Chapter

The Synergistic Impact of Climate Change and Anthropogenic Management on the Lake Kinneret Ecosystem

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Abstract

Anthropogenic and natural processes caused significant changes in Lake Kinneret and its drainage basin ecosystems. Climate change of warming and dryness induced a decline in the lake water level. Changes in the composition structure of the phytoplankton assemblages were enhanced by the decline of nitrogen availability resulting in reduction of Peridinium and enhancement of Cyanobacteria. Increase of the phosphorus availability enhanced Chlorophyta and diatoms. Nutrient export from the Hula Valley to Lake Kinneret is discharge-dependent. The external input decline of organic nitrogen and total dissolved phosphorus is due to anthropogenic achievements. Nitrogen decline and slight increase of phosphorus in Lake Kinneret were followed by Peridinium decline and increase of non-Peridinium algae. The resulting change of food-web structure and water quality in the Kinneret was a shift from phosphorus to nitrogen limitation, which enhanced cyanobacteria.

Keywords: Kinneret, Hula Valley, Peridinium, cyanobacteria, climate change

1. Introduction

1.1 The Kinneret drainage basin

The Kinneret drainage basin (total area 2730 km^2) is located mostly northern to the lake (**Figure 6**). Its maximum length from north to south is 110 km and widest 50 km. The Kinneret drainage basin is bounded between the Mount Hermon block and Litani basin in the north, Meron and Naftali mountain ridges in the west, the Golan Heights in the east, and Kinarot Valley in the south. The highest altitude point within the Kinneret basin (Hermon summit) is 2814 m (ASL). Taking into account Kinneret common water level (WL) as 213 m (BSL), the total slope of 3027 m along 110 km makes the mean surface gradient as 2.8%. The Hula Valley is flat with a mean slope of appox. 0.7%. The Kinneret basin comprises the following subunits: northern basin including Jordan drainage basin drained by the rivers: Hermon, Dan, and Snir, and the Hula Valley-1530 km^2 (56%); eastern basin drained by several rivers (Meshushim, Daliyot, Zavitan, and others)-580 km^2 (21%); western basin drained by the rivers of Zalmon and Amud—450 km^2 (16%); and several other small parts southern and western to the lake.

1.2 A brief historical survey of the Hula Valley management

During the last 80 years, the Lake Kinneret drainage basin ecosystems have undergone significant anthropogenic and natural modifications. Prior to the 1950s, the Hula Valley was mostly (6500 ha) covered with old Lake Hula (1300 ha) and swampy wetlands. This area was not cultivated, malaria was common, and water loss by evapotranspiration (ET) was significant. The Jordan River crossing the Hula Valley contributes about 63% of the downstream of the Lake Kinneret's water budget, but 70% of the total nutrient inputs, of which over 50% originate in the Hula Valley region, including the valley and the slopes on both sides (east and west) of it. Old Lake Hula and swamps were drained and were being converted for agricultural development. Years later, land utilization was modified in an operation referred to as the Hula Reclamation Project (HRP) which was improved later. The HRP included creation of a new shallow lake Agmon (surface area of 1120 ha, mean depth—0.45 m., volume—0.44×10^6 m^3), renewal of 90 km drainage and water supply canals, placing a vertical plastic barrier along 2.8 km crossing the valley from east to west, maintenance of higher underground water table, and functional conversion of 500 ha with lake Agmon in the center from agricultural to eco-tourism usage. The objectives of HPR were aimed at: (1) nutrient removal from the Lake Kinneret external loads through the Lake Agmon hydrological system; (2) to produce an ecological component for eco-tourism-Lake Agmon; and (3) the usage of Lake Agmon as a principal component for the hydrological management and agricultural irrigation system for the entire valley. The following objectives were implemented: improvement of irrigation water supply, maintenance of high underground water table ensuring peat soil moisture to prevent its deterioration, and the achievement of a high diversity of re-establishment of natural flora and fauna emphasizing aquatic birds.

Prior to the drainage of old Lake Hula and adjacent swamps during 1950–1957, Nitrogen was fluxed from the basin to the lake, mostly as highly bioavailable ammonia, but after the Hula drainage, the dominant N was modified to nitrate. Before the mid-1990s, a daily volume of 25×10^3 m^3 of raw sewage and fishpond (1700 ha) effluents rich with ammonia fluxed into Lake Kinneret. The fishpond area was dramatically reduced (450 ha), as well as its effluents, and the raw sewage was stored in reservoirs and reused. As a result of inappropriate irrigation and agricultural methods, the peat soil quality deteriorated by consolidation, destruction, and surface subsidence. It was accompanied by heavy dust storms, blocking of drainage canals, enhancement of underground fires, and outbreaks of rodent populations. These deteriorated processes caused severe damage to agricultural crops. A reclamation project (HRP) was consequently implemented.

The aim of the present paper is to evaluate the outcome of the anthropogenic intervention in the Hula Valley, together with climate change, on the management of Lake Kinneret, its water quality, and the entire ecosystem structure trait.

2. Methods

Climatological (precipitation, air temperature) data was supported by the Israeli Meteoroloical Service. Jordan River discharge and nutrient concentrations were supported by Kinneret Limnological Labortory Data Base and Mekorot Water Supply Company Jordan District. The nutrient concentrations and the phytoplankton composition structure in the epilimnion of Lake Kinneret during 1970–2018, as well as water level and ground water table (GWT) in the Hula Valley were all reevaluated and statistically analyzed. The information was given by Kinneret

Limnological Laboratory (IOLR), Mekorot-Water Supply Company-The Jordan Region Monitor Unit, The Israeli Hydrological Service, National Water Authority, and the Israeli Meteorological Service. The Statistical analyses used were fractional polynomial and linear regressions. The data on Agmon WL and the GWT depths were supplied by the Data Base Center of the Hula Project in the MIGAL-Scientific Research Institute.

3. Results

3.1 Climate change

The periodical occurrence of drought is given in **Table 1**. Results in **Table 1** indicate 62% periods (years) of three levels (A, B, and C) drought as SPI (specific precipitation index) values [1] during 1930–1980, and 42% during 1981–2014. Moreover, percentage of normal conditioned periods was higher during the latter period. Nevertheless, recent 5 years (2014–2018) were consecutive drought seasons.

Data shown in **Figure 3** indicate precipitation decline since mid-1980s. The information that is evaluated in **Figure 1** was collected (from 1940) in the Dafna Station located in northern Hula Valley statistically indicating a decline of appox. 140 mm annually.

Periodical means of air temperatures measured in the meteorological Station in Dafna (Northern Hula Valley) during 62 years (1946–2008) resulted (°C) in the following changes: 20.2, 19.4, 18.9, and 19.8 in 1946–1958, 1959–1982, 1983–1990, and 1991–2008, respectively, indicating fluctuation ranges of −0.8, −0.5, and +0.9°C.

SPI level	1930–1980	1981–2014
A	34	21
B	26	18
C	2	3
D	38	58

A—close to normal conditions; B—moderate drought; C—severe drought; and D—normal conditions.

Table 1.
Drought level (A, B, C, and D) occurrence (%) evaluated as SPI values [1].

