Hydrology and Cranes Attraction Partnership

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The Hula Valley in northern Israel was partly covered by swamps and a shallow lake. The entire valley was drained and converted for agricultural cultivation. Later, an additional soil reclamation operation was implemented, including eco-tourism. From the early 1990s, winter migratory cranes have attracted visitors, thus supporting the hydrological management of the entire valley that protects the downstream Lake Kinneret.

Keywords: cranes ; Hula Valley ; phosphorus ; pollution

1. Introduction

1.1. The Kinneret Drainage Basin

The region that is geographically defined as the Hula Valley (altitude between 100 and 60 mbsl) has a surface area of about 200 km^2 and provides about 7% of the watershed basin of Lake Kinneret [1] (**Figure 1**). The historic Hula wetland area within the valley generally refers to about 60 km^2 of the entire valley [1][2][3]. The regional climate conditions are Mediterranean [1], with an annual winter rainfall of 350–850 mm, followed by a hot and dry summer. The temperature minima and maxima are, respectively, 18 and 35 °C in summer and 3 and 20 °C in winter [3][4]. The Hula Valley and the surrounding slopes are one of the most ancient human habitats [5], dating back to 73,000 BC.

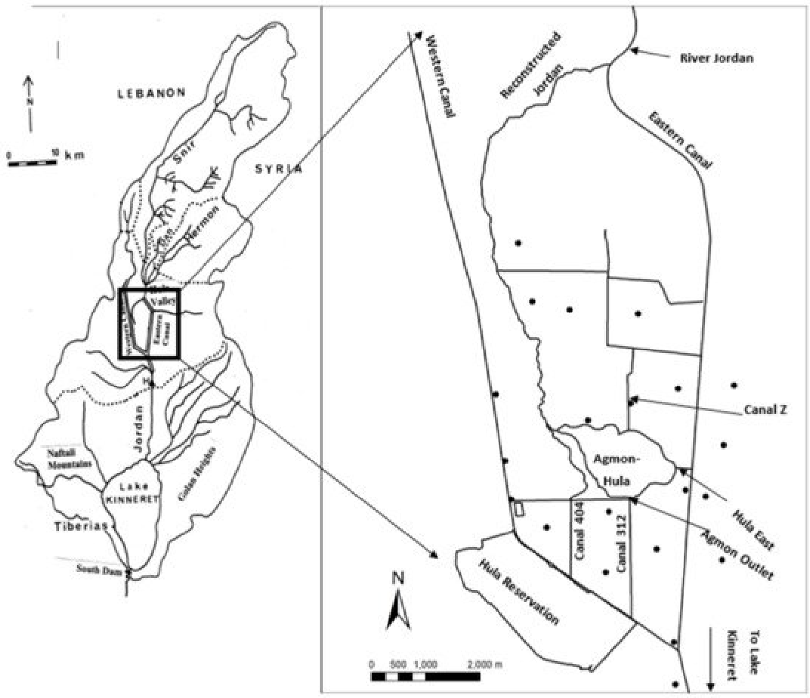


Figure 1. Geographical maps of the Lake Kinneret watershed with inflow rives (**left**) and the Hula Valley (**right**). Bore holes drills are indicated (black spots).

The Kinneret drainage basin (2730 km^2, altitude range 2284–2260 mbsl) is located mostly to the north of the lake. Its maximum length from north to south is 110 km, and the width is 50 km [6]. During the past 80 years, the Lake Kinneret drainage basin ecosystem has undergone significant anthropogenic and natural modifications. Prior to the 1950s, the Hula Valley was mostly (6500 ha) covered with old Lake Hula (1300 ha) and swampy wetlands. This area was not cultivated, malaria was common, and water loss by evapo-transpiration (ET) was high. The Jordan River, which crosses the Hula Valley, contributes about 63% of the downstream Lake Kinneret's water budget and 70% of the total nutrient inputs, of which over 50% originate from the Hula Valley region, including the valley and the slopes on both sides (east and west) of it. The old Lake Hula and its swamps were drained and converted for agricultural development. After the Hula drainage, the dominant N flux from the peat organic soil was modified from ammonium to nitrate. As a result of raw sewage removal and fishpond restrictions, the organic nitrogen flux into Lake Kinneret significantly reduced. As a result of inappropriate irrigation and agricultural methods, the peat soil quality deteriorated due to consolidation, destruction, and surface subsidence. This deterioration was accompanied by heavy dust storms [6] blocking drainage canals, due to peat organic soil dryness, resulting in deep cracks. This was followed by oxygen penetration, which accompanied exogenic decomposition of organic matter and heating, creating underground fires. The underground cracks, together with cultivated plant mater, immediately were populated by severe outbreaks of rodent populations. These deterioration processes caused severe damage to agricultural crops.

