

Precautionary Implications of Climate Change Impact on Lake Kinneret Water Quality

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ABSTRACT

Critical imperatives are considered with respect to the climate change impact on the Kinneret water quality. A positive correlation was found between nutrient (nitrate excluded) concentrations and the rate of headwater discharges (River Jordan), which creates erosion action that is respectively related to rainfall. The impact of rainfall capacity on underground aquifers and influx of sub-lacustrine salty fluxes into the lake, maintaining the lake's saline load. Enhancement of Bleak fish populations and consequently intensification of zooplankton consumption is positively correlated to climate change features of rainfall regime and capacity. These imperatives are considered as climato-ecological trait. This paper ties them into a spread across the entire ecosystem impact on Kinneret water quality. These factors are respected as uncovered hidden climate change features during the "early period" (1970-2000), whilst enhanced during the "later period" (2001-2018).

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Introduction

Climate change, particularly global warming, and its ecological implications on regional and international oceanic and continental ecosystems have recently become widespread concerns [1,2]. Despite Israel's implementation of a costly desalination system, insufficient water resources capacity is predicted. Therefore, investigation and modelling of climate change predictions are crucial for management design.

Lake Kinneret is the only natural freshwater lake in Israel. It and its headwaters supply approximately 26% of the national water budget. Lake Kinneret's uses include domestic supply, commercial fishery, recreation, and tourism [3,4]. During 1970-2010, approximately 336 MCM (10^6 m^3) of Kinneret water were annually withdrawn from the lake and supplied for domestic and agricultural irrigation in the southern regions of the country. The water quality of Lake Kinneret is therefore a national concern. The total national water supply is 2.11 BCM (billion cubic meters), of which 0.55 BCM comes from the Kinneret-Jordan hydrological system. The Kinneret drainage basin covers an area of 2,730 km^2 , including about 200 km^2 of the entire Hula Valley. Three major headwater rivers, Hatzbani, Banyas, and Dan flow from the Hermon Mountain region in the north, join, and form the Jordan

River, crossing the Hula Valley and flowing into Lake Kinneret. Until 1957, the Jordan crossed the Hula Valley through three tributaries flowing into the old Lake Hula. From Lake Hula, at an altitude of 61 meters above mean sea level (masl), the Jordan River flows downstream into Lake Kinneret (mean water level 211 mbsl) for approximately 15 km. The altitude difference between the top of the watershed, Mount Hermon (2,814 masl), and Lake Kinneret's mean water level (211 mbsl) over a distance of about 70 km results in an average slope of 4.3%, creating a strong erosive force. The Jordan River supplies approximately 63% of the Kinneret water budget and more than 50% of the external nutrient inputs. Before 1957, the Hula Valley land was covered by the old Lake Hula swampy wetlands. The wetland area was densely vegetated with submerged and emergent aquatic plants, and the water was mostly anoxic. Ammonium was present, and no nitrate was detected. In the 1950's, the wetland and Lake Hula were drained and converted from a natural ecosystem habitat to agricultural land.

Information about water removal, measured in MCM (million cubic meters) annually and monthly, from Kinneret's northern headwaters (north to Huri) for domestic and agricultural use, as well as the Jordan River's annual discharge measured at Huri station (mcm/year) during 1983-1996, and the monthly removals, are provided in Table 1 [5].

Table 1: Water Removal {mcm- 10⁶ m³; Annually (y) and Monthly (m)} from the Northern Headwaters Resources (northern to Huri) of Lake Kinneret for Domestic and Agricultural Consumption and Jordan Annual Discharge as Measured at Huri Station (mcm/y) During 1983-1996 [5].

Year	Month	mcm/y Consumption	mcm/m Consumption	mcm/y Discharge	mcm/m Discharge
1983/84	10	130.6	8.2	596.3	33.5
1984/85	11	136.6	6.1	559	32.6
1985/86	12	132.1	5.6	422.3	49.5
1986/87	1	157.7	4.9	796.7	61.1
1987/88	2	135.3	4.7	794.1	78.8
1988/89	3	168.5	5.8	474	74.3
1989/90	4	131.5	7.7	346	58.6
1990/91	5	102.7	12.9	353.2	50.8
1991/92	6	116.9	18.7	959.3	43
1992/93	7	133.2	24.3	722	42.1
1993/94	8	140.8	21.9	520.9	40.1
1994/95	9	138.3	14.3	660.9	36
Mean		135.5	11.3	600.4	50

Results shown in Table 1 indicate no significant long-term changes in the total capacity of water consumption north of the lake during 1984-1996. However, as clearly stated, the total and monthly consumption of Kinneret headwater water resources within the territories located north of the lake, during the decade of 1985-1995, was 22.6% of the available capacity [5].

During the 1990s, a limnological change occurred in the Kinneret ecosystem. The nutrient trait status of Lake Kinneret was dramatically changed from Phosphorus to Nitrogen limitation. The eco-physiological feature of Phytoplankton has undergone an upheaval from Nitrogen to Phosphorus limitation. The long-term dominance of the pyrrhophyte *Peridinium gatunense* was replaced by Cyanophyta, including harmful organisms that occasionally formed blooms. Because a major source of the Kinneret Nitrogen load is river discharge mediated, the water budget was investigated. Drought and flood (“rainy”) seasons were defined as higher than 1SD above and below the average are “rainy” and “drought” respectively. Moreover, sequential 3 and 1 cases of drought and rainy periods were indicated, respectively (Figure 5).

Anthropogenic management involvement created a potential confounding impact on the analytical results of natural processes. Lake Kinneret and its drainage basin have undergone anthropogenic management modifications. A thorough consideration is therefore required for evaluating the impacts of climate change. The Hula Valley was once covered by swampy wetlands and an old lake, which was drained in 1957, and land use was converted to agriculture, including aquaculture, which was later changed to field crops. Raw sewage was dumped into the Jordan discharge and was later removed. A dam was constructed on the Jordan outlet. In 1964, a national Water Carrier was constructed, which withdraws about one million m³ of lake water daily for supply. Approximately 25% of the lake’s natural saline water input was removed. These developments, accompanied un-intentioned climate changes, may

have an impact on nutrient dynamics in the drainage basin as well as within the lake ecosystem.

Materials and Methods

Data Sources

The data on nutrient concentrations and phytoplankton density were obtained from the Kinneret Limnological Laboratory Database and Annual reports (1969-2001) (M. Schlichter, courtesy). Annual (1969-2001) and monthly rainfall data measured at the Dafna meteorological station in the northern part of the Hula Valley were provided by the Israeli Meteorological Service (M. Peres, courtesy) [6]. Nitrogen and phosphorus concentrations in the Jordan River (Huri Station) were collected from Annual reports (1967-2001).

Statistical Evaluation

Statistical evaluation was conducted using the software: STATA 17.0-Standard Edition, Statistics and Data Science, Copyright 1985-2021 StataCorp LLC, Lakeway Drive, 4905 800-STATA-PC, Stata license: Single-user perpetual, Serial number: 401706315938, Licensed to: Moshe Gophen, Migal. Three statistical methods were utilized: Linear and Fractional Polynomial (w/95% Confidence interval) Regression (Prediction), and Biplot PCA Multivariate Analysis.

