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Review Article

Fishery Management in Lake Kinneret: A Review

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Summary

Lake Kinneret ecosystem has undergone significant modifications and light alterations of fish food preferences. An overview of the long-term fishery management in Lake Kinneret is presented. Landing decline of all commercial species was indicated. The reduction of fishing pressure, enhancement of Birds predation, the use of illegal fishing nets and reduction of stocking were suggested as major causations for the harvest decrease. The role of zooplankton within the fish food resources is prominent. Predator cyclopoids predation of herbivore zooplankton probably has a minor impact in comparison with the total fish predation pressure on zooplankton. Zooplankton predation by fish has a similar impact on herbivorous and carnivorous animals. The introduction of Silver Carp and Mugilids improve water quality protection and gives significant support to the Fisher's income.

Keywords: Bleaks; Fishery; Kinneret; Management; Mugil; Plankton; Silver Carp; Tilapias

Background

Lake Kinneret is the only freshwater natural lake in Israel. The lake is classified as a warm monomictic body of water that is fully mixed during mid-December and April and stably stratified from June to October [1,2]. De-stratification process continues from November through mid-December and stratification built-up from mid-December to May. Timing and duration of thermal structure changes is climate-dependent: warming trend causes a shorter mixing period and a longer stratification season. The lake ecosystem has undergone significant condition changes of several parameters [3]. Prominent modifications of internal and external conditions occurred during the 1990's [4].

Environmental Conditions, Nutrients and Food-web Structure

Precipitation decline is followed by reduced river inflows and consequently lowered quantitative input of nutrients and mostly Nitrogen reduction [5]. A multiannual decline of the water level was therefore recorded; air temperature increase caused a warming of the Kinneret Epilimnion; the Bioavailability of nutrient in the Epilimnion was altered from Phosphorus to Nitrogen limitation for phytoplankton demands due to the decline of Nitrogen and a slight increase of Phosphorus concentrations. The outcome of these changes was a prompt reduction of the dominant bloom-forming dinoflagellate *Peridinium gatunense* and enhancement of Cyanobacteria, Diatoms and Chlorophyte phytoplankters [6,4,2,7].

Water Supply

Until the early 2000's about 350X10^6 m^3 (mcm) of water were pumped from lake Kinneret through the National Water Carrier (NWC) to be supplied for agricultural irrigation and mostly (>50%) domestic usage [2]. From 2010 water for domestic usage is supplied from Desalinization plants. The demands for Kinneret waters were therefore sharply reduced. They were continued to be supplied to local consumers (domestic and agricultural purposes) and conveyed to Jordan Hashemite Nation as an obligation under the peace agreement between Israel and Jordan.

Present Status of Ecological Services

As part of the ecological modifications combined with the outsourcing (desalinization) supply for domestic demands, the status of the Kinneret ecological services was re-defined. Before the 2000's domestic water supply was top priority but at present, fishery, recreation and tourism have replaced it [3,4,8,9].

Fishery

The concept of fishery management development in Lake Kinneret went through significant changes. At the very beginning of fishery maintenance in Lake Kinneret, the impact of fish communities on water quality was not thoroughly incorporated by managers [5]. After several years of Ichthyological research [1,9-

14]. A construction of bridging between fishery managers and limnologists was implemented. In other words, successful convincing of fishery managers that the national achievement of domestic water supply from Lake Kinneret depends on lake water quality, which is among other parameters also affected by fish, was done. Nevertheless, water managers must also recognize that fishery is an income resource and must therefore be respected accordingly. Long-term statistical information of annual landings is presented in Figures 1, 2, 3, and 4 [6,4,10,13,15]. Evaluation of 50 years of fishery data indicates a decline of Barbels throughout the entire period (Figure 1). Barbels are native species non-stocked with a moderate commercial value and therefore market demands are low. Bleaks fishery (Figure 2) [2,10,14,13,16] is strictly market demand-dependent [6,4]. Consequently, the prominent commercial value reduction caused a sharp decline of Bleak fishery from 1000t/year to negligible landings during 1980-2010 (Figure 2). The total landings were diminished. Tilapia (*Sarotherodon galilaeus*, SG; *Oreochromis aureus*, OA) fishery (Figure 3) is highly correlated to stocking (both OA, SG) and natural population periodical cycles (SG) [4,5,10,13]. Because the stocking of OA was stopped in the mid1980's and that of SG was reduced recently [4], landings of both were decreased since the mid-1980's (Figure 3). Silver Carp [17,18] and Mugilids (Figure 4) [19,5] are both non-native species in Lake Kinneret; therefore, their landings correlated only with their stocking, and decline of introduced fingerlings was followed by landing decline of both species (Figure 4). Because fishery management is partly fisher income resource and therefore market-dependent, a conflict of interest might be initiated. As a result of collaborative understandings and the previous construction of bridging between fishery biologists and limnologist, an ad-hoc parity committee was created for the decision-making of fishery management. This committee verified and signed a long-term master-plan for stocking policy and in annual meetings issues of fishery and introductions were discussed and resolved.

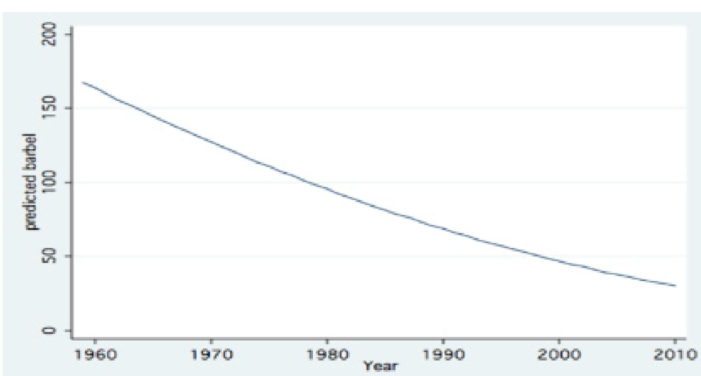

Figure 1: Barbels Annual Landings (t) (1959-2010) (FP).

