The effects of *Oncorhynchus mykiss* culture on the limnological conditions of Hanna Reservoir, Isfahan, Iran

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Abstract

This study was conducted at the Hanna Reservoir located in the southwest of Isfahan Province. According to this study, chemical analyses were conducted to evaluate the magnitude and variations of COD, BOD_5, O_2, NH_3^+ and NO_2^-concentrations in the Hanna Reservoir. In the headwaters the magnitude values of BOD_5, COD and early morning oxygen minima were quite identical to the recommended optimum levels. However the concentrations of unionized ammonia in winter and spring and the concentration of nitrite in summer and autumn exceeded the allowable levels cited in different literature and might have exerted some growth retarding or lethal effects on the fish population. Water quality, zooplankton, benthos and sediments were monitored at sites of 20 m depths to determine the effects of rainbow trout cage culture on the lake environment. Oxygen depletion occurred in the vicinity of the farms due to respiration of the farmed fish. Zooplankton had stronger nutritional value in all six ecosystems of the Hanna Reservoir, and in seasons during which fish feed on these nutritional sources, breeding occurs with higher efficiency. Benthic invertebrates were rare at all six sites of the lake. The sediments below the cages had a pH and organic matter comparable to areas of the lake receiving the natural input of allochthonous material.

Keywords: Hanna reservoir, Fish, Benthos, Zooplankton

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Introduction

Commercial aquaculture in the Isfahan Province of Iran began in the 1990s and has expanded since that time, although it is still neither a large nor a prosperous industry. The availability of marine sites in the province is limited, so freshwater lakes are being considered for expansion of the industry. Consequently, since the wastes are phosphorus-rich, cage fish farming poses an eutrophication risk. In contrast, lake systems developed for aquaculture will probably have smaller volumes and lower flushing rates than marine areas (Ali and Alam, 1996). Oxygen will be recharged slowly and the wastes will remain in the vicinity of lake-based cages. Thus, the potential for the deterioration of site quality is greater in freshwater sites than marine sites. However, the impacts on a given lake are variable, depending on the farming practices, the size of the farm, the nature and volume of the wastes produced, the volume of the lake, the water exchange rate, and other characteristics of the water body (Phillips,1985).

Study site

The Agh Dagh, Rag Hanna, Dare Ali, Dela and Morvarid Mountains located in the southern part of the Isfahan Province form the Hanna River Watershed. The watershed is located at coordinates of 31º N, 51º W, and is adjacent to the south-west part of the large central watershed of the Iranian plateau, and is a small portion of the very large watershed of Karoon River.

Water samples from Hanna Reservoir and the headwaters were taken at monthly intervals from April 2015 through March 2016 in six selected silts. Whole water column samples, from the headwater, the river and shallow parts of the reservoir were taken with P.V.C. tubes with 5-cm diameter and from the deep parts of the reservoir using Ruttner bottle sampler.

During the summer samplings, limitations of the macrophyte community were identified by an Ekman Grab sampler and then the extent of macrophyte coverage was estimated by planimetery of water counter line map of the reservoir (Beveridge, 1984).

The main taxonomic group of macrophytes was identified according to Raju (1996). Six stations on the lake were regularly sampled. However, this was a much localized effect; the sedimentation rate returned to background levels within 10 m of the cages. The control sites were therefore well away from the areas directly affected by the farm wastes (Cressa and Senior,1990).