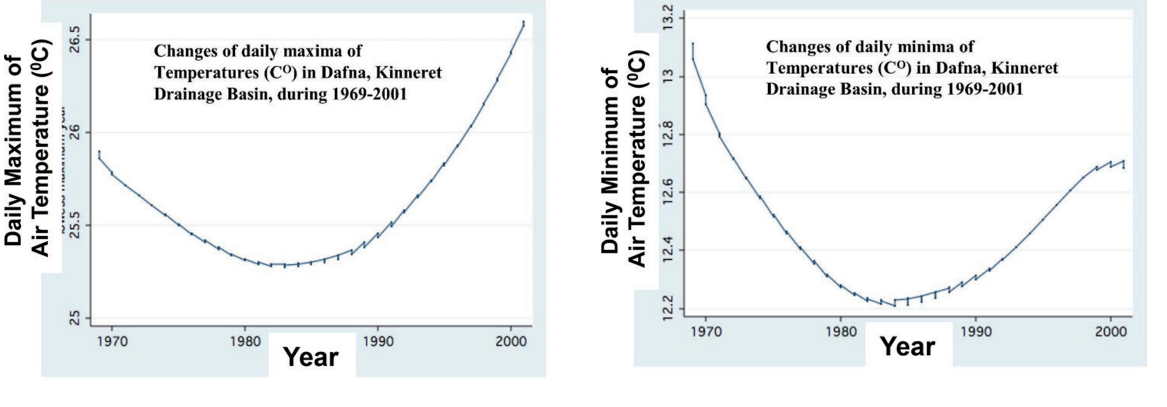


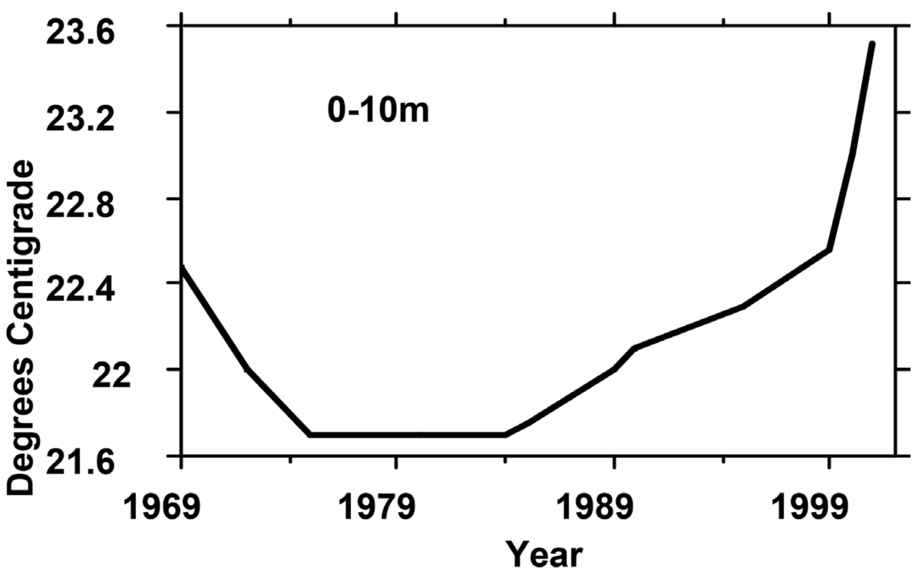
Figure 1.
Trend of changes (LOWESS; 0.8) of daily maxima (left panel) and minima (right panel) of air temperature (°C) Dafna Station (Northern Hula Valley) during 1969–2001.

LOWESS smoothing statistical method provide locally weighted scatterplot smoothing. The smoothed values are obtained by running a regression of Y and X variables weighted where the central value gets the highest weight and other points around receive less weight. Moreover, in relation to those documented air temperature change, the lake water temperatures were fluctuated as well (**Figure 2**): The upper epilimnetic layer (0–10 m) became warmer since the early 1980s until the early 2000s by 1.9 (21.7–23.6), whilet the temperature increased in the lower layer (32 m deep) similarly by app 2.0°C but reasonably later (from late 1980s) (**Figure 2**).

A significant evidence for climate change is given in **Figure 3**, which represents a mean increase of 60 mm from 1940 until the mid-1980s and later a decline of app. 130 mm until present.

3.2 Hula reclamation project

The history and implementation of the Hula Project are given in [2–4]. Long-term data about the underground water table (GWT) in the Hula Valley are presented in **Figures 4** and **5**. The impact of drought condition is reflected from the



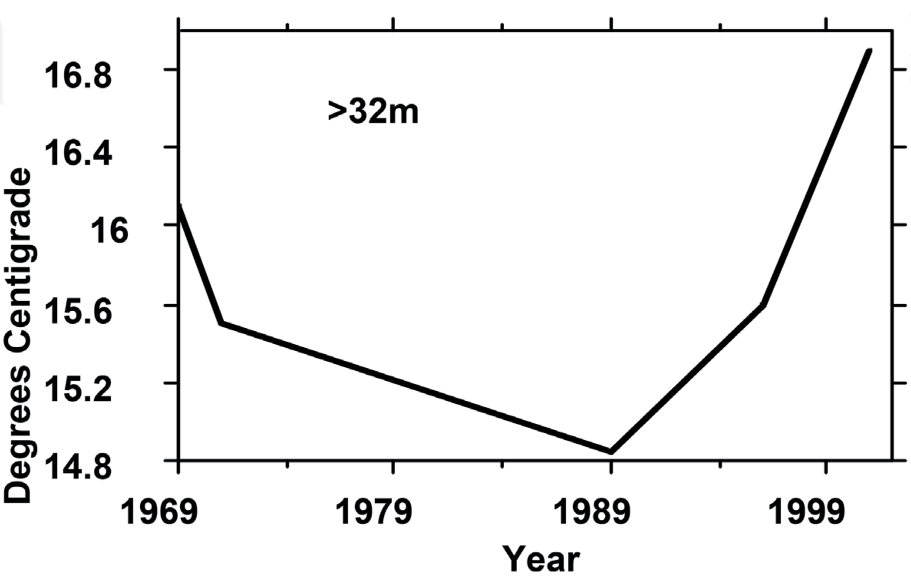


Figure 2.
Annual averages of water layers (0–10 m upper, >32 m lower) in Lake Kinneret during 1969–2001.

deepening of averaged GWT by 30 cm during recent 6–7 years (**Figure 4**). The data presented in **Figure 5** emphasize the underground topographical structure and the impact of the recent drought: the GWT altitude in the northern region of the Hula Valley is higher than that of the southern part. Therefore, hydrological gradient existent induces underground water migration from north to south. Hydraulic forces from north to south induce water flow aimed at south but no such gradient on east-west directions (**Figure 5**).

Significant relations between nutrient inputs from the upper Jordan River watershed into Lake Kinneret and the river discharge were indicated, and the qualitative results are given in **Table 2**.

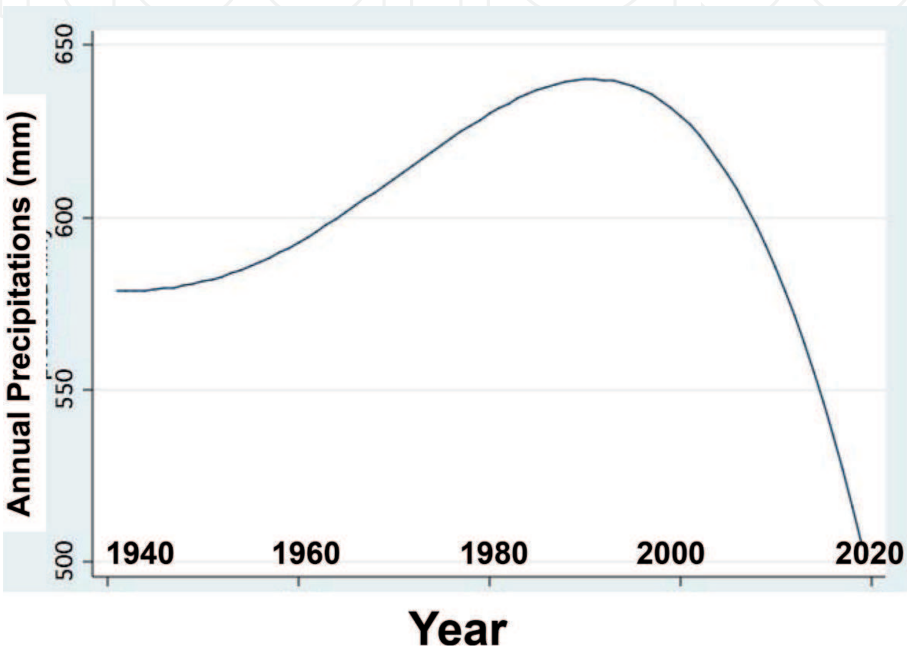


Figure 3.
Fractional polynomial regression between annual (1940–2018) precipitation and years.

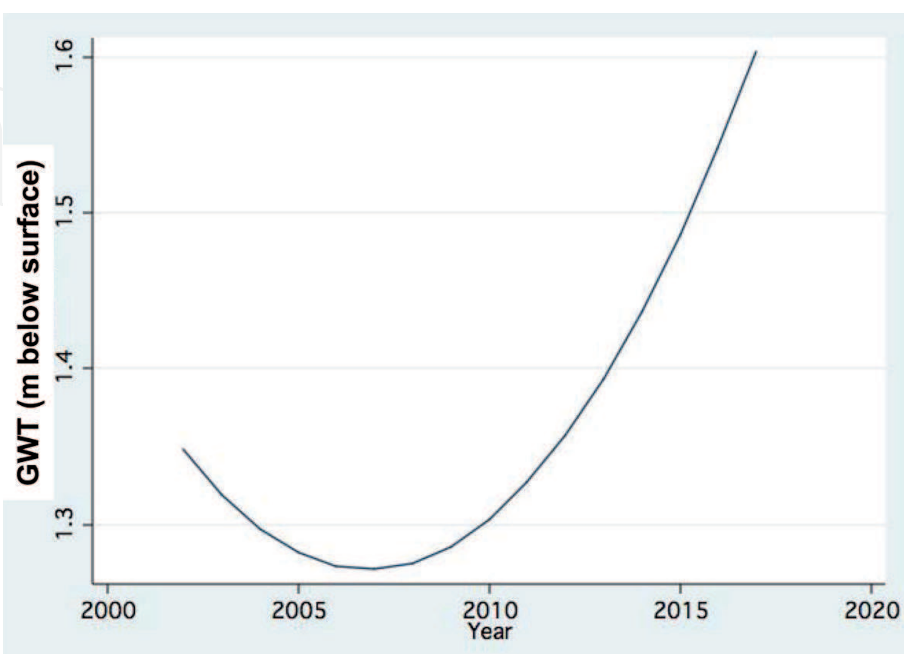


Figure 4.
Annual total (three Hula Valley regions) average of GWT (m below surface) during 2002–2018.

