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GENERAL WETLAND SCIENCE

Gökçeada Salt Lake: a Case Study of Seasonal Dynamics of Wetland Ecological Communities in the Context of Anthropogenic Pressure and Nature Conservation

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Abstract
Gökçeada Salt Lake (GSL) (Gökçeada Island, North Aegean Sea) is an important wetland area situated on established bird migratory routes. The waterbody is subject to significant variability in seasonal water quality and species diversity. Monthly observations indicate that a total of 29 waterbird species were present during 2015–2016. Rainfall was observed to influence waterbird abundance. There was also a strong correlation between waterbird and zooplankton species diversity, with water quality a further influencing factor. The seasonal abundance of 78 other aquatic species was also investigated. Spring and fall seasonal eutrophication, as a consequence of canal construction and suspected warming due to climate change has caused changes in Chlorophyll-a, dissolved oxygen, biological oxygen demand levels and grazing habits of aquatic species. Here, we propose GSL as a coastal lagoon model for a hydrodynamically sensitive habitat undergoing significant change from the combined threats of heavy metal pollution from a waste management facility, pesticide use for tourism and agriculture activity and wider climate impacts. We conclude that our results provide a paradigm for broad-scale monitoring programs encompassing all components of the wetland ecosystem under anthropogenic and climate change pressure, thus providing a tool to support and inform essential management and rehabilitation plans.

Keywords Gökçeada Salt Lake · Global warming · Waterbird · Anthropogenic pressure · Eutrophication · Seasonal dynamics of species diversity

Introduction

Wetlands are essential for regulating, filtering, treating and flood control of water bodies and provide plants and animal habitats for plants and animals like birds to live in (Whittaker and Likens 1971). Although wetlands are highly sensitive areas providing critical ecosystem services, they are often seen as unsightly wastelands and breeding grounds for disease-carrying pests such as mosquitoes. As a consequence, they have historically been allocated as priority areas for pest control and land reclamation leading to widespread destruction and degradation these ecosystems globally (Dahl 1990; Davidson et al. 1991; Kotze et al. 1995; An et al. 2007). Over 64–71% of wetlands in the world have been lost in the past century (Davidson 2014). The Gökçeada Salt Lake or Lagoon (GSL), (Fig. 1), is an important restricted wetland separated from the sea by a fine sand dune barrier. Providing suitable habitat for bird species under conservation, it is under protection in the "Wetlands with National Importance of Turkey" list since February 2019, upgraded from "Wetland of Local Importance" declared in 2014. GSL, surface area about 2 km^2, elevation between 2 and 3 m, is located Southeast of largest island in Turkey: Gökçeada. Gökçeada island covers an area of 290 km^2, with a 95 km coastline on North Aegean Sea (40° 05' 12"- 40° 14' 18" N, 25° 40′ 06″-

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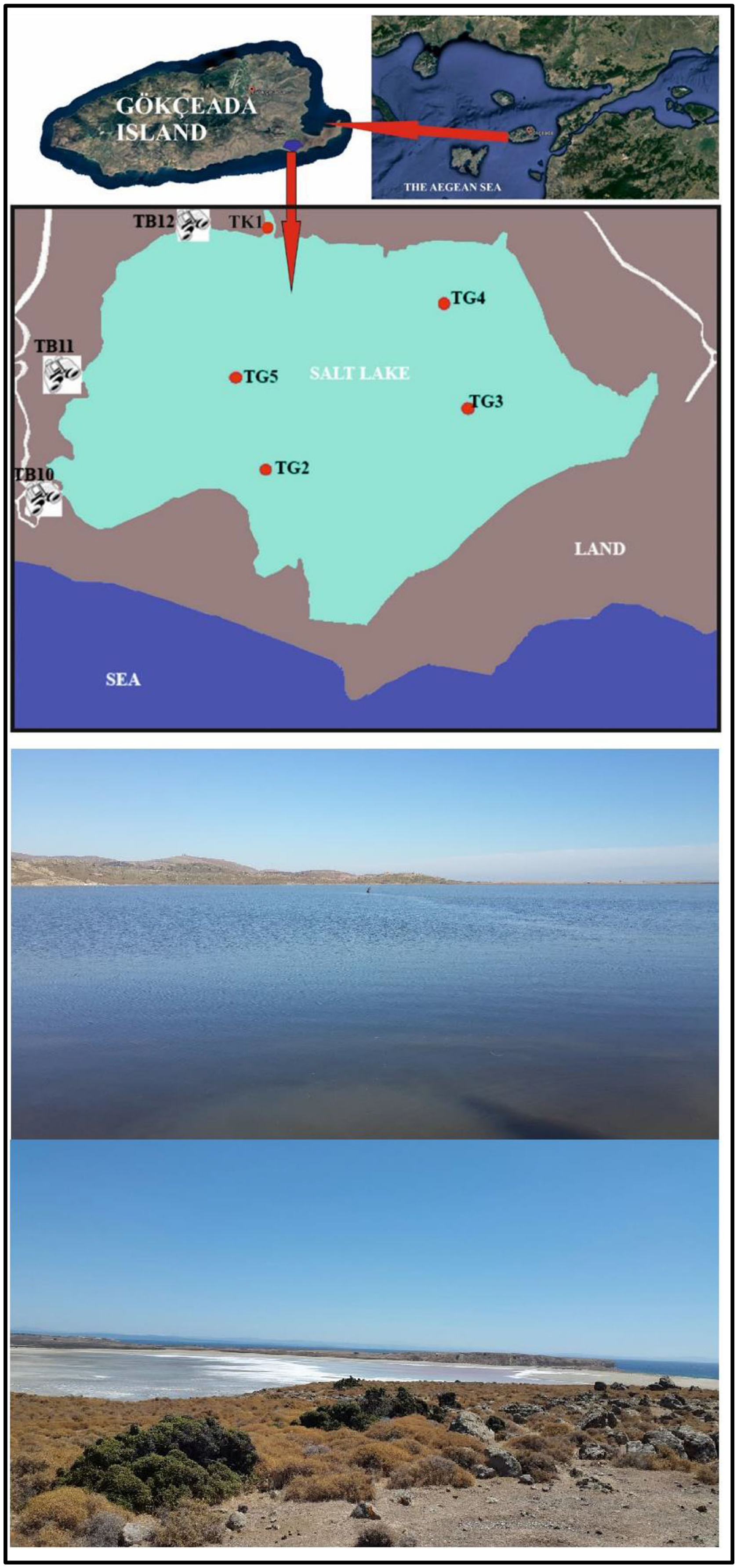

Fig. 1 A map of the study area (red dots show the sampling stations and the binoculars indicate the bird watching locations) and pictures of GSL (on the date January and August in 2016, photos taken by H. Aslan)

26° 01’ 05” E). Southwesterly and Northeasterly winds are prevalent on the island. The lake has a larger area of 31,34 km^2 which is thought to be in interaction with the drainage area and 4,13 km^2 of this area is surface rainfall area (Anonymous 2012). Sea water enters the lake overflowing the bordering dune especially when severe Southwest winds prevail during winter. In addition, the Turkish General Directorate of State Hydraulic Works (DSI) has opened a canal to feed freshwater to the lagoon.

