



The effect of purifying Lake Manzala, Egypt by dredging on the diversity of waterbirds

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Abstract

Birds are very sensitive to habitat change, making them a good indicator of biodiversity response to habitat modifications. Changing any component of the ecosystem will affect the associated species diversity negatively or positively. Plant cover, especially reeds (*Phragmites australis*), shapes the topography of Lake Manzala, northern Egypt, plays an important role in water cleaning, and is a crucial resource for wintering migratory waterbirds. The complete transformation of Lake Manzala due to the dredging process that aimed to restore the lake from brackish to its original saline nature through a broader connection to the sea led to a decline in reed plants. As Lake Manzala is one of Egypt's important bird areas (IBA), and the main stopover for migratory birds that winter in it, this study aimed to assess the difference in waterbird community composition and diversity before and after dredging and give a clear picture of the current situation of one of the main IBAs in Egypt. The study compares the situation before the removal of reeds in the winter season of 2018 and after their removal in the winter season of 2021. The results showed a decline in the overall diversity of waterbirds after dredging. The dredging process resulted in an increase in Pelecaniformes and Anseriformes abundance, a decrease in the abundance of the two orders that mainly structure the waterbird community: The Charadriiformes and Ciconiiformes, and the disappearance of order Gruiformes and the two families Charadriidae (plovers' family) and Scolopacidae (sandpipers' family) of Charadriiformes order. Analysis of biplot ordinations showed that waterbird diversity is associated with vegetation cover. The present data demonstrates that the removal of plant cover negatively affected the suitability of Lake Manzala for different bird communities. It also suggests that recolonization of reeds as an important ecosystem component for migrant birds can help in habitat restoration and biodiversity protection.

Keywords Bird migration · Ecosystem · Habitat change · Plant cover · Waterbirds

Introduction

Wetlands are one of the most biodiversity rich habitats in the world (Mitsch and Gosselink 2000). They are mixtures between land and waterbodies with distinctive soil covered with water seasonally or permanently, dominated by emergent and submerged plants. They can be classified into mudflats, swamps, lagoons, lakes, rivers, and dams (Dronova 2012; Mitsch and Gosselink 2015). According to the Ramsar Convention on Wetlands (Ramsar Convention on Wetlands 2018), 12.1 million km² of the world are covered

by wetlands, of which 54% are constantly submerged and 46% are partially submerged. Wetlands are at the forefront of conservation efforts and serve as the home of life for many different bird species, especially waterbirds (Russi et al. 2013; Sievers et al. 2018). The abundance of vegetation and food resources in wetlands enable a wide range of waterbird species, both resident and migrants, to engage in a variety of activities (Rajpar and Zakaria 2013). Effective conservation management requires continuous monitoring of species and habitat change (Das et al. 2020; van Schalkwyk et al. 2019). Habitat loss and fragmentation are main threats to biodiversity and increase the risk of extinction (Xiao et al. 2021; Sahri et al. 2022). Changes in land structure and topography by losing vegetation can lead to complete alteration in wildlife communities especially birds that mainly rely on vegetation in their life cycle.

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Lake Manzala is one of the most important lakes in Egypt and is declared an important bird area (IBA). It is the main stopover for wintering migratory waterbirds migrating along the two main migration routes, which are the Mediterranean-Black Sea and East Africa-West Asia flyways. Reed swamps constitute the main habitat that shapes the vegetation cover in the lake (Shaltout et al. 2017). Reeds play a prominent role in biodiversity sustainability, beside their economic value to the local people who harvest them (Poulin and Lefebvre 2002; Tanneberger et al. 2009). Also, reeds are considered one of the main habitat requirements for many species, especially birds that count mainly on reeds during their life (Greenberg et al. 2006; Gedan et al. 2009; Mérő et al. 2018). The loss of reeds due to overexploitation and anthropogenic activity resulted in declines in bird species populations (Wilson et al. 2007; Wang et al. 2019). Lake Manzala suffered from pollution, invasive plant species like water hyacinths (*Eichhornia* sp.), overexploitation, illegal building, agricultural activity, non-permitted fish farms, and wastewater discharge which led to habitat fragmentation and decreasing suitable areas for waterbirds. The lake received wastewater drainage from many highly polluted areas. The annual combined discharge of roughly 4000 million m³ included treated and untreated polluted industrial, agricultural, and municipal wastewater, in addition to aquatic plant proliferation (Hegazy et al. 2016; El-Saeed et al. 2020; Redwan and Elhaddad 2022).

