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# Sustainable Utilization of the Lake Kinneret and Its Watershed Ecosystems: A Review

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## Abstract

Lake Kinneret and its watershed have undergone significant structural modifications. Some of them are anthropogenic, and others are natural. Among natural modifications, the climate change is prominent. Among man-made changes, the drainage of the Hula Valley, construction of the National Water Carrier designating Lake Kinneret as a national resource of drinking water, construction of the Dam on the lake south outlet, agricultural developments in the Hula Valley, and others are included. Additional factors that recently have a significant impact on the management of the lake ecosystem are the development of ocean water desalinization capabilities. Nevertheless, these two ecosystems were carefully studied directed by limnological and wetland-agricultural scientific trait. One parameter was not yet accounted intensively, the assurance of long-term sustainability. This paper provides an overviewed insight into the conducted principles of management toward sustainable management after the establishment of the modifications as an attempt of predictive development outline.

**Keywords:** Kinneret, watershed, land use, climate change, sustainability

## 1. Introduction

The Lake Kinneret and its Drainage Basin had been widely investigated [1–6] aimed at enhancing basic scientific knowledge as well as ensuring submission of management recommendation to responsible national authorities. Vast majority of the studies were aimed at ad-hoc tracking ecological and anthropogenic changes. Insufficient attention was given to predictive design of systems sustainability. Anthropogenic management interventions are aimed at both, protection, and sustainable maintenance of the ecological structure and services. Nevertheless, ecosystem structures highly depend on the utilization trait. If a natural structure of an ecosystem is not threatened by anthropogenic intervention and/or by natural constrains, protection is smoothly implemented. Global climate change, increase of human population density, and consequently increasing demands for food production while tackling acute water scarcity became critical over larger global zones. Global promotion of desertification (decline of soil fertility) and afforestation amplified human intervention in natural ecological structure. Therefore, ecological management became a critical parameter which has a significant impact on human society. The ecosystems of Lake Kinneret and its watershed are subject for national

and international concerns as sources for water supply, agricultural development, commercial fishery and aquaculture, territorial land for living (population dispersal), and more. During the last 80 years, natural and anthropogenic modification were accurately carried out over these ecosystems and consequent management operations were implemented aimed at efficient utilization of the natural resources of land and water while ecosystems sustainability will be preserved. A survey of the history and implementation of achievements which accompanied the ecological modifications in lake Kinneret and its watershed to ensure undamaged and sustainable ecosystem functionality is presented in this paper.

## 2. Background

### 2.1 The Lake Kinneret watershed

Lake Kinneret watershed is part of the Northern segment of the Syrian-African great rift Valley. The Lake Kinneret Watershed area (2730 km<sup>2</sup>, of which 73% is an Israeli territory), from Kinarot Valley in the south to Upper Galilee (northeastern Israel) and southern Anti-Lebanon in Lebanon is 110 km long [1–4]. The Total area of the Kinneret drainage basin is 2730 km<sup>2</sup>. It is divided into sub- units: (1) *Northern*: The River Jordan drainage; (2) *Eastern*: The southern part of the Golan Heights; (3) *Western*: The drainage area of Tzalmun and Amud rivers; (4) *South-Eastern and South-Western* minor sections. Versatile vegetations cover, soil and geological formations characterized the Kinneret watershed. Surface mean slope of the Kinneret Watershed is 2.8%. The following major events during the Anthropocene period were: The Lake Kinneret South Dam construction; The drainage of Old Lake Hula and swamps resulted a change of the regional Hydrological conditions; Regional population emigration and immigration; Governmental resolution of Lake Kinneret as major source for water supply and the construction of the National Water Carrier (NWC). These achievements established the long-term national policy of land use and water supply and geo-political boundary [3].

### 2.2 Regional hydrology

Three major headwater rivers (Hatzbani, Banyas and Dan) flow southerly downstream from the Hermon mountain region [2, 3, 5–11]. The Hula drainage 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 maintains its Water Level (WL). Long-term (1926-present) record of WL daily monitor indicates maximal amplitude of 6.67 m (208.20–214.87 MBSL). The upper limited legislation of WL (208.8 mbvsl) was aimed at prevention of damage to previously constructed housing. The lower limit is flexibly affected by the location of the intake of the NWC (215 mbsl) and precaution of water quality impact. Since 1972 the hydrological management of the entire headwater resources was achieved by precipitation range, national water demands and NWC capacities and obviously by the south dam operation. [3]. Maximal lake water storage was achieved by close Dam limited by WL altitude. These were the management rules when 60% of national domestic water supply were originated from the Kinneret. Nevertheless, ecosystem sustainability aimed at water quality, mainly salinity, might be threatened if dam is closed and major withdraw is done through NWC [1–3, 5, 12]. Before Dam construction nutrient rich winter inflows crossed the lake through the upper water layers due to their higher temperature than that of the Epilimnion and naturally flew out through an open outlet. After Dam

construction (1933) the outflow became human controlled aimed at water storing, and enhancement of salt and pollutants removal [1–3, 5, 12]. The final decision was a combination of actual conditions: precipitation-discharge range, desalinized water volume availabilities and lake water quality.

2.3 Land use

The territorial part of Israel within the Kinneret watershed is 2000 km<sup>2</sup> which is 73% of the total of 2730 km<sup>2</sup>. The agricultural land use in the Kinneret watershed area is given in **Table 1** [3, 7, 13–15].

2.4 Water consumption

The total legislated water consumption for agriculture and domestic usage (source: National water authority) indicates the following: Until late 1990’s it was ranged between 100 and 120 mcm (10<sup>6</sup> m<sup>3</sup>) per year of which 99% for agricultural irrigation: 42% -grooves’ 48% - field crops, 7% -fish ponds, and 1% - human domestic supply. Later on, restriction was instructed to 85 mcm/y and further to 68 mcm/y were implemented with additional supply from Lake Kinneret to the Golan Heights of 19 mcm/y [8, 9] (**Tables 2 and 3**).

How does agricultural management accept such constraints of natural drought and the followed legislation of water supply restriction? The answer was given in [15]: During 20 years (1990–2010) the efficiency of water utilization aimed at the beneficial revenue of agricultural production increased from 41,100 to 81,420 US\$ per ha. It was the result of improvement of agricultural technology.

2.5 Land use land cover modifications in the Hula Valley

Before Hula Drainage the Valley was mostly (6500 ha) covered by natural wetlands (Peat soil) and old Lake Hula (1300 ha), Hula drainage, converted natural wetland into agricultural land [7, 15, 17, 19]. It was an infrastructure development for an agricultural income source for the local immigrated residents. Between 1960 and 1990 the Peat-Land area cultivation has yielded economically sufficient products. Nevertheless, contributed nutrient to Lake Kinneret threatened its water quality. It was resulted by inappropriate irrigation methods. The outcome was peat soil destruction and subsidence, dust storms which blocked the drainage canals, underground fires and rodent population outbreaks. Agricultural crops were damaged and Kinneret water quality became threatened. A reclamation

Type of land cover	Area (km <sup>2</sup> )
Field Crops	180
Orchards	197
Fishponds, reservoirs, Agmon, Lake Kinneret	171
Natural Forest and Grove	266
Not Cultivated land	1067
Other	111
Total	1992

**Table 1.**  
*Israeli agricultural land use (km<sup>2</sup>) in the Kinneret watershed as documented in 2004.*

Geographical region	Surface area (km <sup>2</sup> )	Annual rainfall (mm/y)	Annual rain volume (mcm/y)
Eastern-Northern Galilee	542	800	434
Jordan-Hermon	788	900	709
Hula Valley	200	450	90
Golan Height	580	900	522
Western Basin	450	450	202
Small Southern Basins	170	450	77
Total	2730	(Mean: 658)	2034

