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Reforming Provisional (2007-2008) *Sarotherodon galilaeus* Landing Decline in Lake Kinneret (Israel)

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Abstract

The background for the case analysis of the present paper is the landing decline of *Sarotherodon galilaeus* during 2007-2008 to the annual level of <10 ton whilst normal harvests varied between 170 and 350 t/y. The objectives of the study are aimed at exploring limnological conditions and fishery management which might be the cause for this case. The research methods are focusing at long-term analysis of entire environmental conditions. The results indicatively highlight that, as other fluctuations of limnological parameters (Plankton, Nutrients) in Lake Kinneret, the fishery decline of *S. galilaeus* is attributed to normal periodical cyclic trends. Therefore, a recommendation that was submitted as a total fishing ban for three years was strongly opposed. The total fishing ban recommendation was rejected because further demolishing processes within the ecosystem were predicted. This conclusion was justified later (2011-2016) when annual landings came to the normal level. Conclusive recommendations considered that the fishing ban was indicated as "Ecological Disorder" and its replacement by controlled fishing policy as "Order Policy" was successfully implemented.

Keywords

S. galilaeus, Landing, Plankton, Nutrients, Kinneret

1. Introduction

The Kinneret fishery dynamics were previously discussed and presented widely. During the last 20 years, the Kinneret ecosystem structure has undergone significant modifications. Precipitation regimes declined significantly, and water inputs into the lake were, therefore, reduced accompanied by lake water level (WL) decline. Nitrogen to Phosphorus ratio was turned around from Phosphorus to Nitrogen limitation [1] [2]. The dominance of the major food source for *Sarotherodon galilaeus*, the bloom forming *Peridinium*, was replaced by *Cyanobacteria*, *Chlorophyta* and Diatoms, and fish plankton food resources (Phyto and Zoo) were modified, respectively [3] [4] [5]. Independently, other constraints created additional pressures on the fish population: Population increase of the migratory fish predator, Great Cormorant (*Phalacrocorax carbo*), in the lake [5] [6]-[11] reduction of stocked *S. galilaeus* fingerlings, short-time (1992-2000) usage of illegal fishing gill-nets mesh size, the elimination of Bleaks (Sardine: *Mirograx terraesanctae*, *Acanthobrama lissneri*) fishing [5] [6], enhanced piscivory of *S. galilaeus* by *Clarias gariepinus* [12] and outburst of viral diseases, which infected mostly Tilapias [5] [6] [13] [14] [15] (**Photo 1**) as well as global climatological events of ENSO cycles (EL-NIÑO/Southern Oscillation (ENSO) [16].

A fishery crisis alert was publicized when landings of *S. galilaeus* in 2007-2008 declined to less than 10 tons in 2008 whereas the total number of fish (>90% Bleaks) (Eco-Surveys) was gradually increasing from 1987 to 2005 [17]. An ad-hoc emergent meeting was assembled and a resolution was made for a recommendation of a three-year fishing prohibition in Lake Kinneret. This recommended decision was submitted to the Minister of Agriculture and was later submitted to become a government decision. A group of scientists strongly opposed this resolution and alternatively recommended the continuation of fishing under legal legislations as normally implemented earlier. 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. In the present paper, I evaluate the dynamics of the *S. galilaeus* crisis case with the aim of considering the comprehensive cyclic ecological trait of the Kinneret ecosystem (Plankton and Nutrients), which includes fish population and the significant impact of stocking. The significant decline of *S. galilaeus* landing during 2007-2008 was documented previously. Nevertheless, the present paper is the first option for evaluating if earlier predicted indications were implemented. The realization of unknown early novelties is demonstrated here.

2. Methods

The Limnological long-term (1970-2013) data-set [18] of nutrients, plankton,

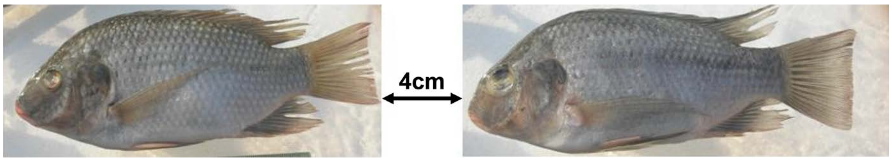

Photo 1. Two specimens of *Sarotherodon galilaeus*. Commercial size: TL: 19 cm (left) and 18 cm (right) collected from purse-seine catch (fisher M.Lev courtesy) in Lake Kinneret (2015) with ruined left eye resulted by the Virus of Blindness (see text) infection.

Secchi depth, DO, TSS, Lake Water Level (WL), and numerical fish (all size frequencies) densities (echo-surveys) was analyzed for an indication of fluctuation dynamics trait. The fishery landings and stocking regimes were evaluated by the Fishery Department [19] and Shapiro per comm. Data source of Rain gauge is The Israeli Meteorological Service.

Statistical Methods

Statistical analyses used in this study were taken from STATA 9.1, Statistics-Data Analysis and StatView 5.1, SAS Institute Inc. The analyses used were: Polynomial Predicted Regressions, Fractional Polynomial (FP), and Trend of Changes, LOWESS (0.8).