In recent years, the government has prioritized cleaning and restoring nature and increasing the efficiency of the northern lakes including Lake Manzala. This took place through a dredging operation in Lake Manzala that started in 2017 and finished in 2022 (Mehanna et al. 2022). The national project helped in removing all unwanted illegal buildings, and non-permitted fishponds that had been in operation for many years in the lake. The dredging operation's main purpose was to increase lake depth and cleanse all plants, weeds, and invasive water hyacinths. Moreover, it increased the width and depth of lake outlets to the Mediterranean Sea (El Komi 2021) to enhance the water quality of the lake by entering more seawater into it.

Birds are an excellent bioindicator of ecosystem health, due to their sensitivity to environmental changes such as wetland loss due to ongoing human exploitation and use (Gregory and Strien 2010; Zhang and Ouyang 2019; Mokany et al. 2022). Thus, studying the factors that shape avian diversity is crucial for both biodiversity and the conservation of wetlands (Li et al. 2019). Waterbirds exhibit a wide range and are not restricted to a certain place, due to their active search for food, especially in fish farms and fishponds (Sun et al. 2021), which are remarkable features in Lake Manzala. Thus, preserving the whole habitat and avoiding the breakdown into small patches are determinant

factors in conserving the waterbird's habitat (Mohammadi et al. 2022). Consequently, identifying and monitoring the suitable habitat for waterbirds is required to maintain the waterbird populations (Ceballos et al. 2021). The goal of this study was to use datasets from two winters 2018 and 2021 to compare the waterbird community structure and plant cover before and after the dredging of Lake Manzala. This comparison aimed to identify the change and suitability of the habitat for migratory waterbirds and give insight into conserving and increasing the suitable areas in one of the main wintering stopover areas in Africa.

Material and methods

Study area

The study sites were in Ashtoum Elgamil protectorate located in the northern east corner of Lake Manzala, south-east of the Mediterranean Sea, between latitudes 31°15'N and 32°10'N. Twenty sites were selected inside the study area shown in Fig. 1. In 2018, at the start of dredging operations, the sites were dominated by native plants mainly *Phragmites australis*, *Typha domingensis* and *Echinochloa stagnina* (Ayache et al. 2009; Bernhardt et al. 2011; HTC (Higher Technical Committee) 2018). The same study points inside the protectorate parts of the lake were visited again in 2021 at the end of the dredging operation. It was nearly empty of plants except for scattered recolonized reeds as shown in Fig. 1.

Waterbird data set

The bird data were collected during winter seasons at the same study sites across the study area in the winter (January and February) seasons of 2018 and 2021, which is considered the peak migration season of waterbirds in Egypt. Birds were surveyed at 20 study sites named S1-S20 across the protectorate according to the method described before (Sheta 2019; Sheta et al. 2023). Large bird flocks >500 individuals were estimated by segmentation methods into 10, 20, 50, or 100 (Li et al. 2011). Only waterbirds data were extracted as a target group in this study and identified as birds belonging to orders *Pelecaniformes*, *Ciconiiformes*, *Anseriformes*, *Gruiformes*, and *Charadriiformes*.

Normalized difference vegetation index (NDVI) data

The NDVI is a normalized spectral index derived from the reflectance of the vegetation in red and infrared portions of the spectrum (Tucker 1979). NDVI was obtained from a freely available MODerate resolution Imaging