**Table 2.**  
*Precipitation Regime: Geographical sub-units of the Lake Kinneret drainage basin, their surface area (Km<sup>2</sup>), annual precipitation gauge (mm/y) and calculated total rainfall volume (mcm/y) are given [8, 9, 13, 14, 16, 17].*

Used-cover type	1949	1958	1976	1986	2010
Water	24%	0	0	2%	2%
Swamps	54%	7%	7%	3%	7%
Flooded	22%	0	0	0	0
Field Crops	0	59%	79%	58%	68%
Uncultivated	0	17%	—	14%	5%
Other	0	8.5%	3%	10%	7%
Orchards	0	0	3%	8%	9%
Fish ponds	0	8.5%	8%	5%	2%

**Table 3.**  
*The history of land use/land cover included in the peat soil convention (PSC) in the Hula Valley (59 km<sup>2</sup>; 5900 ha). Numbers are % of the total area. Historical events: 1952–1957 drainage and conversion to agricultural management; 1989–1995—Hula reclamation project (HRP) implementation [18, 19].*

project (Hula Reclamation Project, HRP) was consequently discussed and implemented. A shift of 500 ha Peat-Land from agriculture to eco-tourism usage was achieved. The HRP concept was aimed at ecosystem sustainability and therefore based on anthropogenic intervention combined with the introduction of natural plants. Reconstruction of the hydrological drainage system of the entire valley was renovated. The critical need for soil structure protection by maintenance of its moisture was achieved by implementation of irrigation method of moveable sprinkle line [14, 17].

2.6 The peat soil convention: Sustainable achievement

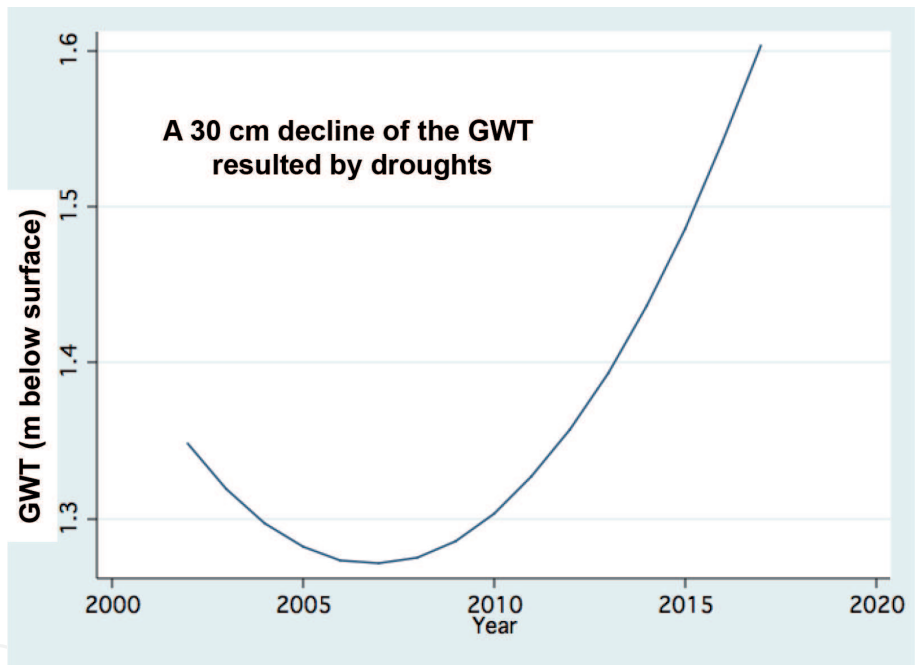
The major significant variable of regional water balance is obviously rainfall contribution. Although a major part of the regional rainy waters input is transformed into runoff, flowing downstream into Lake Kinneret, significant volume of is migrated into unknown underground spaces in the Hula Valley. When climate is changed, and therefore, water consumption and possibly land use policy reduces, it will have an impact on lake water level. The second level of water consumption is due to Evapo-transpiration (ET). This variable of the regional water balance is strongly affected by climate conditions, land plant cover, water availability and soil properties. Dryness conditions enhance soil moisture reduction, which is affected



by land use policy of slow down crops cultivation (plant coverage restriction) and, therefore, reduce regional evaporation capacity. The management of the Kinneret watershed is a good example of protection of sustainability of an ecological ecosystem where natural and anthropogenic interests are together combating dryness in the hula Valley (**Figure 1**) [7, 13–15, 17].

As a result of enhanced dryness and water supply limitations, the national policy of water pricing was reordered. Consequently, cost account of water consumption in the Hula Valley became more expensive. Nevertheless, as part of the National Water Authority recognition of ecosystem sustainable management, a formal confirmation was carried out of the special status of the Hula valley. Followed by legislated water price reduction accompanied by stakeholders' commitment to irrigate fields despite being bare in summer. Nonprofitable expenses were compensated by the lowering of water pricing. The difference between the National and the reduced tariff was dedicated to a stakeholder's managerial foundation to cover those irrigation expenses.

Results in **Table 4** indicate a reduction of Water-Swampy-Flooded area from 100% to less than 5% surface cover. As a result of enhanced dryness (water scarcity)



**Figure 1.**  
Annual Total Hula Valley region average of ground water table (GWT) (m below surface).

WL range (mbsl)	Number of months (%)
Below 214	32 (6)
214–213	65 (11)
213–212	89 (15)
212–211	104 (18)
211–210	144 (24)
210–209	125 (21)
Above 209	30 (5)

**Table 4.**  
Number of months with monthly means of WL with respect to 1 m WL interval in Lake Kinneret (1970–2018).

driven by climate change during the recent 15 years field crops area in the watershed was restricted by 35% and Fishponds by 43%. Although agricultural land-use in the Watershed was reduced as well as water availability (from 110 mcm/y to 68 mcm/y) crops and revenue per areal unit were improved simultaneously. This was resulted by technological improvements and land beneficial significance. In other words, natural constrains of water scarcity were achieved by water and land utilization efficiency aimed at sustainability maintenance.