1.2. The Hula Reclamation Project

The Hula Reclamation Project (HRP) (**Figure 1**) was consequently implemented. The implementation of the HRP resulted in modifications to land use, which affected the regime of nutrient supply to Lake Kinneret. The HRP included the creation of a new shallow lake named Agmon (surface area 820 ha, mean depth 0.2 m, volume 0.164×10^6 m^3) [7]; the renewal of 90 km drainage and water supply canals, placing a vertical plastic barrier of depth 4.5 m such that it spanned a distance of 2.8 km along the valley from east to west; maintenance of a higher underground water table; and functional conversion of 500 ha of the Hula Valley land, including Lake Agmon in the center, from agricultural to eco-tourism usage. The objectives of the HRP were (1) nutrient removal from the Lake Kinneret external loads through the Lake Agmon hydrological system; (2) production of an ecological component for eco-tourism, i.e., Lake Agmon; (3) usage of Lake Agmon as a principle component of hydrological management and agricultural irrigation for the entire valley; (4) improvement of irrigation water supply through portable computerized spray water lines; (5) maintenance of a high underground water table to enhance peat soil moisture and prevent peat soil quality deterioration; and (6) re-establishment of highly diverse natural flora and fauna, with emphasis on aquatic birds.

1.3. Cranes in the Hula Valley

In the early 1990s, peanut cultivation became attractive due to its high beneficial value and productive success as a result of the suitability of the peat organic soil. The winter migrators, cranes (*Grus grus*), on their long-term southern traditional migration to Africa, discovered some leftover peanuts after harvest [8][9]. Thus, the flocks massively landed in October–November in the Hula Valley. The population of cranes in the Hula Valley therefore increased. Unfortunately, when the rains came, the wet peanuts started to ferment and became less attractive to the cranes, resulting in their looking for other food sources, thereby causing damage to agricultural crops. At this point, a conflict arose: on the one hand, cranes attracted bird watchers (eco-tourism), but on the other hand, crop damage became common, where significant water supply enhanced agricultural development, which was damaged by the birds [10][11]. The rationale behind the Hula Reclamation Project was the protection of the Lake Kinneret water quality, combined with the production of beneficial (income source) crops for the citizens of northern Israel. The advantages of the Hula Reclamation Project included additional water allocation and improvement of the canal and irrigation systems (portable computerized spray lines) to improve crops, as well as development of eco-tourism where the soil was unsuitable for agriculture [7][12]. The increase in the crane population resulted in damaging these benefits.

2. Discussion

There is a difference between nitrogen and phosphorus dynamics in Lake Agmon. The lake is a nitrogen sink. Nevertheless, previous studies have confirmed partial removal of nitrogen from the Lake Agmon waters through denitrification and sedimentation. The continuity of a positive TPbalance indicates supplemental TP resources other than peat soil drainage, possibly crane droppings and re-suspension and/or submerged macrophytes. Local daily migration of cranes in the Hula Valley indicates terrestrial allocation during the daytime and in the Lake Agmon shallows at night while excretion of their droppings into the water. A quantitative monitoring of the seasonality of above and sub-surface aquatic vegetation was carried out during 1997–2004 [13]. The submerged vegetation onset started in April and peaked through July–August, followed by offset with dieback disappearance in December. During winter time (December through April), the aquatic plant biomass is negligible. Results indicate an average dry weight biomass of 456.4 tons (min.-max. −140–817) contained 0.9 tons of TP (max.–min. −0.3–1.2) and 7.4 tons of TN (max.-min. −2.7–10.5). The supplemental TP and TN loads to Lake Agmon through aquatic vegetation as related to soil drainage input were 10% and 8%, respectively.

