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36 Fisheries management

Ilia Ostrovsky, Tamar Zohary, James Shapiro, Gregory Snovsky, Doron Markel

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Fish, fish stock, stocking, catch, fishing practice, biomanipulation, water level fluctuation, littoral, fishery, Kinneret bleak, tilapia, silver carp, common carp, mullet, overfishing, water quality, management, subsidized harvest, public education, *Sarotherodon galilaeus*, *Oreochromis aureus*, *Mirogrex* [syn. *Acanthobrama*] *terraesanctae*, *Hypophthalamichthys molitrix*, *Cyprinus carpio*, *Mugil cephalus* , *Liza ramada*,

Abstract
This chapter describes stocking and fishing practices in Lake Kinneret and their roles in lake management, aimed at preservation of the lake as a major source of drinking water while still attempting to protect and promote the commercial fisheries. Multiannual changes in the commercial catch of dominant and commercially important fish species are detailed. These are considered in relation to changes in the amount of fingerlings stocked, increased fishing pressure, and extreme water level fluctuations. Seasonal and multiannual dynamics of water level fluctuations strongly affect littoral habitats and hence also fish reproduction, and fingerling survival. Fishing pressure on large individuals, which are reproductively active, is also coupled with water level fluctuations. Fish stock management in Lake Kinneret should be focused on full or partial restoration of the native fish community and its sustainable fishery.

33 Fisheries management

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Introduction

Fish are at the top of aquatic food webs impacting on other biota as well as on water quality by grazing on phytoplankton, preying on zooplankton, zoobenthos and other fish, by feeding on organic matter, by accumulating phosphorus, P, in their skeleton, and by excreting nitrogen, N, and P (Holmlund and Hammer 1999; Carpenter et al. 2001). Removal of fish from the lake by fishing, or alternatively stocking the lake with desired fish species have the potential to modify not only the fish populations but also various other ecosystem components and thus to indirectly affect water quality (Carpenter and Kitchell 1988). In contrast, ill-management and poor fishery practices can cause major damage to an ecosystem; some of which could be irreversible. As such, fisheries management is an important tool available to managers in order to preserve a lake ecosystem and its water quality.

The primary goal of fisheries management in Lake Kinneret is to contribute to the stabilization of the ecological system as part of the effort to preserve the lake as a major water resource for the State of Israel (Markel 2008; Markel 2012; Chap. 31). A secondary goal is to improve fishery yield and income by sustaining a fishery for commercial species. However, if these two goals contradict, requiring different actions, the first goal overrules, water quality cannot be compromised for the needs of fishery. Fishery management in the lake consists of multiple components including: (1) regulating fishing practices by instituting laws and regulations; (2) enforcing these laws; and (3) stocking fingerlings of desirable species. An additional practice applied in the past was subsidized commercial harvest aimed at the reduction of zooplanktivory to improve water quality.

Considering each of these points in detail:

(1) The laws regarding fishing are designed to ensure that a sufficiently large proportion of the fish reach maturity and have at least one successful year of reproduction, as is common world-wide. Recent investigations show that large, elderly females are far more important than younger fish in maintaining productive fisheries (Berkeley et al. 2004). As such, these laws aim at preventing over-fishing and protecting the fish during spawning, by: (a) dictating a minimum permissible net mesh size, to ensure that the largest specimens of each species are harvested, while the smaller individuals are left to grow and reproduce; (b) limiting the number of fishing boats, the length and number of nets per boat and prohibiting illegal forms of fishing such as poisons, electrofishing, and underwater

hunting with harpoons; (c) forbiding fishing in the Beteha lagoons (at the north-east part of the lake) for two months in spring, when the cichlid species use this region as their main spawning grounds, and (d) forbidding commercial fishing without a license.

(2) The enforcement of these laws in Lake Kinneret has always been limited in its scope due to shortage of enforcement personnel, the prevalence of aggressive behavior of some fishermen, and lenient penalties for violators. As a result, over-fishing continues to impair the state of the fish populations, especially that of the commercially valuable tilapias (*Sarotherodon galilaeus* and *Oreochromis aureus*). Illegal fishing, including fishing by poisoning, continues to be a problem.

(3) Stocking of fingerlings of a few selected species (tilapia, grey mullets and silver carp) is practiced in order to increase the catch and fishermen's income, while at the same time making some contribution to the improvement of the lake's water quality by feeding on phytoplankton, bacteria and detrital organic matter. Regular stocking programs were initiated in the 1950s. The principles underlying fish stocking are: (a) native fish can be introduced cautiously, taking into account the possible decrease in the genetic variability of their populations; (b) exotic fish can be introduced only if they are unable to reproduce in the lake and only after a period of observation in ponds; (c) piscivorous fish should not be introduced, as these may irreversibly affect the Kinneret food web.

(4) Over-abundant small bleak (*Mirogrex* [syn. *Acanthobrama*] *terraesanctae*) in extreme flood years led to the lowest ever levels of zooplankton abundance (Ostrovsky and Walline 2001; Chap. 16). To minimize negative impacts down the food chain, subsidized commercial fishing has been used to reduce predation pressure on zooplankton. In practice, the main objective of this management practice (improved water quality) was not obtained by its application, and it was discarded.

Introduction of alien species such as the grey mullets (*Mugil cephalus* and *Liza ramada*) was motivated by fast growth rates of these species and assessments that their potential food resources were underutilized in Lake Kinneret (Ben Tuvia et al. 1992). Of the stocked alien species, only common carp (*Cyprinus carpio)* is able to reproduce in the lake (e.g. Snovsky et al. 2010), and because of this its intentional stocking was stopped in 1948. The sections below addressing the fisheries of tilapia, grey mullet and carp also provide details on the stocking of these species.