Results

Monthly Changes in Nutrient Dynamics

The next 1-3 figures represent monthly load dynamics (ton/month) of nutrient migration within the Jordan River (Huri Station) discharge during 1970-1986, emphasizing the discrimination between seasonal and temporal fluctuations. The nutrient load is obviously discharge-dependent, and the summer decline is therefore likely. Moreover, Figure 4 confirms a positive correlation between TP concentration (ppm) and Jordan discharge.

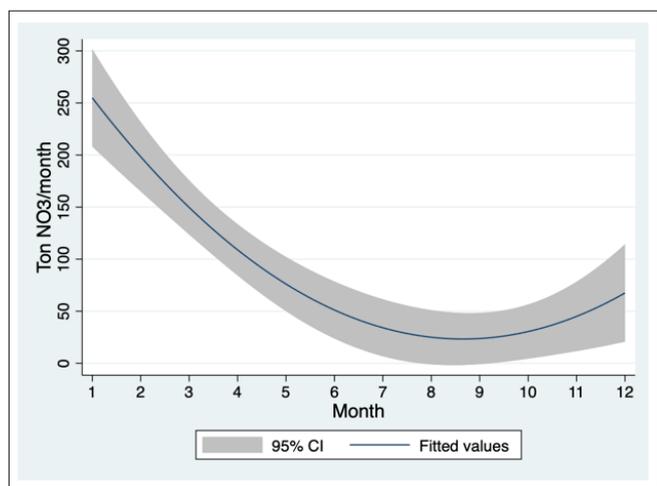


Figure 1: Quadratic Prediction (w/95% CI) Plot of Monthly Averages (1968-1985) of NO_3 Loads (Tons/month) Transported Through Jordan River (Huri). Linear Regression Analysis Indicates $r^2=0.2019$, $p<0.0001$. Total Monthly and Annual Means were 88.7 and 1042 Tons, Respectively.

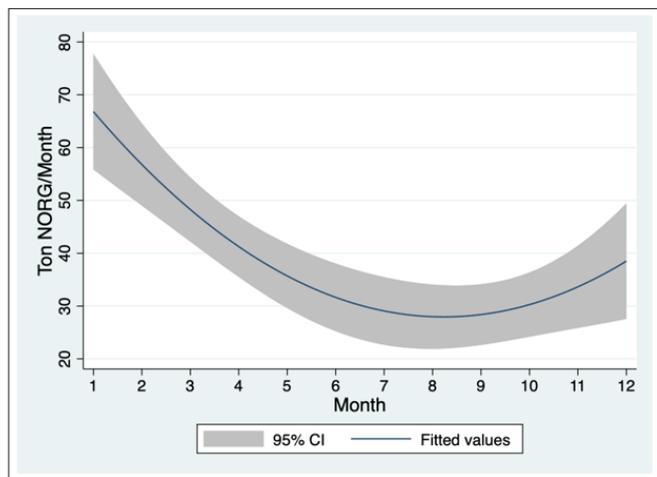


Figure 2: Quadratic Prediction (w/95% CI) Plot of Monthly Averages (1968-1985) of Organic Nitrogen (NORG) Loads (ton/month) Transported Through Jordan River (Huri). Linear Regression Analysis Indicates $r^2=0.0691$, $p<0.0001$. The Total Monthly and Annual Means were 40 and 480 Tons, Respectively.

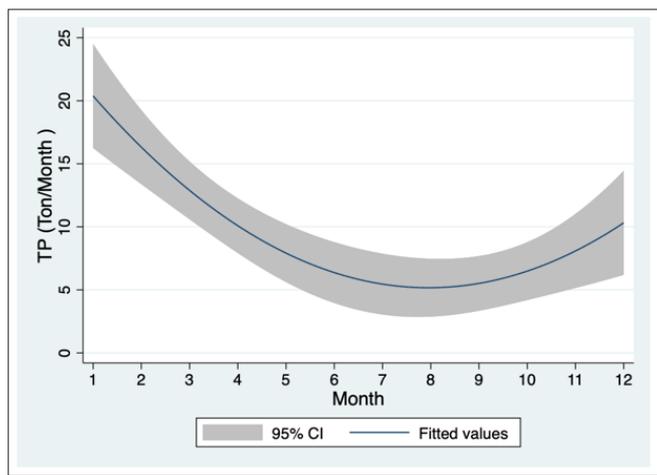


Figure 3: Quadratic Prediction (w/95% CI) Plot of Monthly Averages (1968-1985) of TP Loads (Ton/month) Transported Through Jordan River (Huri). Linear Regression Analysis

Indicates, $r^2=0.0610$, $p=0.0002$. The Total Monthly and Annual Means were 10 and 119 Tons, Respectively.

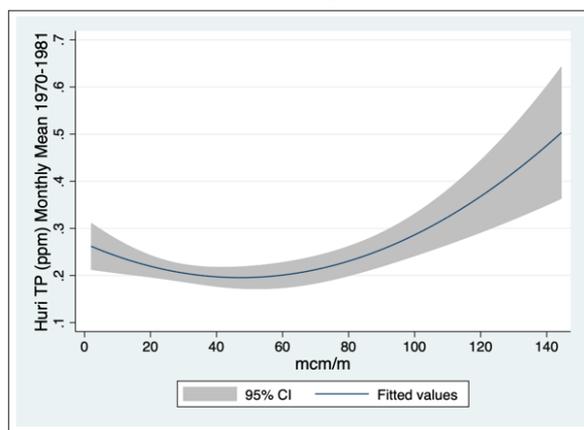


Figure 4: Quadratic Prediction (w/95% CI) Plot of Monthly Averages (1968-1985) of TP Concentration (ppm) Vs Jordan (Huri) Mean monthly discharge (mcm/m).

Results Indicate a Distinct Elevation of TP Concentration in Correlation with Discharge above 40 mcm/m. Thought, Extreme Rainfall Events Followed by Discharge Enhancement were Accompanied by TP Concentration Elevation.

Regional Changes in Climate Conditions
Regional Changes of Air Temperature and Rainfall Capacity are Presented in Figures 5-7.

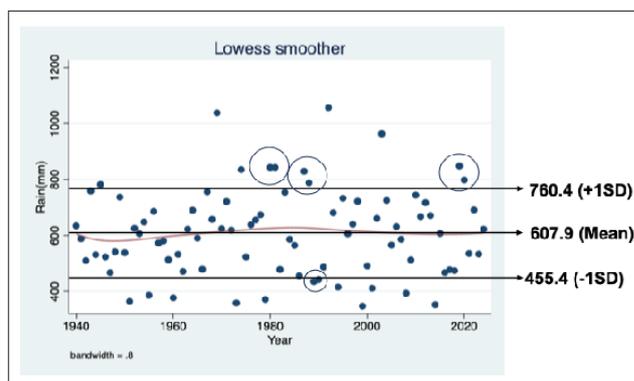


Figure 5: Annual Rainfall Capacity (1946-2024) in Northern Hula Valley (Dafna): Mean (608 mm), Mean Plus 1 SD (Flood Level) (760 mm), and Drought Level (Mean Minus 1 SD) (456 mm) are Shown. Two Consecutive Years of Drought and Flood Conditions are Circled. A Long-Term (1940-2018) Rainfall Assessment for Dafna in the Northern Hula Valley is Detailed in Table 2.