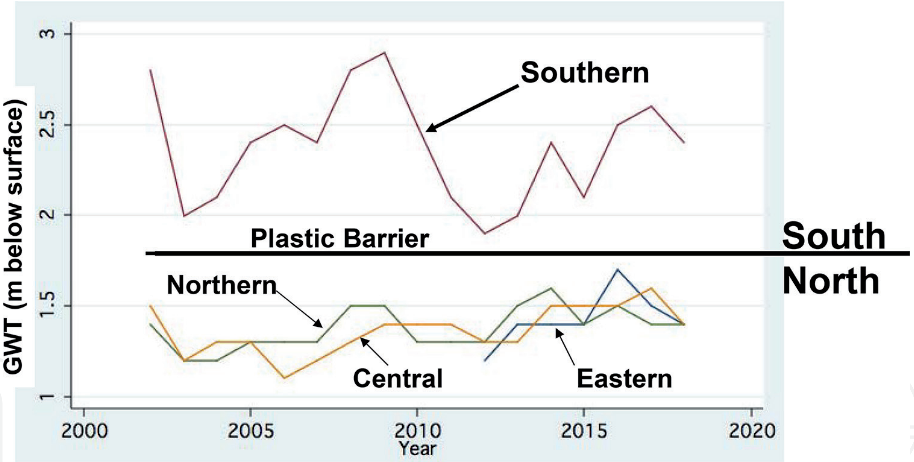


Figure 5.
Line scatter plot of annual (2002–2018) means of GWT (m below surface) in four Hula Valley regions: northern, eastern, western, and southern.

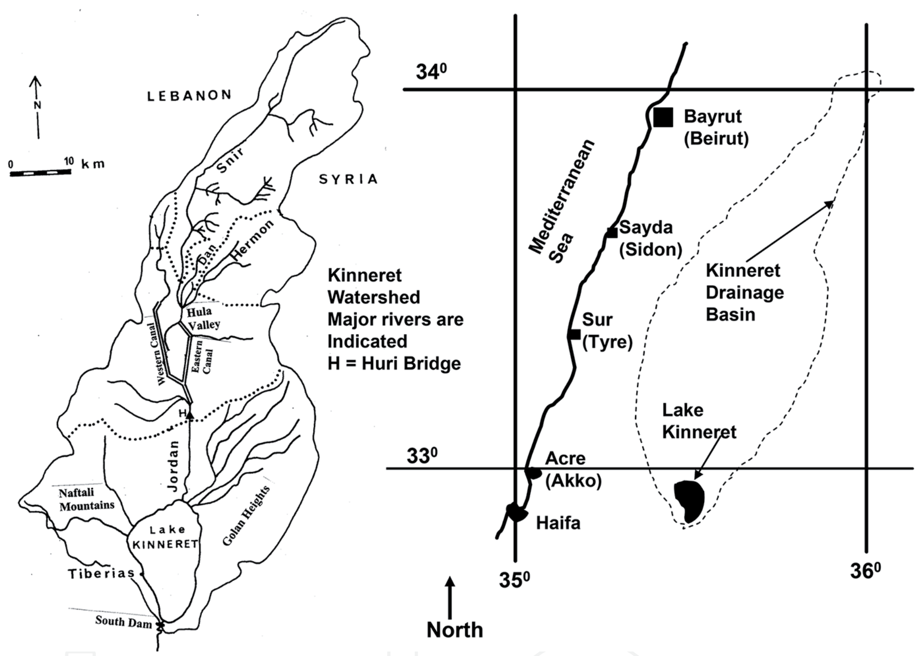


Figure 6.
Regional chart of Lake Kinneret watershed.

The quantitative significant relation between Jordan River Discharge and nutrient loads is obvious and was earlier documented, while data given in **Table 2** indicate the positive significant relation between the river discharge and the nutrient concentrations: the higher the discharge, the higher the nutrient concentration and quantities. The Linear regressions between Jordan discharge and nutrient loads is positively significant as presented in **Table 3**.

Results in **Tables 2** and **3** are compatible and strongly support the statement about positive linear regression between Jordan discharge and nutrient load transport into Lake Kinneret. These linear relations and the temporal decline of Jordan discharge are presented in **Figures 7–12** for organic nitrogen, total nitrogen, total phosphorus, and total dissolved phosphorus. Nevertheless, the pattern of relation between nitrate concentration and the Jordan discharge is different (**Figure 11**): NO_3 concentration increases in relation to time (from 1970 to 2018) and decreases relative to Jordan decline below 300 mcm/y and increases very little when discharge is elevated above 300 mcm/y. The different behavior of nitrate was studied by Geifman (1981) and the results are given in **Figure 12**. The significant increase of

Nutrient	r^2	p
Total nitrogen	0.1383	0.0046 S
Total phosphorus	0.4599	<0.0001 S
Nitrate	0.2012	0.0029 S
Ammonium	0.2527	0.0007 S
Organic nitrogen	0.5984	<0.0001 S
Total dissolved phosphorus	0.2019	0.0028 S
Kjeldahl total	0.6586	<0.0001 S
Kjeldahl dissolved	0.6417	<0.0001 S
Jordan discharge (mcm/y)	0.2004	0.0030 S

Table 2.
Results of linear regression analysis between Jordan River discharge and the multiannual means of nutrient concentrations (ppm): r^2, probability (p) values, and significance (S = significant) values are indicated. The annual Jordan River discharge (mcm/y; 10^6 m^3/y) is given.

Nutrient	r^2	p
Total nitrogen	0.860	<0.0001
Total phosphorus	0.596	<0.0001
TIN (total inorganic nitrogen)	0.776	<0.0001
Sulfate	0.816	<0.0001
Organic nitrogen	0.606	<0.0001
Chloride	0.886	<0.0001

Table 3.
Linear regressions between Jordan River discharge and nutrient loads (tons) r^2 are given and all probabilities were significant (<0.0001).

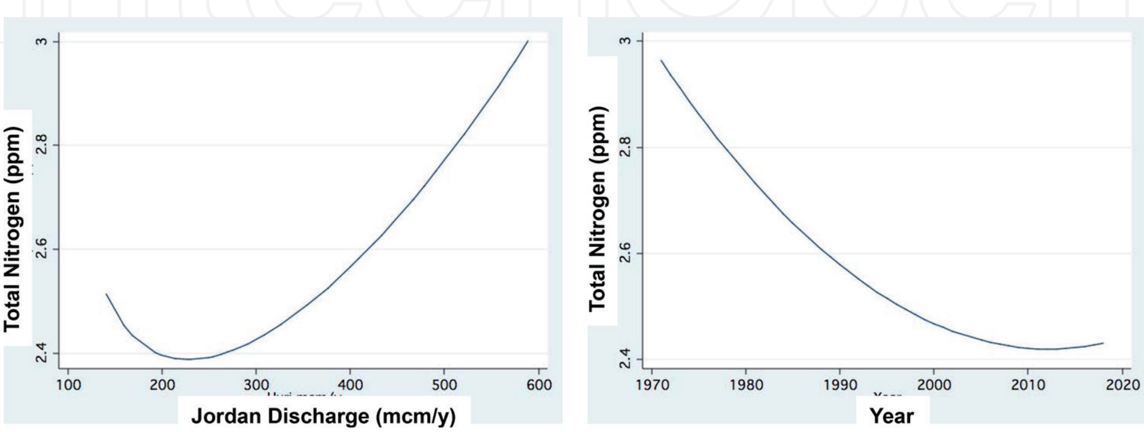


Figure 7.
Fractional polynomial regression between annual mean of the total nitrogen concentration (ppm) in Jordan water and Jordan water yield (mcm/y) (left) and with years (1970–2018) (right).