Although GSL is a protected wetland as described above, the restrictions are not enforced totally, and some human activities are considered as trade-offs for island economy. This in turn has opened the way for increased tourism during the summer leading to intense anthropogenic pressure/impact. The lake is advertised as a popular tourist destination where wind- and kite-surfing are common. Furthermore, the bottom sludge of the lake is promoted as a therapeutic remedy. The island’s waste collection facility is located just 1 km West of the Lake. In addition to leakage from the waste collection site, the GSL receives sewage effluent, fertilizer and pesticides from agricultural activities in nearby villages to the Northwest, and sewage from hotel and restaurant septic tanks. These combine to form substantial pollutant loads to GSL. For public health pest control, insecticides are often applied by the municipality or private enterprises, increasing pollution. At the same time, there are also various activities that will affect the salinity of the GSL. Since 2010 the sea has been artificially connected to GSL with a channel constructed by the hotels, presumably to “keep chironomid flies away from the visitors”, based on the idea is that seawater will lower fly populations and end the “nuisance”. Recent irrigation activities for clover production, have led to reduction of water from streams feeding the lake. Furthermore, strong winds intensify soil erosion around the lake. The freshwater for touristic facilities on the beach is brought through the lake by pipe from the creeks on North side of GSL. Leaks in the pipe, introduce freshwater to the lake and may be a contributor the decrease in salinity. In the past GSL has been used as a military shooting and practice area and therefore there are significant numbers of unexploded projectiles in the lake; furthermore, hunting is permitted during certain times of the year.

Although the species composition of GSL was studied in detail by Aslan et al. (2016) and published (2018), no ecological studies have been conducted so far. This study is based on the species list of Aslan et al. (2018). The samples were obtained seasonally from one station in lotic (TK1), four stations in lentic (TG2, TG3, TG4, TG5), four stations in marine, and several points in terrestrial biotopes (Fig. 1). Briefly, 195 terrestrial vascular flora taxa and 134 aquatic flora species (97 species of phytoplankton, 37 species of benthic algae); 23 macrobenthic invertebrate taxa from the lake and its’ feeding river, 14 reptiles and 3 amphibians were observed in the GSL wetland. One hundred thirty-one marine invertebrate species and four fish species were reported from the sea on back side of the dunes. In addition, selected macro elements and chlorophyll-a distribution of GSL were determined and published by Aslan and Gönülal (2019). On the other hand, studies conducted on Chrinomidae, *Dunaliella viridis, Artemia* and Ostracoda populations made using GSL samples were published by Ozkan (Özkan 2006), Ak (Ak 2008), Eskandari (2014), and Perçin-Paçal et al. (2017), respectively.

The loss and degradation of wetlands has negatively affected waterbirds, which depend on wetland habitats (Castro-Tavares et al. 2015; Thompson-Ambriz et al. 2020). Small and vulnerable wetlands like GSL provide stopover sites for waterbirds essential for successful migration. These wetlands have abundant food and are predictable heterogenous habitats to maintain even more waterbird species (Brown and Dinsmore 1986; Craig and Beal 1992; Scheffer et al. 2006; Ma et al. 2010). Resident species of GSL are few; however, the migrating waterbirds use GSL as a short-term or seasonal stopover and the small size of the system is not a drawback (Kushlan 1986; Skagen and Knopf 1993). A recent review of the literature showed a total of 178 bird species throughout Gökçeada Island (Sevim 2007; Samsa 2014; Aslan et al. 2018) and 71 also belong to GSL (Aslan et al. 2018). Also 28 breeding pairs of Audouin’s gull were reported near the GLS by Onmuş and Gönülal (2019). There have been no studies on the relationship between the waterbirds and the water quality of the lake and other resident species.

The aims of this study are: 1) To study the impacts of natural seasonal changes on topographic, biotic, abiotic characteristics of Gökçeada Salt Lake wetland (GSL) as a case and the relationship with intensity of anthropogenic pressures of human activities; 2) To investigate seasonal dynamics of wetland ecological communities and to assess top trophic food web waterbirds as bioindicators for monitoring good environmental status in the case of GSL; 3) To evaluate water and sediment quality of GSL in terms of eutrophication and damage to this fragile wetland under global warming seasonal water loss; and 4) To provide products of the study for conservation and management of GSL to promote sustainable use of this wetland with recently upgraded protection status.

Materials and Methods

All samples were collected in 2016 during winter (8–9 January), spring (8 May), summer (9 August) and as fall (13 November) from five different stations (TK1, TG2, TG3, TG4, TG5). Bird observations were conducted monthly from three stations overlooking the lake (TB10, TB11 and TB12) (Fig. 1).

Sampling for Abiotic Parameters

Temperature (T), salinity (S), dissolved oxygen (DO), pH, total dissolved solids (TDS), and conductivity of the water column in all sampling stations were measured using a YSI 556 Multiprobe System on site. Water samples taken by Ruttner water sampler were analyzed for physicochemical parameters chlorophyll-a (Chl-a: spectrophotometric method with acetone extraction), BOD (biological oxygen demand: Winkler method, azide modification) and COD (chemical oxygen demand) using standard methods (APHA 1998; Kumar and Reddy 2009).

Sediment samples were collected using an Ekman grab for heavy metals (Al, Fe, and P as ppm; Zn, Pb, Co, Cd, Ni, B, Cr, Cu, Ba, Mn, V, Ag, and Sb as ppb), ion/element (Mg, Ca, Na, K, P, BrO_3^-, Br^-, PO_4^{-3}, F^-, ClO_3^-, Cl^-, ClO_2^-, NO_3^-, NO_2^-, SO_4^{-2} as ppm), and analyses for 190 different type pesticide. All measurements were made seasonally at stations TK1 (from the freshwater canal feeding GSL), TG3, TG4 and TG5. Ion analyses were performed with a Metrohm ion chromatography system using the EPA 300.1 method. Heavy metals in sediments were analysed using ICP-MS (Agilent 770 xx). Pesticides were analysed using an LC-MS/MS system (SHIMADZU LC-MSMS-8040). For extraction and clean up procedures, the official QuEChERS AOAC Method 2007.01 (Lehotay 2007) was used with minor modifications (Bruzzoniti et al. 2014; Polat and Tiryaki 2019; Polat and Tiryaki 2020). Although Gökçeada Municipality applied insecticides to the sides, water surface and coastline of the lagoon in January and March 2016, we collected the samples before insecticide exposure and all samples were transferred to the laboratory, stored until analysis in September.