### **3. Climate change**

#### **3.1 Precipitation and discharges**

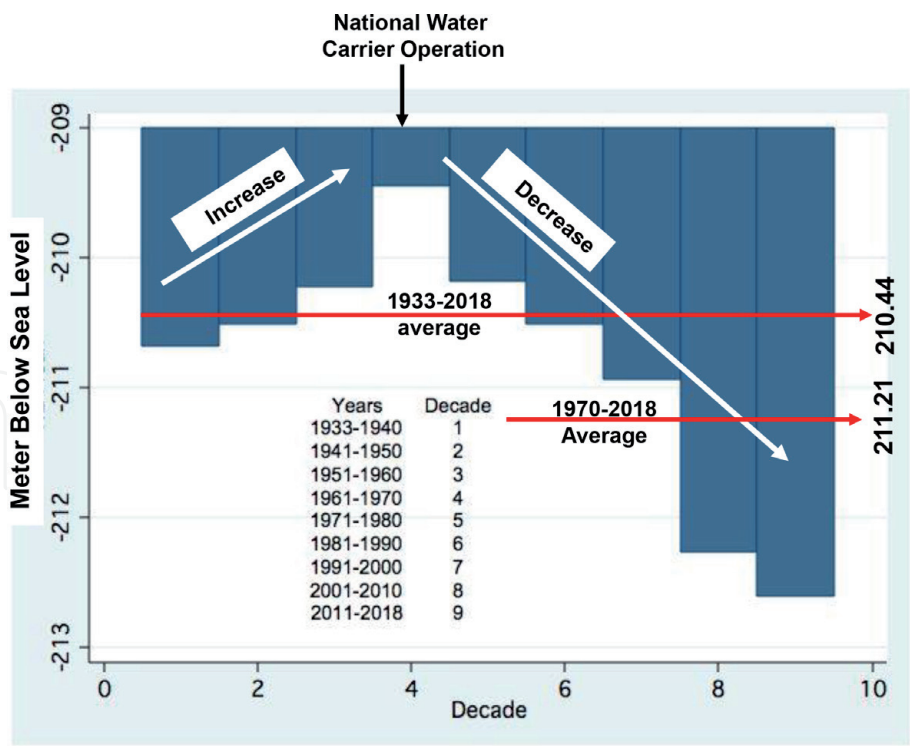
Since mid-1980's precipitation decline in the Kinneret Drainage Basin was documented (**Figures 2–6**). During 2013/14 and 2015/16 seasons rainfall was 47% and 68% respectively below the multiannual mean. Major contributors to the Jordan discharge are Dan and Banias rivers. The discharge of Dan and Banias during 2014 (2.67 and 0.16 m<sup>3</sup>/s respectively) were the lowest since recent 22 years in comparison with the maximum discharges of 12.8 and 7.4 m<sup>3</sup>/s respectively [8, 9]. The annual discharges of those rivers declined by 63 and 14 mcm/y respectively. As a result, annual availability of lake water (inflow minus evaporation) during 1985–2016 indicates a decline from 470 to 225 mcm/y. As the result of promoted trend of dryness, the hydrological dynamics of the Lake Kinneret ecosystem was modified. The Input reduction accompanied by water level decline and elimination of pumping together with close Dam policy eliminated exchange level and prolongation of RT from 5 to 7 to a range of 15–20 years. Evaluation of SPI (Standard Precipitation Index) values from 87 years precipitation record has indicated 11 and 17 negative indexes (aridity level) during 1927–1970 and 1970–2014 respectively, which is an indication of climate change toward dryness. River discharge reduction initiated also changes of the phytoplankton community structure in Lake Kinneret. The Nitrogen supply was diminished resulted *Peridinium* decline which was replaced by *Cyanobacteria* dominance.

#### **3.2 Rain and headwater discharges**

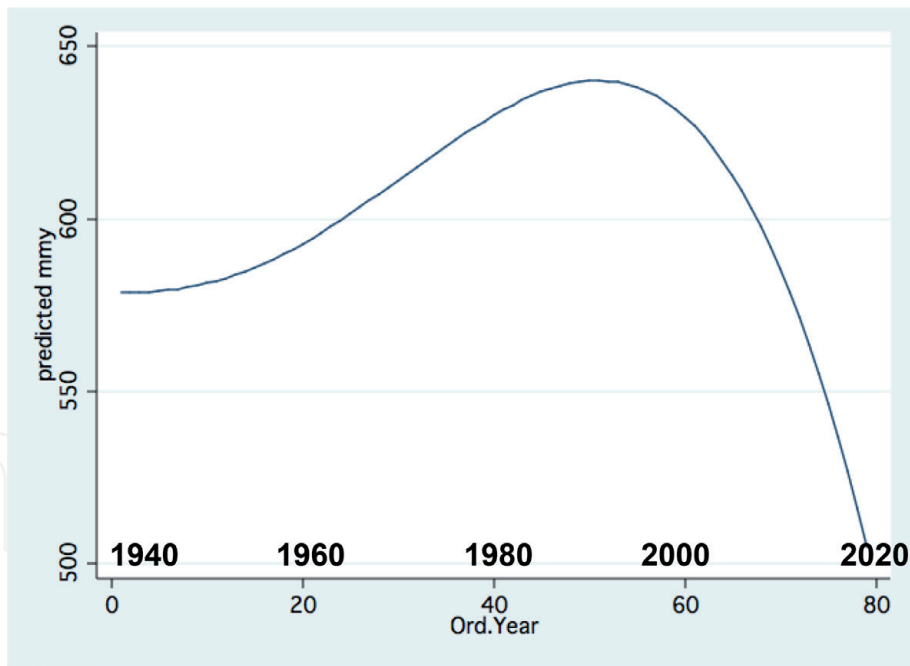
Decline of rainfall and Jordan River discharges during the last 40 years and historical deficiency of aquifers storage in the Israeli Northern Basin for 100 years were documented by the Israel Hydrological Service [1, 5, 8, 9]. During 2013/14 and 2015/16 rainfall was 47 and 68% respectively below the multiannual average. The Rivers Dan and Banias discharge during 2014 (2.67 and 0.16 m<sup>3</sup>/s respectively) were the lowest since recent 22 years. Major contributors to the Jordan flow are Dan and Banias rivers. The annual discharges in those rivers declined by 63 and 14 mcm/y, respectively. A decline from 470 to 225 mcm/y of availability of Kinneret waters (mcm/y) was indicated during 1985–2016.

#### **3.3 Air temperature**

The records of daily Maximum and Minimum of air temperatures measured at the Meteorological Station Dafna (northern part of the Hula Valley) indicates an increase since mid-1980s. The air temperature record indicates [13, 14, 17, 19] an annual maximum and minimum elevation by 2.7 and 1.5°C, respectively. Studies on regional water balances confirmed enhancement of water loss not only as



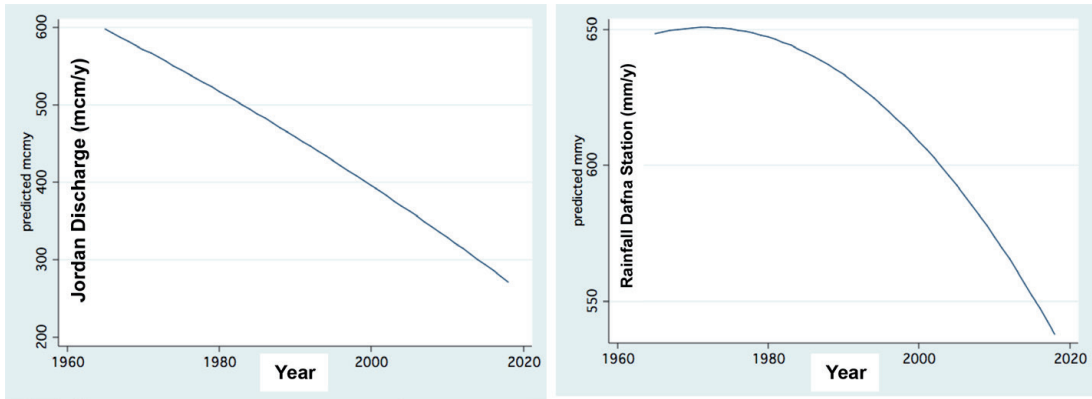
**Figure 2.**  
*Groups of decade (10 years) averages of monthly means of water level in Lake Kinneret. Trend of changes, periodical means, and anthropogenic events are indicated.*



