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ROLE OF DAPHNIA (*Daphnia* spp.) IN SHALLOW LAKES UNDER EUTROPHIC CONDITIONS

M.R. ALAM[1a]* AND M.M. RAHMAN[1b]

[1]MSc student, Environmental Resources Department, UNESCO-IHE Institute for Water Education, Delft, The Netherlands, [a]Senior Assistant Secretary, Ministry of Agriculture, People's Republic of Bangladesh; [b]Lecturer of Environmental Science and Health Management, Jessore Science and Technology University (JSTU), Jessore, Bangladesh.

*Corresponding author: Md. Rezaul Alam, E-mail: rezaulalam22@gmail.com
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ABSTRACT

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Eutrophication problem is common in all over the world. State of eutrophication defines the physico-chemical properties of water. Besides, it has a strong influence on the biotic communities living in that water bodies. On the flip side, grazers (species that grazes on phytoplankton) are believed to have substantial impact on the state of eutrophication. This paper testifies the effect of grazing by *Daphnia* spp. on the state of eutrophication therefore, physico-chemical properties of water in shallow eutrophic lake. The study was conducted with a mesocosm experimental set-up installed at the roof top of IHE Building, Delft, the Netherlands. Four experimental combinations (manipulating grazers (*Daphnia* spp.), nutrients and light) with six replicates were used for the experiment. Statistical test were performed to analyze the outcome of the experiment. The outcome of the experiment suggests that the grazing of *Daphnia* spp. significantly reduce the water turbidity under high eutrophic condition. Moreover, the experiment showed that Daphnid grazing has significant effect on DO and pH under elevated nutrient concentrations while, it failed to show any significance on NO_3-N, PO_4-P, electrical conductivity and water temperature under both low and higher nutrient concentrations.

Key words: *eutrophication, grazers, daphnia, water quality, bio-manipulation*

INTRODUCTION

Eutrophication in lakes or water-bodies is worldwide common environmental problem. Eutrophication often refers as the degradation process of lakes and reservoirs, started with the excessive load of nutrients originating from agricultural run-off and untreated industrial and urban discharges. Excessive nutrients, particularly phosphorus and nitrogen load into the water-bodies leads to water quality deterioration with significant losses of biodiversity, goods and services (Kristensen and Hansen, 1994; Dodson *et al.* 2000). Deterioration of water quality due to eutrophication can lead to a series of problems and causes economic loss. The economic losses range from the loss of biodiversity, breaking of ecological integrity, sustainability to safe use of aquatic ecosystems and their services (NRC 2000). During the past centuries, several lakes of the industrial part of the world become eutrophic. This eutrophication was believed to be induced by the untreated disposal of urban and industrial wastes and agricultural run-offs from the intensive farming practices. Consequently, major changes in biological and physico-chemical water quality had happened, even on the dynamism of the lakes and often transforms from clear to a turbid water state (Qin 2009). In response to the eutrophication problem several approaches and technologies were used to restore and rehabilitate the lake. However, little attention was given to restructure the biological communities as a direct approach to combating eutrophication (Shapiro *et al.* 1975). Restructuring the biological communities hence termed as bio-manipulation is a top-down approach to control of the aquatic food web utilizing zooplankton as algal predators. The idea of bio-manipulation became popular to deal with the eutrophication problem during last two decades (Sagehashi *et al.* 2004). Since the topic appeared, bio-manipulation was considered as an effective and powerful tool for solving eutrophication (Mehner *et al.* 2002).

