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Impact of Zooplankton Grazing on Phytoplankton Community Dynamics in Lake Nasser: An In-Depth Experimental Study of Predator-Prey Interactions

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ABSTRACT
Through managed enclosure experiments conducted in Lake Nasser during autumn 2023, how zooplankton grazing rapidly reshapes phytoplankton communities was addressed. Four treatments were tested: a zooplankton-free control, natural zooplankton density (Treatment A), double density (Treatment B), and triple density (Treatment C). Across the 45 identified phytoplankton species, Cyanophyceae dominated (42% of total density), followed by Bacillariophyceae (31.5%) and Chlorophyceae (18.7%). Within 72 hours, intense grazing pressure in Treatment C reduced total phytoplankton density by 57%, from 2.8×10^6 to 1.2×10^6 cells/L. Zooplankton exhibited clear selective feeding, strongly targeting Bacillariophyceae—particularly *Cyclotella glomerata*, *Synedra ulna*, and *Melosira granulata*—as well as Chlorophyceae, while Cyanophyceae showed greater resistance to grazing. These findings highlight the pivotal role of zooplankton in structuring phytoplankton assemblages and underscore their potential as a biomanipulation tool for managing eutrophic lakes through targeted grazing control.

INTRODUCTION

Planktonic communities form the ecological foundation of aquatic ecosystems, acting as primary engines of productivity and critical regulators of atmospheric processes **(Reynolds, 1984)**. Within these communities, the phytoplankton–zooplankton relationship is particularly important. This predator–prey dynamic, one of the most significant in freshwater systems, influences everything from water clarity to nutrient cycling **(Carpenter *et al.*, 1985)**. As freshwater systems worldwide face increasing stressors such as eutrophication, climate change, and intensified human activities, understanding these interactions has become more critical than ever **(Jeppesen *et al.*, 2005)**.

Zooplankton grazing exerts strong top-down control over phytoplankton populations, shaping community composition, biomass, and seasonal succession **(Brooks & Dodson, 1965)**. However, this regulatory force operates within a network of interacting factors, including environmental conditions, phytoplankton morphology and biochemistry, shifts in zooplankton community structure, and resource availability **(Lampert, 1987)**. In eutrophic systems, the interplay between bottom-up (nutrient enrichment) and top-down (grazing) forces is especially unstable. Lakes may shift between alternative stable states—either clear waters dominated by efficient zooplankton grazers or turbid, algal-dominated conditions favoring grazing-resistant phytoplankton **(Scheffer *et al.*, 1993)**.

Phytoplankton exhibit remarkable morphological and biochemical diversity, creating a spectrum of susceptibilities to zooplankton grazing. Traits such as cell size, shape, colony formation, defensive structures, and chemical deterrents collectively determine edibility **(Porter, 1977)**. Cyanobacteria exemplify defensive adaptation: their large colonies, gelatinous sheaths, and toxins make them unpalatable to many zooplankton **(Fulton & Paerl, 1987)**. According to **Sterner (1989)**, small unicellular diatoms and green algae that are both appropriately sized and nutritionally rich are prime targets for grazing. Size-selective predation further shapes these dynamics. Large-bodied grazers such as *Daphnia* effectively consume small-to-medium phytoplankton, while smaller zooplankton struggle with large or well-defended algae **(Gliwicz, 1990)**. This selective pressure often favors grazing-resistant taxa, sometimes promoting the proliferation of harmful algal blooms **(Sommer *et al.*, 1986)**.

Lake Nasser, one of the world's largest artificial reservoirs, is a critical ecological and socio-economic resource in the arid Nile Basin. Its waters support Egypt and Sudan by providing drinking water, hydroelectric power, and fisheries, making plankton dynamics central to resource management **(Entz, 1976)**. The reservoir's extreme depth gradients (up to 180m), pronounced seasonal temperature variations (up to 10°C), and arid climate create unique ecological conditions **(Abu-Zeid & El-Shibini, 1997)**. Despite its importance, little research has quantified how short-term zooplankton grazing affects phytoplankton communities here—a key gap in understanding needed to predict algal blooms and guide water quality interventions.

