

# Atmospheric CO<sub>2</sub> Increase: A Potential for Primary Production Enhancement in Lake Kinneret

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## Abstract

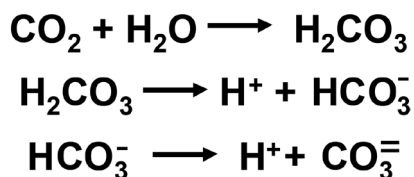
Due to precipitation reduction, nutrient inputs into Lake Kinneret through Jordan river discharge declined. Nitrogen (N) supply into the Kinneret ecosystem is mostly external and that of Phosphorus (P) is partly internal and dust deposition. Therefore, decline of N and slight elevation of P concentrations occurred in the Kinneret Epilimnion. As a result, suppression of Peridinium biomass and enhancement of Cyanophyta, Chlorophyta and Diatoms were recorded. The Peridinium decline caused Primary Production (PP) reduction and although increased later, it accompanied the nano-plankton elevation. It is suggested that the PP enhancement is partly due to the natural photosynthetic capacity of nano-plankton and partly to global increase of atmospheric concentration of CO<sub>2</sub>. The suggestion of atmospheric CO<sub>2</sub> increase and consequently PP, was supported by the pH (and obviously Alkalinity) increase. The enhancement of CO<sub>2</sub> diffusion was an incentive factor which enhanced PP capacity.

## Keywords

Kinneret, CO<sub>2</sub>, pH, Primary, Production, Eutrophication

## 1. Introduction

The well-known fate of CO<sub>2</sub> in aquatic ecosystems was widely documented in freshwater and marine environments. The pathways of CO<sub>2</sub> and its derivatives are fundamental information widely known in limnological, marine, wetland and river/runoff ecosystems (Figure 1). The significant long-term increase of atmospheric greenhouse gases, including CO<sub>2</sub>, is undoubtedly accepted by the scientific community [1]. Carbon dioxide (CO<sub>2</sub>) levels in the atmosphere rise



**Figure 1.** The fate of CO<sub>2</sub> dissolved in water.

and more CO<sub>2</sub> gets absorbed into seawater and freshwaters as well [1]. The study of atmospheric CO<sub>2</sub> enhancement's impact on the ecological trait of aquatic ecosystems was intensified recently (among others) [1] [2] [3] [4].

Among inorganic carbon species, free CO<sub>2</sub> dominates in water at pH 5.0 and below, whilst above pH value of 9.5 Carbonate (CO<sub>3</sub>) is quantitatively significant and Bicarbonate (HCO<sub>3</sub><sup>-</sup>) is predominant at pH between 7.0 and 9.0. The Kinneret is indicated as hard water ecosystem with commonly > 8.0 pH caused by the release of the Hydroxyl ions as a result of CO<sub>2</sub> dissolving. Therefore, enhancement of dissolution, possibly caused by atmospheric "Greenhouse" gasses increase, might cause additional increase in pH.

Photosynthesis of living aquatic organisms (phytoplanktonic algae, submerged macrophytes, photosynthetic bacteria) and respiration of zooplankton, invertebrates, fishes, protozoa and plants affect the amount of CO<sub>2</sub> in aquatic ecosystems. Photosynthesis causing pH elevation and respiration effect is the opposite of pH decline. The final result, in a natural ecosystem, includes the involvement of all components.

## 2. The Kinneret Case

During 1969-2001, the Lake Kinneret ecosystem has undergone ecological changes [5]. The prominent alteration was the change in phytoplankton community composition. The dominance of the bloom-forming Pyrrhophyte-Dinoflagellate *Peridinium gatunenze* was replaced by nano-plankton (Cyanophyta, Chlorophyta Diatoms). Previous studies [6] indicated a higher specific productivity rate of the small cells nano-planktonic algae organisms than that of large cells, net-palnknktonic algae (*Peridinium gatunenze*). Zooplankton standing stock biomass was declining from 1969 to the mid-1990's and increased afterwards.

The following processes were evaluated, aimed at the study of the impact of the increase of atmospheric CO<sub>2</sub>:

- 1) Search for potential (headwaters and Hypolimnetic supply) sources for the enhancement of Carbon supply and Primary Production
- 2) Optional source for the Enhancement of CO<sub>2</sub> inputs caused by greenhouse gas increase.
- 3) The replacement of *Peridinium gatunenze* by nano-planktonic algae and consequently intensified Primary Production activity (Carbon Fixation).
- 4) DO, CO<sub>2</sub> and pH multi-annual and monthly fluctuations caused by photosynthesis enhancement.

### 3. Material and Methods

All data of Primary Production (PP), Dissolved Oxygen (DO), pH and Alkalinity, Headwater nutrient inputs (monthly and annually) were taken from the Data Base and Annual (1970-2014) reports of the Kinneret Limnological Laboratory [7].

Statistical analyses were taken from STATA 9.1, Statistics-Data Analysis: Simple linear predicted correlation and Fractional Polynomial (FP) predicted Regression.

### 4. Results

#### 4.1. Water and Nutrient Inputs from the Drainage Basin

##### External Carbon Sources

It is indicated that all nutrients are positively correlated ( $r^2$ : 0.7929 - 0.9805;  $p$ : <0.0001 - 0.0029) with the Jordan River discharge higher than the rarest value of  $5 \text{ m}^3/\text{s}$ . The data of Dissolved Inorganic Carbon (DIC) inputs through the Jordan River inflows were extrapolated from the respective decline of values presented in **Table 1** & **Table 2** and discharge decline (**Figures 1-4**). [6] documented mean Carbon concentrations in the Jordan River inputs ranging between 5.66 and 7.12 ppm (SD's: 1.27 - 5.34 ppm). It was indicated [6] that 55% of the Jordan River Carbon input is dissolved form (DOC) and 45% is particulate (POC). Headwaters other than the Jordan contribute 15% of total Carbon inputs. The dry weight content of suspended matter carried by the Jordan waters comprises only 2.7% of Carbon. The Jordan water contains 3% of Particulate Organic Carbon (POC) and 1.4% of the total Organic fractions (POC).

