The Impact of Climate Change on the River Jordan-Lake Kinneret (Israel) Ecosystem

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Abstract

The long-term record of River Jordan-Lake Kinneret ecosystem indicates some significant climate condition changes: water temperature increase, decline in rainfall, and diminishing river discharges and lake water inflows accompanied by a reduction in nitrogen and a slight increase in phosphorus in the Lake upper layers (Epilimnion). Lake Water level decreased, Prolongation of Residence Time was documented, nutrient inputs and dynamics modifications resulting water quality deterioration. As a result of temperature elevation and nitrogen deficiency, the biomass of *Peridinium spp* significantly reduced and was replaced by Cyanobacterial biomass enhancement. Dryness trend expressed as enhanced frequency of drought seasons initiated an elevation of lake water salinity. It has been suggested that these changes in the phytoplankton community structure are caused by regional climate change. This study evaluates a multi-annual respective approach although the summer is the most critical. The objective of this research is evaluate the background of the ecosystem structure modification aimed at define future potential management design.

Keywords: Kinneret; Watershed; Climate Change; Nutrients; Hydrology; Phytoplankton

Introduction

Study Area

Lake Kinneret (Surface area-168 km²; Volume - 4 km³) and its watershed is part of the Northern section of the Syrian-African Great Rift Valley. The Watershed area (2730 km²) of Lake Kinneret is stretched between 32° 40’ and 33° 38’ North (Serruya 1978) [37]. The drainage basin length, directed North-South axis is 110 km. The Altitude gradient is between 2814 masl and 214 mbsl (average slope 2.75%).

The lake is located between 32° 42’ 15” and 32° 53’ 44” North and longitudes 35° 30’ 52” and 35° 38’ 55” East. Lake Kinneret is a warm monomictic lake which is fully mixed during cold and wet winter, from mid-December until early May. (Serruya et al 1978; Gophen and Gal 1992; Gophen 2019a) [15, 37, 44]. Three major headwater rivers (Hatzbani, Banyas and Dan) flow southerly downstream from the Hermon mountain region. The Hula Valley drainage (1950’s) changed the hydrological conditions: Jordan river crossing the Hula Valley splitting into two canals which joint at the south end of the Hula Valley flowing southerly downstream into Lake Kinneret maintain its Water Level (WL) (Gvirzman 2002; Givati and Rosenfeld 2007;Givati et al 2019; Gophen2018) [1,3,14, 23].

Limnological Features of Lake Kinneret

The lake is stably stratified from May through Mid-December. The content of anoxic Hypolimnion is rich with Ammonium, CO₂, and Sulfids. Stratification exist during May-early June and De-stratification take occur from mid October through Mid December. Lake management is aimed at water supply, commercial fishery, recreation, and tourism. Lake Kinneret is the only natural body of freshwater in Israel. (Serruya 1978) [37]. Water supply from Lake Kinneret (about 10⁶ m³ daily) is carried out through the National Water Carrier (inaugurated 10.6.1964) (Serruya et al 1980). [38] Since 2010 desalinization technology was implemented and lake water withdraw was significantly reduced leaving free volume for different consumers (Gophen 2019a) [15]. A dam was constructed at the south end of the lake in 1934. A salty springs diversion was operated in 1967 which caused together with heavy floods (1968-1969) lake water salinity decline from 400 ppm to 210 ppm Chloride. Since Mid 1980’s climate change conditions significantly affected the hydro-ecological trait of the ecosystem (Serruya 1978; Gophen 2016b; 2018) [10, 14, 37]. The significance of those modification are discussed in this paper.

Lake Kinneret supplies national multi-ecological services. Besides water supply and recreation, the lake is also exploited for fishing by about 200 licensed fishermen, who remove commercially an average of 1600 ton of fish (94 kg/ha) per
annum. Before the 2000’s the zooplanktivorous fish, Lavanun (Bleak, Acanthobrama sp.), comprises 55% by weight of total catches and over 50% of the stock biomass. Eight out of the 24 recorded species are commercial, with the native Tilapine, Sarotherodon galilaeus (Galilee St. Peters’s Fish; Hebrew: Amnoon Ha’Galil; Arabic Musht Abyad) (average of 326 t/year) the most important in the commercial landings. The protection of water quality and water level (WL) management are of national concern. The definition of uppermost and lowest WL maintenance is a significant part of the management policy. The WL definition is limited between two constraints – the highest 208.8 and the potential lowest of 215.00-but water quality and fishery management might deserve amplitude ranges in-between these two. Nevertheless, the present study is aimed at the impact of climate change on nutrient dynamics and the attendant consequences on the algal community structure, i.e. water quality (Serruya et al 1980; Gophen 2018) [38, 14].