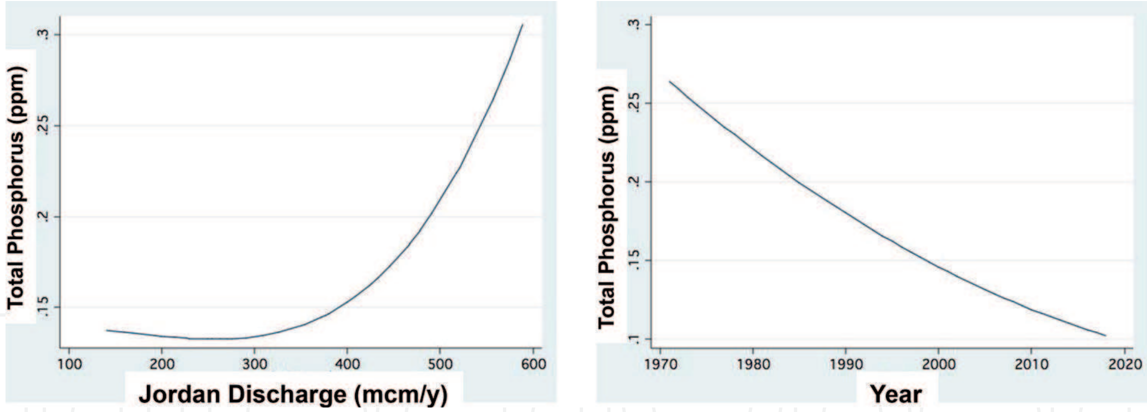


Figure 8.
Fractional polynomial regression between annual mean of the total phosphorus concentration (ppm) in Jordan water and Jordan water yield (mcm/y) (left) and with years (1970–2018) (right).

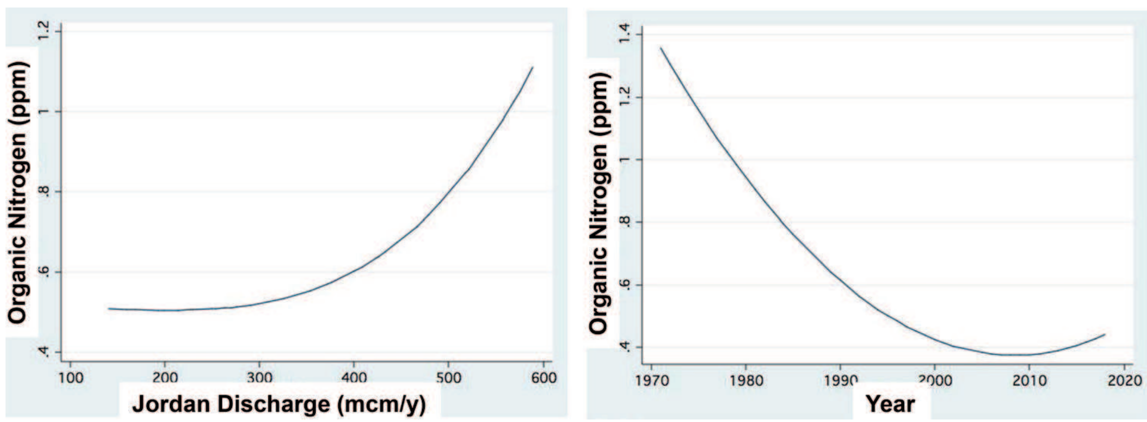


Figure 9.
Fractional polynomial regression between annual mean of the organic nitrogen concentration (ppm) in Jordan water and Jordan water yield (mcm/y) (left) and with years (1970–2018) (right).

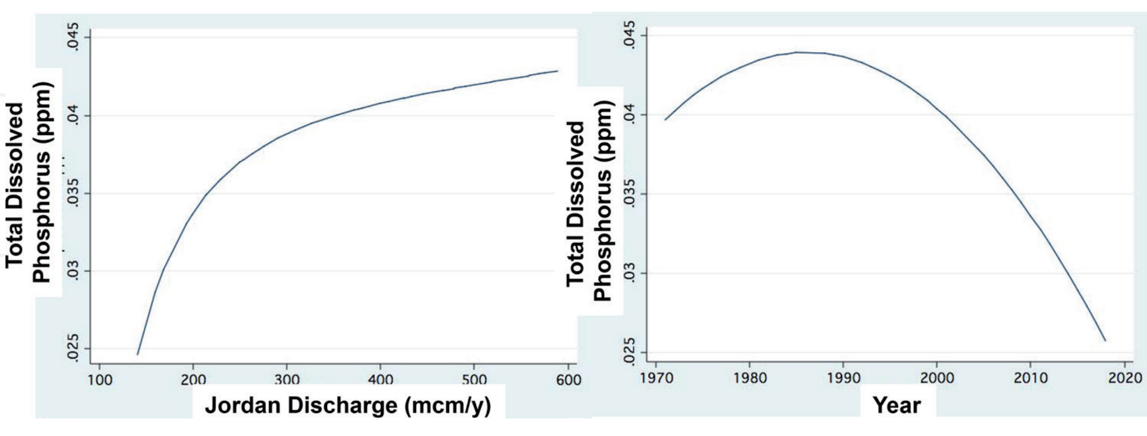


Figure 10.
Fractional polynomial regression between annual mean of the total dissolved phosphorus concentration (ppm) in Jordan water (left) and Jordan water yield (mcm/y) (left) and with years (1970–2018) (right).

NO_3 concentration with elevated discharge above 300 mcm/y as monitored during 1970–2018 is indicated (**Figure 11**). Nevertheless, the dynamic of nitrate flux from the peat soil in the Hula Valley is highly precipitation-dependent. The oxygenation process of the nitrogen rich peat soil produces latent nitrate which is easily released and migrates by precipitation water fluxes. Therefore, the relation between winter rain and nitrate concentration is highly positive. A study carried out in the winters

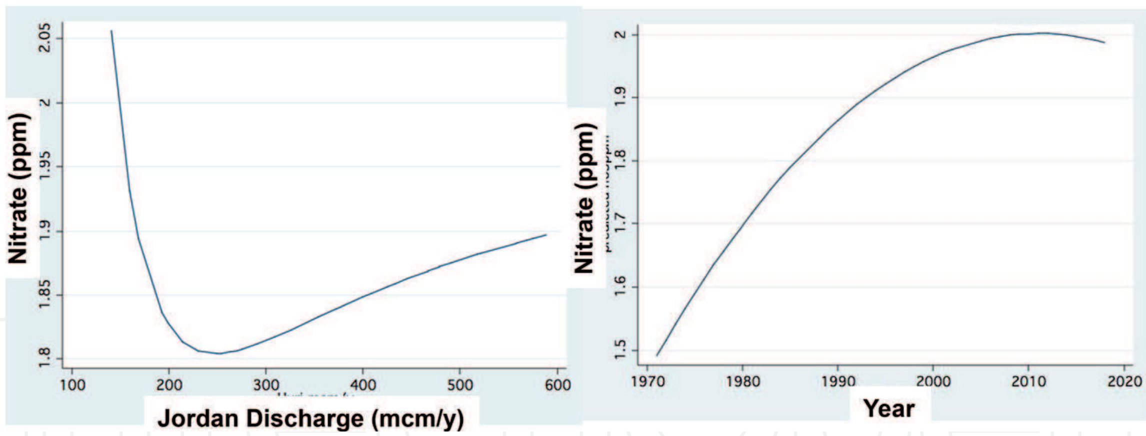


Figure 11.
Fractional polynomial regression between annual mean of the Nitrate concentration (ppm) in Jordan water and Jordan water yield (mcm/y) (left) and with years (1970–2018) (right).

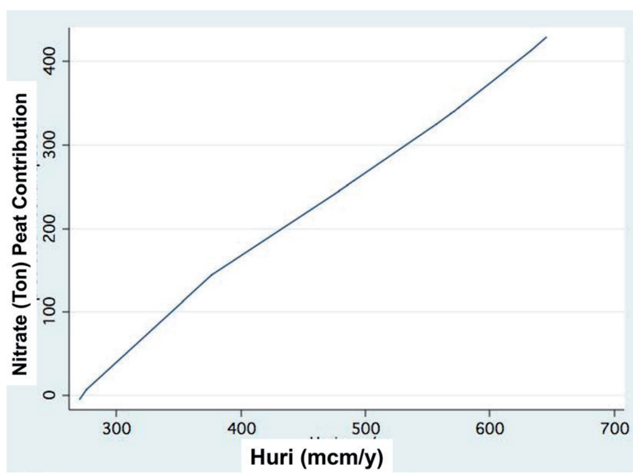


Figure 12.
Linear regression between annual loads (tons) of nitrates contributed by the organic-peat soil of the Hula Valley and the river Jordan annual water yields (m^3/mcm/y; 106 year) during 1969/70–1980/8 (Geifman, 1981, unpublished data).