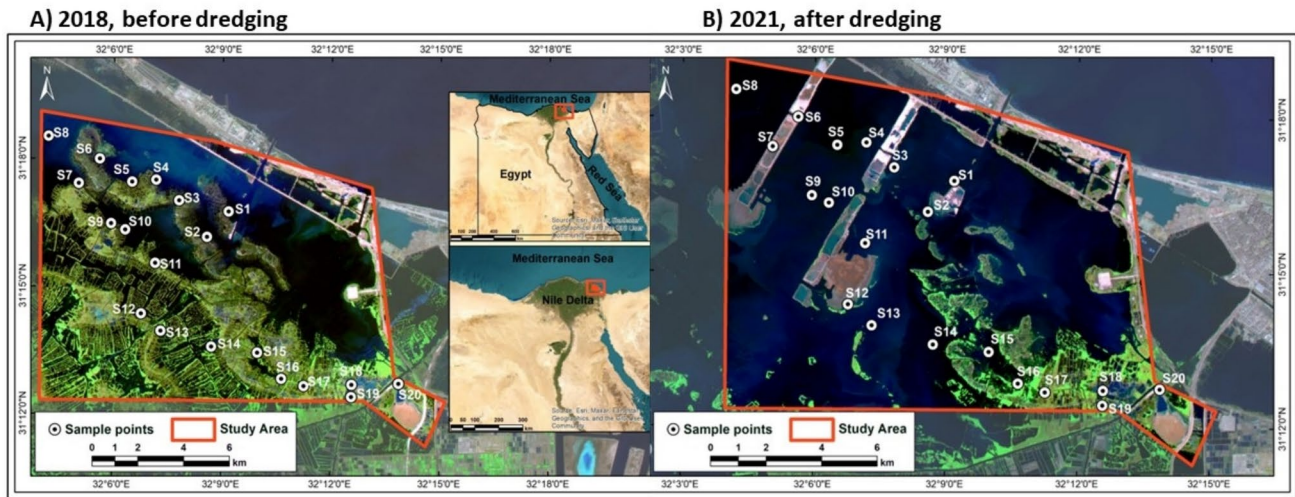


Fig. 1 The study area location including waterbird monitoring study sites S1-S20 in Ashtoum Elgamil, Lake Manzala, Egypt. **A)** The study area in 2018 before dredging, **B)** the study area in 2021 after dredging

Spectroradiometer sensor (MODIS). The mean NDVI value was extracted to estimate the vegetation cover within a 1 km buffer area around each study site in 2018 and 2021 satellite image maps.

Statistical analysis

Waterbird diversity indices including richness, abundance, relative richness, relative abundance, Evenness, Shannon's-Wiener diversity, and Simpson's index were calculated for winter seasons of 2018 and 2021 by PCORD software version 6.12 (McCune and Mefford 2011). The data were expressed in a way to show the differences between 2018 and 2021, through the waterbird orders. The relationship between waterbird order's species richness and abundance was investigated by principal component analysis biplot

using Stata software. Differences among the group values of 2018 and 2021 data were assessed at a 5% level of significance ($P < 0.05$).

Results

NDVI before and after dredging

The results show a dramatic reduction in plant cover. This is reflected by the decrease in the Normalized Difference Vegetation Index (NDVI) in winter 2021, compared with that in 2018. Most sites were vegetation-free except for the southern-east corner (Fig. 2). In Table 1, the NDVI values within 1 km around each study site were extracted. This data shows a great loss of vegetation cover after dredging.

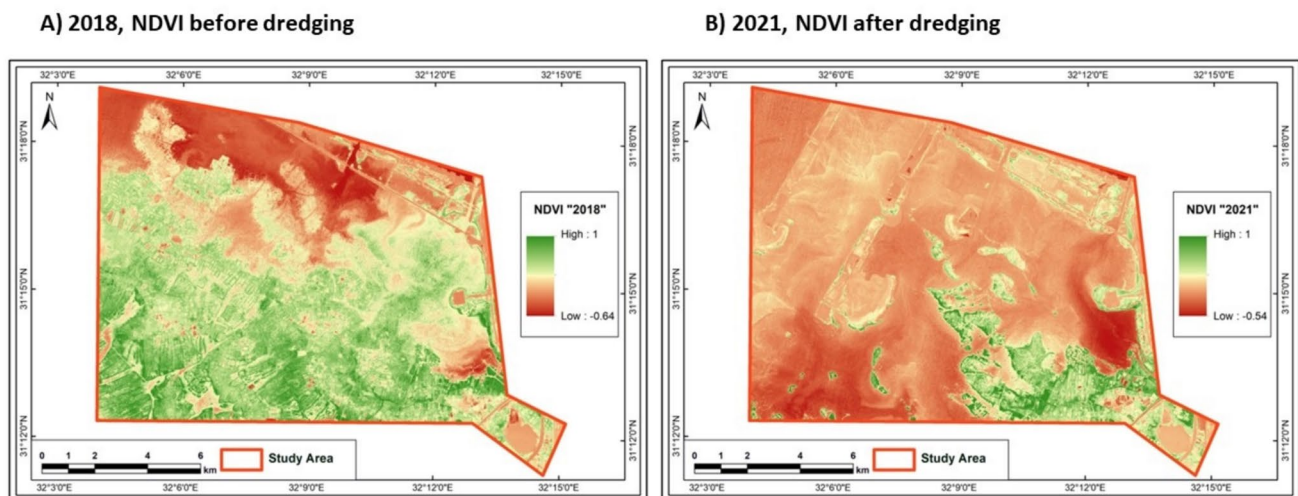


Fig. 2 Normalized Difference Vegetation Index (NDVI) of the study area before and after dredging

Table 1 Normalized Difference Vegetation Index (NDVI) calculated values in the 20 study sites in 2018 and 2021 before and after dredging. The data is extracted for a circle with a diameter of 1 km around each study sampling point

Sites	NDVI 2018	NDVI 2021
1	0.0842	0.0028
2	0.6571	0.2239
3	0.3337	0.0354
4	0.7006	0.0015
5	1.2942	0.0002
6	0.0549	0.0053
7	1.1011	0.0022
8	0	0
9	1.5048	0
10	1.0944	0
11	1.7293	0.0104
12	2.5868	0.1608
13	2.7506	0.1592
14	3.0184	0.3504
15	2.945	1.395
16	2.9479	2.5006
17	2.6374	2.4665
18	1.987	1.7568
19	1.2345	1.0349
20	1.2837	1.1569