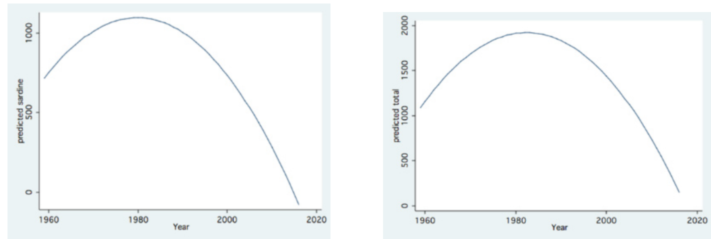

Figure 2: Annual Landings (t) 1959-2010 (FP): Left: Bleaks, Right: Total.

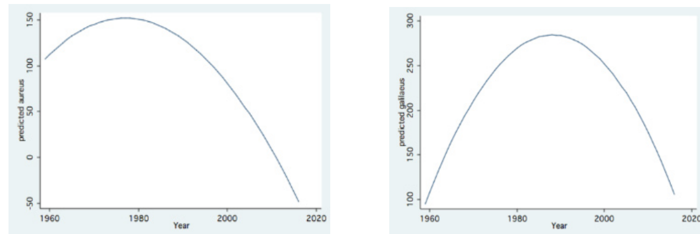

Figure 3: Annual Landings (t) 1959-2010 (FP): Left: *Oreochromis aureus* Right: *Sarotherodon galilaeus.*

Figure 4: Annual Landings (t) 1959-2010 (FP): Left: Silver Carp; Right: Mugilids.

In this paper a constructive scope based on information collected during more than 50 years of fish biology and fishery management research combined with protection of water quality in Lake Kinneret [8,9] is presented.

Feeding Habits

The food composition of the Kinneret fishes was analyzed microscopically and by experimental studies [2,6, 12,14,16,20-26].

Cichllids: *Sarotherodon galilaeus*, *Oreochromis aureus*, *Coptodon (Tilapia) zillii*, *Tristramella simonis simonis*, *Tristramella sacra*, Haplochromis(*Astatotilapia) flaviijosephi*.

Cyprinidae: *Luciobarbus (Barbus) longiceps, Carasobarbus (Tor) canis, Capoeta damascina (Varicorhinus damascinus), Bleaks (Mirogrex terraesanctae (Acanthobrama terraesanctae terraesanctae), Acanthobrama lissneri), Garra jordanica (Garra rufa; Discognathus rufus), Hemigrammocapoeta nana (H.nanus;*

Thyloghnathus steinitziorum), Pseudophoxinus kervillei (Phoxinellus kervillei), Cyprinus carpio, Hypophthalmichthys molitrix.

Mugilidae: *Mugil cephalus, Liza ramada*.

Balitoridae (Cobitidae): *Orthias tigris (Neomaechilus tigris tigris)*.

Clariidae: *Clarias gariepinus (lazera)*.

Cyprinodontidae: *Aphanius mento (Apanius cypris; Cyprinodon mento)*.

Poeciliidae: *Gambusia affinis.*

Blenniidae: *Salaria fluvitilis(Blenius fluviatilis)* .

Special attention of food composition is given to the followings:

The most common component of the fish fauna in Lake Kinneret, the Bleaks is a typical zooplanktivorous feeder through all life cycle stages; Young stages (<5g) *Sarotherodon galilaeus* (SG) are zooplanktivore whilst older stages are filter feeders which preferably utilized *Peridinium* [2,13] but increased level of zooplankton prey from the late 1990's when *Peridinium* decline was documented. The food composition of the adult filter-feeder of OA was plankton, and zooplankton comprised significant component. From the mid-1990's *Oreochromis aureus* (OA) was not yet a significant population component since its stocking was ceased.

The Native assemblages of Lake Kinneret fishes include 19 species of which about 10 are commercially fished and 5 (only 3 were recently documented in PLoSONE13 (6): eO 198747) are endemic [10]. The offshore open water (>3m depth) community structure differ significantly from the inshore shallow habitats. Nevertheless, there is a prominent occasional migration and location changes between the shallows and open water allocation. The permanent population in the shallows is mostly due to small-sized fishes whilst large adult specimens migrate to the inshore zone during the spawning period and sporadically to feed on a daily basis when temperatures are suitable. Those summer (when daily minimum of shallow water temperature is not below 21˚C) migratory species are nest builders and mouth breeders [27,28]. In winter periodical (4-10 days' cycle), shoals of bleaks inhabiting the shallows at night and as free mixed (Males and Females) swimmers release eggs and sperms than fertilized eggs adhered to stones for incubation. Mating performance, nest constructing, mouth-breeding and YOY (young of the year) training are carried out in the shallows whilst feeding in offshore waters [27,28]. The majority of the Kinneret fishes are planktivores of which several are particulate attackers (Particle size selection); the others are filter feeders (all size frequencies ingestion), and piscivory is minimal. A smaller number of species (Barbels) are bottom dwellers, stone scrapers and piscivory is rare [29]. The most abundant feeding habit of the permanent population of small fishes in the shallows are bottom feeders. In spite of distinguished partitioning between food composition compartment among fish groups, there is a high level of inter-specific overlap. Moreover, a natural shift from the majority of certain food sources to others was caused by the long-term ecological modification of the ecosystem.