3. Results

Since the mid-1980's, precipitation decline regime in the northern part of Israel in general and particularly in the Kinneret drainage basin was indicated (**Figure 1**). The direct consequence of it was a decline of river discharges and Lake WL lowering. This temporal dryness trend continued onwards and affected Lake Kinneret's nutrient regime, mostly those that are externally sourced and the results shown in **Figure 2** & **Figure 3** are the respective outcomes. The Nitrogen species which are mostly affected by external inputs through river inflows are Total—Kijeldhal, Particulate Organic Nitrogen and obviously Total Nitrogen. These forms of Nitrogen are dependents of external inputs. Others are the secondary species, Dissolved Kjeldhal, TIN (NO_3 + NO_2 + NH_4) (or DON), and TDN. They are produced by the activities of Bacteria and Cyanobacteria: Nitrogen mineralization, de-nitrification and atmospheric Nitrogen fixation, as well as fish and zooplankters excretions.

The external dependants of Nitrogen species declined and the internally affected increased (**Figure 2**). The opposite trend is presented by Phosphorus dynamics: The primary P species, TP and Particulate, increased and the secondary—SRP and PTD—declined (**Figure 3**). The increase of phytoplankton (*Cyanophyta*, *Chlorophyta*, Diatoms) biomass concentration (Gophen 2017, a,b) was also confirmed by the multi-annual increase of Total Suspended Solids (TSS) measured in the upper 20 meters during 1975-2001 (**Figure 4**). Two statistical methods confirm it: Fractional Polynomial and LOWESS. Nevertheless, two unexpected and partly contradicted ecological results were recorded: increase of water clarity (deeper Secchi depth, **Figure 5**) and decline of DO concentrations (**Figure 6**) during 1990-2001.

3.1. Fishery

3.1.1. Annual Landings

Annual landings of *Oreochromis aureus*, Bleaks and consequently total catch (LOWESS) declined since the early 1980's, but those of *S. galilaeus* (**Figure 7**, upper right panel, LOWESS) are slightly different with two ebbs and one peak

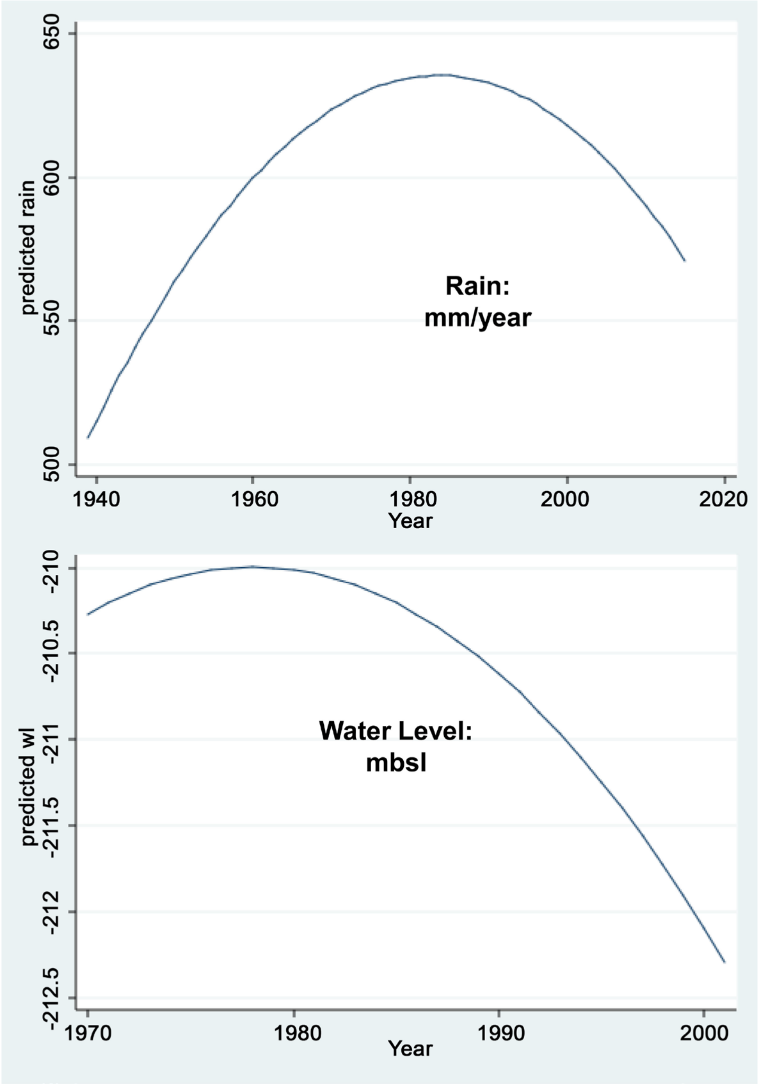

Figure 1. Upper Panel: Fractional Polynomial prediction of Annual Rain Gauge (mm/year) in the Kinneret Watershed (Dafna Station) (Dependant) and years (Independent) (1939-2016). Lower Panel: Fractional Polynomial Prediction of Annual average of Kinneret Water Level (WL) (MBSL) (Dependant) and Years (Independent) (1939-2016).

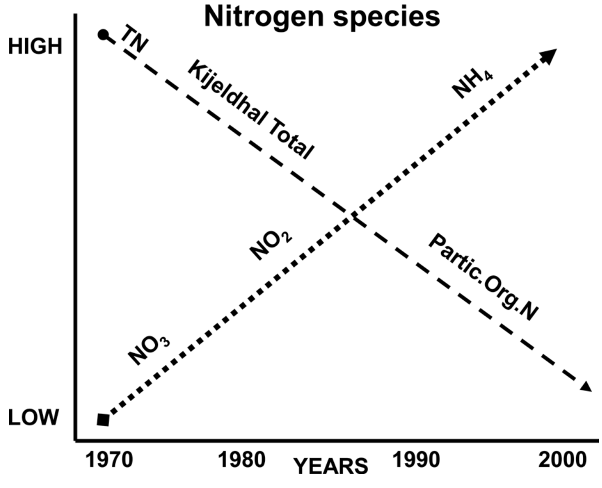

Figure 2. Schematic chart of nitrogen loads long term dynamics in Lake Kinneret (surface to 40 m).