Table 2: Maximum (Max) and Minimum (Min) Annual Rainfall and Total Average of Rainfall Capacities (mm/y) (Dafna) During 1940-2018

Average (SD)	Max-Min	Period
594 (136)	377-1038	1940-1970
637 (159)	358-843	1971-1984
606 (189)	348-1057	1985-2000
590 (152)	352-964	2001-2018
475 (90)	352-607	2014-2018

Results given in Table 2 confirm the consistent conclusion of Figure 5, indicating low fluctuation amplitude and mean

fluctuation excluding sporadic and short-term exceptions (2014-2018 Table 2), whilst a mild (8%) decline during 1971-2018. This decline corresponds significantly (ANOVA test, $p < 0.05$) to the decline of Jordan discharge and consequently the Kinneret water level (Tables 2,3).

Table 3: Periodical Means (SD) of Jordan Discharge (mcm; $10^6\text{m}^3/\text{y}$) and Kinneret Water Level (MBSL)

mcm	MBSL	Period
448(157)	210.02(0.79)	1970-1984
355(181)	211.06 (1.42)	1985-2000

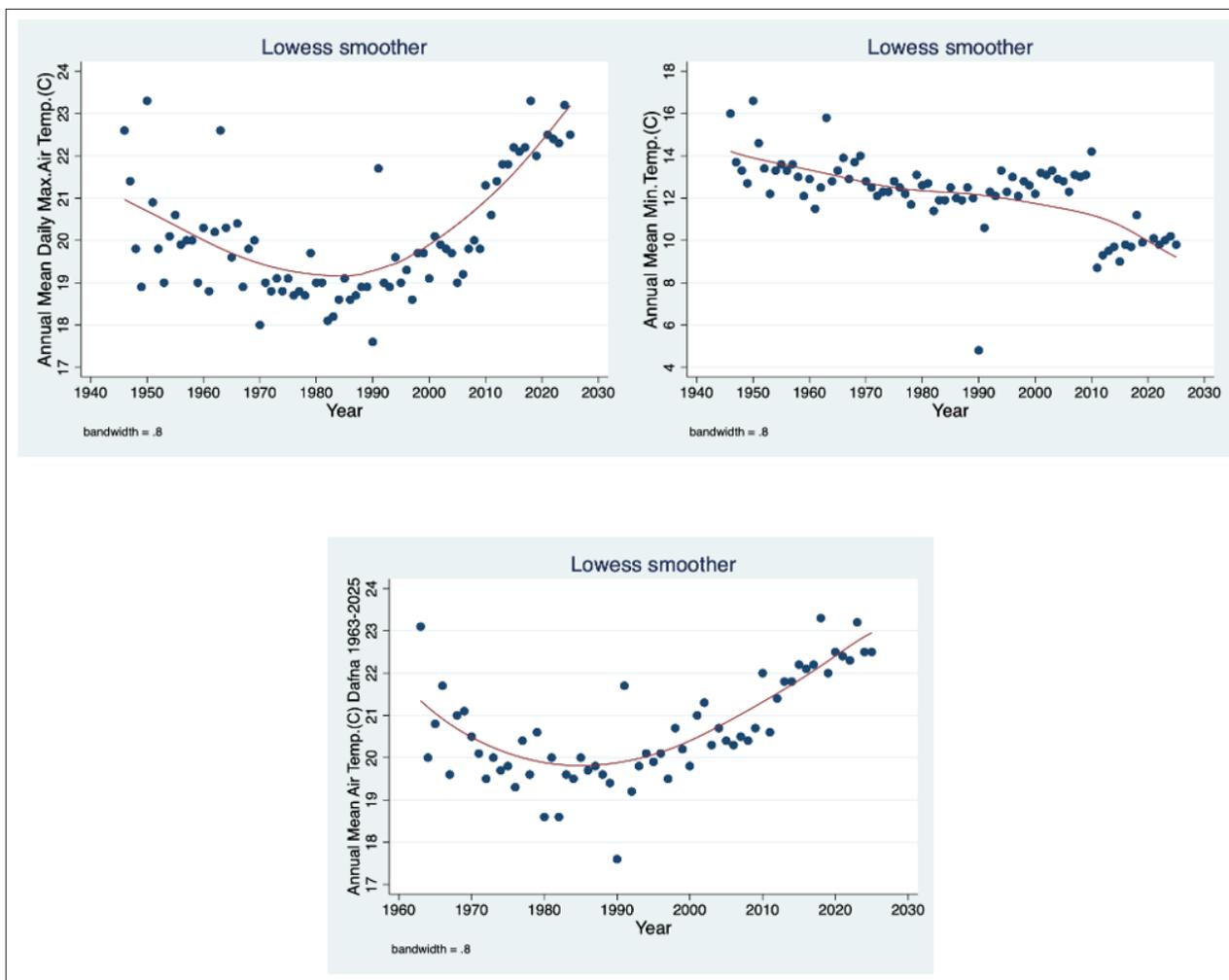


Figure 6: Annual Averages of “Maximal” (upper left), “Minimal” (upper right) and “Mean” (lower), Daily Air Temperature in Northern Hula Valley (Dafna) During 1946-2024.

Precise indication of the results given in Figure 5 indicate 5 drought and 6 flood years between 1946 and 1980 and 11 flood and 9 drought years during 1980-2024 respectively. Thought, an increase by 43% of climate extremes (rainfall, drought, and flood) frequencies during the last 44 years.

Results shown in Figure 6 indicate climate change occurrence: decline in the mid-1980s and increase later of daily maximum and mean air temperature, emphasizing the last 10 years (circled). Whereas continuous decline of daily minima throughout the entire period of 1946-2024, with a distinctive, sharper decline level during the last 10 years. Conclusively, the regional warming enhancement trend from 1980 onwards (Figures 5,6) is confirmed.

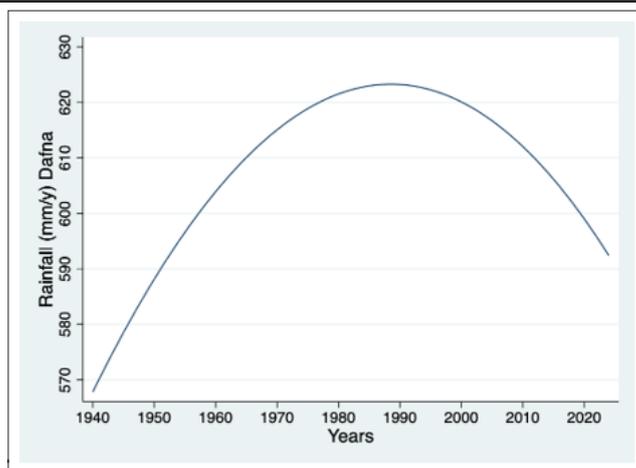


Figure 7: Fractional Polynomial Plot (no Confidence limit is given) of Temporal fluctuations of Annual Rainfall Capacity Changes (mm/y) During 1940-2024 in Northern Hula Valley (Dafna) (Figure 5). Results Shown in Figure 7 may suggest a Climate Change Occurrence in the mid-1980s, When an Increase in Rain Capacity was Replaced by a Decline Trend.

Temporal (1970-2018) fluctuations of Nutrient (TP, TN, NO_3 , NH_4) concentrations (ppm) and Jordan discharge are presented in the next 6 figures (8-13).