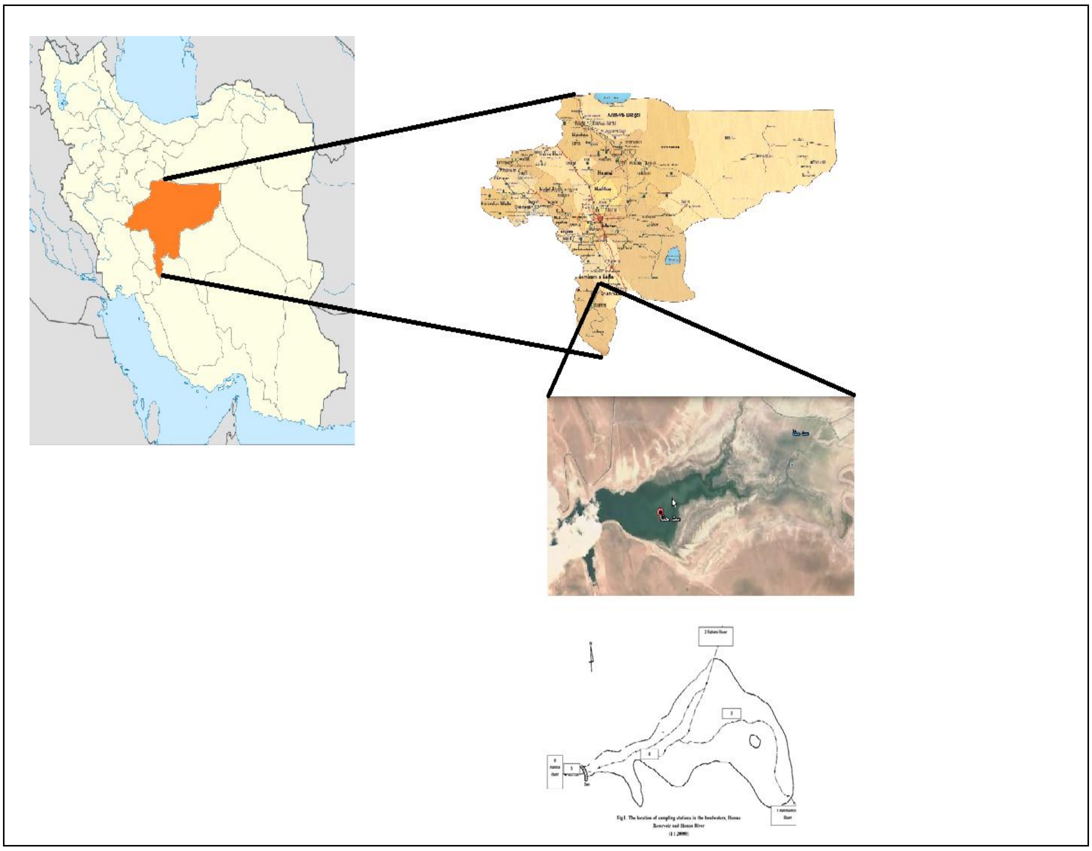

Figure 1: The location of sampling stations in the study area.

Materials and methods

Each of the 6 lake sites of Hanna Reservoir was sampled for indications of environmental impacts of the fish farm on the lake water quality, zooplankton, benthos, and sediments. Samples were taken monthly from March 2015 to April 2016. The input of PO_4 from the farm was determined by an analysis of the feed and by the company records of the feed given to the trout (Hecky and Kilham, 1988). Benthic organisms were sampled from each of the six sites using an Ekman dredge (Weston, 1988). The lake sediments were also sampled using a standard Ekman dredge.

Also in this research, the relationship between zooplankton and benthos with tekton density was studied in different seasons with statistical analysis in order to assess which conditions result in better fish breeding.

Results

Water quality

The highest and lowest values of mean depth, water inflow and surface area of the reservoir were observed in rainy and dry seasons, respectively, and the values of outflow and retention time were completely related to agricultural cultivation and dry seasons (Table 1).

Table 1: Comparisons of annual mean physicochemical parameters at the farm and control sites of Hanna Reservoir, with significance levels of Friedman's analysis of variance (NS=not significant) Relationship between depth, pH, Secchi depth, NH_4, turbidity and chlorophyll a.