Waterbirds abundance, richness, and diversity indices before and after dredging

The current study is concerned mainly with waterbirds as an indicator of habitat changes before and after dredging. A total of 47 waterbird species were recorded in 2018, while in 2021, only 28 species were recorded. In 2018, the highest waterbird richness was recorded in the northern part of the protectorate, while in 2021 the south-eastern corner of the protectorate recorded the highest richness (Fig. 3A). There was a significant difference between species richness of waterbirds orders before and after dredging (Fig. 3B). As shown in (Fig. 3C), The waterbird community structure of the entire study area after dredging was different from that before dredging. Different sites also showed variable community structure in both years the richness for the order Pelecaniformes was almost the same before and after dredging, while the richness for orders Ciconiiformes and Charadriiformes decreased after dredging. Order Gruiformes completely disappeared, while the richness for the order Anseriformes increased after dredging.

Numerous waterbird populations disappeared after dredging due to losing their main niche, the mudflat areas. These species include Glossy ibis (*Plegadis falcinellus*), Little bittern (*Ixobrychus minutus*), Purple swamphen (*Porphyrio madagascariensis*), common moorhen (*Gallinula chloropus*), ringed plover (*Charadrius hiaticula*), Kentish plover (*Anarhynchus alexandrinus*), Grey plover

(*Pluvialis squatarola*), Marsh sandpiper (*Tringa stagnatilis*), Wood sandpiper (*Tringa glareola*), Black-tailed godwit (*Limosa limosa*), Turnstone (*Arenaria interpres*), Sanderling (*Calidris alba*), Dunlin (*Calidris alpina*), Little stint (*Calidris minuta*), Painted snipe (*Rostratula benghalensis*), Ruff (*Calidris pugnax*), Avocet (*Recurvirostra avosetta*), Sandwich tern (*Thalasseus sandvicensis*), White-winged black tern (*Chlidonias leucopterus*), Black tern (*Chlidonias niger*). All these birds escaped into the lake border regions searching for a new suitable habitat after dredging and none of them were found inside the lake.

A total waterbird count of 39,598 was detected in 2018, while only 7897 was detected in 2021 after dredging (Fig. 4). Maps of abundance distribution showed that the northern part of the lake had the highest abundance of birds in 2018 (Fig. 4). In contrast to richness, the Northern half of the study area showed higher abundance in 2021 after dredging (Fig. 4A). The abundance of waterbird species significantly decreased from 2018 to 2021 (Fig. 4B). Comparing the waterbird community structure of different orders varied before and after dredging. The distribution of waterbird species was almost the same in different study sites before and after dredging, but the number of individuals decreased in 2021 (Fig. 4C).

In general, the waterbird diversity indices like Evenness, Shannon-Wiener diversity index, and Simpson's diversity index were significantly higher in 2018 compared to 2021 (Fig. 5.).

The effect of dredging on the association between vegetation and waterbird community structure was further explored. Beta diversity biplot ordination analysis showed that dredging affected waterbird richness. The analysis revealed a distinction between waterbird richness before and after dredging (Fig. 6A). To study the influence of vegetation, the NDVI values extracted in Table 1 were categorized into 0 vegetation (for NDVI values 0-to-1) and 1 (for NDVI values >1). It was found that vegetation influenced waterbird richness. This was a clear distinction between waterbird richness in low and high vegetation. (Fig. 6B). Vegetation level also influenced waterbird abundance. The beta diversity biplot ordination analysis showed a distinction between waterbird abundance in low and high vegetation (Fig. 6C).

Discussion

Losing one or more essential habitat components leads to habitat loss and fragmentation that alter the composition of species inhabiting the suffered habitat and this affects biodiversity and environmental health (Xiao et al. 2021; Sahri et al. 2022; Wang et al. 2021). Lake Manzala experienced complete