Taxonomic Composition and Zoographical Origin (Ben-Tuvia 1978)

The native species in Lake Kinneret represent 6 families: Cyprinidae, Cichlidae, Nemachelidae (Balitoridae, Cobitidae), Clariidae, Cyprinodontidae, and Blleniidae. Nevertheless, as a result of intentioned and non-intentioned stocking (refuge migration), the present Ichthyofauna of Lake Kinneret also include the next families: Salmonidae Poecilidae and Mugilidae. Two exotic species are included in the Cyprinidae family. Among the native species five (or as recently defined) are endemic and the extinction of two others probably eliminated them from the Kinneret inventory. Most of the native species are tropical (Ethiopian) and the origin of several others is Palaearctic. It should be noted that Taxonomy is not totally related to zoogeographical classification. The tropical species reproduce during spring-summer time and the Palaeoarctic representative in winter months. Since Lake Kinneret is located in the sub-tropical zone, the water thermal trait significantly affects the reproductive capacities of both the tropical and "Northern" originated species. The sub-tropical climate trait is characterized by long, dry and hot summer and short, cold and wet winter.

Not only climate zone differentiated fish species but also water quality features. Some of the families include Anadromus species, those which migrated from the Ocean to Freshwater habitats, accounted as secondary freshwater origin, (Cyprinodontidae, Poecilidae, Cichlidae and Blennidae). Other families are primary freshwater species with partial migration from freshwater to the ocean (Catadromus), (Cyprinidae, Balitoridae, and Clariidae). Conclusively, the high diversity of the fish origin resulted in a variety of Kinneret fish's feeding and reproductive habits.

Stocking

A prominent factor which significantly affected fishery management aimed at the maintenance of commercial and water quality values in Lake Kinneret was created by exotic and invading species of the following families: Mugilidae, Poeciliidae, Cyprinidae and Salmonidae [10,17,18,22,23]. Some of the invaders, which are able to reproduce in the Kinneret (*Gambusia affinis* and *Cyrinus carpio*), became permanently resident in the lake whilst the population of several others not able to reproduce in Kinneret is annually renewed by planting (Mugilids, *H. molitrix*).

Material and Methods

This paper evaluates data supported by The Lake Kinneret Data Base (KLL-LKDB 1970-2013): The Limnological data-set of nutrient, phytoplankton, and fish densities as monitored by echo-surveys. The fishery landings and stockings by species and information on fishery legislation supported by The Fishery Department of the Ministry of Agriculture, The Lake Kinneret Fishery

Branch. Data of Densities and Feeding habits of Cormorant was supported by the National Authority of Nature and Parks Authority (NPA) as unpublished data and Interim reports [30,21]. The Statistical evaluation include four procedures: Distribution Line Scatter of Annual Averages, Linear Regression with Confidence Interval, Fractional Polynomial Regression (FP) and Trend of Changes (LOWESS; 0.8).

Results and Discussion

Fish Introduction (Fishery Department 1970–2013; Gophen 2018; Gophen et al. 1983 b; Gophen et al. 2015)

Fish introduction has a prominent impact on commercial fishery in Lake Kinneret. From the 1920's to the present, 13 exotic and native species had been intentionally and accidentally introduced into Lake Kinneret. Gambusia affinis, *Cyprinus carpio*, and *Salmo gairderi* had invaded accidentally [10]. *G. affinis* invaded as a result of a national challenge aimed at the elimination of Mallaria. This fish established permanent minor communities in the Littoral zone without a competitive impact on the local native species. Accidental invasion of Salmonids occurred in 1948 and also during the 1980's but limited survival capabilities were documented through fisher harvest. The viscera of those Salmonids were analyzed and intestines were recorded as completely evacuated probably because the fish found it impossible to allocate and ingest available food items. *Cyprinus carpio* was introduced during 1940-1941 and 1948-1949. Escapers from fish ponds also invaded but as of today it is not clear if those carps reproduce in Lake Kinneret. Nevertheless, the evaluation of the significant growth rate of *C. carpio* evidently proves its successful adaptation within the Kinneret ecosystem. Unintensive cases of *Tinca* and *Ictiobus cyprinella* introductions were carried out in 1948 and 1960, respectively, but no commercial harvests were recorded. Fingerlings of *Anguila* are continually imported accidentally as mixed accompanists within the Mugilids' shoals fished for introduction in coastline rivers outlets. Anguillids are predators and rarely chased by Purse-Seiners as big size specimen. During the early 1980's two significant resolutions were agreed upon by the Fishery management committee: 1) to eliminate the introduction of *Oreochromis aureus* due to its scarcity (comprised <5% of landings) prior to introduction, and the genetics impurity of the stocked fingerlings; and 2) Stocking elimination of Silver carp (*H. molitrix*) due to the documented high level of zooplankton utilization in summer by this fish prior to the 1990's when Cyanobacteria became abundant. Further on, when Cyanobacteria (*Microcystis* spp.) heavily bloomed, this resolution was changed and renewal of its stocking was recommended due to its effective capabilities to graze these algae accompanied by suspended organic particles and the fisher income support. So far, the fishery management committee has agreed on the introduction of Mugilids, *Sarotherodon galilaeus* and Silver carp.