Lake Agmon was constructed during 1993 and filled with water in the summer of 1994. The ecological stability during the first years was partly flexible, and the Lake Agmon ecosystem was not yet stable. Therefore, nutrient mass balances were changed widely. For example, during the early 2000s, when the crane population was below 20,000, the TN and TP mass balance differed from the later period of 2008–2018. The TP balance prior to the crane migration was positive, and four years later, it was negative; therefore a significant contribution of TP by cranes is not suggested. Long-term records

(1995–2018) indicate average (high range of SD) TN and TP concentrations in the Lake Agmon outflow of 4.67 and 0.17 ppm, respectively. Although the total mass removal of nutrients through the Lake Agmon system is not high, how much is affected by crane migration was not primarily predicted. Nevertheless, the seasonality of vegetation growth and consequent nutrient loads was also unpredictible. The ecological significance of a newly constructed system, such as the Hula Reclamation Project, accompanied by crane migration initiated the present study.

The winter migratory cranes, which are fed supplementally by tons of corn seeds, are an essential source of phosphorus for the Lake Kinneret ecosystem. The four-month winter visit of cranes might therefore lead to lake pollution by phosphorus. The dynamics of water-mediated phosphorus input into Lake Kinneret is driven by the hydrological runoff and subterranean linkage between the Hula Valley and Lake Kinneret. Until the early 1990s, cranes were almost absent in the Hula Valley, excluding a few individuals. Since then, the valley has been populated annually from November through March by increasing numbers of cranes, up to 50,000 in the winter of 2019–2020 [8]. Leftover harvested peanuts attract the cranes in October–November. Peanut crops have been found to yield significantly high revenues and are suitable to be grown on the heavy-organic peat soil in the Hula Valley. In early to mid-December, the cranes start looking for other sources of food, thereby causing damage to winter crops. An efficient method aimed at prevention of agricultural damage has been improvised: Money is allocated as rental for a 40 ha field block in the valley, which serves as a feeding station for the cranes; here, corn seeds are purchased and fed to the cranes twice a day. Feeding starts in late December and continues until early March, when the cranes fly back to Europe for breeding [8].

This has proved to be efficient, but it has a costly disadvantage, since there is the tendency of phosphorus leakage into Lake Kinneret. This paper aims at suggesting ways of removal of the pollution parameter but also leaves room for further consideration of the unresolved issue of the financial cover source for the corn seed purchase.

A brief search of the literature about phosphorus metabolism of birds indicates a wide range of its excretion [14][15] Although cranes are not typical water fowls due to their day–night stay discrimination between terrestrial and aquatic habitats, they are not the only Lake Agmon inhabitants. Among other inhabitants are ducks, herons, pelicans, cormorants, mallards, and seagulls [16]. Big flocks of migratory birds, such as cormorants, pelicans, seagulls, and mallards, are distributed among northern water bodies (fishponds, reservoirs, Lake Kinneret, temporal ponds, regional rivers), whilst the cranes create huge flocks located in the Hula Valley and presently (>2004) assembled in Lake Agmon during nighttime. Pelicans create big flocks but stay for a short period (2–3 weeks) partly on terrestrial land and partly in Lake Agmon. Cormorants are scattered in singles and locally migrate to Lake Kinneret. Conclusively, cranes are the major group to be defined as potential TP contributors to Lake Agmon input loads.