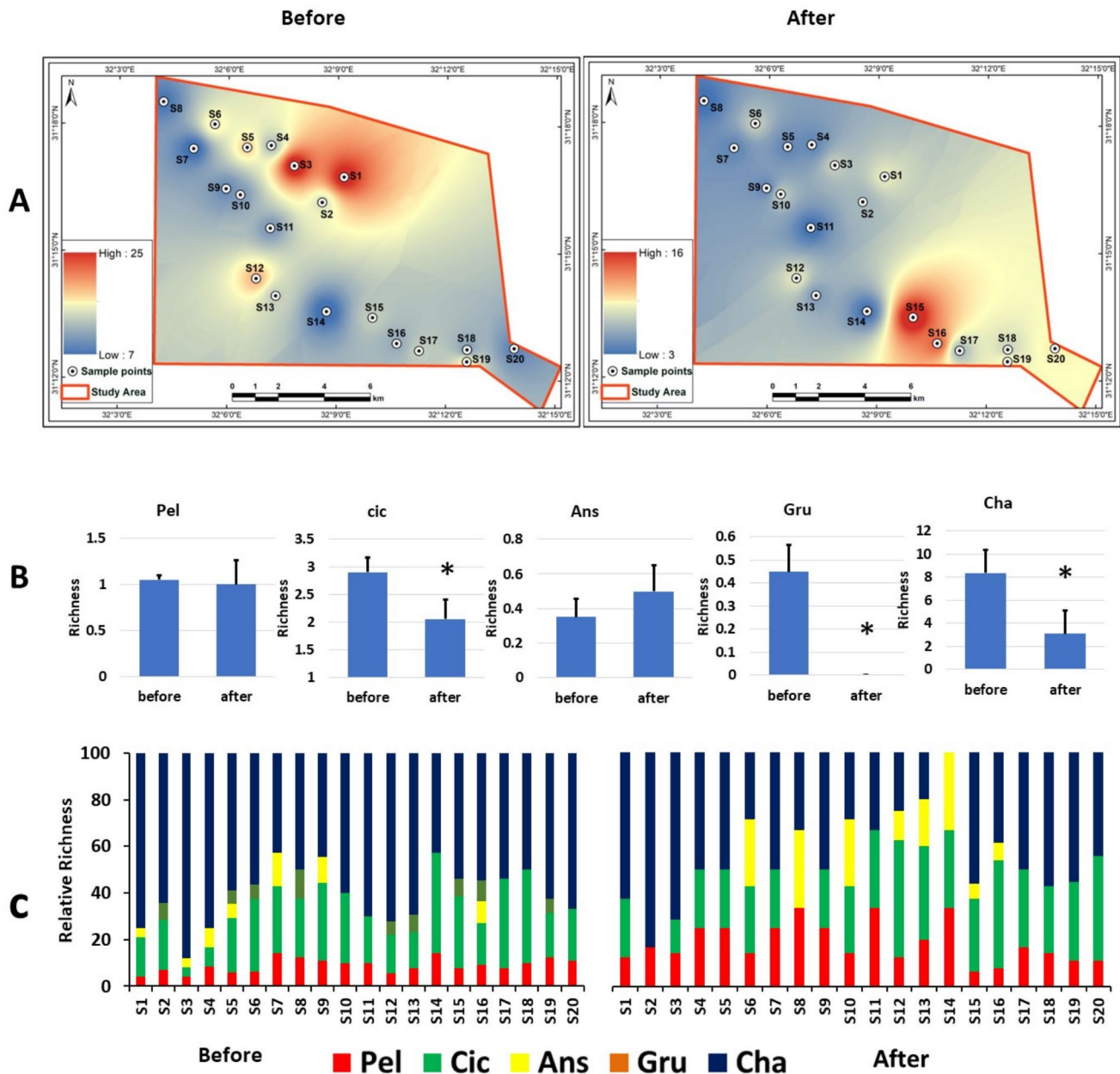


Fig. 3 The waterbird richness in 2018 before (left side) and 2021 after dredging (right side) of Lake Manzala. **(A)** Maps of the change in waterbird richness in the study area before and after dredging. **(B)** Richness values of different waterbird orders before and after dredging. The (*) denotes significantly different values before and after

dredging. **(C)** Relative richness among different waterbird orders in 2018 and 2021 before and after dredging. Waterbird orders include Pelecaniformes (Pel), Ciconiiformes (Cic), Anseriformes (Ans), Gruiformes (Gru), and Charadriiformes (Cha)

alteration in its topographic structure due to the dredging process. The removal of vegetation, and increasing the depth decreased the suitable habitat for wintering migratory waterbirds. Before dredging, the lake was classified into four main habitat types: reedbeds, islands, open waters, and lake shores. The diverse habitats harbored different bird groups and afforded the essential requirements for the bird community. The present result showed that the diversity was higher before dredging than after it. The dredging process altered the

habitat types into two main habitats only: open waters and lake shores. Islands and reedbeds were removed. Some scattered vegetation in the eastern south corner of the protectorate and only the historical Tennis Island was left. The increase of open water areas inside the lake provides a suitable habitat for cormorants (Pelecaniformes) and all national counts confirm its increase in all northern lakes of Egypt (unpublished data).