Mugil spp. (Gophen and Snovsky 2015 b)

Mugilids (*Mugil cephalus* and *Liza ramada*) stocking in Lake Kinneret started in 1958. The stocking concept was aimed at improving Fisher income and lake water quality. The market value of Mugilids is high, the fish cannot reproduce in the lake and fingerlings are available at reasonable cost. Fingerlings fishing is effective during winter time in river outlets along the Mediterranean Israeli coastline (induced reproduction is under investigation). During 1960-2015, 56.2 million fingerlings were introduced into the lake averaged as one million per year of M. cephalus (MC) and L. ramada (LR). The majority (87%) of stocked Mugilid fingerlings were LR, and MC comprised 35% of landing biomass. LR individual fishes in catches were at the age of 3.3 whilst that of MC was at 4.2 years. The higher individual weight of MC (1827 g) than that of LR (467 g) in commercial landings was documented [19]. It is likely that the growth rate of MC is higher than that of LR. The return price (yield) from stocked fingerlings to commercially landed individuals is 3 times higher for MC in comparison with LR.

The overall conclusion of Mugilids introduction as a prominent success: Water quality improvement combined with profited compensated proceeds. The majority of the Mugilids food composition in Lake Kinneret comprised of suspended particles (detritial organic particles). Consequently, no damage to water quality is predicted. The best fitness between recruitment to landings and stocking capacity was evaluated at 3 years interval. The long-term success of Mugilids planting in Lake Kinneret was confirmed by both, no causation of water quality deterioration, and significant contribution to commercial harvest. The introduction of Mugilids into the Lake was shown to be a positive component of the anthropogenic involvement in the management of the Lake Kinneret ecosystem.

Silver Carp (Spataru and Gophen 1985; Gophen and Snovsky 2015 a)

Silver Carp (SC) (*Hypophthalmichthys molitrix*, *Valenciennes*),(1844) was globally spread on through rivers and plantings in about 90 countries around the world. SC was first introduced into Lake Kinneret in 1969 and continues onwards. Total number of stocked fingerlings (1969-2013) was 18.5 X 10^6 (average: 441 X 10^3 / year). The total catch (tons) of SC in Lake Kinneret was 3218 tons, average, 75 t/year. Studies on SC in East Lake, China, revealed that the fish is a phytoplanktivorous and percentage of consumed phytoplankton biomass varied between 83 and 91% where *Microcystis* is the major item. In Lake Kinneret, the effects of SC and the Cichlid, Galilee St. Peters Fish (*S. galilaeus*) on Plankton densities are not independent; therefore, these fishes are potential competitors. Nevertheless, SC is known as an efficient consumer of *Microcystis* [18]. Conditions for recruitment of this fish to commercial size in Lake Kinneret were found to be optimal. The SC do not reproduce in Lake Kinneret and a recommendation was implemented to introduce annually 600-1000 x 10^3

fingerlings aimed at the benefits of water quality protection and fisher income.

The introduction of SC into Lake Kinneret achieved the proposed objectives without the predicted risks. The SC preferably consumes phytoplankton during 8 months (1-8) by selection of large cells *Peridinium* or big size colonies of *Microcystis* [26]. The Index of Satiation and Body Condition Factor were low in summer, indicating food limitation during this season, and high in winter and fall when the *Peridinium* or *Microcystis* are alternately dominant. The exotic SC in Lake Kinneret represents a growth rate higher than those documented in temperate zone countries. The Major contribution of SC to commercial landings is due to the ages of 3-5 years. The positive relation between introduced fingerlings and annual landing 3 years later was statistically confirmed ($p=0.0005$ and $r^2= 0.295$). Data on the weight / length relation in Lake Kinneret during 2000-2001 indicated a high rate of marketable increment. In nature, the reproduction process of SC includes a migration upstream along long (thousands km) rivers (Mississippi, Yangtze) ended with eggs lay and external fertilization. Fertilized eggs floated downstream within turbulent currents and hatched at the river mouth region. Fingerlings for Kinneret stocking are available from hatcheries. SC does not reproduce in Lake Kinneret. The contribution of SC to Kinneret water quality improvement goes through the partial removal of *Microcystis* or *Peridinium* when dominant. Experiments carried out in $5m^3$ outdoor tanks evidently proved that a lot of interaction effects between SC and SG were indicated showing that the effects of SC and SG were not independent and the two species are potential competitors (Gophen 2014). SC had less intense effects on zooplankton than SG. It is suggested that although the impacts of SG and SC on plankton community do differ, both fishes utilize partly similar Kinneret food resources. Nevertheless, the Kinneret ecosystem has undergone ecological changes. During 1970-1990 Kinneret was a Phosphorus-limited ecosystem and objection to SC introduction was justified. From the mid-1990's and onwards, the Kinneret ecosystem is Nitrogen-limited, and Cyanophyte replaced *Peridinium* dominance. Consequently, SC might have an improvement impact on water quality by *Microcystis* removal and its introduction is therefore recommended. After 48 years (1970-2018) of SC introduction into Lake Kinneret, no indications of water quality deterioration attributed to SC effect were confirmed. If *Microcystis* remain dominant in Lake Kinneret-phytoplankton assemblages, the beneficiary of SC is justified [31]. If *Peridinium* will reappear and become dominant SC utilization might also contribute to the organic matter suppression (caused by *Peridinium* bloom crash) and, in addition, enhance fisher income.