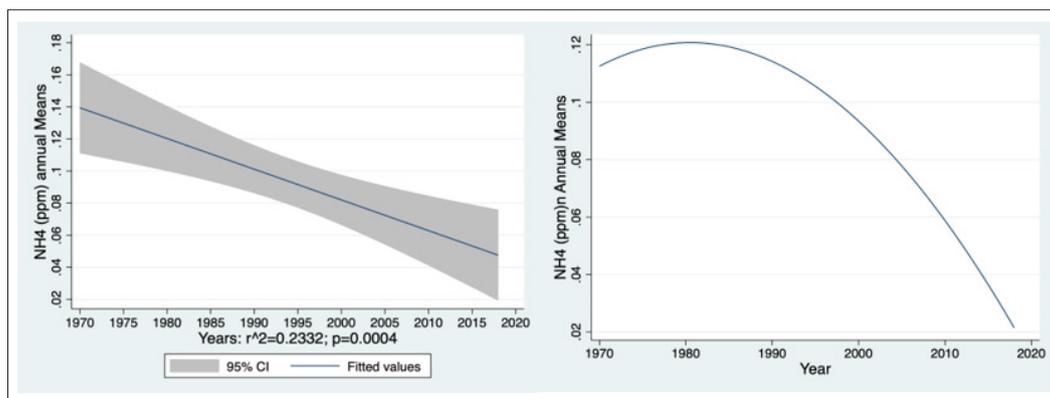


Figure 8: Temporal Changes of NH_4 Concentration (ppm) in the Jordan Discharge, presented as Annual Means: Linear Prediction (w/95%CI) (left panel) Correlation Parameters (r^2 , p) are Given in the Years Horizontal axis: Fractional Polynomial Plot (right panel). Results Indicate Significant Concentration Decline (left) and Uniform Continuous Decline (right).

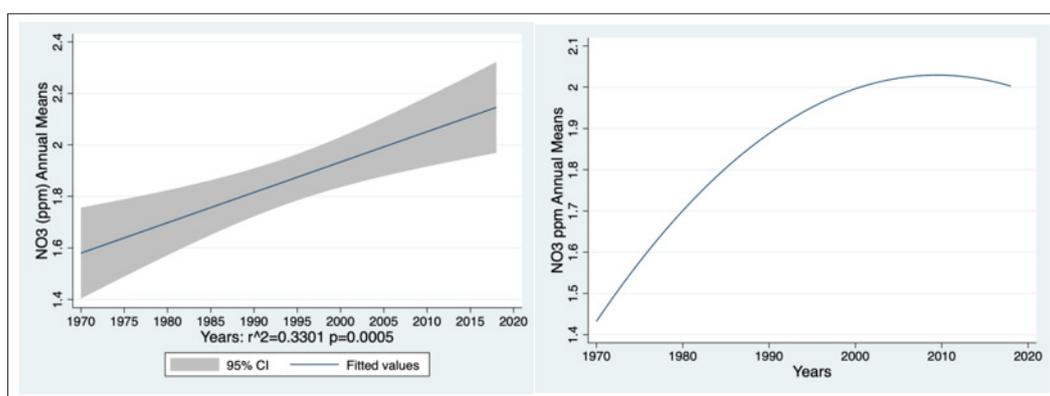


Figure 9: Temporal Changes of NO_3 Concentration (ppm) in the Jordan Discharge, Presented as Annual Means. Linear Prediction (w/95%CI) (left), Correlation Parameters (r^2 , p) are given in the Years Horizontal Axis. Fractional Polynomial plot (right). Results Indicate a Significant Concentration Increase (left) and a Uniform Continuous Increase, Which Slightly Curved During the late 1990s (right).

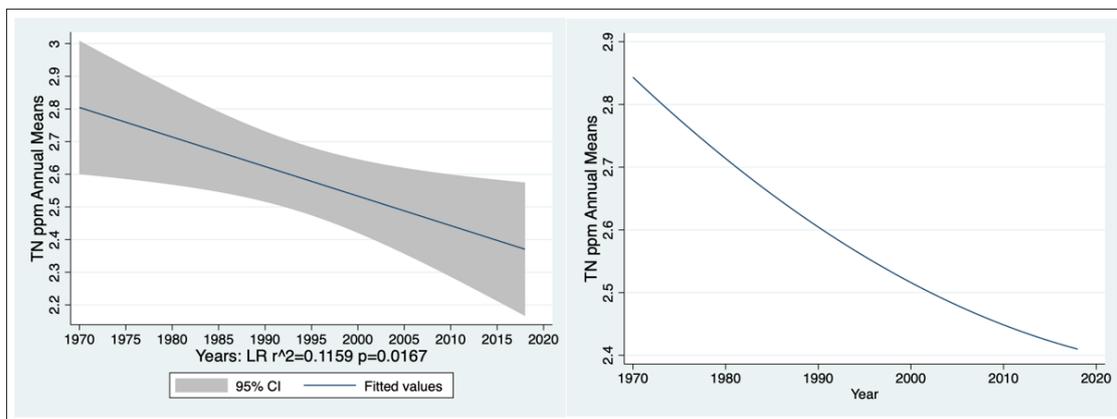


Figure 10: Temporal Changes of TN Concentration (ppm) in the Jordan Discharge, Presented as Annual Means. Linear Prediction (w/95%CI), (left panel), Correlation Parameters (r^2 , p) are Given in the Years Horizontal Axis. Fractional Polynomial plot (right panel). Results Indicate Significant Concentration Decline (left) and Uniform Continuous Decline (right).

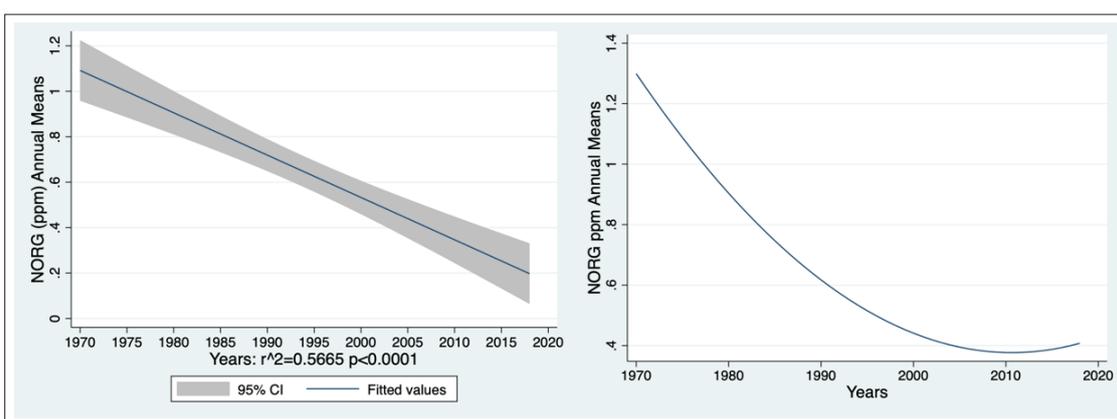


Figure 11: Temporal Changes of NORG Concentration (ppm) in the Jordan discharge, Presented as Annual Means: Linear Prediction (w/95%CI), (left panel) Correlation Parameters (r^2 , p) are given in the Years Horizontal Axis. Fractional Polynomial Plot (right panel). Results Indicate Significant Concentration Decline (left) and Uniform Continuous Decline Until the late 1990s and Leveled off later (right)