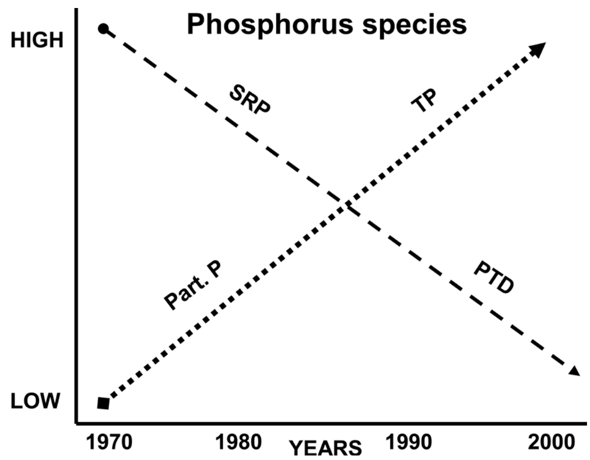

Figure 3. Schematic chart of phosphorus species loads long term dynamics in Lake Kinneret (surface to 40 m).

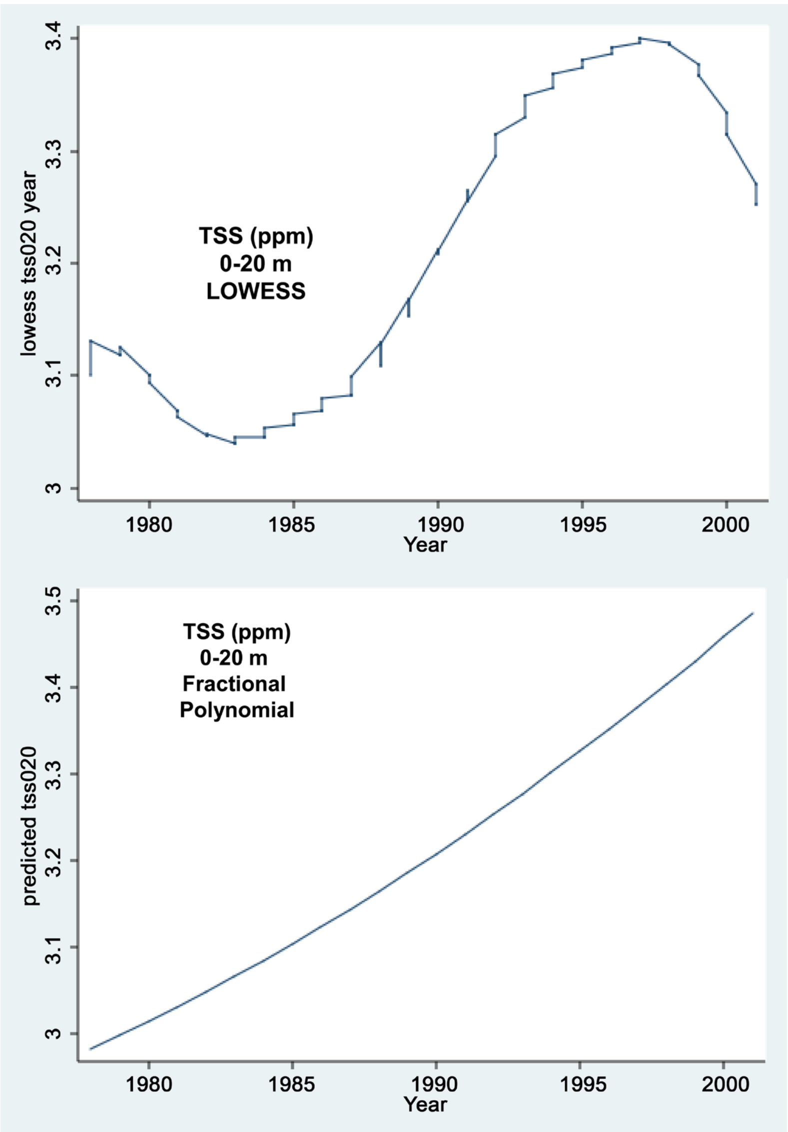

Figure 4. Total Suspended Solids (TSS) (ppm) (monthly means) (1974-2005) averaged for the upper 20 m. Upper Panel: LOWESS Plot; Lower Panel: Fractional Polynomial; Prediction: Years—independent, TSS concentration—dependant.