**Globality of Climate Change and Cyanobacteria Outbreak**


**Material and Methods**

**Data Sources**

The long-term datasets (1970–2018) of Lake Kinneret and its watershed, including the water and air temperature, rainfall gauge, nutrient dynamics, lake plankton community structure, lake water level (WL) and river discharges (in mc/m, that is 10^6 m^3 per annum), (LKDB-IOLR 1969-2020; Gophen 1992; 2019a; Gvirzman 2002; Givati et al 2019) [3, 15, 23, 31, 44] were statistically evaluated. Data were obtained from the following sources: Annual Reports, Kinneret Limnological Laboratory, annual reports of the Israeli National Meteorological Service and the Israeli National Hydrological Service (National Water Authority). Other data sources were MIGAL, Hula Project Service (Gophen 2018) [14], Interim and Annual Reports by Mekorot Water Supply Company Ltd., Monitoring Unit Jordan District, Agriculture Ministry Northern Branch – Upper Galilee Office, and TAHAL Water Planning for Israel.

**Statistical Methods**

Statistical analyses (fractional polynomial regression, Linear Regression and simple averages, Line scattered) were carried out using STATA 9.1.

Statistical analyses (fractional polynomial regression) (FP) were carried out using STATA 9.1, Statistics-Data Analysis: Chapter Fracpoly-Frational, Polynomial regression StataCorp. 2005. Stata Statistical Software: Release 9. College Station TX: StataCorp LP.pp.357-370; See also: Royston, P. and D. G. Altman, 1994.) Regression using Fractional Polynomial of continuous covariates: Parsimonious parametric modeling (with discussion): Applied Statistics 43: 429-467.) The purpose of FPs is to increase the flexibility by the family of conventional polynomial models. Although polynomials are popular in data analysis, linear and quadratic functions are severely limited in their range of curve shape, whereas cubic and higher order curve often produce undesirable artifacts such as ”edge effects and “waves” (STATA 9).

**Sampling Procedures**

The sampling procedures (spatial, temporal and batimetrical program) for the analysis of phytoplankton biomass calculation and chemical parameters are available in LKDB-IOLR Co. Ltd. Jordan water samples were collected at the station located at Huri Bridge (Gesher Ha’Pakak). This sampling site is located downstream of the Hula Valley and 12 km to the north of the lake, and represents all historical water input quality used since 60 years of Lake Kinneret research, Information about sampling procedures (frequencies,location, sample treatment is given in (Serruya 1978; Givati et al 2019; Gophen 2018; 2019b, c; Gophen and Gal 1992; LKDB-IOLR 1969-2020) [3, 14, 16, 17, 31, 37].

**Results and Discussion**

**Climate Change: Temperature, Rainfall, River discharge:**

Figure 1: Temporal (1963-2011) trend of changes (LOWESS 0.8) of daily Maxima (upper) and Minima (lower) of air temperature (0°C) measured in Dafna station (northern Kinneret watershed).
Data given in Figure 1 indicates temperature decline between 1960-1980 and increase afterwards in the Kinneret watershed region. Consequently elevation of lake water temperature increase was documented (Figure 2). Several documentations of the relation between Temperature elevation and Cyanobacteria enhancements were published by Toth and Padisak (1986) [42] and Paerl and Huisman (2008) [35]. Since Mid-1980’s Rainfall decline (Figure 3) and consequently Headwaters discharge reduced (Givati et al 2019; Gophen 2018; Gophen 2019b,c) [3, 14,16,17] resulting Nutrient concentrations decline and consequently reduction of their loads in the river inflows (Figures 4,5,6).

Moreover, dryness trend enhancement increased frequency of drought season. Lake water inputs diminished, and Water level declined (Figure 7) and Thermal structure modified: Epilimnion became thinner by 4% and the Hypolimnion by 23.4% resulting Nutrient concentrations decline in the Epilimnion and increase in the Hypolimnion (Figures 8,9).

Figure 2: Trend of changes (LOWESS; 0.8) of annual mean Temperature of whole water column (left) and in the Epilimnion (right) in Lake Kinneret (1969-2008).

Temperature increase of 1.2 °C of lake Kinneret waters (whole water column and upper layer, Epilimnion) from mid-1980’s clearly indicates climate change.
Long term (1970-2020) trend of climate change confirmed by rainfall and river Jordan discharge decline is shown in Figure 3.

