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Mugilids (*Mugil cepalus*, Linnaeus, 1758; *Liza ramada*, Risso, 1810) Stocking in Lake Kinneret (Israel)

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Abstract

Stocking of Lake Kinneret by exotic fish species (Mugilids: *Mugil cephalus* and *Liza ramada*) started in 1958. The rational stocking of Lake Kinneret with Mugilids was double functioned: To improve fishermen income and the water quality in the lake. Mugilids are chosen as introduction target because their market value is high, the fish cannot reproduce in the lake and fingerlings are low cost available. During 1960-2015, 56.2 million fingerlings were introduced into the lake approximately averaged one million per year of *M. cephalus* (MC) and *L. ramada* (LR). The study of the Mugilids food composition has indicated consumption of suspensoids, mostly detritial organic particles. Therefore no damage to water quality is suggested. The best fitness between recruitment to Dock on Side landings and stocking capacity was evaluated at 3 years interval. Differences were found between recruitments of MC and LR to commercial catches by individual averaged age and weight. The long term success of Mugilid introduction to Lake Kinneret is confirmed.

Keywords

Mugilids, Kinneret, Stocking, Growth, Feeding, Fisheries

1. Introduction

1.1. General

Most of the mugilids (Family: Mugilidae; Grey Mullets) are naturally living in the ocean shallows (0 - 10 m depth) in the Tropical, Sub-Tropical and Temperate regions and also in Fresh and Brackish waters [1]-[3]. The

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family Mugilidae includes about 17 genera and 80 species. More than 50% of these species belongs to Mugil and Liza genera. Most of other genera include only 1 or 2 species. The prominent external feature for taxonomical identification is the absence of the Lateral Line Organ and the two parts split of the dorsal fin. Their body shape is elongated-cylindrical-hydrodynamic shape with tri-angled external shape of the mouth. The body color is silver with black dorsal back. In nature, the fishes are schooled and stay mostly close to the bottom of the ocean shallows. According to international literature, the food of adults comprised of detritus, nano-phytoplankton and benthic small organisms whilst fingerlings, (<3 cm TL) feed on free swimming zooplankters. The fish reach sexual maturity at 3 - 4 years old. The reproduction season is fall-early winter and each female lay 1 - 3 million eggs. The fish is highly marketed demands and the commercial sources are fisheries and aquaculture. In recent years artificial induced reproduction is commonly used in aquaculture productions. The Mugilids are widely known for their high commercial value and therefore income signficance.

1.2. Mugilids in Lake Kinneret

Introduction of native fish species (mostly *Sarotherodon galilaeus*) has a long term history in Lake Kinneret [4]. Nevertheless only three exotic species, Silver Carp and 2 species of Mugilidae were successfully implemented. As obviously required, the introduction of Silver Carp was followed by studies of its feeding habits [5]-[7]. Partial studies on the impact of Mugilids on the Kinneret water quality and commercial fishery were done previously [8] [9]. The start of the long term history of Mugilids stocking in Lake Kinneret was in 1958 [10] and presently continue [8] [11] [12]. None of these studies represented a comprehensive evaluation of the beneficial efficiencies and the ecological trait of this exotic fish on the Kinneret ecosystem combined with marketed fishery outcome. In this paper we try to close several gaps of knowledge within respectful evaluation.

During 1960-2015, 56.2 million fingerlings were introduced into Lake Kinneret, averaged approximately one million per year of *M. cephalus* (MC) and *L. ramada* (LR). The rational of planting oceanic fish in freshwater habitat (Lake Kinneret) was aimed at both improvement of fishermen income and lake water quality [4] [8] [10] by a native salt water organism which could grow but be unable to reproduce in freshwater condition [2]-[4] [10]. Several studies documented the ability of Mugilids to live in a wide range of water salinities [1] [13] including those exist in Lake Kinneret. MC and LR both are living and reproduce in the Mediterranean shallows. It was found that MC and LR survive and efficiently grow in Lake Kinneret by utilization of native food resources, but never reproduce there [3] [13] [14]. Moreover, the commercial value of MC and LR is the top or second highest value in the local market. During 51 years (1963-2013) the averaged (SD) of total fishery catch was 1540 (S.D. 505) ton and the Mugilids landing (1964-2014)—163 (S.D. 71) ton. Consequently, the Mugilids percentage of total catch was 12% (SD 6.6%) by weight but economical value (market price) >26%. The total number of introduced Mugilid fingerlings into Lake Kinneret in millions per period was as follows: 1962-1983—27; 1984-1995—10.4; 1996-2015—17.6; Total—56.2 (**Figures 1-3**). We suggests that the exotic Mugilid fishes in Lake Kinneret prominently contribute to the fishermen income without causing damage to water quality and do not reproduce in the lake. As a result of ecological changes in the Kinneret ecosystem and the increase of demands for the lake Kinneret water supply for domestic and agricultural usage, the issue of Mugilids introduction is recently debated. The objective of this paper is to evaluate the stocking success by analysis of the Mugilids growth increment and the balance between economical benefit and water quality protection.