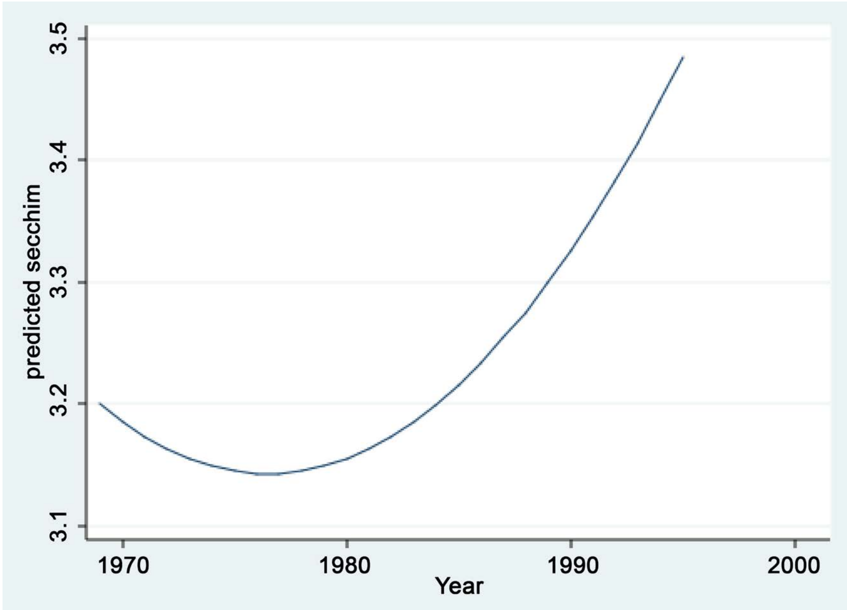

Figure 5. Annual means of monthly averages of Secchi depths (m) in Lake Kinneret (1969-2001): Fractional Polynomial prediction: Secchi depth (dependant) vs years as (independent).

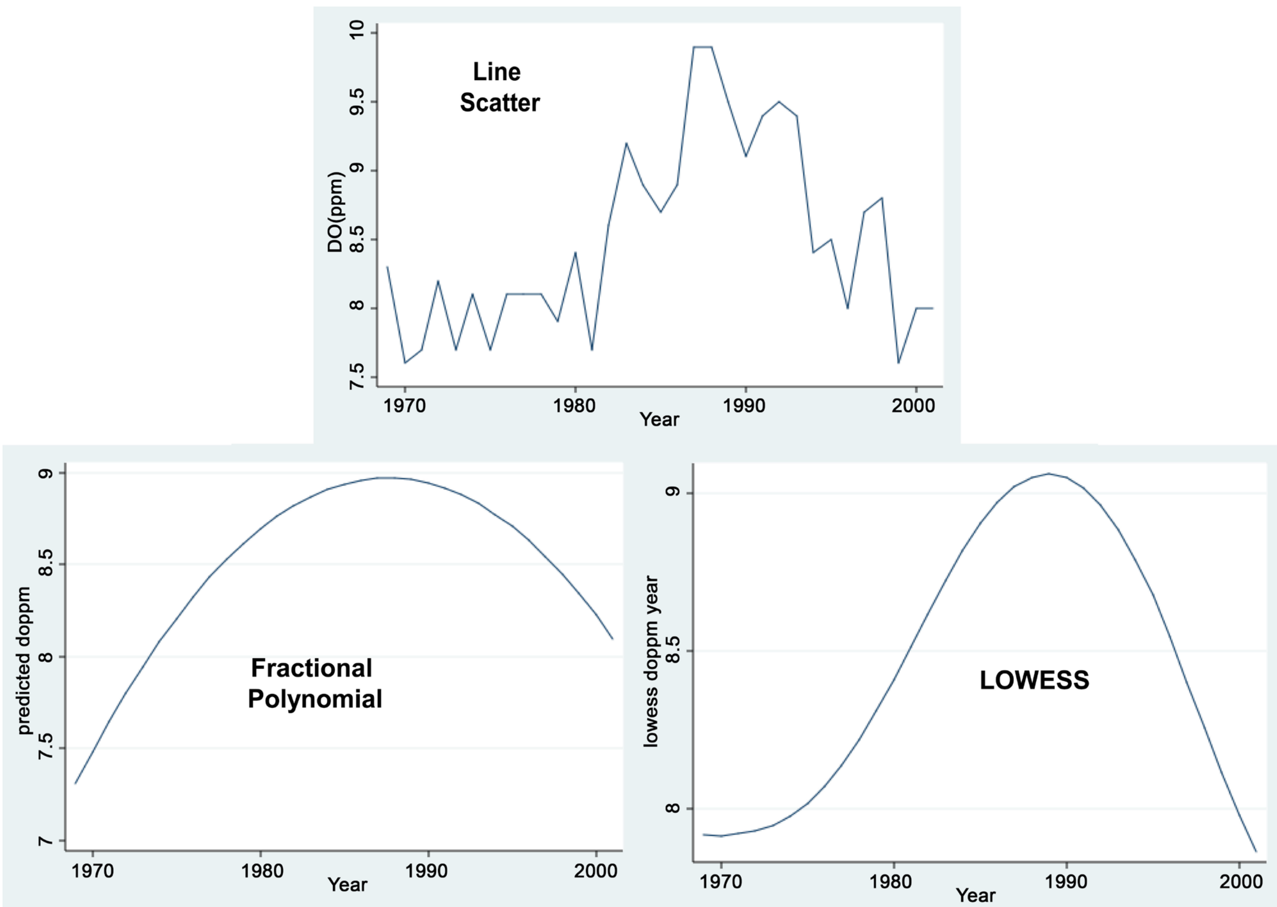

Figure 6. Annual averages of monthly means of oxygen concentrations (ppm) (DO) above 3.0 ppm in Lake Kinneret during 1969-2001: Upper Panel: Line scatter; Lower Panel Left: Fractional polynomial prediction of DO concentration (dependant) vs years (independent); Lower Panel Right: Trend of Changes (LOWESS) of DO concentration during 1969-2001.