Sampling for Biotic Data

Phytoplankton, macroinvertebrates, benthic algae and bird species assemblages were derived from Aslan et al. (2018), but only lentic stations (TG2, TG3, TG4, TG5) were considered seasonally. One lotic station (TK1) was disregarded for aquatic species in this study (Fig. 1). Macrozoobenthos were sampled twice with a van Veen Grab (15 × 15 cm), benthic algae were collected with a glass tube with a diameter of 0.8 cm and a length of 10 cm, phytoplankton with a Hydro-Bios Free Flow Water Sampler (2.5 l) and a plankton net with a 20 µm mesh. Seasonal quantitative and qualitative zooplankton species have not been reported before. A plankton net with a 20 µm mesh size was used for zooplankton concurrently with sampling for other species. No zooplankton data were available during spring due to sampling limitations. All zooplankton samples were transferred to plastic bottles and fixed with 5% formalin. Terrestrial and waterbird monthly distributions for October 2015 to September 2016 were taken from Aslan et al. (2018). In this study, only waterbird species in GSL were observed in detail under the transect work and three more months including (September 2015 and October, November 2016).

Data Analyses

Univariate analyses were applied to characterize the community in terms of relative abundance and diversity. The Margalef richness index (d), Pielou evenness index (J') and Shannon-Wiener diversity index ($\log_e$ base) (H′) were calculated for each station and season.

A PCA analysis was performed for each season to ordinate samples both according to water temperature, salinity, TDS, conductivity and dissolved oxygen of surface water using four matrices (one per season) based on 'environmental variable x sampling sites' (standardized values, 5 parameters × 4 stations). Investigations into the environmental factors having a potential influence on the species distribution were carried out using the BIOENV routine (Clarke and Gorley 2015).

The numerical abundance data were analyzed using cluster and multidimensional scaling (MDS) techniques, based on Bray Curtis similarity, using the PRIMER package ver. 7.0 (Clarke and Gorley 2015). The cluster analysis was based on $\log_{10}(x + 1)$ transformation with the 'Taylor's Power Law' method concepts (Taylor 1961). The one-way ANOSIM permutation test was used to assess if significant differences existed among groups of sample sites as pre-defined by the cluster analysis. SIMPER analysis was performed to identify the percentage contribution of each species to the overall similarity/dissimilarity within each group as identified from cluster analysis. A RELATE test was also performed to find any relationships between the taxonomic groups. Spearman's rank correlation coefficient was used in order to determine correlations between biotic data.

Results

Abiotic Properties

The size of the study varied seasonally in response to changes in evaporative losses and flows into the lake. The area of the lake ranged from 194 ha in winter, then declinesd to 151 ha in early August and 100 ha in late September. During the fall station TG4 was dry. Salt formations emerged towards the end of summer. Salinity increased from 37.3‰ in spring to 185‰ in summer after which salinity declined to 158‰ in fall and 28.5‰ during winter. While maximum depth was 1.2 m in winter, it was only 20 cm during the summer and 1 m and 70 cm, at spring and fall, respectively. The average water temperatures that cause all these seasonal differences are recorded as average 12 °C in winter, 26 °C in spring, 32 °C in summer and 19 °C in fall. TDS and conductivity average values of water increased from 29 g/l to 135 g/l and 44 mS/cm to 259 mS/cm, respectively from winter to summer in accordance with the salinity values of the lake. The dissolved oxygen average values decreased sharply to 2.3 mg/l in the spring from 12.7 mg/l in winter and increased slightly to 3.5 in summer and 5.2 to fall. The BOD and COD values also increased from 0.1 mg/l and 9.4 mg/l to 146.7 mg/l and 253.6 mg/l in winter, respectively, in parallel with the decrease in DO values. PCA analysis results (Fig. 2) applied to the temperature, salinity, TDS, conductivity and dissolved oxygen variables confirmed seasonal changes. The first two PC axes together explained 92.8% of the variability, but the first axis contributed 71.9%. Whereas DO had negative correlation with the PC1 axis (−0.360), the rest of variables had stronger positive correlation with the PC1 axis (between 0.505–0.391). In the contrast, only temperature showed negative correlation with the second PC axis (−0.566) and had strongest positive correlation (0.617) with DO.

pH increased from 6.9 in winter to 7.9 in spring with the increase of macrophytes. The maximum suspended solids was measured in the summer as 1017.4, the minimum was 0.3 in winter. Chl-a values increased from 2.7 μg/l in winter to 11.8 μg/l in spring, then decreased sharply to 0.7 μg/l in summer.

Al, Fe, Zn, Pb, Co, Cd, Cu and Sb levels were higher in TK1 station in all seasons, showing that heavy metals enter the lagoon through artificial channels. It was found that the values of the other ions measured changed as a result of the bioactivity in the lake. Nutrients in water could only be analyzed during the fall. Nitrate were 17 ppm, nitrite was between 5 and 6.7 ppm, sulfate were 8492–8576 ppm and phosphate were 78 ppm (Supplementary Data 1).

Gökçeada was declared an organic agriculture island before the year of 2023, even though air spraying is not allowed, not only the farmers are using pesticides but also the Municipality is using insecticide to control specific Chironomid species to support tourism during the summer time. Pesticide levels in sediments are given in the Supplementary Data 2. According to the results, a total of 43 different pesticides were found in the GSL. Among them 17 were insecticides and acaricides, 9 fungicides and rest 17 herbicides.

Biotic Properties

In this study, a total of 29 waterbird species (10,908 individuals) were observed during 15 months. *Larus michahellis* (Yellow-legged Gull) was the only species that was continuously observed during the 15 months of observation, followed by *Tadorna ferruginea* (Ruddy Shelduck), which was observed for 12 months, and *Phoenicopterus roseus* (Greater Flamingo) and *Tadorna tadorna* (Common Shelduck) which were observed for 11 months. The highest number of individuals were Yellow-legged Gulls ($n = 4344$), followed by Greater Flamingos ($n = 4141$). The maximum number of individual Greater Flamingos ($n = 965$) occurred in June. In September (2015–2016), there were no other waterbird species other than Yellow-legged Gull. Low waterbird species richness and numbers were also documented in August, October and November (2016). The highest species richness occurred in May (12 species) and the highest species abundance occurred in June ($n = 2007$; Table 1).