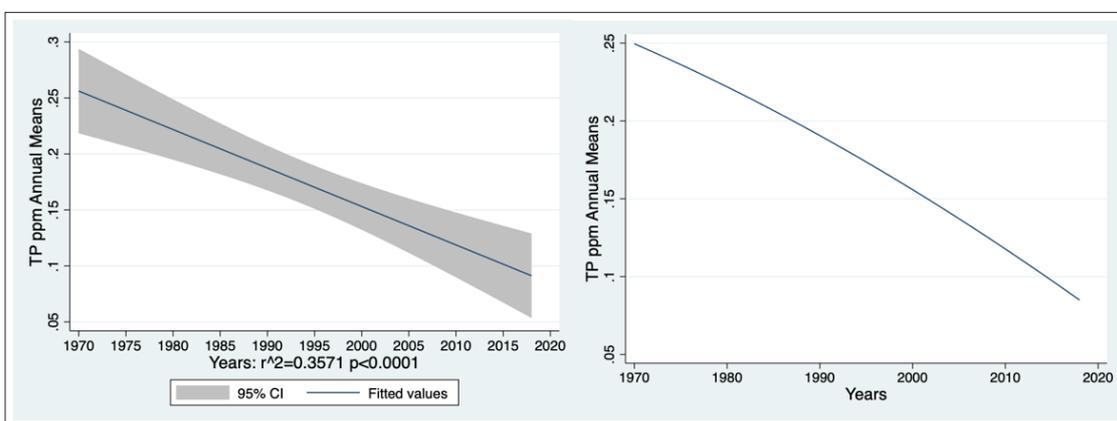


Figure 12: Temporal Changes of TP Concentration (ppm) in the Jordan Discharge, presented as Annual Means. Linear Prediction (w/95%CI), (left panel) Correlation Parameters (r^2 , p) are given in the Years Horizontal Axis. Fractional Polynomial Plot (Right panel). Results Indicate Significant Concentration Decline (left) and Uniform Continuous Decline (right).

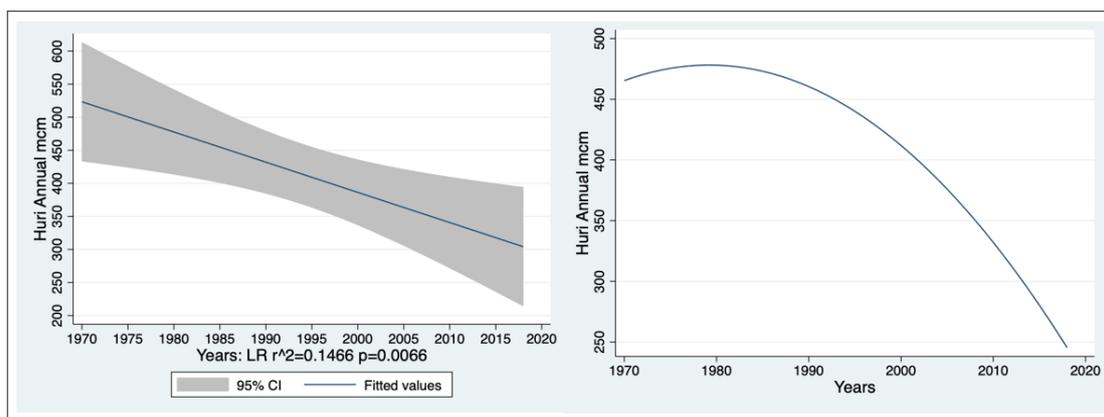


Figure 13: Temporal Changes of Jordan River Discharge, presented as Annual Means: Linear Prediction (w/95%CI), (left panel), Correlation Parameters (r^2 , p) are: $r^2=0.1466$; $p=0.0066$; Fractional Polynomial Plot (right panel). Results Indicate Significant Discharge Decline (left) and Distinct Decline from the High Level Before the 1990s and Uniform Continuous Decline Later on (right).

Lake Water Salinity

Precipitation and consequently river runoff discharge have an impact on solute loads input and are influenced by changes in climate conditions. Water yield through the aquifers is dependent on rainfall capacity. Upper part of the Solutes that are located in deep underground strata are transported by the aquifer water flows migrating into the lake through sub-lacustrine bottom emergence. Though, precipitation regime and capacity are influencing the underground water and migrating saline yield and further impact on the total dissolved lake load of salinity, which is controlled through water balance dynamics of open dam or pumping or sources capture and removal. Consequently, lake water salinity is mostly affected by changes in climate conditions. The overall pattern of salinity (ppm) changes in Lake Kinneret (Figure 14) is dictated by anthropogenic constraints of water storage and supply and salt removal [7, 8].

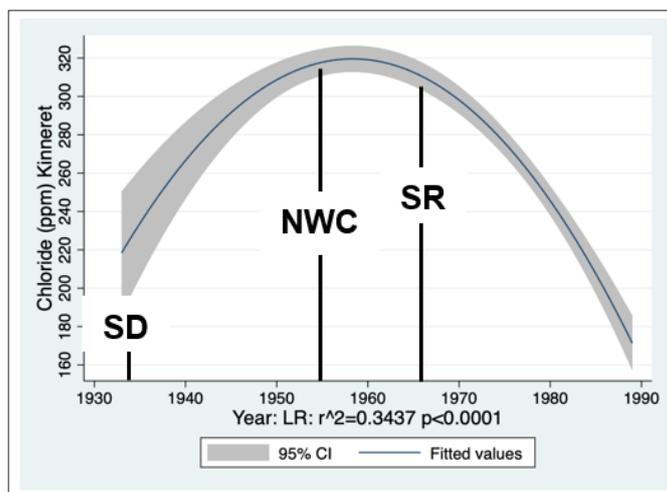


Figure 14: Quadratic Prediction Plot of Annual Means of Monthly Averages of Lake Kinneret Chloride Concentration (ppm) (salinity) During 1933-1989. Parameters (r^2 , p) are Indicated on the Year Horizontal axis. The South Dam Construction (SD), National Water Carrier construction (NWC) and Salt Removal Operation (SR) are Indicated.

Water storage as a supply insurance constraint is maintained by a close dam policy was incidentally accompanied by enhancement of salt storage. From 1933 (Dame construction) to 1964 (NWC operation), water storage policy was therefore resulted in exceptional high salinity levels (396 ppm Chloride) while the open dam policy later, salt removal and heavy floods decline of salinity were documented (220 ppm Chloride). The trend of salinity changes is the result of anthropogenic involvement, whereas short-term fluctuations are affected by climate conditions (rainfall) changes [9-13]. An ecological overview of the long-term data record of Kinneret water salinity confirms a mixed structure of climate change and anthropogenic impacts. Close dam policy enhances salinity, whilst anthropogenic salt removal (SR) and open dam (1968-1969) reduces salinity; consequently, the impact of climate change conditions can't be denied. Though, despite anthropogenic management, confounding changes in climate conditions existed.

Temporal Changes of the Nutrient Concentration in the Jordan (Huri) Discharge

Comparative (ANOVA test; $p < 0.05$) of periodical (1970-1984; 1985-2000) means of nutrient concentrations (ppm) in the Jordan discharges were evaluated (Tables 4,5) for Nitrogen and Phosphorus forms. Table 4: 1970-2000 and 2001-2018; Table 5: 1970-1984 and 1985-2000.

Table 4: Results of Periodical (1970-2000 and 2001-2018) Comparative ANOVA Test ($p < 0.05$) are given: The Periodical mean Concentration (ppm) (SD) and Probability (p) value: S=Significant; NS=Not Significant are Indicated for the Following Nutrients: Kjeldhal Total (KJLT), Kjeldhal Dissolved (KJLD), Ammonium (NH₄), Nitrate (NO₃), Organic Nitrogen (NORG), Total Nitrogen (TN), Soluble Reactive Phosphorus (SRP), Total Dissolved Phosphorus (TDP), and Total Phosphorus (TP).