	Depth	Farm	Lake	CSI	Friedman's
$PO_4(mgL^{-1})$	0	0/1	0/09	0/11	NS
$PO_4(mgL^{-1})$	7	0/09	0/10	0/10	NS
$PO_4(mgL^{-1})$	14	0/11	0/11	0/10	NS
$NO_3(mgL^{-1})$	0	0/05	0/09	0/07	NS
$NO_3(mgL^{-1})$	7	0/06	0/05	0/07	NS
$NO_3(mgL^{-1})$	14	0/06	0/06	0/05	NS
$NH_4(mgL^{-1})$	0	0/04	0/06	0/03	NS
$NH_4(mgL^{-1})$	7	0/04	0/04	0/05	NS
$NH_4(mgL^{-1})$	14	0/03	0/03	0/04	NS
Turbidity(Flu)	0	0/87	0/17	0/69	NS
Turbidity(Flu)	7	1/50	0/52	1/01	NS
Turbidity(Flu)	14	0/52	0/68	1/41	NS
Secchi Depth(m)		6/7	5/9	5/8	NS
Secchi Depth(m)	Max	9/8	10/8	10/0	
Secchi Depth(m)	Min	3/5	3/9	3/9	
pH	0	7	7/3	7/2	NS
pH	Max	8/1	8/1	8/1	
pH	Min	5/4	5/0	5/2	
Chlorophyll a	0	2/33	2/45	2/62	NS
Chlorophyll a	7	3/14	3/97	4/27	NS
Chlorophyll a	14	1/65	1/61	1/83	NS

Due to decrease in depth and volume of water in summer and autumn, approximately 2/3 of the surface area of the reservoir's upper shallow part dried out and its macrophyte communities were exposed to air (McQueen *et al*., 1986).

Rainy season in Hanna district lasted from November to April with monthly precipitation variation of 12 to 105 millimeters. The total annual precipitation was 248 millimeters. During the surveyed year Hanna area was very windy, especially in the summer months, when there were only three calm days in a month. But in late autumn and the whole winter, windy days significantly reduced.

There were significant differences in chloride concentrations between the two branches of headwaters. In Bahmanzad River, chloride concentration was minimum in April, May and December. The maximum amount was recorded in June. However Rahimi River was characterized by slightly higher chloride concentrations with two minima in April and July and two maxima in May and September followed by no significant changes in autumn and winter. Values remained similar to the levels of other oligotrophic lakes. Comparisons of annual mean physicochemical parameters at the farm and control sites of Hanna Reservoir, were carried with significance levels of Friedman's analysis of variance (NS=not significant) (Wetzel, 1983; Hart and Sherman, 1991).

In the mid-lake site only, as observed in other studies, PO_4 and NH_4 had accumulated in the hypolimnion. In the summer, they reached maximum levels of 8.1 mgL^{-1} and 5.97 mgL^{-1}, respectively. In two years, the O_2 in Hanna Reservoir, as in Lac du Passage, reached a maximum of 12 mgL^{-1} at the surface and a minimum of 0.7 mgL^{-1} at the depth of 14 m. On day 18 of the 28 sampling days, O_2 was significantly lower at the farm than at the control sites due to a depletion in the 0-9-m cage zone (Rast and Holland, 1988) (Fig. 2).

Figure 2: [Chl a] of (A) the epilimnion, (B) the metalimnion at the farm and control sites of Hanna Reservoir from 2015 to 2016.

The pH values were similar at the three sampling sites, indicating that the farm has had no effect on the pH (Table 1).

Epilimnetic, metalimnetic and hypolimnetic [PO_4], [NO_3], [NH_4], and turbidity levels at the farm and two of the control sites were similar (Table 1).

Sediments

The amount of organic matter in the farm sediments was similar to that at CS1. However, both of these sites were significantly higher in organic matter than the mid lake site (Friedman's ANOVA SS = 13.4, PC 0.00).

Zooplankton, benthos and tekton

A total of 236 Ekman grabs at the six lake sites produced only three benthic individuals, all chironomids. Benthic organisms were present in the littoral areas of the lake to a depth of 13 m. The dipteran bloodworm, Chironemus was most widespread, occurring in 32 of the 35 samples (Golterman, 1975; Cressa and Senior, 1990). Numerically, Daphnia spp. was the most abundant zooplankton throughout the year, constituting about 90% of the individuals counted (Clarke and Phillips, 1989).