Bio-manipulation often refers as the intentional reduction, removal or introduction of species in the food web of an ecosystem (more commonly reduction of planktivory small fish species that results an increase of zooplankton, introduction of carnivorous big fishes that control the population of small fishes etc.). Interest in the utilization of zooplankton as algal predators has been growing (Shapiro and Wright, 1984; Perrow *et al.* 1997; Hosper and Meijer, 1999). The bio-manipulation usually followed by an increase in the abundance and size of zooplankton thus results in increased grazing pressure on phytoplankton (Mehner *et al.* 2002). Bio-manipulation predominantly increases the population of *Daphnia* spp. due to their comparative advantages (opportunistic reproduction response to phytoplankton abundance, better growth rate, size and indiscriminate feeding behavior) over others (Scholten *et al.* 2005). Deliberate manipulation of fish populations in several turbid shallow eutrophic lakes has been reported their success in terms of switch from phytoplankton-dominated state to clear-water state (van Donk and Gulati, 1995) while, also noted several failure cases (Gulati *et al.* 2008). The success of bio-manipulation is mainly judged by the water transparency and phytoplankton biomass (Benndorf *et al.* 2002). However, the long-term effectiveness of bio-manipulation depends on the rate of nutrient loading and level of the eutrophication (Jeppesen *et al.* 1990). In a eutrophic lake, the fate of pollutants is not only determined by hydrological process but also physico-chemical processes in water column. In addition, aquatic plants and animals may alter the physical and chemical water quality in direct and indirect way, which can enhance controlling eutrophication. Hence, understanding the relation between biological communities and physico-chemical quality of water in eutrophic lake is important.

This paper presents the effect of grazers (*Daphnia* spp.) on physico-chemical water quality in shallow lake, which can provide information for bio-manipulation process to control eutrophication.

MATERIALS AND METHODS

Experimental Setup

The experiment was carried out by using 24 plastic containers (dimension 65x45x40 cm, maximum water height 15 cm) and was set-up on the roof of UNESCO-IHE building (Delft, The Netherlands). All tanks were filled up with Delft canal and tap water. In each experimental tank contains water plants (*Myriophyllum* spp.) with initial biomass of 75g FW. To simulate light, nutrients and grazers among the experimental tanks four combinations were produced where, level of nutrients and grazers (*Daphnia* spp.) were manipulated with keeping the same similar light condition. The experimental tank-1 contains no additional nutrients and grazers (background condition), tank-2 was manipulated by adding only nutrients, only grazers were added in tank-3 and tank-4 contains additional nutrients and grazers. Each experimental tank had six randomly arranged replicates. The tanks were kept exposed to open air from 29 April 2010 until 16 June 2010.

Sampling

Dissolve Oxygen (DO), pH, electrical conductivity and water temperature were measured on-site with portable pre-calibrated meters. Then about 10 liters of water sample was collected in a plastic bucket from various places of each experimental tank. During the sample collection minimum disturbance to the settled material of each tank was ensured. The sample was then taken to the UNESCO-IHE laboratory for rest of the analysis.

Procedures for laboratory analysis

Light extinction coefficient

Light transmission was determined at 750nm wavelength with calibrated spectrophotometer. The extinction coefficient (ε) was determined using Lambert-Beer equation for exponential extinction.

Nitrate Nitrogen (NO_3-N) and Orthophosphate (PO_4-P)

Water samples were collected for phosphorus and nitrogen determination. To preserve the sample the water sample were taken in pre acid washed plastic bottles and HCl were added. Sample collected for determination of nitrate nitrogen and orthophosphate were filtered by using 1 µm glass fiber filter (for the dissolved phase) and were properly labeled. Dr. Lange's field kit was used for the measurement of Nitrate-Nitrogen (NO_3-N) and Orthophosphate (PO_4- P).

Phytoplankton identification

About 1L of sample water from each tank was filtered through a membrane filter. A paintbrush was used to homogenize the phytoplankton and identification was done with normal microscope (100-400x).

Zooplankton identification

About 1L of sample water from each tank was filtered over a 5µm mesh net. The filtrate was released into small amount of water in a Petri dish and brought under dissecting microscope (10-40x) to identify zooplankton.