2. Material and Methods

The information about feeding habits of Mugilids in nature and in Lake Kinneret was taken from [11] [15] [16]. The data on Mugilids fishery (landings and introduction) is given in the Lake Kinneret Fishery Statistics, annual (1960-2015) reports submitted by the Israeli Ministry of Agriculture and Agricultural Settlements Development, Fishery Department, (AMFD, 1960-2015). For the Statistical evaluations of relationship analysis between dependent variables like catchments or % of landings and independent variables (time, years) was done by usage of two statistical procedures: 1) Simple Linear Regression—relationship modeling between one independent and one dependent variables; and 2) Polynomial regression—fits a non-linear model to data which is a multiple linear regression. For the individual growth increment of Mugilids we used the following fishery record: Introduction—1995-2010; Dock on Side Landing—1997-2011. For the computation of the relation between introduction and landing we implemented intervals of 1, 2, and 3 years between stocking and later catches. We indicated two years as the appropriate time needed for 3 - 4 g introduced fingerling to be incremented (grown) to a

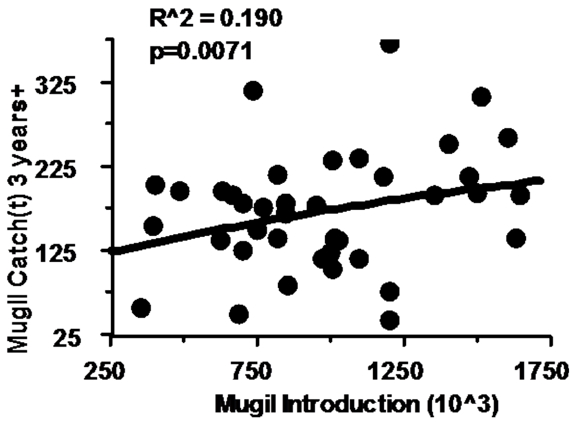


Figure 1. Polynomial regression (r^2 and p values are given) between introduced 10^3 fingerlings and annual catches of Mugilids 3 years later (1958-2014).

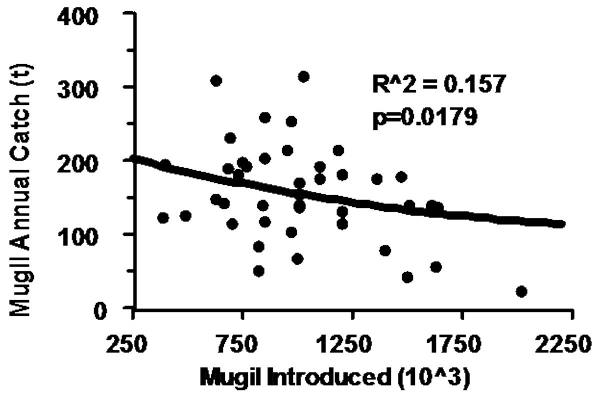


Figure 2. Polynomial regression (r^2 and p values are given) between introduced 10^3 fingerlings and annual catches of Mugilids next year (1958-2014).