	Month					
	January		February		March	
	Station					
Year	**Huri**	**Josef**	**Huri**	**Josef**	**Huri**	**Josef**
1975	1.30	1.28	1.77	1.49	1.56	1.23
1976	1.47	1.40	1.38	1.30	1.45	1.18
1977	1.90	1.41	1.88	1.18	1.43	1.18
1978	2.15	1.28	1.74	1.16	1.43	0.99
1979	1.45	1.40	1.57	1.23	1.43	1.19
1980	2.61	1.58	2.25	1.18	3.68	1.21
1981	4.71	1.57	4.49	1.35	2.20	1.11
Average	2.23	1.42	2.15	1.27	1.88	1.56

So far, any concentration elevation in the southern station is due to peat soil contribution of nitrate.

Table 4.
Monthly (rainy season: January–March) mean concentrations (ppm) in two sampling stations on the Jordan River: "Josef Bridge" located before crossing the Hula Valley and "Huri Bridge" at the southern part of the region after leaving the Hula valley.

Nutrient	Inlet		Outlet		Balance (tons/y)
	ppm	tons/y	ppm	tons/y	
TP	0.10	0.8	0.20	1.2	−0.4
TDP	0.04	0.2	0.04	0.2	0
TN	17.8	38.1	6.5	27.3	+10.8
TDN	17.4	34.7	6.4	21.6	+13.1
NO_3	11.8	19.4	5.3	3.3	+16.1
NH_4	5.3	10.1	1.2	7.2	+2.9

Table 5.
Annual mass balance (input minus output) (tons/y) of nutrients in Lake Agmon system during 2005.

during 1875–1981 (Geifman, 1981) documented the relative contribution of nitrate by the Hula Valley Peat soils (**Table 4**).

Results shown in **Table 4** indicate a supplemental mean peat soil contribution of nitrogen concentration (ppm) of 0.32 (March), 0.88 (February), and 0.83 (January). The Nitrate increment decline from January high precipitation gauge to lower rain regime in March is prominent.

The major objectives of the Hula Reclamation Project (HRP) were to ensure agricultural beneficiary and protect the quality of Lake Kinneret water. The achievement of agricultural development improvement was successfully accomplished; nevertheless, the removal of polluted nutrients was summarized as insignificant. Nitrogen removal was achieved mostly through the restriction of fishponds and sewage treatment; both were separately operated but not through the HRP operation. Results given in **Table 5** indicate the minor impact of Lake Agmon System (HPR) on polluted nutrient removal from the Lake Kinneret input loads. Kinneret Nitrogen sources are mostly external from the watershed and after restriction of fishpond and domestic sewage removal significant loads of organic Nitrogen were removed. Phosphorus supplemental resources to Lake Kinneret are dust deposition and lake bottom release; therefore, sewage removal and fishpond restriction did not lower supplement flux into lake water.

Results in **Table 5** indicate Lake Agmon system functioning as a sink for retained Phosphorus and removal of minor loads of nitrogen. The source of supplemental TP concentration in the Lake Agmon ecosystem is probably submerged plant mediated P intake from bottom sediments. The removal of 10.8 tons of TN is probably due to de-nitrification and sedimentation processes. Earlier studies documented the following long-term changes in the epilimnion of Lake Kinneret.

The cyanobacteria: Chlorophyta and diatoms proliferated and the dominance was shifted from large cell bloom forming dinoflagellate Peridinium gatunenze to cyanobacteria phytoplankton dominance where some of them are nitrogen fixers and the majority non-Nitrogen fixers. The nutritional structure of the Kinneret Epilimnion shifted from phosphorus to nitrogen limitation.

3.3 The impact of climate change on Lake Kinneret ecosystem

The decline of water level (WL) in Lake Kinneret (**Figures 13** and **14**) is an obvious result of climate change (precipitation and discharge decline). Nevertheless, it is likely that agricultural consumption might be an impact factor as well. Therefore, this anthropogenic factor was studied. The following data confirmed that anthropogenic usage of headwater discharges in the upper Jordan watershed until 1985 water consumption was declined from 100 to 120 mcm/y to 85 in 2015 and continuation of restriction came down to 68 mcm/y in 2018. The only significant long-term change of agricultural water usage in the Upper Jordan watershed is significant reduction. The outcome of WL decline was decline of nutrient content in the epilimnion of Lake Kinneret (**Figures 15** and **16**): the lower the WL, the lower the nutrient capacities in the epilimnion. Nevertheless, water quality implication is attributed to phytoplankton assemblages and the interrelations between

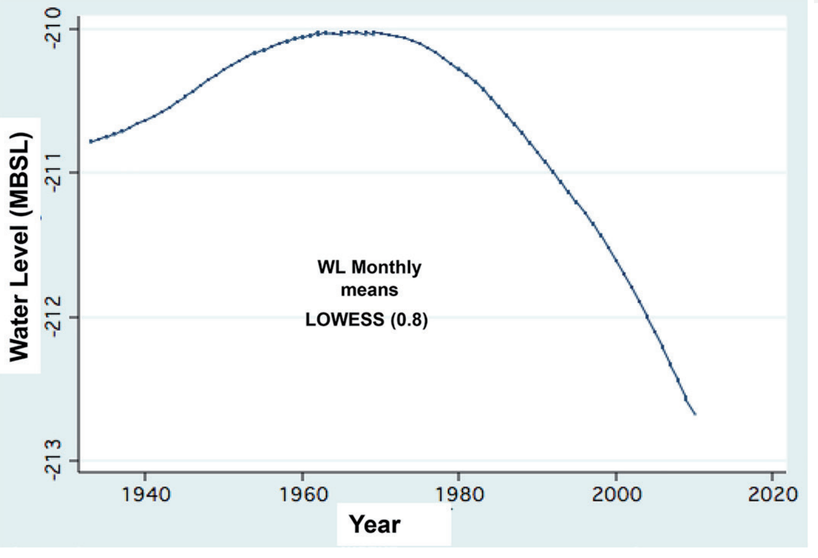


Figure 13.
Trend of changes (LOWESS 0.8) of monthly means of water level (MBSL) in Lake Kinneret during 1934–2018.

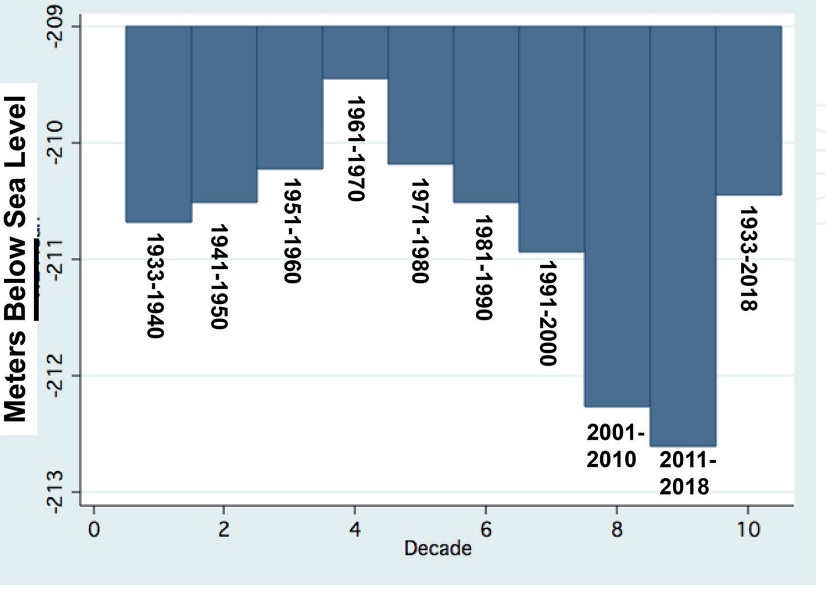


Figure 14.
Decade means of monthly averages of daily measured water level (MBSL) in Lake Kinneret during 1933–2018; decade no. 10 is total average.