#### 4.2. Carbon Content in the Kinneret Food-Web Compartment

**Table 3** represents the Carbon content within the Kinneret ecosystem compartment.

**Table 1.** Results of Linear Regressions ( $r^2$  and  $p$  values are given) between annual loads of nutrient (t/y) inputs and Jordan River discharge ( $10^6 \text{ m}^3/\text{y}$ ; mcm/y) during 1970-2001.

Nutrient	$r^2$	$p^{\text{®}}$
Total Phosphorus	0.7311	<0.0001 S
Soluble Reactive Phosphorus	0.5921	<0.0001 S
Ammonia	0.2440	0.0026 S
Nitrate	0.7249	<0.0001 S
Organic N	0.5749	<0.0001 S
TSS	0.6078	<0.0001 S
Chloride	0.8436	<0.0001 S
Sulphate	0.8239	<0.0001 S

$^{\text{®}}\text{S}$  = Significant. All annual loads of inputs through the Jordan flows represent significant relations with annual Jordan discharges.

**Table 2.** Monthly means (1970-2001) of nutrient concentrations in the Jordan River waters. Results of Linear Regressions ( $r^2$  and p values are given) between monthly loads of nutrient (tones per month) inputs and Jordan River discharge ( $10^6$  m<sup>3</sup>/m; million cubic meters per month).

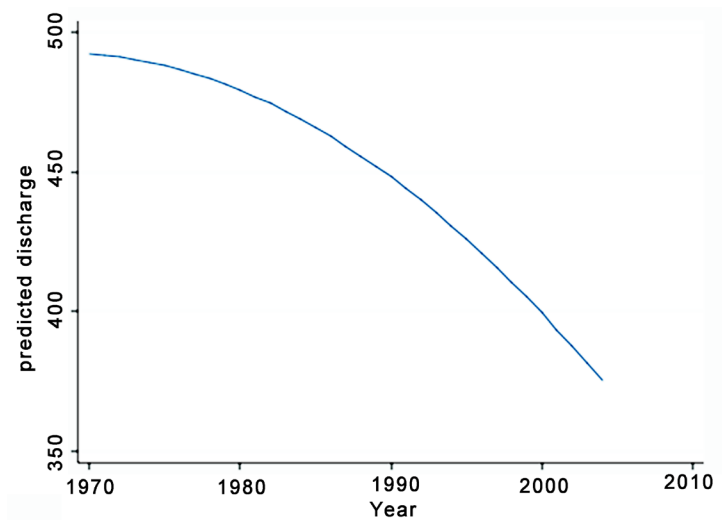
Month	10 <sup>6</sup> m <sup>3</sup> /month	TP	SRP	NH <sub>4</sub>	NO <sub>3</sub>	Org.N	TSS	Cl <sup>-</sup>	SO <sub>4</sub>
1	53	13.66	2.34	7.8	159	43	5522	1116	2423
2	69	17.77	2.97	8.6	219	57	7106	1497	3161
3	74	14.65	2.41	7.4	206	45	5627	1513	3045
4	57	8.83	1.35	3.8	109	34	3680	1023	1744
5	38	4.4	0.86	2.4	55	24	1420	640	1004
6	24	3.17	0.6	1.7	35	16	935	401	736
7	16	2.2	0.41	1.6	27	13	643	309	644
8	17	2.47	0.43	1.5	26	14	699	320	610
9	21	3.23	0.52	1.6	30	16	900	349	622
10	24	5.63	0.71	2.2	34	20	1866	376	630
11	25	5.31	0.83	3.2	39	19	2208	405	735
12	36	11.59	1.42	4.8	77	31	4796	685	1357
Total	454	92.91	14.85	46.6	1016	332	35402	8634	16711
r <sup>2</sup>		0.8104	0.8560	0.7883	0.9232	0.8979	0.7929	0.9805	0.9250
p		<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

All monthly inputs Jordan inflows represent significant relations with monthly Jordan discharges.

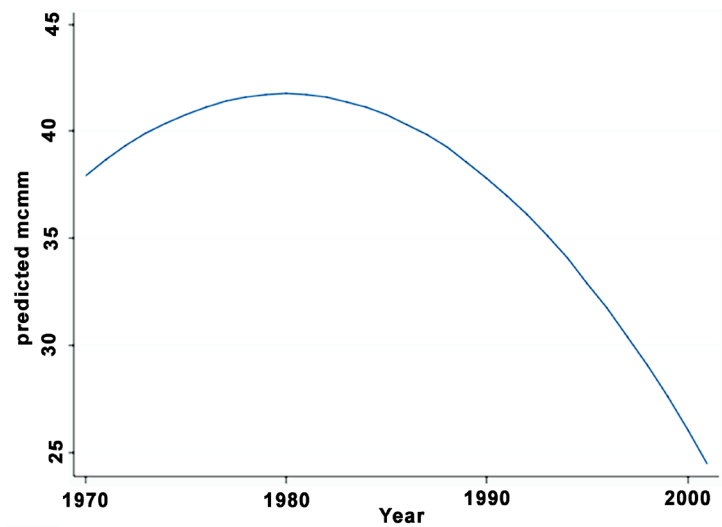
**Table 3.** The Carbon content within the kinneret food-web compartments (POM = Particulate organic matter; DOM = Dissolved organic matter.)