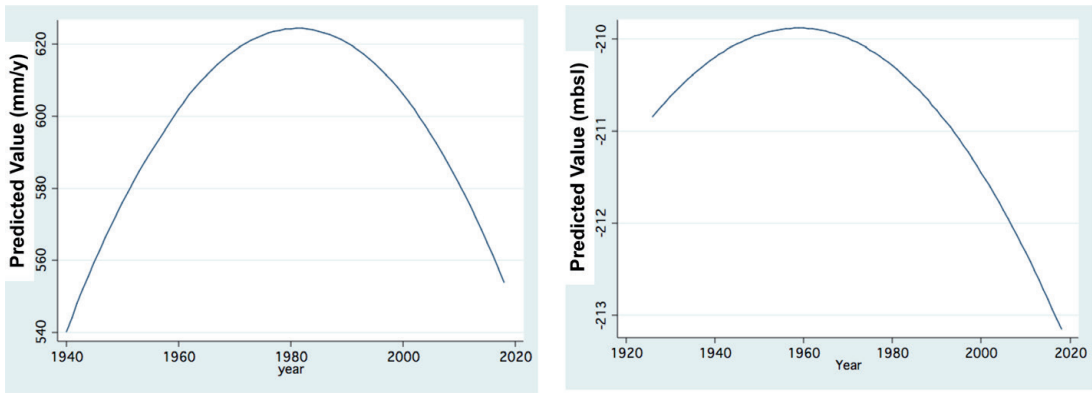
**Figure 3.**  
*Fractional polynomial regression between annual (1940–2018) precipitation and years.*

precipitation and runoffs but also in the underground preferential cavities in the peat soil. Dryness processes of the Hula Valley soil confirm the potential loss of water during dryness periods. Therefore, it was recommended to prevent decline level of soil moisture by suitable irrigation method. Recommended Optimal management is, therefore, moisture enhancement especially during summer time. Climate change and consequent dryness constrains initiated a special legislation, the Peat Soil Convention, which ensured summer water supply for irrigation.

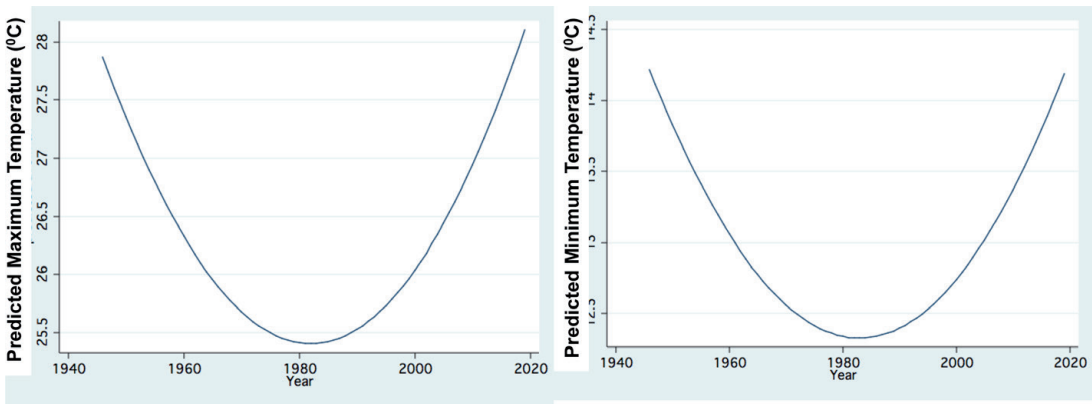




**Figure 4.**  
*Fractional polynomial regression between annual Jordan discharge (mcm/y) (left panel) and rainfall (mm/y) (Dafna Station, right panel) during 1969–2018.*



**Figure 5.**  
*Fractional polynomial regressions between rainfall (left panel, Dafna Station), and annual means of WL (mbsl) (right panel), and years.*



**Figure 6.**  
*Fractional polynomial regressions between annual means of daily maximum (left panel) and minimum (right panel) air temperature measured in Dafna Station and years during 1940–2020.*

## 4. Lake Kinneret ecosystem

### 4.1 Water level fluctuations in Lake Kinneret

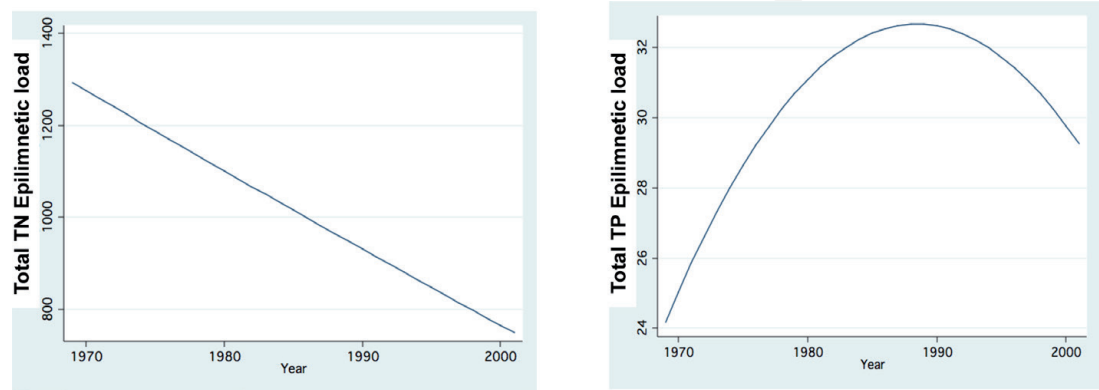
The obvious direct relation between Kinneret WL and precipitation regime in the watershed was documented widely in previous studies. Historical (9000 years before present) data of the Kinneret WL was investigated by two different methods [20, 21] and indicated an amplitude of 20 m (197–217 mbsl) WL fluctuations.

Monthly means of daily WL measurements has indicated that during 48 years only 97 months (17%) WL was lower than the legislated bottom line of 213 mbsl occurred mostly during recent 18 years (**Table 4**) [1, 3, 10, 16, 18–23] .

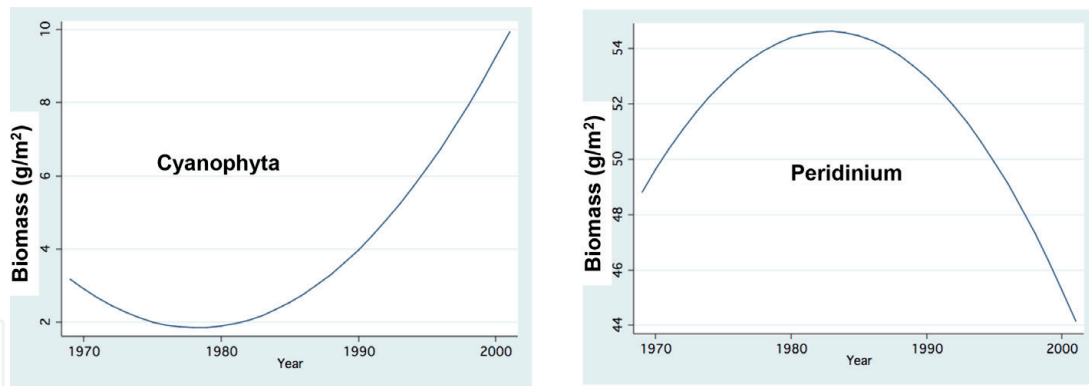
Results in **Table 4** and **Figure 2** indicate that during most of the time (83%) the Kinneret WL was not lower than 213 mbsl and, before 2000th, WL was higher than the minimal legislated altitude. The decline of WL below the instructed WL bottom- line (213 mbsl) was recorded during years of exceptional decline of rainfall: 2000–2002, 2008–2011, and 2016–2018, which consequently resulted in significant restriction of agricultural water allocation by the National Water Authority.