The following data about phosphorus excretion by fowls were considered: *Mallard platyrinchos* and *Larus ridibundum*, 1–0.1 gP/bird/day [14]; cultured poultry broilers, 0.2–0.3 gP/bird/day [15]; and different migratory water fowls, 5.24 gP/bird/day (cranes and pelicans) and 3.5 gP/bird/day (cormorants) [17][18][19][20][21]. For the maximal effective value, the P excretion of cranes at 5.24 gP/bird/day was considered. Considering the presence of 50×10^3 cranes for 150 days (November through March) with 100% influx of their droppings into Lake Agmon waters, the annual P load from the birds would be (5.24 g) × (50,000 birds) × (150 days), which is equivalent to 39.3 tons. This is doubtless a significant extra load, which is almost 45% of the total measured annual input into Lake Kinneret from the River Jordan discharge. Nevertheless, this additional P load is not confirmed to be an extra loading to Lake Kinneret and likely also not a source of P to Lake Agmon. However, it was confirmed that this excreted P accumulates in the peat soil within the Hula Valley [22][23][24][25][26][27]. It is likely that P accumulation in the uppermost peat soil layer is probably not unlimited, and P migrates into the shallow subterranean groundwater table and most probably even much deeper. The role of migratory water fowls as nutrient vectors in managed wetlands was documented by Post et al. [28]. However, cranes as P vectors of corn seed P mediated into Lake Agmon and further on into Lake Kinneret were not confirmed.

The conflict between cranes and agriculture is well known and highly documented [8]. Cranes are protected by international laws; shooting them is illegal, and thus deportation should be done without shooting. A collaborative solution between farmers, nature authorities, water managers, landowners, and regional municipalities was contracted and implemented. Cranes that land prior to mid-December are deported without shooting, with the aim to reduce the number of potential feeders, thereby preventing damage and reducing the cost of corn seeds. Corn seed feeding starts in mid-December. Cranes are not nocturnal, and their diurnal behavior includes feeding during the day; then they spend the full-darkness period (about 12–14 h) in Lake Agmon. The daily schedule of the cranes comprises 10–12 terrestrial day hours and a 12–14-h night period in Lake Agmon. Their noisy and remarkable local migration is aimed at reducing their vulnerability to predators. It is likely that most of the crane excretion takes place in the Lake Agmon waters at night. Studies carried out on migratory birds documented an increase in daily foraging activity with daytime (light time) prolongation, and the opposite is reasonable because daytime activity levels depend on light conditions (sun elevation)

[29]. Moreover, Haynes et al. [30] documented intensive night activity of foraging and copulation by many species of water (wetland) birds, such as gulls (Laridae). Kostecke et al. [31] documented nocturnal time activity budgets consisted of foraging (62%) and resting (20%). A greater percentage of time was devoted to foraging and aggression, and less was spent resting at night [31]. Therefore, searching for the TP migration rate through Lake Agmon effluents is justified. Moreover, since 1994, the routine sampling of the Lake Agmon outflow has been carried out on a weekly basis in the mornings. The relevance of these samples to the evaluation of the impact of crane excretion on Lake Kinneret inputs might be criticized because the nocturnal stay of the birds is terminated before routine sampling. To avoid a biased conclusion, a calculation of the residence time (RT = inflow/volume) in Lake Agmon was done: the mean (2008–2018) value of the Lake Agmon daily inflow was 25.2×10^3 m^3, the Lake Agmon surface area is 82 ha, and the mean depth is 20 cm. Consequently, the Lake Agmon total volume is 164×10^3 m^3 and RT = 6.5 days, confirming the minority of daily flushing out of excreted crane droppings with accumulative potential. A major part of TP content in the crane droppings is due to the daily ingestion of food (corn seeds) collected outside Lake Agmon and results from resuspension carried out by bird stepping. Mass balances for TP in Lake Agmon indicate a negative regime, i.e., outflow is higher than inflow loads. These results, together with the results presented in **Figure 1**, support the conclusion about other sources besides crane droppings of the summer increase in TP in the Lake Agmon effluent. Moreover, during the period of 1970–1993, before the crane era (CE), the mean TP concentration was 0.224 ppm, whilst later (1994–2018), during the CE, it was 0.126 ppm. Conclusively, an increase in the TP concentration in Lake Agmon due to the activities of cranes is not confirmed. The Hula Valley annual contribution of TP and TN through the hydrological system of Lake Agmon, after the implementation of the Hula Reclamation Project (1996–2008), confirms the following: 1.2 and 26 tons of TP and TN, respectively, were removed from the Lake Kinneret external loads, which comprised 1.7% and 2.4% of the total loads of TP and TN, respectively [3][7][12][32][33]. Long- and short-term geochemical research on phosphorus and nitrogen dynamics within the peat soil in the Hula Valley, as well as in drainage canals in the vicinity of Lake Agmon [22][23][24][25][26][27] and in the subterranean waters, indicated high TP and TN levels. Nevertheless, the composition and dynamics of these pollutants in the River Jordan waters was not positively related to the soil and underground flows from the geochemical findings.