Biomanipulation—the deliberate restructuring of food webs to improve water quality—has been proposed as a potential tool against eutrophication **(Shapiro *et al.*, 1975)**. By enhancing zooplankton abundance through predator removal or stocking, managers can increase grazing pressure to suppress phytoplankton, improving water clarity and reducing algal biomass **(Benndorf, 1990)**. However, the success of this strategy depends on understanding local grazing selectivity, particularly in understudied large reservoirs.

This study examined the short-term effects of varying zooplankton densities on phytoplankton community structure in Lake Nasser, addressing the growing need for effective lake management strategies and the limited knowledge of plankton dynamics in large artificial reservoirs. The specific objectives were to: 1) Quantify the effects of different zooplankton grazing intensities on total phytoplankton biomass; 2) Compare the responses of major phytoplankton groups to grazing pressure; 3) Identify patterns of grazing selectivity among phytoplankton taxa, 4) Assess the potential implications for biomanipulation and water quality management.

MATERIALS AND METHODS

Study site and experimental design

The grazing experiment was conducted on-site in Lake Nasser during autumn 2023. Lake Nasser, formed by the construction of the Aswan High Dam, is located approximately 500km south of Aswan, Egypt. It has a maximum depth of 180m and a surface area of about 5,250km². The experimental site was situated in the lake's northern section, which is characterized by relatively stable water conditions and representative phytoplankton and zooplankton communities.

Water collection and preparation

Using acid-cleaned plastic containers, approximately 200 liters of surface water (0– 2m depth) were collected from the lake. To minimize initial zooplankton contamination, the collected water was immediately filtered through a 200µm mesh net, effectively removing most zooplankton while retaining the majority of phytoplankton. The filtered water was then used to fill the experimental enclosures.

Experimental setup

Four experimental treatments were established in 20-liter transparent polyethylene bottles, each replicated four times for a total of 16 experimental units:

1. Control: filtered lake water with no zooplankton added.
2. Treatment A: natural zooplankton density (ambient lake concentration).
3. Treatment B: twice the natural zooplankton density (2× ambient concentration).
4. Treatment C: three times the natural zooplankton density (3× ambient concentration).

Zooplankton used for inoculation were collected from the same location with a 55µm plankton net and immediately transferred to the respective treatments. Natural zooplankton density was determined through preliminary sampling and microscopic enumeration. To maintain natural temperature and light conditions and to prevent external contamination, all enclosures were suspended approximately 1m below the lake's surface.

Sampling protocol

Water samples were collected from each experimental unit at four time points: 0, 24, 48, and 72 hours after inoculation. At each time point, 500ml subsamples were taken for phytoplankton analysis, along with additional samples for zooplankton enumeration. Zooplankton samples were collected by filtering 2 liters of water through a 55µm mesh net, after which individuals were counted and identified in the laboratory, and densities were expressed as organisms per liter (org./L).

Phytoplankton analysis

Phytoplankton samples were preserved immediately in 4% neutral formalin to prevent cell degradation and maintain morphological integrity. After transfer to sterile 100ml graduated cylinders, a few drops of Lugol's iodine solution were added to enhance cell visibility for microscopic analysis. Samples were allowed to settle for three days in a dark, temperature-controlled environment. Following sedimentation, the supernatant was carefully removed using a fine plastic siphon fitted with a 20µm mesh filter to retain phytoplankton cells.

The concentrated samples (approximately 10 ml) were examined under an inverted microscope at 400× magnification using the drop-count method described by **APHA (2017)**. Species identification was based on standard taxonomic keys and morphological characteristics. Cell counts were converted to cells per liter using the concentration factor and original sample volume. Phytoplankton were classified into four major taxonomic groups: Dinophyceae (dinoflagellates), Chrysophyceae (golden algae), Bacillariophyceae (diatoms), and Cyanophyceae (blue-green algae).

