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Research Article

Assessment of Lotic Macroinvertebrate Assemblage in the Oconaluftee River Basin in Cherokee, North Carolina

Sierra B. Benfield[1], **Shem D. Unger**[2]

Cite this article as: Benfield, S.B., & Unger, S.D.U. (2023). Assessment of lotic macroinvertebrate assemblage in the oconaluftee river basin in cherokee, North Carolina. *Aquatic Sciences and Engineering, 38(4)*, 189-193. DOI: https://doi.org/10.26650/ASE20231285476

ABSTRACT

Macroinvertebrate assemblage assessments act as useful analysis tools for assessing aquatic ecosystems health. These animals also serve as a base trophic level, acting as a source of food for many other aquatic organisms including fish and salamanders. Obtaining baseline data for monitoring aquatic insects and subsequent river health is vital to understand food chains and river ecological interactions. We sampled macroinvertebrate communities in two streams in the Oconaluftee River basin, in the Cherokee Qualla, North Carolina. Over 600 macroinvertebrates were collected and identified to the lowest taxonomic level possible, providing a macroinvertebrate profile of both riffle and run habitats. We identified over 35 genera and report on functional feeding groups, with biotic indices of water quality. Ephemeroptera, Plecoptera, and Trichoptera values varied, 21% and 65.43% for Raven's Fork and 22% and 79.06% for the Oconaluftee rivers. This macroinvertebrate community suggests healthy stream aquatic insects and above average water quality, in spite of the urban land use found in the riparian zones of the sample sites. This research can be used as a baseline for future monitoring of aquatic streams in the area of the Cherokee Qualla.

Keywords: Aquatic insects, freshwater biology, water quality, biological surveys

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INTRODUCTION

Among the many threats to freshwater ecosystems, anthropogenic habitat loss and degradation have among the most visible and well documented impacts to biodiversity (Prakash & Verma, 2022). Aquatic insects can provide baseline data and act as early indicators of biotic change due to anthropogenic changes, as they are sensitive to fluctuations in water quality (Ghani et al., 2016). As human populations continue to increase, and potentially encroach more on protected areas, the potential to impact riparian communities, such as streams, may increase. Moreover, the reliance on water resources for future management requires baseline data on biodiversity so that monitoring efforts have comparative data to observe any changes in stream health.

Appalachian streams of the United States house a diverse array of aquatic predators which play integral parts in native food webs, and in North Carolina include recreationally important species of native brook trout, *Salvelinus fontinalis*, introduced brown trout, *Salmo trutta*, and introduced rainbow trout, *Oncorhynchus mykiss* (Rhode et al., 1994; Flebbe & Dolloff, 1995). However, the presence of trout can have a varying effect on the trophic dynamics in streams, including decreases in the proportion of grazers (such as mayfly species densities) within the functional feeding groups (Meissner & Muotka, 2006). Moreover, many trout species seasonally shift their diet according to time of year depending on the availability of aquatic insect groups (Hubert & Rhodes, 1989) or even time of day (Giroux et al., 2000). Non-native trout introduced in streams can also indirectly alter total macroinvertebrate biomass by selecting larger individuals and consuming shredder and scraper functional feeding groups at a higher rate than others (Buria et al., 2007). Both the diversity and relative abundance of stream macroinvertebrates can vary by habitat type (either riffles, runs, or pools) sampled by researchers (Logan & Brooker, 1983). In addition, many studies which assess stream water quality and stream health quantify macroinvertebrate communities using only timed dip net surveys of riffles and do not account for surface area using Surber sampling, which may provide benefits to understanding macroinvertebrate structure by allowing researchers to estimate abundance per area across habitats.

The objectives of this study were to 1) characterize the aquatic insect abundance (Ephemeroptera, Plecoptera, and Trichoptera presence and distribution, indicators of stream health, and ecological importance of insect groupings of trout streams on the Cherokee Qualla (reservation) and 2) report on the potential role many of these aquatic insects have in food webs of Appalachia. These findings provide baseline biodiversity data on the overall stream health and also quantify potential macroinvertebrate prey of aquatic predators in these streams in North Carolina, including trout and other stream vertebrates.

MATERIALS AND METHODS

Study Locations and Aquatic Insect Identification

Samples were obtained from two streams in the Oconaluftee River watershed (Oconaluftee and Raven's Fork) of Cherokee, North Carolina in May of 2016. Stream locations sampled were categorized into two broad level habitat types, and the containers of organisms labelled with site location and area habitat type (riffle or run). Raven's Fork has been previously noted to be slightly acidic (pH of ~6.0) with low alkalinity during baseflow conditions (Armitage & Tennessen, 1984), whereas the Oconaluftee River has been documented to have a pH of 7.8 and Dissolved Oxygen of 6.6 ppm, and conductivity of 10 (Nickerson et al., 2022). We utilized more comprehensive sampling method (a Surber sampler: 0.3 meter X 0.3 meter metal frame placed above a collection net) to collect aquatic insects, with all stream locations being randomized for specific site of sampling. At each stream location, we sampled ten subsamples from both riffles and runs for aquatic insects and included at least three areas of at least fifty meters in length (Figure 1). Aquatic insect samples for each stream site were then combined as either a run or riffle habitat for that stream sample location to collect data for comparisons. Following each sample collection, all the area within the sampler was checked for any remaining aquatic insects and all rock substrate within the sample area was checked for additional aquatic insects, and these were included into our samples using fine forceps and careful inspection of sample net. Aquatic insects from sample habitats were stored in ninety-five percent ethanol. Identification, enumeration, and inventory of the collected samples was completed in the laboratory using standard dichotomous keys to identify all aquatic insects collected down to the lowest taxonomic level of genus within orders by both authors.

Data analysis

Several indices were selected to assess stream health based on the identified aquatic insect assemblages. Aquatic insects after identification were further placed into functional groups to inform stream health indicators, and we used the standard approach of placing insects into categories of EPT, or insects within the Trichoptera, Plecoptera, or Ephemeroptera orders were combined and analyzed across habitat types and stream locations. We compared numbers of EPT between our two sample streams using a Chi square analysis with our significance value as 0.05. Both the Hilsenhoff, Shannon diversity, Beta diversity, and Dominance indexes were calculated for all sample rivers. Aquatic insects were also placed into various categories (feeding function groupings), to examine the potential these aquatic insects have not only for water quality, but also for food webs or in the riverine food chain.

RESULTS AND DISCUSSION

In sum from the macroinvertebrate samples of both streams (Oconaluftee and Raven's Fork) and microhabitat types (riffle and runs), over 600 individuals were identified across 36 taxa belonging to 28 families (Table 1). Macroinvertebrates from the sampled Cherokee streams exhibited a broad range of functional feeding groups, with relatively high concentrations of gatherers in both streams (28.61% in the Oconaluftee and 27.14% in Raven's Fork) (Table 4). Both streams sampled for aquatic insects were characterized as having high biodiversity categories using the diversity indexes (Table 2). Moreover, both river locations were ranked high for river quality using the percent Ephemeroptera Plecoptera and Trichoptera method (Table 3). The Oconaluftee had a high ranking or percentage of Ephemeroptera, Plecoptera, and Trichoptera, approximately eighty-five percent in the runs and just over seventy-nine percent overall. These high scores were closely followed by Raven's Fork sample river, with an overall percentage of sixty-nine Ephemeroptera, Plecoptera, and Trichoptera, which was higher in the runs than in the riffles in both sampled streams, which is especially interesting as the runs are not usually sampled for macroinvertebrates and are often assumed to have low densities of sensitive insect taxa. There was not a significant difference between Ephemeroptera, Plecoptera, and Trichoptera combined taxa between our two sample locations, X^2 (2, N = 444) = 1.877, p =0.391, indicating both likely house di-

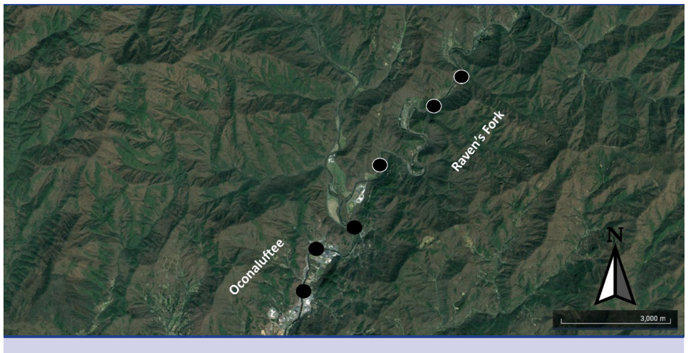

Figure 1. Map of Sample Locations for Oconaluftee (black borders) and Raven's Fork (white borders), North Carolina.

Table 1. Cherokee Qualla aquatic insect community richness and relative abundance sampled from the Oconaluftee and Raven's Fork rivers.

Order:Family	Genus:Species	Oconaluftee	Raven's Fork	Total
Coleoptera				
Elmidae	*Acryronyx sp.*	-	2	2
Psephinidae	*Psephenus sp.*	9	4	13
Ptilodactylidae	*Anchytarsus bicolor*	-	3	3
Diptera				
Chironomidae	*Paramerina sp.*	34	13	47
Ceratopogonidae	*Dasyhelea sp.*	4	3	7
Simuliidae	*Greniera sp.*	19	51	70
Tipulidae	*Tipula sp.*	-	3	3
	Leptotarsus sp.	1	9	10
Emphemeroptera				
Baetidae	*Baetis sp.*	3	-	3
Ephemerellidae	*Eurylophella sp.*	26	18	44
	Dannella sp.	22	1	23
Heptageniidae	*Maccafertium sp.*	2	2	4
Isonychidae	*Isonychia sp.*	13	8	21
Leptohyphidae	*Homoleptohyphes sp.*	30	6	36
	Hydrosmilodon sp.	24	9	33
	Leptohyphes sp.	15	35	50
	Tichorythodes sp.	-	3	3
Neophemeridae	*Neophemera sp.*	44	27	71
Polymitarcyidae	*Tortopus sp.*	1	-	1
Odonata				
Gomphidae	*Progomphus sp.*	-	2	2
Plecoptera				
Perlidae	*Beloneuria sp.*	10	9	19
Perlolidae	*Isoperla sp.*	1	9	10
Peltoperlidae	*Viehoperla ada*	1	-	1
Pteronarcyidae	*Pteronarcys sp.*	7	-	7
Megaloptera				
Corydalidae	*Corydalus sp.*	4	-	4
Trichoptera				
Baraeidae	*Baraea sp.*	1	2	3
Goeridae	*Goerita sp.*	14	2	16
Hydropsychidae	*Hydropsyche sp.*	11	5	16
	Potamyia sp.	-	1	1
Hydroptilidae	*Stactobiella sp.*	1	1	2
Leptoceridae	*Leptocerus americanus*	1	-	1
Philopotamidae	*Chimara sp.*	-	4	4
	Dolophilodes sp.	23	9	32
Polycentropidae	*Nyctiophylax sp.*	-	1	1
	Phylocentropus sp.	13	21	34
Uenoidae	*Fattigia pele*	5	3	8
Total:		**339**	**266**	**605**

verse aquatic insect communities. Subsequently, both rivers exhibited a high percentage of gatherer feeding group organisms, with Raven's Fork river having more filterers (21.46%) and the Oconaluftee having more predators (17.99%), indicating some variation in ecosystem groupings of aquatic insects (Table 4).

The Dominance Index for Oconaluftee was 0.935, while the Dominance index for Raven's Fork was 0.917. The mean number of taxa for Oconaluftee was 12.11, whereas the mean number of taxa was 8.87 for Raven's Fork. Beta Diversity Index between sites was 0.759, with 36 total taxa identified comprising of 28 taxa for Oconaluftee and 30 for Raven's Fork, with 22 shared, common taxa (found in both streams).

This work provides a water quality assessment and aquatic insect biodiversity survey for streams of the Cherokee Qualla, North Carolina. The data reported here indicate that streams in this geographic area have relatively high levels of aquatic insect biodiversity with taxa functioning across an array of ecological feeding groupings, likely due to the river's proximity to protected forests and the extensive efforts of the tribal community to preserve riverine health. These streams lie within the Eastern Band of the Cherokee Qualla, and their headwaters originate in the Great Smoky Mountains National Park, which is protected. However, the watersheds do include a combination of developed, forest, and mixed riparian zones and access. In particular, the run habitats housed a large percentage of Ephemeroptera, Plectoptera and Trichoptera, in all cases larger percentages than the riffle habitats. This may be due to riffle habitats being more intrinsically difficult to sample or the potential for higher flowing water to result in a different overall community of aquatic insects present in faster flowing riffles. Subsequently, we report on a wide assortment of macroinvertebrates, which not only provide a variety of ecosystem services but also are likely a vital component of the riverine food web, providing connections for other aquatic organisms.

Table 2. Hilsenhoff (HBI) and Shannon Diversity Indexes (SDI) calculated for both sample rivers in this study.

River	SDI	HBI
Oconaluftee	2.887	3.79
Raven's Fork	2.861	4.51

The aquatic communities of streams in North Carolina are often measurably affected by varying land use (urban, forested, or agricultural), with lower biotic indexes and low species richness in urban areas (Lenat & Crawford, 1994). The area of Cherokee North Carolina is historically characterized by increasing growth of tourism (Tooman, 1997) while geographically situated in close proximity to the Great Smoky Mountains National Park, which was farmed and logged prior to becoming a national park. Our sampling occurred near the developed town of Cherokee, North Carolina, yet yielded high % EPT and overall high water quality metrics. Moreover, our study is the first published quantitative assessment of macroinvertebrate communities on the Cherokee Qualla, as our research involved sampling multiple habitats, which can produce greater number of taxa per site (Lenat, 1988). Our results report similar observations of taxa compared to other studies from western North Carolina (Loch et al., 1996), albeit at high densities.

Knowledge on stream trophic webs is important for the conservation of any aquatic ecosystem, as these processes can be affected at various levels by many factors with differential impacts on specific taxa or overall survival or populations of macroinvertebrates, which are often sensitive to water chemistry or siltation changes. Many of these aquatic insects provide food for other aquatic organisms. Future work could assess the impact of predatory trout abundance on macroinvertebrate communities. Sampling the diet (trout gut contents) of both wild and native trout could also provide further information on food webs in this ecosystem. Previous studies in this area have indicated both rainbow (*Oncorhynchus mykiss*) and brown trout (*Salmo trutta*) rely on a variety of available food items including terrestrial inputs, or allochthonous resources (Cada et al., 1987). The macroinvertebrate communities we observed as part of this research may provide additional food for not only fish species, but also larval salamanders, such as the eastern hellbender, *Cryptobranchus alleganiensis*, as adults are occasionally observed within this area (C. Hickman, unpublished data). Continued monitoring of the river habitat and macroinvertebrate communities of the Oconaluftee riparian areas of Cherokee should be conducted to ensure this area remains protected and harbors high overall stream biodiversity.

Table 3. River health metrics of percent EPT aquatic insects across habitat types from samples collected from the Cherokee Qualla.

River	%Ephemeroptera	%Plecoptera	%Trichoptera	% EPT- Riffle	% EPT- Run	% EPT-Stream	EPT Richness Index
Oconaluftee	53.39	5.60	20.06	74.88	85.29	79.06	22
Raven's Fork	40.52	6.69	18.22	58.99	78.02	65.43	21

Table 4. Ecological feeding groupings for aquatic insects from rivers in the Cherokee Qualla.

Functional Group	% shredders	% scrapers	% filterers	% gatherers	% predators
Oconaluftee	0.00	3.24	15.63	28.61	17.99
Raven's Fork	1.12	2.23	24.16	27.14	11.90

CONCLUSION

With this study, we utilized a Surber Sampler to assess benthic aquatic insects as potential indicators of stream health in an area of the United States that is highly visited by recreationalists, tourists, and has significant cultural influence to the Eastern Band of the Cherokee Indians. We hope this macroinvertebrate survey can provide a baseline of diversity and functional feeding group estimates for future monitoring, as well as illustrate the importance of sampling with more than a dip net across an array of in-stream habitats. Sampling in both runs and riffles also appears to be informative, as we noted differences between these two habitats across our sample locations. Protecting water resources is a vital component of management of aquatic habitats. Future research should be undertaken to monitor changes in these parameters within this unique watershed as the surrounding community continues to likely increase in population. Further sampling of water chemistry and other land use parameters could be used to help determine ideal locations for watershed protection to manage this system as efficiently as possible to maintain ecological food web connections to other inhabitants such as trout, hellbender salamanders, river otters, and other fish species.

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Research Article

Urban Lakes, South Tangerang City Based on Water Quality Index and Phytoplankton Composition as Bioindicator

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ABSTRACT

An assessment of water quality in 8 urban lakes in South Tangerang City was conducted, as their condition was a concern. This research aims to assess water quality based on the condition of chemical-physical variables and phytoplankton composition. This research was conducted from late May to early October 2021 (the dry season until the inter-seasonal period). The Water Quality Index (WQI) ranged from 61.18-79.53 (medium-good). Phytoplankton composition consisted of 65 genera from 11 classes and 6 divisions. Oscillatoria, Euglena and Pediastrum were the dominant genera, meanwhile, Cyanophyceae and Chlorophyceae were the dominant class. Phytoplankton communities in all lakes were stable except RL and based on Jaccard index the value of inter-lakes show no identical similarities (≠ 1). In (Nygaard) values ranged from 2.50-undefined (slight-high eutrophication), and X (Saprobic indices) values ranged from 0.33-1.80 (very slight pollution-moderate pollution). The best correlations (both values were r = 0.53) in water quality between the variables were DO (ppm) and BOD (ppm) Urban lakes require further improvement in their lake management to be used as sources of drinking water.

Keywords: Water quality variables, Phytoplankton, Urban lakes

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INTRODUCTION

The South Tangerang City lakes are located in urban areas with a high human population density and a high level of public interface (Birch & McCaskie, 1999); therefore, South Tangerang City lakes are classified as urban lakes. An urban lake is susceptible to water quality deterioration (Birch & McCaskie, 1999; Norris & Laws, 2017). There are 8 urban lakes in South Tangerang City, Banten with concerning conditions (Regional Regulation of South Tangerang City Number 9, 2019). Information indicating the deterioration of their water quality is available (Fauzi, 2016).

Water quality deterioration in South Tangerang City lakes occurred because of domestic sewage flow and recreational and aquaculture activities therein, which led to an increase in water pollution and eutrophication with a potential phytoplankton bloom (Vardaka et al., 2000; Katsiapi et al., 2013; Wang et al., 2013). Phytoplankton bloom can be harmful to the aquatic ecosystem. Moreover, it can be harmful to humans and can cause illness and death when ingested or when humans are exposed to it (Vardaka et al., 2000; Norris & Laws, 2017). On the other hand, the local government had been designing lake management for South Tangerang City lakes as source waters for drinking water (Regional Regulation of South Tangerang City Number 9 of 2019, 2019). Before using the lakes for drinking water and other daily activities, it is important to conduct an assessment of water quality (Bhateria & Jain, 2016).

The Water Quality Index (WQI) method based on Pesce & Wunderlin (2000) and Kannel et al.'s

(2007) research has been generally known as one of the most important indices for water quality assessment (Bhateria & Jain, 2016; Dunca, 2018). Although it is a good indicator of water quality, if applied with no biological variable, the result will be insufficient and it will lack ecological factors (Bordoloi & Baruah, 2014; Yusuf, 2020). It requires a biological variable analysis based on a phytoplankton analysis. Phytoplankton is tolerant, it rapidly responds to the alteration of its environmental condition and it possesses a short life cycle (Bellinger & Sigee, 2010; Maznah & Makhlough, 2014). It is important to assess phytoplankton indices and their composition in urban lakes. The high human population density in urban lakes is closely related to water pollution, which leads to eutrophication (Kalaji et al., 2016). Nutrient loading from anthropogenic activities and increasing temperatures induce eutrophication and may favor the predominance of harmful phytoplankton (de Souza et al., 2018).

Phytoplankton indices such as saprobic and Nygaard have been widely applied for pollution and eutrophic assessments in lakes (Jafari & Gunale, 2006; Maznah & Makhlough, 2014; Prasetyaningsih & Sahidin, 2019; Toma, 2019). The saprobic index was applied for a pollution level assessment. The Nygaard index was applied for a trophic level assessment (Nygaard, 1949; Dresscher & Mark, 1976). Dominant phytoplankton genus and class assessments were also applied widely to assess pollution and eutrophication in lakes (Wang et al., 2013; Zhu et al., 2021). Thus, phytoplankton has been a good bioindicator for water quality assessment.

Eutrophication and phytoplankton bloom information was not acquired in previous research (Bahri et al., 2015; Assuyuti et al., 2019; Zharifa et al., 2019) although, it is good to perform water quality assessment before using lakes as drinking water or recreational areas (Vardaka et al., 2000; Wang et al., 2013; Norris & Laws, 2017). Therefore, an assessment water quality of 8 urban lakes in South Tangerang City is required for lake management information. This research aims to assess the water quality of the 8 urban lakes in South Tangerang City based on chemical-physical variables analysis, the Water Quality Index (WQI) and phytoplankton analyses.

MATERIALS AND METHODS

Site study and sampling

The research was conducted in 8 urban lakes in South Tangerang City, Banten, Indonesia from late May to early October 2021, representing the dry season until the inter-seasonal period. The Urban lakes in South Tangerang City were Pondok Jagung Lake (PJL), Parigi Lake (PARL), Rompong Lake (RL), Bungur Lake (BL), Gintung Lake (GL), Kuru Lake (KL), Ciledug Lake (CL) and Pamulang Lake (PAML). Local people use the lake in South Tangerang City for household waste disposal, tourism and fishing. There were 5 sampling points for each lake, which were determined based on their inlet, outlet and utilizations area, such as aquacultures and recreational activities (Figure 1).