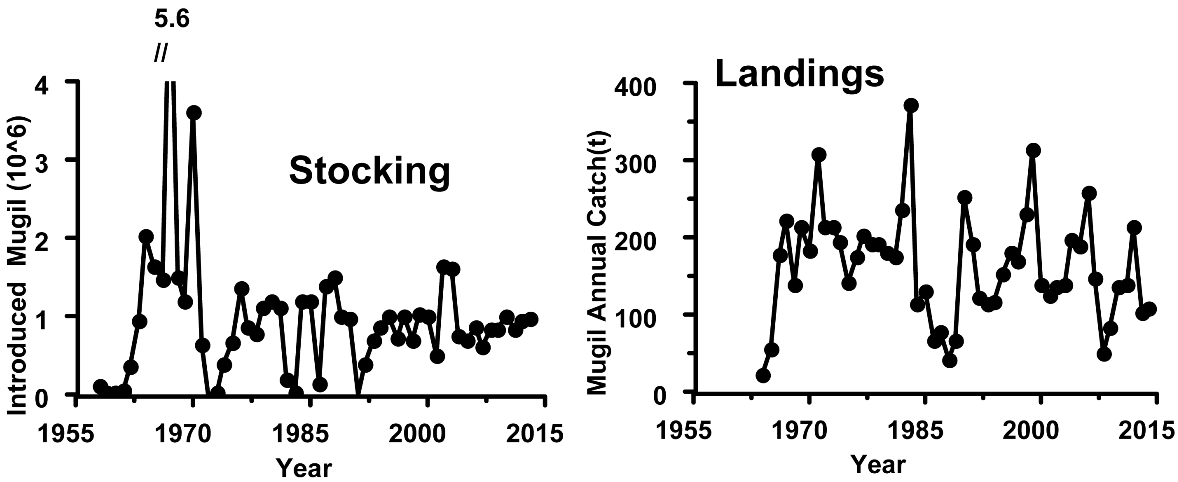


Figure 3. Mugilids annual fishery: introduction (left panel), 10^6 fingerlings and catch (t) (right panel) during 1958-2013.

commercial size. In our model of increment we used parameters of Total Length (TL) and weight (W). The total number of measured individuals was 58,000:48,000 lengths and 890 weight of LR and 9900 lengths and 230 weight of MC. The fishes were taken arbitrary on dock from fishermen catches and from commercial fish dealers. The individual ratio between Total Length and Weight of sampled fish was calculated aimed at the definition of their total weight in the commercial landings. The ratio between TL and W was found to be for MC and LR as follows:

For MC: $W = 0.088*L^{3.045}$;

For LR: $W = 0.0788*L^{3.03}$;

where W = Fish Weight (g); L = Fish TL (cm).

Growth increment was computed by using Equation No.1 [17]:

$$L_t = L_{\max}\left(1-e^{-k*(t-t_0)}\right) \quad (1)$$

where:

L_t = Predicted TL (cm) at the age of t;

L_{max} = Maximal Length (cm) of species;

k = Growth Factor ($year^{-1}$);

t = Age of individual fish (year);

t_0 = Theoretical age (year) when initial TL is zero.

For each Mugil species (MC, LR) we used the following equations presented in [9]:

LR: $L_t = 52*\left(1-e^{-0.53*(t-0.25)}\right)$;

MC: $L_t = 80*\left(1-e^{-0.32*(t-0.46)}\right)$;

Mugilids do not reproduce in freshwaters [14] and the only source for new generations is controlled (counted) stocking deliveries. Consequently the calculation of stocking contribution to landing (stocking Vs landing ratio) is logically acceptable as well as the identification of rate of mortality. Rate of mortality was calculated by using Equation No. 2 [18]:

$$M_{\text{avg}} = \frac{\ln\left(N_{\text{catch}}\right)-\ln\left(N_{\text{stock}}\right)}{\Delta T_{\text{avg}}} \quad (2)$$

where:

M_{avg} = Factor of natural mortality ($year^{-1}$);

N_{stock} = Number of docked fishes;

N_{stock} = Number of stocked fingerlings;

ΔT_{avg} = The Mean age of dock on side fishes ($year^{-1}$).

Commercial Values

Three years of local market survey was carried out for the indications of the commercial costs of Mugilids: MC—5 US$ per Kg, and LR—3 US$ per Kg [9].