Data analysis

To perform statistical analysis RGui-2.8.1(http://www.r-project.org) and MS Excel software were used. Parametric test (t-test) for normally distributed independent data and non-parametric test (Mann-Whitney U-test) for not normally distributed independent data set were used to compare the results of treatments. Correlation coefficient between electrical conductivity and NO_3-N concentration was drawn.

RESULTS

Effect of grazers on physical parameters (light extinction coefficient, temperature)

With absence of externally added nutrient concentrations there were no significant difference in light extinction coefficient between experimental tanks with background grazers (T1) and tanks with additional grazers (T3) (t-test, P=0.257) however, under the elevated nutrient (nutrient added) concentrations, containers with additional external grazers (T4) showed significant effect in light extinction coefficient than that of tanks with background grazers (T2) (t-test, P=0.0097) (Fig.1).

On the other hand, under the low nutrient concentrations (background nutrient) the effects on temperature was found statistically insignificant in between tanks with background grazers (T1) and tanks with additional grazers (T3) (t-test, P=0.2867). Similar results were observed between tanks with background grazers (T2) and tanks with additional grazers (T4) under the added nutrient condition (t-test, P=0.3488) (Fig.2).

Effect of grazers on chemical parameters (DO, pH, NO_3-N, PO_4-P & EC)

Under background nutrient concentration, the data set failed to demonstrate any significance difference on dissolve oxygen between tanks with background grazers (T1) and tanks with additional grazers (T3) (t=test, P=0.176). In contrast, under additional nutrient concentration the dissolve oxygen (DO) was found significantly different between tanks with background grazers (T2) and the tanks with additional grazers (T4) (t-test, P=0.002) (Fig.3).

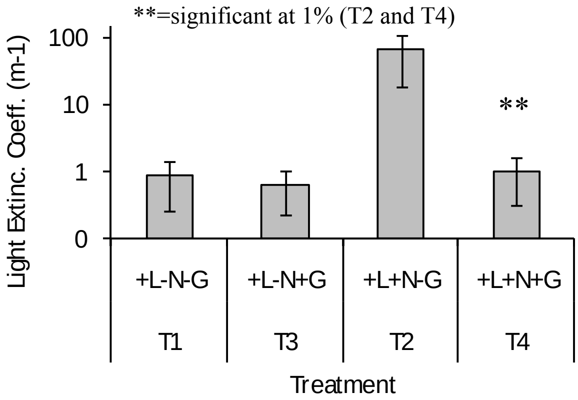

Fig. 1. Effect of Daphnid grazing on Light Extinction Coefficient (m^{-1}) (Error bar represent standard deviations)

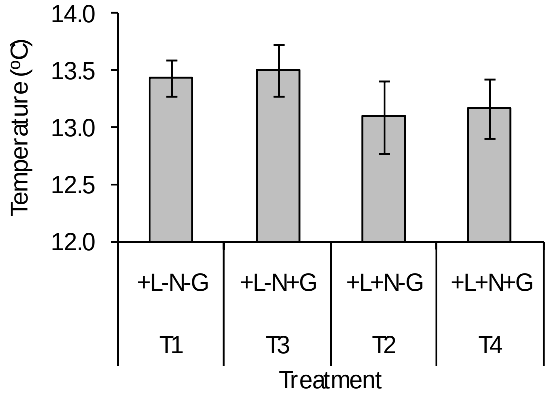

Fig. 2. Effect of Daphnid grazing on Temperature (ºC) (Error bar represent standard deviations)

No significant difference in pH levels was observed between the tanks with background grazers (T1) and the tanks with additional grazers (T3) (t-test, P=0-176) under background nutrient level. However, the effects become significant under additional nutrient concentration between the tanks with additional grazers (T4) and tanks with background grazers (T2) (t-test, P=0.0007) (Fig.4).