Waterbirds are a significant constituent of wetland wildlife. Changes in land cover, especially vegetation, constitute

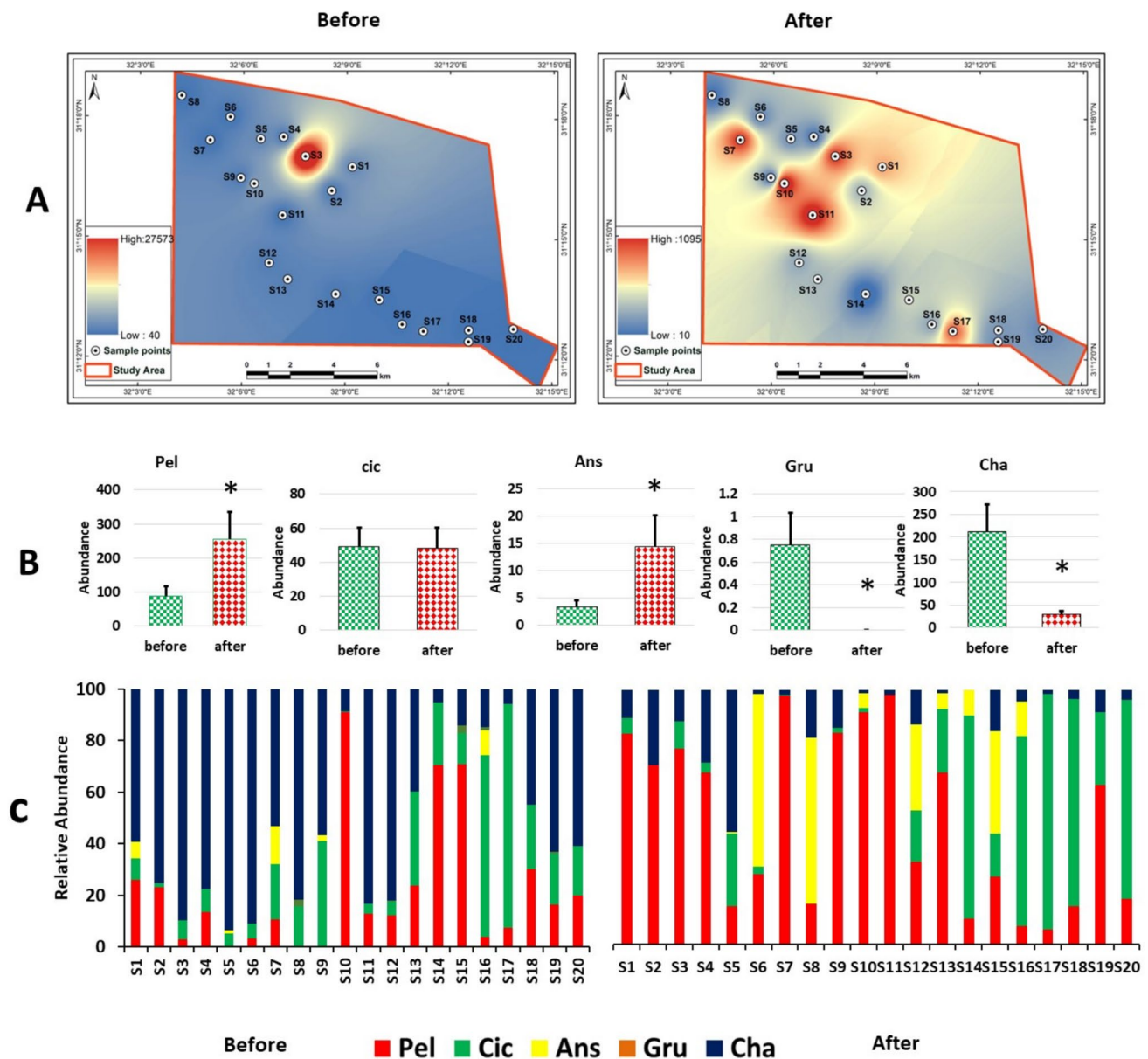


Fig. 4 Waterbird Abundances in 2018 before (left side) and 2021 after (right side) dredging of Lake Manzala. **(A)** Mapping of Abundance in study area. **(B)** Abundances of different waterbird orders before and after dredging. The (*) denotes a significantly different value from the

other corresponding values. **(C)** Relative abundance among different waterbird orders in 2018 and 2021 before and after dredging. Order groups include Pelecaniformes (Pel), Ciconiiformes (Cic), Anseriformes (Ans), Gruiformes (Gru), and Charadriiformes (Cha)

