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Original article

Aquatic ecosystem health and trophic status classification of the Bitter Lakes along the main connecting link between the Red Sea and the Mediterranean

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ABSTRACT

The Bitter Lakes are the most significant water bodies of the Suez Canal, comprising 85% of the water volume, but spreading over only 24% of the length of the canal. The present study aims at investigation of the trophic status of the Bitter Lakes employing various trophic state indices, biotic and abiotic parameters, thus reporting the health of the Lake ecosystem according to the internationally accepted classification criteria's. The composition and abundance of phytoplankton with a dominance of diatoms and a decreased population density of 4315–7376 ind. l^{-1} reflect the oligotrophic nature of this water body. The intense growth of diatoms in the Bitter Lakes depends on silicate availability, in addition to nitrate and phosphate. If the trophic state index (TSI) is applied to the lakes under study it records that the Bitter Lakes have an index under 40. Moreover, in the total chlorophyll-*a* measurements of 0.35–0.96 $\mu g\, l^{-1}$ there are more indicative of little algal biomass and lower biological productivity. At 0.76–2.3 $\mu g\, l^{-1}$, meanwhile, the low quantity of Phosphorus is a further measure of low biological productivity. In the Bitter Lakes, TN/TP ratios are high and recorded 147.4, and 184.7 for minimum and maximum ratios, respectively. These values indicate that in Bitter lakes, the limiting nutrient is phosphorus and confirm the oligotrophic status of the Bitter Lakes. The latter conclusion is supported by Secchi disc water clarity measurements, showing that light can penetrate, and thus algae can photosynthesize, as deep as >13 m. This study, therefore, showed that the Bitter Lakes of the Suez Canal exhibit oligotrophic conditions with clear water, low productivity and with no algal blooming.

1. Introduction

The quality of the water and the health of the aquatic ecosystem of lakes are very sensitive issues and lakes in different regions of the world particularly in developing countries are facing a variety of problems associated with anthropogenic activities and unsustainable use of their resources.

Monitoring and assessing the aquatic environment for eutrophication is essential to mitigate or prevent adverse environmental and economic impacts (Devlin et al., 2011; Napiórkowska-Krzebietke and Hutorowicz, 2014). To ensure the environmental health of aquatic ecosystem including lakes, different regulatory instruments are in place across the regions and the world. The Water Framework Directive 2000/60/EC is one such example demanding the European Union (EU) member states to assess the ecological state of their lake waters, and it has become the guiding principle in other countries as well (Mischke et al., 2008; Kaiblinger et al., 2009; Hutorowicz et al., 2011; Phillips et al., 2013), although it is adopted with some modifications in other areas (Hutorowicz and Pasztaleniec, 2009, 2014). The environmen-

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tal health of any lake system is essentially determined through its trophic status; basically on a classification scale for how productive the lake is. Such a trophic status is calculated by exploiting a combination of quality parameters like water clarity and light penetrance; chlorophyll-*a* concentration, as a measure of algal activity and phosphorus concentration, an essential nutrient needed by aquatic plants and algae to grow. The protocol classifies lakes as eutrophic, mesotrophic or oligotrophic (Gholizadeh et al., 2016). The dynamic nature of the productivity and eutrophication due to natural and anthropogenic factors leaves no single assessment variable as a true measure of the eutrophication status of a given water body (Xu et al., 2001; Padisák et al., 2009) and a combination of physical and chemical parameters are widely used in determining the health of a lake ecosystem (Phillips et al., 2013).

The bitter lake has attracted the attention of researchers and many studies have focused on different aspects of natural, biological and socio-economic aspects of the lake (Ghazzawi, 1939; Heimdal, et al., 1977; Dorgham, 1985; Nassar and Shams El-Din, 2006; Hamed et al., 2012; El-Serehy et al., 2014; Nassar and Fahmy, 2016). The lake system together with the Suez canal are not merely an ecosystem on environmental value, rather these are efficient shipping routes (Schøyen and Bråthen, 2011; Baccelli et al., 2015; Galal, 2015; Galil et al., 2015) greatly shortening the voyage and contributing to the nature conservation on a broader environmental spectrum. In the wake of new and emerging needs and development, activities and potential biological impact in spread on invasive species (Elton, 2000; Galil et al., 2015), together with changing hydrological and thermal regimens (Ahmad and Kaiser, 2014) a focused research was indicated. Especially concerning the trophic status of the Bitter Lake using diverse criteria.