Phytoplankton sampling was carried out by plankton net (50 μm mesh size) in the euphotic zone (0-50 cm) of each lake. Phytoplankton samples were preserved using Lugol 10% drop by drop until they changed color to a yellowish-brown or a dark brown. They were then stored in a refrigerator (Suthers and Rissik, 2009). Surface water from each lake was collected for Biological Oxygen Demand (BOD), PO_4-P and NO_3-N analyses in the Laboratory of Ecology, Center of Integrated Laboratory, Syarif Hidayatullah State Islamic University.

Water variables and phytoplankton identification

Electrical Conductivity (EC), Total Dissolved Solids (TDS), pH and Water Temperature (W_{temp}) were measured using a Hanna multi-parameter instrument (HI 9811). Dissolved Oxygen (DO) was measured using a Lutron DO meter (DO-5510) and Turbidity (TUR) was measured using a Hanna Turbidity meter (HI 9373). Water transparency based on Secchi Disk Depth (SDD) was measured as described in (Adhar et al., 2021). PO_4-P, NO_3-N and Biological Oxygen Demand (BOD) analyses were conducted based on standard methods described in EPA (1983) and APHA (2017). Phytoplankton identification was assisted by an Olympus light binocular microscope and Sedgwick-Rafter Cell (SRC) as counting chamber. Phytoplankton was identified based on Karacaoğlu et al., (2004), van Vuuren et al., (2006), Bellinger & Sigee (2010) and Sulastri (2018). The naming of taxa was based on currently accepted nomenclature (Guiry & Guiry, 2021).

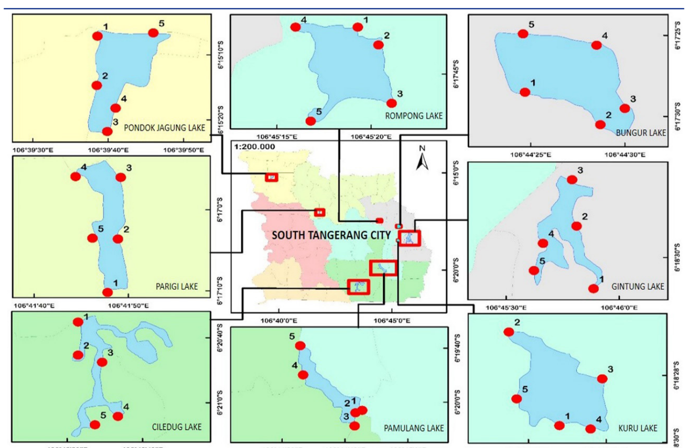

Figure 1. Map of 8 urban lakes in South Tangerang City and their sampling point locations.

Data analysis

Chemical-physical variables measurement results were analyzed using Water Quality Index (WQI) with the following categories: very bad (0–25), bad (26–50), medium (51–70), good (71–90), and excellent (90–100) (Kannel et al., 2007). Phytoplankton genera were counted and analyzed based on a formulation described in APHA (2017). Phytoplankton genus and class domination were analyzed using relative abundance calculation based on Kumar & Mina (2021). The phytoplankton community was analyzed using the Shannon-Wiener diversity index (H'), Pielou evenness index (J') and Simpson dominance index (D) based on the formulation as described in Dash & Dash (2009). Clustering analysis was conducted based on the UPGMA (Unweighted Pair

Group Method with Arithmetic Mean) method, which is suitable for describing the relationship inter-lakes based on phytoplankton similarity (Carteron et al., 2012). Jaccard similarity index measurement and phytoplankton similarity clustering inter-lakes were assisted by PAST 4.03. Trophic and pollution degree were assessed by Nygaard (In) and saprobic indices (X) based on the formulation as described in Nygaard (1949) and Dresscher & Mark (1976).

Statistical analysis

A non-parametric Kruskal-Wallis H test (One-way ANOVA on ranks) was used to determine statistically significant differences in chemical-physical measurement results, WQI results and phytoplankton abundances between lakes. Non-parametric Spearman's correlation was used to correlate chemical-physical variables measurement result and phytoplankton abundance toward water quality index result. Spearman's correlation coefficient describes the correlation's strength and direction. The strength and direction of correlation between research variables refer to Verla et al. (2020). Statistical analyses were assisted by IBM SPSS 20.

RESULTS AND DISCUSSION

Water Variables

Physical variables measurement results in the lakes ranged from 28.7-32.4°C (Wtemp), 82-236 ppm (TDS), 140-488 μs·cm^{-1} (EC), 24.6-50.2 cm (SDD) and 29.7-75.4 FTU (TUR). Meanwhile, chemical variables measurement results in the lakes ranged from 7.3-9.6 (pH), 4-7.5 ppm (DO), 1.3-24.1 ppm (BOD), 0.01-0.4 ppm (PO_4-P), 0.1-7.6 ppm (NO_3-N) (Table 1). Based on the non-parametric Kruskal-Wallis H test for chemical-physical variables measurement, results between lakes indicated a significant difference ($p<0.05$) unless the SDD value indicated no significant difference between lakes ($p>0.05$). Chemical-physical variables conditions in the lakes were out of the range of water quality standards for drinking water (Government Regulation of Republic Indonesia Number 22 of 2021, 2021; World Health Organization, 2017).

Chemical-physical variables conditions in the lakes were outside of the range from water quality standards for drinking water, except for TDS and EC (Table 1). W_{temp} in the lakes ranged within the optimum range for the metabolic processes of aquatic organisms, i.e., 20-35°C (Piranti et al., 2021a). TDS and EC conditions in the lakes ranged within water quality standards for drinking water, however, their results in GL were excessively higher than other lakes. High values of TDS and EC indicate high levels of dissolved ions as a result of household wastewater and leachate from municipal solid waste discharge into the lake (Pujiindiyati et al., 2019; Sulastri et al., 2019).

SDD and TUR values are closely related to light penetration in lakes, which affected phytoplankton growth (Sobolev et al., 2009; Zhou et al., 2019). TUR results in the lakes exceeded the optimum value for phytoplankton growth, i.e., 15 FTU (Sobolev et al., 2009). pH result in BL was solely out of the range from water quality standards for drinking waters, i.e., 9.6. However, a high pH value in the lake indicates a productive lake with a high intensity of photosynthesis (Sulawesty & Aisyah, 2020).

DO levels in PARL and RL were out of the range of water quality standards for drinking water. Mainly, the DO level in RL was much lower than other lakes in South Tangerang City, i.e., 4 ppm. A low level of DO in RL was the indication of water hyacinth bloom, as water hyacinth bloom shades the water column of the lake and limits light intensity for photosynthesis (Mironga et al., 2012). BOD level in PJL was solely within water quality standards for drinking water, i.e., 1.3 ppm. Different results for BOD in BL were obtained where the value was outside of water quality standards for drinking water with a value of 24.1 ppm. BOD level was a good indicator of water pollution (Dhanam et al., 2016; Mohamed et al., 2017). As a productive lake, BL was a lake with the highest BOD level. It occurred as the increase of phytoplankton photosynthesis and growth rate parallel to phytoplankton death, which led to the increase of oxygen consumption for aerobic microorganisms' decomposition (Sulawesty & Aisyah, 2020).

NO_3-N and PO_4-P are required for phytoplankton growth, but their presence in lakes might produce phytoplankton bloom, which deteriorated water quality (Mohamed et al., 2017; Wijaya & Elfiansyah, 2022). PO_4-P levels in PJL, PARL and KL ranged within water quality standards for drinking water, otherwise,

Table 1. Chemical-physical variables conditions in 8 urban lakes in South Tangerang City

Variables	PJL	PARL	RL	BL	GL	KL	CL	PAML	QS^{A,B}
Wtemp (°C)	30.9±1	29.4±0.6	29.5±1.4	32.4±0.4	29.4±1	28.7±0.5	30.7±0.5	31.5±1.4	25^{B}
TDS (ppm)	62±11.7	98±7.5	164±18.5	72±9.8	236±33.8	82±7.5	138±47.9	126±25.8	1000^{A}
EC (μs·cm^{-1})	140±26.1	218±9.8	354±39.3	160±15.5	488±69.4	186±17.4	308±110.3	290±83.7	1200^{B}
SDD (cm)	28±10.3	50.2±11.9	32.6±20	27.9±12.2	24.6±5.7	38.3±13	46.8±13.2	35.1±16.1	1000^{A*}
TUR (FTU)	57.7±6	29.7±7.9	36.7±17.2	75.4±2.6	29.7±16.8	66.8±7.7	31.9±11.2	40.1±23.5	1^{B}
pH	8.3±0.7	7.3±0.1	7.3±0.2	9.6±0.3	7.8±0.1	8±0.5	7.7±0.6	7.9±0.6	6-9^{A}
DO (ppm)	6.7±0.6	5.9±0.7	4±0.6	7±1.1	6.8±2	7.3±1.3	6.6±1.8	7.5±1.2	6^{A*}
BOD (ppm)	1.3±0.7	9.2±5.5	6.1±5.3	24.1±7.3	6.5±1.8	6.4±2.3	12.6±6.2	8.2±3	2^{A}
PO_4-P (ppm)	0.01±0.01	0.01±0.01	0.02±0.01	0.02±0.01	0.1±0.1	0.01±0.01	0.4±0.5	0.1±0.1	0.01^{A}
NO_3-N (ppm)	0.2±0.1	3.1±3.9	1.4±1.5	1.9±1.5	0.2±0.1	7.6±14.2	0.2±0.1	0.1±0.04	0.65^{A}

Note: A = Water quality standards based on Government Regulation of Republic Indonesia Number 22 of 2021, 2021; B = Water quality standards based on World Health Organization, 2017; * = Minimum quality standards limit.

PO_4-P levels in GL, CL and PAML ranged within optimum PO_4-P levels for phytoplankton growth (0.09-1.8 ppm) (Yuliana & Irfan, 2018). NO_3-N level in PJL ranged within water quality standards for drinking waters along with GL, CL and PAML. PARL, RL, BL and KL ranged within the optimum range for phytoplankton growth (0.9-3.5 ppm) except the NO_3-N level in KL (Yuliana & Irfan, 2018).

Water quality index

Water Quality Index (WQI) measurement results in the lakes ranged from 61.18-79.53. PJL, GL, KL and PAML lakes had values >71 within the good category otherwise. Furthermore, PARL, RL, BL and CL had values >51 within the medium category (Table 2).

Table 2. WQI results in 8 urban lakes in South Tangerang City.

Lakes	Average WQI	Category
PJL	79.53±1.95	Good
PARL	68.82±5.35	Medium
RL	67.41±6.89	Medium
BL	61.18±5.53	Medium
GL	72.71±5.71	Good
KL	72.94±8.71	Good
CL	66.82±7.95	Medium
PAML	72.71±6.30	Good

The results of the non-parametric Kruskal-Wallis H test between lakes for WQI results indicated a significant difference ($p<0.05$). WQI values variation in the lakes occurred as a result of various situations in each lake location and waste discharge into the lakes (Kannel et al., 2007; Assuyuti et al., 2019). The previously reported average WQI values in GL were >74 in each period (before, on and after Ramadan) (Assuyuti et al., 2019).

WQI results in PJL were categorized as good with low levels of PO_4-P and NO_3-N, indistinct from other lakes, which had higher levels of PO_4-P and NO_3-N. Increasing levels of PO_4-P and NO_3-N are associated with household waste discharge from the community surrounding the lakes (Patil et al., 2012; Mohamed et al., 2017; Naqqiuddin et al., 2017). Household waste pollution in RL, BL and CL induced them to have a moderate category based on WQI. GL, KL and PAML were contaminated based on PO_4-P and NO_3-N levels but were categorized in the good category based on WQI. It occurred because GL, KL and PAML had high DO levels, while their BOD levels were low. According to Kannel et al. (2007) and Bhateria & Jain (2016), DO and BOD levels are important parameters for aquatic organisms and ecosystems.

Composition of phytoplankton

There were 65 phytoplankton genera from 11 classes and 6 divisions observed in the lakes. The dominant phytoplankton genus in PJL, PARL, RL, BL, GL and PAML was *Oscillatoria* spp. Meanwhile,

Table 3. Phytoplankton genera's relative abundance in 8 urban lakes in South Tangerang City.

Phytoplankton	Relative abundance percentages							
	PJL	PARL	RL	BL	GL	KL	CL	PAML
Achnanthes spp. Bory, 1822	0%	0%	0%	0%	0%	0%	0%	0%
Actinastrum spp. Lagerheim, 1882	0%	0%	0%	0%	0%	0%	0%	0%
Amphipleura spp. Kützing, 1844	0%	0%	0%	0%	0%	0%	0%	0%
Anabaena spp. Bory ex Bornet & Flahault, 1886	0%	0%	0%	0%	0%	0%	0%	0%
Ankistrodesmus spp. Corda, 1838	0%	0%	0%	0%	1%	0%	0%	0%
Aphanizomenon spp. Morren ex Bornet & Flahault, 1888	0%	0%	0%	0%	0%	0%	0%	0%
Arthrospira spp. Sitzenberger ex Gomont,1892	0%	13%	0%	0%	3%	0%	0%	6%
Aulacoseira spp. Thwaites, 1848	1%	2%	1%	0%	6%	0%	0%	0%
Chlamydomonas spp. Ehrenberg,1833	0%	0%	0%	0%	0%	0%	1%	1%
Chlorella spp. Beijerinck, 1890	0%	0%	0%	0%	0%	0%	2%	1%
Chroococcus spp. Nägeli, 1849	0%	0%	0%	0%	0%	0%	0%	0%
Cladophora spp. Kützing, 1843	0%	0%	0%	0%	0%	0%	0%	0%
Closterium spp. Nitzsch ex Ralfs, 1848	0%	0%	28%	0%	0%	0%	0%	0%
Coelastrum spp. Nägeli, 1849	0%	0%	0%	0%	0%	1%	1%	0%
Coelosphaerium spp. Nägeli, 1849	0%	0%	0%	5%	1%	0%	1%	0%
Cosmarium spp. Corda ex Ralfs, 1848	0%	0%	0%	0%	0%	0%	0%	0%
Cyclotella spp. (Kützing) Brébisson, 1838	2%	8%	0%	1%	2%	7%	0%	0%
Cylindrospermopsis spp. Seenayya & Subba Raju, 1972	0%	0%	0%	0%	1%	0%	0%	0%
Cymbella spp. Agardh, 1830	0%	0%	0%	0%	0%	0%	0%	0%
Desmidium spp. Agardh ex Ralfs, 1848	0%	0%	0%	0%	0%	0%	0%	0%
Dictyosphaerium spp. Nägeli, 1849	0%	0%	0%	0%	2%	0%	2%	0%
Eudorina spp. Ehrenberg, 1832	0%	1%	0%	0%	0%	0%	3%	0%
Euglena spp. Ehrenberg, 1830	1%	2%	5%	1%	8%	**25%**	23%	5%
Fragilaria spp. Lyngbye, 1819	0%	8%	0%	2%	0%	0%	0%	0%

Table 3. Continue.

Phytoplankton	Relative abundance percentages							
	PJL	PARL	RL	BL	GL	KL	CL	PAML
Gleocapsa spp. Kützing, 1843	0%	1%	0%	0%	0%	0%	0%	0%
Gomphonema spp. Ehrenberg, 1832	0%	0%	0%	0%	0%	0%	0%	0%
Gomphosphaeria spp. Kützing, 1836	0%	0%	0%	0%	0%	0%	0%	0%
Gonium spp. Müller, 1773	0%	0%	0%	0%	0%	0%	0%	1%
Gyrosigma spp. Hassall, 1845	0%	0%	0%	0%	0%	0%	0%	0%
Haematococcus spp. Flotow, 1844	0%	0%	0%	0%	1%	0%	1%	1%
Kirchneriella spp. Schmidle, 1893	0%	0%	0%	0%	0%	0%	0%	0%
Lyngbya spp. Agardh ex Gomont, 1892	0%	3%	3%	0%	0%	15%	0%	0%
Mallomonas sp. Perty, 1852	0%	0%	0%	0%	0%	0%	0%	0%
Melosira spp. Agardh, 1824	2%	0%	0%	0%	0%	0%	0%	0%
Merismopedia spp. Meyen, 1839	0%	0%	0%	20%	0%	0%	0%	1%
Micrasterias spp. Agardh ex Ralfs, 1848	0%	0%	0%	0%	0%	0%	0%	0%
Microcystis spp. Lemmermann, 1907	2%	0%	3%	15%	1%	3%	3%	1%
Navicula spp. Bory, 1822	5%	0%	1%	1%	0%	5%	1%	1%
Nitzschia spp. Hassall, 1845	0%	0%	0%	0%	0%	4%	6%	0%
Oocystis spp. Nägeli ex Braun, 1855	7%	1%	0%	6%	1%	1%	1%	1%
Oscillatoria spp. Vaucher ex Gomont, 1892	**63%**	**47%**	**42%**	**34%**	**43%**	23%	15%	**25%**
Pandorina spp. Bory, 1826	0%	0%	0%	0%	0%	0%	3%	12%
Pediastrum spp. Meyen, 1829	0%	9%	0%	2%	0%	0%	**28%**	16%
Penium spp. Brébisson ex Ralfs, 1848	5%	1%	0%	0%	0%	0%	0%	0%
Phacus spp. Dujardin, 1841	1%	2%	13%	7%	21%	8%	5%	19%
Phormidium spp. Kützing ex Gomont, 1892	0%	0%	0%	0%	0%	1%	0%	0%
Pinnularia spp. Ehrenberg, 1843	0%	0%	0%	0%	0%	0%	0%	0%
Pleurotaenium spp. Nägeli, 1849	3%	0%	0%	0%	0%	0%	0%	0%
Pseudaanabaena spp. Lauterborn, 1915	7%	0%	1%	0%	5%	0%	0%	0%
Quadrigula spp. Printz, 1916	0%	0%	0%	0%	0%	0%	0%	0%
Scenedesmus spp. Meyen, 1829	0%	0%	0%	5%	0%	1%	1%	2%
Selenastrum spp. Reinsch,1866	0%	0%	0%	0%	0%	0%	0%	0%
Sphaerocystis spp. Chodat, 1897	0%	0%	0%	1%	0%	0%	2%	3%
Spirogyra spp. Link, 1820	0%	0%	1%	0%	0%	0%	0%	0%
Stephanodiscus spp. Ehrenberg, 1845	0%	0%	0%	0%	0%	0%	0%	0%
Strombomonas spp. Deflandre, 1930	0%	0%	0%	0%	0%	0%	1%	0%
Surirella spp. Turpin, 1828	0%	0%	0%	0%	0%	0%	0%	0%
Synechococcus spp. Nägeli, 1849	0%	0%	0%	0%	0%	1%	0%	0%
Synedra spp. Ehrenberg, 1830	0%	1%	0%	0%	0%	1%	0%	0%
Tetraëdron spp. Kützing, 1845	0%	0%	0%	0%	0%	0%	0%	0%
Tetrastrum spp. Chodat, 1895	0%	0%	0%	0%	0%	0%	0%	0%
Trachelomonas spp. Ehrenberg, 1834	0%	0%	0%	0%	0%	0%	0%	0%
Tribonema spp. Derbès & Solier, 1851	0%	0%	0%	0%	0%	0%	0%	0%
Ulothrix spp. Kützing, 1833	0%	1%	0%	0%	0%	0%	0%	0%
Volvox spp. Linnaeus, 1758	0%	0%	0%	0%	0%	0%	0%	0%

Note: bold = Dominant genus in each lake (phytoplankton genus with the highest relative abundance)

the dominant phytoplankton genera in KL and CL were *Euglena* spp. and *Pediastrum* spp. respectively (Table 3). The abundance percentage of phytoplankton classes in PJL, PARL, RL, BL, GL and KL were dominated by Cyanophyceae (72%, 64%, 49%, 74%, 54% and 44%). Meanwhile, the abundance percentage in CL and PAML was dominated by Chlorophyceae (39% and 38%). Bacillariophyceae, Coscinodiscophyceae, Mediophyceae, Trebouxiophyceae and Ulvophyceae classes had low abundance percentages in each lake (<10%) (Table 4). Total phytoplankton abundance values in the lakes ranged from 175-3224 ind·L^{-1}. RL is the highest (3224 Ind·L^{-1}) and PJL is the lowest (175 Ind·L^{-1}) (Table 5). The non-parametric Kruskal–Wallis H test indicated a significant difference in phyto-

Table 4. Phytoplankton classes' relative abundance percentage in 8 urban lakes in South Tangerang City.

Classes	Lakes							
	PJL	PARL	RL	BL	GL	KL	CL	PAML
	Relative abundance percentages							
Bacillariophyceae	5%	9%	1%	2%	0%	10%	7%	1%
Chlorophyceae	0%	11%	1%	8%	5%	2%	39%	38%
Coscinodiscophyceae	3%	2%	1%	0%	6%	0%	0%	0%
Cyanophyceae	72%	64%	49%	74%	54%	44%	21%	34%
Euglenophyceae	2%	4%	18%	7%	28%	34%	29%	24%
Mediophyceae	2%	8%	0%	1%	2%	7%	0%	0%
Chrysophyceae	0%	0%	0%	0%	0%	0%	0%	0%
Trebouxiophyceae	8%	1%	0%	6%	3%	1%	5%	3%
Ulvophyceae	0%	1%	0%	0%	1%	0%	0%	0%
Xanthophyceae	0%	0%	0%	0%	0%	0%	0%	0%
Zygnematophyceae	8%	1%	30%	0%	0%	1%	0%	0%

Table 5. Total phytoplankton abundance (Indv/L^{-1}) values in 8 urban lakes in South Tangerang City.