Although a total of 23 macrozoobenthos species were found in the lake (Aslan et al. 2018), only 8 species were endemic to the lake when the freshwater channel results were omitted. Densities were low in winter (mean = 2 m^{-2}) representing 3 species. Densities and species richness increased in spring (33 m^{-2}, 8 species), declined in summer (1 m^{-2}, 1 species) and entirely disappeared in fall.

A total of 11 zooplankton species were identified from the study area. Whereas rotifers were dominant group with minimum abundance 73 cell/l in station TG4 and maximum

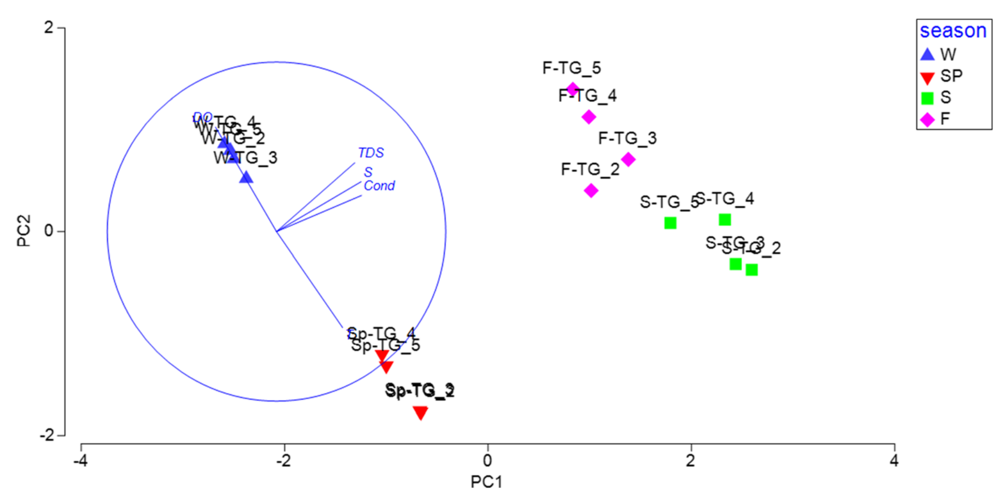

Fig. 2 PCA ordination plot derived from the abundance matrices of the biological samples (blue triangles: winter samples, red triangles: spring samples, green squares: summer samples and purple rhombus: fall samples) and vectors of environmental variables (blue lines)

Table 1 The waterbird species and abundances with the monthly results of the biotic index. *BERN Appendix II, d: Margalef richness index, J': Pielou evenness index H′: Shannon-Wiener diversity index

Species	Sep.15	Oct.15	Nov.15	Dec.15	Jan.16	Feb.16	Mar.16	Apr.16	May.16	June.16	July.16	Aug.16	Sep.16	Oct.16	Nov.16
Podiceps cristatus (Linnaeus, 1758)	–	–	–	–	–	–	–	–	1	–	2	–	–	2	–
Phalacrocorax carbo (Linnaeus, 1758)	–	–	–	30	–	–	–	–	–	–	–	–	–	–	–
Ardea alba Linnaeus, 1758	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–
Ardea cinerea Linnaeus, 1758	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–
**Egretta garzetta* (Linnaeus, 1766)	–	–	–	–	–	–	–	2	–	–	–	–	–	–	–
**Phoenicopterus ruber* Linnaeus, 1758	–	366	83	114	273	368	470	325	532	965	586	–	–	–	59
**Tadorna ferruginea* (Pallas, 1764)	–	670	230	45	98	39	33	41	228	448	90	12	–	–	140
**Tadorna tadorna* (Linnaeus, 1758)	–	32	35	236	67	156	55	106	74	307	46	4	–	–	–
Anas platyrhynchos Linnaeus, 1758	–	38	–	60	42	–	–	33	42	44	–	–	–	–	–
Anas penelope Linnaeus, 1758	–	–	–	–	70	26	–	–	–	–	–	–	–	–	–
Aythya ferina (Linnaeus, 1758)	–	–	–	8	–	–	−165	–	–	–	–	–	–	–	–
Haematopus ostralegus Linnaeus, 1758	–	–	–	–	–	–	–	–	2	–	–	–	–	–	–
**Himantopus himantopus* (Linnaeus, 1758)	–	–	–	–	–	–	–	–	–	–	2	–	–	–	–
**Recurvirostra avosetta* Linnaeus, 1758	–	–	–	–	–	12	6	–	–	–	–	–	–	–	–
**Charadrius dubius* Scopoli, 1786	–	–	–	–	12	14	22	2	10	15	8	–	–	4	5
**Charadrius hiaticula* Linnaeus, 1758	–	–	–	–	–	–	–	–	2	–	–	–	–	–	–
**Charadrius alexandrinus* Linnaeus, 1758	–	–	–	–	–	6	–	2	–	–	3	–	–	–	–

Table 1 (continued)

Species	Sep.15	Oct.15	Nov.15	Dec.15	Jan.16	Feb.16	Mar.16	Apr.16	May.16	June.16	July.16	Aug.16	Sep.16	Oct.16	Nov.16
Pluvialis apricaria (Linnaeus, 1758)	–	–	–	–	–	–	–	–	–	–	–	–	–	3	–
Pluvialis squatarola (Linnaeus, 1758)	–	–	–	–	13	–	315	–	4	6	–	–	–	–	–
**Calidris alba* (Pallas, 1764)	–	–	–	–	26	–	8	–	31	–	–	–	–	–	–
**Calidris minuta* (Leisler, 1812)	–	–	–	–	32	–	–	–	–	–	–	–	–	–	–
**Calidris alpina* (Linnaeus, 1758)	–	–	–	–	–	–	4	–	–	–	–	–	–	–	–
Gallinago gallinago (Linnaeus, 1758)	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–
Numenius arquata (Linnaeus, 1758)	–	–	2	–	–	–	–	–	2	–	–	–	–	–	3
Tringa totanus (Linnaeus, 1758)	–	–	–	–	–	–	13	–	–	–	–	–	–	–	–
Tringa nebularia (Gunnerus, 1767)	–	–	–	–	–	–	–	4	–	2	–	–	–	–	–
**Larus audouinii* Payraudeau, 1826	–	–	–	–	–	39	–	–	–	–	44	–	–	–	–
Larus michahellis J.F. Naumann, 1840	30	26	365	456	390	940	152	222	414	220	320	95	68	18	230
**Acrocephalus scirpaceus* (Hermann, 1804)	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–
Total individuals	**30**	**1132**	**515**	**678**	**858**	**947**	**913**	**742**	**1342**	**2007**	**1101**	**111**	**68**	**27**	**437**
Number of species	**1**	**5**	**5**	**7**	**10**	**11**	**11**	**11**	**12**	**8**	**9**	**3**	**1**	**4**	**5**
d	0,00	0,57	0,61	0,88	1,30	1,36	1,28	1,43	1,53	0,92	1,14	0,42	0,00	0,91	0,66
J		0.61	0.70	0.73	0.76	0.51	0.65	0.52	0.59	0.65	0.56	0.45		0.71	0.66
H	0,00	0,98	1,12	1,42	1,75	1,23	1,49	1,24	1,47	1,36	1,24	0,49	0,00	0,99	1,06