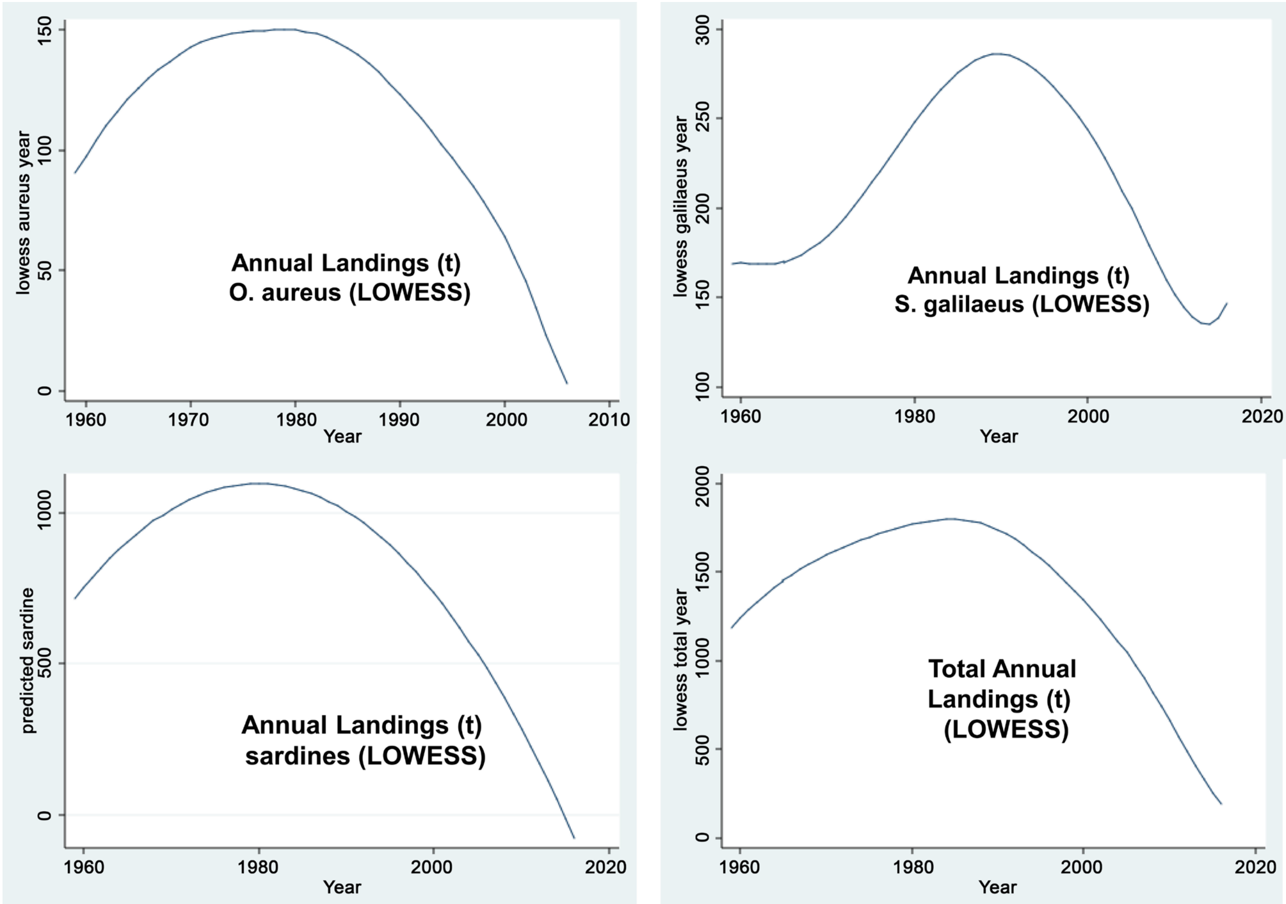

Figure 7. LOWESS plots of annual fish landings (t) in Lake Kinneret (1959-2016) of (clockwise): *Oreochromis aureus*, *Sarotherodon galilaeus*, sardines and total catches.

Table 1. Periodical means (SD) of *Sarotherodon galilaeus* landings (t/year) and indication of trend of changes.

Period (No. of Years)	Significant Trend of Change	Periodical Average (t/year)	Standard Deviation
1959-1970 (13)	Stable	175	28
1970-1990 (20)	Increase	248	112
1990-2010 (20)	Decline	231	154
2011-2016 (5)	Increase	184	99

[20] [21].

Periodical evaluation of annual landings of *S. galilaeus* is given in **Table 1**.

3.1.2. Stocking

Fish (fingerlings) Stocking in Lake Kinneret started in the late 1950's [21]. Since then, several species were introduced but the planting of only 4 of them lasted continually until the present: Mugilids, Silver Carp, and *S. galilaeus.* As of today, commercial profit is achieved from the stocking of Mugilids, *S. galilaeus* and Silver Carp. The stocking of *O. aureus* was profitable until termination of its introduction in the late 1980's. The number of annual stocked fingerlings of *O. aureus* and *S. galilaeus* accompanied by their annual landings are shown in Table 2.

Results given in Table 2 and Figure 8 represent how the elimination of *O. aureus* stocking (the mid-1980's) was respectively accompanied later by the decline of its landing.

Not surprising is the significant increase of the fish (>90% sardine) population size from the late 1980's and onwards (Figure 9) (Walline 1987-2005) because the elimination of Sardine fishery caused by near-zero market demands.

4. Discussion

4.1. Plankton and Nutrients Fluctuations

As part of the Kinneret ecosystem dynamics, the Phytoplankton and Zooplankton communities in Lake Kinneret have undergone significant modifications of taxonomic structure and biomass compositions that have been widely documented

Table 2. Periodical averages of stocked *O. aureus* and *S. galilaeus* fingerlings (10^6/y) and annual respective landings (t/y) in Lake Kinneret during 1960-2010.