Nutrient	1970-2000	2001-2018	p
KJLT	0.912 (0.270)	0.434 (0.069)	<0.0001 S
KJLD	0.459 (0.171)	0.230 (0.038)	<0.0001 S
NH ₄	0.114 (0.062)	0.058 (0.013)	0.0004 S
NO ₃	1.771 (0.379)	2.021 (0.229)	0.0124 S
NORG	0.789 (0.363)	0.381 (0.063)	<0.0001 S
TN	2.673 (0.425)	2.440 (0.228)	0.0367 S
SRP	0.030 (0.007)	0.026 (0.005)	0.0755 NS
TDP	0.042 (0.010)	0.033 (0.006)	0.0004 S
TP	0.207 (0.085)	0.117 (0.030)	<0.0001 S

Table 5: Results of Periodical (1970-1984 and 1985-2000) Comparative ANOVA Test ($p < 0.05$) are given: The Periodical mean Concentration (ppm) (SD) and Probability (p) value: S=Significant; NS=Not Significant are indicated for the following nutrients: Kjeldhal Total (KJLT), Kjeldhal Dissolved (KJLD), Ammonium (NH₄), Nitrate (NO₃), Organic Nitrogen (NORG), Total Nitrogen (TN), Soluble Reactive Phosphorus (SRP), Total Dissolved Phosphorus (TDP), and Total Phosphorus (TP)

Nutrient	1970-1984	1985-2000	p
KJLT	1.197 (0.341)	0.645 (0.092)	<0.0001 S
KJLD	0.583 (0.157)	0.342 (0.076)	<0.0001 S
NH ₄	0.129 (0.068)	0.100 (0.054)	0.1915 NS
NO ₃	1.621 (0.363)	1.911 (0.348)	0.0308 S
NORG	1.068 (0.353)	0.545 (0.077)	<0.0001 S
TN	2.804 (0.451)	2.550 (0.370)	0.0965 NS
SRP	0.027 (0.008)	0.033 (0.005)	0.0143 S
TDP	0.044 (0.013)	0.040 (0.004)	0.2485 NS
TP	0.239 (0.083)	0.176 (0.078)	0.0381 S

Results given in tables 4,5 indicate a breaking point of the nutrient concentrations decline trend during the 1980s. Despite this general trend of decline, Nitrate and consequently TN are not included due to Peat soil oxidation and Nitrate production resulting from Hula drainage. The insignificant decline of TDP probably reflects erosion enhancement, whilst chemical processes at a lesser impact.

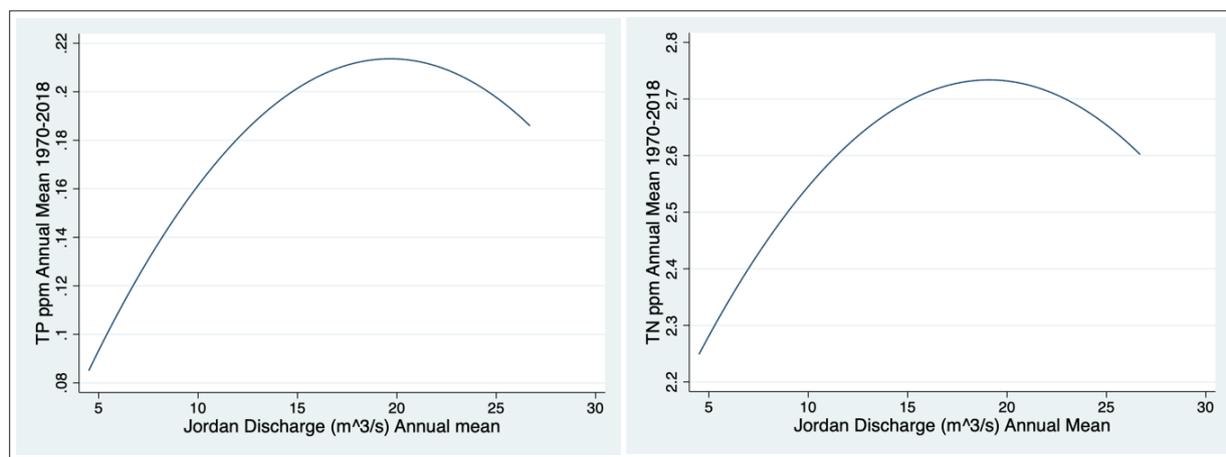


Figure 15: Quadratic Prediction Plot of Fluctuated Changes Trend of Annual Mean TP (left) and TN (right) Concentration (ppm) Measured in Jordan Waters (Huri) During 1970-2018 in Respect to Discharge (m³/s).

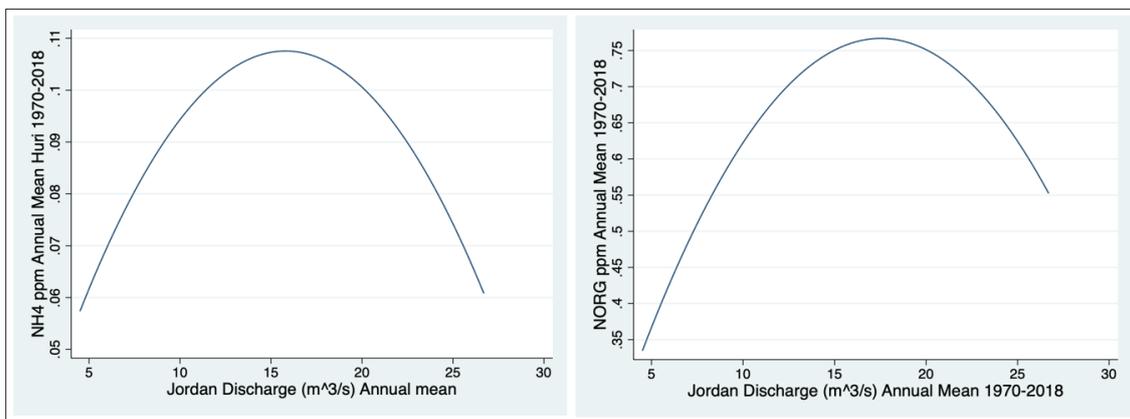


Figure 16: Quadratic Prediction Plot of Fluctuated Changes Trend of Annual mean NH4 (left) and Organic Nitrogen (right) concentration (ppm) Measured in Jordan Waters (Huri) During 1970-2018 in Respect to Discharge (m³/s).

Figures 15,16 confirm a positive correlation between Jordan discharge below 15-20 m³/s and nutrients (TP, TN, NH4, Organic Nitrogen), and discharge whilst under a higher rate, the correlation is negative. On the contrary, referring to NO₃ (Figure 17), those kinds of relations are inverse: mild decline below 12 m³/s and strict increase in relation to discharge elevation, probably caused by different nutrient sources. A major load of migrated nitrate originates from the oxidized peat soil in the Hula Valley beyond drainage, whilst sources of the others (TP and Nitrogen forms) are external to the valley. The result of weak bond efficiency of Nitrate to the peat soil particles is enhanced NO₃ migration capacity, whereas the flushing of the others is erosion factor dependent, which increases respectively with discharge elevation rate below 20 m³/s.