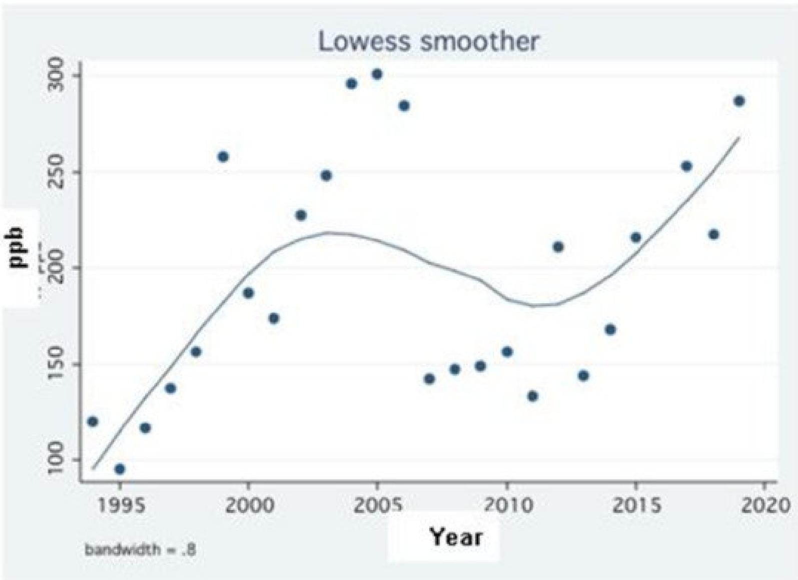


Figure 1. LOWESS smoother plot (bandwidth = 0.8) plot of the temporal (1994–2018) changes in annual averages of TP concentrations (ppb) in the Lake Agmon outflow.

This achievement initiated benefits for both landowners and farmers by generating income from about half a million bird watchers (charged visit), whilst the Hula Valley effluents were not significantly deteriorated. Moreover, the cranes were allotted a night habitat underneath the terrestrial eucalyptus trees, where they became vulnerable to predators (fox, wolf, mongoose, jackal). Therefore, the bird flocks changed from the night habitat to the protected refuge site in the newly created shallow Lake Agmon–Hula.

The crane management project (deportation and feeding) was designed to be part of a comprehensive objective aimed at enhancing ecosystem sustainability. The solution is conclusively summarized as follows: to reduce the agricultural damage on a fixed land site where cranes have gathered during the day to feed on corn seeds, leaving this area for the shallow lake at night, where they would be protected from predators. Bird watchers visits and the Hula Project lead to nutrient removal from Lake Kinneret loads. This crane management project represents an efficient “marriage” by establishing a balance between bird and limnological interests for the prevention of eutrophication in Lake Kinneret.

The Hula Reclamation Project was aimed at ensuring sustainability of modified eco-systems by formulation of a conflict between agricultural development, Lake Kinneret water quality protection, and nature conservation. The tension between farmers, water managers, and nature preservers was reduced, and there was collaboration instead. The outcome of the HRP was renewal of the ecosystem, which had become a tourist attraction, enriching the biological diversity with approximately 300 species of birds, including 40,000–50,000 wintering cranes annually, 40 species of water plants, and 12 species of fish. The new ecosystem of the shallow Lake Agmon–Hula with surrounded safari habitats ecosystem became a tourist attraction and maintenance investment. The potential contributors of water-mediated phosphorus include the following: Lake Kinneret headwaters, Lake Agmon–Hula, crane droppings, aquatic vegetation, and the major peat-soil-drained water pathways in the Hula Valley.