#### 4.2 Nutrient dynamics

The discussion about dependence relations between phytoplankton and nutrients presented here emphasize the paradigm of an everlasting dilemma: Between phytoplankton composition and nutrient concentrations, who is the boss? (**Figures 7** and **8**) Algal community structure responds to the concentration of the nutrients or the contrary: does the nutrient concentrations is primary or secondary result of the algal density [6, 11, 23–33]? Nitrogen input is defined as predictor of algal domination in Lake Kinneret: Peridinium or Cyanobacteria. A decline of epilimnetic TN standing stock was documented during 1969 to 2001 accompanied by decline of Peridinium biomass while the biomass of Cyanobacteria increased. TN decline initiated Nitrogen deficiency, which is favored by Cyanobacteria [32] due to their ability of maintain the fixation of atmospheric Nitrogen by the enzyme of Nitrogenase. Earlier studies suggested two elements as key factors for the Peridinium bloom formation: Copper (Cu) and Selenium (Se) [6, 23, 29–33]. The study of the Cu impact was not thoroughly developed but that of Se did it thoroughly. It was confirmed that Se is a limiting factor of Peridinium growth. Before Hula drainage, the chemical conditions of the peat soil were mostly reductive but presently more oxidative and, therefore, limitation of Se is not impossible. Earlier Studies [29, 30], suggested that precipitation and runoff discharges are an important source of bioavailable Se (Selenites and Organic Se) and high availability of Se in surface waters of Kinneret watershed might be a significant supporter of the Peridinium heavy blooms. Therefore, it is suggested that in addition to Nitrogen deficiency, Se input decline affected the decline of Peridinium biomass. Conclusively, the replacement of Peridinium by Cyanobacteria is mostly due to change of nutrients dynamic resulted by climate change. The depletion of Nitrogen supply is based on a long-term record and the recorded data about Se dynamics is partial.



**Figure 7.**  
*Fractional polynomial regressions between annual averages of Epilimnetic loads (ton) of Total nitrogen (TN) (left), Total phosphorus (TP) (right) inputs through Jordan inflow and years.*



**Figure 8.**

*Fractional polynomial regressions between annual averages of phytoplankton biomass ( $\text{g/m}^2$ ) (Peridinium, Cyanophyta) and years.*

### 4.3 Dam management: to open or not to open?

Open or Not to Open (ONO) the South Dam when WL is high? That is the question for Sustainability by hydrological managers [23, 34, 35]. Regional trends of climate change and dryness process were recorded: Standard Precipitation Index (SPI) enhancement precipitation decline, air and lake water temperature increase, river discharges and restriction of lake input volumes and consequent decline of WL, elongation of RT duration. The decline of water availability for domestic and agricultural supply created a national concern accompanied by increase of Lake water salinity, epilimnetic Nitrogen deficiency and Phosphorus sufficiency which enhanced biomass replacement of Peridinium by Cyanobacteria [28]. These natural ecological modifications were accompanied since 2010 by replacement of the lake as principle supplier of drinking water by desalinization of mediterranean waters. The following additional parameters made the ONO dilemma more significant. Multi-annual (1933–2020) daily record of WL indicates an average annual increase of 1.6 m. Nevertheless several annual exceptions of higher and/or lower of it are common. These exceptions are critical for decision makers with regard to the dynamics and management policy of water supply which was dependent of pumping rate and Dam management: high WL indicate pumping potential enhancement and low WL dictate withdraw restrictions. Several cases which represent not common conditions are: During fall 2001 WL was lowered to the lowest altitude ever recorded since 1933–214.87 mbsl and pumping was exceptionally restricted; during winter 1969 WL increased up to 208.2 mbsl and the dam was maximally opened; Five hydrological years (October–September next year) 2013/2014–2017/2018 were a drought sequence in a row when the annual increase of the WL varied between 0.35 and 1.58 m. At the end of this drought period the epilimnetic salinity was 325 ppm Chloride which was even predicted to increase higher if dryness trend would be continued. Three years earlier (2011–2013) the WL annual elevation varied between 1.75 and 2.58 m. After five drought seasons (2014–2018) heavy rain winters came and WL elevation was 3.41 in 2019 and 3.0 m in 2020. In December 2019 when WL was 211.89 mbsl, salinity was measured as 325 ppm chloride. Later on in winter 2019 the heavy input discharges during January – mid-March when dam was closed dilution effect resulted salinity decline to 273 ppm chloride, (52 ppm decline). It is likely that enhanced water exchange (RT shortening) by open dam might cause higher decline of salt concentration. Moreover, it is also predicted to enhance nutrients and Microcystis biomass removal which enhance improvement of water quality. Since late 1990's the phytoplankton assemblages are dominated by Cyanobacteria, mostly due to the toxic Microcystis spp. The recent lake situation is

therefore creating a dilemma for future management of sustainability: Water supply is done by desalinization, while salinity and Microcystis are enhanced supported by close dam and RT elongation water quality is therefore deteriorated. It is likely that, within future design for sustainability other than hydrological factors must be included. For example, salinity, nutrients and toxic Cyanobacteria biomass. Consequently, during rainy winter a partial open of the dam is recommended aimed at quality improvement.

#### 4.4 Salinity

The salinity of Lake Kinneret water was a critical parameter when supply for agricultural utilization was actually required. The major supply of salt to the lake are fluxed through the lake bottom through two major process: surface infiltration (superficial) and welling up. Salts' contribution through rivers and tributary inflows are much lower in comparison the sub-lacustrine sources. The salinity of River Jordan (65% of total inflows) is more than 10 times lower than that of the lake. Nevertheless, until late 1950's about 25% (total about 160000 tons annually) of salt input came 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. As a result of this anthropogenic implementation accompanied by the heavy floods during the winter of 1968–1969 (25% of lake water were exchanged) lake water salinity declined from 400 to 210 ppm Chloride. Historical information indicates Chloride concentration range before the 1950's between 290 and 325 ppm. A critical question is therefore arise: why salinity was increased during 1948–1968 from 280 to 400 ppm Chloride when negligible consumption of lake water was supplied for domestic and agricultural usage and the only one management tool, Dam operation (NWC was not in use yet) was available? The WL record indicates an increase of more than 2 m during 20 years (1948–1968). It is therefore suggested that Dam operation policy was aimed at long-term water accumulation causing WL elevation accompanied by Salt accumulation which resulted significant concentration increase of Chloride by more than 100 ppm. It has to be noted that during 1948–1968 there was also a sequence of several drought seasons in a row. Conclusively, for 20 years, the water exchange was low resulting elongation of Residence Time duration. The 1948–1968 event is a case study example for future consideration of sustainability design. The case study of 1948–1968 was not the only one for future consideration. Two other closely related cases which continued only one winter each are relevant: During two winters with heavy rain, in 1968/69 and 1991/92 similar inputs of  $1 \times 10^9 \text{ m}^3$  were fluxed into the lake during 2 months. The difference between the two winters was the Dam operation [23, 34]: During the first winter the Dam was maximal open and during the second winter completely closed. It has to be considered that the input of low salinity river waters into the much higher salt concentration of lake water create a dilution effect in winter and salt concentration in the lake decline but the level of the decline is dependent on two parameters: input volume and water replacement dynamic and the level of replacement is the dependent of open Dam policy. Results indicated that open Dam operation enhanced water replacement (exchange) which is in fact Residence Time shortening. Therefore during the winter of 1968/69 the Chloride concentration declined by 64 ppm while in the winter of 1991/92 the decline was smaller – 39 ppm. 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) if water storage for supply is not critical resulted by desalinization supply.