3. Results

Polynomial Regression ($r^2 = 0.190$; $p = 0.0071$) (**Figure 1**) between Mugilids introduction and Catches indicated increase of landings 3 years later (**Figure 1**). On the other hand when evaluation was done by 1 year interval between stocking and catches (next year) the trend was negative (**Figure 2**): increase of stocking and decline of catches. The annual (1958-2015) fluctuations of stocking and landing are presented in **Figure 3** where multiannual fluctuations are shown. Nevertheless, with regard to the individual fish weight and age, in landed catches of both species, LR and MC multiannual changes are similar: decline during 1995-2004 and increase between 2005 and 2011. The fishery dynamics of the stocked Mugilids (MC, LR) in Lake Kinneret was evaluated for the period of 1995-2009. Missing values are due to technical difficulties. Nevertheless, partial presentation accompanied by discussion for earlier and later periods will be given. During 1997-2011 about 14 million fingerlings (annual mean 0.93×10^6) of mugilids (12.2×10^6 LR; 1.8×10^6 MC) were planted in Lake Kinneret and the total landings were 2456 ton: 1596 t (65%) LR and 860 t (35%) of MC. Annual averages of landings, stocking, individual fish weight (g), individual fish age in landings, and total number of fishes in landings are given in **Table 1**.

Results given in **Table 1** indicate significant difference between averages of individual fish in the Dock on side catches. The individual averaged age of landed fishes was also different between the two species.

Table 1. Annual averages of stocking, landings, fish weight, age and number in catches of *Liza ramada* (LR) and *Mugil cephalus* (MC) during 1997-2011 in Lake Kinneret.

Parameter	LR	MC	Total
Stocking (10^6)	0.8 (85%)	0.13 (15%)	0.93
Mean weight of individual fish in landings (g)	467	1827	
Age of individual fish in landings (year)	3.3	4.2	
Landings (ton)	107 (65%)	57 (35%)	164
Number of individual fishes in landings (10^6)	229 (87%)	34 (13%)	263

3.1. Recruitment of LR and MC to the Catches

Our size/age analysis of individual specimen in the commercial landings of the two species, LR and MC indicated different incremented ages: LR at the mean age of 3.3 years whilst MC at 4.2 years, *i.e*. longer growth period of MC. Moreover, fishermen reported that LR are naturally schooled and therefore more efficiently fished at a younger age. On the other hand MC are usually solitary and flocked during short winter period which is the time they form a reproductive shoals in nature. The evaluated significant correlation between individual fish weight and age (**Table 1**) confirm the existent of optimal growth conditions available for LR and MC in Lake Kinneret. ANOVA Test ($p < 0.05$) for the period of 1997-2011 has indicated that during 1997-2000 individual fish age and weight of MC were significantly (Weight and age, $p < 0.0001$) higher than later (2001-2011). LR represented similar trend but statistically not significant ($p = 0.105$). Moreover, averages of landed Individual fish weight and age of MC and LR significantly decreased during 1997-2000 and increase afterwards (**Figure 3** and **Figure 4**). Unpredicted decline of total fishery docked during 1997-2011 (**Figure 5** lower panel) accompanied by stable catches of Mugilids resulted an elevation of their % in the total catches during the same period (**Figure 5**, Upper panel).

3.2. Relation between Landings and Stocking

The ratios between total number of landed fishes and total number of stocked fingerlings for the period of 1997-2011 for LR and MC are given in **Table 2**:

3.3. Survival and Long Term Increment Success of the Mugilids

Although growth rate, ecological behavior of the two Mugilid species (LR, MC) is different, we find very close values of survival. The calculated Factor of natural mortality [18] with respect to growth rate [17] and landing statistics resulted similar survival for both species: 27% and 28% of stocked fingerlings recruited into the "catchments categories" for LR and MC respectively. Moreover, data presented in **Table 3** indicates high similarity (strengthening reliability) of the Factors of Natural Mortalities (M_{avg}) with respect to Time Interval (years) of 1, 2, and 3 years between stocking and fishing (landings).

Data in **Table 3** indicates that if interval of one year is considered LR represent 5.2% higher contribution of stocking to landing and 2 years interval is accounted for higher contribution of MC by 4.8% and the two factors of mortality by interval of 3 years and the difference between LR and MC is negligible.

3.4. Economical Evaluation

Several financial parameters related to the economical aspects of Mugilids planting in Lake Kinneret were calculated and presented in **Table 4**.

Results in **Table 4** define that stocking cost was 1.3% and 4.0% of their catchment value for MC and LR respectively, *i.e*. LR is 3 times costly than that of MC.