Compartment	gC/m <sup>2</sup>	Turnover Time
Heterotrophic Bacteria	1.0	Hours
Protozoa	0.7	Hours
Phytoplankton	27.0 - 3.0	Days
Zooplankton	1.8	Weeks
Benthos	0.5	Years
Fish	8.8	Years
POM & DOM	85.0 - 120.0	Months

The known Carbon inputs into the Kinneret Ecosystem is originated as 95% by phytoplankton photosynthesis and about 2% from the drainage basin and 3% by benthic algal photosynthesis [6]. The quantitative input of atmospheric Carbon is unknown but indirect indication is possible. Approximation of respired Carbon is 30%, 30% and 40% by phytoplankton, animals (fish and zooplankton) and bacterial-Protozoan sources respectively [6]. The total annual input of Organic Carbon through the Jordan River varied between 80,000 and 90,000 tons.



**Figure 2.** Annual water inputs ( $10^6 \text{ m}^3/\text{y}$ ) through the Jordan River during 1970-2001 (Fractional Polynomial).

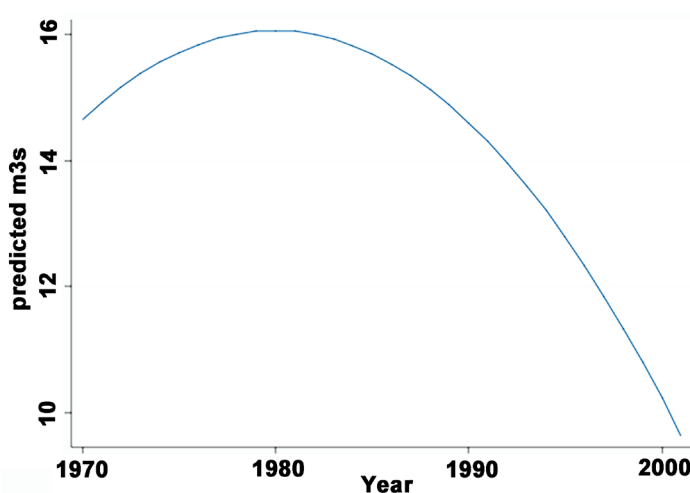


**Figure 3.** Annual means of monthly discharge, ( $10^6 \text{ m}^3/\text{m}$ ) during 1970-2001 (Fractional Polynomial).

About 1.5% of annually removed organic Carbon was due to National Water Carrier (NWC) pumping for water supply and 85% as sedimentation. Consequently, external Carbon sources as substrate for phytoplankton photosynthetic activity are of secondary importance level whilst Atmospheric  $\text{CO}_2$  is the major source. Nevertheless, Atmospheric outsourcing and diffusion rates were not routinely monitored.

### 4.3. Internal $\text{CO}_2$ Sources

Kinneret is a warm monomictic lake that is stably stratified during 7 - 8 months a year. During stratification, the Hypolimnion is totally anoxic containing sulfides, ammonium,  $\text{CO}_2$  and  $\text{NH}_4$ . De-stratification occurs during 3 months when the Thermocline deepens accompanied by fluxes of Ammonium, Sulfides and  $\text{CO}_2$



**Figure 4.** Annual mean of discharge ( $\text{m}^3/\text{s}$ ) in the Jordan River During 1970-2001 (Fractional Polynomial).

into the newly established Oxygenated Epilimnion. Nevertheless, De-stratification is completed in mid-December when the concentration range of  $\text{CO}_2$  throughout the entire water column is 1.6 - 8.3 ppm. During June - October, the lake is stably stratified (thermal range of differences between Epilimnion and Hypolimnion is  $11^\circ\text{C}$  -  $15^\circ\text{C}$ ) and  $\text{CO}_2$  concentrations (Max.-Min.) are 0 - 3.4 in the Epilimnion and 9.3 - 14.5 in the Hypolimnion. Then, if lake water level (WL) is 212 mbsl the lake volume is  $3822 \times 10^6 \text{ m}^3$ , and the total  $\text{CO}_2$  load is (Max.-Min.) 6115 - 31,722 tons. Moreover, the Hypolimnetic load of  $\text{CO}_2$  during summer stratification is (Max.-Min.) 12,517 - 19,517 tons. Total averaged PP rate value (**Figure 7**) is  $1.75 \text{ gC}/\text{m}^2/\text{day}$ , resulting in daily photosynthetic Carbon fixation averaged as (Lake WL at 212 mbsl -  $162.9 \text{ Km}^2$ ) of 285.1 ton of  $\text{CO}_2$  daily.

Carbon demands by Phytoplankton in Lake Kinneret were previously studied [6]. Between 1970 and 2001, a significant change of the Phytoplankton assemblages composition occurs when the Peridinium dominance in winter/spring was replaced by the dominance of Cyanophyte, Chlorophytes and Diatoms mostly in Summer/fall months. It is not only a composition and biomass alteration but also the rate of Primary Production and accompanied Carbon demands (**Table 4**).