The stocking programs and fisheries on Lake Kinneret are controlled by the Israel Water Authority and by the Israel Fisheries Department of the Ministry of Agriculture. An inter-governmental committee, the "Stocking and Fisheries Management Committee", directs and oversees these management activities. This committee includes representatives from the Ministry of Agriculture (Chair), Israel Water Authority (deputy chair), Fisheries Department, Kinneret Limnological Laboratory of IOLR, Kinneret Authority, fish experts from the Israeli universities and a representative of the Kinneret fishermen. The Fisheries Department is responsible for issuing fishing licenses to fishermen and fishing boats, rearing or purchasing fingerlings to be stocked, monitoring the size structure of the harvested fish and the total mass landed for each species. Its officers are also responsible for enforcing the fishing regulations.

The largest fishery on Lake Kinneret in terms of annual fisheries biomass yield has been for many years that of the endemic bleak, *M. terraesanctae*, locally known as lavnun or the "Kinneret sardine". However, the main income to fishermen came from several other, larger body-size fishes of much higher commercial value. These include the two native tilapias, *S. galilaeus* and *O. aureus*, and four alien stocked species: the grey mullets *M. cephalus and L. ramada*, silver carp *Hypophthalamichthys molitrix*, and common carp *C. carpio* (that is no longer stocked).

On various occasions it was proposed to introduce into Lake Kinneret a high commercial value piscivorous fish that cannot reproduce in the lake, such as the European Seabass (*Dicentrarchus labrax*), but such suggestions were always rejected. According to the trophic cascade theory, adding a piscivor to the lake ecosystem may suppress the productivity of planktivorous fish. This may diminish their ability to clean the water by feeding on phytoplankton and organic matter (Hairston et al. 1960; Drenner and Hambright 2002), and as such would contradict the primary goal of the fish introduction program. Furthermore, since the seabass was shown to feed well on *Sarotherodon* sp. (Chervinski and Shapiro 1980), the most valuable native tilapia in Lake Kinneret, its introduction could suppress the tilapia standing stock and reduce its yield, another an undesirable likely outcome.

The objective of this chapter is to give an overview of the historical and current thinking with respect to fisheries management in Lake Kinneret.

The recent history of fishery on Lake Kinneret

The history of fishery on Lake Kinneret dates back to prehistoric civilizations ~5000 years ago, with archeological evidence especially from Beit Yerach, an ancient city on the southern shore of the lake by the Jordan River outflow (Nun 1977). Stories of this fishery at the times of Jesus comprise an integral part of the New Testament. Nun (1977) provides a detailed account of the history of fishing on Lake Kinneret. This chapter is restricted to fisheries practices and its management in recent times.

During the 18th and 19th centuries, under Ottoman rule, fishery on Lake Kinneret was low; commercial fishing was revived in 1920, when the British abolished the practice of renting fishing rights and levying a fishing tax and permitted unlimited fishery by all licensed fishermen (Nun 1977). During 1935-1945 the number of licensed fisherman on the lake was 180-204, the number of small fishing boats was 36-57 and the yield was about 400 t of fish annually (A survey of Palestine 1946). Fish biologists analyzing the Kinneret fisheries suggested that the unlimited fishery policy since 1920 resulted in overfishing (A survey of Palestine 1946). As such, strict rules and fishery regulations were invoked leading to improvement of the harvest by the early 1940s (Nun 1977). For comparison, in 2011 the number of licensed small fishing boats on Lake Kinneret was 65, with 284 licensed fishermen (C Angiuni, Department of Fisheries, personal communication).

Between 1950 and 1970 the fish catch gradually increased, from ~ 400 to 1500 – 2000 t annually, as a result of the combined effect of (1) improved fishing gear (2) increased fishing effort, and (3) intensive stocking of fingerlings (Ben Tuvia et al. 1992). The improvement in fishing gear (Fig. 1) included more powerful boat engines, introduction of multi-species nets, replacement of coarse mesh cotton nets by fine monofilament nets, use of fish finding echo sounders, mechanization of purse-seine units and introduction of labor-saving devices for packing and storage of large catches. All these resulted in a large increase in the fishing effort.

In the early 1970s, the total catch reached a plateau of 1500-2000 t, which lasted until 1999-2000. From then on the catch declined, reaching an all-time minimum in 2008, with only moderate recovery since then (Fig. 2). The decline was attributed mainly to overfishing of commercially valuable fish (Zohary et al. 2008; Ostrovsky et al. 2013), concurrent with a sharp decrease in market demand for bleak. Other possible factors that could affect the fish populations and their landings are discussed below and in Chap. 16.

Gill and trammel nets and purse seining are the two main methods of fishing used currently. In the 1970s, 6-9 m deep trammel monofilament nets were introduced. In the early 1980s, 90 small (4 to 6 m) fishing boats were employed, deploying multiple floating and sinking gill and trammel nets (Bar Ilan 1985). Purse-seining was introduced as early as 1939 (Ben Tuvia et al. 1992) and used mostly for fishing bleak in the pelagic waters. By the 1980s this method was employed by seven 10 to 12 m boats. With a sharp decline in the market for bleak, purse seining has nearly stopped since ~ 2005, with only one boat operating a purse seine on the lake in 2012.