Lakes	Total Abundances Phytoplankton
PJL	175
PARL	700
RL	3224
BL	496
GL	805
KL	671
CL	878
PAML	1147

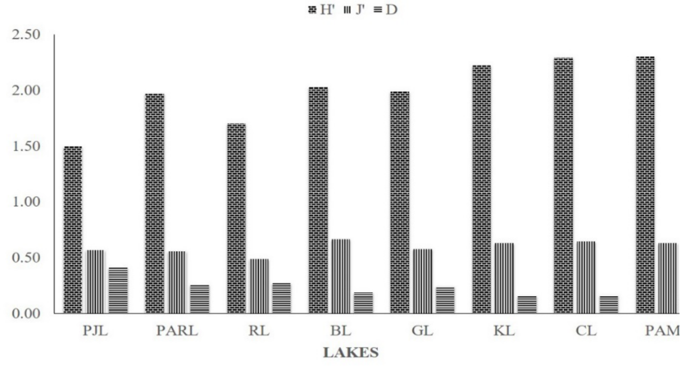

Figure 2. Diversity (H'), evenness (J') and dominance (D) indices' values in 8 urban lakes in South Tangerang City.

plankton abundances between lakes ($p<0.05$). H' values in the lakes ranged from 1.50-2.30. J' values in the lakes ranged from 0.49-0.67. D values ranged from 0.19 to 0.41.

Oscillatoria, *Euglena* and *Pediastrum* were found to be the dominant genera in the lakes. The results indicated that they were polluted and underwent eutrophication. According to Kshirsagar (2013), *Oscillatoria*, *Euglena* and *Pediastrum* are genera of phytoplankton used for pollution indicators. Furthermore, *Oscillatoria* was abundant in each lake, reinforcing pollution indications which occurred in the lakes. It was also reported by previous research in Ousteri Lake, India and Segara Anakan, Indonesia that *Oscillatoria* spp. was dominant as it is the highly tolerant genus to polluted waters (Dhanam et al., 2016; Piranti et al., 2021b). Relative abundance of phytoplankton genera might change rapidly as their physiological mechanisms for growth and loss respond to the alteration of chemical-physical variables condition (Kagami et al., 2002; Bellinger & Sigee, 2010; Utomo et al., 2013).

Increasing organic pollution and eutrophication led domination of Cyanophyceae and Chlorophyceae. This is reinforced by the domination of high pollution-tolerant genera from them, i.e., *Oscillatoria*, *Pediastrum* and *Pandorina* (Jafari & Gunale, 2006; Kshirsagar, 2013). Domination of Cyanophyceae and Chlorophyceae also occurred previously in Baiyangdian Lake, China due to increasing organic pollution (Wang et al., 2013). PJL had slight organic pollution based on the BOD level, followed by low levels of PO_4-P and NO_3-N. The limited content of NO_3-N on the PJL surface waters is thought to have caused the Cyanophyceae class, mainly *Oscillatoria*, to become dominant which is a nitrogen-fixing genus and can generate gas vacuoles to remain in the water surface of the lake (Padmavathi & Prasad, 2007).

Cyanophyceae class domination caused blooming to form as a green surface scum or foam on the surface of the lake, which interfered with light intensity to a water column of the lake (Howard, 1994; van Vuuren et al., 2006). Low light intensity and toxin secretion from several genera of Cyanophyceae established low abundance percentages for Trebouxiophyceae and Ulvophyceae, as they are limiting factors for phytoplankton photosynthesis (Bellinger & Sigee, 2010; Liang et al., 2015). Based on previous research, diatom taxa (Bacillariophyceae, Coscinodiscophyceae and Mediophyceae) were unable to adapt to the limited phosphorus competition with Cyanophyceae class (Amano et al., 2010).

Total phytoplankton abundance in RL was higher than other lakes in South Tangerang City because of invasive aquatic plants overgrown, i.e., water hyacinth. The adsorption function of root trap in water hyacinth increased phytoplankton abundance surrounding it (Wang & Yan, 2017). Mainly, it increased phytoplankton abundance of tolerant genera in high-pollutant lakes such as *Oscillatoria* and *Closterium*, which were observed abundant in RL (Table 3). A high density of water hyacinth also inhibits the growth of submerged aquatic plants, which play an important role in controlling the phytoplankton population (Mironga et al., 2012; Zeng et al., 2017; da Silva et al., 2018).

PJL was the lowest total phytoplankton abundance in the lakes, followed by BL, as BL was the lowest total phytoplankton abundance in the lakes behind PJL (<500 Ind·L^{-1}). The total abundance of phytoplankton decreased allegedly because the sediments in PJL and BL were dredged. The previous research also reported a decrease in phytoplankton biomass after sediment dredging occurred (Norris & Laws, 2017). Total phytoplankton abundances in PJL and BL were decreased, but Cyanophyceae constantly dominated in them. Presumably, sediment dredging merely reduces phytoplankton biomass and nutrient loading without controlling Cyanophyceae's population.

H' values in PJL, PARL, RL and GL indicated heavy pollution (1<H'<2), meanwhile H' values in BL, CL, KL and PAML indicated moderate pollution (2<H'<3) (Gao et al., 2018). The lakes in South Tangerang City had undergone moderate-heavy pollution, however, there was no dominant phytoplankton genus within phytoplankton communities in the lakes as D values in the lakes were low and phytoplankton communities were stable (D<0.5) (Nurfadillah et al., 2022). The D values were supported by J' values in the lakes, except RL, which was high with even dispersion of phytoplankton genera (J'>0.5). RL had J' values categorized as low (J'<5) with uneven dispersion of phytoplankton genera (Nurfadillah et al., 2022). Uneven distribution conditions cause the phytoplankton community to be vulnerable to the presence of dominant genera (Al-Thahaibawi et al., 2021).

Based on previous research, BL was reported to be heavily polluted with H' values in the range of 0.151-0.158 (Salam, 2010). Increasing H' in BL occurred as BL had undergone lake management by sediment dredging in 2019. According to Salam (2010), BL had a low DO level (3.13-5.62) before sediment dredging and it was increased as sediment dredging occurred (7±1.1). Phytoplankton was stressed before dredging the sediment due to low DO and H' levels, but after dredging DO and H' in BL increased. According to Cronberg (1982), sediment dredging decreases nutrient loading and increases the diversity of phytoplankton.

Phytoplankton indices pollution

Trophic and pollution degree based on Nygaard (In) values in the lakes ranged from 2.50-undefined. PJL had the smallest In value (2.50), which was categorized in slight eutrophication, otherwise, BL, GL, CL and PAML were undefined with high eutrophication. Saprobik (X) values ranged from 0.33-1.80. The highest X value occurred in PJL, which included in oligo/β-mesosaprobic phase with very slight pollution. The lowest X values occurred in BL and GL which indicated the β/α-mesosaprobic phase had moderate pollution (Table 6).

The In value was categorized as slight eutrophication and the X value indicated very slight pollution in PJL. Both these results were identified by low levels of BOD, PO_4-P and NO_3-N in PJL. PJL had a satisfying mixing process as the phytoplankton genus, which is a bioindicator for the low nutrient lake, i.e., *Pleurotaenium*, was found (Reynolds et al., 2002; Padisák et al., 2009). Otherwise, BL had high BOD and NO_3-N despite sediment dredging occurring in BL. Therefore, BL was categorized as having moderate pollution based on the X value. This occurred as a negative impact of sediment dredging, which produced secondary pollutants (Chen et al., 2021).

Moderate eutrophication based on the In value and slight pollution based on the X value occurred in RL. Anthropogenic activity around RL was high; it was supported by high-pollution tolerant phytoplankton genera, such as *Oscillatoria* and *Closterium*, being found in RL (Jafari & Gunale, 2006; Kshirsagar, 2013; Stamenković et al., 2021). Moderate eutrophication in RL occurred as a result of the anthropogenic activity around RL's increasing PO_4-P and NO_3-N levels. According to (Patil et al., 2012; Vicentin et al., 2018), high levels of PO_4-P and NO_3-N are an indication of eutrophication in a lake.

In values in PARL and KL were categorized as high eutrophication, furthermore In values in BL, GL, CL and PAML were undefined as the absences of Desmidiales in BL, GL, CL and PAML were observed. Undefined conditions indicate that high eutrophication occurred as Desmidiales were absent in BL, GL, CL and PAML. Generally, Desmidiales was the bioindicator for the oligotrophic lake (Jindal et al., 2014; Stamenković et al., 2021). Therefore, based on In values, PARL, BL, GL, KL, CL and PAML

Table 6. Nygaard and saprobic indices' values in 8 urban lakes in South Tangerang City.

Lakes	In	Trophic degree	X	Saprobic phase (pollution degree)
PJL	2.50	Slight eutrophication	1.80	Oligo/β-mesosaprobic (very slight pollution)
PARL	7.50	High eutrophication	1.00	β-mesosaprobic (slight Pollution)
RL	4.67	Moderate eutrophication	1.15	β-meso/oligosaprobic (slight pollution)
BL	Undefined	-	0.33	β/α-mesosaprobik (moderate pollution)
GL	Undefined	-	0.33	β/α-mesosaprobic (moderate pollution)
KL	11.00	High eutrophication	0.75	β-mesosaprobic (slight pollution)
CL	Undefined	-	0.45	β/α-mesosaprobic (moderate pollution)
PAML	Undefined	-	0.56	β-mesosaprobic (slight pollution)

were categorized as high eutrophic lakes. Otherwise, X values in PARL, KL and PAML indicated slight pollution has occurred. Different results from previous research observed moderate and heavy pollution in PARL and KL, respectively (Rijaluddin et al., 2017; Zharifa et al., 2019). Based on (Dresscher and Mark, 1976), incompatibility results of the saprobic index indicate that a heavy disruption in the environmental condition in the lakes occurred.

Inter-lake correlation based on Jaccard Index

Jaccard index values for inter-lakes were not equal to 1. CL and PAML formed a cluster with the highest Jaccard index value (0.62). PARL with KL and GL with RL formed a cluster with similar Jaccard index values (0.52). BL and PJL were separated and isolated from other lakes with low Jaccard index values (<0.5) (Figure 3).

Jaccard index values in the lakes (≠1) indicate there are no identical similarities in the composition and diversity of phytoplankton communities' inter-lakes (Cermeño et al., 2010; Vijayakumari et al., 2018). According to a report from Li et al. (2021), there were 4 similarity conditions based on Jaccard index values, i.e. extremely dissimilar (0>0,25), dissimilar (0,25>0,5), similar (0,5>0,75) and extremely similar (0,75>1). CL with PAML, PARL with KL and GL with RL had inter-lake similarities but BL and PJL were dissimilar with other lakes. According to Niyoyitungiye et al. (2020), environmental conditions, mainly chemical-physical variables conditions, impact the distribution of phytoplankton differently. JPL (PO_4-P and NO_3-N limitation) and BL (High pH and BOD level) had extreme chemical-physical variables conditions, which inhibited several phytoplankton genera's growth. They had no inter-lake similarities and they were isolated from the cluster.

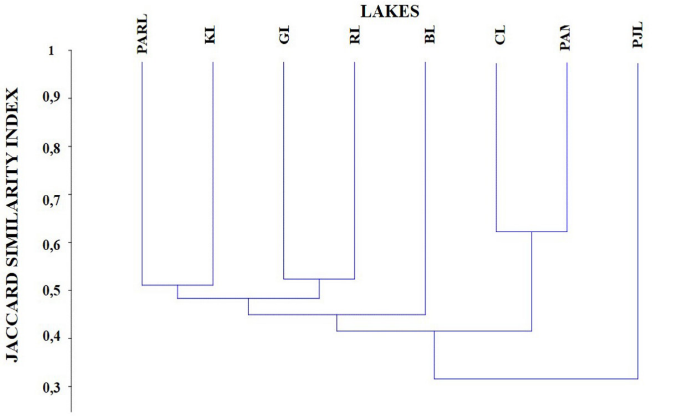

Figure 3. Inter-lake correlation in South Tangerang City.

Water variables and phytoplankton towards WQI

Based on Spearman's correlation results, the best correlation between the research variables and WQI were DO and BOD levels. DO levels indicated a moderate positive correlation with WQI values (r = 0.53), while indistinct with BOD levels indicated a strong negative correlation (r = -0.75). Phytoplankton abundances (A) indicated a low negative correlation with WQI values (r = -0.17) (Table 7).

A high BOD level is depleting DO level in the lake and harming aquatic ecosystems (Bhateria & Jain, 2016). Therefore, the decreasing DO level indicated deterioration of water quality by high BOD level. Meanwhile, a high DO level sustains aquatic organism respiration in the lake for respiration (Sulawesty & Aisyah, 2020). It also affirms the previous presumption, which indicated BOD and DO levels as the important factors for WQI. Phytoplankton abundance indicated a low negative correlation with WQI. It indicated an indirect interaction between phytoplankton abundance and water quality.

Table 7. Spearman's coefficient correlation results.

Variables		Wtemp	TDS	EC	SDD	TUR	pH	DO	BOD	PO_4-P	NO_3-N	A	WQI
		r											
Wtemp	r	1											
TDS		-0.29	1										
EC		-0.30	0.99	1									
SDD		-0.16	-0.06	-0.06	1								
TUR		0.21	-0.55	-0.53	-0.26	1							
pH		0.10	0.27	0.24	-0.29	-0.27	1						
DO		0.29	-0.28	-0.27	-0.03	0.31	0.04	1					
BOD		0.37	0.01	-0.04	0.14	0.18	-0.18	0.09	1				
PO_4-P		0.10	0.51	0.52	-0.03	-0.33	0.31	0.14	0.02	1			
NO_3-N		-0.08	-0.30	-0.33	-0.07	0.12	-0.08	-0.29	0.11	-0.55	1		
A		-0.06	0.55	0.58	-0.08	-0.36	0.02	-0.25	0.04	0.17	0.04	1	
WQI		-0.11	-0.20	-0.16	-0.09	-0.07	0.18	**0.53**	**-0.75**	0.06	-0.26	-0.17	1

Note: Bold = the best correlation coefficient with WQI results

CONCLUSIONS

The water quality of the lakes in South Tangerang City was not compatible with drinking water based on chemical-physical variables condition analysis. WQI values were categorized as a medium-good category. Based on phytoplankton composition, there was a domination of high-tolerant phytoplankton genera and classes in polluted waters. Phytoplankton communities were stable in the lakes in South Tangerang City, except for RL, which was vulnerable. Phytoplankton compositions between lakes were not identical based on the similarity index. Correlations of DO and BOD with WQI results were the best correlation. DO had the highest positive correlation, whilst BOD had the highest negative correlation. Sediment dredging needs to be done periodically and further improvement in lake management is required. Submerged macrophytes restoration is highly recommended for controlling Cyanophyceae's population.

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Research Article

Cyanocidal Effect of H_2O_2 on the Bloom-Forming *Microcystis aeruginosa* and *Sphaerospermopsis aphanizomenoides*

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ABSTRACT

Cyanobacterial blooms are a global concern causing water quality problems that have serious effects on recreational activities, irrigation, and drinking water usage. Various approaches are available to control cyanobacterial blooms in which Hydrogen Peroxide (H_2O_2) emerges as a noteworthy environmentally safe oxidizing agent selectively inhibiting the growth of cyanobacteria and leaving no residue. The objective of this study was to assess how different concentrations of H_2O_2 (1, 2, and 4 mg L^{-1}) affect the growth of unicellular *Microcystis aeruginosa* and filamentous *Sphaerospermopsis aphanizomenoides* cultures obtained from inland waters in Türkiye and to compare the effectiveness of H_2O_2 application in monocultures and mixed cultures. For this purpose, the experimental setups were conducted in 96-well microtiter plates with eight replicates, and the growth of cultures during the experiment was monitored by measuring cell optical density at 665 nm (OD_{665}). The results showed that 1 mg L^{-1} H_2O_2 had a significant effect on the growth of monocultures of *Microcystis* with cell densities of 100x10^3 cell mL^{-1} ($p<0.05$) and *Sphaerospermopsis* with 50x103 cell mL^{-1}. The cell growth of Microcystis cultures with higher densities declined at 4 mg L^{-1} H_2O_2 addition, significantly. However, 4 mg L^{-1} H_2O_2 dosage was effective up to 200x10^3 cell mL^{-1} *Sphaerospermopsis*. In the mixtures of these species, 2 mg L^{-1} H_2O_2 application was effective to suppress the tested cell densities in the case of *Microcystis* dominance.

Keywords: Cyanobacteria bloom, hydrogen peroxide, freshwater management

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INTRODUCTION

Harmful cyanobacterial blooms are a globally major concern in freshwater resources (Mantzouki, Lürling, et al. 2018; Schuurmans et al. 2018; Svirčev et al. 2019). Cyanobacteria have unique and highly adaptable eco-physiological properties such as nitrogen fixation, buoyancy regulation, and toxin production (Carey et al. 2012; Ganf & Oliver 1982; Litchman & Klausmeier 2008; Mantzouki et al. 2016). These eco-physiological characteristics contribute to the competitiveness of cyanobacteria, allowing them to adapt rapidly to changing environmental conditions and outcompete other phytoplankton species (Mantzouki et al. 2018). They achieve high population densities within water bodies, and form dense blooms which are visible scums on the water surface and as mats along the edges of water bodies (Svirčev et al. 2019). Studies have shown that prolonged periods of stratification in water bodies, resulting from climate change, can benefit fast-growing and buoyant cyanobacteria (Carey et al. 2012; Mantzouki et al. 2018). As nutrient loadings and stratification increase in water bodies, cyanobacteria with access to well-lit surface waters or nutrient-rich hypolimnetic layers have a competitive advantage and can become dominant (Ganf & Oliver 1982; Mantzouki et al. 2018).

The occurrence of cyanobacterial proliferation is promoted by eutrophication, increasing CO_2 levels, and global warming (Mantzouki et al. 2018; Paerl & Huisman 2009; Sandrini et al. 2020; Schuurmans et al. 2018). Cyanobacterial blooms can result in various water quality issues, including turbidity, nocturnal oxygen deficiency, undesirable appearance, and unpleasant taste and odor (Bláha et al. 2009; Kang et al. 2022), and the possibility of producing various cyanotoxins which also result in human health risks (Azevedo et al. 2002; Bláha et al. 2009; Köker et al. 2017). Thus, these blooms pose a significant risk to drinking water reservoirs, recreational waters, and overall ecological balance, resulting in economic and ecological damage (Sandrini et al. 2020). The impact of eutrophication and cyanobacterial blooms extends beyond the environment, affecting ecosystem services including the decline of commercial fisheries, aquaculture, and property values, as well as disruptions to recreational activities, irrigation, and drinking water usage (Akcaalan et al. 2014; Albay et al. 2003a; Kang et al. 2022).

Current management methods for algal blooms include using activated carbon, membrane filtration, or UV disinfection (Akcaalan et al. 2006; Westrick et al. 2010). Using oxidants like copper-based substances is one of the most common procedures for combating algal blooms (Albay et al. 2003b). However, due to its detrimental effect on the ecosystem, alternative methods that involve the use of various oxidizing agents are being considered (Huang & Zimba 2020). Among these agents, Hydrogen Peroxide (H_2O_2) stands out as an environmentally friendly oxidant. The major advantages of H_2O_2 are the rapid degradation into water and oxygen through chemical and biological oxidation-reduction reactions which do not persist in the environment and result in no traces, as well as selective suppression of cyanobacteria (Matthijs et al. 2016; Piel et al. 2019).

Studies have shown that the use of low concentrations of H_2O_2 ranging from 2-10 mg L^{-1} effectively induces oxidative stress to suppress cyanobacterial proliferations. As opposed to other phytoplankton groups, such as green algae, phycobilisomes of cyanobacteria are located directly on the outside of the membranes (Bauzá et al. 2014), which are highly sensitive to the oxidizing agents. In contrast, green algae and diatoms experience significantly less impact from this treatment (Sandrini et al. 2020). Although there are many variables to affect H_2O_2 efficiency, H_2O_2 dose, and algal biomass are of great importance (Jia et al. 2014; Liu et al. 2017).

Cyanobacterial blooms are a global phenomenon; *Microcystis* spp., *Anabaena* spp., *Dolichospermum* spp., *Sphaerospermopsis* spp., and *Planktothrix* spp. are the most commonly found cyanobacteria in the world that are known as actual or potential cyanotoxin producers (Svirčev et al. 2019). *Microcystis* spp. and *Sphaerospermopsis* spp. are also widely encountered cyanobacteria in Turkish freshwater resources (Koker et al. 2017). Although the first cyanobacterial bloom records in Türkiye started in the 1980s, monitoring studies started in the 1990s. Since then, cyanobacterial blooms have been a growing concern in Turkish freshwater resources (Akcaalan et al. 2006; Albay et al. 2003a; Albay et al., 2005; Köker et al. 2022). It is observed that most of the cyanobacteria species proliferate from May to September, whereas *Planktothrix rubescens* can be found in high numbers throughout the year in some lakes in Türkiye. Following the results of the aforementioned study and the increase in problems related to cyanobacteria and their toxins, guidelines for cyanobacterial toxins have been prepared for drinking and recreational waters (Anonymous 2019a; 2019b).

