible particles. Small cladocerans and rotifers have the upper boundary about 20 µm whereas larger cladocerans and copepods can ingest food particle with maximum size of 50 µm (Sommer and Lampert, 1997). These facts show that even large cladocerans and copepods cannot remove larger phytoplankton easily.

Higher grazing rate (>100%) on smaller phytoplankton (<10 µm) coincided with higher relative abundance of larger zooplankton (copepods) in this study. The relative abundance of copepods was 70.1, 84.3 and 82.8% on October 28, January 18 and February 2, respectively (Table 3). Thus, higher grazing rate on smaller-sized phytoplankton in the lake seems to be regulated mainly through grazing by larger zooplankton.

Table 3. Relative proportion of zooplankton abundance in individual count at both sites during the study period

Date	Copepoda		Cladocera		Rotifera	
	Open	Littoral	Open	Littoral	Open	Littoral
August 21	ND	43.4	ND	17.4	ND	39.2
September 2	63.3	29.2	13.0	5.8	26.7	65.0
September 21	42.0	60.2	1.0	1.1	57.0	38.7
October 14	30.7	21.3	4.4	12.0	64.9	66.7
October 28	70.1	NP	2.1	NP	27.8	NP
November 19	54.9	NP	27.5	NP	17.6	NP
December 13	57.3	36.5	18.6	13.5	24.1	48.9
January 9	66.6	79.2	22.2	18.8	11.2	1.4
January 18	84.3	61.1	8.7	31.8	7.0	7.1
February 2	82.8	65.6	12.6	19.4	4.4	15.0
March 1	NP	42.4	NP	4.2	NP	53.4
March 24	NP	65.1	NP	21.4	NP	14.5

ND, Not done; NP, Not present

Grazing rate by large-sized zooplankton (>250 µm) was higher than small-sized ones in all cases, and even reached 108% in January (Fig. 3). The same result was obtained in all lakes that Habte Jebessa (1994) studied and in some temperate lakes (*e.g.*, Kobayashi *et al.*, 1998). This could be due to the ability of larger zooplankton to consume a wider range of algae types compared to smaller zooplankton (Cooke *et al.*, 1986). Larger-sized zooplankton increase the range of energy rich resources available to them (Hecky, 1984). However, mean grazing rate for large-sized zooplankton in Lake Kuriftu was intermediate (54.12%), though it was relatively higher than smaller zooplankton rate. Thus, the overall impact of zooplankton of all size classes on the phytoplankton community structure in Lake Kuriftu seemes to be insignificant.

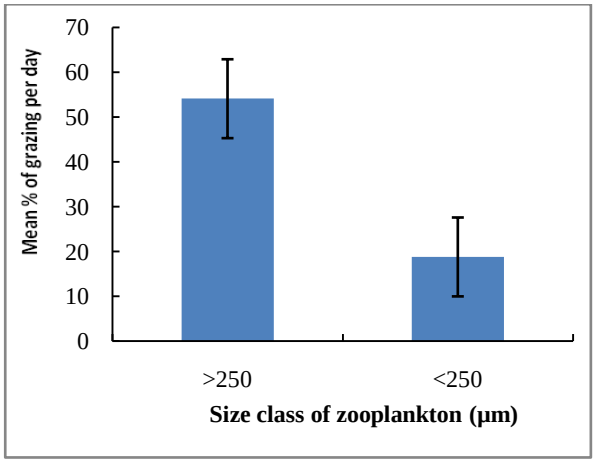

Figure 3. Result for phytoplankton size fraction study (mean of 5 incubations), bars show standard error.

Zooplankton size was found to be an important indicator to affect grazing rate intensities in many studied lakes as indicated above. According to Knoechel and Holtby (1986) variation in filtering rate of zooplankton can be attributed largely to variation in body length regardless of species and temperature. In spite of all these reports, other researchers have reported that no general relationship exists between zooplankton size distribution and grazing rate (*e.g.*, Cyr and Pace, 1992).

Increasing food concentration did not increase zooplankton community grazing rates (Fig. 4). On the other hand, diluting the natural food concentration increased the grazing rate with maximum grazing at ¼ of natural concentration (Fig. 5). Similar results were recorded by Folt *et al.* (1993) who found that phytoplankton abundance was negatively correlated with zooplankton grazing rates. The results indicate that grazing rate of zooplankton in Lake Kuriftu was lowered in response to increasing food concentration. In general, grazing rate decreases above incipient limiting food concentration levels, where the grazing rate is a negative function of food concentration (Gulati *et al.*, 1982). This is because above the incipient level, the condition leads to superfluous feeding because of saturation and could ultimately lead to the situation where there will be no more ingestion. It can be observed from the result of this *in situ* study that the ambient food concentration in Lake Kuriftu is already above the incipient limiting level and partly explains the trend of lower grazing rate with increasing food concentration.

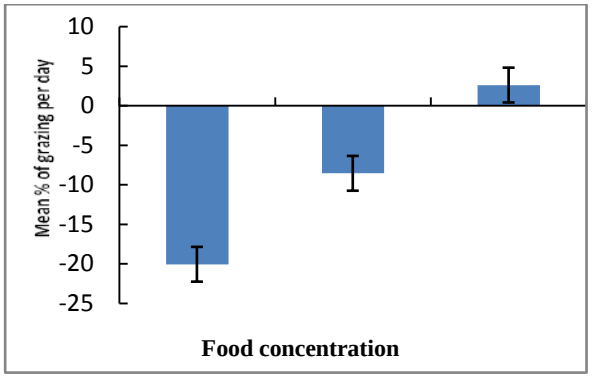

Figure 4. Effect of food concentration on grazing rates in Lake Kuriftu (mean of 6 incubations), bars show standard error.

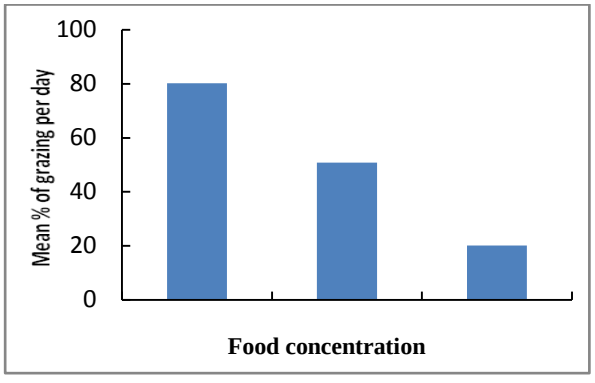

Figure 5. Effect of dilution on grazing rates upto ¼ factors (Not replicated).

Regression analysis between grazing rates and algal biomass (R^2 = 0.017 for littoral and 0.17 for open water) indicated that grazing by zooplankton did not explain the regulation of the biomass of phytoplankton or chlorophyll-*a* concentration in Lake Kuriftu. That means the variation in phytoplankton biomass is largely dependent on other factors, mainly nutrients, light, water chemistry, *etc*. rather than grazing.

In conclusion, prevention or control of external nutrient inputs into the lake should be given priority to suppress larger and filamentous algae in the lake, since the bottom-up route appears more important in controlling the biomass of algae in Lake Kuriftu, rather than grazing by the existing zooplankton community (even using large-sized zooplankton). This can be achieved by diverting sewage and storm water from resorts and other catchment management practices around Lake Kuriftu.

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