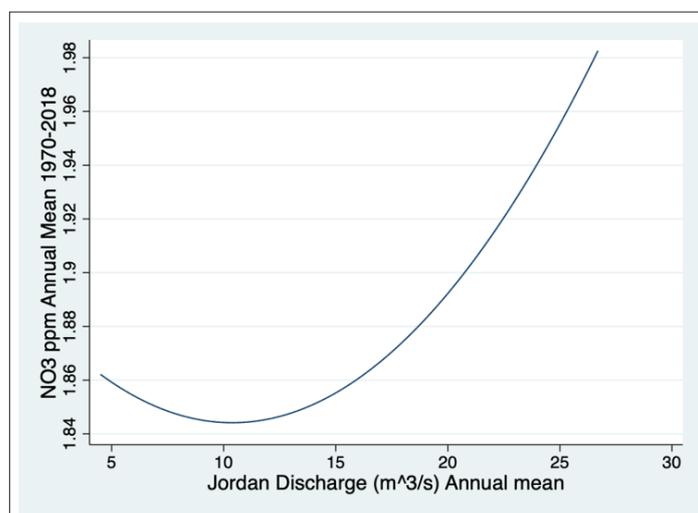


Figure 17: Quadratic Prediction plot of Fluctuated Changes Trend of Annual Mean NO3 Concentration (ppm) in Jordan Waters (Huri) During 1970-2018 in Respect to Discharge (m³/s).

Ecosystem Response to Climatic Impact on Hydrological Changes

A 31-year record of limnological parameters collected in Lake Kinneret was sorted into two periodical terms, 1969-1984 and 1985-2000. A statistical evaluation (ANOVA Test, $p < 0.05$) of total lake averages (6 stations, weekly sampling, 5-10 discrete sampling depths) aimed at exploring long-term periodical changes was carried out, and the results are given in the next 6-9 tables.

Table 6: Zooplankton Biomass (g(ww)/m²): Periodical mean (SD) of all copepod's life cycle stages and Cladocera, Rotifera, Herbivore copepods, predator cyclopoid copepods, p values (S=significant, NS= Not significant) and Biomass ratio of Total Phytoplankton (see Table 7) / Zooplankton, (Phyt/Zoop).

Parameter	1969-1984	1985-2000	p
Copepoda	12.2 (6.2)	7.3 (4.6)	<0.0001 S
Cladocera	19.4 (11.6)	15.2 (9.7)	0.0001 S
Rotifera	2.3 (2.9)	2.0 (3.0)	0.2135 NS
Total Zooplankton	33.9 (14.5)	24.5 (12.5)	<0.0001 S
Herbivore Copepods	4.5 (2.3)	2.7 (1.7)	<0.0001 S
Predator cyclopoid	7.7 (3.9)	4.6 (2.9)	<0.0001 S
Phyt/Zoop	1.9	3.6	<0.0001 S

Results shown in Table 6 indicate a simultaneous decline of zooplankton components, whilst a relative enhancement of phytoplankton biomass. The decline of algal consumption pressure by zooplankton is likely.

Table 7: Results of Comparative ANOVA Test (p<0.05) Between Periodical (1969-1984,1985-2000) means (SD) of Phytoplankton groups, p values, and S=significant, NS= Not significant of Phytoplankton components Biomass(g(ww)/m²) are given. Algal groups are: Cyanophyta, Bacillariophyta (diatoms), Chlorophyta, Peridinium spp, total Phytoplankton, and non-pyrrhophyta (phytoplankton excluded Peridinium).

Parameter	1969-1984	1985-2000	p
Cyanophyta	3.0 (4.4)	4.3 (8.0)	0.0387 S
Diatoms	4.4 (12.0)	12.8 (32.3)	0.0007 S
Chlorophyta	8.0 (6.3)	14.1 (14.0)	<0.0001 S
Peridinium spp	49.2 (70.0)	55.7 (79.0)	0.3888 NS
Total Phytoplankton	65.7 (68.1)	87.2 (79.0)	0.0044 S
Non-Pyrrhophyta	15.3 (16.9)	31.5 (38.9)	<0.0001 S

Results given in Table 7 indicate the natural high variability of algal groups' biomass density distribution in Lake Kinneret. The biomass density of Cyanophyta, Chlorophyta, and Bacillariophyta groups, during 1985-2000, was significantly higher than during the previous period (1969-1984), whereas no significant change in Peridinium spp biomass density was indicated. Though confirming the inverse periodical difference between zooplankton (Table 6) and edible algal biomass. Herbivore animal biomass declines whilst their food resources density is enhanced. Significant enhancement of Dissolved Oxygen (DO) concentration (ppm) in the upper 0-10 m depth (8.5 and 9.4, during 1970-2018, respectively) was recorded, probably resulting from non-pyrrhophyta biomass elevation during the late period. Enhancement by 32 cm of periodical mean Secchi depth was recorded: 3.04 m (0.88 SD) and 3.36 m (0.74 SD) during early and late periods, respectively. Biomass enhancement of non-pyrrhophyta algae, whilst the decline of zooplankton biovolume (biomass) densities in the late period (Tables 6, 7) is suggested to be the reason for that difference. Zooplankton numerical density (number of particles per volume unit) data (Table 8) supported conformity to this discrepancy as well.

Table 8: Results of Comparative ANOVA Test (p<0.05) between Periodical (1969-1984,1985-2000) means (SD) of Numerical Densities (No./L) of Zooplankton groups, p values (S=significant indication), are given. Zooplankton groups are: Ceriodaphnia spp., Bosmina spp., Diaphanosoma sp., Adult Cyclopoid Copepod, 1-4 Cyclopoid Copepod stages, and total Copepods Nauplii.

Parameter	1969-1984	1985-2000	p
Ceriodaphnia spp.	30 (13)	22 (8)	0.0542 S
Bosmina spp.	29 (10)	22 (8)	0.0419 S
Diaphanosoma sp.	17 (8)	8 (5)	0.0008 S
Adult Cyclopoids	47 (24)	19 (13)	0.0003 S
Cyclopoids copepodte	80 (29)	50 (21)	0.0024 S
Cyclopoids Nauplii	89 (19)	58 (32)	0.0027 S

Results given in Table 8 indicate significantly lower numerical densities (no./l) of zooplankton “particles” during the late period compared to the early period, which means lower turbidity and thus deeper Secchi depth.

The average (SD) loads in the Epilimnion (Ton) of nutrients during early and late periods (1969-1984, 1985-2000) for phosphorus (TDP, SRP) and nitrogen forms (Total Kjeldahl - KJLT, Dissolved Kjeldahl - KJLD, Total Nitrogen - TN, and Organic Nitrogen - NORG) are shown in Table 9.

Table 9: Results of Comparative ANOVA Test (p<0.05) Between Periodical (1969-1984,1985-2000) means (SD) of nutrient loads in the Epilimnion (Ton), (p values, and S=significant indication), of Phosphorus forms (Total Dissolved Phosphorus-TDP, Soluble Reactive Phosphorus -SRP and Nitrogen forms (Total Kjeldahl- KJLT, Dissolved Kjeldhal -KJLD, Total Nitrogen -TN, and Organic Nitrogen- NORG.