Data analysis

Phytoplankton density data were analyzed to assess temporal changes in total biomass and taxonomic composition among treatments. At each time point, densities from control and grazed treatments were compared to evaluate grazing effects. Selectivity indices were calculated following the method of **Vanderploeg and Scavia (1979)** to assess preferential grazing on specific taxonomic groups. Differences among treatments were tested using one-way ANOVA followed by Tukey's HSD post-hoc tests. All statistical analyses were performed using R software **(R Core Team, 2023)**.

RESULTS

Phytoplankton community composition

Microscopic analysis identified 45 phytoplankton species across five taxonomic classes, with community dominance showing a clear hierarchy. Cyanophyceae (52% relative abundance) were the most abundant, dominated by *Microcystis aeruginosa*, *Dolichospermum circinale*, and *Planktothrix agardhii*. Bacillariophyceae (28.5%) were represented mainly by *Nitzschia acicularis*, *Cyclotella meneghiniana*, and *Aulacoseira granulata*. Chlorophyceae (15.3%) were dominated by *Scenedesmus quadricauda* and *Monoraphidium contortum*. Dinophyceae (3.1%) and Chrysophyceae (1.1%) were minor components of the community. This taxonomic structure reflects Lake Nasser's autumn phytoplankton assemblage, characterized by the predominance of cyanobacteria under warm (26.4°C), stratified conditions.

Zooplankton community structure and density

The experimental zooplankton community comprised three functional groups: Cladocera (mainly *Daphnia longispina*), accounting for 68% of total biomass; Copepoda (cyclopoids and nauplii), representing 27%; and Rotifera (*Brachionus* spp., *Keratella* spp.), comprising 5%. Table (1) presents the group densities across experimental treatments, illustrating community organization patterns and confirming the effectiveness of the experimental design in creating distinct grazing pressure levels.

The results showed successful establishment of graded zooplankton densities across treatments, with total densities increasing from 0 in the control to 78,000 org./m³ in Treatment C. Copepoda dominated the zooplankton community in all treatments containing zooplankton, accounting for approximately 59% of total zooplankton density in Treatments A, B, and C. Cladocera were the second most abundant group (about 32% across treatments), while Rotifera formed the smallest proportion (roughly 8%).

List of phytoplankton species recorded during grazing experimental period in Lake Nasser during autumn 2023.

Bacillariophyceae
Amphora ovalis Kutz.
Cyclotella glomerata (Bachmann)
Cyclotella meneghiniana Kutz.
Cyclotella ocellata Pant.
Cyclotella operculata Kutz.
Fragilaria construens ver.venete

Oocystis solitaria (Wittrock)
Pediastrum simplex
Staurastrum paradoxium (Ehrenberg)

<u>Cyanophyceae</u>
Aphanocapsa elachista ver.conferta (Wittrock)
Beggiatoa minima Winogradsky
Chroococcus cohren (Keissier) Lemmermann

(Ehr.)Grun

Melosira distans (Her.) Ralfs
Melosira granulata (Her.) Ralfs
Melosira granulata var. angustissima (Her.)
Nitzschia frustulum (Kutz.)W. Smith
Nitzschia lanceolata (EHr.)
Nitzschia palea (Kutz.)W. Smith
Nitzschia amphibia (Kutz.)Grun.
Syndra ulna (EHr.)

Chlorophyceae
Actinastrum hanzchii (lagerheim)
Ankistrodesmus fusiformis (Corda.)
Ankistrodesmus convulatus (Corda.)
Ankistrodesmus falcutus (Corda.)
Coelastrum sp Naegeli
Cosmarium galenitum
Crucigenia tetrapedia (Kirchner) West and West
Dictyosphaerium pulchellum (Wood)
Elakatothrix gelatinosa (Wille)
Kirchneriella lunaris (Kirchner) Mobius

Lagerheimia ciliata Chodat.
Micractium quadrisetum (Lemm.) G. M. Smith
Oocystis borgei (Wittrock)
Oocystis gigas (Wittrock)

Chroococcus dispersus (Keissier) Lemmermann
Coelosphaerium kuetzingianum Nag.