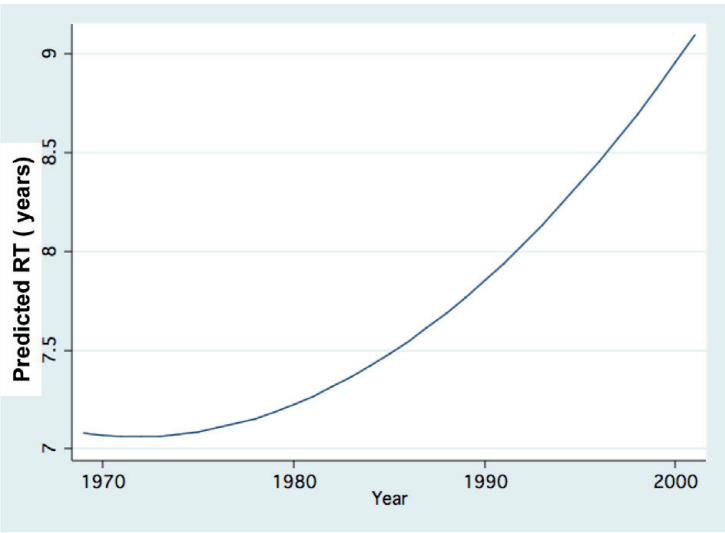
#### **4.5 Residence time (RT) prolongation**

Residence Time prolongation (Water exchange reduction) affected also Nitrogen and Phosphorus dynamics (**Figures 9–11**). The process of Peridinium decline and Cyanobacteria enhancement was also supported by RT prolongation. The climate change initiated a linkage of chain events. Discharge decline and water scarcity (dryness) resulted WL decrease, RT prolongation and nutrient supply reduction accompanied by the modification of algal community structure. Normally, the higher the discharge is the faster is the increase of the WL and the shorter is the RT. and vice versa. The decline of discharge and Nitrogen input was accompanied by decline of epilimnetic TN stock and decrease of TN/TP mass ratio. Optimal Ecosystem management is aimed at protecting sustainability and the operation tool is through hydrological control: desirable ranges of pumping, WL fluctuations, nutrient dynamics preventing water quality deterioration resulting adequate water quality. Before 2010 the majority of domestic water supply originated from Lake Kinneret but essential climate change condition constrains created the need for the construction of alternative water source - Desalinization. The decline of discharge and insufficient Nitrogen input caused the phytoplankton community change. The newly created ecosystem structure enforced management adaptation for sustainability protection. When water budget is positive accompanied by appropriate withdraw (pumping and/or open Dam options) RT become shorter and water exchange is high. Decline of Nitrogen availability accompanied by Phosphorus enhancement caused the decline of TN/TP mass ratio [23, 35]. Hydrological management of Lake Kinneret is creating a dilemma for future implementation: Water supply is done by desalinization, salinity and Microcystis are enhanced as supported by close dams that enhance RT prolongation and water quality deterioration. It is therefore likely that recently, WL regime is not the management key factors and other parameters should step forward on the scale of priorities such as: salinity, nutrients and toxic Cyanobacteria biomass. For example, during heavy rain a partial open of the Dam is recommended to remove salt, phosphorus and Cyanobacteria biomass while water supply is not critical.

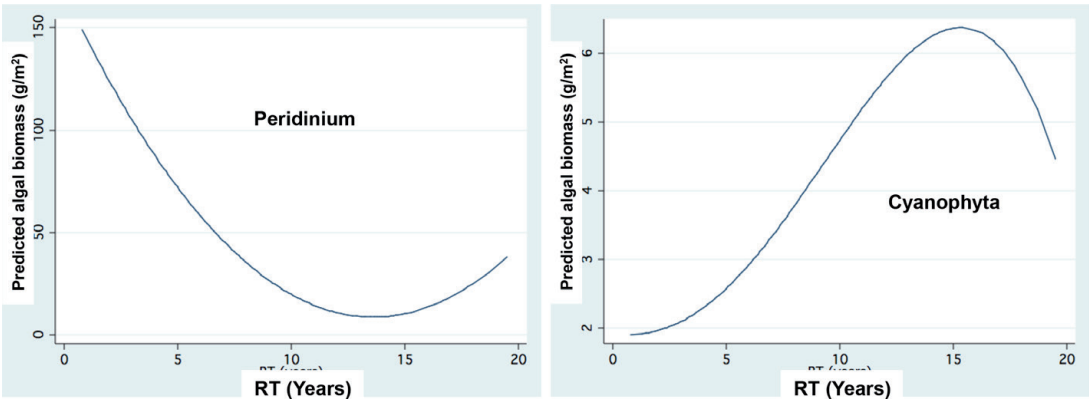
#### **4.6 The impact of residence time on nutrients and phytoplankton dynamics**

Monthly changes of epilimnetic TN stock were found to be related to the length of Residence Time (RT; the ratio between inflows rate and Lake Volume): higher TN stock accompanied longer RT [23, 27, 28]. Lake Volume increase and shorter RT are correlated with the epilimnetic load decline of TN an increase of epilimnetic TP loads during January–April and gradual decline later on until December was correlated with the Hydrological parameters: RT elongation during January–September, became shorter later; The decline of TN/TP Mass ratio is respective to RT prolongation: The higher the RT value is, the lower is the Epilimnetic TN/TP mass ratio [24, 26, 27]. The biomass of Peridinium contributes Phosphorus and the headwater input are carriers of Nitrogen. The shortest RTs were recorded during the Peridinium bloom onset and later when RT length declines, P-mediated Peridinium dissipates, and Epilimnetic stock diminishes. Shortest RT's were recorded during winter, and later in the year RT becomes longer. Conclusively, external hydrology (water discharge) contribute Nitrogen and Peridinium bloom in addition to dust deposition, external inputs, and bottom sediments by microbial activity contribute Phosphorus. When Nitrogen supply was declined Peridinium bloom was deleted and Phosphorus fluxes were shortened and TN/TP mass ratio was lowered. The final result was enhancement of Peridinium replacement by Cyanobacteria [28].

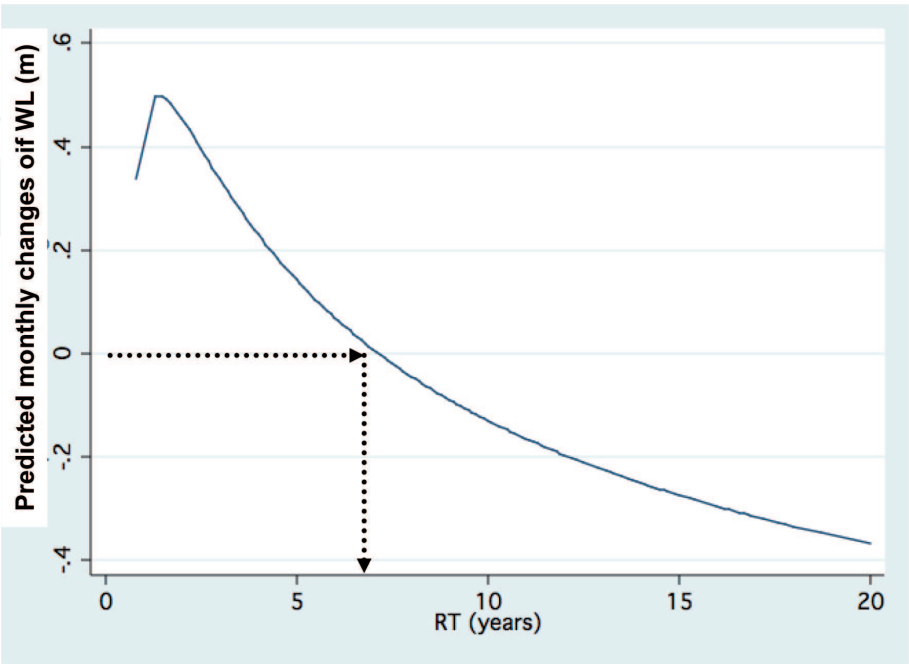




**Figure 9.**  
*Fractional polynomial regression between annual means of monthly residence time (RT in years) and years.*



**Figure 10.**  
*Fractional polynomial regression between RT length (years) and algal (Peridinium, Cyanophyta) biomass (g/m²).*



**Figure 11.**  
*Fractional polynomial regression between RT length (years) and monthly changes of water level (m).*

4.6.1 Peridinium

Elongation of RT corresponds to the reduction of the Peridinium biomass. The RT elongation is a signal of Nitrogen availability deficiency. A slight increase of Peridinium biomass documented during the longest RT, is probably attributed to Nitrogen input by fixation carried out by Cyanobacteria.