3.5. Feeding Habits

Mugilids in general, and particularly in Lake Kinneret, utilize a wide spectrum of food items [11] [15] [16]: free swimming planktonic organisms, detritus, benthic tiny animals, and others. In Lake Kinneret it was found that

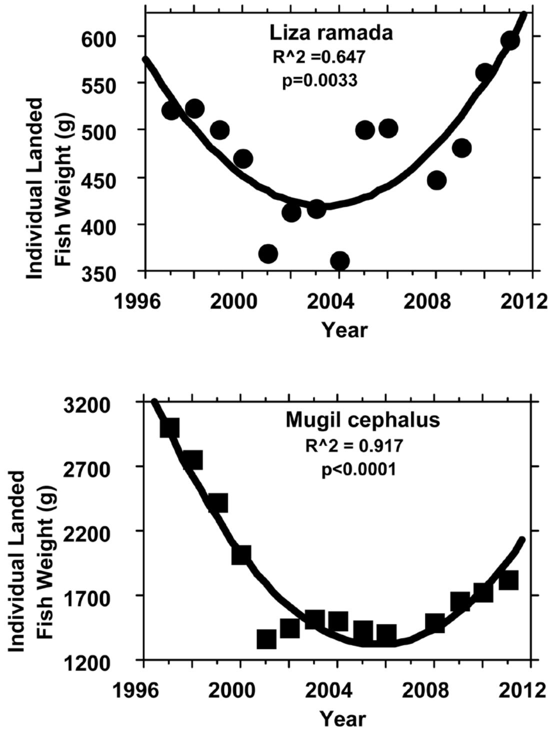


Figure 4. Polynomial regressions (r^2 & p values are given) between averaged (1997-2011) individual Fish weight (g) and years: Upper: *Liza ramada*; Lower: *Mugil cephalus*.

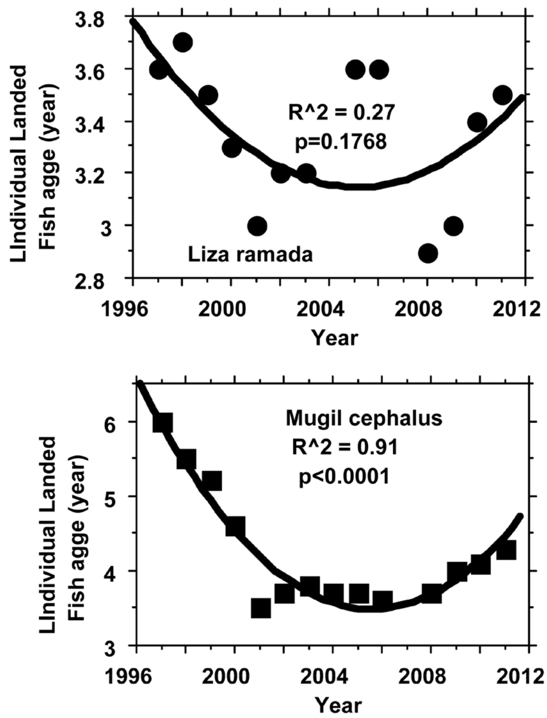


Figure 5. Polynomial regressions (r^2 & p values are given) between averaged (1997-2011) individual Fish age (year) and years: Upper: *Liza ramada*; Lower: *Mugil cephalus*.

Table 2. Number of fishes in landing (10^6) (1997-2011) and stocking (10^6) (1995-2009) and the ratio (%) of landing/stocking of LR and MC.

Species	%	Stocked (10^6)	Landings (10^6)
LR	27	12.2	3.3
MC	28	1.8	0.5
Total	27	14.0	3.8

Table 3. Factors of Natural Mortality (NM: M_{avg} ($year^{-1}$) and % of landing from stocked individuals (%SL) of LR and MC during 1997-2011, with 1, 2, and 3 years interval between stocking and fishing.

Time Interval (years)	% SL:LR	% SL:MC	NM M_{avg} ($year^{-1}$) LR	NM M_{avg} ($year^{-1}$) MC
1	28.5	27.1	0.38	0.31
2	27.2	28.5	0.39	0.30
3	27.3	27.5	0.39	0.31

Table 4. Economical evaluation (based on 2010 local cost accounting in US$) for *Mugil cephalus* (MC) and *Liza ramada* (LR).