Cylindrospermopsis raciboroskii Wolosz.
Eucapsis minuta (F.E.Fritsch)
Eudrina unicocca (G.M.Smith)
Gomphospharium compacta (Lemmer.)
Gomphospharium lacustris (Lemmer.)
Gomphospharium aponina (Lemmer.)
Gomphospharium lacustris var. compacta (Lemmer.)
Lyngbya limnetica Lemmer.
Merismopedia punctata (Meyen)
Microcystis aeruginosa Kutz.
Oscillatoria limnetica (Klebahn) Geitler
Phormidium interruptum (Kutz.)
Synechococcus aeruginosus Nag.

Dinophyceae

Gymnodinum aeruginosum (Stein)
Peridinium umbonatum
Peridinium volzii
Ceratium hirundinella (O. F. Muell.) Dujardin

Chrysophyceae
Mallomonas acaroides (Perty)
Ochromonas mutabilis (Klebs.)

Temporal dynamics of total phytoplankton density

Significant temporal variations in phytoplankton density were observed across all experimental treatments after the first 24 hours. In the control treatment, phytoplankton numbers remained relatively stable throughout the experiment, with only minor fluctuations attributed to natural growth and mortality. In contrast, all grazing treatments exhibited marked reductions in total phytoplankton density, with the magnitude of decline directly proportional to zooplankton density. Treatment B (double density) recorded the highest initial phytoplankton abundance at 3.5×10^6 cells/L at time zero, whereas Treatment C (triple density) experienced the steepest decline, reaching a minimum of 1.1×10^6 cells/L after 72 hours. Fig. (2) illustrates the temporal changes in total phytoplankton density and the composition of phytoplankton classes across Treatments A, B, and C.

Differential response of phytoplankton classes

Cyanophyceae – Cyanophyceae demonstrated greater tolerance to grazing stress compared to other taxonomic groups. This class was dominated by *Eucapsis minuta* (35% of total), *Lyngbya limnetica* (28%), *Merismopedia punctata* (22%), and *Microcystis aeruginosa* (15%). In Treatment C, densities declined from 2.1×10^6 cells/L at time zero to 1.8×10^6 cells/L after 72 hours. Despite this reduction, Cyanophyceae increased in relative abundance under high grazing pressure, indicating inherent resilience mechanisms.

Bacillariophyceae – Diatoms were the most vulnerable group to zooplankton grazing. In Treatment C, populations declined by 75%, from 1.2×10^6 cells/L to 0.3×10^6 cells/L after 72 hours. Similar patterns occurred across all grazing treatments, though declines were less pronounced at lower grazing intensities. The diatom community was dominated by *Cyclotella glomerata* (42%), *Cyclotella operculata* (28%), *Synedra ulna* (18%), and *Melosira granulata* (12%). These species likely exhibited high susceptibility due to their optimal size range and high nutritional value for zooplankton.

Chlorophyceae – Green algae showed intermediate susceptibility to grazing, with variable responses among species. The group was dominated by *Actinastrum hantzschii* (38%), *Dictyosphaerium pulchellum* (32%), and *Staurastrum paradoxium* (30%). In Treatment B, densities decreased from 0.8×10^6 cells/L at time zero to 0.4×10^6 cells/L after 72 hours.

Minor Taxonomic Groups – Dinophyceae and Chrysophyceae remained consistently rare across all treatments. Their low abundance suggests either limited representation in Lake Nasser's autumn phytoplankton community or heightened sensitivity to the experimental conditions and grazing pressure.