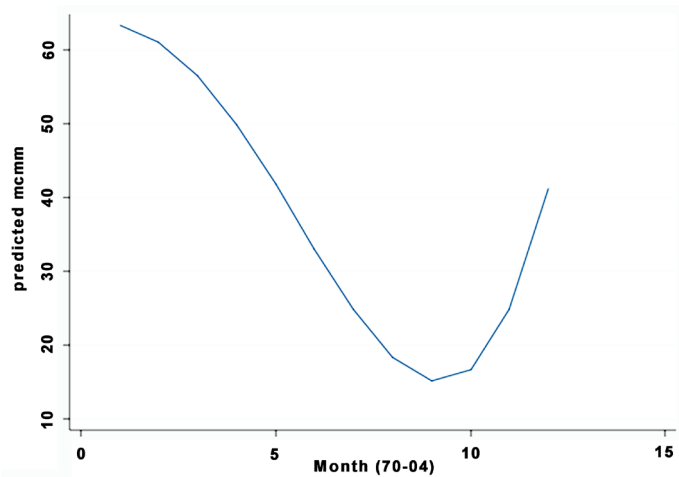
The Hypolimnetic total range of  $\text{CO}_2$  loads was approximated as 12,517 - 19,517 tons. The chemical "migration" of that load continues and remains relevant as an internal source for algal Primary Production only during 2 - 3 months of thermal de-stratification and is, therefore, limited on a long-term basis. The total annual algal demands of Carbon is app  $> 100 \times 10^3$  tons (**Table 4**) whilst hypolimnetic supply of Carbon cover only  $< 20\%$  of it during a short time. For the maintenance of such a  $\text{CO}_2$  load in oxygenated waters during 5 months (mid-December - Mid May), the Hypolimnion supply via de-stratification is probably insufficient, and supplemental supply is required by diffusion from atmospheric sources.

**Table 4.** Carbon loads and fluxes within phytoplanktonic compartment of the Kinneret Food-Web averaged seasonally for the period of 1970-2001.

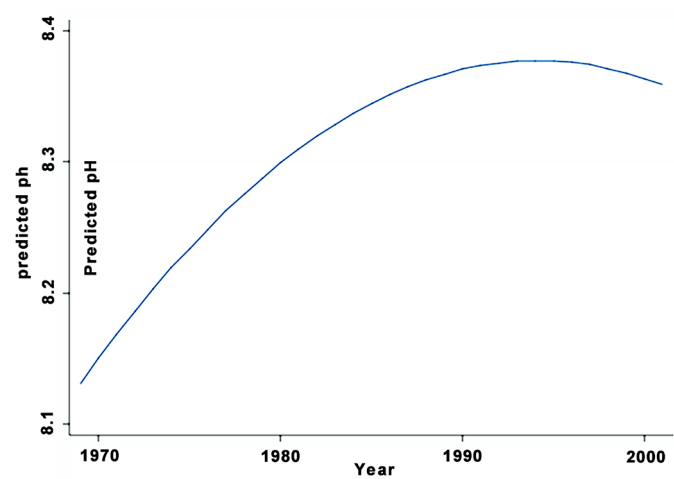
Parameter	Winter/Spring (5 Months)	Summer/Fall (7 months)
Number of days	152	213
Monthly Mean Biomass: g(ww)/m <sup>2</sup>	128.4	38.4
PP: mgC/m <sup>2</sup> /day	1945	1615
Specific PP:mgC/g(ww)	15.6	43.4
Daily C demands: tC/Lake/day	327	271
Annual C demands: tC/Lake × 10 <sup>3</sup>	50	58

#### 4.4. The Fate of CO<sub>2</sub> in Aquatic Ecosystem

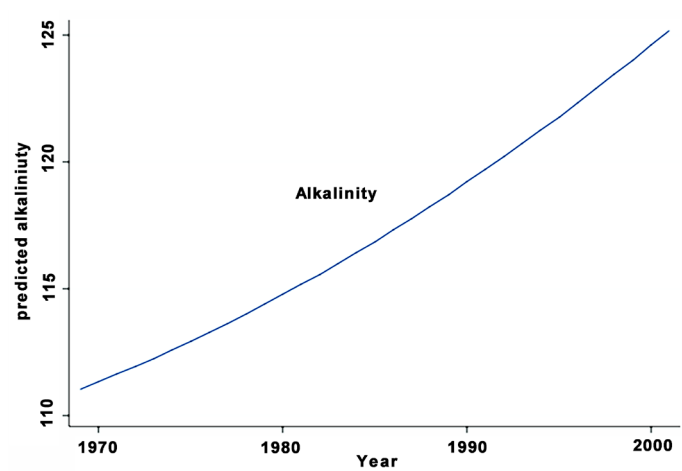
Carbon as CO<sub>2</sub> is incorporated by phytoplankton through their Photosynthetic day/light time activity, *i.e.* organic matter production, Primary Production (PP) by the primary producers. The incorporation of CO<sub>2</sub> and photosynthesis activity results in its decline and consequently pH increases. The fate of CO<sub>2</sub> dissolution is presented in **Figure 14**. Increase of pH is followed by Bicarbonate decline, and Carbonate increase and CaCO<sub>3</sub> are precipitated (app. 245 g/m<sup>2</sup>/year in Lake Kinneret) [6]. This flow direction is typical to fall/winter (November - April) conditions in Lake Kinneret when algal production is highest. During dark time and/or deeper depths due to light dissipation, respiration process exceeded photosynthesis and organic matter is utilized and CO<sub>2</sub> is produced; Bicarbonate concentration increases and CaCO<sub>3</sub> is dissolved. If Photosynthesis-Respiration balance is positive, organic matter stock is enhanced and long-term record of CO<sub>2</sub> concentration declines and vice versa. Deviations from such process balance are mostly due to changes in external fluxes of CO<sub>2</sub> (**Figures 2-5**), or internal fluxes of CO<sub>2</sub> and/or changes of the rate of PP caused by climate conditions or Phytoplankton assemblage compositions (**Figures 6-10**). Consolidation of pH increase results was done by comparison of pH and Alkalinity (**Figure 7**). The increase of DO concentration caused by the increase of PP is shown in **Figure 11**. The decline of CO<sub>2</sub> caused by enhancement of PP is presented in **Figure 12**. The relative increase of PP enhancement with pH elevation and CO<sub>2</sub> decline are shown in **Figure 13** and **Figure 14**. Significant parameter is Specific PP which is a value indicating how much Carbon is produced per phytoplankton unit. **Figure 15** indicates a decline of Specific PP from the early 1970's until the early 1990's which is due to the decrease of Peridinium dominance, whilst elevation of Specific PP during the 1990's is due to the nano-plankton enhancement. The Specific PP of Peridinium is 3 times lower than that of nano-phytoplankton [6]. The two panels of **Figure 15** represent the controversy between the biomass and specific PP of the two algal groups: the small size algae maintain the high value of Specific PP but produce low biomass. Monthly mean evaluations (**Figure 16**) indicate the inverse relation between biomass and specific PP caused by change of the phytoplankton community structure.