The purpose of the current study was to determine the response of various densities of unicellular *Microcystis aeruginosa* and filamentous *Sphaerospermopsis aphanizomenoides* cultures isolated from Turkish inland waters to 1, 2, and 4 mg L^{-1} H_2O_2 concentration and to compare the efficiency of H_2O_2 application in terms of monocultures and their mixtures.

MATERIALS AND METHODS

Cultivation of cyanobacteria

Two different species of cyanobacteria isolated from freshwater sources in Türkiye were used. The filamentous cyanobacterium *Sphaerospermopsis aphanizomenoides* was isolated from Lake Iznik and the unicellular cyanobacterium *Microcystis aeruginosa* was isolated from Küçükçekmece Lagoon.

Media and flasks were sterilized in an autoclave at 121°C for 20 min before starting the experimental sets. For the cultivation of *S. aphanizomenoides*, a medium without nitrogen was used, while *M. aeruginosa* was cultivated in the BG11 medium with nitrogen. The specific contents of the BG11 media are presented in Table 1.

Table 1. Media used for cyanobacteria cultures.

Component	BG-11	$BG\text{-}11_0$
	M. aeruginosa	***S. aphanizomenoides***
$NaNO_3$	1.5 g L^{-1}	-
$CaCl_2$	0.0272 g L^{-1}	0.0272 g L^{-1}
Ferric ammonium citrate	0.012 g L^{-1}	0.012 g L^{-1}
Na_2EDTA	0.001 g L^{-1}	0.001 g L^{-1}
K_2HPO_4	0.04 g L^{-1}	0.04 g L^{-1}
$MgSO_4$	0.0361 g L^{-1}	0.0361 g L^{-1}
Na_2CO_3	0.02 g L^{-1}	0.02 g L^{-1}
Sodium citrate	0.00882 g L^{-1}	0.00882 g L^{-1}
Trace minerals	1 mL stock L^{-1} *	1 mL stock L^{-1} *

*Trace minerals contain of 2.86 g of H_3BO_3, 1.81 g of $MnCl_2.4H_2O$, 0.39 g of $NaMoO_4.2H_2O$, 0.079 g of $CuSO_4.5H_2O$, and 0.494 g of $Co(NO_3)_2.6H_2O$ in 1 L of ultrapure water.

To calculate the initial cell count was in the experiment, the samples from cultures were fixed by Lugol's iodine solution for the enumeration. For the abundance analysis of *S. aphanizomenoides*, the Utermöhl (1958) method was employed using a Zeiss Axiovert inverted microscope, and the cell counting of *M. aeruginosa* was done using a Neubauer chamber (hemocytometer).

The growth of cultures during the experiment was monitored by measuring cell optical density at 665 nm (OD_{665}) by using a microplate reader (Thermo Scientific Multiskan FC, Waltham, MA). Measurements were taken prior to H_2O_2 addition (t=0) and t=1, 2, 4, and 6 h after H_2O_2 addition, and then densities were monitored on a daily basis.

Experimental setup

Two different experimental setups were conducted within the scope of this study. All treatments were performed with eight replicates. First, the sensitivity of various densities of monocultures of *M. aeruginosa* and *S. aphanizomenoides* to 1, 2, and 4 mg L^{-1} H_2O_2 was determined in 96-well microtiter plates. After the first experiment, the second experiment was conducted according to the appropriate dose. Since zooplankton is sensitive to H_2O_2 in a concentration exceeding 2.5 mg L^{-1}, it is not applicable to use H_2O_2 in higher concentrations (Matthijs et al. 2012). Thus, the second experiment was prepared to demonstrate the various densities of *M. aeruginosa* and *S. aphanizomenoides* mixtures to 2 mg L^{-1} H_2O_2 dosage. The control groups were also included in the experiment without H_2O_2 addition (0 mg L^{-1} H_2O_2). The experimental setups were summarized in Table 2. For each species and mixture, 96-well plates were inoculated with 340 µL cultures with different densities and 10 µL of H_2O_2 was added at different concentrations. Well-plates were placed in the Plant Growth Chamber (MLR-351, Sanyo) at 21 °C temperature with an 18:6 hour day cycle (day: night) and the tests were continued for 6 days.

Statistics

All the experimental sets were replicated and the mean values were used. The differences between controls and H_2O_2 added cultures were assessed by the Student's t-test.

RESULTS AND DISCUSSION

Controlling cyanobacterial blooms with H_2O_2 treatment needs to be thoroughly studied, since there are so many physical (light intensity), chemical (concentration of dissolved organic materials), and biological factors (algal density, cyanobacterial biomass) at play (Agustina et al. 2005; Chen et al. 2021; Matthijs et al. 2012). This study was designed to assess the effects of low H_2O_2 dosages on the presence of various densities of *S. aphanizomenoides* and *M. aeruginosa*.

The sensitivity of the monoculture of *S. aphanizomenoides* to H_2O_2 dosages is given in Figure 1. 1 mg L^{-1} H_2O_2 concentration was only effective for the cell density of 50x10^3 cell mL^{-1} ($p<0.05$) and cell growths were not affected by 1 mg L^{-1} H_2O_2 at higher cell densities ($p>0.05$). The growth of *S. aphanizomenoides* was significantly decreased at 2 mg L^{-1} and 4 mg L^{-1} H_2O_2 addition at 100x10^3 cell mL^{-1} ($p<0.05$). For higher cell densities, 4 mg L^{-1} H_2O_2 dosage was effective at 150 x10^3 cell mL^{-1} ($p<0.05$) and 200 x10^3 cell mL^{-1} ($p<0.05$). Higher cell densities were resistant to assessed H_2O_2 dosages ($p>0.05$).

The sensitivity of the monoculture of *M. aeruginosa* to H_2O_2 dosages is depicted in Figure 2. 1 mg L^{-1} H_2O_2 had a significant effect on 100x10^3 cell mL^{-1} and a slightly increase in biomass was observed at 250x10^3 cell mL^{-1} and 500x10^3 cell mL^{-1} ($p<0.05$). Although the addition of 1 mg L^{-1} H_2O_2 did not affect the cell growth of *M. aeruginosa* cultures with higher densities (750 x10^3 cell mL^{-1}, 1000x10^3 cell mL^{-1}, and 1750x10^3 cell mL^{-1}) ($p>0.05$), the cell growth declined significantly at 2 mg L^{-1} and 4 mg L^{-1} H_2O_2 addition ($p<0.05$). The results of this study are in line with a recent study carried out by Kang et al. (2022), in which the authors found that the addition of 1, 3, and 10 mg L^{-1} H_2O_2 decrease *M. aeruginosa* growth. In another study, Wang et al. (2022) investigated the effectiveness of H_2O_2 on *Microcystis* with a cell density of 1.5x10^{10} cells L^{-1}. The authors found that 5.4 mg L^{-1} H_2O_2 dosage caused a decrease in chl-*a* concentration and lower dosages did not reveal any significant effects on *Microcystis* cells.

Table 2. Experimental setup.

Experiment 1	Monoculture		
	S. aphanizomenoides **(S)**	***M. aeruginosa*** **(M)**	**H_2O_2 addition**
	10^3 x cell mL^{-1}		
	50	100	H_2O_2 was added as 0, 1, 2, and 4 mg L^{-1}.
	100	250	
	150	500	
	200	750	
	250	1.000	
	500	1.750	

Experiment 2	Mixture					
	S. aphanizomenoides **(S)**	**+**	***M. aeruginosa*** **(M)**	**Total cyanobacteria**		
	10^3 x cell mL^{-1}					
	25	+	100	125	Set I	H_2O_2 was set as 0 and 2 mg L^{-1}
	25	+	150	175	Set II	
	25	+	200	225	Set III	
	25	+	250	275	Set IV	
	50	+	100	150	Set V	
	50	+	250	300	Set VI	

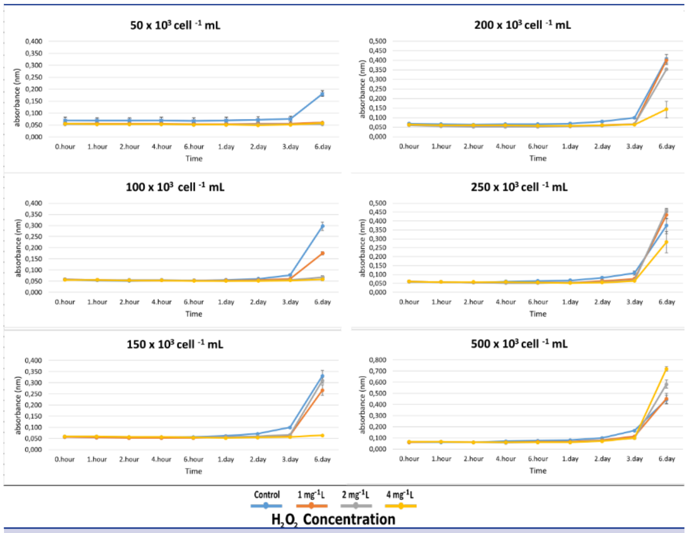

Figure 1. The cell densities of *S. aphanizomenoides* after the addition of 1, 2, and 4 mg L^{-1} H_2O_2 addition.

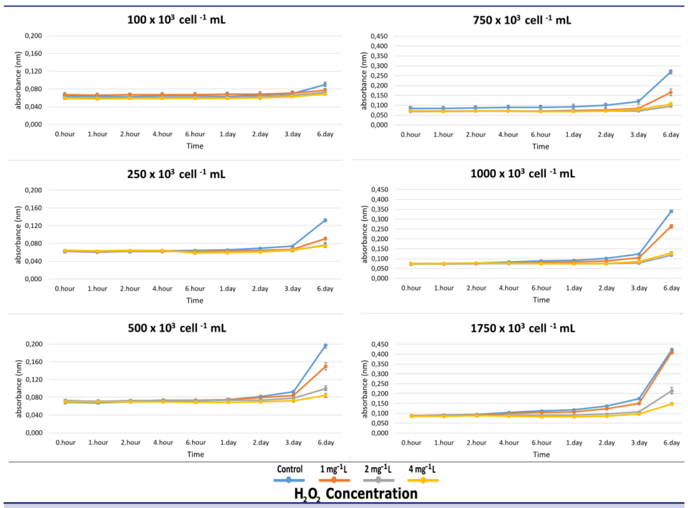

Figure 2. The cell densities of *M. aeruginosa* after the addition of 1, 2, and 4 mg L^{-1} H_2O_2 addition.

The results revealed that *M. aeruginosa* cultures were more sensitive to H_2O_2 compared to *S. aphanizomenoides* culture. The potential reason for the relatively higher resistance to H_2O_2 in *Sphaerospermopsis* compared to *Microcystis* species might be explained in this way: *M. aeruginosa* has lost its colony structure in the culture conditions and has been exposed to H_2O_2 more intensely because it is in the form of a single cell. Since *Sphaerospermopsis* has a filamentous structure, it has higher resistance to H_2O_2 application. A possible explanation for the biomass decrease might be related to the loss of membrane integrity and cell lysis of *M. aeruginosa*. Studies showed that higher than 2 mg L^{-1} H_2O_2 concentrations effectively killed cyanobacteria, but can cause the substantial release of toxins into the water (Lürling et al. 2014). Furthermore, since zooplankton is sensitive to H_2O_2 in a concentration exceeding 2.5 mg L^{-1}, it is not applicable to use H_2O_2 in higher concentrations (Matthijs et al. 2012). Thus, in the following experiment, we decided to apply a dosage of 2 mg L^{-1} H_2O_2. Since freshwater algal blooms can be predominantly composed of a single cyanobacterial genus or multiple genera, it is important to evaluate the effects of H_2O_2 application to different species' interspecific variations (Yang et al. 2018). Thus, in Experiment 2, we assessed a mixture of *S. aphanizomenoides* and *M. aeruginosa* cultures with different cell densities and tried to see the interspecific effect of 2 mg L^{-1} H_2O_2. Figure 3 shows the cell densities of *S. aphanizomenoides* and *M. aeruginosa* after the addition of 2 mg L^{-1} H_2O_2 dosage. H_2O_2 addition had significant effects on cell densities ($p<0.05$). The increase in each group did not reveal resistance to H_2O_2. When the mixture of these two species was compared, effective suppression was observed at 125, 175, and 225 x10^3 cell mL^{-1}. 2 mg L^{-1} H_2O_2 application is effective on the coexistence of *S. aphanizomenoides* and *M. aeruginosa* in the case of *M. aeruginosa* dominance.

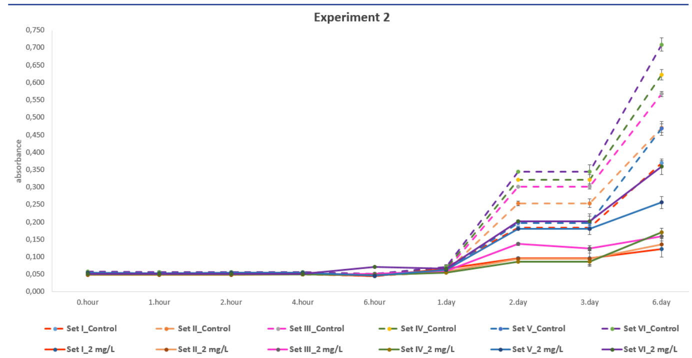

Figure 3. The cell densities of *M. aeruginosa* and *S. aphanizomenoides* mixtures after the addition of 2 mg L^{-1} H_2O_2.

Taken together, we can recommend that the application of H_2O_2 to control cyanobacterial blooms should be carried out in the early stage of a bloom, when algal density is relatively low (Chen et al. 2021; Fan et al. 2013; Liu et al. 2017). It should be noted that different cyanobacteria species exhibit varying responses to the application of H_2O_2, which can be attributed to their distinct survival strategies (Lusty & Gobler 2020). Thus, the application of H_2O_2 should be specifically optimized.

CONCLUSION

The main goal of the current study was to assess the response of various densities of two cyanobacteria species that were commonly found in Turkish freshwater, *M. aeruginosa* and *S. aphanizomenoides*, to 1, 2, and 4 mg L^{-1} H_2O_2 addition and evaluate the efficiency of H_2O_2 application in terms cell growth of monocultures and their mixtures. This study has found that H_2O_2 treatment is much more effective for generally low cell densities and *M. aeruginosa* cultures were more sensitive to H_2O_2 application compared to *S. aphanizomenoides* culture. More information on the application of H_2O_2 in larger-scale experiments would help to establish a greater degree of accuracy on this matter. A further study could assess the effects of H_2O_2 addition in the lake using mesocosm experiments.

Conflict of Interest: The author has no conflicts of interest to declare.

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Research Article

Fish and Shellfish Diversity of Malam *Beel*, Bangladesh: Status, Trends, and Management Strategies

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ABSTRACT

Most of the waterbodies in Bangladesh's north-eastern *haor* basin have seen a gradual decline in their biodiversity, but little study has been done to determine their current condition. To address this issue, this research was conducted in the Malam beel under the Hakaluki *haor* – one of the largest wetland resources of the country. The study was conducted using a pre-tested questionnaire and a direct catch assessment survey in the *beel*. From 11 orders and 32 families, a total of 69 fish and shellfish species were identified. Of the species documented, 15.94% were classified as abundant, 39.13% were common, 27.54% were moderately available, and 17.39% were rare. Among the orders, Cypriniformes accounted for 37.68% of the total fish recorded. The most prevalent family was Cyprinidae found in Malam *beel*. Based on the findings, it can be concluded that Malam *beel* is a highly valuable inland open water body that has the potential to function as a key source of fishery resources as well as a gene bank for various fish species. However, some manmade and natural threats such as fishing by dewatering, brush pile fishing, illegal/destructive fishing and siltation were identified during the present study. Therefore, to ensure the sustainable maintenance of these water bodies, ecosystem-based fisheries management involving the local community is strongly advised.

Keywords: Biodiversity, threats, conservation, management

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INTRODUCTION

Fisheries and aquaculture are of paramount importance for ensuring global food security. These sectors are instrumental in supplying essential animal protein to billions of individuals across the globe, while also serving as a source of livelihood for 10-12% of the world's population (FAO, 2012). Bangladesh is rich in Inland and marine fisheries that make up the country's diverse fisheries resources. Bangladesh boasts abundant water resources, which host a diverse array of aquatic ecosystems that serve as habitats for a wide variety of species of fish (Sultana et al., 2016; Islam & Sultana, 2016). The biodiversity is extremely abundant, with about 260 freshwater fish species (DoF, 2018; Khan et al., 2018). In terms of inland open water capture production, Bangladesh secured the third position globally. The most popular animal source food in Bangladesh is fish, which is consumed at an average rate of 14 kg per year across all societal categories, meeting up to 60% of the country's demand for animal protein (FAO, 2022; DoF, 2018; Khan et al., 2018). Following China and India, Bangladesh is the third-ranked country in Asia for its diverse range of aquatic fish species. The country is home to around 800 species that can be found in freshwater, marine water, and brackish waters (Shamsuzzaman et al., 2017). However, a notable downward trend of fish diversity within Bangladesh's freshwater resources has become evident, with many freshwater species experiencing decreasing population trends (Hanif et al., 2015; Kamal et al., 2022; Das et al., 2022). About a quarter of these species are categorized as threatened, with 25 vulnerable, 30 endangered, and 9 severely endangered species. Also, 27 species have been listed as being near threatened (IUCN Bangladesh, 2015).

The term '*beel*,' which originates from the Bengali language, pertains to a substantial surface water body that is equipped with internal drainage channels for the purpose of collecting surface runoff water (Banglapedia, 2021; Kunda et al., 2022). Bangladesh has thousands of *beels*, and indigenous fishes used the *beel* as a natural habitat for food and shelter (Rahman et al., 2019). Malam *beel* is an important *beel* in the Hakaluki *haor*. It is 45 km away from Kulaura bazar. During the monsoon season, the *beel* is flooded yet remains dry for over six months. It is home to different fauna and flora. Moreover, the *beel* serves as a source of livelihood for thousands of people, providing them with income as well as food, fuelwood, recreational opportunities, and aesthetic benefits.

However, several human interventions, including the building of drainage systems, sluice gates, and flood control embankments, as well as the conversion of waterlogged area to cropland, have led to a reduction in the water area of the *beel* ecosystems, thereby posing a severe threat to aquatic life. Additionally, the careless application of herbicides is also contributing to the degradation of the *beel* ecosystem. Pollution from household, industrial, and agrochemical wastes, as well as mining runoff, has resulted in the demise of many aquatic organisms (Chakraborty, 2011; Pandit et al., 2023). Physicochemical characteristics, climatic parameters, industrial pollutants, municipal wastes, agricultural run-off, and irregular floods are all contributing to the decline of biodiversity in the Malam *beel*. Therefore, it is essential to implement practical management measures to enhance the biodiversity status of the *beel*, upon which local communities depend. However, to devise effective management strategies, understanding the current situation, patterns, and dangers to the aquatic biodiversity of the *beel* is essential. Due to a scarcity of existing research in this area, our study endeavors to fulfill a vital purpose. Specifically, our investigation aims to evaluate the current state of aquatic biodiversity within Malam *beel*. By identifying discernible trends and potential threats, we seek to contribute to a comprehensive understanding of this vital water body. Furthermore, our study strives to generate comprehensive guidelines that facilitate effective management strategies for sustaining the ecological balance of the Malam *beel*.

MATERIALS AND METHODS

Study site and duration

The study was conducted in the Malam *beel* which is a notable *beel* of Hakaluki *haor* (Figure 1), is situated 45 km away from Kulaura bazar. The total area of the Malam *beel* is around 400 acres during the rainy season and 70 acres in the dry season. A geographically suitable coverage that would include a range of fish biodiversity was one of the main selection factors for the study area, as well as the involvement of local fishers who rely on the *beel* for their livelihood. Four villages were selected for interview surrounding the *beel* named Borni, Khutaura, Kazirbond and Golapnagar. The research was done over a span of six months, from October 2017 to March 2018. But the catch assessment of fish was done only in the dry season (December, January, and February). Fishing in the Malam *beel* is exclusively conducted during the dry season. In the rainy season, the *beel* becomes submerged underwater, rendering fishing activities impractical during that period.

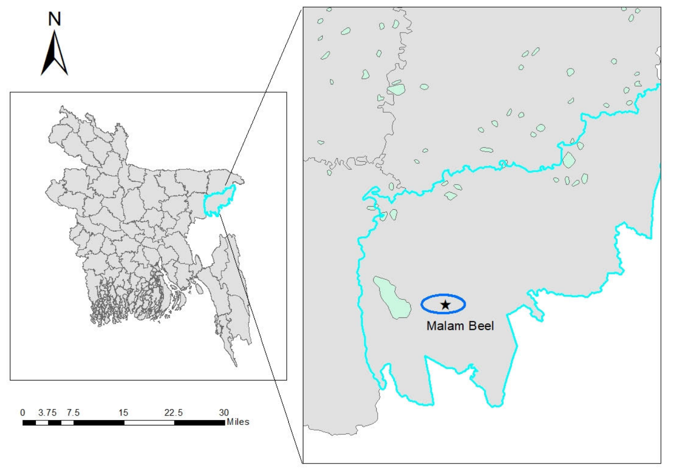

Figure 1. Malam *beel*.

Data collection methods

In this study, 80 fishers, 10 aratdars (fish trader), and 10 fish retailers from four chosen villages made up the total for the questionnaire interviews (QIs). Four focus group discussions (FGDs) were conducted in these villages, with participants from different age groups of fishers. Following the collection of data through FGDs and QIs, key informant interviews (KIIs) were conducted with experienced fishers, Upazila Fisheries Officers (UFO), District Fisheries Officers (DFO), community leaders, and NGO personnel.