abundance 389,667 cell/l during the winter, they were absent at the other sampling seasons. Also, during the winter season 537,105 zooplankters representing 6 species were present. No zooplankton were present during the summer and 175 individuals of 8 species were obtained in fall. However, no sampling could be made in spring (Supplementary Data 3).

In the fall when there were no macrozoobenthos species and the lowest species and specimens number of birds and zooplankton in the lake, the phytoplankton abundance reached a maximum of avarage 52,291 cells/l. *Gyrosigma attenuatum* (Kützing) Rabenhorst 1853, *Chlamydomonas reinhardtii* P.A.Dangeard 1888, *Dunaliella viridis* Teodoresco, 1905, *Cryptomonas ovata* Ehrenberg, 1832, *Plagioselmis nannoplanctica* (H.Skuja) G.Novarino, I.A.N.Lucas & S.Morrall, 1994, *Teleaulax acuta* (Butcher) D.R.A.Hill, 1991 and *Prorocentrum cordatum* (Ostenfeld) J.D.Dodge, 1975 developed from after August and reached highest abundance in November and caused a bloom. While a total of 10,786 cells were detected in 20 species in winter, 95,770 cells in 5 species were counted in spring. All these species, which did not withstand high salinity, disappeared, and

1354 cells of *Ulnaria danica* (Kützing) Compère & Bukhtiyarova, 2006 species known to be tolerant to salinity were found in the summer sampling. The number of species of benthic algae detected at the stations sampled in the lake was found to be 13 in winter and decreased to 7 in spring and 3 in summer and increased to 8 in fall.

During fall, when macroinvertebrates were absent and waterbird abundances were minimal, phytoplankton bloomed leading to an increase in zooplankton (Fig. 3). Grazing by zooplankton reduced phytoplankton densities somewhat while declines in salinity were accompanied by increases in macroinvertebrates and birds in winter (Fig. 3). During spring, phytoplankton remained abundant along with macroinvertebrates and waterbirds. In summer, macroinvertebrates were generally absent (except at TG3) while zooplankton were also absent and both phytoplankton and waterbird abundances were low (Fig. 3).

In terms of diversity indices, richness (d) ranged from 0 to 1.7; evenness (J) ranged from 0.03–0.93; and the Shannon-Weiner (H) raned from 0 to 2.01 among all taxa. According to the Spearman's rank correlation, the number of waterbird species had a strong positive correlation ($p < 0.01$) with species number ($r = 0.862$), abundance ($r = 0.827$) and richness, evenness, Shannon-Wiener diversity ($r = 0.607$, $p < 0.05$) of zoobenthos. Moreover, bird abundance was strongly correlated with zoobenthos abundance ($r = 0.741$, $p < 0.01$) and species richness ($r = 0.689$, $p < 0.05$). At the same time, species number of birds have a correlation with species number of benthic algae ($r = 0.700$, $p < 0.05$). Furthermore, species number ($r = 0.624$), richness ($r = 0.602$), evenness ($r = 0.602$) and diversity ($r = 0.602$) of zoobenthos has correlations ($p < 0.05$) with species number of benthic algae. Species number of benthic algae also has correlations ($p < 0.05$) with abundance of zooplankton ($r = 0.858$) and phytoplankton ($r = 0.628$). In addition, species number of zooplankton has positive correlation with phytoplankton abundance ($r = 0.896$, $p < 0.01$), evenness ($r = 0.877$, $p < 0.01$) and diversity ($r = 0.827$, $p < 0.05$). Result of the RELATE analysis birds and zoobenthos have a high relate ($r = 0.424$, $p = 0.04$).

The n-MDS analysis applied to the total abundance of waterbirds, invertebrate, zooplankton, phytoplankton and benthic algae by season as a factor can be seen in the Fig. 4.

While the waterbirds of the lake were rich in terms of species and abundance between December and July, there was a significant decline in the number of waterbirds due to the biological life that changed in parallel with physicochemical structure of the lake between August and November as can be seen in the n-MDS (Fig. 4). According to ANOSIM, the rate of dissimilarity among the two groups (September in 2015 and August, September, October in 2016 were group one, the rest of the other months were consisting on the group two) was statistically significant ($R = 0.98$, $p = 0.02$). *Phoenicopterus roseus* (Greater Flamingo), *Tadorna ferruginea* (Ruddy Shelduck) and *T. tadorna* (Common Shelduck) caused the dissimilarity according to SIMPER.

According to one-way ANOSIM results, zooplankton ($R = 0.986$, $p = 0.005$), phytoplankton ($R = 0.847$, $p = 0.001$) and benthic algae ($R = 0.761$, $p = 0.001$) differed significant depending on season, whereas no significant differences were found for invertebrates ($p > 0.05$). Result of a pairwise test and SIMPER analysis applied to the total abundance of zooplankton, phytoplankton and benthic algae for significant differences among sampling stations are shown in Table 2. ANOSIM results showed significant difference ($p < 0.05$) for phytoplankton except between Spring and Fall, all other seasons were significantly different ($p < 0.05$) and, most discriminating species were *Gyrosigma acuminatum* (Kützing) Rabenhorst, 1853, *Leptolyngbya fragilis* (Gomont) Anagnostidis & Komárek, 1988*, Ulnaria danica, Chlamydomonas reinhardtii, Cryptomonas ovata*; benthic algae were statistically significant only between Winter and Summer ($p = 0.029$); *Gyrosigma acuminatum* and *Epithemia sorex* Kützing, 1844 were most discriminating species for these seasons using SIMPER. A pairwise test showed no significant differences among seasons.