**Figure 5.** Monthly means (1970-2001) of Jordan water flow  $10^6 \text{ m}^3$  per month (Fractional Polynomial).

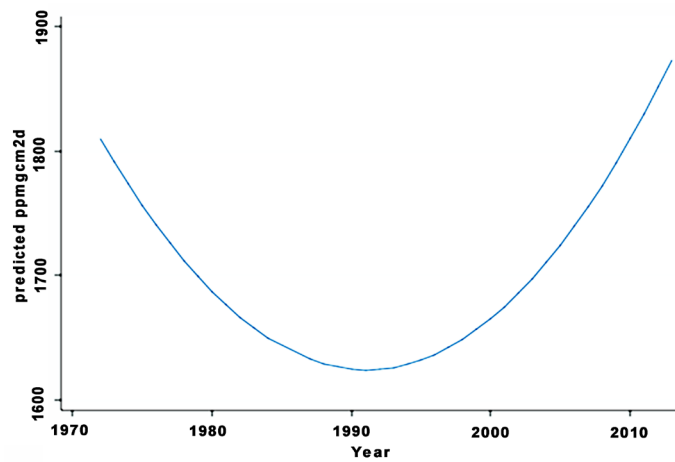


**Figure 6.** Annual (1970-2001) means of epilimnetic pH (Fractional Polynomial).

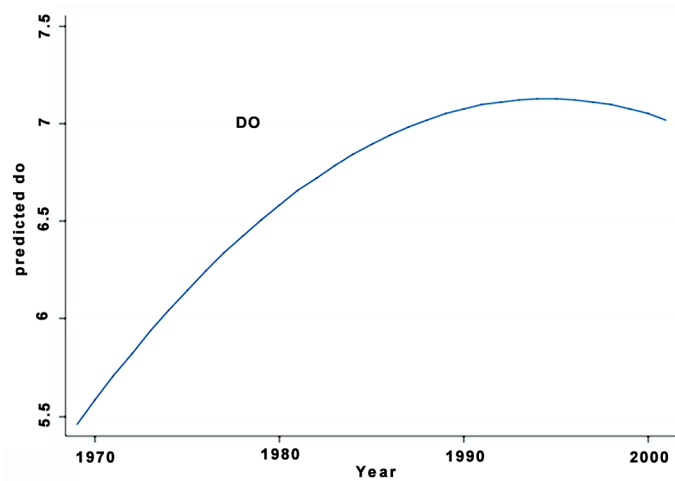


**Figure 7.** Annual (1970-2001) means of epilimnetic Alkalinity (ppm as  $\text{CaCO}_3$ ) (Fractional Polynomial).

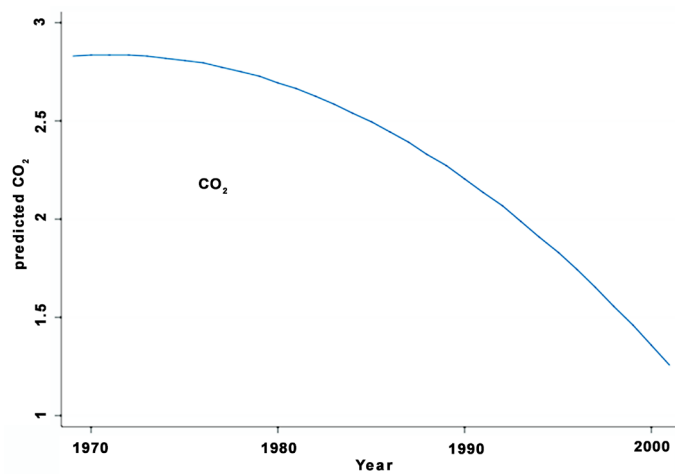




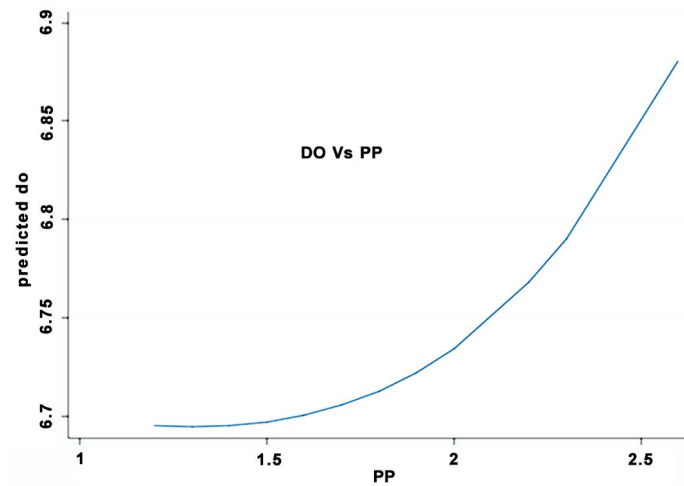
**Figure 8.** Annual (1972-2014) means of Primary Production ( $\text{mgC}/\text{m}^2/\text{day}$ ) (Fractional Polynomial) (multi-annual mean:  $1692 \text{ mgC}/\text{m}^2/\text{d}$ ).