Subsidized harvesting of the endemic bleak, *Mirogrex terraesanctae*

As the dominant pelagic fish and a zooplanktivore, the bleak plays an important role in trophic interactions in Lake Kinneret. Despite its relatively low commercial value, a canning industry supported the bleak fishery so that its annual catch increased from ~ 200 t in the 1940s to ~1000 t at the beginning of the 1970s through the early 1990s (Fig. 2), contributing on average 50-60% of all landed fish by mass. The situation changed in the early 1990s, when extreme fluctuations in water level took place as a result of increased abstraction in response to a rising demand for freshwater, concomitant with a long-term decline of inflow volumes (Zohary and Ostrovsky 2011; Chap. 7). Large rises in water level (> 4 m, in comparison with a natural amplitude of ~ 1.5 m, Hambright et al. 1997) in exceptionally wet winters, were followed by a huge reproductive success and enormous increases in bleak abundance, as recorded by acoustic surveys (Ostrovsky and Walline 2001; Ostrovsky et al. 2013). Excessive abundance and therefore excessive food requirements of this zooplanktivorous fish in the following 2-3 years suppressed zooplankton biomass and eventually led to a population of almost only sub-commercial sized fish and the collapse of the bleak fishery (Chap. 13, 16). In an attempt to reduce fish predation pressure on zooplankton, increase the biomass of herbivorous zooplankton, improve water quality, and to revive the purse seine fishery, a subsidized harvest of the bleak was initiated and funded by the Israel Water Authority. The so-called "bleak culling program" was implemented to supplement the commercial fishery. Starting in winter 1994-95, fishermen were paid to harvest bleak of all sizes and particularly fish smaller than commercial size. These fish were subsequently dumped outside the lake drainage basin. The fishermen were required to use regular purse seine nets with an added panel of smaller than regular mesh net (bunt) for retaining small fish. In practice, such net design was implemented during the first two years whereas later, the fishermen caught fish with standard nets only in order to have the flexibility to sell the larger fish commercially. The culling program removed a total ~6000 t of bleak from 1994 to 2006; at the same time, the bleak commercial fishery removed an additional total of ~4000 t (Shapiro 2009).

The bleak thinning program was controversial from the start of its implementation, with contrasting expert opinions regarding the reasons for the fishery collapse and different predictions regarding the likely outcome of subsidizing the harvest of sub-commercial sized fish (Hambright and Shapiro 1997; Gophen et al. 1999). Hambright and Shapiro (1997) suggested that the fishing collapse in 1993 was due to a decade-long shift in harvested fish size and two consecutive fishing seasons of severe overharvest. Ostrovsky et al. (2013) argued that the fishery collapse was a result of high mortality of large post-spawning individuals following years of unusually high reproductive success. This reproductive success was attributed to major water level rises and caused a deficiency of zooplankton food resulting from excessive predation pressure on zooplankton (Chap. 16). Blumenshine and Hambright (2003) compared potential predation pressure on Kinneret herbivorous zooplankton by bleak to that by the other major zooplankton predators, the cyclopoid copepods. They concluded that copepods accounted for a greater portion of the predation mortality on herbivorous zooplankton than bleak. These authors suggested that reduction in bleak predation pressure (by a subsidized harvest) may have led to increases in cyclopoid copepod abundance and thereby a net increase in predation pressure on herbivorous zooplankton, i.e. the opposite of the desired outcome. Walline et al. (2000) used data from acoustic measurements of fish populations and a spatially explicit bioenergetic model to calculate the potential consumption of zooplankton by fish. Their calculations indicated that the culling program reduced the potential for consumption of zooplankton by bleak and that targeting smaller fish in the removal program could have had a greater effect than that achieved by using commercial size mesh nets.

Looking back, it is now possible to summarize the pros and cons of the bleak thinning program, as conducted on Lake Kinneret during 1994-2006. The objectives of the thinning program were only partially accomplished. While fish predation pressure on zooplankton was apparently reduced, it remains unclear whether the subsidized bleak removal led to an increase in the biomass of herbivorous zooplankton and to increased cleaning of the water by those herbivores. Certainly there was no direct evidence to an improvement of water quality resulting from this program. The two most intensive ever blooms of harmful cyanobacteria on Lake Kinneret, in summer 1994 and again in summer 2005 (Chap. 12), both occurred despite subsidized harvest, within two years after a major rise in water level (Zohary and Ostrovsky 2011). It also remains inconclusive whether the thinning program contributed significantly to the observed eventual recovery of the bleak population. Management of the lake water levels within a narrower range of seasonal fluctuations could naturally prevent the unwanted changes in the bleak population, making the subsidized harvest unnecessary.

Irrespective of the thinning program, since 2006 the commercial fishery of the bleak has dwindled down to less than 100 t annually (Fig. 2), due to a sharp decline in market demand for this species, as a result of the closure of the market in Gaza and closure of 3 of the 4 local sardine canning factories.

The native tilapias, *Sarotherodon galilaeus* (amnun hagalil) and *Oreochromis aureus* (amnun hayarden): stocking and overfishing

Sarotherodon galilaeus (also known as *St. Peter's fish* in English, *musht abiad* in Arabic or *amnun hagalil* in Hebrew) was the most commercially valuable fish in Lake Kinneret until 1999 when catches began decline significantly. *Oreochromis aureus* (*musht lubbad* in Arabic or *amnun hayarden* in Hebrew) is another commercially important tilapia species. Intensive stocking of these indigenous cichlids was motivated by their high economic contribution to the local fishery, as well as their being considered major players in the Kinneret food web by feeding primarily on the bloom-forming dinoflagellate, *Peridinium gatunense* and on zooplankton (Zohary et al. 1994). It was believed that the lake ecosystem was capable of supporting much higher standing stocks of these tilapia species which could not be attained naturally due to the shortage of suitable spawning grounds and/or high natural mortality of fry (Bar Ilan 1985).

The stocking of native tilapia *S. galilaeus* was initiated in 1951 and has continued since (Table 1). A brood stock kept at the Fisheries Department Station at Ginnosar, on the western shore of Lake Kinneret, produces fingerlings grown in ponds until their release to the lake, usually in August-September each year. Stocking of *O. aureus* began in 1958, but was stopped in 1984, as *O. aureus* was assumed to compete for food with *S. galilaeus*, the latter having higher commercial value and considered better for water quality as it fed more on *Peridinium* and less on zooplankton (Gophen et al. 1983; Zohary et al. 1994). While the stocking of *O. aureus* was followed by a remarkable increase in its catches (Reich 1976), no increase of landing was associated with stocking of *S. galilaeus* (Serruya and Leventer 1984). Moreover, at certain times, an increase in *S. galilaeus* stocking coincided with a decrease in its catch in the following years (Reich 1976 and Fig. 3b). In the mid 1980s, the stocking of *S. galilaeus* was intensified, reaching a maximum of six million fingerlings annually from 1999 to 2002 (Table 1). However, the assertion of Bar Ilan (1985) that a million stocked *S. galilaeus* fingerlings would lead to an additional 80-90 t of landed fish was not confirmed. Overall, no significant correlation was found between the number of stocked fish and their annual catch two years later, when the stocked fish should have reached the minimum commercial length of 20 cm. Moreover, an unexpected but highly significant negative correlation coefficient (R=-0.79) was observed between the number of *S. galilaeus* fingerlings introduced during years of increasing stocking effort (Fig. 3a), and the catch two years later (Fig. 3b). It could be that this is an artifact associated with two concurrent but independent trends. One trend is increased tilapia stocking in an attempt to compensate for the "insufficient" natural reproduction. The other trend of decreasing catch resulted from an extended period of gradually declining water levels, from 1995 to 2002. In the earlier years of this period, insufficient fishery control led to notably high catches as the fish had little refuge (see below). But, as a result, the stock became very small and catch decreased markedly in the later years. This demonstrates that the lack of fishery control can negate the expected benefits of stocking. Consequently, the stocking strategy was changed. From 2008, a smaller number (~ 1 million) of larger-size fry with higher chances of survival have been stocked.