Tilapias (Gophen et al. 1983 a, b; Gophen 2018; Pisanti 2005; Ben Tuvia 1978)

The history of introduction of Tilapias into Lake Kinneret started in the late 1950's with the stocking of *Oreochromis Aureus* (OA) and *Sarotherodon Galilaeus* (SG). The genetic background of the fingerlings of OA was unclear and probably included genomic elements of a mixture of several species ("Genetic Soup") as free reproductive unwanted fingerlings from aquaculture (fishponds). After the establishment (1983) of the Kinneret Limnologist and Fishery Department fish biologists' parity committee and the confirmation of agreement on master plan for fishery management in Lake Kinneret, the stocking of OA was terminated. As part of the master plan, a significant decision was also legislated: increase of the stocked fingerlings of SG weight from 2-4 g to 5-10 g each. It was a significant step forward since those fingerlings of SG are the outcome of costly feeding in intensive fishpond culture. It was recognized by all partners that the financial cover would be invested by the Water and Agriculture authorities. During 48 years (1960-2010) 112.2 millions of SG (averaged 2.3/y) were planted in Lake Kinneret, of which about 30 million weighted 2–5 g each and the rest 5–10g each. The fingerlings weight feeding elevation was followed by survival improvement and harvest contribution. Due to stock cease of OA in the late 1990's its landing became negligible.

Numerical and Biomass fish stock (KLL-LKDB and Fishery Department 1970–2013)

The determination of fish stock in Lake Kinneret can be done through two methods: landings analysis and Acoustic survey. Analysis of landings includes only commercial species, and acoustic survey requires precise calibration values for the conversion of recorded body size targets to fish biomass (weight). None of these requirements was fully implemented and therefore, the data presented here represent approximations. The data shown here resulted from multiannual routinely collected or sporadically monitored acoustic surveys. Stock estimation [1,2,9,13-15] was calculated on the basis of landings analysis where fish stock was approximated as (Min.-Max.): Bleak - 3000-6000 tons; Tilapias – 140 – 800 tons; Mugilids – 300 – 1000 tons. Later on Gophen (1986 in collaboration with T. Lindem (Oslo,Norway) carried out the first Acoustic survey in Lake Kinneret accompanied by fish sampling and the data evaluation resulted in the followings: <10 cm TL-1547 tons; 10-20 cm TL - 4173 tons and >20 cm TL - 441 tons: total stock biomass - 6161 tons. Walline et al. (1990) used eco-physiological equations and harvest data which resulted in total fish biomass in Lake Kinneret as 5429 tons. A monthly routine Acoustic survey in Lake Kinneret was carried out during 1987-2016 [32]. Results are reported as total (total of 4 size classes) fish number in the lake and varied (Min.-Max.) between 40-800 millions.

Fishery

Fishery in Lake Kinneret is as old as human being living in the vicinity. There are documented evidences which confirm human fishing in Lake Kinneret throughout a long history from the earliest migration of Homo Erectus out of Africa (1.5×10^6 years BP) throughout the Stone - age, Bronze and Iron Ages and during the periods of Helenic, Roman, Byzantine, Islamic, Middle Ages, Crusaders, Mamluk, as well as during the Ottoman Era, British Mandate Period and the era of Israel Independent State. Reasonable quantitative and qualitative data of fishery is available only since the British Mandate Period (1935/6 – 1947) and significant information is available since early 1950`s. Until the late 1990's the major fishing harvest was due to Bleak: 800-1200 tons/year. The commercial value of Bleak was highly correlated with the industrial development of preserved products. On the other hand, it was found that the bleak population might produce an intensive top-down predation pressure on zooplankton biomass [2,16,24,14,6,11]. Other species also prey on zooplankton but to a lesser extent [25,26]. Consequently, fishing pressure decline on Bleaks enhanced their population size and intensified predation pressure on herbivore zooplankton [2]. Grazing decline of zooplankton on Nano-phytoplankton might deteriorate water quality. That was the reason for subsidized Bleak fishery during 1994-2002). The Bleak population declined but unfortunately Nano-phytoplankton was enhanced as a result of nutrient enrichment: the enhancement of Phosphorus fluxes into the lake was caused by dust deposition and inappropriate agricultural development in the drainage basin. From the early 2000's the Bleak fishery is not subsidized anymore and market demands are neglected' and therefore, its fishery declined, resulting in the enhancement of the zooplanktivore fish population. External Phosphorus supply from the catchment was not reduced, dust deposition continued and herbivore zooplankton biomass intensified, creating optimal trait for algal growth.

Sarotherodon galilaeus (SG) Fishery

SG is the most valuable fish among harvested native species in the lake. The annual harvest is a dependent of implementation of fishery legislation (net mesh-size), stocking policy, Cormorants predation pressure [21,29], natural cycles of population size, and the impact of disease (Blindness Virus) [4]. The 11-year cycles of population size were documented [15]. Nevertheless, the amplitude of the fluctuation is varied. No direct impact of natural conditions was pointed out. The Cormorant predation is a new factor introduced into the Kinneret ecosystem caused by the inland migratory bird distribution policy implemented by Nature Protection Authorities. A predation of 200-300 tons of sub-commercial size tilapias was approximated [4]. Considering the growth potential of preyed Tilapias to a plate size, the income damage to fishers was evaluated as 2-3 X10^6 USD: 5000 Cormorants, 500g prey per day, majority of Tilapias prey during 100 days. The long-term period of SG fishery (1959-2016) indicated four terms: 1959-1970, 1970-1990, 1990-2010, and 2011-2016. The annual average for the entire period landings was 308 tons of SG per year. An exceptional lowest annual harvests of SG were recorded during 2007-2008 (<10 tons annually). A suggestion was considered to implement a total fishing ban in Lake Kinneret during 3 years due to possible over-fishing. Contrary opinions based on an indication of the low harvest which excluded overfishing successfully convinced fishery managers to reject a fishing ban. It was evidently justified when SG landings came to their normal level 4 years later.