Collection of fish samples

Fish and shellfish samples were taken during the catch from previously known fishers and local fish landing sites at 15 day intervals throughout the study period. In the study region, local fishers employ a variety of fishing equipment, such as seine nets, gill nets, lift nets, hooks, and traps. Each of these methods is designed to capture specific species and sizes of fish, and their efficiency varies, as outlined in Kundu et al.'s (2020) study. The sampling methods used in data collection were consistent in the dry season.

Identification of the collected fish samples

Based on their distinctive morphological traits, the collected fish and shellfish were divided into distinct categories. If a species proved challenging to identify during fieldwork, it was preserved in a buffered formalin solution of 10% and later transported to the Fisheries Biology and Genetics laboratory at Bangladesh Agricultural University for in-depth examination. The process of identification encompassed analyzing the specimens' morphometric and meristic traits, as well as their coloration. The taxonomic evaluation adhered to the methods detailed by Rahman (2005), Talwar & Jhingran (1991), and IUCN Bangladesh (2015), while the classification of fish species aligned with the system established by Nelson (2006).

Determination of availability status

The fish and shellfish were identified in terms of the respondent's opinion, their frequency of occurrence and finally, categorized into four classes based on their availability status (Pandit et al., 2020,2021). The categories were defined as: abundantly available (AA) - species consistently observed year-round, repeating over 75% of the time; commonly available (CA) - species frequently seen but in smaller quantities, repeating 51-75% of the time; moderately available (MA) - species encountered occasionally, with a repetition rate ranging from 26 to 50%; and rarely available (RA) - species observed infrequently, repeating in small amounts at a repetition rate equal to or less than 25% (Pandit et al., 2020,2021; Kamal et al., 2022; Kunda et al., 2022).

Statistical analysis

The gathered data underwent input, preprocessing, and analysis using V25.0 of the Statistical Package for the Social Sciences (SPSS) software. A map of the study area was crafted by integrating ArcGIS 10.0 software with the assistance of a global positioning system (GPS).

RESULTS AND DISCUSSION

Fish and shellfish diversity status

In Malam *beel*, 69 species of fauna were identified, including 67 species of finfish and 2 species of prawns, which belonged to 11 different orders and 32 families (Table 2). Although there were no previous studies on fish and shellfish diversity in this *beel* for comparison, the current study provides a baseline for future fish assemblage assessments. Previous studies on fish diversity and richness in the surrounding areas supported the findings of this study. Numerous studies have examined fish species diversity in various water bodies across Bangladesh (Table 1).

The study's findings revealed a distribution of fish and shellfish species availability as follows: 15.94% were abundantly available, 39.13% were commonly available, 27.54% were moderately available, and 17.39% were rarely available. Respondents attributed this pattern to a diminishing fish biodiversity. Kamal et al. (2022) mirrored this trend in Kawadighi *haor*, with 18% abundantly available, 20% commonly available, 42% moderately available, and 20% rarely available species. Parallel results have emerged from studies focused on fish diversity in river and *haor* ecosystems. For instance, Pandit et al. (2020) found that the Gurukchi River displayed a predominance of rarely available fish species (29.82%), followed by commonly available (28.07%), moderately available (22.81%), and abundantly available (19.30%). Similarly, Pandit et al. (2021) documented 17.4% abundantly available, 27.5% commonly available, 31.9% moderately available, and 23.1% rarely available fish species in the Dhanu River and its surrounding *haor* ecosystems. These collective findings highlight the consistent distribution of fish species across different water bodies within the region.

Cypriniformes, Siluriformes, and Anabantiformes were discovered to be the most prominent orders among the eleven recognized orders, contributing for 37.68%, 23.19%, and 11.59% of the total fish population in Malam *beel*, respectively (Figure 3). Other eight orders were constituted by Perciformes, Synbranchiformes, Clupeiformes, Osteoglossiformes, Beloniformes, Decapoda, Tetraodontiformes, and Cyprinodontiformes. Many studies have consistently shown that Siluriformes and Cypriniformes are the most common orders in Bangladesh (Rahman, 2005; Iqbal et al., 2015; Hossain et al., 2016; Mondol et al., 2015; Sultana et al., 2018, 2019; Debnath et al., 2020; Talukder et al., 2021), which is like the current study. Sulta-

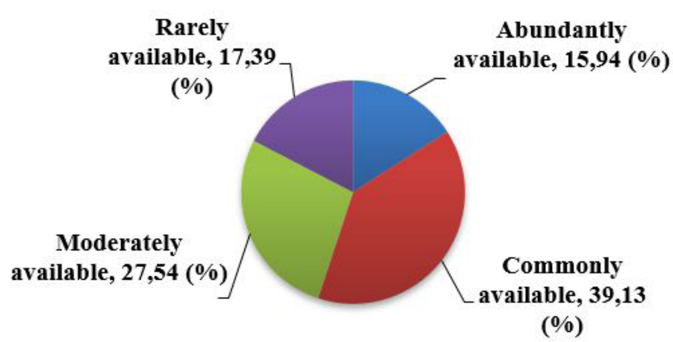

Figure 2. Pie chart for percentage of availability status of fish and shellfish species in Malam *beel*.

Table 1. Comparison of fish and shellfish diversity with other studies.

Sl. No.	Study Area	Order	Family	No. of Species	References
1	Malam *beel*	11	32	69	Present Study
2	Hakaluki *haor*	10	28	83	Iqbal et al. 2015
3	Hakaluki *haor*	12	27	63	Aziz et al. 2021
4	Bhawal *beel*	10	23	56	Sultana et al. 2019
5	Chalan *beel*	10	26	78	Siddique et al. 2016
6	Basurabad *beel*	6	-	33	Rahman et al. 2019
7	Banar River	10	24	62	Sultana et al. 2018
8	Juri River	-	25	75	Islam et al. 2019
9	Basuakhali *beel*,	10	21	38	Rahman et al. 2019
10	Shari-Goyain River	9	27	66	Talukder et al. 2021

Table 2. Recorded fish and shellfish species from the Malam *beel*.

SL No.	Order	Family	Scientific Name	English Name	Local Name	Present Status	Conservation Status		Native status	Major Fishing Gear	Catch Preference
							BD	GL			
1	Anabantiformes	Osphronemidae	Trichogaster fasciata (Bloch & Schneider 1801)	Banded gourami	Baro khlisha	CA	LC	LC	Native	CN	BC
2	Anabantiformes	Osphronemidae	Trichogaster fasciata (Bloch & Schneider 1801)	Honey gourami	Lal khalisha	CA	LC	LC	Native	CN	BC
3	Anabantiformes	Anabantidae	Anabas testudineus (Bloch, 1792)	Climbing perch	Koi	MA	LC	LC	Native	CN	TC
4	Anabantiformes	Channidae	Channa marulius (Hamilton, 1822)	Giant snakehead	Gozar	RA	EN	LC	Native	H	TC
5	Anabantiformes	Channidae	Channa striata (Bloch, 1793)	Snakehead murrel	Shol	CA	LC	LC	Native	H	TC
6	Anabantiformes	Channidae	Channa orientalis (Bloch & Schneider, 1801)	Asiatic snakehead	Cheng	CA	LC	VU	Native	H	TC
7	Anabantiformes	Channidae	Channa punctata (Bloch, 1793)	Spotted Snakehead	Taki	CA	LC	LC	Native	H	TC
8	Anabantiformes	Nandidae	Nandus nandus (Hamilton, 1822)	Gangetic leaffish	Meni/Veda	CA	NT	LC	Native	SN	TC
9	Beloniformes	Belonidae	Xenentodon cancila (Hamilton, 1822)	Freshwater garfish	Kankila	CA	LC	LC	Native	SN	BC
10	Beloniformes	Hemiramphidae	Hyporhamphus limbatus (Valenciennes, 1847)	Congaturi halfbeak	Ekthutia	CA	LC	LC	Native	SN	BC
11	Clupeiformes	Dorosomatidae	Gudusia chapra (Hamilton, 1822)	Indian river shad	Chapila	AA	VU	LC	Native	GN	TC
12	Clupeiformes	Dorosomatidae	Corica soborna (Hamilton, 1822)	The Ganges River sprat	Kachki	AA	LC	LC	Native	CN	TC
13	Cypriniformes	Cobitidae	Lepidocephalichthys guntea (Hamilton, 1822)	Guntea loach	Gutum	CA	LC	LC	Native	SN	TC
14	Cypriniformes	Botiidae	Botia dario (Hamilton, 1822)	Bengal loach	Bou/Rani	CA	EN	LC	Native	SN	BC
15	Cypriniformes	Cyprinidae	Labeo rohita (Hamilton, 1822)	Rohu	Rui	MA	LC	LC	Native	SN	TC
16	Cypriniformes	Cyprinidae	Labeo catla (Hamilton, 1822)	South Asian carp	Catla	RA	LC	NE	Native	SN	TC
17	Cypriniformes	Cyprinidae	Cirrhinus mrigala (Bloch, 1795)	Mrigal carp	Mrigal	MA	NT	VU	Native	SN	TC
18	Cypriniformes	Cyprinidae	Cirrhinus reba (Day, 1878)	Reba carp	Lachu	CA	NT	LC	Native	SN	TC
19	Cypriniformes	Cyprinidae	Cyprinus carpio (Linnaeus, 1758)	Common carp	Carpio	MA	NT	VU	Native	SN	TC

Table 2. Recorded fish and shellfish species from the Malam *beel*.

SL No.	Order	Family	Scientific Name	English Name	Local Name	Present Status	Conservation Status BD	Conservation Status GL	Native status	Major Fishing Gear	Catch Preference
20	Cypriniformes	Xenocyprididae	Hypophthalmichthys molitrix (Valenciennes, 1844)	Freshwater cyprinid fish	Silver carp	RA	LC	NT	Non-native	SN	TC
21	Cypriniformes	Xenocyprididae	Ctenopharyngodon idella (Valenciennes, 1844)	Ray-finned fishes	Grass carp	MA	NT	NE	Non-native	SN	TC
22	Cypriniformes	Cyprinidae	Labeo gonius (Hamilton, 1822)	Kuria labeo	Gonia	MA	NT	LC	Native	SN	TC
23	Cypriniformes	Cyprinidae	Pethia ticto (Hamilton, 1822)	Ticto barb	Tit punti	AA	VU	LC	Native	CN	TC
24	Cypriniformes	Cyprinidae	Puntius sophore (Hamilton, 1822)	Spotfin swamp barb	Jat punti	AA	LC	LC	Native	CN	TC
25	Cypriniformes	Cyprinidae	Pethia phutunio (Hamilton, 1822)	Spottedsail barb	Phutanio punti	MA	LC	LC	Native	CN	TC
26	Cypriniformes	Cyprinidae	Systomus sarana (Hamilton, 1822)	Olive barb	Shorputi	MA	NT	LC	Native	CN	TC
27	Cypriniformes	Danionidae	Amblypharyngodon mola (Hamilton, 1822)	Mola carplet	Mola	AA	LC	LC	Native	CN	TC
28	Cypriniformes	Cyprinidae	Osteobrama cotio (Hamilton, 1822)	Cotio	Dhela	RA	NT	LC	Native	CN	TC
29	Cypriniformes	Danionidae	Esomus danrica (Hamilton, 1822)	Stripped flying barb	Darkina	CA	DD	NE	Native	CN	BC
30	Cypriniformes	Danionidae	Securicula gora (Hamilton, 1822)	Chela gora	Ghora chela	CA	NT	LC	Native	CN	BC
31	Cypriniformes	Danionidae	Salmostoma acinaces (Valenciennes, 1844)	Silver razor belly minnow	Chela	MA	DD	LC	Native	CN	BC
32	Cypriniformes	Cyprinidae	Puntius terio (Hamilton, 1822)	One spotted barb	Teri punti	CA	LC	LC	Native	CN	TC
33	Cypriniformes	Cyprinidae	Pethia guganio (Hamilton, 1822)	Glass-barb	Mola punti	AA	LC	LC	Native	CN	TC
34	Cypriniformes	Danionidae	Salmostoma phulo (Hamilton, 1822)	Finescale razorbelly minnow	Phulo-chela	RA	NT	LC	Native	CN	TC
35	Cypriniformes	Cyprinidae	Pethia gelius (Hamilton, 1822)	Golden barb	Jelly puti	AA	NT	LC	Native	CN	TC

Table 2. Recorded fish and shellfish species from the Malam *beel*.

SL No.	Order	Family	Scientific Name	English Name	Local Name	Present Status	Conservation Status		Native status	Major Fishing Gear	Catch Preference
							BD	GL			
36	Cypriniformes	Cyprinidae	Labeo bata (Hamilton, 1822)	Bata labeo	Bata	MA	LC	LC	Native	SN	TC
37	Cypriniformes	Cyprinidae	Labeo calbasu (Hamilton, 1822)	Orange Fin labeo	Kalibaus	MA	LC	LC	Native	SN	TC
38	Cypriniformes	Psilorhynchidae	Psilorhynchus balitora (Hamilton, 1822)	Balitora Minnow	Balichata	MA	LC	LC	Native	CN	TC
39	Cyprinodontiformes	Aplocheilidae	Aplocheilus panchax (Hamilton, 1822)	Blue panchax	Kanpona	CA	LC	NT	Native	CN	BC
40	Decapoda	Soleniceridae	Solenocera crassicornis (H. Milne Edwards, 1837)	Red prawn	Gura chingri	AA	LC	NE	Native	T	TC
41	Decapoda	Palaeomonidae	Macrobrachium rosenbergii (De Man, 1879)	Giant river prawn	Golda chingri	CA	LC	LC	Native	T	TC
42	Osteoglossiformes	Notopteridae	Notopterus notopterus (Pallas, 1769)	Bronze featherback	Foli	CA	VU	LC	Native	SN	TC
43	Osteoglossiformes	Notopteridae	Chitala chitala (Hamilton, 1822)	Clown knifefish	Chital	RA	EN	NT	Native	CN	TC
44	Perciformes	Ambassidae	Chanda nama (Hamilton, 1822)	Elongate glass perchlet	Lamba chanda	MA	LC	LC	Native	SN	BC
45	Perciformes	Ambassidae	Parambassis ranga (Hamilton, 1822)	Highfin glassy perchlet	Gol chanda	CA	LC	LC	Native	GN	BC
46	Perciformes	Cichlidae	Oreochromis mossambicus (Peters, 1852)	Hawaiian perch	Tilapia	MA	LC	VU	Non-native	SN	TC
47	Perciformes	Badidae	Badis badis (Hamilton, 1822)	Blue perch	Napit koi	MA	NT	LC	Native	GN	TC
48	Perciformes	Gobiidae	Glossogobius giuris (Hamilton, 1822)	Tank goby	Bele	CA	LC	LC	Native	T	BC
49	Siluriformes	Siluridae	Wallago attu (Bloch & Schneider, 1801)	Freshwater shark	Boal	CA	VU	VU	Native	H	TC
50	Siluriformes	Siluridae	Ompok pabo (Hamilton, 1822)	Pabo catfish	Pabda	CA	CR	NT	Native	GN	TC
51	Siluriformes	Siluridae	Ompok pabda (Hamilton, 1822)	Butter catfish	Modhu pabda	RA	EN	NT	Native	SN	TC
52	Siluriformes	Pangasiidae	Pangasius pangasius (Hamilton, 1822)	Pungas catfish	Deshi pan-gus	RA	EN	LC	Native	SN	TC
53	Siluriformes	Ailiidae	Eutropiichthys vacha (Hamilton, 1822)	Batchwa vacha	Bacha	CA	LC	LC	Native	CN	TC
54	Siluriformes	Horabagridae	Pachypterus atherinoides (Bloch, 1754)	Indian potasi	Batashi	AA	LC	NE	Native	CN	TC

Table 2. Recorded fish and shellfish species from the Malam *beel*.

SL No.	Order	Family	Scientific Name	English Name	Local Name	Present Status	Conservation Status		Native status	Major Fishing Gear	Catch Preference
							BD	GL			
55	Siluriformes	Bagridae	Sperata aor (Hamilton, 1822)	Long-whiskered catfish	Air	CA	VU	LC	Native	H	TC
56	Siluriformes	Sisoridae	Bagarius bagarius (Hamilton, 1822)	Gangetic goonch	Baghair	RA	CR	NT	Native	H	TC
57	Siluriformes	Bagridae	Mystus bleekeri (Day, 1877)	Bleeker's mystus	Gulsha tengra	AA	LC	LC	Native	CN	TC
58	Siluriformes	Bagridae	Mystus vittatus (Bloch, 1794)	Asian striped catfish	Tengra	AA	LC	LC	Native	CN	TC
59	Siluriformes	Bagridae	Rita rita (Hamilton, 1822)	Rita	Rita	MA	EN	LC	Native	CN	TC
60	Siluriformes	Bagridae	Sperata seenghala (Sykes, 1839)	Giant river-catfish	Guizza air	RA	LC	LC	Native	SN	TC
61	Siluriformes	Bagridae	Mystus tengara (Hamilton, 1822)	Striped dwarf catfish	Bujuri tengra	CA	LC	LC	Native	CN	TC
62	Siluriformes	Clariidae	Clarias batrachus (Linnaeus, 1758)	Walking catfish	Magur	MA	LC	LC	Native	H	TC
63	Siluriformes	Heteropneustidae	Heteropneustes fossilis (Bloch, 1794)	Stinging catfish	Shing	CA	LC	LC	Native	H/T	TC
64	Siluriformes	Bagridae	Mystus cavasius (Hamilton, 1822)	Gangetic mystus	Kabasi tengra	CA	NT	LC	Native	H/T	TC
65	Synbranchiformes	Mastacembelidae	Mastacembelus pancalus (Hamilton, 1822)	Striped spiny eel	Guchi baim	RA	LC	LC	Native	T	TC
66	Synbranchiformes	Mastacembelidae	Mastacembelus armatus (Lacepede, 1800)	Zig-zag eel	Baim	MA	EN	NE	Native	T	TC
67	Synbranchiformes	Mastacembelidae	Macrognathus aculeatus (Bloch, 1786)	Lesser spiny eel	Tara baim	MA	DD	LC	Native	T	TC
68	Synbranchiformes	Synbranchidae	Ophichthys cuchia (Hamilton, 1822)	Gangetic mudee	Kuchia	RA	VU	VU	Native	T	TC
69	Tetraodontiformes	Tetraodontidae	Leiodon cutcutia (Hamilton, 1822)	Ocellated puffer fish	Potka	CA	LC	LC	Native	LN	BC

BD – Bangladesh, GL – Global, LC - Least concern, NT - Near threatened, NE - Not evaluated, DD - Data deficient, VU - Vulnerable, EN - Endangered, and CR - Critically endangered (IUCN Bangladesh, 2015); AA - Abundantly available, CA - Commonly available, MA - Moderately available, RA - Rarely available; SN – Seine Net, GN – Gill Net, LN – Lift Net, CN – Cast Net, H – Hooks, T – Traps; TC – Target Catch, BC – Bycatch.

na et al. (2019) revealed the order-based percentage analysis of the existing aquatic fauna from Bhawal *beel* and found as Cypriniformes (33.93%), Siluriformes (21.43%) and Perciformes (19.65%).

In Malam *beel*, the prevailing family was identified as Cyprinidae, contributing to 23.19% of the overall fish diversity (Figure 3b). While smaller proportions were attributed to families like Bagridae, Anabantidae, and others, their presence was observed. These outcomes parallel the conclusions drawn from earlier investigations by Sultana et al. (2019) on Bhawal *beel* and Islam et al. (2019) on Juri River, both of which underscored the dominance of Cyprinidae as the primary family in terms of fish population.

According to IUCN Bangladesh (2015), 21.74% of the identified fish and shellfish in Malam *beel* were classified as endangered, while 18.84% were near threatened (Figure 3c). However, most of the fish populations (55%) were categorized as least concern (LC). When considering the global IUCN status, most fish species in Malam *beel* were categorized as least concern (LC), constituting 73.90% of the total. Following this, near threatened (NT), data deficient (DD), and not evaluated (NE) species accounted for 8.70% each (IUCN Bangladesh, 2015).

The investigation unveiled that within Malam *beel*, there existed a collective of 15 fish species categorized as threatened. Among these, 6 were deemed vulnerable, 7 as endangered, and 2 as critically endangered, as per the IUCN Bangladesh (2015) classification (Figure 6). In comparison, previous studies conducted in Hakaluki *Haor* and Bhawal *beel* identified 41 and 13 threatened species, respectively, with varying levels of vulnerability. Similarly, the Juri River study found 19 threatened species, with 10 being vulnerable, 8 endangered, and 1 critically endangered, which aligns with the present study's findings.

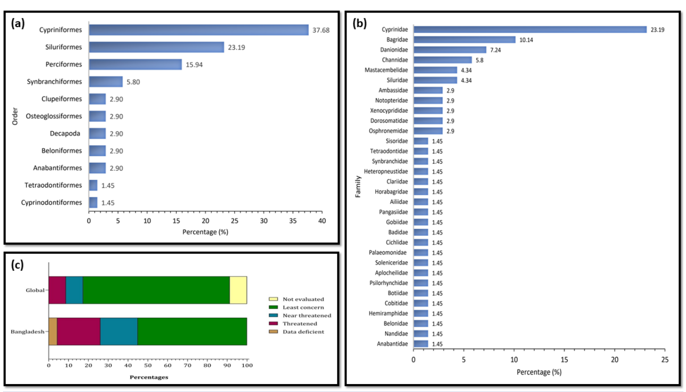

Figure 3. Recorded fish and shellfish species distribution according to their (a) orders, (b) families and (c) conservation status.