nitrogen and phosphorus. **Figure 17** represents significant decline of nitrogen and a slight increase of the epilimnetic loads. The outcome was decline of the mass ratio between N and P from 70 to 23 (**Figures 17** and **18**). Such conditions are known as favored by nitrogen toxic cyanobacteria (17). Moreover, the insufficiency of

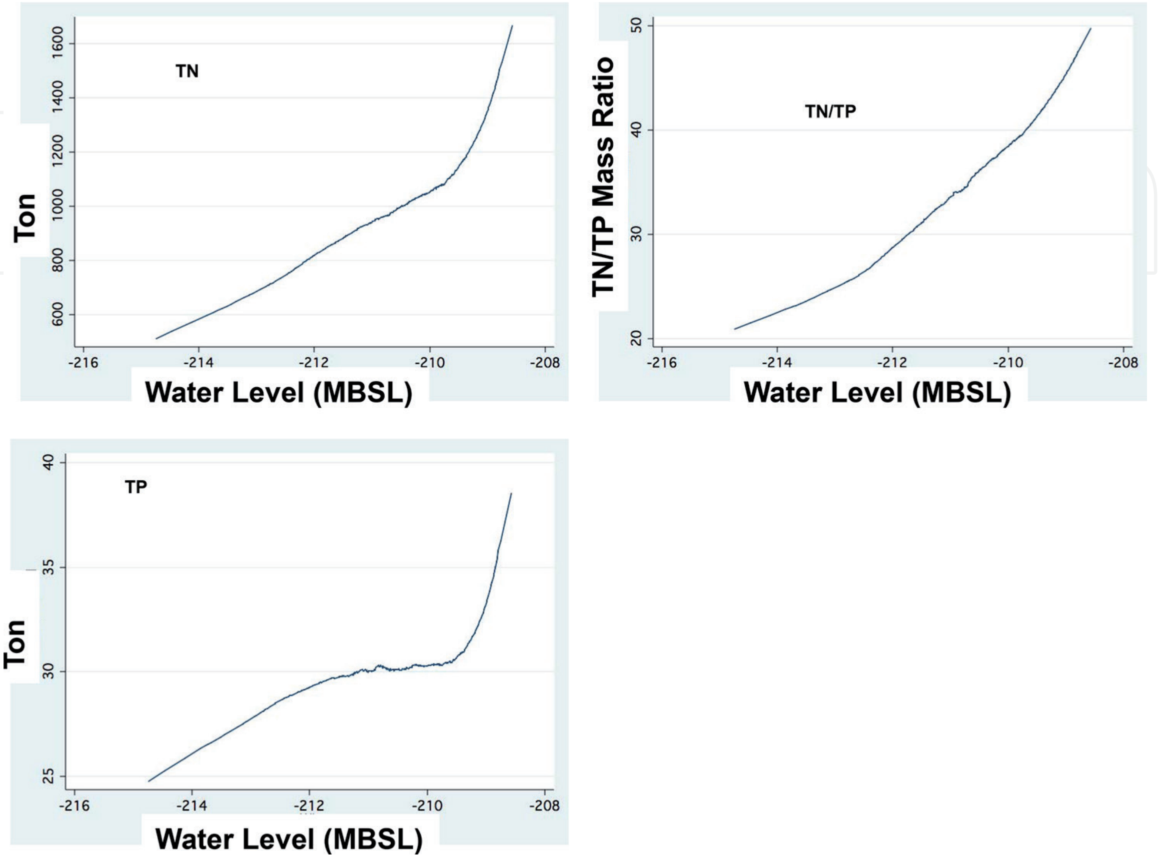


Figure 15.
Trend of changes (LOWESS 0.8) of epilimnetic load (T) of TN (upper left) and TN (lower left) and the TN/TP mass ratio (upper right in relation to water level (MBSL)) decline during 1969–2001.

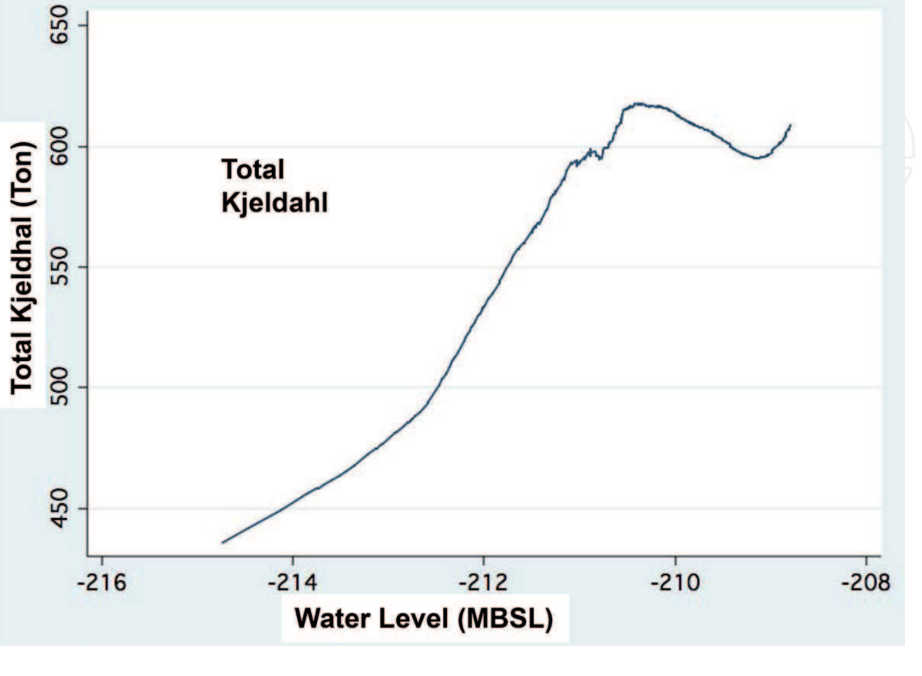


Figure 16.
Trend of changes (LOWESS 0.8) of epilimnetic load (T) of total Kjeldahl in relation to water level (MBSL) decline during 1969–2001.

nitrogen is unfavored by the long-term dominant bloom forming dinoflagellated Peridinium gatunenze and cyanobacteria became dominant accompanied by enhancement of Chlorophyta and diatoms (**Figures 19** and **20**).

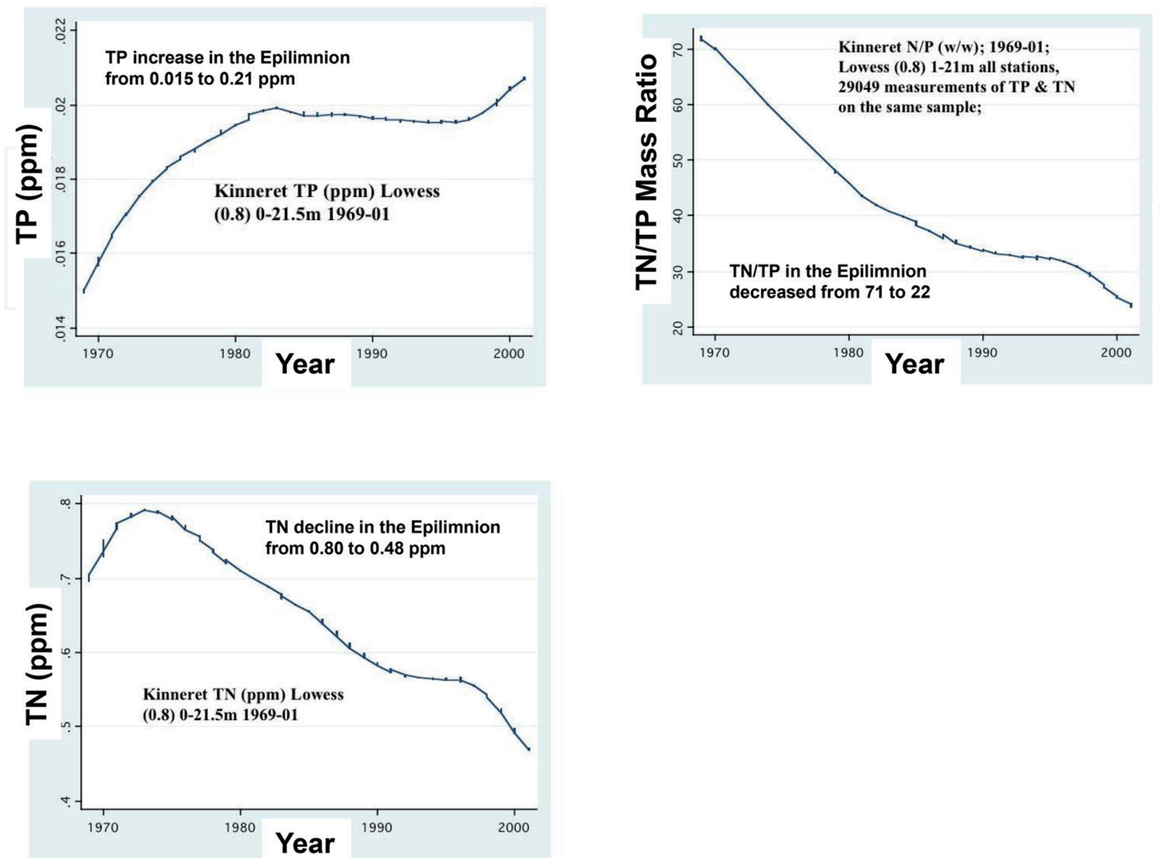


Figure 17.
Trend of temporal changes (LOWESS 0.8) of the concentration (ppm) of TP (upper left), TN (lower left), and TN/TP mass ratio in the epilimnion of Lake Kinneret during 1969–2001.