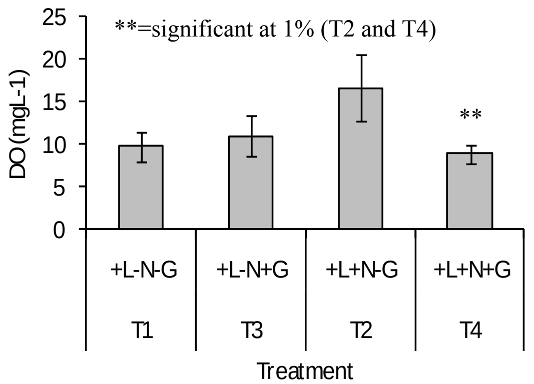

Fig. 3. Effect of Daphnid grazing on Dissolve Oxygen (mgL^{-1}) (Error bar represent standard deviations)

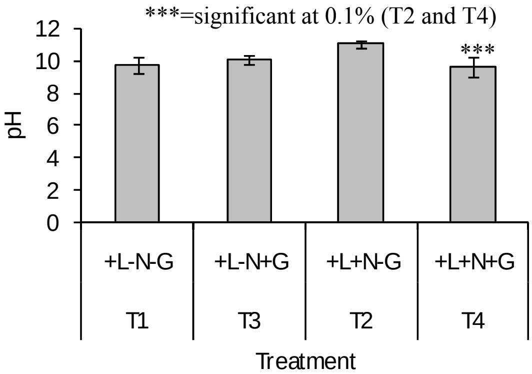

Fig. 4. Effect of Daphnid grazing on pH (Error bar represent standard deviations)

The dataset failed to show any significant effect on Nitrate-nitrogen (NO_3-N) concentration between T1 and T3 (t-test, P=0.956), (Fig.5) and between T2 and T4 (t-test, P=0.286) (Fig.6) under both added and background nutrient conditions. Similarly, it did not show any significant effect of phytoplankton grazing on Orthophosphate (PO_4-P) concentration between treatment T1 and T3 (t-test, P=0.272) (Fig.7) and between treatment T2 and T4 (U-test, P=0.370) (Fig.8) under both nutrient concentrations.

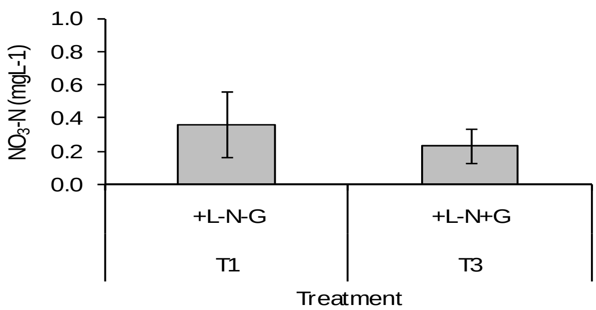

Fig. 5. Effect of Daphnid grazing on NO_3-N (mgL^{-1}) without addition of nutrient (Error bar represent standard deviations)

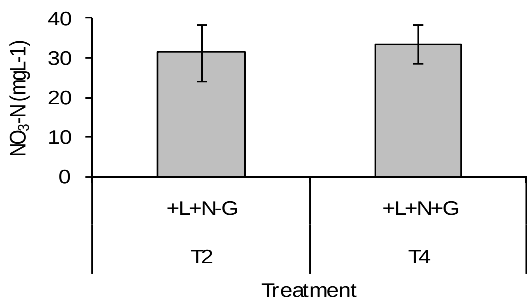

Fig. 6. Effect of Daphnid grazing on NO_3-N (mgl^{-1}) with addition of nutrient (Error bar represent standard deviations)