Grazing selectivity patterns

Grazing selectivity analysis revealed clear feeding preferences among zooplankton. Bacillariophyceae, particularly *Cyclotella glomerata*, *Synedra ulna*, and *Melosira granulata*, were consistently the most preferred food sources. This selectivity was most pronounced in Treatment C, where grazing intensity peaked on the third day. The observed pattern suggests that Lake Nasser zooplankton preferentially consume diatoms over cyanobacteria and green algae, likely due to their higher nutritional quality, greater palatability, and ease of ingestion. Such selective grazing can strongly influence succession dynamics and the structural composition of phytoplankton communities.

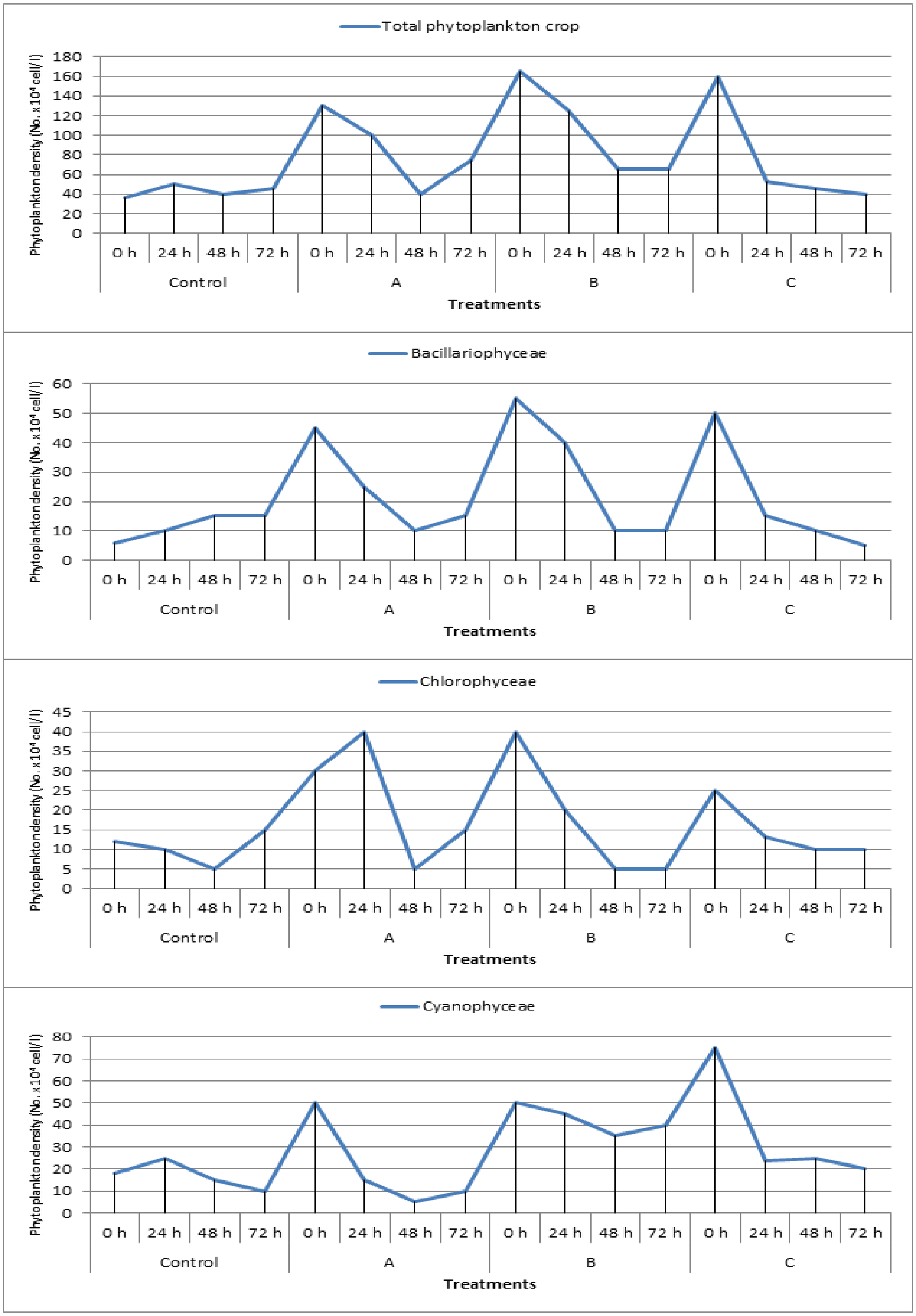

Fig. 1. Total phytoplankton density and the main algal groups in the different water lake treatments during autumn 2023