Figure 4: FP regression between nutrient (Total Kijeldhal, TN) concentrations (ppm) and Jordan River Discharge (mcm/y) (lower panels), and between Nutrient (Total Kijeldhal, TN) loads in Jordan River (ton/y) and years (upper panels).

Figure 5: FP Regressions between nutrients concentrations (ppm) and Years (right), and total loads (ton) and Jordan river Discharge (mcm/y) (left)

Figures 4 & 5 indicates the impact of climate change on Nutrients (Phosphorus, Nitrogen) inputs from the watershed into the Lake through Jordan River discharge: the decline of total loads (ton) and concentration (ppm) of total P, total N and Kijeldhal -N are shown.
Figure 6: Linear Regression (parameters are given) between River Jordan Discharge (m$^3$/s) and total Nitrogen load input through the Jordan flows. Calculated $r^2$ values for other nutrients are: TP - 0.596, TIN - 0.776, SO4 - 0.816, Org. N - 0.606, Chloride - 0.886 (p<0.0001).

Figure 7: Ten year Group averages of monthly means of water level in Lake Kinneret (1933-2018).
Table 1: WL Decline of 209-213 (4 m): Epilimnion volume reduction of 4% (from 1891 to 1814 mcm*) and Hypolimnion volume reduction of 23.4% (from 2411 to 1846 mcm*) *mcm=10^6 m^3

Data shown in Figure 6 indicates the linear relation between discharge and nutrient load capacities: the higher the discharge is the higher is he load inputs. Figure 7 and Table 1, represent the long-term decline of Water Level (WL) in Lake Kinneret.

The data given in Figure 8 indicates the different response of the Epilimnion and the Hypolimnion to Water Level decline: the Hypolimnion volume reduced by 23.4% and that of the epilimnion by 4.5% only. Moreover nutrient concentrations and total mass in the Hypolimnion increase and that of the Epilimnion decline (Figure 8 & 9). Date given in Figure 10 indicates the decline trend of Nitrogen stock in the Epilimnion and Hypolimnion and obviously in the whole lake. The resulted conditions of nutrient (P and N) stocks decline of Nitrogen, increase of Phosphorus and decrease of the TN/TP mass ratio. These long-term changes initiated conditions of Peridinium suppression whereas suitable for Cyanobacteria enhancement as shown in Figures 12, 13 & 14. Peridinium require Nitrogen and Cyanobacteria are able to incorporate atmospheric Nitrogen by Nitrogenase enzyme through Nitrogen fixation process. Therefore Peridinium disappeared and replaced by Cyanobacteria. A documentation of the invasion of the HFCB’s species Aphanizomenon ovalisporum (APO) was done by Hadas et al (2012) [25]. The impact of insufficient ambient Nitrogen accompanied by APO ability to maintain atmospheric Nitrogen fixation supported its invasion (Hadas et al 2012) [25]. The Nitrogen decline not only enhanced bloom of a Diazotrophic Cyanobacterium but also generated a modification of the Phytoplankton community structure in Lake Kinneret (Hadas et al 2015). [26] These kind of changes were widely studied: O’Neil et al (2012) [34] indicate HFCB domination as a symptom of Eutrophication. Essential consideration is given in many studies to the role of Nitrogen in association with Phosphorus availabilities to the outbreak of Cyanobacteria (GUILFORD and HECKY 2000; McQUEEN and LEAN 1987; SMITH 1983; FRISTACHI and SINCLAIR).

**Residence Time**

As a result of WL decline, nutrient concentrations in the Hypolimnion significantly increased whilst in the Epilimnion a minor change was documented (Figure 10, 11). Nevertheless, dissimilar developments of Epilimnetic Nitrogen and Phosphorus concentrations occur: Nitrogen concentration decrease, whilst Phosphorus concentration was partly stable and slightly increase by dust deposition (Nishri 2014) [33] and released from bottom sediments, therefore TN/TP mass ratio decline (Figure 11). The prominent consequence of climate change was Nitrogen insufficiency (Figure 10). Nitrogen depletion caused Peridinium suppression and enhancement of Cyanobacteria. Peridinium domination decline occur as a result of the ultimate demand for available Nitrogen by Peridinium, whilst Cyanobacteria recover Nitrogen insufficiency by Nitrogen fixation (Figures 12, 13). Water inflow decline affected WL decline and consequently prolongation of Residence Time (RT) which supported also enhancement of changes of nutrient dynamics and modification of Phytoplankton composition (Figure 14).