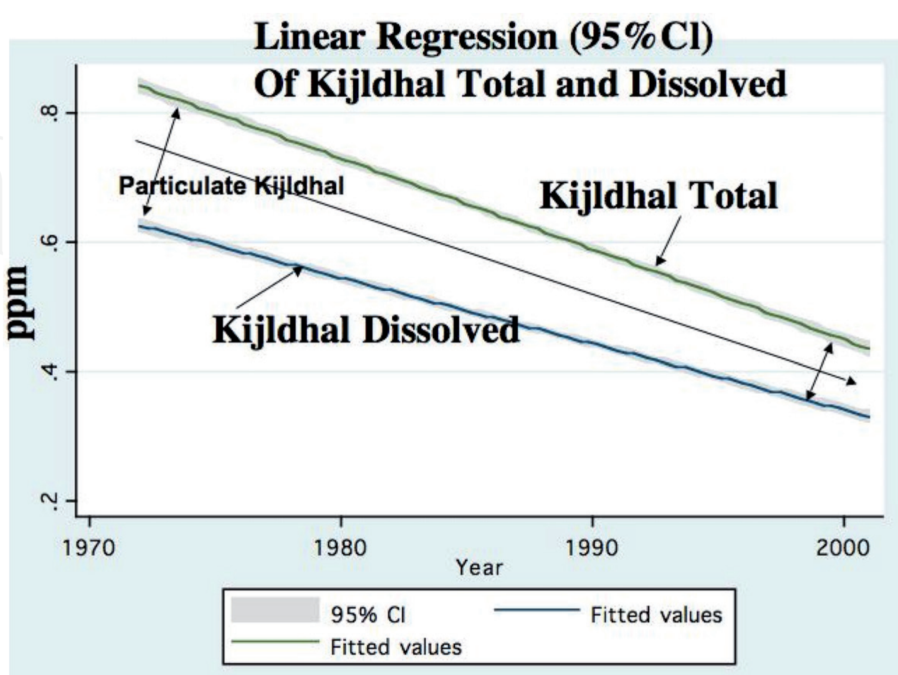


Figure 18.
Linear regression with 95% CI of temporal changes of total Kjeldahl and dissolved Kjeldahl in the epilimnion of Lake Kinneret during 1969–2001.

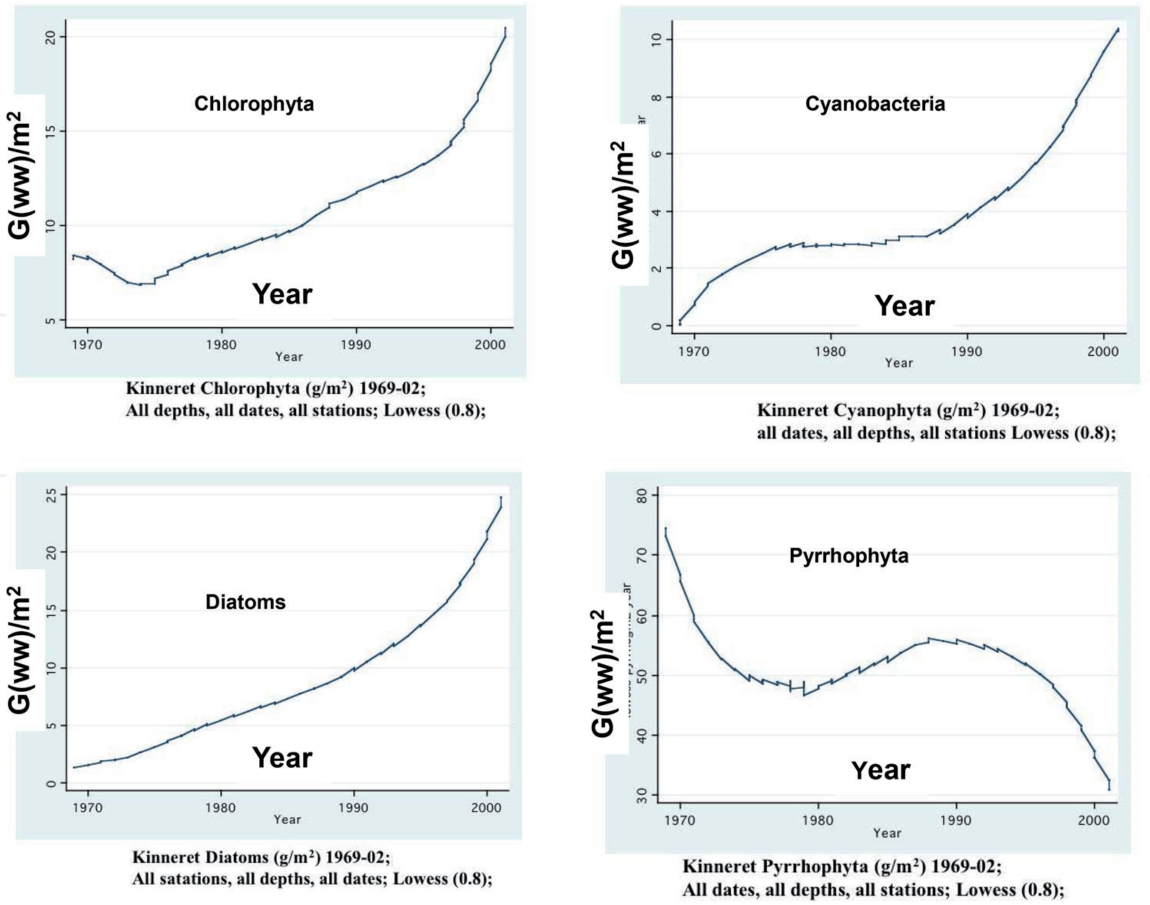


Figure 19.
Temporal trend of changes (LOWESS 0.8) of monthly means of the biomass ($g(ww)/m^2$) of chlorophyta (upper left), cyanobacteria (upper right), diatoms (lower left), and Pyrrhophyta (lower right) in Lake Kinneret during 1969–2002.

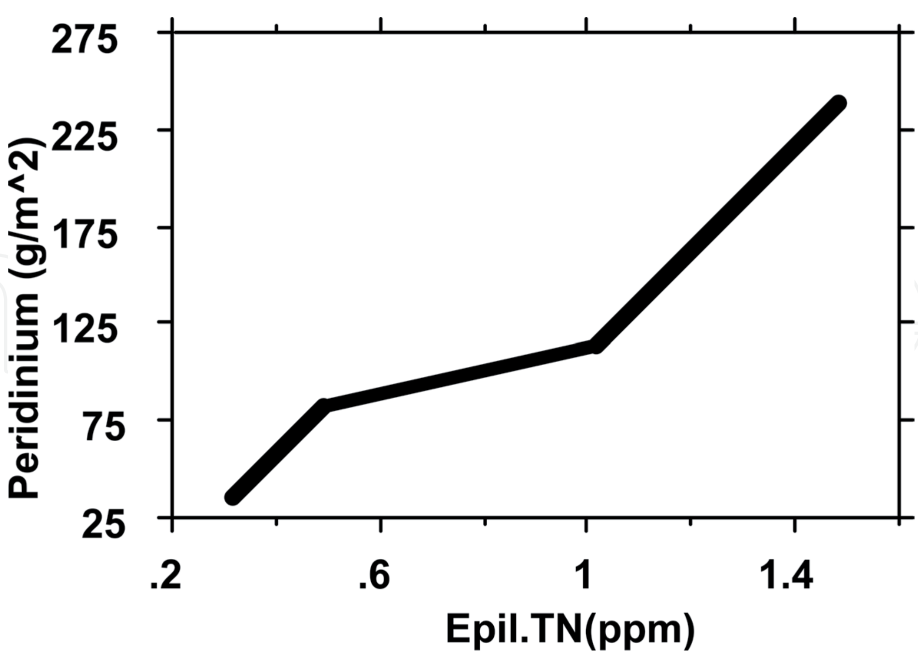


Figure 20.
Linear regression between multiannual averages of epilimnetic TN concentrations (ppm) and Peridinium biomass ($g(ww)/m^2$) in Lake Kinneret during 1969–2001.