In fact, it remains unknown whether and how much stocking has contributed to the catch of *S. galilaeus*. Current research focuses on finding a suitable means of marking the stocked fingerlings of *S. galilaeus* by a physical tag, dye, or molecular marker, so that in the future it will be possible to estimate directly the contribution of stocked fish to the catch.

Long-term production of fingerlings from a genetically limited brood stock may, over time, lead to a declined in the genetic variability of the entire population of *S. galilaeus* in the lake. Surprisingly, Shitenberg (2006) has revealed particularly small genetic variability of *S. galilaeus* from native populations of all over Israel in comparison with the genetic variability of this species in native populations in Ghana. The low natural genetic variability in Israel may be attributed to Israel being at the northernmost tip of the biogeographic distribution of this African fish. Probably the entire population in Israel stems from a small number of founding parents. Thus, further limiting the genetic variability of the Kinneret *S. galilaeus* by long-term stocking is a definite concern.

A time series of Lake Kinneret water levels and the annual catches of *S. galilaeus* (Fig. 4), shows apparent relationships between these two variables. A strong negative correlation (R=-0.84, P<0.01) between the tilapia catch and water level was recorded from 1985 through 1998; subsequently the two variables were positively correlated. A possible explanation for the negative correlation is that during 1985 to 1998 low water levels made it easier to catch the fish at the lake periphery; at lower lake levels the proportion of sandy littoral areas progressively increases at the expense of stony and rocky substrates, the latter providing better refuge for fish (Gasith and Gafny 1990). Furthermore, at declining water levels the sandy littoral was devoid of vegetation, (Chap. 29). Thus, at lower water levels, *S. galilaeus* had less refuge, especially during the spawning season (April to July) when the fish congregate in shallow water and are easy to harvest. Eventually, the average size of landed fish (length and weight per individual) declined (Ostrovsky 2005; Ostrovsky et al. 2013), as is typical for fish subjected to strong fishing pressure.

From 1998 onwards, the correlation between water level and *S. galilaeus* harvest became positive. With an impoverished population depleted of its larger individuals, especially its maternal stock, low water levels no longer provided opportunities for easy fishing, as the large fish simply did not exist. The high rainfall winter of 2002/2003, with its rapid rise in water level, provided a "window of opportunity" for fish reproduction (*sensu* Gasith and Gafny 1998; Chap. 29). The dense shoreline vegetation that had developed on the exposed beaches during the previous years of low water levels, was inundated by the rising waters, providing refuge and shelter from predators and fishermen, abundant food in the form of algae and invertebrates, suitable spawning grounds, and excellent growth conditions for the young-of-year. This winter was followed by improved catch in the following 2 to 3 years.

From 1997 through 2002, years with a steady decline of the mean water level, an unusually high increase in fishing mortality caused a large rise in the proportion of sub-commercial size *S. galilaeus* (<20 cm total length) in the catch, from 43% in 1997 to ~80% in 2002 (Ostrovsky 2005). The observed increase in fishing pressure, decline in the mean size of caught fish, and concurrent drop in the mass of landed *S. galilaeus* indicated intense overfishing. Continued intensive fishing on *S. galilaeus* during the years with declining water levels from 2005 onwards caused a collapse of the tilapia fishery by 2008 (Fig. 2). Venturelli et al. (2009) showed a direct link between population age structure and reproductive rate, consistent with strong effects of maternal quality on population dynamics. They concluded that a population of older, larger individuals has a higher maximum reproductive rate than a population of the same number of younger, smaller individuals and that this difference increases with the reproductive lifespan of the population. In Lake Kinneret, the observed collapse of the most commercially important fish was probably caused by removal of the older female fish by intensive fishing (Ostrovsky, unpublished results).

Predation by the piscivorous Great Cormorant *Phalacrocorax carbo* may have influenced the abundance of some fish species over the last years. The numbers of these birds have increased over the last decade and presently flocks of thousands of cormorants populate the northern part of Lake Kinneret in winter (Shy et al. 2003).

While on the lake, they consume mostly bleak and cichlids (about 50% of each species, Artzi 2011). Still, the proportion of *S. galilaeus* out of the total cichlids in cormorant diet has not been estimated and thus it is currently impossible to conclude definitely if these birds affect the *S. galilaeus* catch.

Several other factors may have contributed to the 2008 collapse of the *S. galilaeus* fishery and the Kinneret fishery in general, as summarized by Zohary et al. (2008). These included the lack *Peridinium gatunense,* the main food item of *S. galilaeus* as this species failed to bloom in most (10 out of 16) of the years between 1996 and 2011 (Zohary et al. 2012)*;* illegal fishing with pesticides causing fish kills (Chap. 33.2); and possible predation of fingerlings by catfish, *Clarias lazera*. However, solid data to support any of these suggestions is lacking.