The BIOENV procedure shows that the best combination of environmental variables (T, S, TDS, DO and conductivity) with the highest negative correlation with zoobenthos fauna ($p < 0.05$). Also, Spearman correlation was used to determine the relationships between heavy metals, ions, elements and the species abundance. However, the results were not significant.

Discussion

Despite the small size of GSL (average 2 km^2) the system experiences large seasonal fluctuations in its biological and chemical characteristics due to precipitation, evaporation, and winds. The most significant changes determined by this study (2015–2016) were 20 cm −1.20 cm of water level, 1.1 to 2 km^2 in surface area, 12 °C- 32 °C in temperature, salinity from 28.5‰ to185‰ and 2.3 mg/l to 12.7 mg/l dissolved oxygen. Ak et al. (2008) reported the sea level change was from 50 cm to 150 cm, temperature was from 7.6 °C to 29.2 °C and salinity was from 49.55‰ to 206.61‰ by seasonally in 2005 and 2006. When the results of the studies which were carried out 10 years apart were compared, GSL became shallow, warmed up and salinity decreased significantly. Back 40 years ago, settlers of the island obtained their salt from GSL, but there is no more salt today. Meanwhile, in the Eskandari study (Eskandari 2014), where *Artemia* species from GSL were reported, the Salt Lake was shallower (depth 10–85 cm) and less salty (between 18 and 53‰) in 2009–2010 sampling period.

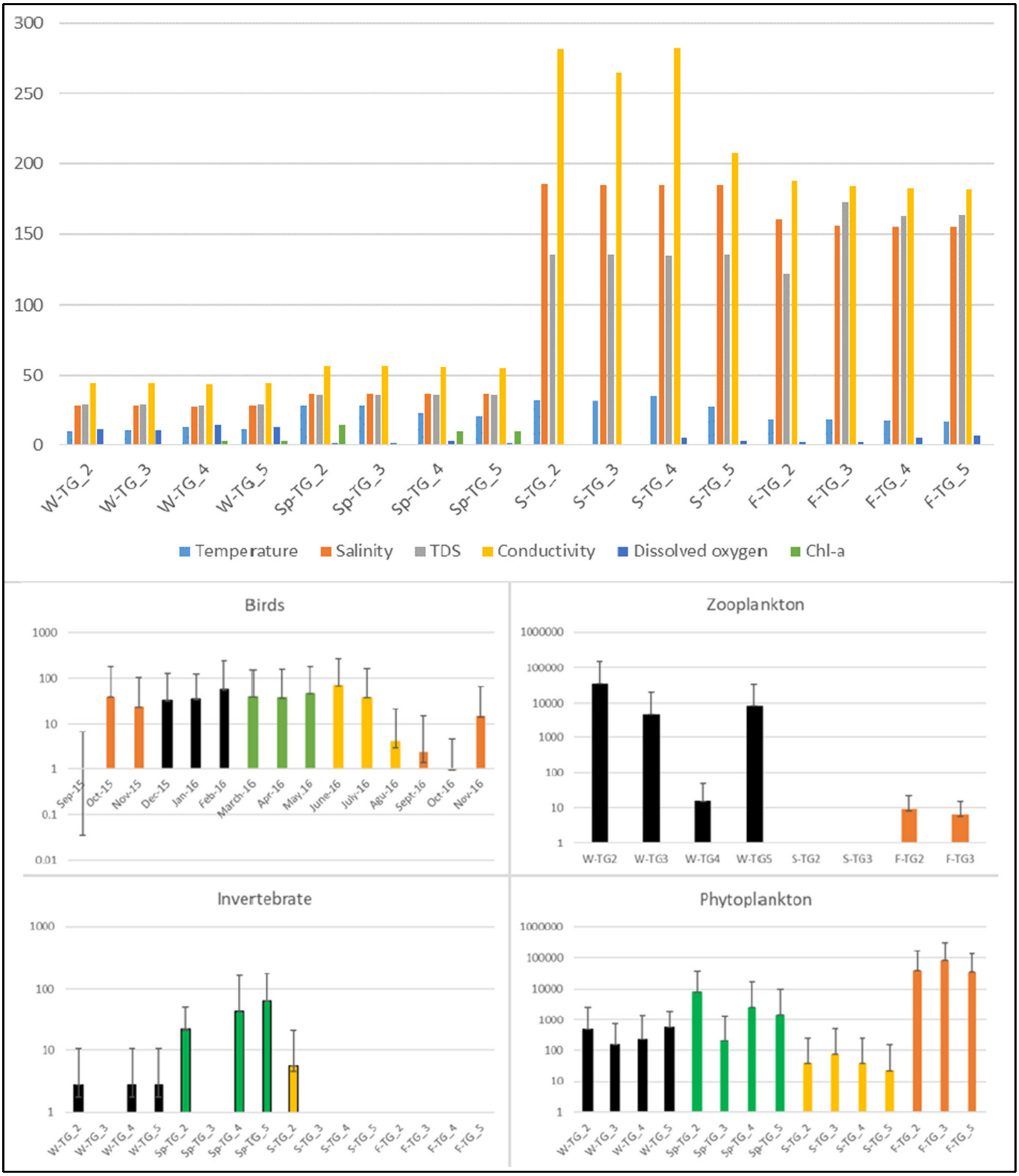

Fig. 3 Seasonal histograms showing the temperature (°C), salinity (‰), TDS (g/l), conductivity (mS/cm), dissolved oxygen (mg/l), Chl-a (μg/l) and logarithmic abundances of the biological groups: birds, zooplankton, invertebrates and phytoplankton. Black bars: winter, green bars: spring, yellow bars: summer, orange bars: fall

The decrease in salinity of GSL caused *Chironomus* species to increase, our results are in agreement with those of Belyakova et al. (Belyakova et al. 2018). However, the tourism sector considers this situation a problem for their visitors. GSL is located in Aydincik Bay (Kefalos), a very attractive destination for tourists with abundant hotels. Major