A tentative semi-conclusion at this point indicates two major points: Phosphorus removal from the Lake Kinneret loads through the Lake Agmon system is minor, and phosphorus enrichment occurs in the late summer–fall season. A working hypothetical assumption suggests sources of phosphorus other than crane droppings and resuspension. These other sources are peat soil geochemical flushing introduced into the Lake Agmon water column through water inflow. The second source is phosphorus uptake from the sediments, incorporated into plant tissues and later, as a result of plant decomposition, into the Lake Agmon water column. Earlier studies [34][35][36] and long-term records have indicated peat-soil-bounded phosphorus release mostly during summer dryness, which enhances linkage breaks between organic phosphorus and peat soil particles [37][38]. The dynamics of submerged high plants and algal organisms was documented. The most abundant organisms were, among others, submerged *Potamogeton* spp., *Najas* spp., *Myriophillum* sp., filamentous mats and scum of Cyanobacteria and Chlorophyta plants that stand out of the water, *Typha* sp., *Phragmites* spp., and others [39]. The seasonal dynamics of their growth rate, dry weight, and nutrient (N, P, K) content were documented. These measurements clearly indicated onset of vegetation growth during late March–early April and offset during September–November. It was confirmed that the plant degradation during fall contributes a significant amount of phosphorus as dissolved and particulate forms [39]. Earlier studies [40] have confirmed a significant elevation in the phosphorus concentration in the Lake Agmon waters during summer months. Moreover, the Hula Reclamation Project annual reports (1994–2018) documented a continuous increase in phosphorus concentration during summer months in the major canal that drains organic peat soil. The TP elevation is due to vegetation degradation and not crane activity. Therefore, to achieve a beneficial ecological project of crane attraction, the potential damage due to phosphorus pollution is eliminated and prevention of agricultural damage remains a major target. The long-term record confirmed that such an objective is feasible but expensive. Goodwill and friendly relations between all partners involved—landowners, farmers, hydrologists, and nature and Lake Kinneret protectors—make this achievement feasible.

The combination of beneficial crane attraction as bird watcher visits and hydrological management was confirmed. The merit of cranes as a complementary achievement of eco-tourism policy to the hydrological management of the Hula Valley was also confirmed. Data shown in **Figure 2** indicate similar enhancement of the TP concentration in the Lake Agmon effluent during 1994–2018 (Figure 13, left panel) without a particular impact of the crane migration. Moreover, a close relationship is shown (**Figure 3**) of the temporal pattern of changes between TP input and TP balance in Lake Agmon. No significant crane impact on these parameters is therefore suggested. The TP sources for the input loads are terrestrial, with probably a minor impact by cranes. Monthly means of the TP concentration in the Lake Agmon effluent (**Figure 4**, **Figure 5** right panel) justify the conclusion of significant TP concentration enhancement resulting from summer decomposition of aquatic macrophytes when cranes are absent. Moreover, during 1994–2018, the TP concentration during winter months (12, 1, 2, 3, 4) was quite stable (240 ppb), declined in May–June, followed by an abrupt and sharp increase (250–360 ppb) in summer–fall (July–November). Conclusively, the domination of TP concentration in the Lake Agmon waters is due to input (winter) and macrophyte decomposition (summer–fall) (**Figure 5** and **Figure 6**). Although the possibility of phosphorus pollution of the Lake Agmon waters by cranes was rejected, their agricultural damage is significant, and the solution to this damage is costly. Crane migration starts in late October, and they stay until late February to early March, for a total of 150 days. As of mid-December, cranes feed on the leftover peanut harvest and deportation is implemented by the landowners. From mid-December until backward natural migration, they are fed corn seeds in designated blocks, accompanied by partial low-level deportation from other blocks. During the 2003/4–2005/6 season, 250 tons of corn seeds were fed to the cranes in their designated blocks, whilst in 2020/21, 361 tons were fed to them. The crane population in the Hula Valley increased from below 20,000 before the 2000s to 50,000 in 2021 (**Figure 7**). Moreover, the number of visitors and bird watchers increased dramatically from <200,000 in the years 2005–2008 to 500,000 in 2021 (E. Naim and I. Inbar, JNF-KKL unpublished data).