Period	*S. galilaeus* Stock (10^6/y)	*S. galilaeus* Landing (t/y)	*O. aureus* Stock (10^6/y)	*O. aureus* Landing (t/y)
1960-1984	1.2	186	1.4	144
1985-2002	4.0	347	Negligible*	111
2003-2010	2.2	191	Negligible*	15

*During 1985-2010 *O. aureus* stocking was eliminated totally.

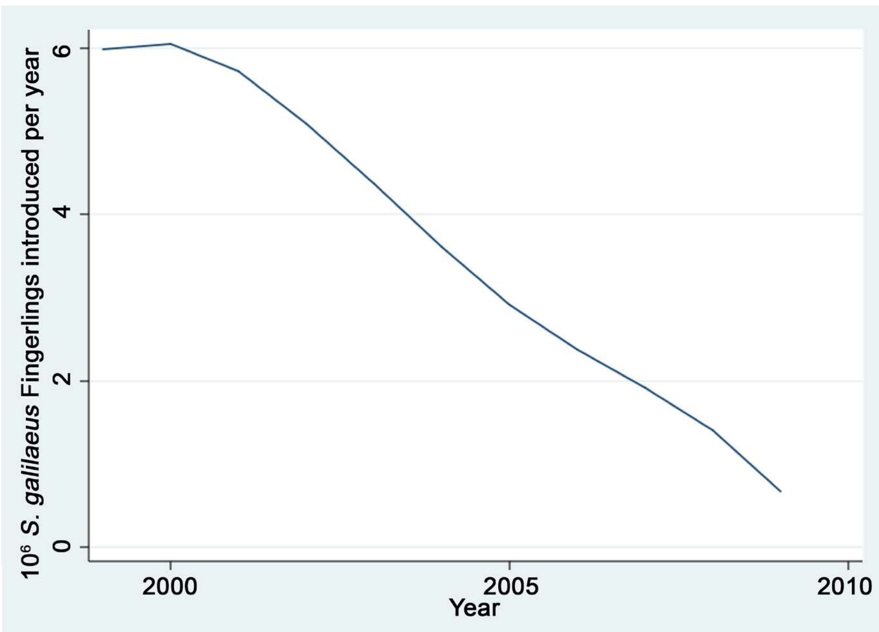

Figure 8. LOWESS plot of annually stocked (10^6) *Sarotherodon galilaeus* fingerlings (1998-2009).

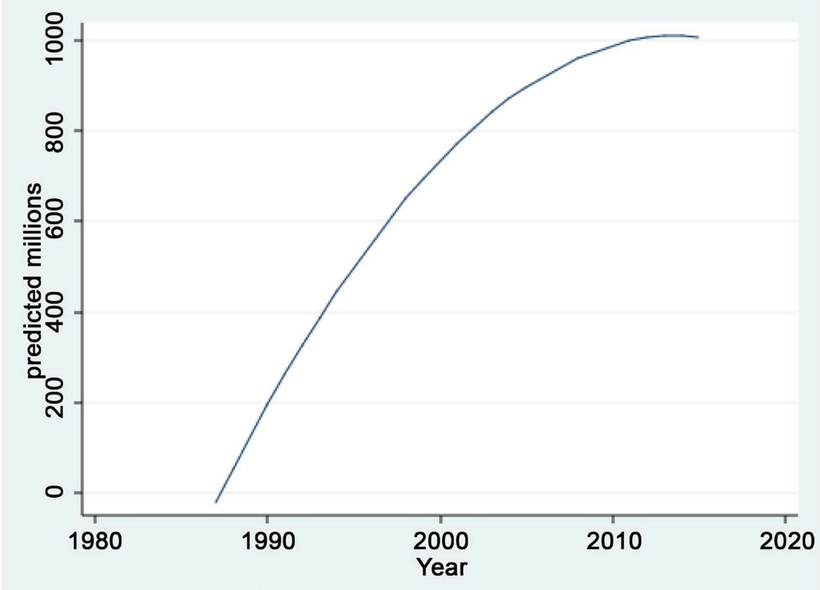

Figure 9. Fractional polynomial prediction of annual means of total fish number (dependant) (10^6), (all sizes), acoustically recorded in Lake Kinneret during 1987-2016 (independent).

[2] [3] [4] [5] [6] [13] [14] [22]. Nevertheless, for the accomplishment of the entire system, the nutrient fluctuations require additional considerations.

4.1.2. Nitrogen Dynamics

The majority of Nitrogen inputs originate externally and partly internally. External inputs of all nutrients are definitely correlated with precipitation and river discharges. Following the enhanced regime of precipitation prior to the 1980's, a trend of decline was documented afterwards, consequently lowering the lake's Water Level (**Figure 1**). The majority of external input of Nitrogen is represented as TN, Total Kjeldahl and Particulate forms and its decline is attributed to the retreat of river discharges. It should be considered that external input which enhances "Particulate Nitrogen" (**Figure 2**) also includes fixation of atmospheric N_2 after the mid-1990's by Cyanobacteria. The increase of dissolved-N forms (TIN: NO_3, NO_2, NH_4) (**Figure 2**) is attributed to the enhancement of microbial activity within the processes of nitrification and de-nitrification. Conclusively, the Nitrogen load was suppressed. Those modifications of nitrogen changes induced two response types: the decline of *Peridinium* and enhancement of *Cyanobacteria*. Since *Peridinium* is known to be a significant component of the food composition of *S. galilaeus*, its decline might be accounted as a factor which has an effect on the decline of this fish. Nevertheless, there was not a periodical overlap between *Peridinium* (1987) retreat and *S. galilaeus* landing decline (2007-2008). Moreover, it was recently documented [6] that *S. galilaeus* efficiently consumes Zooplankton as a food resource replacement.