Hypophthalamichthys molitrix (Silver carp)

The silver carp was first introduced and stocked in the lake in 1969. While its commercial value per mass is relatively small compared to tilapia and grey mullets, its large body mass makes it commercially valuable. Because these fish graze on phytoplankton and other small organic particles it was assumed that the silver carp would contribute to cleaning the water. For a decade between 1973 and 1983, about one million fingerlings of this species, raised at the Nir David Station of the Department of Fisheries and Agriculture, were stocked annually (Table 1). Silver carp grows in Lake Kinneret at extremely fast rates, similar to that in fishponds (Shefler and Reich 1977; Snovsky 2000). It is an obligate filter-feeding planktivore, consuming anything suspended in the water (Shapiro 1985; Spataru and Gophen 1985a). In the early 1980s concern was raised that *H. molitrix* competed with *S. galilaeus* and *O. aureus* for zooplankton (Sparatu, 1976; Gophen and Pollinger 1985; Sparatu and Gophen 1985a,b). Because of this, its stocking was stopped in 1984. Due to recurrent requests from fishermen, the understanding that this species does not reproduce in Lake Kinneret or its inflowing rivers and that this fish at low densities will not have adverse impacts on the ecosystem, stocking was re-instated in 1988, at a reduced amount of 200,000 fingerlings annually, which was increased to 400,000 fingerlings in 2005 (Table 1). Currently, the stocking of silver carp in Lake Kinneret is being reconsidered, and in the meantime the amount stocked in 2012 was 300,000. The primary concern with regards to silver carp stems from the bad experience with this species in the USA, where silver carp and related species are considered some of the worst alien species to have invaded their lakes and rivers (Chick and Pegg 2001). Moreover, since a proportion of the silver carp's diet comes from zooplankton, it catalyzes nutrient turnover and availability and thus usually causes an increase rather than decrease in phytoplankton biomass (Zhang et al. 2008). Hence this species should not be used for biomanipulation in mesotrophic lakes (Radke and Kahl 2002).

Shortly after the initiation of stocking, during the period 1976-1988, the catch of silver carp followed closely the number of fingerlings stocked three years earlier (Fig.

5a), as expected for a species that cannot reproduce in the lake or its catchment, and a significant correlation (R=0.73, $P<0.01$) was found between the two variables (Fig. 5b). However, since 1989-1990 correlation between the catch and number of stocked fish disappeared and from then on the harvest was not related to the number of fingerlings stocked (Fig. 5). Since this species cannot reproduce in the lake or its catchment, we suggest that survival of the fingerlings varied from year to year, with changes in water level and the availability of inundated vegetation in the littoral zone (Chap. 29). Other possible factors leading to the observed lack of correlation since the early 1990s could be parameters related to the size and health of fingerlings, conditions at the time of stocking, and changes in phytoplankton species composition.

Cyprinus carpio (common carp): stocking and catch

Stocking of *C. carpio* was intentional only in 1948; later large numbers of fingerlings and adults escaped from fishponds in the watershed and populated the lake. In spite of this and the low ability of this species to reproduce in Lake Kinneret, prior to the early 1990s the catch of common carp has remained low, averaging 13.5 t yr^{-1} (Fig. 2). This led Reich (1976) to conclude that the conditions in Lake Kinneret were not optimal for its growth and breeding. However, this seems to have changed over time. Since 1990 carp catches increased to ~100 t yr^{-1}, even though carp farming in the Kinneret watershed was stopped in the early 1990s. These changes occurred concurrently with low lake water levels and increased lake level fluctuations that in wet winters created large littoral areas with flooded shoreline vegetation, which probably could serve as suitable spawning grounds of carp and habitat for the growth and survival of its fingerlings.

Mugil cephalus and *Liza ramada* (grey mullets, buri): stocked aliens that do not reproduce in L Kinneret

Two species of alien grey mullets (*M. cephalus, L. ramada)* have been introduced to the lake annually since 1958. These marine species cannot reproduce in the freshwater lake. The small (<0.1 g) fry are collected from December to March in the Mediterranean estuaries, acclimated, and then released into Lake Kinneret. Stocking of grey mullets is efficient due to high growth rate and low mortality rate. The return rate of the stocked fish in the commercial catch is assessed at ~30% (Snovsky 1993). Of the two species, *M. cephalus* has higher growth rate, reaches larger sizes, and thus has higher market value, so was considered more desirable than *L. ramada*. However, *L. ramada* fry are usually more available than those of *M. cephalus* and the price per fingerling is considerably lower. Therefore, on average since 1995 ~ 90% of the stocked grey mullets were *L. ramada*.

Currently, grey mullets have the highest value per kg of any commercial fish caught in Lake Kinneret. During the years following the collapse of the tilapia fishery in 2008, grey mullets comprised the primary income-generating commercial catch.

Grey mullets are bottom feeders, consuming the lake sediments and sieving out organic matter and living organisms, so they are assumed not to compete with the native tilapias for food. Still, since benthivorous species may cause recurrent resuspension of bottom sediments and thus stimulate upward nutrient flux to the water column (Katz et al. 2012), the actual ecological role of grey mullets should be carefully investigated and the amount of stocked fingerlings needs to be reassessed accordingly. At present the number of stocked fry is limited to one million fingerlings of both species combined per year.

Conclusions and Recommendations

1. *Reduction of overfishing.* The extensive overfishing that has been observed in the lake (Ostrovsky 2005) suggests that fish standing stocks and landings can be increased by optimization of the amount of fishing effort through catch and effort controls (e.g. introduction of fishing quotas, moratoria), by enforcing the established minimum fish size limits, by regulating the gear and fishing methods used (net mesh size, number and length of nets per fishing boat) and by regulating when and where fishing is permitted or prohibited. Furthermore, the authorities should monitor the mass, size and age of the catch (FAO 1997) and enforce the fishing laws in response to the observed status of the fishery. Some of these control measures are already part of the Kinneret Fishing Law and the activities of the Department of Fisheries. However, due to limited law enforcement and lack of fast feedback from the fishery monitoring program, fish continue to be harvested at an average size that is smaller than that which would produce the maximum yield per recruit (i.e. “growth overfishing”).