Fig. 4 The n-MDS analyses of the biological groups: birds, zooplankton, invertebrates, phytoplankton and benthic algae which are derived from the Bray-Curtis Similarities and samples are grouped by factors as seasons (blue triangles: winter samples, red triangles: spring samples, green squares: summer samples and purple rhombus: fall samples)

human activities from tourism are: swimming, sun bathing, SCUBA, wind and kite surfing. The tourism establishments in the region considered the flies a "nuisance", and opened a channel connecting GSL to the sea to "eliminate flies" during the summer months, starting 2010. They thought continuous entry of sea water higher in salinity then to GSL would decrease the fly population. On the other hand, our results showed heavy metal and pesticide pollution loads in GSL sediment, from land sources of artificial channels, clover agriculture and leaks from the wild waste collection area just 1 km away. Herbicides, fungicides and acaricides were used throughout the year in agriculture around GSL, furthermore insecticides are applied by the municipality as described in detail in Material and Method. These anthropogenic impacts

Table 2 Results of the SIMPER protocol of different biological groups according to the results of one-way ANOSIM and systematic groups with significant differences by seasons

Taxa	Groups	One-way ANOSIM		SIMPER		
		R value	*P* value	Average Dissimilarity (%)	Discriminating species	Contribution (%)
Phytoplankton	W vs Sp	0.75	**0.029**	100	*Gyrosigma acuminatum* *Leptolyngbya fragilis*	17.93 16.19
	W vs S	1	**0.029**	100	*Gyrosigma acuminatum* *Ulnaria danica*	21.68 17.73
	W vs F	1	**0.029**	93.26	*Chlamydomonas reinhardtii* *Cryptomonas ovata*	13.69 12.75
	Sp vs S	0.75	**0.029**	100	*Leptolyngbya fragilis* *Ulnaria danica*	36.22 34.5
	Sp vs F	1	0.057	100	*Chlamydomonas reinhardtii*	15.45
	S vs F	1	**0.029**	100	*Chlamydomonas reinhardtii* *Cryptomonas ovata*	17.26 16.08
Benthic algae	W vs S	0.99	**0.029**	87.56	*Gyrosigma acuminatum* *Epithemia sorex*	23.66 21.21
	W vs Sp	0.75	0.067	92.25	*Gyrosigma acuminatum*	13.44
	W vs F	0.929	0.067	89.77	*Gyrosigma acuminatum*	17.23
	Sp vs S	0.839	0.067	97.70	*Epithemia sorex*	20.01
	Sp vs F	0.125	0.66	91.96	*Epithemia sorex*	14.64
	S vs F	0.536	0.13	50.47	*Entomoneis ornate*	20.61
Zooplankton	W vs S	1	0.067	100	*Polyarthra* sp.	34.74
	W vs F	0.964	0.067	73.99	*Polyarthra* sp.	28.37
	S vs F	1	0.33	100	Harpacticoida	18.03

W Winter, *SP* Spring, *S* Summer, *F* Fall. *P* values lower than %5 are indicated bold.

on the aquatic ecosystems caused deteriorations in water quality and likely damaged biodiversity. For example, during the monitoring period of this study we observed 50 skeletons of large flamingos, abundant dead amphipods, and some dead crabs (*Carcinus maenas*) and barnacles (*Balanus* sp.).

Heavy metal levels were found within allowed limits for Pb, Cr, Cu, Ni, Zn, Co, and Ba as per Turkey Soil Pollution Control Regulation (SPCR, 2019) while Cd levels were very high in the canal during winter sampling. Also, the values of Na and Cl were very much higher than values permitted by the SPCR. Each pesticide may have different half-lives in the water column and in the sediment (http://npic.orst.edu/factsheets/half-life.html). They could have been analyzed even though 6 months after sampling. Among 190 different kind of pesticides, total of 43 pesticides were detected in the sediment at ppt levels in the GSL's sediment. Although it is below LD_{50} values (ppm) for birds and mammals (https://sitem.herts.ac.uk/aeru/ppdb/en/atoz.htm), pesticides tend to bioconcentrate, bioaccumulate and biomagnify and are transferred to higher trophic levels through the food chain. Even at low concentrations in the sediment or water, their presence may lead to chronic toxicity in non-target organisms like vertebrates, invertebrates and even in humans. For this reason, heavy metals and pesticides should be monitored in biota. The concentrations of heavy metals and pesticides in the GSL sediments are very relevant to public health given that they are marketed as having therapeutic properties. Our results showed that the mud should not be used therapeutically.

A total of 78 species (28 benthic algae, 31 phytoplankton, 11 zooplankton and 8 invertebrates) were detected from four GSL stations in this study; however 157 species (134 species aquatic flora, 23 species zoobenthos) were reported by Aslan et al. (2018) due to one more station located in the channel (station TK1) as a lotic biotope. The channel feeding the GSL has 15 unique invertebrates, 66 phytoplankton and 9 benthic algae species as different from GSL. Due to differences in species salinity tolerances the lower salinity of the channel supported a different species assemblage from the GSL. Differences in number of species and their abundance were recorded seasonally. The number of individuals in the species decreased from winter to summer (species number: 40 in winter, 20 in spring, 5 in summer; abundance: 145079 in winter, 96,030 in spring, 145 in summer) and tendency to increase in fall with 23 species and 162,193.

Rotifera species, *Polyarthra* sp., predominant zooplankton in GSL during winter sampling, retreated in summer and fall when salinity increased. In agreement Bielańska-Grajner and Cudak (2014) reported low salinity tolerance of rotifers.

Chironomus plumosus (Linnaeus, 1758), a widely distributed species worldwide, (Giberson et al. 2001), is reported from GSL for the first time in this study. Reached highest frequency among macrozoobenthos species. *Chironomus salinurus* Kieffer, 1915, reported by Özkan (2006) was not observed in the present study. Even in summer, the species found in TG2 station with only very low DO levels (1.2 mg/l) are in agreement with Nagell and Landahl (Nagell and Landah 1978), surviving even under anoxic conditions. While no zooplankton species were recorded in summer, macrozoobenthos species disappeared in fall. Amphipod deaths were abundant in summer, when the lake was dry.