one of the significant global stressors that impact biodiversity in general and waterbirds in specific (Zhou et al. 2020; Chatterjee et al. 2020; Xu et al. 2022). Vegetation cover is considered a main habitat component in the wetland ecosystem for all wildlife. Water resources and waterbirds are abundant in the region with extensive wetland cover in this region dominated by *Phragmites australis* and *Suaeda salsa*. Plants provide shelters, roosting areas, food, and nesting materials for waterbirds (Sheta 2019; Sheta et al. 2023). Reed swamps are the main habitat type that shapes Lake Manzala and provide many ecosystem services like water

cleaning, a home for invertebrate dwellings, their root gathers aquatic insects, and the fry of young fishes (Greenberg et al. 2006; Gedan et al. 2009; Móró et al. 2018; Schmidt et al. 2005). Also, it is a shelter for shy big herons that rest or roost inside it, a good place for nesting resident waterfowls like purple swamphen and moorhen (Gould and Mackey 2015; Antoniazza et al. 2018). Not only waterbirds rely on reeds and vegetation in general, but also migrating and resident passerines for which reeds are the main suitable realized niche like reed warblers (*Acrocephalus spp.*), stone chat (*Saxicola torquatus*), and graceful prinia (*Prinia gracilis*)

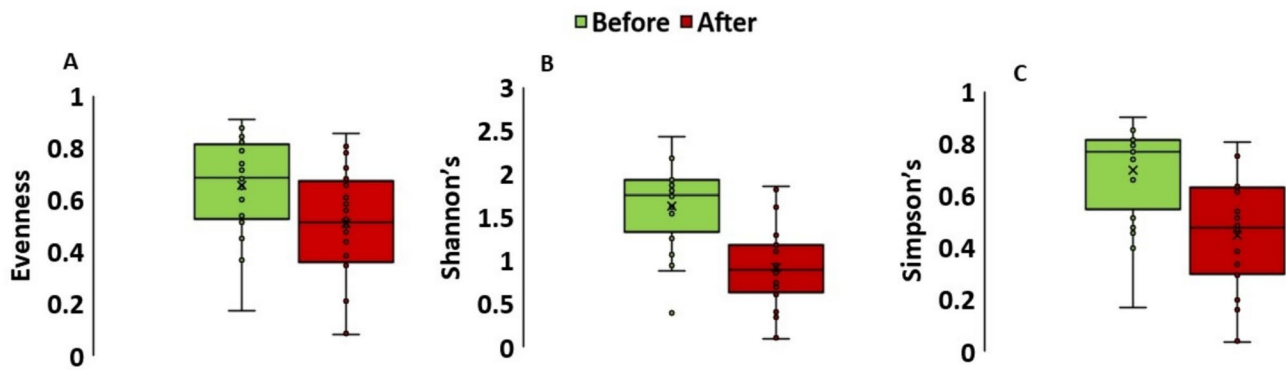


Fig. 5 Diversity indices including **A)** Evenness, **B)** Shannon-Wiener, and **C)** Simpson's diversity index of waterbird identified 2018 before and 2021 after the dredging of lake Manzala. The "*" denotes a significantly lower value than the 2018 value