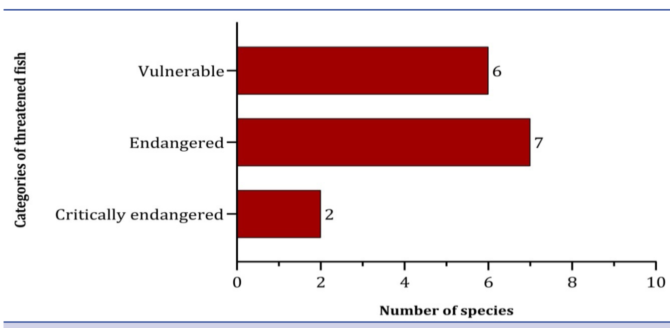

Figure 4. Threatened fish species found in Malam *beel*.

Threats to fish biodiversity of Malam beel

The fish and shellfish species diversity of Malam *beel* is affected by both natural and anthropogenic factors. The major threats identified by respondents were overfishing, fishing by dewatering, and brush pile fishing, which were reported by 85%, 77.5%, and 72.5% of the respondents, respectively. Additionally, the use of illegal/destructive fishing equipment, the unregulated use of insecticides, pesticides and chemical fertilizers on agricultural lands, siltation and sedimentation, and water abstraction for irrigation were identified as factors affecting fish biodiversity, with 65%, 56.25%, 51.25%, and 47.5% of respondents reporting these as issues. The conversion of *beel* to agricultural fields and habitat loss due to siltation were also mentioned. Climate change was identified as a natural cause of impact on the *beel*'s biodiversity due to changes in water temperature and extreme rainfall events. The lack of awareness and fishing by poor and illiterate individuals were also mentioned as contributing factors. Furthermore, *Oreochromis mossambicus*, *Hypophthalmichthys molitrix*, and *Ctenopharyngodon idella* are non-native fish species that have been introduced to various aquatic environments for different purposes. While they are not traditionally considered invasive species in the sense of causing significant harm to native ecosystems in Bangladesh. These findings highlight the urgent need to take measures to address the identified threats to fish biodiversity in Malam *beel*. Details shown in Table 3.

The decrease in fish and shellfish abundance observed in Hakaluki *haor* in northeast Bangladesh can be attributed to several factors such as the drying up of *beel*s, flooding, siltation, overfishing, use of harmful fishing tools, temperature fluctuations, and the use of inorganic fertilizers to catch fish. Similar trends

Table 3. Threats to fish biodiversity of Malam *beel*.

Factors affecting fish biodiversity	Percentage of respondents
Overfishing	85.0%
Fishing by dewatering	77.5%
Brush pile fishing	72.5%
Use of illegal/destructive fishing gears	65.0%
Unregulated application of pesticides, insecticides, chemical fertilizers on agricultural lands.	56.25%
Siltation and sedimentation	51.25%
Water abstraction for irrigation	47.5%
Climate change (altered pattern in temperature and rainfall)	31.25%
Construction of developmental infrastructure	26.25%
Water pollution	10.0%

have been identified as catalysts for the decline in biodiversity in various other investigations conducted by Rahman et al. (2019), Sultana et al. (2019), Das et al. (2022), Tasnim et al. (2022), and Sultana et al. (2022). Additionally, the conversion of *beel* fringes into agricultural fields remains an ongoing process in the region. Overfishing stands out as a prominent contributor to the decline in fisheries, while the application of pesticides, known for their high toxicity, poses a substantial threat to aquatic organisms, impacting the integrity and function of ecosystems (Parveen and Faisal, 2002). The sedimentation of water bodies also emerges as a significant factor contributing to the deterioration and degradation of aquatic ecosystems (Craig et al., 2004). In the context of Kawadighi *haor*, crucial drivers that have led to a reduction in species diversity within the *beel* encompass dewatering, overfishing, the usage of destructive fishing equipment, intensified agricultural activities, road and embankment construction, pesticide utilization, sediment deposition, barrage establishment, improper fish farming, and drought (Kamal et al., 2022).

Management options

Preventing overfishing, illegal fishing equipment usage, and the destruction of fish eggs and seeds through illegal fishing methods and tools is crucial. Enforcing minimum mesh size requirements for various gears will help accomplish this and prohibiting the use of monofilament nets.

The unregulated building of bridges, culverts, sluice gates, and flood control embankments has disrupted the natural migration patterns of fish during their spawning, breeding, and feeding activities. To counteract the adverse effects on fishery resources, it has become imperative to establish and uphold fish-friendly migration pathways.

To safeguard fish biodiversity, it is essential to prevent the complete draining of *beel*s, and the withdrawal of water from *beel*s for irrigation in the dry season should be managed or discouraged. To ensure a minimum water depth in the *beel*, the extraction of water needs to be regulated.

It is important to limit the widespread use of inorganic fertilizers and insecticides through integrated pest management programmes.

To keep a sustainable year-round production, stock enhancement programs should be implemented. Species like thai sarpunti, silver carp, common carp, catla, mrigal, kalibaus, and rui can be introduced in the *beel*.

Fish sanctuaries should be established, and brush pile fishing should be stopped to conserve the existing fish species for sustainable fish production.

Existing fisheries rules and regulations should be strictly enforced.

To achieve sustainable management of the *beel* ecosystem, it is vital to formulate ecosystem-based management strategies that engage various stakeholders, such as researchers, policymakers, resource managers, governmental bodies, and non-governmental organizations. These strategies should focus on balancing the ecological, economic, and social aspects of the *beel*'s management while preserving its biodiversity and ecosystem functions. These plans ought to focus on increasing production, sustainably preserving biodiversity, and enhancing local fishermen's incomes. Further research is necessary in this area to enhance biodiversity, production patterns, and conserve resources.

CONCLUSION

The study conducted in Malam *beel*, nestled within the expansive Hakaluki *Haor*, addresses the lack of understanding about the current state of aquatic biodiversity. Across eleven orders and 32 families, the research meticulously recorded 69 distinct fish and prawn species. Notably, Cypriniformes emerged as a key contributor, constituting 37.68% of the total fish population, with Cyprinidae being the dominant family. This study shines a spotlight on the remarkable potential of Malam *Beel* as a valuable inland water body. It holds promise as a critical fishery resource and a repository for preserving genetic diversity. Amidst this promise, the study also uncovers threats, from human-induced activities like dewatering and destructive fishing to natural processes such as siltation, posing significant challenges to the ecosystem's sustainability. These findings underscore the call for ecosystem-based fisheries management that actively involves local communities. The importance of conserving diverse fish populations has become evident. Balancing the availability of resources with conservation emerges as a vital consideration, necessitating comprehensive and adaptable management strategies. By embracing an ecosystem-based approach, we can harness the potential of these water bodies while safeguarding their vitality for the well-being of current and future generations.

Conflicts of interest: The authors assert the absence of any conflicts of interest.

Ethics committee approval: Ethical approval was granted by the "Bangladesh Agricultural University Ethical Committee" for all experiments involving human subjects and animals (fish). The procedures employed adhered to the established ethical standards. Furthermore, informed consent was obtained from all survey respondents, ensuring compliance with ethical principles governing research involving human participants.

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Review Article

Sturgeon Aquaculture Potentiality in Egypt in View of the Global Development of Aquaculture and Fisheries Conservation Techniques: An Overview and Outlook

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ABSTRACT

Sturgeon conservation is a global issue, with wild sturgeon amounts dropping rapidly and continuously. This article explores the essential role that aquaculture plays in the conservation of these critically endangered fish, the replenishing of the natural population, fulfilling the expanding demand and possibilities for caviar markets, and reducing pressure on fisheries' catch. It also reviews the history of controlled breeding programs designed to supplement wild Caspian Sea populations, the possibilities for sturgeon aquaculture production, and the worldwide caviar trade industry in the coming years. Globally, the successful and profitable expansion of captive sturgeon farming over the last three decades has fulfilled the consumer market's demand for caviar and meat, resulting in a considerable decline in the global caviar price. Given the presence of successful sturgeon farming in the Arabian Gulf region (Saudi Arabia and the United Arab Emirates), the prospect of introducing the sturgeon farming industry in Egypt is underlined. In comparison to other nations in the region, Egypt has excellent prospects for establishing such an aquaculture business, as Egypt's aquaculture sector is by far the largest in Africa and the sixth largest internationally. Furthermore, the availability of qualified workers, the diversity of water sources, and Egypt's moderate climate and environment increase the likelihood of successful sturgeon farming.

Keywords: Sturgeon, aquaculture techniques, fishery conservation, replenishment, caviar, Egypt

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INTRODUCTION

The aquaculture industry plays a crucial role by providing nearly half of the animal protein required globally (Abdel-Rahim et al., 2023; Shahin et al., 2023), and doubling per capita human consumption from 9.9 kg in the 1960s to more than 20.2 kg in 2020 (FAO, 2022). In 2020, global fisheries and aquaculture yielded 214 million tonnes, including 178 million tonnes from aquatic animals and 36 million tonnes from phytoplankton, an increase of 3% over the previous record set in 2018 (FAO, 2022). Aquaculture's share of global production in 2020 was 122.6 million tonnes, composed of 87.5 million tonnes of aquatic animals and 35.1 million tonnes of phytoplankton worth a total of USD$ 281.5 billion (FAO, 2022). Furthermore, aquaculture plays an important role in the conservation of endangered species like sturgeon by allowing breeders to raise them outside of their natural habitats (Vasilyeva, Elhetawy, Sudakova, & Astafyeva, 2019). Sturgeon farming is a relatively new sector of aquaculture that is currently of great interest, as farmed sturgeon is the world's main provider of caviar in light of the dramatic decline in sturgeon fisheries and the rising demand for caviar worldwide (Bronzi & Rosenthal, 2014).

Acipenseriformes are a unique group of ancient aquatic animals that first appeared between 200 and 250 million years ago; today, they are the most primitive class of endangered vertebrates on Earth (Vasilyeva et al., 2019; Chandra & Fopp-Bayat, 2021). Two families, Acipenseridae (sturgeon) and Polyodontidae (paddlefish), are included in the order of Acipenseriformes. The family of Acipenseridae includes 4 genera, namely *Acipenser*, *Huso*, *Pseudoscaphirhynchus*, and *Scaphirhynchus* (Billard & Lecointre, 2001). In general, sturgeons dwelt in Northern Hemisphere reservoirs above the 30th parallel, including the Pacific, Atlantic, Mediterranean, and Black Seas, as well as rivers, lakes, and inland seas (Chandra & Fopp-Bayat, 2021). Historically, the wild sturgeon population had significant value because it supplied the world market with sturgeon products for many years before drastic fluctuations occurred in all major species. In 1977, the highest yield (32078 tonnes) of wild sturgeon was recorded (Bronzi et al., 2011). In the late 1980s, approximately 24000-26000 tonnes of Beluga (*Huso huso*), Russian sturgeon (*Acipenser gueldenstaedtii*), and stellate sturgeon (*Acipenser stellatus*) were captured annually in the Volga-Caspian region, which accounted for over 90% of the world's sturgeon production (Kokoza, 2004). However, subsequent FAO statistics on caviar removal from the Caspian Sea indicated that it was 2.1 tonnes in 2013, compared to 261 tonnes in 1992 (FAO, 2014).

In the majority of the last century, natural sturgeon populations have settled in the basins of the Sea of Azov, the Black Sea, and the Caspian Sea, with around 90% of global stocks concentrated in the Caspian Sea (Vasilyeva et al., 2019). Since the late 1980s, natural sturgeon populations have experienced a dramatic decline due to severe habitat degradation and overexploitation of both wild and artificially produced individuals for caviar production (Vasilyeva et al., 2019; Chandra & Fopp-Bayat, 2021: Brevé et al., 2022). During the period from 1985 to 2005, the sturgeon fishery was severely depleted due to a variety of factors. Politically, the collapse of the Soviet Union was accompanied by a sharp decline in the otherwise stringent enforcement measures governing this lucrative fishery; concurrently, the economic and social difficulties that coincided with this disintegration encouraged massive overfishing. In addition, fragmentation of the river (damming) and pollution exacerbated the environmental stress on the declining stocks. Moreover, the previous extensive stocking programs have decreased to their lowest level ever (Vasilyeva et al., 2019). Consequently, a four-fold decrease was observed in the number of wild sturgeon fish between 1992 and 1995, as experts confirmed that sturgeon numbers in the Caspian Sea decreased from 200 million to 50 million pieces and continued to decline, reaching a reduction of 90% in 2005 (Vasilyeva et al., 2019). At present, according to the International Union for Conservation of Nature and Natural Resources (IUCN), four Acipenseriformes species are now extinct, and 85% of the remaining 23 species are highly endangered (GAIN Report, 2014; WWF, 2017; Brevé et al., 2022).

As wild sturgeon numbers continued to decline sharply after the collapse of the Soviet Union, caviar production from sturgeon fisheries has reached zero, according to CITES quotas. This sharp fall in the number of sturgeons in nature coincided with rising global market demand for sturgeon products (meat and caviar), resulting in the emergence of sturgeon aquaculture, primarily for caviar production. The countries where sturgeon farming originated are those where sturgeon is naturally prevalent, such as Russia and Iran, along with members of the European Union and the USA, and sturgeon aquaculture is now prevalent in all six continents (Bronzi et al., 2019). The purpose of this work is to highlight the critical role that aquaculture plays in preventing the extinction of these unique fish, to examine the global expansion of sturgeon farming, to indicate the state of sturgeon fisheries renewal, and to provide a glimpse into opportunities for sturgeon aquaculture in Egypt.

Initiation of sturgeon aquaculture

Historically, sturgeons are ancient aquatic animals that live in littoral and inland waters and produce caviar, which is a gastronomic subtlety and is one of the most expensive products produced by wild animals for people all over the world; it is the unfertilized roe of sturgeon and paddlefish. Earlier, the world production of sturgeon products was sourced from sturgeon fishery, and caviar was produced only in the "river" and the coastal areas, particularly in Russia and the Caspian zone. However, with the subsequent dramatic declines in many sturgeon populations in the wild, scientists have undertaken attempts to breed and cultivate sturgeon in captivity, principally for caviar production. The history of sturgeon aquaculture dates back to 1869 when Russian academician Fyodor Ovsyannikov successfully conducted trials on artificial impregnation of sterlet caviar, and then this branch flourished during the subsequent period of the Soviet Union time. Within the years 1869-1915, Soviet scientists established the scientific foundation for controlled fertilization of sturgeon bleaching, as well as the development of progeny. In 1941, for the first time under controlled conditions, scientists used a suspension of the sturgeon pituitary gland as a hormonal excitant to conduct sturgeon gametogenesis. In the 1960s, Burtsev used a small cut into the ventral cavity to harvest caviar from sturgeon females in vivo, while Burtsev and others enhanced biotechnologies for mercantile sturgeon farming. Furthermore, scientists were able to obtain the hybrid "bester" for the first time in 1985, which became an important facility in sturgeon aquaculture throughout Russia (Vasilyeva et al., 2019). Studies conducted by Soviet scientists formed a large basis for subsequent experiments involving the growing of sturgeon in captivity in many places across the world, leading to the current global expansion of sturgeon farming.

Global growth of sturgeon aquaculture

The first FAO-recorded harvest of farmed sturgeon was in 1984, with an amount of 150 tonnes (Harris & Shiraishi, 2018). It gradually increased until the early 2000s, when it began to boom tremendously. With a production level of 51500 tonnes in 2011, the estimated global sturgeon yield from aquaculture exceeded the peak fishery production in 1977 by more than 73%. Keeping its upward trend, farmed sturgeon yield reached its peak in 2015 (129608 tonnes), an increase of more than 36% over 2014 and more than three times over 2010. After peaking in 2015, global cultured sturgeon production fluctuated before reaching an all-time high yield in 2021, as illustrated in Figure 1 (Bronzi et al., 2019; EUMOFA, 2021; FAO, 2023). By 2021, the global yield of

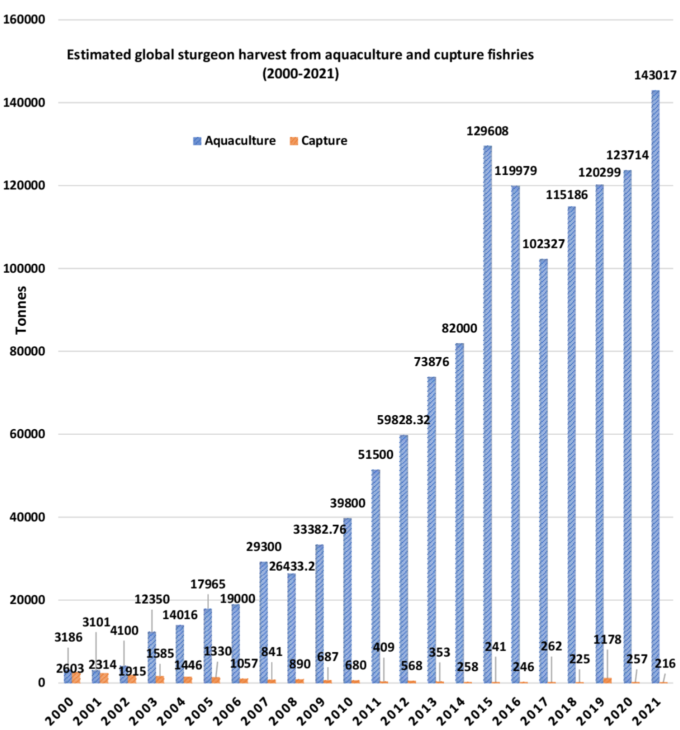

Figure 1. Estimated global sturgeon production from fisheries and aquaculture during 2000-2021. (Data from Bronzi & Rosenthal, 2014; EUMOFA, 2018 & 2021; Bronzi et al., 2019; FAO, 2023).

sturgeon peaked at 143234 tonnes, with 143017 tonnes originating from aquaculture and 216 tonnes sourced from fisheries (FAO, 2023). This was driven by China, with China's production accounting for more than 85% of global output in 2021 (FAO, 2023). The number of countries involved in sturgeon farming has been steadily increasing year by year. FAO (2015) indicated that the harvest of farmed sturgeon came from more than 38 countries embroiled in sturgeon cultivation, and that number increased to approximately 56 in 2017, and 80 in 2021 (FAO, 2015 & 2023; Bronzi et al., 2019). According to FAO statistics (2023), 144 countries contributed to sturgeon production in 2021 (aquaculture 80, and fishery 64) (FAO, 2023).

Over the past two decades, sturgeon aquaculture has experienced exponential expansion. According to the FAO, global production of sturgeon reached 4100 tonnes in 2002, half of which came from Russia and the rest of the European Union, and then tripled in 2003, when China's production began to rise. By 2021 China's production increased more than thirteen-fold between 2003 and 2021, from 9000 tonnes to nearly 121875 tonnes (EUMOFA, 2021; FAO, 2023). The world's largest producers of sturgeon in 2021 are China (121875 tonnes), Russia (5047 tonnes), Armenia (4300 tonnes), Iran (3145 tonnes), Vietnam (2660.2 tonnes), Italy (1252 tonnes), and the USA (1166.2 tonnes) (FAO, 2023). Among the Arab countries, the UAE contributed 65.13 tonnes to global sturgeon production (FAO, 2023). According to Bronzi et al. (2019), there are approximately 2329 sturgeon and paddlefish farms involved in sturgeon farming worldwide.

Global caviar production from aquaculture

Since the first kilograms of cultured sturgeon caviar came onto the market in the early 1990s, the harvest of farmed caviar production has exhibited an upward curve. In 2008, the estimated global production of caviar from aquaculture for all species was between 110 and 120 tonnes, harvested from 80 farms in 16 different countries. This shape has changed rapidly, with the majority deriving from at least six hybrids that are all cultivated in more than 30 countries, including some outside the natural range of sturgeons (such as South America) (Bronzi et al., 2011). Consequently, the estimated global caviar yield in 2012 was over 260 tonnes. This significant increase was intended to compensate for the lack of sturgeon fisheries. As demonstrated by Figure 2, global caviar output climbed steadily, peaking in 2019 at 592.74 tonnes before declining to 571.9 tonnes in 2020 (EUMOFA, 2018; Bronzi et al., 2019; FAO, 2022).

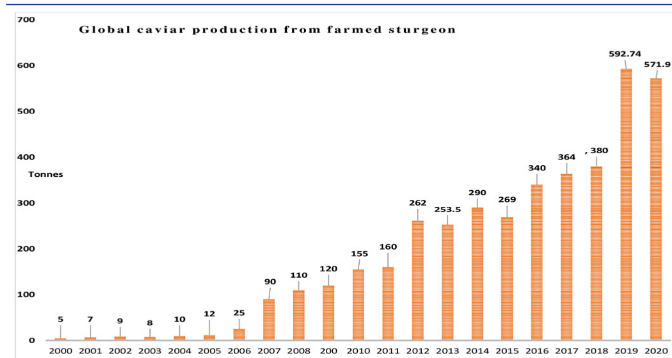

Figure 2. Estimated global caviar harvested from aquaculture sector during 2000-2020. Data retrieved from (Bronzi & Rosenthal, 2014; EUMOFA, 2018 & 2021; Bronzi et al., 2019; FAO, 2022).

China is the greatest producer of caviar in the world, accounting for more than a third (205 tonnes and 200 tonnes) of global production in 2019 and 2020, respectively (FAO, 2022). Denmark follows China as the second largest contributor to global caviar output with 60 tonnes, accounting for more than 10% of worldwide production, in 2020. After Denmark, came Russia (58 tonnes), Italy (55 tonnes), France (49 tonnes), Germany and Poland each had 18 tonnes, Armenia (15 tonnes), and Iran (12 tonnes) in 2020 (FAO, 2022). In addition, the Arab countries, represented by the Kingdom of Saudi Arabia, contributed 6 tonnes of caviar to global production in 2020 (FAO, 2022).