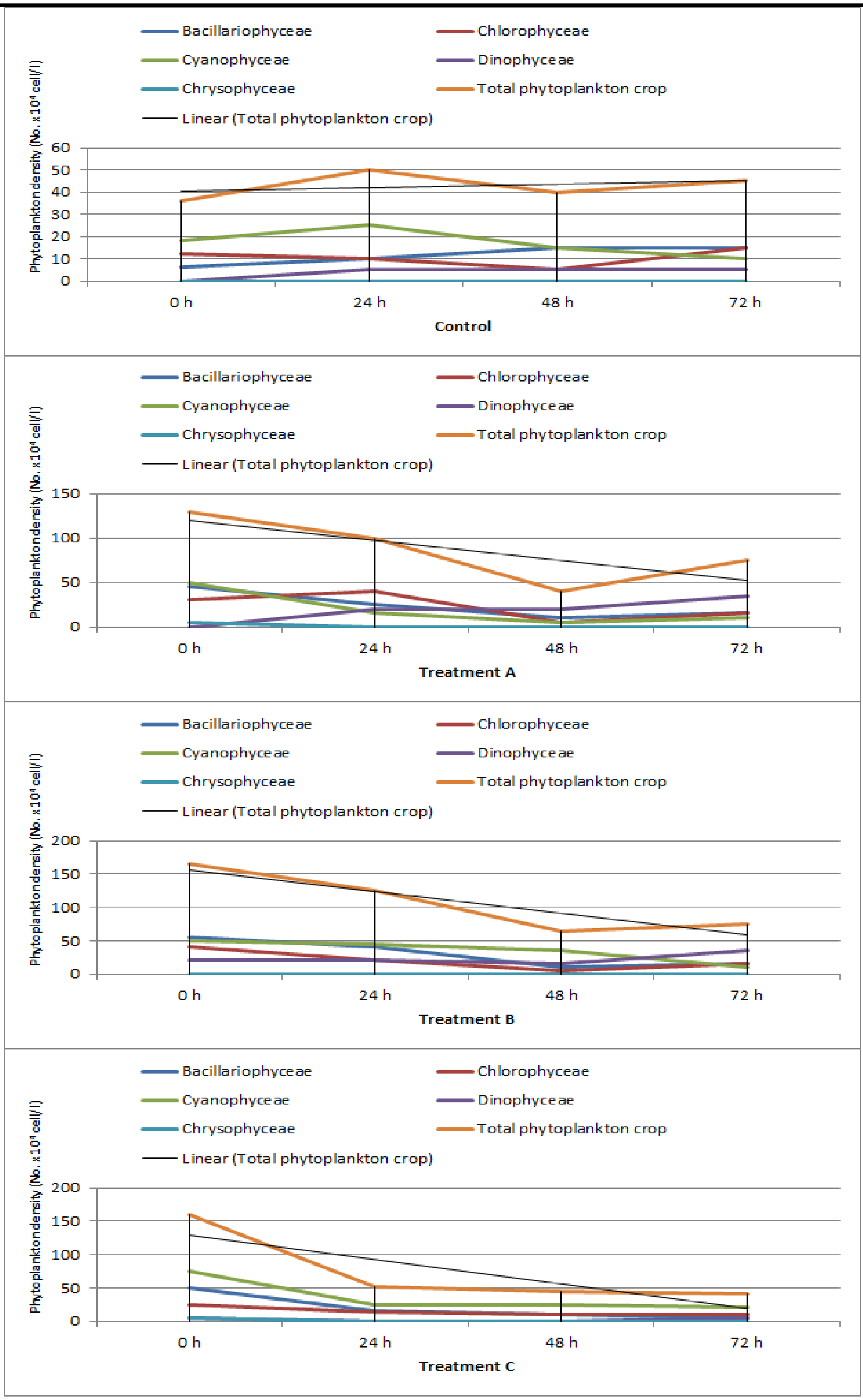

Fig. 2. Distribution of the total phytoplankton density and phytoplankton classes during different period of the treatments A, B and C

Table 1. Zooplankton density (organic/m³) at the beginning of the experimental treatments

Zooplankton classes	Control	Treatment A	Treatment B	Treatment C
Rotifera (org./m³)	0	550	1,101	1,651
Cladocera (org./m³)	0	4,219	8,439	12,658
Copepoda (org./m³)	0	37,057	74,114	111,171
Total Zooplankton density (org./m³)	0	41,827	83,653	125,48O

Table 2. Total phytoplankton crop (No. x 10^4 cell/l) and phytoplankton classes in the different water treatments of Lake Nasser during autumn 2023

Phytoplankton class	Control				A				B				C			
	0 h	24 h	48 h	72 h	0 h	24 h	48 h	72 h	0 h	24 h	48 h	72 h	0 h	24 h	48 h	72 h
Bacillariophyceae	6	10	15	15	45	25	10	15	55	40	10	10	50	15	10	5
Chlorophyceae	12	10	5	15	30	40	5	15	40	20	5	5	25	13	10	10
Cyanophyceae	18	25	15	10	50	15	5	10	50	45	35	40	75	24	25	20
Dinophyceae	0	5	5	5	0	20	20	35	20	20	15	10	5	0	0	5
Chrysophyceae	0	0	0	0	5	0	0	0	0	0	0	0	5	0	0	0
Total phytoplankton crop	36	50	40	45	130	100	40	75	165	125	65	65	160	52	45	40

DISCUSSION

Grazing impact on community structure

The results of this study provide compelling evidence for the significant role of zooplankton grazing in structuring phytoplankton communities in Lake Nasser. The observed decrease in total phytoplankton with increased zooplankton density supports the effectiveness of top-down manipulation techniques in aquatic environments **(Carpenter *et al.*, 1985)**. These findings are consistent with previous studies that have documented the capacity of zooplankton to dramatically reduce phytoplankton standing stocks through extensive grazing pressure **(Lampert, 1987)**.

The differential response of phytoplankton taxonomic groups to grazing pressure observed in this study aligns with established ecological principles concerning selective feeding by zooplankton **(DeMott, 1986)**. The notable resistance of Cyanophyceae to grazing pressure, compared to the high vulnerability of Bacillariophyceae, reflects well-documented patterns of zooplankton feeding preferences **(Porter, 1977)**. Cyanobacteria possess several characteristics that reduce their palatability to zooplankton grazers, including large colony size, mucilaginous sheaths, and the production of toxic or deterrent compounds **(Fulton & Paerl, 1987; Lampert, 1987)**.

Selective grazing and community dynamics

The pronounced selectivity for diatoms found in this study has important implications for phytoplankton community succession and water quality management **(Reynolds, 1984)**. Diatoms—particularly the species *Cyclotella glomerata*, *Syndra ulna*, and *Melosira granulata*—were identified as preferred prey items and are generally considered excellent food sources for zooplankton due to their optimal size range, lack of protective structures, and favorable biochemical composition **(Sterner, 1989)**. The preferential removal of these species through selective grazing can shift community composition toward less edible taxa, potentially favoring the development of cyanobacterial blooms **(Sommer *et al.*, 1986)**.