4.1.3. Phosphorus Dynamics

Contrary to Nitrogen, Particulate and Total Phosphorus (TP) were enhanced whilst dissolved P fractions declined (**Figure 3**). External P sources are river discharges and dust deposition, and dissolved inputs are due to bacterial mineralization in the sediments and epilimnetic supply also attributed to *Peridinium* Cyst-mediated P. Consequently, the dissolved forms' decline is attributed to the *Peridinium* disappearance whilst the enhancement of the particulate forms is due to the biomass increase of non-*Peridinium* algae (*Chlorophyta*, *Cyanophyta*, Diatoms) known as efficient incorporators of dissolved P. The data given as Trend of Change (LOWESS) and Predicted Regression (Fractional Polynomial) plots (**Figure 4**) indicate the enhancement of Particles in the Epilimnion of Lake Kinneret since the mid-1980's. Surprisingly, Predicted Regression of Secchi Depth (**Figure 5**) indicates increased clarity (deeper Secchi Depth) from the 1980's. These data probably reflect the change in Phytoplankton composition from *Peridinium* (turbid water) to non-*Peridinium* algae (clear water) (**Figure 5**). The data of temporal fluctuations of DO concentration (**Figure 6**) support this conclusion: the decline of *Peridinium* replaced by non-Peridinium algae initiates a higher efficiency of photosynthetic DO production as well as reduction of DO consumption caused by organic matter decomposition due to the *Peridinium* Bloom collapse. Conclusively, independent dynamics of N & P has probably no impact on the decline of *S. galilaeus* stock and landing reduction.

4.1.4. Overfishing

Overfishing is a case of overexploitation of fish (one or more species, or population size) where stocks are reduced to the level below renewal capability. The outcome is, therefore, the disordered sustainable existence of the aquatic ecosystem. Further development is resource depletion through low fish biomass growth rate and consequently reduction of their stocks. The outcome of overfishing succession is a critical situation where fish population is no longer capable of sustaining itself. When this occurs, it is relevant to a single or several species or even the entire ecosystem's fish assemblages. Overfishing malfunction occurs when more fish biomass is removed than can be replaced by natural or induced (stocking) reproduction.

S. galilaeus is a native component of the Kinneret ecosystem. Therefore, overfishing is not only commercial interference but also a measure of damage to the ecosystem structure. Overfishing occurs not only by biomass removal but also by long-term use of illegal small mesh-size of fishing gill-nets and the over-exploitation of the small-size specimen. If harvested target specimens are of an illegally small size, the maximum yield per recruit is reduced because fewer individuals reach maturity. Overfishing is also due to excessive removal of spawners. Excessive depletion of spawner biomass results in reduction of replenishment of reproductive capacity. Harvest control by implementation of regulated fishing legislations is, therefore, ultimately required.

The focus of this paper is clarifying whether the extreme decline of *S. galilaeus* landings during 2007-2008 was affected by over-fishing constraints or not and, therefore, other exceptional ecosystem modifications were involved. The practical benefit of such a search might give the optimal management indication to the fishery managers and provide guidance for optimal recovery of the harvest decline [5] [21]. The decision makers considered, therefore, two contradicting options. 1) The harvest decline was caused by classic overfishing and, therefore, 3 years of total fishing ban is recommended. 2) The harvest decline represents an exceptional natural and partly anthropogenic fluctuation of the ecosystem, and a fishing ban might be damageable and is thus not recommended; predator removal, enhancement of *S. galilaeus* stocking, enforcement of existed legislations and bleaks fishing renewal are recommended.

Landau [23] [24] [25] documented outstanding studies on the impact of several factors on the stock and catches of *S. galilaeus* in Lake Kinneret. Among those factors, the influence of water quality, the stock size of Bleaks, the availability of zooplankton food resources and the intensity of fishing effort (Catch Per Unit Effort, CPUE) were evaluated. None of those factors included over-fishing trait. The positive relations between fingerling stocking and landing, as well as the negative impact of Bleak's stock size on *S. galilaeus* catches, were indicated. The elimination of Bleaks fishing is also shown in **Figure 9**, indicating a significant enlargement of the fish population (by number) from the late 1980's as recorded by Eco-Survey. This increase in the fish population is mostly (>90%) due to all life stages and body sizes of Bleaks [17]. If food sources of *S. galilaeus* and Bleaks even partly overlap, predicted competition might contribute a growth rate suppression of *S. galilaeus*. Pisanti *et al.* [26] and Pisanti [27] have indicated Quasi-Cyclic trended periodical (10 - 11 years) modification of *S. galilaeus* stock biomass and landing, respectively. It was established by Auto-Correlation and Spectral Analysis of 49 years data record (1935-1984) of landings and 25 years of CPUE data. They also concluded that the *S. galilaeus* landing declines are not caused by a long-term decrease of its stock. The long-term stock reduction as a reason for the landing decline is a malfunction, and fluctuations of landings and stock are periodically correlated, and multi-annual trend of stock reduction does not actually exist. The recommendation was achieved to reduce fishing effort during periods of ebb in landing aimed at increasing the lake's fish population and fishers' profit.