4.6.2 Cyanobacteria

A prominent increase of the Cyanophyta Biomass (from 1.9 to 6.3 g/m<sup>2</sup>) was documented in response to RT elongation of 1 to 15 years accompanied by decline of Nitrogen availability. It is likely that the Nitrogen deficiency in lake water was compensated by Nitrogen fixation maintained by Cyanobacteria. It is assumed that the minor decline of Cyanobacteria biomass observed during the longest RT is due to the lack of Phosphorus when Peridinium is absent.

5. Fishery

The Fishery management in Lake Kinneret is aimed at both, commercial income and water quality protection and ecosystem sustainability [34]. As a result, stocking of exotic fish species was confirmed just of those which cannot reproduce in the lake, their feeding habit improve water quality and their contribution to commercial fishery is essential. Final confirmation was given after a thorough investigation which confirm the implementation of those three objectives. The *Tilapia Sarotherodon galilaeus* was indicated as an optimal species target: the species is native, feed intensively on the bloom forming Peridinium and have a high commercial value. Therefore, fishing efforts are mostly aimed at this fish and the lake population is enhanced by commercial fingerlings production. Results in **Table 5** summarized annual landings of *S. galilaeus* [36–40].

Respective data of other stocked species indicates the followings: The stocking of *Oreochromis aureus* which is not pure native species in the lake was eliminated due to food competition with preferred *S. galilaeus*; Until the mid-1990s, stocking of Silver Carp (*Hypophthalmichthys molitrix*) was not recommended aimed at enhancement of zooplanktonic algal grazers whereas later on when *Microcystis* replaced Peridinium its stocking was recommended due to its efficient consumption of this algae. Three Gray mullet species (Marine origin) are successfully stocked because of ecological adaptation to improve water quality, not able to reproduce in Lake Kinneret and has high commercial value. Another 7 other species of exotic species were totally deleted from stocking program. Conclusively, stocking resources are invested toward fish species that has positive impact on water quality, fishermen income, and the exotics are unable to reproduce in the lake. The fishery (landing and stocking) management policy contribute strengthening of

Period	Trend of change	Periodical averaged landing (t/year) (SD)
1959–1970	Stable	175 (28)
1970–1990	Increase	248 (112)
1990–2010	Decline	231 (154)
2011–2016	Increase	184 (99)

**Table 5.**  
Periodical means (SD) of *Sarotherodon galilaeus* landings (t/year) and indication of trend of changes [36, 37].

ecosystem sustainability. *Peridinium* was the major food source for *Sarotherodon galilaeus*. Several other constraints created additional pressures on the fish population: Increased population of the migratory fish predator, Great Cormorant (*Phalacrocorax carbo*), reduction of stocked *S. galilaeus* fingerlings, usage of illegal fishing gill-nets mesh size, the elimination of Bleaks (Sardine: *Mirograx terraesanctae terraesanctae*, *Acanthobrama lissneri*) fishing, enhanced piscivory of *S. galilaeus* by *Clarias gariepinus* and outburst of Viral diseases, which infected mostly Tilapias. Ecological structure with complicated interactions require informative record long enough to ensure appropriate management decision in response to actual and unusual developed changes. Inappropriate alerted conclusions were followed a fishery crisis in Lake Kinneret when annual landings of *S. galilaeus* in 2007–2008 were less than 10 tons while normally its varied between 100 and 300. Simultaneously, documentation of the total number of fish (>90% Bleaks) was gradually increasing between 1987 and 2005. A recommendation of a three-year total fishing ban in Lake Kinneret was concluded. This decision was alternatively replaced by a recommendation of normal continuation of fishing. The fishing ban decision was canceled, and fishing continuation was confirmed formally. During 2010–2016, the population of *S. galilaeus* and consequently their landings were recovered and came to its normal level. During 2007–2008, Tilapia fishery in Lake Kinneret collapsed [18, 19]. A governmental decision of 3 years total commercial fishing ban was undertaken. Nevertheless, as part of ecological sustainability clarification of potential reasons the resolution was canceled and within 3 years the *T. galilaeus* population recovered. [36, 39]. The changes of the Phytoplankton composition were also accompanied by a modification of the fish feeding habits. During its dominance, *Peridinium spp.* was the major food component of the most valued native fish (*Sarotherodon galilaeus*) in the lake. Zooplankton was the major food constituent of the endemic Bleak cypriids (*Acanthobrama terraesanctae terraesanctae*, *Acanthobrama lissneri*). To ensure water quality, it is important to maintain high grazing pressure of zooplankton on nano-phytoplankton. Removal of the unwanted Bleaks by intensified fishery management and the introduction of the exotic Silver Carp (*Hyphophthalmichthis molitrix*), an efficient consumer of *Microcystis*, is therefore beneficial. Zooplankton biomass in Lake Kinneret declined from 1970 to the early 1990s but increased thereafter. Both, the biomass and size frequency of cladocerans were affected by fish predation. Under the modified food web structure, Tilapia became a competitor with Bleaks on Zooplankton consumption. Information given in previous studies including the long-term record of the Kinneret zooplankton [1–3, 6] distribution, population dynamics and physiological trait was re-evaluated in the present paper.

### 5.1 Zooplankton dynamics

The Zooplankton compartment within the Kinneret ecosystem exemplify the necessity for multi targeted maintenance evaluation [1, 2, 5, 6]. The complex interaction relationships require a comprehensive implementation. Long term (1969–2001) averages of zooplankton biomass (WW) density in Lake Kinneret is given in **Table 6** as averages and ranges (Max-Min) of annual means.

A deeper insight into the Zooplankton temporal distribution indicates long term decline since mid-1980s accompanied enhancement of Bleak populations. The Bleaks population increase was resulted by decline of fishing pressure. Therefore, a recommendation was submitted and accepted to subsidize Bleak fishing. The concept of sustainability included reduction of cascaded top-down pressure on algal grazers to improve water quality. Nevertheless, ecosystem sustainability protection requires a comprehensive approach of which only fishery was accounted. To achieve water quality improvement by algal biomass reduction in oligotrophic deep

Group	Average (g(ww)/m <sup>2</sup> ) (%)	Max-min range (g(ww)/m <sup>2</sup> )
Copepoda	9.0 (33)	2.3–17.7
Cladoceraa	15.9 (59)	8.8–25.1
Rotifera	2.1 (8)	0.9–5.2
Total	27.0	12–48

**Table 6.**  
Averages of annual (1969–2001) means and max-min ranges of zooplankton groups (Copepoda, Cladocera, Rotifera, Total) WW-biomass (g(ww)/m<sup>2</sup>).