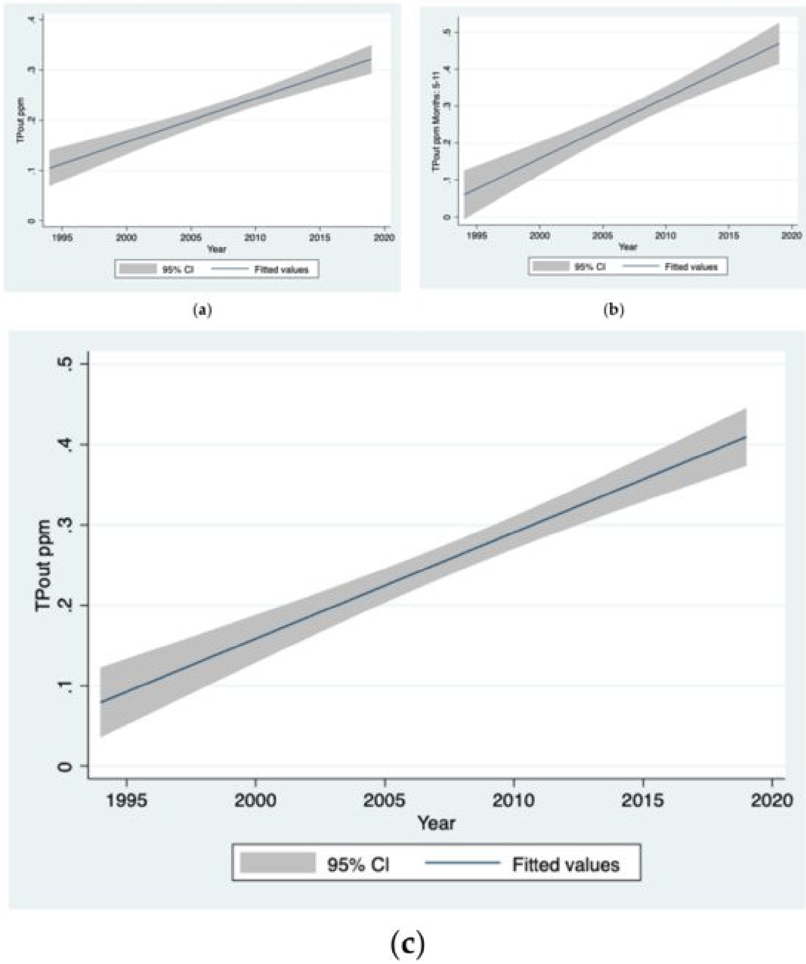


Figure 2. Linear regression (95% CI) between monthly means of TPout concentration (ppm) during crane months (12, 1, 2, 3, 4) (**a**) and no-crane months (5–11) (**b**) in 1994–2018. Linear regression (95% CI) between annual means of TPout concentrations (ppm) in (1994–2018) (**c**).

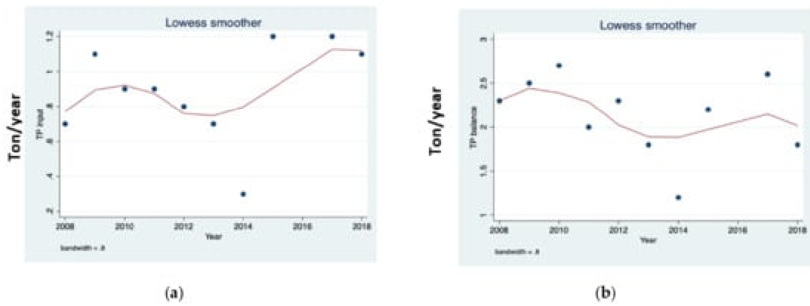


Figure 3. LOWESS smoother plot of trend in changes in annual loads (tons/year) of TPin (**a**) and TPbalance (**b**) during 2008–2018.