4.2. Ecological Perspectives

The event which is discussed here is extremism of decline of *S. galilaeus*. On the other hand, the major contributor to the total fish catch in Lake Kinneret was until mid the 1980's the fishery of Bleaks. As a result of the low commercial value of Bleaks, the fishing effort operated on this fish is strictly dependent of market demands. From the mid-1980's, Bleaks fishery was reduced and almost completely eliminated and the total landing declined (**Figure 7**). Nevertheless, the fishing effort towards *S. galilaeus* is caused by its high commercial value, but reward in terms of catch from this intensive pressure is partly dependent on stocking. *O. aureus* is not a pure native species in Lake Kinneret [20]. From the late 1950's, this species was intensively introduced but stocking has been eliminated since the mid-1980's; consequently, rewarded catch dropped to a minimum in the mid-2000's (**Figure 7**). *S. galilaeus* is partly dependent on stocking (Ben-Tuvia and Reich 1983), but as a result of being native in the Kinneret ecosystem it also naturally reproduces successfully. The spawning grounds of this mouth breeder fish are partly seasonally protected. Ben-Tuvia and Reich [28] documented a high level of correlation coefficients ($r^2 = 0.6$; $p = 0.003$) between number of introduced fingerlings of *O. aureus* and the annual landing one year later. They [28] approximated a contribution of 59.5 tons to the annual landing per 1 million fingerlings that were introduced one year earlier. Results shown in **Table 2** and **Figure 7** indicate periodical peaks and ebbs (see also [26] [27]). Financial difficulties caused the reduction of stocking since 2000. The stocking decline contributed significantly to the decline of *S. galilaeus* landing during the 2000's. Data presented in **Table 2** also indicates a strong relation between stocking and landing of the semi-native species of *O. aureus*; after complete stoppage of the introduction, landings respectively vanished.

Long-term fluctuations of ecological parameters are commonly a natural trait of the environmental feature. Presently, anthropogenic involvement becomes more intensive as a result of events of extremism and human population increase accompanied by greater environmental demands. The extremity of the environmental event is mostly due to global warming, water scarcity, and consequent desertification processes. As a result of the elevation of the human mode of life, the society requires the magnification of aquatic (lakes) food supply as well as recreational infrastructure. Consequently, the intensity of pressure constraints on the Kinneret ecosystem was operated. Such a background encouraged the need for appropriate management of the Kinneret Ecosystem where fishery is a priority. Fishery management is aimed at both water quality protection and fisher profit. One of the required conditions for the implementation of those two missions is ecosystem stability. Nevertheless, ecological parameter fluctuations do not necessarily indicate instability. Moreover, cyclic trends (partial or complete) represent the ecosystem's capability for environmental swinging or resilience where extremes are not desirable. The decline of *S. galilaeus* was part of an ecological cycling "seesaw" (Pisanti *et al.* 1987; Pisanti 2005). Beside several known parameters, which supported the decline of *S. galilaeus* landing, the forwarded consequent increase without a total fishing ban was predicted. The long-term study of the biological dynamics of the population of this fish in Lake Kinneret justified that forecast. Among factors that implied *S. galilaeus*' landing decline were stock reduction, Cormorant and *Clarias gariepinus* predation, periodical (1992-2000) usage of small-sized illegal gill-net, the viral blindness disease, and food competition with an enhanced Bleak population. The Kinneret limnological cycled fluctuation dynamics include plankton and nutrients. Consequently, recommended response for the ecological reform design in Lake Kinneret is not "disorder "enhancement but an "ordered" management policy. The "ordered" policy includes continuation of controlled fishery, deportation of

Cormorants, intensive removal of *C. gariepinus* and bleaks, stocking reinforcement, and implementation of existing fishery legislation. The tri-annual total fishing ban as discussed may open unexpected developments such as *S. galilaeus* population collapse. Beyond all disputes, the final test of the result and the return of normal landing of harvests confirmed the continuation of the controlled fishing policy and fishing ban rejection.

Ironically, the "Ecological-Disordered" management design was basically evaluated on the misleading hypothesis of over-fishing pressure on the *S. galilaeus* stock. The stock was reduced as part of the natural trait, and its negative amplitude was accelerated slightly by several supported factors, including the short period (1992-2000) of the use of illegal small-mesh gill-nets. In [6] [23]-[28] the decline of *S. galilaeus* stock was documented, but overfishing was not accounted as a cause are documented. Conclusively, it was suggested that "Decline Factors" should be considered and reformed but the tri-annual total fishing ban is not an optimal management approach. This case and the administrative treatment it was given exemplify the need for comprehensive view where not only entire conditions and\or limnological parameters should be incorporated but also long term records and full board of experts involvement are ultimately required. Future perspectives for research include a comprehensive analysis of the Kinneret ecosystem.

Filming verification (Gophen, M. unpublished data) of *S. galilaeus* nest construction confirmed that spawning ground type is quite often are at open bare (no vegetation) area. The dimple type of the nest constructed by *S. galilaeus* is shallow and constructed by removal (not dig out as *O. aureus* do) of coarse items like small pebbles and empty mollusc conches. These shallow nests on bare bottom is exposed to wave action impact and therefore promptly demolished after egg laying and consequently less observed and documented. In contrast to wave action impact on bare bottom, vegetation produce physical protection and therefore dimple spawn better survived, observed and documented. Recent published information [29] documented *S. galilaeus* nest densities ranged around 20 - 30 per 100 m^2 which briefly calculated as much lower than required to support fish stock recruitment to maintain the present annual landings. The reason is probably eliminating active spawning on bare bottom and absence of wave action protection given by vegetation.

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