Parameter	MC	LR
Stocked fingerling price (US$)	0.04	0.02
Stocked fingerling in catchment price (US$)	15	5.5
Market fish price (US$ per Kg)	6.25	3.0
Average weight of individual landed fish (Kg)	1.83	0.47
Landed fish price (US$ per Dock on side Fish)	11.43	1.4
Return per dock on side Fish (US$)	11.28	1.35
Landed stocked fish cost in % from total return (%)	1.3	4.0
Price ratio of catchment/stocking.	76	25

Mugilids are not dwellers and therefore re-suspension process cannot be attributed to their food search trait. The study presented by [11] indicates Mugilids as omnivores fishes which collect their food mostly in the shallow part of the lake and partly from the water column of the Pelagial. Migilids are equipped with thick-wide lips oriented forward (not downward) which is typical to planktivorous fishes. The morphological features of Mugilids are commonly belonging to planktivores and not to bottom dwellers. Previously documented and published studies confirmed that common organisms in the bottom sediments of Lake Kinneret include Harpacticoid and Ostracode crustaceans, Oligochaets, Nematodes and Chironomid Larvae [18]. In his study [11], Shapiro did not recorded none of them within the Mugilid food composition. Nevertheless this study [11] clearly indicated that sand grains, foraminifers, Spiculae of spongilids (*Porifera*). We suggested that those benthic items were ingested by Mugilids as a result of being re-suspended by wave action in the shallows and the planktivore Mugilids ingested them as part of their planktivory habits. The majority (98%) of the Mugilids food is due to detritial sources and only 8% are organisms.

4. Discussion

The fish population in lakes is an important component of the ecosystem and might be beneficial through two major channels: 1) Their direct or indirect impact on water quality; and 2) fishery income. Therefore among all components of the ecosystem structure fishery management is probably the most efficient in control design. The fishery management is implemented through several kinds of operations: introduction of native and exotic species, fishery regulation directed by legislations of number of boats, total catch permitted, net mesh size to regulate marketed fish size, seasonal and site regulations, etc. Priorities of Lake Kinneret ecosystem services were formulated in early 1950's when national decision was done to supply more than 50% of the national drinking water demands from Lake Kinneret through the National Water Carrier (operated-10.6.1964). Then, water quality became a national concern and was fixed as top priority of lake usage and management while the other utilizations were fixed at lower level. Fishery, tourism, recreation, nature conservation were fixed on the scale below quality of drinking water for domestic supply. Therefore the impact of fishery management was a priori viewed how it was affecting water quality and secondly as supplemental fishery income [4]. None of those factor were individually isolated but had been mixed all as mutual constrains into one conceptual management background for discussion and conclusion. Consequently we evaluate the impact of Mugilids on water quality. The results presented here indicate that the Mugilids are not dwellers and therefore they do not enhance re-suspension of nutrients from the bottom. If the factor of natural mortality is 0.35% and 28% of stocked fingerlings (1 million per year) are removed as commercial landing (**Table 3**) the population size of remaining Mugilids per year is 0.3 - 0.4 million individuals. Considering Lake Kinneret entire bottom surface area available for fish food searching during turnover winter period as 170 Km^2 the average density is 20 fish per ha (10^4 m^2) which is negligible. During summer time when the lake is stratified and the available bottom surface for food search is restricted to only about 50 Km^2 the averaged fish density is app. 70 per ha which is also negligible from the view point of fish dwelling pollution. It is likely that Mugilids consume suspended organic matters that are ingested as a result of planktivorous habit intake. The utilization of surplus organic matter might be a positive contribution to water quality improvement. The data documented by [11] confirm consumption of suspended particles and benthonic organisms are absent excluding those which were re-suspended by wave action in the shallows and ingested by the fish. Not like other littoral fishes which actively collect small organisms from underneath stones (Harpacticods, Amphipods, small snails, etc.) Mugilids are not doing it. Moreover common benthic animals inhabiting subsurface bottom mud like *Tubificidae*, *Lumbricidae*, Nematodes or *Turbellaria* were not documented as food components in the digestive trucks of the Kinneret Mugilids [19]. Conclusively, Mugilids do not deteriorate water quality by bottom dwelling and probably improve Kinneret water quality by consumption of organic substances.