2. *Maintenance of native fish stocks.* Fish stock management in Lake Kinneret should focus on the *restoration* of native fish populations and their sustainable fishery. These species are evolutionarily adapted to the natural ambient conditions. The maintenance of native fish stocks at productive levels requires an adequate abundance of reproductively mature adults (spawners) and suitable habitats for successfully passing through the different stages in the life history. Overfishing results in lowering the number of reproductively capable individuals below a certain critical level, leading to a decrease in the reproductive capacity of the population and the collapse of its standing stock (i.e. “recruitment overfishing”). To resolve this, the spawning stock biomass should be restored to sustainable levels. In particular, fishing in the littoral zone, or at least in some parts of the littoral zone, must be restricted during the spawning and nesting periods. Such restrictions are already implemented in the Beteha region on the north eastern lake shore for two months in spring each year, but their enforcement is limited. The restrictions should be fully enforced and expanded to the littoral zone around the entire lake. Concurrently, the stocking policy of alien species should be re-assessed.

3. *Water level fluctuations.* Water level fluctuations and the mean annual water level strongly affect the littoral habitats, fish reproduction, and fingerling survival. Fishing pressure on large individuals, which are reproductively active, is linked to the mean water level. Therefore, restricting water level fluctuations to the range to which native Kinneret fishes have been evolutionary adapted should be an important stabilizing measure for sustainable management of fish resources. This recommendation has been accepted by the Water Authority, and in accordance with the new Master Plan for the Water System of Israel, the Lake Kinneret water level will be kept in the future above the "red line" of -213 m..

4. *Technology transfer and public education.* Overfishing and usage of illegal fishing methods, together with unintentional introduction of alien species have frequently led to the destruction of aquatic ecosystems and fisheries (Pauly et al. 2002). Often the damaging actions are due to lack of understanding by those conducting them. An urgent need exists to develop the means to educate fishermen and residents of the Kinneret region about sustainable fisheries and ecosystem management so that they will take part in the conservation of the lake rather than harming it unintentionally.

5. A *sound fisheries biology program*. This chapter highlights many areas where our knowledge is limited and further research and monitoring are urgently needed in order to improve the management of Lake Kinneret fish populations and its fisheries. Examples of current knowledge gaps include monitoring data on the actual standing stocks of the different species, maximum sustainable yields for the commercial species, the contribution of stocked *S. galilaeus* to the harvest, the role of silver carp and grey mullets in the foodweb, effort and catch impacts, the role of catfish as top predators, competition for food resources between native and alien species.. Such studies require multi-institutional and multi-disciplinary efforts, special funding and equipment, and dedicated personnel.

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Table 1 Annual stocking (number of fingerlings x10^6) of commercially important fish species in Lake Kinneret. S. gal - *S. galilaeus*; O. aur - *O. aureus*; Mug – Mugilids; H. mol - *H. molitrix*. Data: Ministry of Agriculture and Rural Development, Department of Fisheries and Agriculture

Year	S. gal	O. aur	Mug.	H. mol	Year	S. gal	O. aur	Mug.	H. mol
1970	0.70	2.45	3.62	0.02	1991	2.70	0.00	0.00	0.16
1971	2.15	1.09	0.63	0.00	1992	1.50	0.27	0.39	0.20
1972	2.13	1.04	0.01	0.02	1993	3.00	0.00	0.70	0.20
1973	1.54	0.25	0.03	0.63	1994	2.80	0.00	0.85	0.20
1974	1.87	3.19	0.00	1.33	1995	3.50	0.00	1.00	0.20
1975	1.27	3.85	0.57	0.67	1996	3.50	0.00	0.74	0.20
1976	1.75	0.44	1.36	1.04	1997	4.00	0.00	1.00	0.03
1977	1.64	3.22	0.85	1.86	1998	4.00	0.00	1.02	0.20
1978	2.25	0.00	0.77	1.10	1999	6.00	0.00	0.70	0.20
1979	2.00	0.00	1.10	1.20	2000	6.02	0.00	1.03	0.20
1980	1.80	0.40	1.20	1.70	2001	6.02	0.00	1.00	0.20
1981	1.80	0.95	0.90	1.50	2002	6.00	0.00	0.49	0.20
1982	1.70	1.50	0.20	0.60	2003	4.00	0.00	1.64	0.20
1983	2.36	0.17	0.03	0.56	2004	3.00	0.00	0.49	0.20
1984	4.63	0.03	1.20	0.00	2005	2.50	0.00	1.20	0.40
1985	5.50	0.00	1.23	0.00	2006	2.50	0.00	0.69	0.40
1986	3.00	0.00	0.14	0.00	2007	2.50	0.00	0.85	0.19
1987	3.50	0.00	1.40	0.02	2008	1.20	0.00	0.71	0.50
1988	3.50	0.10	1.50	0.07	2009	0.73	0.00	0.82	0.38
1989	2.80	0.00	1.00	0.07	2010	0.77	0.00	0.40	0.42
1990	2.85	0.00	0.97	0.26	2011	0.77	0.00	1.01	0.37

Figure

Fig. 1 Fishermen on Lake Kinneret in the 1940s (left, photo by G. Eric Matson, the Library of Congress) and in the 2013, using a purse seine (right, photo by I. Ostrovsky).