Oreochromis aureus (OA) Fishery

The stocking of Lake Kinneret with OA in the late 1950's resulted in an increase of its harvests until the mid-1980's and a significant decline afterwards. In the mid-2000's its landing became negligible as a result of introduction ceasing in the late 1980's. The fishery case of OA is therefore a good exemplification of the relationship between introduction and harvest. Nevertheless, the OA case also exemplifies the unwanted consequence of the aggressive capabilities of the residual population to control spawning grounds which might be suitable also to the native SG and other native species [27,28].

The similarity of annual fluctuations between Bleaks and OA are shown in figures 2 and 3. Nevertheless, the potential reasons for the landing decline since the early 1980's are the result of different reasons: fishery decline of Bleaks was due to market difficulties which cause reduced fishing effort, and the elimination of OA stocking was the reason for its landings decline.

A long-term (1959-2016) changes of the fishery management (annual landings) of the native and introduced species are presented in Figures 1,2,3,4. It is prominently confirmed that there was a general decline of harvests and probably fishing efforts started early - mid-1980's affected by both stocking reduction and probably reduced fishing effort whilst native specimen as Barbels (Figure 1) by only fishing pressure facilitating.

The Impact of Fishery Management on Water Quality

Energy flow through the food web compartment in Lake Kinneret presented two different periods. Until the mid-1990's the ecosystem was defined as Phosphorus-limited and later on an alteration to Nitrogen limitation occurred followed by the decline of *Peridinium* [7]. The major impact on that change was due to the reduction of Nitrogen supply from the catchment. Due to the high pH and high content of carbonates in Lake Kinneret, the external Phosphorus inputs from the drainage basin are abruptly sedimented as un-dissolved complexes of P-carbonates. Prior to the nutritional change, the sources of bio-available P were mostly dust deposition and *Peridinium*-mediated bottom sediments P transported by dormant stages of *Peridinium* cysts [2]. Nevertheless, *Peridinium* demands for nitrogen were insufficient after the mid-1990's. The decline of *Peridinium* also reduced P supply from the sediments but other external sources such as dust deposition partly replaced algal demands. Finally, Nano-phytoplankton (especially Cyanobacteria) dominance replaced *Peridinium* [7] and the grazing of those phytoplankters is therefore critical for water quality protection. But, zooplankton comprised major food component for Bleaks and others. Presently also SG slightly shifted its diet towards zooplankton. Consequently, competition between Bleaks and SG is presently predicted and the design of fishery management is therefore required for tackling a dilemma: SG is highly wanted whilst Bleaks un-wanted fishery targets and zooplankton predation should be better channeled to SG. The improvement of the lake management is therefore a combined mission of external P input reduction together with enhanced Bleak fishery. Predicted results of such a management policy are both water quality improvement as well as SG growth and followed harvest enhancement. Additional contribution to water quality improvement beside enhanced N supply and reduced P input is proposed and intensification of Cyanobacteria utilization, by the most appropriate fish for that "mission" is SC.

The Role of Silver Carp and Mugil in the Kinneret Ecosystem

Silver Carp

The stocking of Silver Carp in Lake Kinneret started in 1959. The rationale of stocking was several beneficial advantages to the Kinneret management are attributed to this fish [5]: The fish cannot reproduce in Lake Kinneret; contribution to water quality improvement by the removal of organics through consumption of detritus, preferential selectivity of large size algae (*Peridinium* and/or *Microcystis*), efficient utilization of the harmful Cyanobacteria, *Microcystis*; significant merit to the fishers income; efficient fingerlings production in hatcheries, reasonable survivorship in the lake and high growth rate. Until recent years the stocked species was pure *Hypophthalmichthys molitrix*. Recently fishers indicated a change of this fish's feeding habits by enhancement of zooplankton predation. Recent indications of its food content confirmed partial preference of zooplankton component which was not the case earlier. The potential change of the genetic purity of the stocked brood pointed towards a negative impact on water quality. This issue is presently under investigation. Microcystis can be effectively removed by SC. Thorough studies [33] about the impact of SC on phytoplankton composition documented that algal cells smaller than 5 microns (*Chlamydomonas* spp. *Platymonas* spp) were not sieved by SC, phytoplankters with the size between 5 and 20μ were partly filtered, and large size phytoplankton, mainly colonial *Microcystis*, were entirely collected [32]. SC induced the phytoplankton size distribution to be shifted towards minimizing particle size. Conclusively, SC is a treatment recommendation for *Microcystis*-dominated waters [31,33].

Mugil

Mugilids in Lake Kinneret utilize a wide spectrum of food items: free-swimming planktonic organisms, detritus, benthic tiny animals, and others. It was found that Mugilids are not dwellers and, therefore, nutrient re-suspension cannot be attributed to their food search trait. Mugilids were indicated as omnivore [19] fishes which collect their food mostly in the shallow part of the lake and partly in the Pelagial. Migilids are equipped with thick-wide lips oriented forward which is typical to planktivorous fishes. The morphological features of Mugilids are typical to planktivores but not to bottom dwellers. Common organisms living within the bottom sediments of Lake Kinneret (Harpacticoids, Ostracods, Oligochaetes, Nematodes and/or Chironomid Larvae) are not utilized by Mugil in Lake Kinneret. Nevertheless, sand grains, Foraminifera, and Spongillid (Porifera) Spicules were found in the Mugilid guts. It is suggested that those benthic items were ingested by Mugilids as a result of being re-suspended by wave action in the shallows and were ingested. The majority (98%) of the Mugilid food is due to detritial sources and only 8% were defined as organisms [19]. The Mugilids introduction into Lake Kinneret is a prominent success component in the fishery management of Lake Kinneret. The majority (87%) of stocked Mugilid fingerlings are *Liza ramada* (LR) and *Mugil cephalus* (MC) comprising 35% of the landings biomass. Mugilids' introduction into Lake Kinneret profited Water quality improvement and compensated proceeds to fisher income.