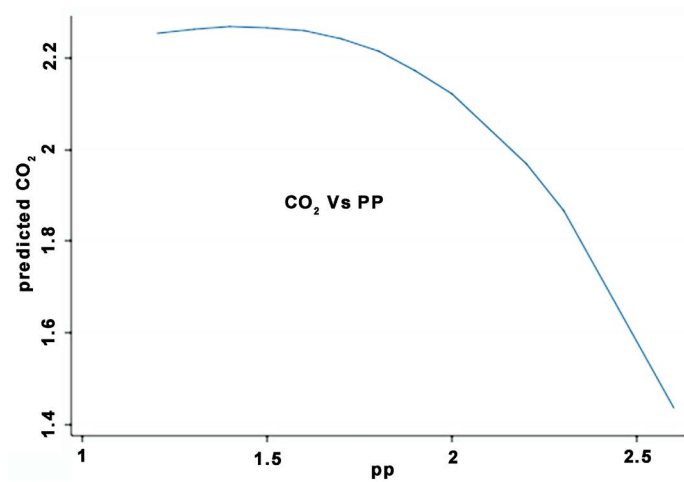
**Figure 9.** Annual (1972-2001) means of DO (ppm) (Fractional Polynomial).



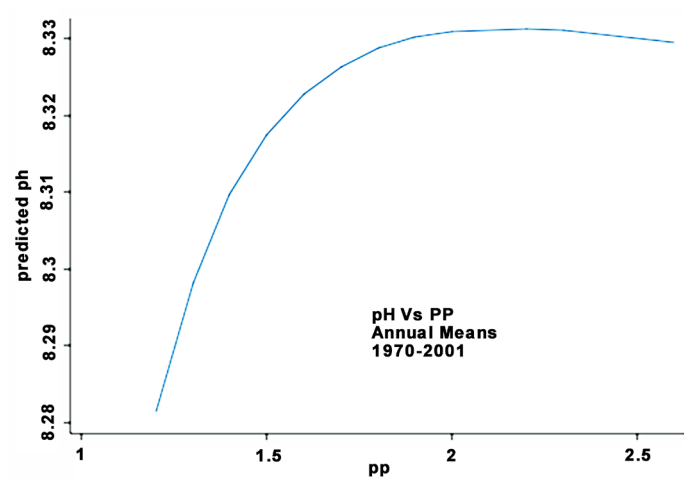
**Figure 10.** Annual (1972-2001) means of  $\text{CO}_2$  (ppm) (Fractional Polynomial).



**Figure 11.** Annual (1970-2001) means of epilimnetic DO (ppm) Vs Primary Production (gC/m<sup>2</sup>/d).



**Figure 12.** Annual (1970-2001) means of epilimnetic CO<sub>2</sub> (ppm) Vs Primary Production (gC/m<sup>2</sup>/d).



**Figure 13.** Annual (1970-2001) means of epilimnetic pH Vs Primary Production (gC/m<sup>2</sup>/d).

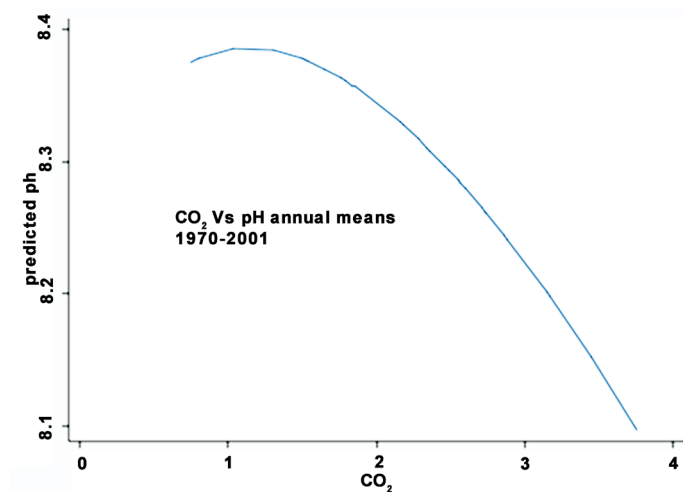


Figure 14. Annual (1970-2001) means of epilimnetic CO<sub>2</sub> Vs pH.