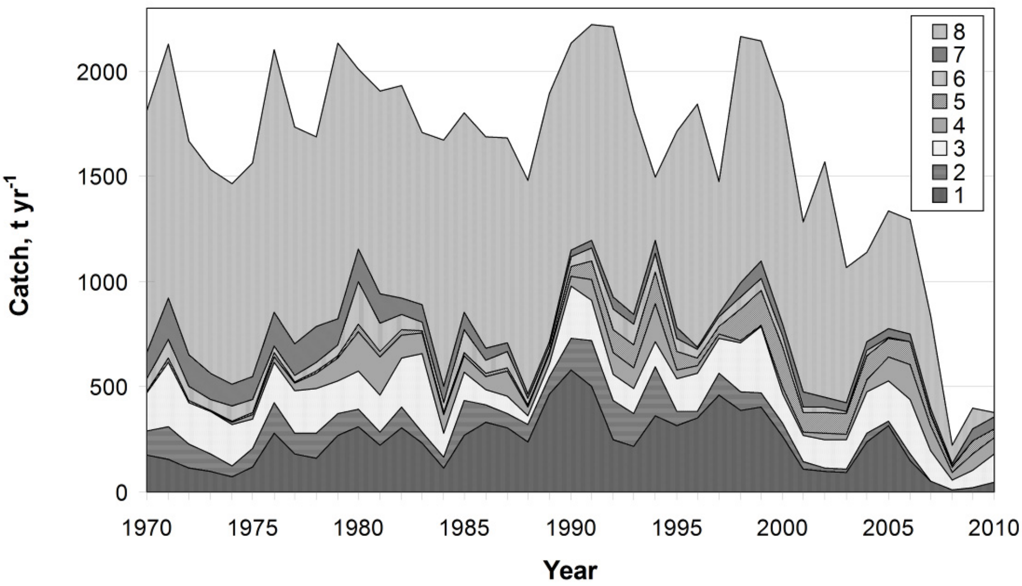

Fig. 2 Annual catches of the main fish species in Lake Kinneret, 1970-2010.

1- *Sarotherodon galilaeus*, 2- *Oreochromis aureus*, 3- Mugilids (*Liza ramada* and *Mugil cephalus*), 4- *Hypophthalmichthys molitrix*, 5- *Cyprinus carpio*, 6- *Tristramella simonis*, 7- *Barbus spp*., 8- *Mirogrex terraesanctae*. Data: Ministry of Agriculture and Rural Development, Department of Fisheries and Agriculture.

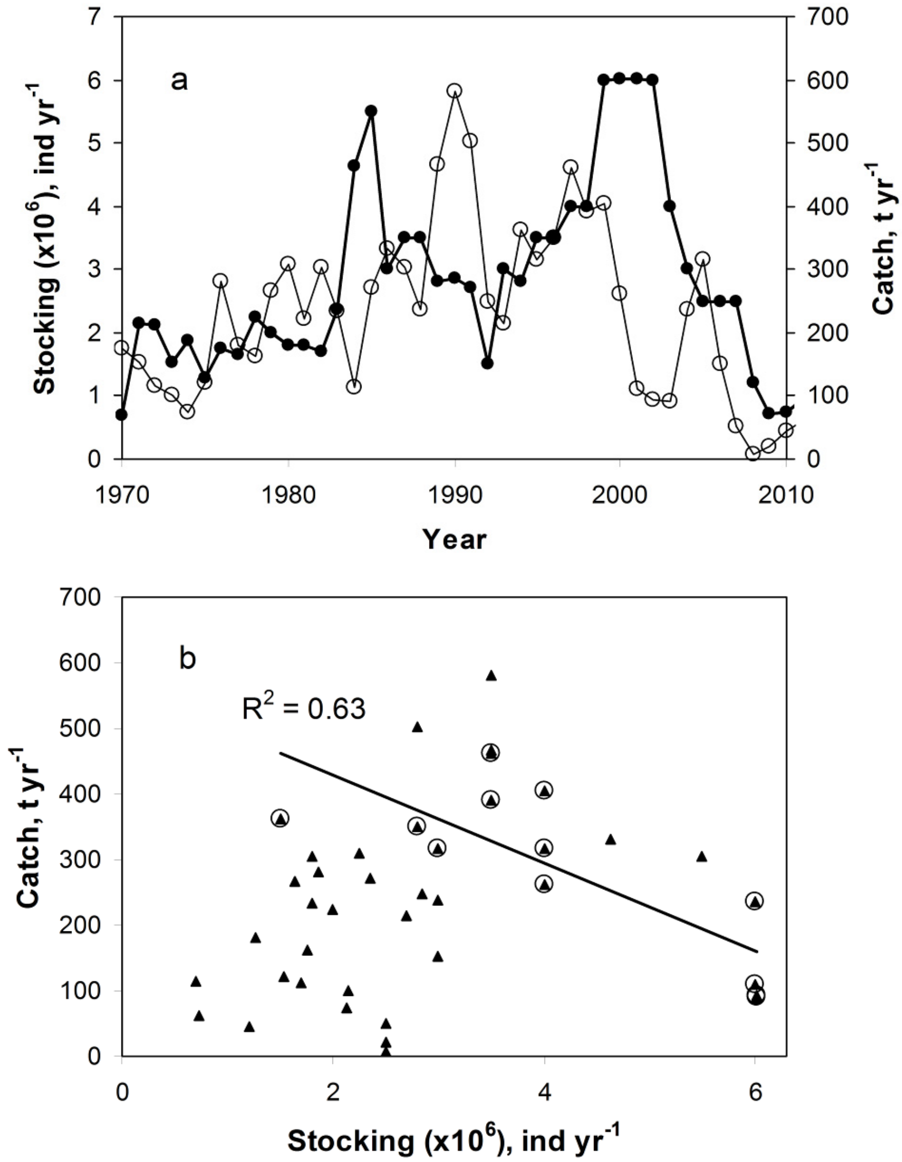

Fig. 3 Annual stocking and catch of *S. galilaeus* in Lake Kinneret.
(a) The temporal dynamics; fish stocked are shown in filled circles; catches are shown in empty circles. (b) The relationship between the number of fingerlings stocked and their catch two years later; fish stocked between 1970 and 2009 are shown in small triangles (R^2 = 0.032, n=40, P>0.05); fish stocked between 1992 and 2003 are circled (R^2 = 0.63, n=12, P<0.01). Data: Ministry of Agriculture and Rural Development, Department of Fisheries and Agriculture.