The intermediate response of Chlorophyceae to grazing pressure suggests that green algae occupy a middle position on the palatability spectrum for Lake Nasser zooplankton. This finding is consistent with research from other freshwater systems, where green algae have shown variable susceptibility to grazing depending on species-specific traits such as cell size, morphology, and chemical composition **(Porter, 1973; Gliwicz, 1990)**.

Implications for lake management

The results of this study have significant implications for the management of Lake Nasser and other large artificial reservoirs **(Shapiro *et al.*, 1975)**. The demonstrated effectiveness of zooplankton grazing in controlling phytoplankton biomass suggests that biomanipulation strategies could be employed to enhance water quality in this system **(Carpenter *et al.*, 1985)**. Managers could potentially increase grazing pressure on phytoplankton by boosting zooplankton populations through direct stocking or predator control, thereby improving water clarity and reducing algal density **(Benndorf, 1990)**.

However, the selective nature of zooplankton grazing also highlights the limitations of biomanipulation **(DeMott & Kerfoot, 1982)**. The resistance of Cyanophyceae to grazing pressure indicates that increasing zooplankton abundance alone may not suffice to control cyanobacterial blooms, which often present the most pressing water quality issues in eutrophic environments **(Carpenter *et al.*, 1987)**. A comprehensive management approach that incorporates both top-down (grazing) and bottom-up (nutrient) controls may be essential to achieving desired water quality improvements **(McQueen *et al.*, 1986)**.

Methodological considerations

The experimental approach used in this study—employing *in situ* enclosures with manipulated zooplankton densities—provides a realistic assessment of grazing effects under natural environmental conditions **(Haney, 1971)**. The short duration of the experiment (72 hours) minimizes potential artifacts associated with enclosure effects while capturing the immediate impacts of grazing pressure on phytoplankton communities **(Roman & Rublee, 1981)**. The use of multiple zooplankton density treatments enables quantification of dose–response relationships and offers insights into the potential effectiveness of different biomanipulation intensities **(Griffiths & Caperon, 1979)**.

The taxonomic resolution employed here provides important insights into the mechanisms underlying selective grazing patterns, including species-level identification for dominant taxa. Future research could benefit from incorporating additional measurements of phytoplankton traits—such as cell size distributions, biovolume estimates, and biochemical composition—to better understand the factors influencing grazing selectivity **(Sterner, 1989)**.

Ecological significance

The study's conclusions underscore the importance of zooplankton as keystone species in aquatic food webs and enhance our understanding of predator–prey relationships in freshwater environments **(Power *et al.*, 1996)**. The rapid and substantial changes in phytoplankton community structure observed within just 72 hours illustrate the dynamic nature of planktonic communities and their capacity to quickly respond to changes in grazing pressure **(Sommer *et al.*, 1986)**.

The selective grazing patterns documented in this study also have implications for nutrient cycling and energy flow in Lake Nasser. Preferential consumption of large diatoms may enhance the efficiency of energy transfer to higher trophic levels, while the accumulation of grazing-resistant cyanobacteria may lead to nutrient storage in less accessible forms **(Sterner, 1989)**. Such effects could cascade through the food web, influencing fish production and overall ecosystem productivity **(Carpenter *et al.*, 1985)**.

CONCLUSION

This study demonstrates the significant influence of zooplankton grazing on phytoplankton community dynamics in Lake Nasser, with clear evidence of selective feeding that favors diatoms over cyanobacteria and green algae. The findings highlight the potential for biomanipulation strategies in large artificial reservoirs, while also emphasizing the need for comprehensive management approaches that address the selective nature of zooplankton grazing. The rapid community shifts observed over short time scales underscore the dynamic nature of planktonic ecosystems and the importance of incorporating predator–prey interactions into water quality management decisions.

Future research should focus on longer-term experiments to evaluate the sustainability of grazing effects and the potential for phytoplankton community adaptation. Investigating the specific mechanisms underlying grazing selectivity—as well as the roles of chemical and morphological deterrents—could provide valuable insights into how these systems may respond to management interventions.

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