Global cultured species of sturgeons

The gap between the substantial commercial interest in sturgeon products and the limited availability of native sturgeon populations drives the global expansion of sturgeon farming. As a result, in 2017, 22 of the 27 sturgeon species (12 original and 10 hybrids) were farmed in more than 2329 sturgeon and paddlefish farms spread over 56 countries (Harris & Shiraishi, 2018). The most well-known original species for commercial cultivation are Siberian sturgeon (*Acipenser baerii*), Russian sturgeon, Beluga, Sterlet (*Acipenser ruthenus*), and some other species in regional dependence, such as Adriatic sturgeon (*Acipenser naccarii*) in Italy and White sturgeon (*Acipenser transmontanus*) in North America (Bronzi et al., 2019).

Regarding the pure species, the Siberian sturgeon, Adriatic sturgeon, sterlet, beluga, and white sturgeon are the pure forms that dominate global aquaculture for meat production, with 39.5%, 10.2%, 1.9%, 1.3%, and 1.1%, respectively. Siberian sturgeon, Russian sturgeon, white sturgeon, sterlet, Kaluga sturgeon (*Huso dauricus*), beluga, Adriatic sturgeon, and Stellate sturgeon dominate the global culture for caviar production, with quotas of 30.9%, 20.4%, 12.1%, 5.2%, 4.4%, 1.2%, 0.58%, and 0.47% (Bronzi et al., 2019).

In terms of hybrids, there are various hybrid forms around the world; however, the most common ones utilized in commercial farming are those that show the effect of heterosis, which allows for increased fish productivity in comparison to the original parental forms. The dominant hybrids utilized in meat production around the world are *Huso dauricus* × *Acipenser schrenckii* and *A. baerii* × *A. schrenckii*, which account for 35.6%, while additional hybrid forms (some of which have been named, while others have not) account for more than 10%. *Huso. dauricus* × *A. schrenckii* is the largest hybrid contributing to caviar collected from aquaculture (13.1%) globally. Other variants with more than an 11% share include *A gueldenstaedtii* × *A baerii*, H huso× A *ruthenus*, *A baerii* × *A gueldenstaedtii*, *A baerii* × *A naccarii*, and others (Harris & Shiraishi, 2018; Bronzi et al., 2019). Table 1 shows

Table 1. Distribution of cultivated sturgeon species and/or hybrids worldwide.

Acipenseriformes	Common name	Distribution
Subfamily Acipenseridae		
Genus Acipenser		
Acipenser baerii Brandt, 1869	Siberian sturgeon	Russia (Siberian rivers) & Kazakhstan
Acipenser gueldenstaedtii Brandt, 1833	Russian sturgeon	Russia, Kazakhstan & Black, Caspian, Azov seas
Acipenser ruthenus L., 1758	Sterlet	Russia, Romania & Eurasian countries
Acipenser stellatus Pallas, 1771	Stellate sturgeon	Caspian, Azov, Black, Aegean
Acipenser schrenckii Brandt, 1869	Amur sturgeon	Amur River (China)
Acipenser persicus Borodin, 1897	Persian sturgeon	Caspian Sea
Acipenser oxyrynchus Mitchill, 1815	Atlantic sturgeon	North American East coasts
Acipenser nudiventris Lovetzky, 1828	Ship sturgeon	Aral, Black, Caspian & rivers
Acipenser naccarii Bonaparte, 1836	Adriatic sturgeon	Adriatic Sea & tributaries
Acipenser fulvescens Rafinesque, 1817	Lake sturgeon	Great Lake, southern Canada
Acipenser dabryanus Dumeril, 1868	Yangtze sturgeon	Yangtze River system
Acipenser brevirostrum Le Sueur, 1818	Shortnose sturgeon	North American east coast
Acipenser transmontanus Richardson, 1836	White sturgeon	North American Pacific coasts
Acipenser sturio L., 1758	Common sturgeon	Baltic, N. Atlant., Medit., Black
Acipenser mikadoi	Sakhalin Sturgeon	Sakhalin, Japan Sea Rivers & Amur River
Genus Huso		
Huso dauricus Georgi, 1775	Kaluga sturgeon	China (Amur River system), Russia
Huso huso L., 1758	Beluga	Russia, countries around the Caspian & Black Seas, the northern part of Adriatic Sea (Po River).
Subfamily Scaphirhynchinae		
Genus Scaphirhynchus		
Scaphirhynchus platorynchus Rafinesque, 1820	Shovelnose sturgeon	Mississippi Missouri system
Family Polyodontidae		
Polyodon spatula Walbaum in Artedi, 1792	Paddlefish	Mississippi River (USA)
Psephurus gladius Martens, 1862	Chinese Paddlefish	Yangtze River system
Hybrids		
H. huso × *A. Ruthenus*	Bester	
A. baerii × *A. Gueldenstaedtii*	BAGU	
H. dauricus♀× *A. schrenckii*♂ or reversed cross		China, Russia
H. huso♀ × *A. baerii*♂		Russia, countries around Caspian Sea
A. baerii♀ × *A. schrenckii*♂ and reversed cross		
A. gueldenstaedti × *A. Schrenckii*		
A. naccarii × *A. Baerii*	AL, Baccarii	
A. stellatus × *A. Ruthenus*	Schipp	

Data retrieved fromBronzi & Rosenthal, 2014; Shen et al., 2014; Vasilyeva et al., 2019. In Russian.

the most common sturgeon species and/or hybrids used in aquaculture around the world.

At the state level, each country has its own variety of sturgeon hybrids; for example, in China, the most common hybrids employed in commercial aquaculture are *H dauricus*♀ × *A. schrencki*♂, *A. schrencki*♀ × *H. dauricus*♂, *A. baerii*♀ × *A. schrenckii*♂, and A. *schrenckii*♀ × *A. baerii*♂, accounting for 26% of the total output (Shen, Shi, Zou, Zhou, & Wei, 2014). In Russia, numerous hybrid forms and domesticated breeds are documented in the sturgeon polity registry. For instance, the following five domesticated breeds were listed in 1993: (1) Beluga by OJSC "Volgorechenskrybkhoz," Kostroma region; (2) Paddlefish by the fish breeding farm "Hot Key," Krasnodar region; (3) Russian sturgeon by the Federal Center of Fish Selection and Genetics, Leningrad Region; (4) Siberian sturgeon by the Konakovsky hatchery for sturgeon trade of the VNIRO Institute (http://vniroinfo.ru), Moscow region; and (5) Sterlet by the Konakovo hatchery for sturgeon trade, Tver region (Bogeruk, 2008). In addition, three hybrids (beluga x sterlet, called Burtsevsky bester, sterlet x bester, called Aksai bester, and Vnirovsky bester, beluga x bester, i.e., *Acipenser nikoljukini*) were registered in 2000 (Vasilyeva et al., 2019). With a 7% production share, one hybrid, Bester (*H. huso* × *A. ruthenus*), is the predominant form in Russian aquaculture (Vasilyeva et al., 2019).

Systems and technologies for sturgeon aquaculture

Various systems and techniques are applied in sturgeon farming around the world, depending on the country, location, climatic conditions, available water resources, the country's economic status, farmers, and so on. According to Bronzi et al. (2019), the flow-through method (FTM) and recirculating aquaculture systems (RAS) are the dominant two methods used in sturgeon aquaculture worldwide. FTM and RAS have a combined share of up to 68% in sturgeon farming around the world, with 36% for FTM, 21% for RAS, and 11% for a combined technology of FTM/RAS (Bronzi et al., 2019). Then there were cages and ponds, with 18% and 6%, respectively. However, the situation varies by state; for example, in China and Russia (the two world's top producers), cages account for roughly one-quarter and two-thirds of total output from farmed sturgeon in these countries, respectively. Furthermore, the pond-rearing method is widely used in Central and Western European countries, and the RAS is found all over the world, primarily in countries with limited water resources, unfavorable climatic conditions, and high levels of ecological emissions (Bronzi et al., 2019; Vasilyeva et al., 2019).

The culturing programs implemented to back up the natural sturgeon populations

Historically, the culturing programs that succeeded in reversing the declines of the natural population of sturgeon in the Caspian Sea date back to the late 1950s. Since the number of wild sturgeons in the Caspian and Azov Seas had begun to decrease at that time, a sturgeon breeding program was initiated. Soviet scientists managed to develop a technique for replenishing wild sturgeon populations through controlled reproduction. Using this technique, they were able to conduct the hormonal induction of the mature brooders in captivity, obtain eggs and sperm, perform artificial insemination, incubate the vivid fetus until it hatches, and then raise the larvae in tanks and/or ponds, aiming for fingerlings aged 1–1.5 months with an average body weight of 3–5 g to be released into the spawning rivers or sea estuaries (Milstein, 1982: Vasilyeva et al., 2019).

Since 1953, over 3 billion sturgeon fingerlings have been released into the Caspian basin (Figure 3). Four countries (Russia, Kazakhstan, Azerbaijan, and Iran) have contributed to this number; however, the majority (2.22 billion specimens, or 74%) of the total fingerlings, were produced by Russian hatcheries (Vasilyeva et al., 2019). In the lower Volga region, nine sturgeon hatcheries (7 in Astrakhan and 2 in Volgograd) were constructed for commercial aquaculture and release, along with two in Dagestan, two in Kazakhstan, three in Azerbaijan, and five controlled sturgeon hatcheries in Iran. The annual capacity of hatcheries to produce sturgeon juveniles (*Huso huso*, *Acipenser gueldenstaedtii*, *Acipenser nudiventris*, *Acipenser stellatus*, and *Acipenser ruthenus*) was 90–92 million. In the late 1980s and early 1990s, the release of sturgeon juveniles reached a peak value of 101 million pieces, with the USSR accounting for 90% of the total number released (Kokoza, 2004). In the Black Sea, Turkey has implemented programs to rehabilitate and protect sturgeon populations in Turkish waters since 1997 (Akbulut et al., 2001). Conservation and rehabilitation programs included six anadromous sturgeon species (*H. huso*, *A. gueldenstaedtii*, *A. sturio*, *A. nudiventris*, *A. stellatus*, and *A. ruthenus*) that entered the Kzlrmak, Yeşilrmak, Sakarya, and Çoruh rivers for spawning, and the majority of the sturgeon fingerlings released were in the Yeşilırmak River and Sakarya between 2001 and 2013. (Akbulut et al., 2001; Zengin, Tiril, Dağtekin, Gül & Eryildirim, 2010; Tiril & Memiş, 2018).

In general, the controlled propagation strategy is based on utilizing mature adult broodstock collected from the wild to produce sturgeon progeny in hatcheries following adaptation to controlled conditions. However, due to a severe scarcity of wild broodstocks taken from nature to operate hatcheries and pro-

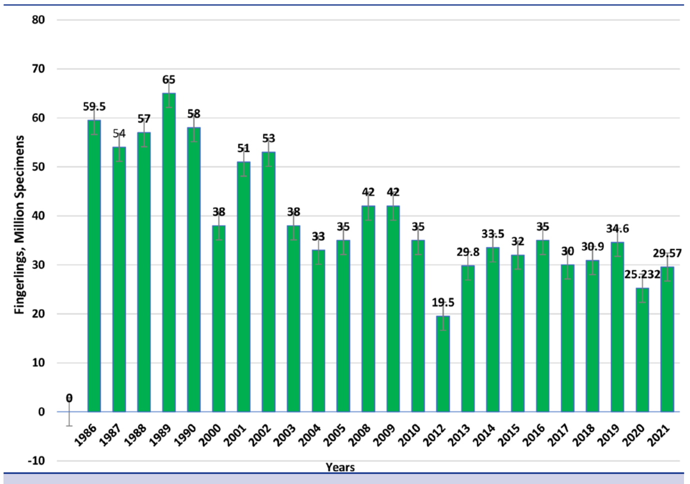

Figure 3. The figure of sturgeon juveniles released into the Volga-Caspian basin within the period of 1986-2021. Retrived from Rosrybolovstvo activities and tasks 2009-2021: https://fish.gov.ru/about/kollegiya-rosrybolovstva/.

duce sturgeon seedlings, it has begun to develop a sturgeon broodstock from overripe adult fishes raised from hatchery fry (Kokoza, 2004; Vasilyeva, Naumov, & Sudakova, 2015).

Global marketing of sturgeon caviar

Focusing on the global trade of wild sturgeon products (meat and caviar), until 1991, the majority of the world's sturgeon catch and caviar harvest came from Russian fisheries, which supplied up to 28000 tonnes of sturgeons and up to 2000-28000 tonnes of caviar, while the annual world export market for caviar was over 570 tonnes at that time (Vasilyeva et al., 2019). The total global capture of sturgeons in 2021 was 216 tonnes. Except for Uzbekistan (quota of 20 living specimens of Amu Darya Sturgeon *Pseudoscaphirhynchus kaufmanni* in 2017), no quotas for wild captures of *Acipenseriformes* spp. have been reported since 2011. Azerbaijan supplied all caviar from wild Russian sturgeon between 2010 and 2015 (Harris & Shiraishi, 2018). Furthermore, the top two exporting countries for wild caviar were the United States (40 tonnes) and Germany (19.4 tonnes), while the top three species producing wild caviar were American Paddlefish *Polyodon spathula* (48.011 tonnes), Russian sturgeon (6.030 tonnes), and shovelnose sturgeon *Scaphirhynchus platorynchus* (5.416 tonnes) (Harris & Shiraishi, 2018; EUMOFA, 2018).

The CITES trade statistics showed that reported caviar (re) exports (from wild and aquaculture) totaled 1599 tonnes between 2000 and 2015, and exhibited a general decrease during that time, from 229 tonnes in 2000 to 108 tonnes in 2015. Aquaculture caviar exports increased throughout the same period of time, reaching 102 tonnes in 2015, accounting for 95% of total trade by weight (Harris & Shiraishi, 2018 EUMOFA, 2018). During this period, the majority of direct exports were caviar harvested from aquaculture, but 66% of USA exports were wild-derived caviar (Paddlefish and Shovelnose Sturgeon). Between 2010 and 2015, the top three species of farmed sturgeon that produced caviar for the global market were Siberian sturgeon, a hybrid *Huso dauricus* x *Acipenser schrenckii*, and Russian sturgeon. Figure 4 shows the main aquacultured sturgeon species contributing to sturgeon caviar exports (Harris & Shiraishi, 2018; EUMOFA, 2018).

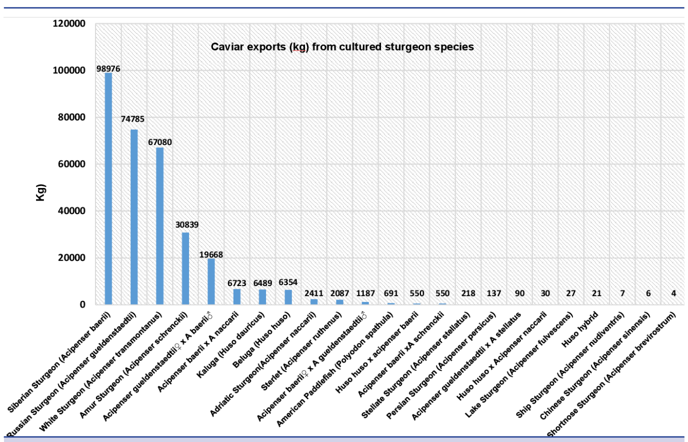

Figure 4. Cultured sturgeon species contributing to sturgeon caviar exports. Data retrieved from (Harris & Shiraishi, 2018; EUMOFA, 2018).

According to FAO statics (2022), the exported amounts of caviar accounted for 762.21 tonnes in 2020. There was a quota for about 52 countries that contributed to the export of caviar in 2020. Denmark topped the exporting countries with about a 30% share of global caviar exports, followed by China with a share of about 16% of global caviar exports (FAO, 2022). There are quotas for UAE caviar exported in 2019 (10.55 tonnes) and in 2020 (0.01 tonnes) (FAO, 2022). Figure 5 illustrates the major exporting countries of sturgeon caviar in 2020 (FAO, 2022). In 2020, Egypt imported sturgeon caviar (net product) with an amount of 14.34 tonnes from Denmark, Norway, Sweden, Thailand, the UAE, and others, while it imported caviar and caviar substitutes with an amount of 15.15 tonnes from China, Denmark, Norway, and Sweden (FAO, 2022).

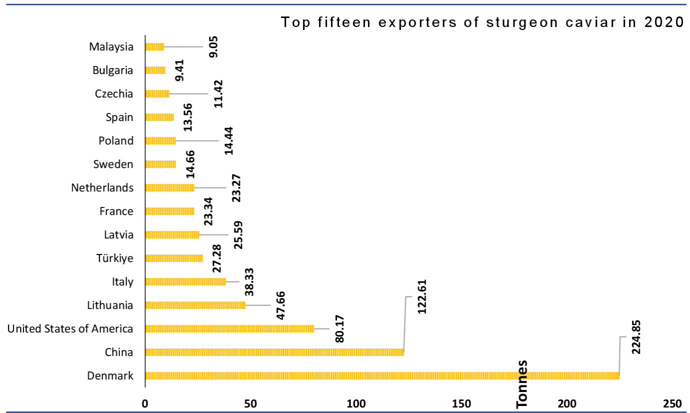

Figure 5. The leading exporting countries of sturgeon caviar in 2020. (Data retrieved fron FAO, 2022).

Prospects for caviar production

According to FAO statistics, the harvest quantity of farmed sturgeon has increased substantially, from 19000 tonnes in 2006 to 105000 tonnes in 2016. Sturgeon production is thought to consist of early male harvesting within 3-4 years of growing, as well as raising females for caviar production. Taking into account (on a global basis) that the average cycle time necessary to create caviar is 8 years from hatch to first reaping of ripe sturgeon, the 340 tonnes of caviar harvested in 2016 resulted from a world sturgeon production of 26000 tonnes (FAO production estimate 2007/2008). In 2017, global production was four times more than in 2007/2008, reaching 103000 tonnes. According to Harris and Shiraishi (2018), when these sturgeons reach maturity, the production of caviar can reach a thousand tonnes if the same caviar/sturgeon ratio as described above for sturgeon production in 2017 is used. This amount is supported by other literature, with future production predictions ranging from 500 to 2000 tonnes (Sicuro, 2018).

The global caviar trade market recorded a growth rate of 6.7%, with an estimated market size of US$76123 million in 2022, and a projected market value of US$ 86764 million in 2023. Furthermore, the caviar trade industry is predicted to rise at a 14.43% CAGR to reach a value of US$ 223885 million by 2030 (Global Caviar Market, 2022; Market Research Future, 2023). This raises concerns about the possibility of greater supply versus demand, which means reduced pricing and profitability, particularly given the constant expansion in Chinese caviar production, which has already resulted in considerable drops in the worldwide caviar price (EUMOFA, 2018 & 2021). Substandard quality control and the need to format due to increasing consumer demand for caviar production are the key challenges encountered by aquaculture companies throughout the caviar-trading encounter (Sicuro, 2018).

Prospects for sturgeon aquaculture in Egypt: an overview

Egypt is located in the Middle East region, which has around 186 sturgeon farms, accounting for 8% of all sturgeon facilities globally (Bronzi et al., 2019). The United Arab Emirates and Saudi Arabia are two of the main countries in this field that are near Egypt and have achieved exceptional success in sturgeon aquaculture. In comparison to these countries, Egypt has a high potential due to significant advantages such as moderate climatic conditions and well-trained and inexpensive labor. Egypt also possesses natural fresh, marine, and brackish water resources, such as the Nile and delta, the Mediterranean and Red Seas, open and closed lakes, and oases. Furthermore, huge aquifers that run the length of the country supply suitable water for aquaculture in general and sturgeon farming in particular. These characteristics are significantly superior to those of the other countries indicated, which are currently involved in successful sturgeon farming.

Egypt has the biggest aquaculture production share in the Mediterranean region, with 31%, followed by Turkey (29%), Italy (21%), and Greece (14%) (FAO, 2019). Furthermore, Egyptian aquaculture is the largest in Africa, accounting for more than 67.5% of the continental industry. In 2020, Africa contributed 2354000.3 tonnes to worldwide aquaculture of all farmed species, accounting for 1.92% of total global aquaculture (FAO, 2022). Egypt's aquaculture ranked sixth in the world in 2020, with 1591900 tonnes (FAO, 2022). On a global scale, Egypt is the leading producer of mullet (family *Mugilidae*) with 351197 tonnes (93.8%) of global mullet production, totaling 374072 tonnes, in 2021 (FAO, 2023). Furthermore, with 954154 tonnes, Egypt is the third-largest producer of Nile tilapia (*Oreochromis niloticus*) after China (1241410 tonnes) and Indonesia (1172633 tonnes) (Geletu & Zhao, 2022). After Turkey and Greece, Egypt is the third largest producer of European seabass (*Dicentrarchus labrax*) and gilthead seabream (*Sparus aurata*) (Lotfy et al., 201: Abdel-Rahim et al., 2023). Egypt produced 33245 tonnes of European seabass and 42743 tonnes of gilthead seabream in 2021, while the world's two largest producers, Turkey and Greece, produced 155151 tonnes and 51231.8 tonnes of European seabass and 133476 tonnes and 66890.8 tonnes of gilthead seabream, respectively (FAO, 2023).