The Trophic Status of Kinneret Fishes

An attempt at the trophic status definition of the Kinneret fishes within the Kinneret ecosystem as related to their role in the Carbon flow patterns. The input sources of Carbon in the Kinneret ecosystem are mostly (>90%) internal as algal and bacterial Photosynthetic and Chemostatic activity (Primary Production). External sources from the catchment and Atmospheric CO_2 comprised <10% of the total. Removal of Carbon through respiration processes are 30%, and 30% as due respectively to Phytoplankton and aquatic animals (Fishes, Zooplankton and other large body invertebrates) whilst 40% respired by Bacteria and Protists (mainly Protozoa). Nevertheless, the majority of system carbon removal is flow through sedimentation (>85%). Prior to the present water balance management when 35-45% of the total budget was pumped, about 15% of Carbon removal was due to pumping.

Under the present pumping regime, this Carbon flow channel is negligible. Carbon stock capacities (%) within the Kinneret ecosystem living compartments are [34]:

Phytoplankton and Phytobenthic----69%

Fish ($100X10^6$ by number or

5000t as wet biomass) --------------------22%

Zooplankton----------------------------------5%

Bacteria and Protists-----------------------4%

These Stock Biomass values are insufficient for the dynamic evaluation of Carbon flow where generation time and rate of activities (doubling time) of the components are highly different [2]:

Bacteria and Protists-----------------------Hours

Phytoplankton and Phytobenthos---------Days

Zooplankton--------------------------------Weeks

Fishes---------------------------------------Years

Comparative daily P/B dimensionless values (Production/Biomass) are better for the evaluation of the Carbon transfer between the ecosystem compartments [34]:

Bacteria and Protists------0.581-0.822

Phytoplankton-------------0.274

Zooplankton---------------0.134

Benthos--------------------0.014

Fish------------------------0.002

The total Carbon load in the Kinneret ecosystem include also about 100t of particulate and dissolved organic Carbon. The daily consumption of zooplankton by a stock of 3000t of bleaks is calculated as follows:

Lake Stocks:

Bleak (3000t/lake) ---4.4 (gC/m^2);

Zooplankton ----1.8 (gC/m^2)

Daily Production calculated from the P/B values:

Bleak: 4.4X0.002= 0.009 (gC/m^2/day);

Zooplankton: 1.8X0.134= 0.241(gC/m^2/day)

Bleaks Food Consumption (daily 5% of biomass): 4.4/100X5=0.220 (gC/m^2/day).

The significance of those calculations is:

Zooplankton production is close to zooplankton consumption by Bleaks.

Several supplemental informative inferences should be considered:

1) The monthly P/B ratios of Zooplankton fluctuates seasonally between 1.8 and 6.3;

2) Bleaks also partly utilize other food sources;

3) The feeding rate of bleaks probably fluctuates in relation to seasonal changes of temperature and reproduction activity.

4) The existence of zooplankton consumption by other fish species or other invertebrates.

5) Finally, the zooplankton food resources might be defined as a limiting factor and therefore significantly affected by fish behavior.

Invertebrate predation of Zooplankton (Figures 5, 6, 7, 8, 9)

Earlier studies documented that not only fishes but also zooplankton predation occurs by adult predator cyclopoids. Therefore, estimation of potential lake carrying capacity of zooplanktivorous fishes in relation to food resource availability requires a study of the herbivore/predator zooplankton interrelationships. Kinneret Cyclopoid development, like other freshwater copepods, go through 10 lifecycle stages of nauplii, copepodites and adults. Previous studies documented predation of *Ceriodaphnia* spp., and partly *Diaphanosoma* sp. as well as the cannibalistic behavior of adult cyclopoids towards those of younger stages. Nevertheless, no confirmation was documented of predation of *Bosmina* spp. by predator cyclopoids. Those findings justified investigation of related stock dynamics of herbivore (all cladocerans) and predator (adult cyclopoids and copepodite stages 4-5) zooplankter (Figures 5-9). The evaluated data include annual means of zooplankton numerical densities (No./L). The temporal fluctuations presented as annual means (Figure 5) indicates a general decline of Copepoda and Rotifera during 1970-the mid-1990's and increased later, but with low-range fluctuations of cladoceran concentrations and highest densities of Copepoda (all life cycle stages). Figure 6 (higher left and lower panels) indicates a linear positive relationship between Cladocerana and Rotifers with predator copepods. It is an indirect confirmation that the numerical densities of all three zooplankton groups are affected by mutual and probably similar factors and, at least, one of them is fish predation. No preferential predation was confirmed specifically on each of the taxonomic components. Cladoceran taxa included *Ceriodaphnia* spp. and Rotifera with about 15 species. Nevertheless, the right top panel (Figure 6) indicates preferential predation pressure on large body Cladocerans (3 genera) as shown by a temporal increase of the Small/Large organism density ratios, which imply heavier fish predation selecting large organisms (neonate 3-5 stages) in comparison with younger (1-3 neonate stages). Figures 7, 8, and 9, prominently indicates linear regression of simultaneous decline of predator (Cyclopoids) and herbivore (Cladocera and rotifer) zooplankters. The proof of mutual conditions effect and insignificant intra-species competition or predation.