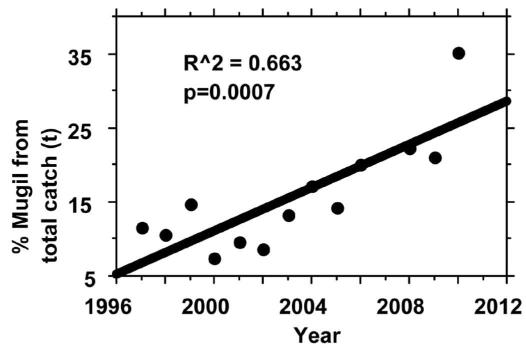
The fishery of Mugilids in Lake Kinneret restrictively correlates to stockings policy. The introduction of Mugilids was initiated in 1958 but not before 1964 the commercial catch was significant. The fingerlings are collected during winter time in the shallows of the Mediterranean coast in sites of inland rivers outlets. From there they are transported into the Kinneret after 1 - 2 days stay in freshwater ponds for adaptation. The cost of these operations is covered by the Governmental Fishery Department and Water Authority (Agricultural and Energy and Infrastructure Ministries). These authorities are Governmental-Non-Profit-Organizations. The fishermen revenue that will be discussed here does not represent a comprehensive complete financial evaluation but relay on the practical advantage as documented by local fishermen interests and fingerlings supply expenses are excluded. Stocking costs is therefore discussed separately. The question given by the Governmental Authorities is one: Does stocking investment is rewarded? The answer given in this paper is-yes.: Contribution to lake ecology and water quality improvement by utilization of excess of organic matter and significant income to the fishermen. The removed organics is mostly due to Phytoplankton Photosynthetic activity. From early 1970's until mid 1990's the dominant algae in the lake was the bloom forming Pyrrhophyte *Peridinium* and presently the Cyanobacterium *Microcystis*. Only small part of the vast organic matter produced by both algae is utilized by fish and almost nothing by zooplankters. Consequently organic consumption is beneficial for water quality improvement. The present market conditions for Mugilids are excellent and therefore fishermen reward ensure intensive fishery which ultimately require regulations by enforced legislations. The overall detailed financial evaluation is not needed in this case if the controlled Mugilid population improves water quality and prominently without deterioration risk and the fishermen income is satisfied. The stocking investment is done by "Non-Profit-Government-Organization" and the fishing activity is fishermen responsibility accompanied by ecological improvement. The data presented in **Table 4** indicates that Mugilids stocking cost was 4% and 1.3% of their Dock on side value for LR and MC respectively.

Data given in **Figure 1** and **Figure 2** indicates that evaluation of introduction and catch data in one year sequenced interval result in inverse related regression: the more fingerlings are introduced the catch next year is relatively lowered. It is probably an indirect confirmation for commercial recruitment at an age of longer than a year as presented in **Table 1**. The data in **Figure 2** confirm that the more stocked fingerlings which survive longer time than 1 - 2 years to recruit the catch in the third year the higher is the dock on side landings. Surprisingly, statistical (Polynomial Regression) evaluation of the landing data (**Figure 4** and **Figure 5**) during 1995-

2014 indicated decline of individual fish weight and age during 2000-2008 (lowest: 2007-2008) of LR and MC. These changes can be interpreted as intensification of fishing pressure resulted by smaller recruited and landed LR and MC as well as decline of catches of other fish species. This was probably resulted by a fishery crisis symptom in Lake Kinneret. The crisis symptom was actually recorded (**Figure 6**): the total fish landing prominently declined (**Figure 6**) especially that of the top valuable commercial species, *Sarotherodon galilaeus* sharply declined from averaged 300 t to <10 t. Therefore fishing pressure on Mugilids was enhanced and individual Mugilids were younger and lighter (**Figure 4** and **Figure 5**) without stocking reinforcement. After 2008 the fishery was gradually recovered (**Figure 4** and **Figure 5**). A confirmation of the enhancement of Mugilid fishery during the total landings decline is given in **Figure 6** and **Figure 7**. The % of Mugilids in total landing increased as a reflection of insignificant changes of Mugilids when total catches declined. Recent investigation of Mugilids increment to commercial landings was documented (Snovsky, 2015). Results given in this report [20] indicated a prominent increase of individual averaged Total Length (TL) and Weight (W) of landed Mugilids during fishery recovery (2014) (n = 882) compared to the period of crisis (2004-2008) (see **Table 3**). Results are presented in **Table 5**.

Table 5. Averages of weight (W; g) and total length (TL; cm) individual landed mugilid (LR, MC) fishes during 2004, 2008, 2014.