lakes Phosphorus removal is ultimately required. Because Phosphorus removal was excluded Sustainability protection was only a partial success: zooplankton biomass was recovered but algal biomass was not reduced [36–39]. The suppression of the enhanced population winter migratory fish consumer Cormorants in Lake Kinneret became essential as a protector of ecosystem sustainability [36–39]. The deportation of Cormorant from Lake Kinneret is a useful implementation of water quality protection. The number of Great Cormorant (*Phalcororax carbo*) wintering (from the end of October through March) in the Lake Kinneret Region is approximated as 6000 (5000–7000). The predation rate of the Cormorants indicates a daily ration varying between 300 and 1000 grams per bird with the more common value of 700 grams per bird [37, 38]. Six thousand Great Cormorants preying daily at 500 g fish per bird during 100 days removed 300 tons of sub-commercial-sized Tilapia (Mostly *S. galilaeus*) from the lake. However, we have to take into account that the fishes preyed on are below the commercial size of 100 g per fish, that is to say that the potential damage is bigger (legal size >200 g/fish). Individual Tilapia preyed on weighted 50–70 g; if not preyed on they might grow up to commercial size within 5–6 months to be marketed. Consequently, the commercial value of such losses is between 1.5 and 3.0 million US\$. Such a damage to fishermen’s income and ecologically to the system can be reduced by aggressive deportation of the Cormorants from Lake Kinneret and simultaneously from their night station site. The ecological contribution of Tilapia to the ecosystem aimed at water quality protection is done through the consumption of *Peridinium* biomass gradually reappeared recently. The recommended accompanied operation is Bleaks removal aimed at releasing zooplankton food biomass to *S. galilaeus*. Predictive recommendations include, among others, is a practical design which is presently under consideration aimed at achieving reduction of fish predation by Cormorant without violating accepted legislations. In other words to protect nature items together with improvement of fishery and water quality in Lake Kinneret.

6. Shallows: beach vegetation interface

The lake shallows/beach interface is a contradiction between public and eco-limnological services. The surface area of the inundation zone is about 11 km<sup>2</sup> according to: Annual WL fluctuates between 209 with lake bottom area is 168.9 km<sup>2</sup>, and 213 mbsl with lake bottom area of 161.4 km<sup>2</sup>, lake shoreline length is 55 km and adjacent beach belt width is 50 m. This nearby water beach area is potentially open for recreation service entitled “Aquatic Recreation Belt” (ARB) [41]. Nevertheless, under temporal long-term inundation regime the ARB allocation is not precisely predictive. During heavy precipitation season WL is high and major part of the ABR area is shrunk while after low rainfall season ABR area is wider



and immediately covered by beach aquatic vegetation. The fast grower aquatic plants create a nuisance for aquatic recreational activities such as water access and favored environmental conditions for unwanted animals like Venomous Snakes. Fox, Mongoose, Jackal, etc. Moreover, next year the aquatic plants would be flooded and decomposed forming optimal conditions for Mosquitoes reproduction accompanied by accumulation of rotten bad smell organic matters. Reasonable solution might be mowing of those plants which on the other hand probably create shortage of spawning ground for *S. galilaeus* [10]. The Kinneret shoreline length is 55 km of which only 12.7 km (23%) are legal open public beaches. So far, prognosis of damage is practically negligible while enhancing *S. galilaeus* population biomass is possible by commercial production of fingerlings. Conclusively, partial mowing of beach vegetation and *S. galilaeus* reproduction would not be interfered. These objectives are due to the high (212–213 mbsl) WL regime. A recent computation of lake water surface area in respect to WL obviously indicates close positive significant linear regression when WL was below 210 mbsl. Under higher WL the relation was insignificant. It is because WL came the Bethsaida lagoons altitude. Resulting lower elevation of WL with respect to wide flooding area. The Beteicha lagoons densely covered by aquatic plants (*Tamarix spp.*, *Typha spp.*, and *Phragmites spp.*) are known as an optimal spawning ground, YOY care treatment for *S. galilaeus*. Conclusively [10], beach vegetation mowing as a compromise between fish reproduction interference and human recreation is relevant when WL altitude is lower than 212 mbsl.

## 7. Hula valley farmers and Kinneret limnologists should be friends

Since 1993 flocks of migratory Cranes (*Grus grus*) stay during 4 winter months in the Hula Valley. The Crane wintering provided the most attractive target for Eco-tourism [42]. The winter migrating of app. 50,000 Cranes in the Hula Valley during 4 months are very attractive, and the touristic visits were enhanced significantly from about 50,000 during the early 1990's to almost half a million presently. The Crane wintering flocks created severe difficulties, including damage of agricultural crop and nutrient (excretions) sources in Lake Agmon-Hula and further downstream into Lake Kinneret. It might be risky for the stability of the Kinneret Sustainable trait:  $50 \times 10^3$  Cranes excrete 5.24 gP/Ind./day during 170 days produce approximately 44.5 tons of TP [42] beside other TP sources in the Hula Peat soil, agricultural fertilization and ecological processes in Lake Agmon.

Protection of aquatic Ecosystem sustainability require anthropogenic control throughout the entire watershed. The social, agricultural, hydrological and ecological activities of development in the Hula Valley justify a careful approach., The Crane case, among others, require a significant consideration. The Hula Valley contribute above 50% of the external nutrient inputs into Lake Kinneret and the agricultural management has an impact on nutrients merit to the lake. Ecotouristic management including Crane wintering as visitors' attraction is part of reasonable entire Valley management and Kinneret water quality protection. Therefore collaborative management by the farmers and tourism managers is vital. A collaborative solution between farmers, nature authorities, water managers, land owners, and regional municipalities was budgeted and implemented. Money was allocated for the renting of a 40 ha field block in the valley dedicated as "Feeding Station" where purchased Corn seeds are given to the cranes twice a day. Feeding start in late December and continue until early March when the Cranes fly back to Europe for breeding. Cranes which land prior to Mid-December are deported aimed at reducing number of potential feeders, prevention damage and reduction of the cost of Corn seeds. This



achievement initiated benefits for both the landowner farmers by income resource as half a million bird visiting watchers (priced entrance) while the Hula Valley effluents were not significantly deteriorated.

It is suggested that Cranes do not contribute a significant addition of TP to lake Kinneret and the Epilimnion increase is the result of internal sources. Moreover, positive regressions were indicated between River Jordan discharge and nutrient inflow loads which is  $r^2 = 0.596$ , ( $p < 0.0001$ ) for TP. Independently, the discharges in the Jordan River were declined since the mid-1980's from 15 to  $<10 \text{ m}^3/\text{s}$  caused by precipitation decline.

The reconstruction of the old Hula native Flora and Fauna indicated approximately 300 bird species 12 fish species, 40 plant species observed in the Hula Valley.

The Eco-Touristic Crane Project was designed to be a part of a comprehensive objective aimed at establishment of watershed and lake Kinneret ecosystems sustainability.

The Hula Reclamation Project was aimed at ensuring sustainability of modified eco-systems by bridging over the conflict between agriculture development, Kinneret water quality protection and nature conservation. The tension between farmers, water managers, nature preservation was reduced, and collaboration came instead. The outcome of the HP was renewal of an ecosystem, which has become a tourist attraction including enriching the biological diversity.

## 8. Conclusive summary

The management of Lake Kinneret and its watershed require a national attempt to ensure their sustainability. These ecosystems are crucial for the nation and their protection is the national concern. Their functional efficiency can be achieved by long term managerial operation conducted by principles of sustainability. The outcome of this paper evaluations are the following recommendations: Lake Management: (1) Shorter length of residence time to enhance water exchange and input of desalinized waters and together with pumped withdraw for supply and Dam open policy and lowering of WL are accepted options; (2) Recommended WL range between 208.8 and 213 mbsl with annual fluctuated amplitude of 1.5 m; (3) Enhance nitrogen supply to the epilimnion to encourage Peridinium bloom renovation; (4) Stocking of *Sarotherodon galilaeus* and *Hypophthalmichthys molitrix* and implementation and enforcement of fishery regulations; (5): Renewal bleaks fishery; (6): Mowing of aquatic vegetation in public beaches; Management of the Watershed: Enhance peat soil moisture through continuation of the "Peat Soil Convention"; agricultural maintenance accompanied by eco-tourism with reasonable population size of cranes and regulated number of visitors.

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