Phytoplankton, both in lotic and lentic environments are considered to be a reliable measure of environmental health reporting on different levels of eutrophication (Wetzel, 1983; Xu et al., 2001; Soylu and Gönülol, 2010; Ferreira et al., 2011; Demir et al., 2014), however with different levels of accuracy. Carlson's Trophic State Index is invariably used as a standard tool with sound foundation (Xu et al., 2001) in quantitative estimation of productivity and status of lakes on spatial and temporal basis (Rajashekar and Vijaykumar, 2008; Elmaci et al., 2009; Prasad and Siddaraju, 2012; Barki and Singa, 2014).

Recognizing the significance of the Bitter Lakes with regard to fishing, tourism, navigation in the Suez Canal especially in the presence of development agenda, it is important to classify the current trophic status using established and internationally accepted protocols to add to the existing knowledge and aid in future conservation efforts for the Bitter Lakes ecosystem. Here, we utilized information based on nutrient concentrations, nutrient ratio of N/P, Redfield ratio, chlorophyll *a* concentrations, Secchi disc water clarity measurements, trophic state indices (TSI) used by Carlson (1977), as well as, phytoplankton species composition and community structure in the Bitter Lakes as indicators to classify their trophic status.

2. Material and methods

2.1. Study area

Red Sea in the south is connected directly with the Mediterranean in the north via the Suez Canal. The Suez Canal water system, about 164 km long stretch of sea-level waterway includes several natural lakes. The Bitter Lakes (Great Bitter Lake and Little Bitter Lake) (Fig. 1) are considered significant, representing 85% of the water volume, although only spreading over 24% of the canal length. The lakes have exhibited somewhat unusual hydrological regimens since the canal was opened for navigation (Thorson, 1971). Table 1 summarizes the limnological parameters of the little and the Great Bitter Lakes of the Suez Canal. At the time when the canal was excavated and operational, in 1869, a massive salt deposit was found spread over the bottom of the Great Bitter Lake (Heimdal et al., 1977) that later covered the Little Bitter Lake as well, and subsequently has been gradually dissolved by the overlying water. The later has become high saline from surface salinity of 50–52‰ and at the bottom even higher (68–80‰) in 1869. Today salt deposit layered at the bottom has been washed away thus reducing the level of salinity to 43–44‰ at the surface and 45–46‰ at the bottom (El-Serehy et al., 2014). Table 1 summarises

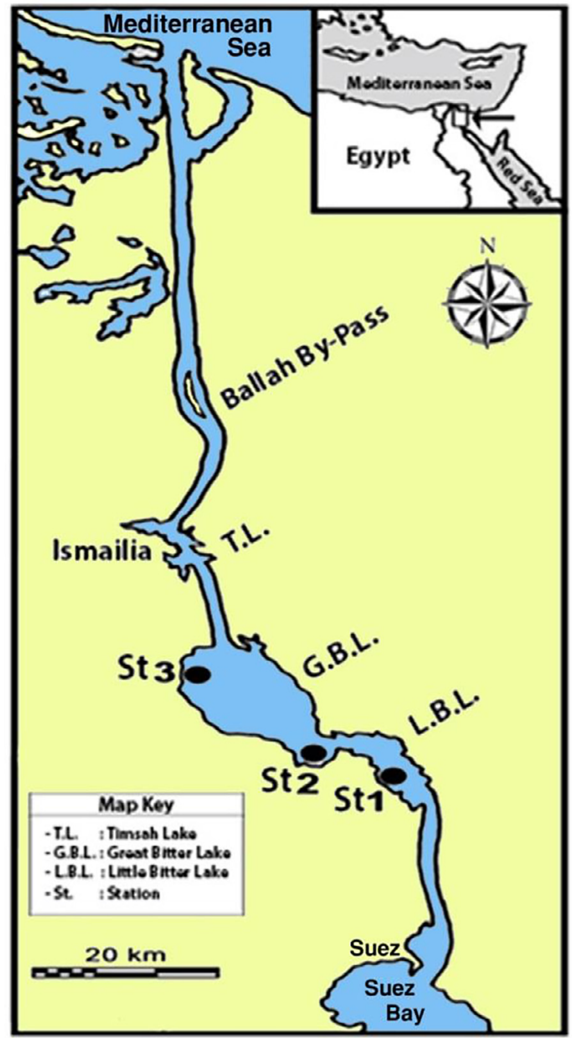

Fig. 1. The location of the three sampling sites in the Bitter Lakes on the Suez Canal. The inset shows the position of the Suez Canal as a link between the Mediterranean and the Red Sea.

Table 1
The limnological parameters of the Little and the Great Bitter Lakes of the Suez Canal.

Parameter	Little Bitter Lake	Great Bitter Lake
Surface area (m^2)	40×10^3	194×10^3
Maximum depth (m)	28	28
Mean depth (m)	11	18
Maximum length (m)	15,000	24,000
Maximum width (m)	2760	13,000
Maximum Secchi disc depth (m)	11.81	14.83

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