**Residence Time (RT) computation was as follows:**

\[
RT \text{ (in months or years)} = \frac{V}{W}
\]

Where:

\[
W = \text{Monthly inflow in mcm per month} \left(10^6 \text{ m}^3/\text{month}\right)
\]

\[
V = \text{Monthly values of lake Volume in mcm} \left(10^6 \text{ m}^3\right)
\]

Temperature increase and dryness enhancement and the increase of negative trend of Kinneret Water Balance caused elevation of lake water salinity making the need for RT shortening (water exchange) critical.
Figure 8: Comparison of Ammonium and Total phosphorus loads in the Epilimnion and Hypolimnion under 209 and 214 WL altitude.

Figure 9: Trend of Changes (LOWESS, 0.8) of Epilimnetic loads (ton) of Total Inorganic Nitrogen (upper right) and Total Nitrogen (upper left) and whole lake TNTP mass ratio (lower) in relation to WL fluctuations.

**Figure 10:** Decline of Nitrogen content in the Epilimnion (Red) and Hypolimnion (Blue) and whole lake of lake Kinneret (green) (1970-2005).

**Figure 11:** Trend of Changes (LOWESS); Whole lake loads of TN and TP (ton) and the Mass Ratio TN/TP; Annual averages of monthly means.

Figure 12: FP regression of Maximal values of Cyanobacteria biomass (g/m²) (HFCB: Harmful Cyanobacteria) and years In Lake Kinneret (1969 – 2016).

Figure 13: Relation between Peridinium Biomass and Epilimnetic concentration (ppm) of Total Nitrogen (Left) and the Temporal distribution of Peridinium biomass (right).

Figure 14: FP regressions between Residence Time Length (years) and Cyanobacteria (upper left), Peridinium (upper right) biomass (g/m²) and Epilimnetic load (ton) of total Nitrogen.
Figure 15: Polynomial Regressions ($r^2$ and $p$ are given) between annual averages of Epilimnetic salinity (Chloride, ppm) (1945 – 1965): Upper panel before winter rain floods in October and lower panel April at the end of winter inflows. heavy

Figure 16: Annual averages of salinity (Chloride, ppm) in Lake Kinneret during 1933 – 1989 (single value in 1913). South Dam construction and operation, salty springs diversion and heavy floods are indicated. During last 10 years values increased gradually up to 325 and heavy rain seasons in recent 2 years caused a decline to 269 presently (spring 2020).
Salinity

Another aspect of long term Climate Change development was the increased salinity of Lake Kinneret waters (as shown in figures 15 &16).

The major supply of salt into the lake is fluxed through the lake bottom through surface infiltration (superficial) and welling up. Salts contribution through rivers and tributaries inflows are much lower than the sub-lacustrine sources. Until late 1957 about 25% (total about 160000 tons) of salt input influxed into the lake through the runoff of two hot-salty springs located close to the north-western lake shoreline. Those two springs were diverted (1967) and about 40,000 tons of salt were eliminated from the lake budget (Serruya 1978; Gvirzman 2002; Gophen and Gal 1992; Gophen 2016b, 2018 ;)[10, 14, 23, 37]. As a result lake water salinity declined from 400 to 210 ppm Chloride. Results indicated that open Dam operation enhanced water replacement (exchange) (Gophen 2020a, b,c) [20, 21, 22] which is Residence Time shortening and salinity decline. It is therefore recommended to enhance water exchange (shorter Residence Time) through open Dam or pumping regime to remove salt and other pollutants (including biomass of Cyanobacteria (Figures 15, 16). Increase salinity might be favoured by Cyanobacteri (Tonk et al 2007) [40].

Summary

Precipitation decline followed by headwater discharge reduction caused high frequency of drought conditions Temperature increase and dryness enhancement Increase of negative trend of Kinneret Water Balance caused elevation of lake water salinity the need for RT shortening became critical, that is to say- water exchange enhancement is crucial

Future Perspectives Recommendations

A) Enhance Nitrogen input from the watershed (potential source: Peat soil)
B) Reduce Phosphorus inputs from the watershed
C) Enhance Water exchange i.e. shorter RT (potential implementation: Withdraw through an open Dam; input desalinized water).
D) Renovation of Fishery management: implement fishing pressure on the most common zooplantctivore fishes, Bleaks, enhance stocking of known efficient Cyanobacteria consumer, Silver Carp (not reproduce in Lake Kinneret).

References

15. Gophen M (2019a) Different Kinneret,Gilit Publisher and Migal, 158.p.(in Hebrew).
31. LKDB, 1970-2018, Kinneret Limnological Laboratory, IOLR, Annual Reports.
44. Gophen, M and I. Gal 1992; Lake Kinneret, Book; Defence Ministry and Kinneret Authority Publisher; 335 p.