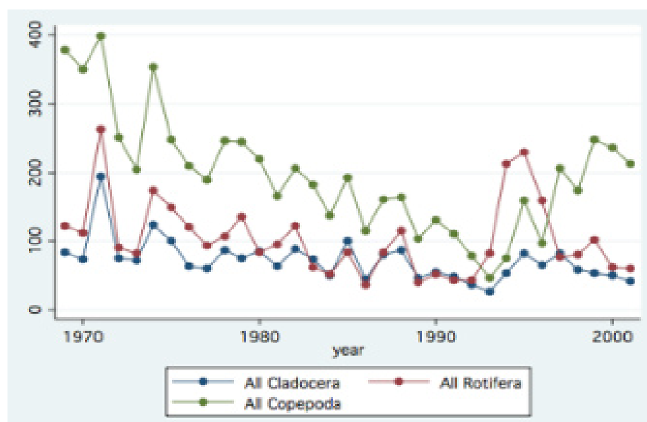

Figure 5: Line Scatter of Zooplankton Densities (No/L) in Lake Kinneret during 1970-2010: Cladocera, Copepoda, Rotifera, Annual Means.

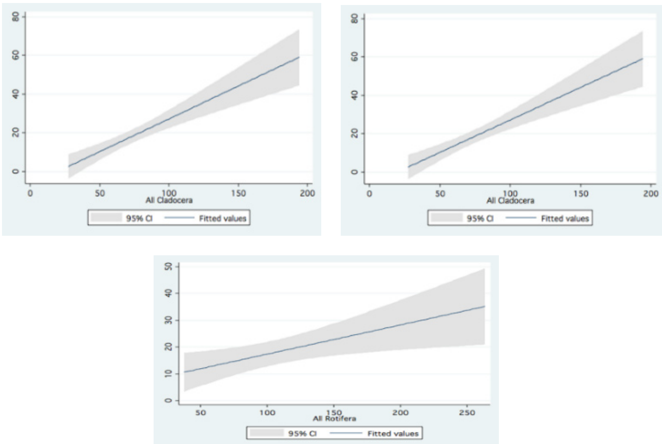

Figure 6: Linear Regressions with 95% CI between Predator Copepods and Cladocera (Upper left) and Rotifera (Lower); Upper Right: Small /Large Cladocerans Vs. Predator Cyclopoids; Annual Means Densities (No/L).

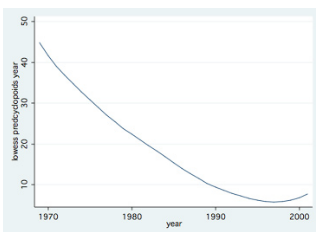

Figure 7: Predator Cyclopoids densities. (No./L) Vs. Year (69-01); (LOWESS; 0.8); Annual Means.

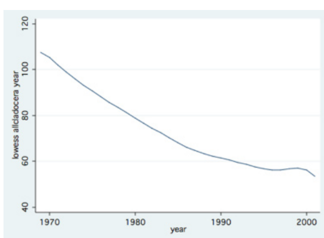

Figure 8: Cladocerans densities. (No./L) Vs. Year (69-01); (LOWESS; 0.8); Annual Means.

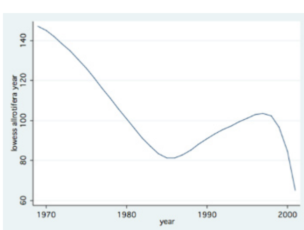

Figure 9: Rotifer densities. (No./L) Vs. Year (69-01); (LOWESS; 0.8); Annual Mean.

Conclusive Summary

1) Lake Kinneret ecosystem has undergone structure modifications: Shift from Phosphorus to Nitrogen limitation; Phytoplankton community structure was therefore altered from *Peridinium* to nano-Phyto planktonic genera of Chlorophytes, Diatoms and mostly Cyanobacteria with the majority of large size colonial *Microcystis*.

2) As a result of the *Peridinium* natural elimination, Zooplankton became a supplemental food component for Tilapias in addition to a major source for Bleaks.

3) Zooplankton became preferential food source for Kinneret Fishes.

4) Intra-relative impacts of predator zooplankton organisms indicate the absence of significant pressure of carnivore Cyclopoids on herbivore Zooplankters.

5) Landing decline of all commercial fish species since the mid-1980's caused mostly by stocking reduction, natural cycling of ups and downs, and lower fishing pressure.

6) Mugilids and Silver Carp introduction were found to benefit water quality and result in significant income merit, and S. galilaeus stocking requires enhancement by number and body weight.

7) Birds (Cormorants) predation damage Tilapia fishery and partly contribute to eliminate Bleaks.

8) The renewal of Bleak fishing is critical for optimal fishery management.

Future Recommendations

1) Reduce zooplankton suppression by renewal of Bleak fishery.

2) Enhance Stocking of Silver Carp to improve *Microcystis* consumption.

3) Enhance stocking of Sarotherodon galilaeus and protect its spawning grounds for the benefit of fisher income and water quality improvement by grazing of *Peridinium* in case it will reappear.

4) Enhance the Introduction of Mugilids to intensify consumption of suspended particulate organic matter and for the benefit of fisher income.

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