4. Discussion

Ecological changes of natural ecosystems were widely studied and documented. Nevertheless, cases such as Lake Kinneret-River Jordan ecosystem, which is strongly affected by anthropogenic intervention, are a typical issue being under crucial scientific and practical research. This is aimed at both prevention of natural and the human society benefits. The Kinneret-River Jordan ecosystem was under complete natural impact until the early 1930s of the previous century, while later on the "Anthropocene Era" of this system was started [5] accompanied by natural climate change. The latest periodical season (1970–2018) was especially a very sensitive factor of significant impact on this system due to two major constrains: (1) water consumption and agricultural development in the watershed and (2) lake water supply. The major changes of regional climate change and the modifications within the Lake Kinneret Limnological trait are briefly presented: elevation of air temperature and Lake Kinneret water, decline of precipitation, agricultural and hydrological management of the Hula Valley land, decline of lake water level, reduced input loads of nitrogen and phosphorus accompanied by reduction of nitrogen and a slight elevation of phosphorus in the Kinneret Epilimnion, dominance replacement of Peridinium by cyanobacteria, chlorophytes, and diatoms. The tentative objective of this paper is aimed at an answer to the question: why and how were those changes developed? It was previously documented [6] that Nitrogen sources for Lake Kinneret are mostly external and mostly effective is nitrate from the Hula Valley Peat soil degradation and fishponds and domestic sewage. Therefore, after removal of sewage and restriction of fishponds, input loads of organic nitrogen were reduced significantly and the supply of nitrate is primarily precipitation-dependent. Nevertheless, input loads of phosphorus from the watershed were reduced but P availability for the Lake Kinneret biota was slightly enhanced due to internal flux from the sediments and dust storm deposition. The dynamic changes of Phytoplankton composition in Lake Kinneret followed the nutrient alterations: the nitrogen consumer Peridinium was declined and cyanobacterial nitrogen fixers were enhanced [7].

4.1 Water level and lake shrinkage

A disputable issue was highlighted: agricultural water consumption or climate change?

Agricultural population in the "Upper Galilee" region (Upper Jordan River Watershed) was initiated during the early 1920s. From the very beginning, water supply for agricultural development was in the past and presently continues to be a major national concern. Nevertheless, the upper Jordan Watershed headwaters are the major source for the Lake Kinneret water budget but also for agricultural consumption. The multipurpose services of the Kinneret ecosystem are aimed at water supply, fishery, recreation, and tourism. Kinneret is the only natural freshwater lake in Israel, and environmental and water quality protection is essential. Moreover, water sharing is crucial and precautionary nationally and internationally guaranteed. Availability of preferential pathways in the undergrounds of the Hula Valley for subterranean water migration (obviously gravitating) is not an imaginary black hole but integrated component of the Hula Hydrological system. Evaporation is supposed to be reduced by enhancement of vegetation cover (Karacus 2019; [8–12]). The Hula Project Monitor Data Base documented annual 1376 mm with variations of 10% during the last 10 years and averaged as 1401 mm/y. This record is based on climatological parameters (Penman-Monteith equation). Multi-annual record (1960–2018) indicates no significant change in the vegetation cover in the Hula Valley region except the seasonality of crop cycling. The ET capacities were, therefore, potentially stable more or less unless climate conditions changed. That is because ET records in the Hula Valley (Hula Project–Migal Data Base) are mostly climatologically dependent (Penman-Monteith formula). Wine [13] and Wine et al. [5] documented the absence of significant climate change conditions in the Upper

Jordan watershed. Givati [1] approximated an increase of 40 mcm/y consumption of Kinneret Headwaters.

Water legislative consumption inspected by the "Water Authority" was significantly reduced from >100 to 68 mcm/y at present implementation. Confirmed information documented restriction from 200 to 68 mcm/y. Conclusively, climate change, precipitation decline, and restricted legislative allocation essentially make sense. The whole Hula Valley is under plant cover since the late 1950s of which 48×10^3 dunams are presently tree covered (groves). The Golan Heights area is tree covered (grove and vineyard) by about 74.5×10^3 dunams. Consequently, total tree covered area of the Upper Jordan Watershed Upstream during 2017 is about 123×10^3 dunams. A small quantity of water ($14–17 \times 10^6$ m^3) is also conveyed from headwater sources (Hula Valley Western Canal) to irrigate crops on the Dalton Plateau (Western part of the Upper Galilee). Water consumption for irrigation in this part of Israel is fully monitored and absolutely restricted to legislated permission.

4.2 Vegetation cover changes in the Hula Valley

Water supply for irrigation on the Golan Heights (part of the upper Jordan watershed) is precipitation-dependent. Thirty-two reservoirs (total capacity 34 mcm; 10^6 m^3) were constructed on the Golan Heights to store natural runoff water. Therefore, maximum water reduction from the Kinneret budget is 34 mcm/y. The maximum reduction of water removal from the Kinneret budget attributed to the increase in vegetation cover is worth only to 20 cm of the lake water level. Maximum storage in the Golan reservoirs occurs when regional precipitation is surplus while all other resources are plentiful and Kinneret WL is increasing anyhow.

Givati [1] documented the decline of 77 mcm/y of Dan and Banias river (major sources of River Jordan) discharges and an annual decrease of precipitations on the Golan Heights of 246 mm during 1970–2010 (Mean 6.2 mm/y).

A reasonable option for invisible water loss in the Hula Valley is the underground preferential pathways gravitating subterranean water migration. Gophen [3, 4] and Gophen et al. [2] suggested 38 mcm/y water loss during drought seasons in the Hula Valley. The Kinneret water balance management was optimized between the dependents of natural parameters (precipitations and river discharge) and human demands (agriculture and domestic). The lake water level resulted in the fluctuations caused by those fluctuating parameters. The national supply (direct pumping from the lake and northern consumption) continued until a severe long-term (5 years) drought led to insufficiency; then a desalinization solution was implemented. Throughout this long-term process, Galilee and the Golan were populated, followed by agricultural flourishing, and the lake was not devastated.

Calculated drought level using the SPI (standard precipitation index) scale during 1930–2016 [1] indicated 13 and 17 years of severe drought during 1930–1970 and 1970–2016, respectively; it also indicates climate change.

The search for well-known cases of water level (WL) decline in lakes is common among limnologists and hydrologists. Deterioration of water quality quite often by water level decline is accompanied by other factors. However, shrinkage measure of the lake is closely related to the Bathymetric features of the lake. In shallow lakes with a flat bottom surface (such as the Aral Sea and Lake Chad), a minor decline of WL exposes a vast bottom area and extreme shrinkage while in deep lakes (steep bottom surface) the opposite occurs: exceptional WL decline exposes a smaller area of the bottom surface. A WL amplitude fluctuation of 20 m (197–217 mbsl) in

Lake Kinneret during 9000 years did not threaten its existence as much as a decline of 19.5 m in Lake Sivan (Armenia). Water utilization for agriculture sometimes (Aral Sea and Lake Chad) led to a huge shrinkage in water bodies, while in other cases (Kinneret, Sivan), a much smaller shrinkage occurs. The top priority of Lake Kinneret exploitation is water supply for domestic use. Removal of water from the Kinneret budget for agricultural development north of the lake by the national authority has led to exceptional shrinkage of Lake Kinneret, which is not realistic. Insufficient replenishment of the Kinneret storage capacity by reduction in water inputs is due mostly to climate change.

5. Conclusive remarks

The impact of climate change in the Upper Jordan Watershed was precipitation and consequently river discharges and available water capacities since the mid-1980s decline [14–16]. Regional air temperature increase was accompanied by the elevation of Lake Kinneret water temperatures. The ET regime during 2005-2018 in the Hula Valley was approximately stable (± 10%). Air temperature increase did not caused significant fluctuations of the ET values due to the high density of vegetation cover which reduced soil surface warming. The changes of the ecological Lake Kinneret trait were mostly due to nutrient dynamics of limitation shift from Phosphorus to Nitrogen.

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