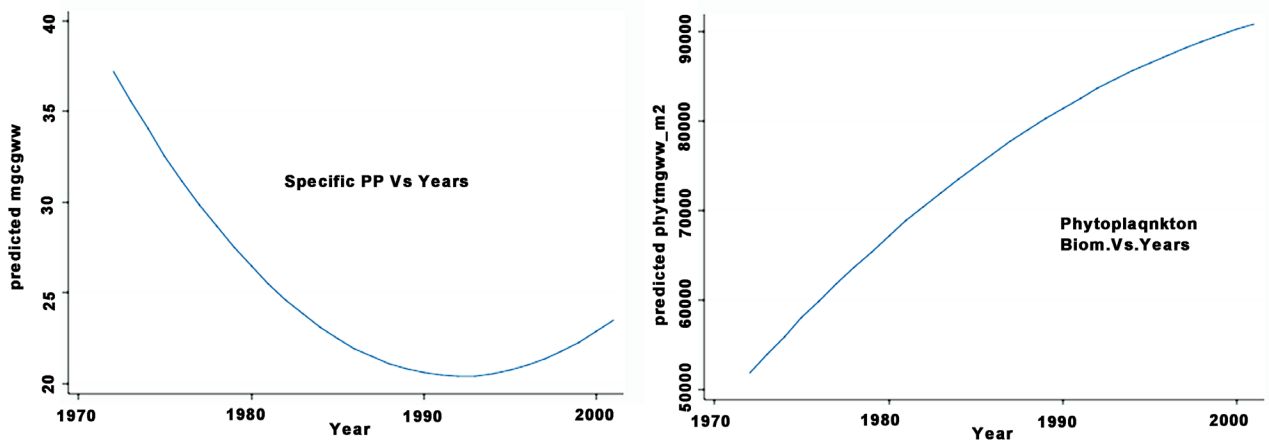


Figure 15. Left panel: Annual means of specific primary production (mgC/g(ww). Vs. Years (1972-2001) (Fractional Polynomial). Right Panel: Annual means of phytoplankton Biomass (g(ww)/m<sup>2</sup>) Vs. Years (1970-2001).

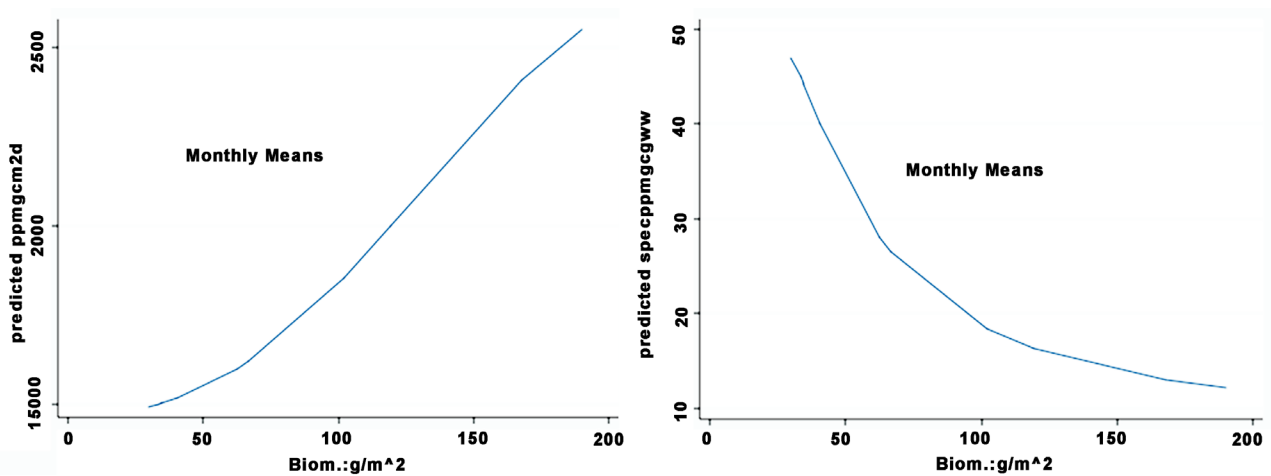


Figure 16. Left Panel: Annual Means (1972-2001) of Primary Production (mgC/m<sup>2</sup>/d) Vs. Phytoplankton Biomass (g(ww)/m<sub>2</sub>) (Fractional Polynomial). Right Panel: Annual means (1972-2001) of Specific Primary Production (mgC/g(ww)) Vs. Phytoplankton Biomass (g(ww)/m<sup>2</sup>); (Fractional Polynomial).

## 5. Discussion

Lake Kinneret is located in northern part of Israel, in the central part of the Jordan Rift Valley within the Syrian-African Graben. Its watershed (2730 km<sup>2</sup>) is situated between 32°40' and 33°38' North. Concentrations of DIC and DO in freshwater ecosystems depend on many factors in addition to ecosystem metabolism, among others, gas exchange with the atmosphere and inputs in precipitation, ground and surface water [8]. They [8] documented that diel cycles are controlled among others by exchange with the atmosphere. Lakes are sources rather than sinks of atmospheric CO<sub>2</sub> and are potentially important conduits for Carbon from terrestrial sources to the atmospheric sink as indicated by Cole *et al.* [9]. The increase of CO<sub>2</sub> dissolution into the liquid increased proportionally when CO<sub>2</sub> in the air rose, DIC availability was increased, photosynthesis was enhanced, and the photosynthetic energy cost decrease was documented by Qiu and Gao [10]. Yang and Gao [11] found significant enhancement of the growth rate of chlorophytes with CO<sub>2</sub> enrichment. Doubling of phytoplankton productivity as a result of doubling of the atmospheric CO<sub>2</sub> concentration was documented in [12] and in [13]. They [12] indicated that the doubling of atmospheric CO<sub>2</sub> concentration might result in an increase of productivity of more than 50% Freshwaters with low alkalinity and elevated atmospheric CO<sub>2</sub> may enhance aggravating phytoplankton bloom nuisance. Riebesell [14] documented confirmations of CO<sub>2</sub> supply limitation of Diatoms growth rate under optimal light and nutrient conditions. Yan *et al.* [15] concluded that enriched atmospheric CO<sub>2</sub> enhanced photosynthesis and growth of phytoplanktonic species which have a lower capacity of CO<sub>2</sub>-concentrating mechanism. Recent studies showed that elevated CO<sub>2</sub> concentrations enhanced the growth of freshwater green algae [12]. The important role of inland waters as Carbon source to the atmosphere through evasion of greenhouse gases such as CO<sub>2</sub> and CH<sub>4</sub> and also as a sink through sedimentation was studied by [16]. Marks *et al.* [17] reviewed terrestrial Carbon export via inland aquatic systems as a key process in the global cycle, including out-gassing from lakes and fixation and sedimentation. Golub *et al.* [4] documented lake ponds and rivers that process large amounts of organic matter and some of which is emitted to the atmosphere as greenhouse gases influencing climate change. Vaughan [18] reported [3] in The Guardian that in March 2015 CO<sub>2</sub> concentration in the atmosphere was 400.83 ppm and 406.82 and 404.42 ppm in December 2017 and December 2016, respectively. The long-term record monitored by NOAA indicates that between 1980-1998 and 1998-2016 CO<sub>2</sub> concentrations increased by 7.9% and 10.2%, respectively. A signal of precaution is given in [19] with regard to environmental changes including atmospheric deposition and climate, respectively, with consequences for eutrophication of freshwaters [13]. Prediction of increasing photosynthetic rates of herbaceous woodland species by elevation of atmospheric CO<sub>2</sub> is presented in [2].