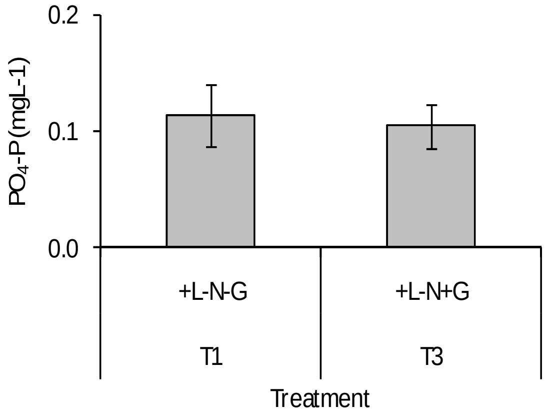

Fig. 7. Effect of Daphnid grazing on PO_4-P (mgL^{-1}) without addition of nutrient (Error bar represent standard deviations)

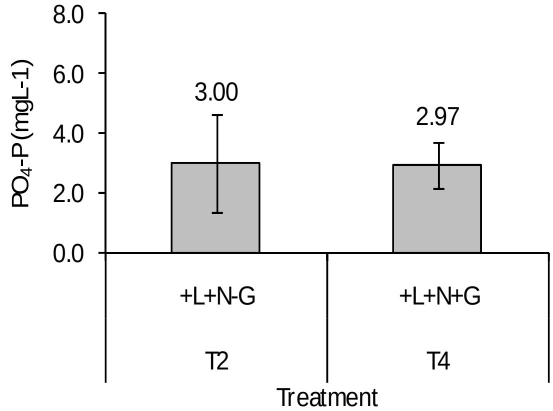

Fig. 8. Effect of Daphnid grazing PO_4-P(mg^{-1}) with addition of nutrient (Error bar represent standard error)

Grazing (*Daphnia* spp.*)* effects on electrical conductivity was found statistically insignificant under both low and high nutrient concentration (between T1 & T3, U-test, P=0.425; and between T2 & T4, t-test, P=0.185) (Fig.9). Besides, strong correlation between electrical conductivity and NO_3-N was observed (R^2=0.9268) (Fig.10).

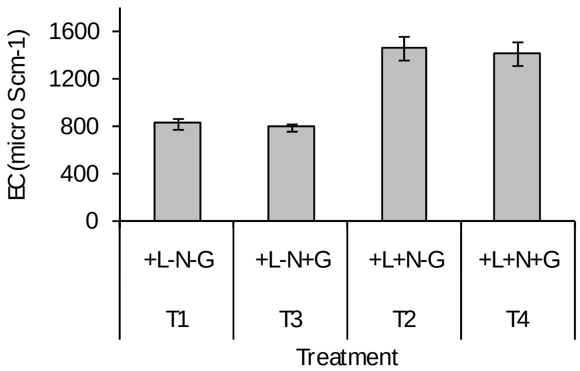

Fig. 9. Effect of Daphnid grazing on Electrical Conductivity (micro S cm^{-1}) (Error bar represent standard deviations)

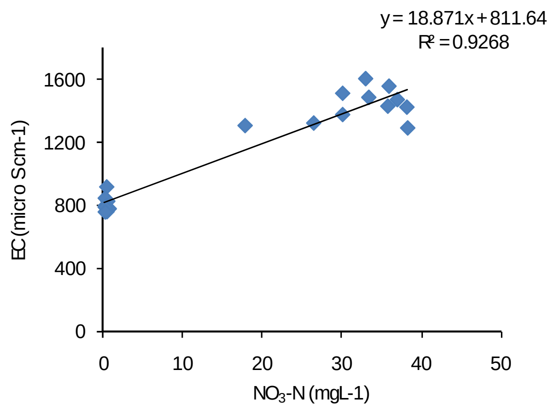

Fig. 10. Correlation between Electrical Conductivity (micro S cm^{-1}) and NO_3-N (mgL^{-1})

DISCUSSION

With addition of external nutrient concentration, significant difference was observed in the mean light extinction co-efficient between the tanks with background grazers and the tanks with additional grazers (Fig.1). On the flip side, maintaining the similar situation while, only nutrient concentration remains in background condition, statistically insignificant difference was observed in the mean values on light extinction coefficient in between tanks with and without presence of added grazers. This finding could be attributed to the fact that in tanks with externally added nutrient and with background grazers, phytoplankton and seston biomass grew rapidly and decreased transparency of water (the greater light extinction coefficient). However, in tanks with added nutrient concentration, phytoplankton as well as seston biomass grew less due to the presence of additional grazers thus results the increase of transparency in the water column (lower light extinction coefficient). Shapiro and Wright (1984); Gulati and van Donk (2002) and Rahman *et al.* (2011) support the daphnid grazing effects in water clarity.