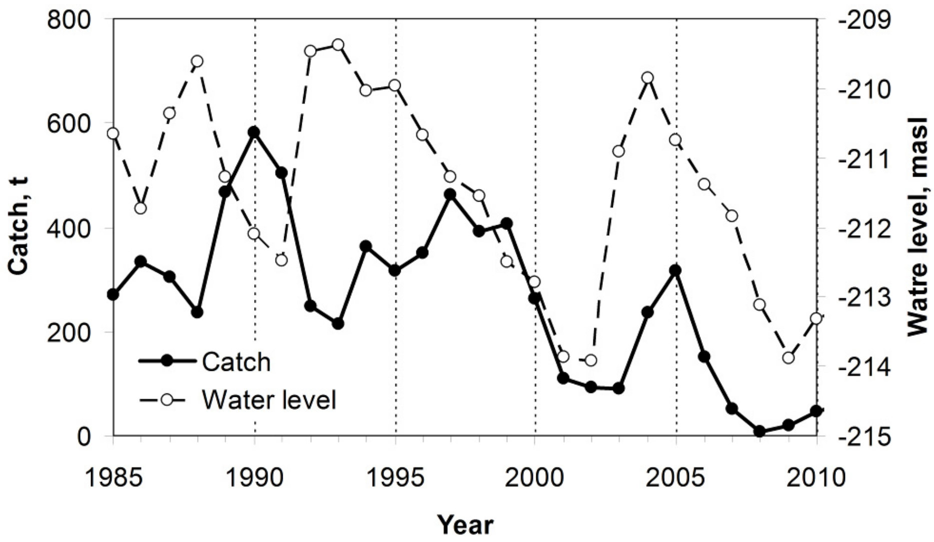

Fig. 4 Changes in annual catches of tilapia *S. galileus* (full circles) in relation to the mean annual water level (empty circles). A negative correlation between *S. galilaeus* annual catch and annual mean water level was observed until 1998. Since 1999 the catch co-varied with water level, until the virtual disappearance of *S. galilaeus* in the catches of 2007-2011. Water level is presented in meters above sea level (masl). Data sources: Catch - Ministry of Agriculture and Rural Development, Department of Fisheries and Agriculture; water level - Israel Hydrological Services.

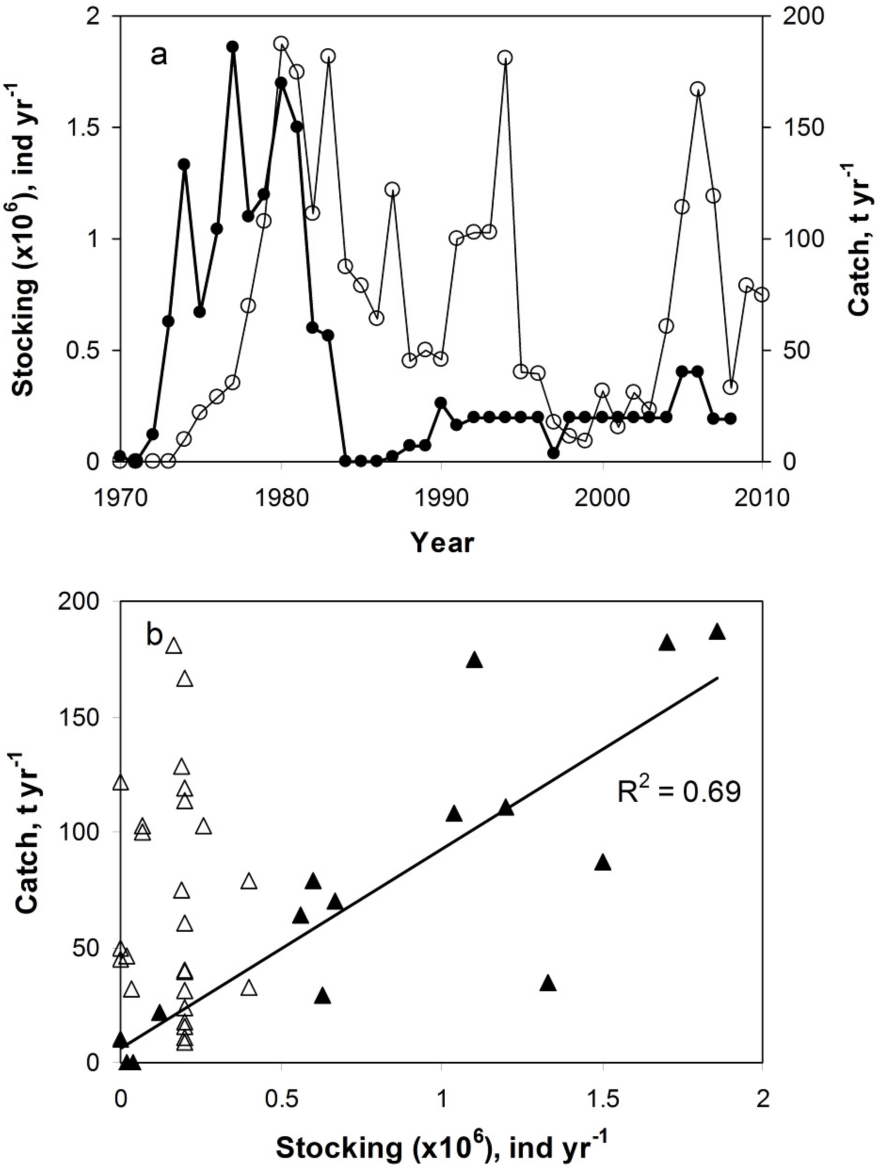

Fig 5: Stocking and annual catch of *H. molitrix* in Lake Kinneret, 1969-2011.
(a) Temporal dynamics; fish stocked are shown in filled circles; catches are shown in empty circles. (b) The relationships between the number of stocked fish and their catch three years later, when they first reached commercial size; fish stocked between 1969 and 1983 are shown in filled triangles (R^2 = 0.69, n=15, p<0.001); fish stocked between 1984 and 2008 are shown in empty triangles (R^2 = 0.0035, n=25, p>0.05). Data: Ministry of Agriculture and Rural Development, Department of Fisheries and Agriculture.