Species	Parameter	2004	2008	2014
MC	TL (cm)	57.3	52	---
MC	W (g)	2130	1593	---
MC	+Deviation (%)	34		---
LR	TL (cm)	44.3	37.7	37.1
LR	W (g)	763	459	437
LR	+Deviation (%)	75	5	---



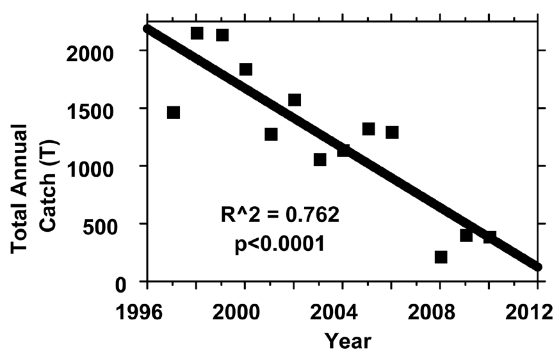


Figure 6. Linear regressions (r^2 & p values are given). Upper: averaged (1997-2011) % of Mugilids annual catches from total landings and years; and Lower: Total landings and years.

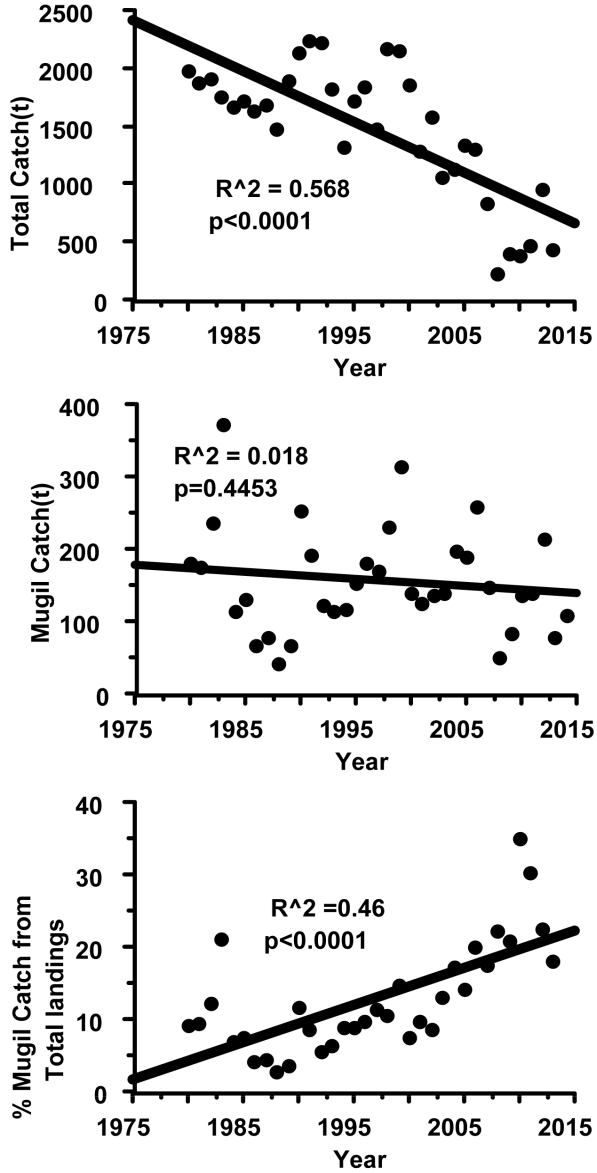


Figure 7. Lake Kinneret fishery during 1980-2015: Upper panel: annual total catch; Middle Panel: Mugil annual catches; Lower panel: % of mugil in total catches.

5. Summary

The Mugilids introduction into Lake Kinneret is a significant component in the management implementation of the Lake Kinneret ecosystem. The ecological services supplied by Lake Kinneret ecosystem include planting of exotic fish species, Mugilids, which contribute to water quality protection as well as to fishery enhancement. The majority (87%) of stocked Mugilid fingerlings was *Liza ramada* (LR) and *Mugil cephalus* (MC), but *Mugil cephalus* (MC) comprised 35% of landings biomass. LR individual fishes in catches were at the age of 3.3 whilst that of MC—4.2 years. The higher weight of MC (1827 g) than that of LR (467 g) in commercial landings was documented. It is likely that 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. Overall conclusion indicates a long term success of Mugilids introduction into Lake Kinneret: Water quality improvement combines with profited compensated proceeds.

Note: Information about Sexual maturity (♀-4th year, ♂-3rd year) and females fecundity (0.5 - 2.0 × 10^6 eggs) are given in [21] [22].

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