Zooplankton and phytoplankton abundances varied inversely in winter and all suggesting that zooplankton grazing regulates phytoplankton abundance. Whereas total of 134,276 zooplankton and 10,786 cells/l phytoplankton were present during the winter, 1,621,025 cells/l phytoplankton and only 88 cells/l zooplankton were found during fall in GSL, so it can be inferred that zooplankton has a grazing effect on phytoplankton and controlled phytoplankton abundance. The average Chl-a varied seasonally from the lowest 0.91 μg/l to highest 11.8 μg/l in numbers, showing some compatible fluctuations with previous studies (Eskandari 2014). In spring, phytoplankton abundance reached 95,770 cells/l and Chl-a had highest value: 11.8; however, DO was the lowest (2.24 mg/l). The reason of high Chl-a and low DO is highly likely due to light limitation for photosynthesis. High rates of phytoplankton production was dependent on abundant nutrients. However, algae can produce oxygen only when there is enough light (Wetzel 2001). When enough light is not available, algae stop producing oxygen, switch to oxygen consumption and finally die (Schindler 2006), leading to oxygen depletion with bacterial decomposer activity. Atmospheric conditions and higher riverine input reduced water transparency in spring, limiting photosynthesis in GSL. The high TDS (40830) and high BOD values (146.7 mg/l) support this process. On the other hand, in fall when phytoplankton are highest, Chl-a was very low (0.91 μg/l). Decreases both in total Chl-a and carotenoid content associated with increased light intensity. Culture growth was fast at higher light intensity; therefore, pigment accumulation could not be promoted (Ak et al. 2008). Furthermore, Chl-a and carotenoid content of the cultures decreased with increasing salinity. Another possibility is that the lower Chl-a could be because of smaller cryptoflagellates and chlorophyte species in this period. Those tiny flagellate phytoplankton species have lower biomass compared to diatoms and other larger species (Peter and Sommer 2012). SIMPER statistical protocol suggested that most discriminating species in fall were *Chlamydomonas reinhardtii* and *Cryptomonas ovata*, whereas the fall was the only period where diatoms were not dominant in phytoplankton community. Chlorophyll content varies greatly among different phytoplankton species as well as light conditions and growth rates (Álvarez et al. 2017). Salinity tolerant diatoms such as *Gyrosigma acuminatum* and *Ulnaria danica* prevailed in the phytoplankton community especially in summer and fall during high salinity. These results are compatible with optimal salinities of diatom species as calculated by Potapova (2011). Among the others, salinity tolerant chlorophytes (*Chlamydomonas reinhardtii* and *Dunaliella viridis*) or marine cryptophytes (*Cryptomonas ovata*, *Prorocentrum nannoplanctica* and *Teleaulax acuta*) and marine dinoflagellate (*Plagioselmis cordatum*) were in succession in fall.

Birds provide important ecosystem services such as seed dispersal, pollination, pest control, carcass and waste disposal, nutrient deposition and ecosystem engineering (Sekercioglu 2006). It is very important to understand the factors that affect the habitat use of waterbirds in determining the ecological conditions of wetlands today and in the future (Amat and Green 2010; Zhang and Ma 2011; Castro-Tavares et al. 2015; Thompson-Ambriz et al. 2020). Water depth is an important factor for wading and dabbling waterbirds, furthermore shallow water enhances foraging efficiency. High salinity is another important factor for waterbirds which can adversely impact body mass via dehydration and reducing feather water proofing. Salinity is also very important for aquatic vegetation and those zoobenthos that constitute waterbirds prey as well as dissolved oxygen and other water and sediment quality parameters (Ma et al. 2010). Shallow GSL is a good case to test which of these features are more important for the distribution of waterbirds.

MDS analysis suggested that October 2015 and 2016 were quite different in terms of waterbirds. Both abundance ($n = 1132$) and species richness ($n = 5$) were higher in 2015 relative to 2016 ($n = 27$, $n = 4$, respectively). *Larus michahellis* was the only species present in both years. Heavy rainfall (~141.8 mm/m^2) fell between October 22 and October 24, the day when the birds were counted. In contrast there was no rain throughout October 2016 (General Directorate of State Hydraulic Works). Waterbird abundance has been correlated with precipitation (Haig et al. 2019) and Herrando et al. (2019) reported that precipitation was the most significant parameter for birds in the Mediterranean area. In the GSL, our statistical analysis suggests that water quality has a significant impact on zooplankton, which in turn, affect waterbird abundances. Many waterbirds are highly mobile and the GSL may serve as an important stopover for species crossing the Aegean Sea. While *Larus michahellis* and *Tadorna ferruginea* were residents, other species were present only in summer or winter as migrants. Thus the GSL can be considered a Special Protection Area (SPA) under the NATURA 2000 criteria because of the high numbers of *Phoenicopterus roseus* (>600), *T. ferruginea* ($n > 200$) and *L. michahellsi* ($n > 575$). Fourteen species (Table 1) are in Appendix II of the Convention on the Conservation of European Wildlife and Natural Habitats (BERN). *Aythya ferina* is “Vulnerable”, while the rest of the species are “Least Concern” in the IUCN Red List of Threatened Species.

Turkey hosts one of the largest flamingo populations of the Mediterranean region with up to 19,000 breeding pairs in 2005 in two colonies, the Gediz Delta and Tuz Lake (Balkız et al. 2007). Flamingos are adapted to use shallow wetlands where water levels are highly variable (Amat 2005). While there were no flamingos in August, September and October, there were 965 individuals observed during daylight in July 2016. Although GSL is not a breeding site for flamingos, a few chicks were reported during the study. They are very sensitive birds to human presence, they gather in the lake when nobody is present, otherwise they fly to different wetlands. Amat et al. (Amat 2005) reported flamingos to travel 500–640 km in one night and stop to rest for a few hours in small wetlands during long-range movements between major wetland complexes. Wetlands on migration routes are important stations for migratory routes for many bird species that will have difficulty crossing the vast distances connecting sites in the Aegean Sea during migration. Ayvalık Salt marshes were reported to host total 850 flamingos in winter (https://www.tarimorman.gov.tr/DKMP) and Suvla Salt marshes 28 individuals in September 2015 (personal communication with İbrahim Uysal). Gökçeada Salt Lake appears to be a stopover for flamingos during migration between breeding habitats in Gediz and Gala Lakes. During dispersal or migration, wetland connectivity may depend not only on the distance between two sites, but also on the presence of stepping-stones, whose protection may be essential to facilitate very long-range movements. The conservation of such stopover sites may contribute to metapopulation persistence (Amat 2005).

Conclusions

Although under wetland conservation status, Gökçeada Lagoon faces multiple, serious environmental problems: increases in human population during summer, surfing activities, uncontrolled tourism, domestic waste and sewage from settlements, pesticides, and seasonal environmental factors such as global warming and dessication (or hypersalinization), among others. In wetlands subject to environmental variations and fluctuations, responses may vary among constituent species. Monitoring programs can provide a general view; however, the use of a single bioindicator may not provide information on changes in other taxa. Therefore, an integrated biodiversity monitoring together with environmental quality assessment should be preferred instead of monitoring only one taxa or organism group. We have provided the case of GSL as a model for holistic management and environmental quality evaluation. Our study also serves the decision making process, regulatory agencies and invites further regional and international level collaboration.

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