Several documented changes occur within the Kinneret ecosystem: changes of the phytoplankton assemblage composition of which the decline of *Peridinium*

and enhancement of Cyanophyta, Chlorophyta and Diatoms are dominant; decline and reforming of the Zooplankton density; floods and dryness; extreme fluctuations of WL; Thermal fluctuations with respective changes of stratification span and timing; wide range of salinity changes; changes of the water utilization policy; onset and die-off of the beach vegetation; modified fishery management; and anthropogenic intervention of man-made changes in the drainage basin. None of these modifications was ever suggested to be correlated with the global case of increasing atmospheric CO<sub>2</sub> concentration. A tentative comprehensive evaluation is presented here aimed at correlating limnological fluctuations with increasing concentrations of atmospheric CO<sub>2</sub>. As a test case the periodical term of 1970-2001 was chosen as having detailed records of relevant data. This period represents the lake conditions prior to major changes together with transition time towards the modified ecosystem and the beginning of the alternate situation. The key process is the enhancement of Carbon fixation by the photosynthetic production of organic matter after the early 1990's (**Figure 8**). Consequently, sources of additional Carbon sources should be defined. Two options are most relevant: 1) through river inflows and/or 2) from the anoxic Hypolimnion during de-stratification following the existence of 8-month stable stratification. Quantitative evaluation of river inflows and hypolimnetic supply eliminate sufficient merit. Moreover, it is questionable how the high biomass of phytoplankton prior to the 1990's maintained primary production. The answer is given by indicating the species biomass and its physiological features. The dominant algal species prior to the 1990's was Peridinium. The Specific PP activity of this primary producer is lower than that of non-phyrrhophytes which became dominant later. The need for enhanced Carbon supply following the species alteration became essential. On the other hand the external inputs declined (**Table 1, Table 2**) (**Figures 1-4**). Moreover, the external inputs routinely decline sharply in summer (**Figure 5**) when nutrients are mostly demanded, resulting in the creation of Kinneret summer steady-state ecosystem where food is limited for all food-web compartments. The most relevant option for additional supply of photosynthetic substrate is atmospheric CO<sub>2</sub> diffused input. An indirect indication for the CO<sub>2</sub> diffusion input enhancement is shown by the elevated pH (**Figure 6**) and consolidated by a similar increase of Alkalinity (**Figure 7**). What was the reason for the algal composition change? Peridinium requires plenty of Nitrogen which was mostly supplied from external sources in the drainage basin through river inputs. Due to anthropogenic implementations in the drainage basin, Nitrogen inputs declined dramatically and internal sources are absent, resulting in Peridinium reduction. The followers, the non-Phyrrhophytes, especially nitrogen-fixers Cyanophytes, require much less Nitrogen, causing their predominance and the Phosphorus supply from external and internal sources not to decline. **Figure 8** represents these developments: the Nitrogen elimination caused the decline of Peridinium and its Primary Produced products, whilst later non-phyrrhophytes predominated and Primary Production was elevated (**Figure 8**), causing the increase of DO (photosynthetic product) con-

centration (**Figure 9**). It is likely that, due to the enhanced Photosynthetic activity, CO<sub>2</sub> input flux was enhanced, but its concentration in the water declined as a result of algal intake. The positive interrelation between intensified PP and DO elevation is shown in **Figure 11**. The influence of PP enhancement on CO<sub>2</sub> uptake and its remains is shown in **Figure 12**: The higher the PP is the lower the CO<sub>2</sub> concentration in the water. These combined effects are consolidated in **Figure 13** and **Figure 14**: pH is elevated proportionally to PP activity (**Figure 13**) and CO<sub>2</sub> concentration decline (**Figure 14**). The exclusive dependence of Primary Production by the Kinneret Phytoplankton on atmospheric pCO<sub>2</sub> is presented in **Table 4**.

Conclusively, with respect to global trends of atmospheric gas changes [19], it is suggested that as a result of a combination of modified conditions and increase of atmospheric “Greenhouse” gasses, CO<sub>2</sub>, the eutrophication threat in the Kinneret ecosystem was probably aggravated. If predictions are correct and Greenhouse atmospheric gasses increase, the management of Lake Kinneret and its drainage basin should be thoroughly reconsidered.

## 6. Conclusive Summary

Major changes of several parameters were altered within the Lake Kinneret ecosystem. External Nutrient fluxes were lowered significantly probably including dissolved inorganic Carbon. The epilimnetic pH and DO levels increased and consequently the rate of Primary Production increased. Independently, atmospheric “Greenhouse” gasses (CO<sub>2</sub>, NH<sub>4</sub>) increased. The photosynthetic activity of the planktonic algae was intensified since the early 1990’s. Carbon demands for PP enhancement followed by pH and DO increase might be supplied from diffusion of atmospheric sources. If Greenhouse gasses continue to be elevated in future, the Eutrophication in Lake Kinneret might be realistic and require re-consideration.

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