Egypt's aquaculture industry is diverse in terms of farmed (fresh, brackish, and mariculture) species and culture systems, including governmental and private farms, cages, aquaculture in rice fields, semi-intensive, and intensive aquaculture systems (GAFRD, 2016 & 2020). Aquaculture characteristics include diversity and large scale, as well as current modernization through the construction of mega-projects implemented by the country in recent years, such as: (a) the national project for mariculture in the Suez Canal, with a potential target production capacity of 150000 tonnes/year; (b) the Ghalion aquaculture project in Kafr El-Sheikh governorate on a total area of 2000 hectares, including 453 marine fish ponds, 626 shrimp ponds, 186 nursery ponds, and a marine hatchery; and (c) the national project for developing East Port Said, over an area of 10,920 hectares with a potential annual target production of 50000 tonnes (GAIN Report, 2016). All of these factors contribute to and boost the possibility of successful sturgeon farming in Egypt.

Currently, Egyptian authorities, legislative bodies, and research institutions are working to pass legislation that will make it easier for investors and international experts to collaborate with Egypt in this field. Restrictions have been discussed, focusing on the environmental and disease-controlling aspects of non-endemic species, along with continuous monitoring by specialized research and supervision bodies. Moreover, the Egyptian authorities are very open to introducing new species of fish and crustaceans. The non-endemic aquatic species that have recently entered Egypt, such as the Basa fish (*Pangasius sp*.), and Whiteleg shrimp (*Litopenaeus vannamei*), have become vital species in the Egyptian aquaculture industry (Kaleem & Sabi, 2020).

With the beginning of sturgeon cultivation in Egypt, there are three candidate species with rapid growth and rapid reproductive maturation in captivity. The first is Sterlet sturgeon, a freshwater, brackish, and demersal fish with a maximum weight of 16 kilograms, a maximum length of 1.25 meters, and a maximum lifespan of 25 years. They consume benthic organisms, including crustaceans, worms, and insect larvae. Females reach puberty at the age of four, ovulation occurs between mid-April and early June, and they lay between 15,000 and 44,000 eggs at optimum water temperatures of 12 to 17 °C (Gesner, Freyhof, & Kottelat, 2010). The second candidate species is Siberian sturgeon. Due to its easy reproduction, rapid growth, and lack of pathological issues, Siberian sturgeon is a better candidate for aquaculture than other species. It is a freshwater, brackish, and demersal fish that typically weighs up to 65 kg and lives up to 63 years, with a maximum recorded weight of 210 kg and length of 2 meters. In the environment, benthic organisms such as crustaceans and chironomid larvae comprise the food chain. Females reach sexual maturity at five years of age in captivity. They spawn in June-July with eggs measuring 3.0-3.6 mm, newly hatched larvae measuring 10-12 mm in length, and an incubation period of approximately 16 days at 10-15°C (We et al., 2011; Williot, Nonnotte, Vizziano-Cantonnet, & Chebanov, 2018). The third candidate species is Russian sturgeon: its farming represents a significant portion of global sturgeon aquaculture due to its superior meat and caviar quality among all sturgeons, with the exception of beluga caviar, which has a more exquisite flavor and higher nutritional value. This species is an anadromous euryhaline fish that is endemic to the Black, Azov, and Caspian Seas and migrates into the river systems that drain into these seas to reproduce. This species lives up to 47 years, achieving a body weight of roughly 115 kg and a length of 236 cm by the age of 7 years in RAS, whereas prototypes can mature in the fifth year (Elhetawy et al., 2020). They consume benthos (mollusks, crustaceans, worms, small fish-bulls, and sprats) and spawn between mid-May and early June at water temperatures between 8 and 15 °C. Individual fecundity ranges from 50 to 600 thousand eggs and can reach 1 million on occasion (We et al., 2011; Aquaculture Russia, 2023).

The use of these three species in the development of the sturgeon aquaculture industry will allow us to generate revenue from sturgeon meat by the end of the second year of cultivation, sturgeon caviar by the fourth year with sterlet, and sturgeon caviar by the fifth year with sterlet, Siberian sturgeon, and the best specimens of Russian sturgeon. In addition, other species with a high economic value for meat and caviar, such as beluga and Sevruga, will be introduced progressively. Furthermore, each of these native species has hybrids with others; hence, hybridization by systematic research on the crossing of sturgeon chromosomes may lead to the development of suitable varieties for Egypt's conditions, as has been done in China and Russia (Elhetawy et al., 2020).

Sturgeon aquaculture in Egypt requires the use of cutting-edge technology such as RAS, which will technically improve and modernize the aquaculture industry. The RAS and ponds (concrete and earthen) with groundwater utilization are the most convenient sturgeon-rearing technologies for Egyptian conditions. RAS allows for continuous growth throughout the year under completely controlled conditions, whereas ponds allow fish to grow in natural conditions, which improves the quality of meat and caviar produced and considerably reduces production costs (Elhetawy, Sudakova, Anokhina & Vasilieva, 2018). With the application of a combined RAS/pond technology, sturgeon farming could achieve tremendous success and generate substantial revenue. In the RAS system, sturgeon will grow for 7-8 months (during spring and summer, when environmental conditions are not ideal for sturgeon growth), and then continue to grow in reservoirs for the remainder of the year. Table 2 shows the water quality requirements for sturgeon growth using different culture methods (Vasilyeva et al., 2010).

The Northern region of Egypt, including the Nile Delta and Siwa Oasis, is most suited for creating sturgeon farms. The Nile Delta and Siwa Oasis's climatic conditions and groundwater quality are ideal for promoting the growth of sturgeon with the use of the RAS/ponds technology. The average daily temperature in the Delta is between 17 and 20 ° C, while the maximum temperature is between 26 and 34 ° C and the lowest is between 6 and 13 ° C (Abd-Elaty, Abd-Elhamid, & Negm, 2018; Negm, Sakr, Abd-Elaty, & Abd-Elhamid, 2019). The Siwa Oasis has a maximum temperature of 16.4 - 36 ° C (January - July) and a minimum temperature of 7.3 - 23.3 ° C (January - August), with an average daily temperature of 12.1 - 29.9 ° C (Climate-Data.Org).

In 2003, the gross annual freshwater abstraction from groundwater from the Nile Delta accounted for 2.0, 0.6, and 0.9 billion cubic meters (BCM) for the eastern, middle, and western regions, respectively (Abd-Elaty et al., 2018; Negm et al., 2019). The total groundwater prospect for each of the three zones (Western, Middle, and Eastern Delta) was calculated to be 1.2, 2.4, and 0.71 BCM per annum, respectively (Negm et al., 2019; Negm, 2019). The south and central regions of the Nile Delta have significant groundwater potential, where aquifer features (semi-confined) and recharge form and continuity (surface Nile water) allow for the extraction of huge volumes of high-quality groundwater from shallow depths. The salinity ranges from 0.296 to 0.810 g/l, with an increase to more than 5 g/l in the North Delta, while the pH ranges from 6.72 to 8.65 (Abd El-Fattah, 2014).

In the Siwa Oasis, freshwater is distributed throughout the oasis in the form of a significant number of wells and eyes (up to 200 eyes), from which 190 thousand cubic meters of water flow daily and are used for irrigation, drinking, bottled natural water, and treatment. Groundwater water may be divided into three major groups: fresh samples have been discovered in the Nubian sandstone aquifer, brackish samples are found in the fractured dolomite limestone aquifer, and saline samples are found in the

Table 2. Water quality requirements for sturgeon rearing.

Parameter	Ponds	Cages	RAS
Water temperature	19-24	12-24	18-24
Oxygen concentration, mg / l	6.0-8.0	8.0-9.0	6.0-10
Smells, tastes	Water should not have any odors or taste		
Transparency, m	Not less than 1.5		
Suspended solids, g / m^3	>25	>25	>10
Permanganate oxide, mg O_2 / m^3	>15	>10	>15
Bichromate, mg O_2 / m^3	>50	>30	>50
pH	7.2-8.5	7.5-8.5	7.0-8.0
Carbon dioxide, g / m^3	Not more than 10.0	-	-
Dissolved ammonia, g / m^3	>0.05	-	-
Ammonium ion, gN / m^3	0.5	0.5	2.0-4.0
Nitrite –ion, gN / m	0.01	0.01	0.1
Nitrate ion, gN / m^3	2.0-3.0	2.0-3.0	>60
Phosphate ion, g / m^3	0.1	0.1	0.3
Total Iron, g / m^3	0.5	0.5	-

Data retrieved from Vasilyeva et al., 2010. In Russian.

broken dolomite limestone aquifer. The salinity of the water ranges from 0.1688 g/l to 7.4728 g/l, with pH values ranging from 6.9-7.5 (Abo EL-Fadl, Wassel, Sayed, & Mahmod, 2015).

In these two locations, using RAS or the combined RAS/Ponds technology in the cultivation of the aforementioned species, Egyptian authorities may conduct the necessary feasibility studies and then launch an ambitious sturgeon aquaculture program in Egypt. Feasibility studies should contain short, medium, and long-term strategies for developing the project and introducing new sturgeon species with worldwide economic significance. The establishment of laboratories is required to perform experiments and scientific research in order to continuously promote farming techniques.

CONCLUSION

In the past quarter century, aquaculture has helped prevent the extinction of sturgeon. Controlled sturgeon reproduction is crucial for replenishing natural resources and operating sturgeon aquaculture to meet growing caviar demand. Controlled reproduction is needed not only to replenish natural populations, but also to preserve genetic diversity. To date, sturgeon aquaculture has contributed to the conservation of these species and compensated for the relative lack of caviar from wild resources by supplying farmed products to the global market. Only through sustainable aquaculture can these distinct, ancient species be preserved for future generations. In comparison to other countries in the region, Egypt has tremendous potential to successfully start sturgeon farming. Sturgeon aquaculture in Egypt will grow and modernize the aquaculture business by utilizing current technologies and increasing aquaculturists' efficiency. Furthermore, it will maximize groundwater utilization, generate new urban settlements, and provide an extra source of income to preserve hard currency, among other benefits. Furthermore, because Egypt is the northern entrance to Africa, the introduction of sturgeon aquaculture in Egypt would motivate many other nations in the region to take part in the business, which will be reflected in the global extension of its farming area and, ultimately, its wealth. Finally, the purpose of this review was to highlight the global importance of sturgeon farming and provide an overview of the potential opportunities for sturgeon farming in Egypt as a source of information for Egyptian decision-makers and fish producers. More in-depth research is needed to investigate, evaluate, and establish the basic guidelines for this industry.

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Short Communication

The Sea Slug *Tethys fimbria* Linnaeus, 1767 (Nudibranchia: Tethydidae) Expands its Distribution Northwards to the Sea of Marmara

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ABSTRACT

This study reports our observation of the large sea slug *Tethys fimbria* Linnaeus, 1767 in the northern-eastern Sea of Marmara (the Princes' Islands). We observed *T. fimbria* on the detrital bottom of the sea at a depth of 35 m in June 2022. This species had previously been reported during spawning in a recent study conducted in the southern part of the Çanakkale Strait (the Dardanelles Strait that connects the Marmara Sea with the Aegean Sea). Prior to 2022 there had been no reports of this conspicuous species from the Marmara Sea in the scientific literature or in photo-records among divers. Following our observation of the species in the sea around the Princes' Islands, underwater photographers reported pictures of *T. fimbria* from different locations in the Marmara Sea on social media platforms. The sea slug seems to extend its distribution northwards. The potentially new arrival of the large sea slug in the Sea of Marmara, rather than a distribution shift from deoxygenated deep Marmara basins or a climate-related northwards expansion, is discussed.

Keywords: Sea of Marmara, *Tethys fimbria*, Species Distribution, Nudibranchia, Mollusca

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INTRODUCTION

The Sea of Marmara is an inner sea with a complex geological history involving episodic connections located between the Black Sea and the Mediterranean Sea (Yanko-Hombach et al. 2007; Büyükmeriç 2016). The colonization of the Marmara Sea is therefore assumed to be relatively recent, following the establishment of the present-day two layered stratification system (Meriç and Algan 2007; McHugh et al. 2008). The inner sea connects two nearly isolated seas with highly different oceanographic features through two narrow channels (Beşiktepe et al. 1994). The Sea of Marmara along with the Istanbul Strait (the Bosphorus) and the Çanakkale Strait (the Dardanelles) is described as the Turkish Straits System and acts as a corridor for two-way translocation of species from their native habitats in the Black and Mediterranean Seas (Öztürk and Öztürk 1996). In recent years climate change has accelerated shifts of species from the Mediterranean Sea into the Sea of Marmara, and from there to the Black Sea under the process of 'Mediterranization' (Oğuz and Öztürk 2011; Öztürk, 2021). The presence of Atlantic-Mediterranean and Indo-Pacific species in the Sea of Marmara and the Black Sea could represent important signs of the process of Mediterranization (Turan et al. 2016). Changes in species distribution, shifts in range and introduction of alien species are increasing concerns in the marine environment related to climate driven factors, among others (Azzurro et al. 2019; Pinsky et al. 2020). Therefore, monitoring studies are essential in determining changes in marine communities (Bianchi and Morri 2000; Philippart et al. 2011). This study reports on the sea slug *Tethys fimbria* Linnaeus, 1767, observed in the northern part of the Sea of Marmara during a monitoring study in a place where there had been no previous records of the species. This study briefly discusses the observation of the species in the Sea of Marmara, its potentially new arrival, and relations to climate driven or perturbation caused processes.

MATERIAL AND METHODS

The study site is in the north-eastern Sea of Marmara, in the Princes' Islands. In the Sea of Marmara an evident stratification is present; the upper layer is dominated by brackish waters from the Black Sea, while the lower layer is dominated by saline Mediterranean waters flowing northwards from the Aegean Sea (Beşiktepe et al. 1994). The two water masses are separated by a permanent halocline. The lower layer below the halocline does not undergo major seasonal variations and has a salinity of ‰38, a temperature of approximately 14 °C, and dim light.

The study was carried out in June 2022 during a monitoring study by SCUBA diving around the Burgazada, Kalpazankaya station in the Princes' Islands region, northeastern Sea of Marmara [Latitude: 40°52'40.84"N, Longitude: 29° 3'7.19"E] (Figure 1).

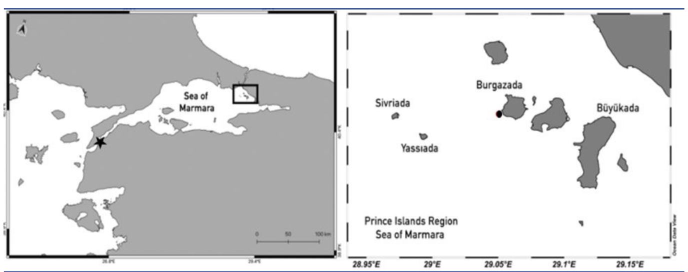

Figure 1. Location of the Princes' Islands and the monitoring station (black dot) where *T. fimbria* was observed. The location of the previous observation of the species (Özalp et al. 2022), where spawning was observed in January, is shown with a star.

RESULTS AND DISCUSSION

The specimen described here was observed on a sandy/muddy sea bottom at a depth of 35 m at midday (Figure 2). It was observed first on the seafloor and then swimming in the water column. The sea slug measured approximately 25 cm in length (Fig. 1). An updated checklist of marine molluscs documents two species along Turkish coasts belonging to the Tethydidae family; *Melibe viridis* (Kelaart, 1858), and *T. fimbria* (Öztürk et al. 2014). The latter was first recorded from the Aegean Sea (Forbes, 1844) and later was reported from the Levantine coast (Swennen, 1961). Another study reports the large sea slug from the central Aegean Sea (Geldiay and Kocataş, 1972). Recently, Özalp et al. (2022) reported *T. fimbria* in the Dardanos MPA (southern coast of the Çanakkale Strait) between 10-28 m on soft substrate and around the Posidonia beds. The authors observed large numbers of sea slugs spawning in January. The species distribution ranges from the Mediterranean Sea (Domenech et al. 2006; Crocetta et al. 2020; Betti et al. 2021; Toma et al. 2022) to the Atlantic Ocean, including the Spanish coast off the Gulf of Biscay, the mainland coast of Portugal, the Andalusian Atlantic coast, the Andalusian Mediterranean coast, the Spanish Levant, from Cape Gata to Catalonia, Catalonia, the Balearic Islands, the Canary and Selvagens Islands (Cervera et al. 2006) and the Cape Verde Islands (Wirtz et al. 2016).

The sea slug *T. fimbria* is one of the largest heterobranchs, with a length of up to 30 cm, and is the only species of the genus *Tethys*, closely related to the genus *Melibe*. Both have a large oral hood (velum) used in the capture of food, mainly represented by small crustaceans, ophiuroids and other invertebrates (Thompson and Brown, 1984). *Tethys* is characterized by a stout translucent white body, with a pair of small rhinophores and a series of five to six flattened cerata, whitish to yellowish in color, with orange marks and numerous black spots. The cerata of this sea slug possess great amounts of PG derivatives used in defense mechanisms (Marin et al. 1991) and can be autotomized.

T. fimbria is defined as a euribathic and euryphagous species since it has been observed both in deep and shallow areas (Toma et al. 2022 and references therein). The shallow (< 50 m) records of the species usually report one or few individuals (Sigovini et al. 2014; Trainito and Doneddu, 2015) while deeper reports generally include numerous individuals (Domenech et al. 2006; Crocetta et al. 2020; Toma et al. 2022). We should keep in mind that different sampling strategies have typically been used in each of the two layers. For example, studies in shallow waters were accomplished by SCUBA diving while studies in deeper waters utilized bottom trawling, except that of Toma et al. (2022) whose study was carried out by means of remotely operated vehicles. Photo-records of the species in underwater photography or marine life related websites (e.g. seaslugforum.net; opistobranquis.info) also seem to report few individuals generally observed during night dives. *T. fimbria* is relatively common in the Adriatic Sea characterized by turbid waters and dim light conditions, as the Sea of Marmara (Sigovini et al. 2014; Zenetos et al. 2016; Betti et al. 2021).

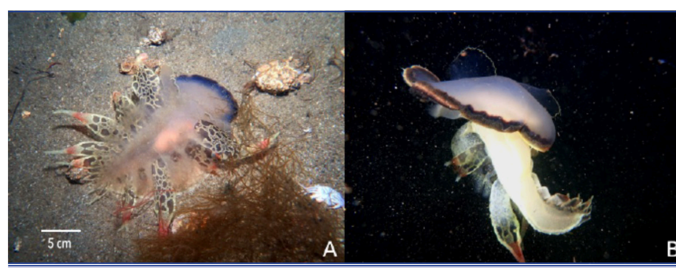

Figure 2. *Tethys fimbria* specimen encountered in June at Kalpazankaya resting on soft substrate (A); and swimming (B).

The Princes' Islands are the most favored diving spot of the Sea of Marmara. This large sea slug is very conspicuous and cannot be unnoticed to divers, particularly to underwater photographers, and yet we could find no observations of this sea slug prior to 2022. However, we encountered two entries on social media with photos of this species taken by underwater photographers and by diving clubs in summer 2022. These photos had been taken in the southeastern Marmara coastal waters. Hence, *T. fimbria* seems to be a late arrival in the Sea of Marmara, possibly due to ongoing Mediterranization.

A possible reason for the previous non-sighting of this species in the area could be that *T. fimbria* may have used exclusively deeper areas in the Sea of Marmara and thus gone unnoticed to divers. The sea slugs may have escaped the recent deoxygenation of deep Marmara basin (Mantıkçı et al. 2022; Yalçın et al. 2017) and shown up at shallow depths. However, under this scenario, the species would have been found in trawling surveys as in the Mediterranean, where it is usually reported in large numbers (Domenech et al. 2006; Crocetta et al. 2020; Toma et al. 2022). There are several surveys by towing gears undertaken in the Marmara Sea that report sandy/muddy bottom fauna from different depth layers (Altuğ et al. 2011; Bök et al. 2011; Zengin et al. 2017; Çolakoğlu, 2020 among others). However there are none that report *T. fimbria*.

In the Mediterranean Sea, climate-driven surface water warming, among other factors such as habitat degradation, competition with others and changing environmental parameters may alter the species abundances in a severe way by extending the species range and enhancing the poleward migrations (Azzurro et al. 2019; Yapıcı et al. 2016). Therefore, some species, especially invasive ones, may move to new regions to survive where they were absent before, and some native thermophilic species thus extend northwards (Azzurro et al. 2008, 2011, 2019). Similar warming trends are also present in the Sea of Marmara, an inner sea that connects the Black Sea and the Aegean Sea and acts as an ecological barrier in between. An increase of 2.11°C in sea surface temperature values and 0.95 PSU in surface salinity values was already reported in the small basin (Latif et al. 2022). Along with the ongoing warming trend from climate change, the semi-enclosed Marmara Sea might be subject to other warming contributors, such as warm industrial wastewater discharges and the loss of natural coasts with increasing coastal constructions (thus giving rise to the loss of natural cooling mechanisms through wave actions). However, *T. fimbria* is not a thermophilic species and its presumed new arrival in the Marmara Sea cannot be a consequence of the warming trend. We therefore relate the recent observation of *T. fimbria* in the Marmara Sea mainly to its recent arrival in this inner sea.

CONCLUSION

In this study a northern expansion of the distribution of the large nudibranchia *Tethys fimbria* was reported in the northeastern Sea of Marmara near Burgazada. The recent observation of this large sea slug in the Sea of Marmara seems to be related mainly to its new arrival in the Marmara Sea rather than to a distribution shift from deoxygenated deep basins or to a climate-related expansion.

Conflict of Interests: Authors declare that there is no conflict of interest.

Ethics committee approval: Authors declare that ethical approval is not required for this type of study.

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