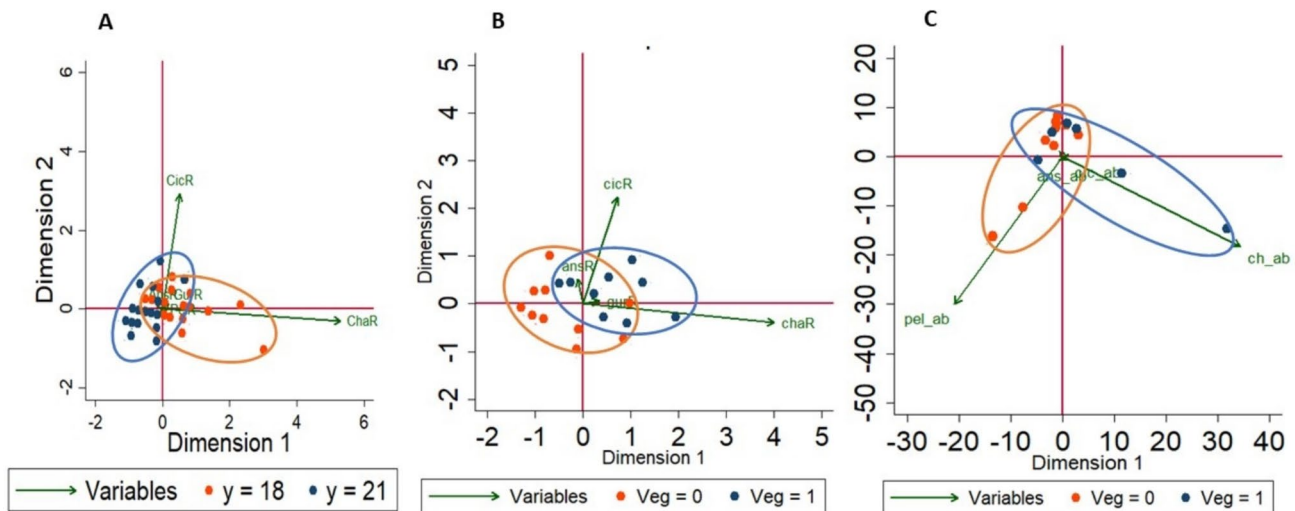


Fig. 6 Effect of dredging on the relationship between vegetation and waterbird community structure. **(A)** Dredging affected waterbird richness. Beta diversity biplot ordination analysis showing distinction between waterbird richness before (orange) and after dredging (blue). **(B)** Vegetation influences waterbird richness. Beta diversity biplot ordination analysis showing distinction between waterbird richness in low (orange) and high (green) vegetation. The NDVI values (Table 1)

(Antoniazza et al. 2018; Poulin et al. 2002; Valkama et al. 2008). Some studies documented the importance of vegetation to birds (Poulin and Lefebvre 2002; Tanneberger et al. 2009) and reed as a crucial component for waterbirds (Gawlik 2002) and in wetlands in general (Mérő et al. 2018; Messter et al. 2015; Frías et al. 2018; Yang et al. 2021).

Also, the dredging process resulted in deeper depths, removing the mudflat areas suitable for waders and plovers, they move to the lake borders, which explains the decrease of Charadriiformes after dredging. The two families Charadriidae (plovers' family) and Scolopacidae (sandpipers' family) completely disappeared. This result is consistent with that of (Sun et al. 2021) who detected a decrease in shorebirds in tidal mudflats with a decrease in their suitable habitat.

were categorized into 0 vegetation (NDVI=0-to-1) and 1 (NDVI >1). **(C)** Vegetation influences waterbird abundance. Beta diversity biplot ordination analysis shows distinction between waterbird abundance in low (orange) and high (green) vegetation. Data was obtained by a 20-sites' waterbird monitoring in 2018 (before) and 2021 (after dredging and vegetation removal)

The result revealed that both orders Charadriiformes and Ciconiiformes were the main representatives of waterbird communities in Lake Manzala. They were affected by the dredging process and their richness and abundance decreased due to the loss of their main vegetated habitat. Thus, the decline of vegetated habitats and islands led the Charadriiformes and Ciconiiformes to concentrate closer to the lake shores where they were more easily observed. On the contrary, both Pelecaniformes represented by only one species (great cormorant) and Anseriformes increased after the dredging process, and this can be explained by the fact that both Pelecaniformes and Anseriformes are usually more active in open water habitats. This result matches that of (Li et al. 2021) in the Liaohe Estuary, China.

In particular interest, for reviving conservation strategy to the protectorate and all of the Lake Manzala, restoring the diverse four main habitats of the lake is advisable. This can take place by allowing the recolonization of reeds again, especially in the southern part of the protectorate away from the sea inlets and since this place is a little bit quiet and suitable for roosting and breeding as before. Also, the creation of mudflat areas on lake shores of the lake with different depths ranging from 10 to 50 not exceeding 70 cm to attract the waders and all shorebirds to the lake.

Conclusion

Identifying the essential requirements that waterbirds need for their survival is a main step toward conserving their suitable habitats. Lake Manzala is an important bird area and the largest lake in Egypt and a main wintering stopover site for wintering migratory waterbirds. The cleaning and purification of all northern lakes is essential to restore the Egyptian wetlands and improve their conditions. The loss of mudflats and areas vegetated with reed swamps decreased the diversity of waterbird populations, especially the orders Charadriiformes and Ciconiiformes. This habitat loss led to the disappearance of all waders inside the lake. Understanding the response of these waterbirds to dredging is necessary to better revive the lake and efficiently guide the strategies for the management to increase waterbird diversity and conservation. Studying the impact of dredging in Lake Manzala revealed that (1) The richness, abundance, and diversity of waterbird community has decreased after dredging of lake Manzala. (2) Orders Charadriiformes and Ciconiiformes in the study area account for almost half the waterbird community abundance before and after dredging but their richness and abundance decreased after dredging. (3) Orders Pelecaniformes and Anseriformes positively responded to the dredging process and increased in abundance after providing them clean and increased area with open water habitat. (4) Disappearance of the order Gruiformes after dredging. (5) Waterbird diversity is associated with vegetation. The lake will continue to play a progressively main habitat for wintering migratory waterbirds, but recolonization of vegetation is essential and should be considered.

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Data Availability Data will be available upon request.

Declarations

Ethics approval and consent to participate N/A.

Conflict of Interests The author declares no conflict of interest.

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