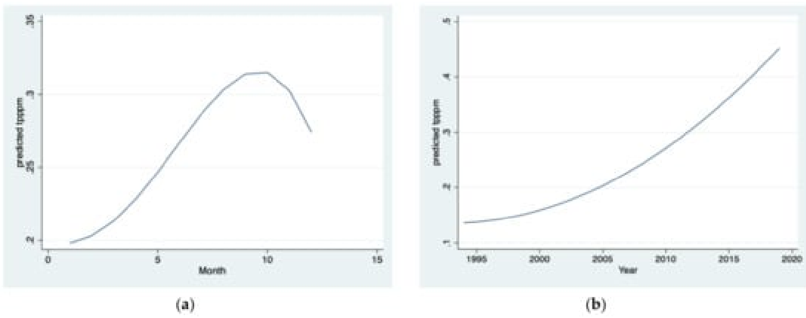
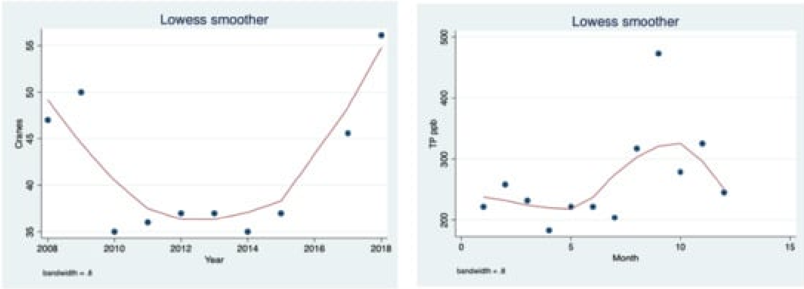
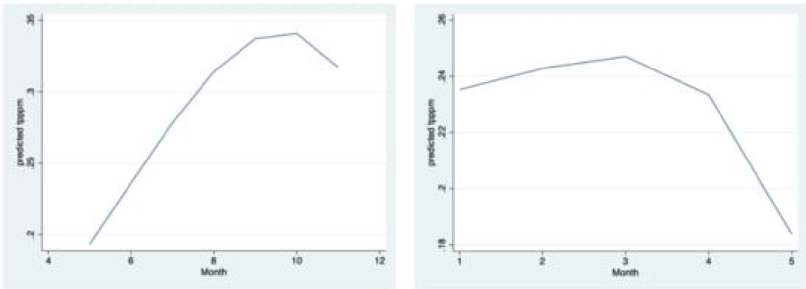


Figure 4. Fractional polynomial regression between monthly (**a**) and annual (**b**) means (1994–2018) of TPout concentrations (ppm).



(a) (b)

Figure 5. (**a**) Maximum cranes counted (10^3). (**b**) LOWESS smoother trend plot of changes in monthly means of TPout (ppb) during 1994–2018.



(a) (b)

Figure 6. Fractional polynomial regression between monthly means (1994–2018) of TPout concentration (ppm) and no-crane months (5–11) (**a**) and crane months (12, 1, 2, 3, 4) (**b**).

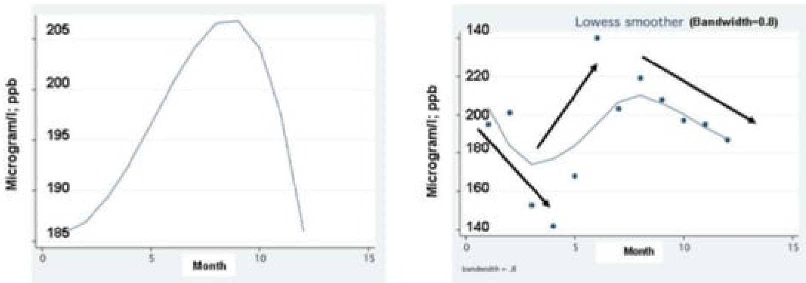


Figure 7. Monthly mean (1994–2018) fluctuations of TP concentrations (microgram/L; ppb) in the Lake Agmon outflow: **Left**: fractional polynomial regression. **Right**: LOWESS smoother plot (bandwidth = 0.8). Trends are arrowed.

The significance of the controversial conflict between the three ecological compartments is better understandable by supplemental information about the financial management of the crane project during the winter of 2020–2021 (O. Barnea, Director of the Agricultural Society of the Upper Galilee municipality, unpublished):

- Total fed (107 days) corn seeds—361 tons (cost 225,000 US$)
- Total cost of crane deportation (6552.3 ha)—2 × 10^6 US$.

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