Under the additional nutrient concentrations, higher rate of oxygen production was observed in tanks with background grazers as compared to the tanks with additional grazers (Fig.3). This finding could be attributed to the absence of additional grazers under eutrophic condition (additional nutrients) would have facilitated the biomass production and thereby enhance photosynthetic activity and ultimately produced oxygen. However, the oxygen production rate could be different in highly eutrophic condition. Highly eutrophic water bodies usually has high BOD thus consumes most of the oxygen produced from the photosynthetic process. Besides, high biomass concentration would hamper the light availability that affects the rate of photosynthesis. The mesocosm experimental tanks were exposed to the air for only 48 days and assume to have sufficient space for biomass growth with relatively less biomass concentration and less oxygen demand. Therefore, oxygen production rate was higher even in the eutrophic condition. On the flip side, difference in oxygen production rate between the tanks with background grazers and the tanks with additional grazers did not statistically significant under the background nutrient condition (no additional nutrient). This could be happened due to the fact that background nutrient would not support the phytoplankton and plant biomass production hence, less dissolve oxygen production was observed. Rahman *et al.* (2011) reported similar findings under an identical experimental set-up.

The higher value of pH was observed in tanks with background grazers and with high nutrient concentrations (Fig.4). This could describe rapid growth of biomass under the absence of additional grazers (*Daphnia* spp.) under elevated nutrient concentrations and thus more photosynthetic activities occurred. During the photosynthesis, plant absorbs carbon dioxide from the water column that raises the level of pH.

Under low and high nutrient concentrations, Daphnid grazing activities did not show significant effect on the concentration of NO_3-N and PO_4-P (Fig.5-8). This could be attributed to the fact that there is no out flux of nutrient from the system hence the concentration of total NO_3-N and PO_4-P remains the same. In other words, the inorganic P and N are incorporated into the organic matter in algae biomass during the primary production; later, the algae became dead organic matter, which is then decomposed by bacterioplankton and released the inorganic nutrient into the water column. Alternatively, the dead organic matter, algae and bacterial cell settle on the lake bottom, decomposed into the sediment and release P and N. Herodek *et al.* (1982) described more detail activities and reactions that occur in a similar system as in the Balaton ecosystem.

Simultaneously, no significant effect of grazing activities on electrical conductivity was observed among all the experimental tanks (Fig.9). The EC of the tank water is directly related to the nutrient concentration (Fig.10). As we have explained earlier that grazing did not have any significant effect on nutrient concentration (Fig.5-8), the same result was observed in case of the EC of the tank water.

CONCLUSION

The paper testified that the grazing activities of *Daphnia* spp. has significant effects on light extinction coefficient, dissolve oxygen and pH in water column in the simulated lakes under elevated nutrient concentrations. Therefore, the study concludes that under the elevated nutrients concentration (say eutrophic condition) the grazing activity of zooplankton especially by the *Daphnia* spp. can change the physico-chemical parameters of water. Therefore, the top down approach of bio-manipulation targeting the population of *Daphnia* spp. would be successful in controlling the eutrophication problem as well as to restore the eutrophicated water bodies. However, the experimental condition was simplified and would not match the real situation of a natural water bodies. Moreover, the size and the density of the added *Daphnia* spp. allelopathic interactions between macrophytes and algae and all other biological and limnological factors were not considered during the analysis. Thus, further investigation is still needed and more abiotic and biotic components should be included in future bio-manipulation research.

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