Parameter	1969-1984	1985-2000	p
TDP	17 (5)	11 (5)	<0.0001 S
SRP	4 (2)	2 (2)	<0.0001 S
KJLT	1069 (361)	680 (201)	<0.0001 S
KJLD	756 (237)	457 (130)	<0.0001 S
TN	1195 (418)	848 (357)	<0.0001 S
NORG	927 (350)	582 (195)	0.0027 S

Results given in Table 9 indicate a significant reduction of Phosphorus and Nitrogen forms in the late period, resulting probably from the input decline of organic Nitrogen, whilst the moderate decline of TDP and SRP was probably affected by internal geochemical-microbiological processes. A significant part of the Phosphorus input sources is external through erosion action and dust deposition.

Discussion

Concern about regional vulnerability to climate change was recently documented in a neighboring country, Egypt [14]. The impact of climate change on the discharge of the Nile River and its consequences on agriculture, urban, and socioeconomic conditions in Cairo and coastal cities were discussed. The rationale for the required investigation is aimed at designing an adaptive infrastructure to combat these challenges. Awareness of changes in climate conditions, symptoms of induction, and international cooperation to mitigate predicted ecological damages due to climate change have been documented [15-20]. Climate change significantly influences ecosystems and human life. The causes of climate change and its effects on nature, society, the economy, and human health are key concerns, especially regarding agricultural vulnerability, where food production is threatened by unpredictable weather patterns [2]. The critical turning point of the relationship between climate conditions and the sustainability of human society has sparked a global awakening to seek solutions. Climate change presents an urgent and complex challenge that demands a holistic, multidisciplinary response. Innovative solutions for climate change mitigation are essential. The mission of scientific research for innovative adaptation strategies emphasizes the interconnected roles of technological advancements, nature-based approaches, policy frameworks, and community engagement [1].

Kinneret, the only freshwater lake in Israel, serves as a national source for drinking water, commercial fisheries, tourism, and aquatic recreation. Lake water quality is therefore a national concern, emphasizing interactions within the food web. Ecological relationships between two dependent food web compartments, zooplankton and fish, were studied using statistical evaluation of long-term records of their densities. Predatory fish exert top-down control, confirming it as the dominant factor influencing zooplankton density. Recommended management strategies include controlling nutrient dynamics and removing unwanted fish species.

The ecosystem structure of Kinneret has been a subject of ecolimnological exploration for several decades. The research became a national mission due to intensive human involvement: the construction of a dam on the Jordan River outflow (1933); the establishment of the National Water Carrier system (1964); conversion of natural wetlands in the Hula Valley into agricultural land (1957); and governmental resolutions designating Kinneret as a national reservoir for drinking water, fisheries, and recreation. These efforts culminated in the establishment of the Limnological Research Institute (KLL), inaugurated in 1968. The long-term data collected since then form the basis of the present study. Data evaluation routinely results in management recommendations.

Kinneret hosts 19 native and 6 invasive fish species, of which 11 are commercially utilized and 4 are endemic [21,22]. The ecological role of these fish includes contributing to fishery productivity and influencing food web dynamics, impacting water quality. An extraordinary example involves *Peridinium* spp., a primary food source during bloom onset: *Sarotherodon galilaeus* efficiently utilizes *Peridinium*, while Bleaks do not, despite both having commercial value. Additionally, adult *S. galilaeus* filter non-selectively on zooplankton and phytoplankton, while fingerlings prey selectively on large zooplankton [23,24]. Bleak species consume all sizes and species of zooplankton throughout their life cycle. Human activities such as fisheries and stocking policies are therefore critical. Water level (WL) elevation occurs regularly during winter and is not necessarily linked to exceptional climate change conditions [25,26]. Bleak breeding seasons overlap with

rainy seasons and WL increases. The population size of bleaks depends on WL and fishing pressure. Enhanced rainfall and prolonged seasons improve breeding success, increasing bleak populations and predation on zooplankton. The rate of WL rise—measured in centimeters per day, is a key factor. Heavy rainfall causes high discharge, accelerating WL rise, which boosts breeding success and total bleak biomass. Extreme rainfall events (e.g., 1992, 2003, 2019) lead to increased predation on zooplankton over subsequent years and may be compounded by reduced fishing due to market challenges. Overall, increasing rainfall extremes, coupled with fishery reductions, intensify zooplankton decline. Over two 42-year periods (1940-1982; 1982-2014), five and seven extreme drought and flood events, respectively, were recorded. These data suggest increasing climate variability over the past 80 years in Lake Kinneret. This paper clarifies fish predation as a controlling factor for zooplankton density, with Cyclopoid contributions being minor compared to fish predation. Data on fish and zooplankton dynamics from earlier studies support these conclusions [3,4,21,27-29]. The lake's food web is complex, involving biological, chemical, and physical factors. Improving water quality by reducing phytoplankton biomass and increasing herbivorous zooplankton is desirable; reducing fish predation can help achieve this, but nutrient management must also be addressed.

Climate conditions during 1969-2000 showed early signs of change, which became more evident from 2001-2018. The earlier period's ecosystem was characterized by late-winter bloom onset and early summer offset of *Peridinium* blooms [23]. Later, significant modifications occurred: a shift in algal limitation from phosphorus to nitrogen, a reduction of *Peridinium* dominance, and increased Cyanobacteria density. Additionally, the bleak-fish population increased, and zooplankton biomass declined [3,4,21]. Despite these changes, drinking water standards remained within permissible limits. Since the mid-1980s, rainfall capacity has declined by about 8%, reflected in decreased Jordan River discharges and lowered water levels in Kinneret (Table 2, 3; Figure 7). Most notably, air temperatures have been rising since 1984 (Figure 6), confirming regional warming. Data also show a decrease in ammonium, total nitrogen, organic nitrogen, and total phosphorus in Jordan waters, with an increase in nitrate levels, while discharge decreased (Figure 7).

Tables 4 and 5 present periodic changes in nutrient concentrations in Jordan River water during the early (1970-2000) and late (2001-2018) periods, including subdivisions within the early period. Since the mid-1980s, all nitrogen forms except ammonium, along with phosphorus, have decreased, a trend confirmed over the full 48-year record. Climate change since the mid-1980's, characterized by rising temperatures, declining headwater discharges, and reduced lake inflow has impacted the Kinneret ecosystem. Comparative analysis of early and late periods (Tables 6-9) shows declines in zooplankton biomass density, as well as nutrient loads in the epilimnion, alongside increased phytoplankton biomass, indicating some ecosystem adaptation. Nutrient flow in the Jordan River also shows periodic shifts since the mid-1980s, affected by climate change, human activities like sewage removal, and aquaculture restrictions in the Hula valley. Major lake ecosystem shifts include a decrease in *Peridinium* dominance, an increase in Cyanobacteria, and a change from phosphorus to nitrogen limitation, possibly driven by underlying climate modifications. Short-term extreme rainfall events leading to sudden water level increases, trigger heavy bleak breeding and long-lasting effects on populations, reducing zooplankton over subsequent years. Heavy rainfall influences bleak populations for years, negatively impacting zooplankton. The present paper indicate the relevance of

periodical ecological changes as an advanced noticeable awareness to regional climate change.

Concluding Remarks

Three key factors are critical in understanding climate change's impact on Kinneret water quality: 1) the relationship between nutrient levels and headwater river discharge driven by rainfall; 2) the effect of rainfall on aquifers and saline intrusions into the lake; 3) the influence of climate change on lake water levels and quality via nutrient availabilities and Phytoplankton composition and density and increased bleak fish populations and zooplankton consumption. These factors are interconnected parts of an ecosystem affected by underlying climate variations observed from 1970 onward, with more pronounced effects after 2000.

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Competing Interests

The authors have no conflict of interest that may affect this article.

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