Also in this research, we studied the relationship between the density of zooplankton and benthos with tekton density in different seasons in the Hanna Reservoir in order to assess which conditions result in increased fish productivity. The results are presented below.

A) Spring

According to the correlation coefficient (R = 0.407), the correlation between the density of zooplankton with tekton and benthos, in the spring season was moderate and in inverse. In other words, in spring in all six ecosystems, with zooplankton density proliferation, the tekton and benthos density decreased, and the reduction process was moderate.

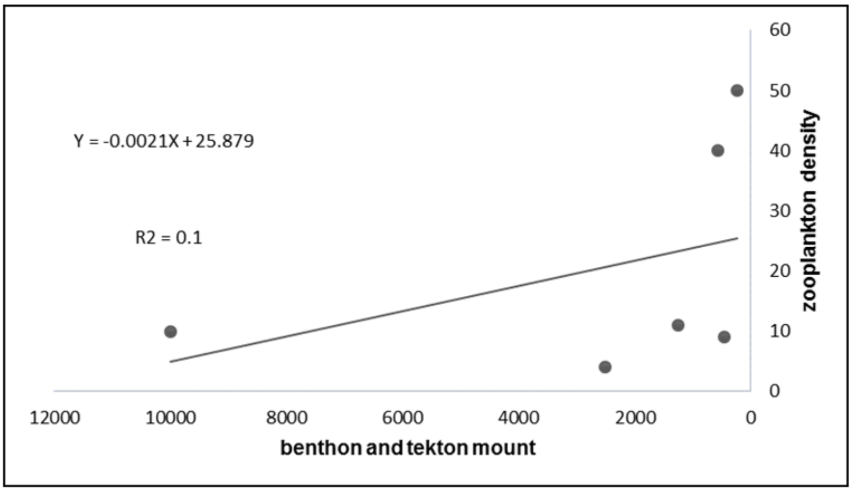

Figure 3a: Relationship between zooplankton density and benthos and tekton amounts in spring.

B) Summer

According to the correlation coefficient (R = 0.3232), the correlation between the density of zooplankton with tekton and benthos, in summer was weak and inverse. In other words, in summer, like in spring, increase in zooplankton density resulted in a decrease in tekton and benthos density. But unlike in spring the reduction process occurred with less intensity.

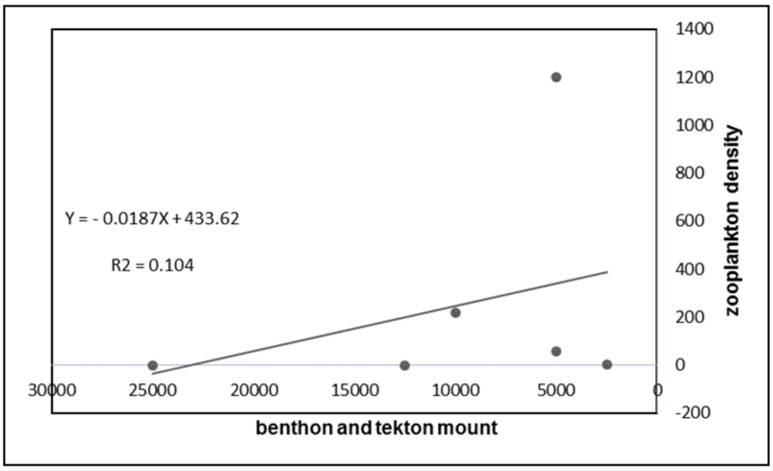

Figure 3b: Relationship between zooplankton density and benthos and tekton amount in summer.

C) Autumn

According to the correlation coefficient (R = 0.6091), the correlation between the density of zooplanktons with tekton and benthos, in autumn was strong and inverse. In other words, in autumn, unlike in other seasons, in all six ecosystems, with an increase in zooplankton density the tekton and benthos communities experienced proliferation as well. According to the figure the promotion process was strong.

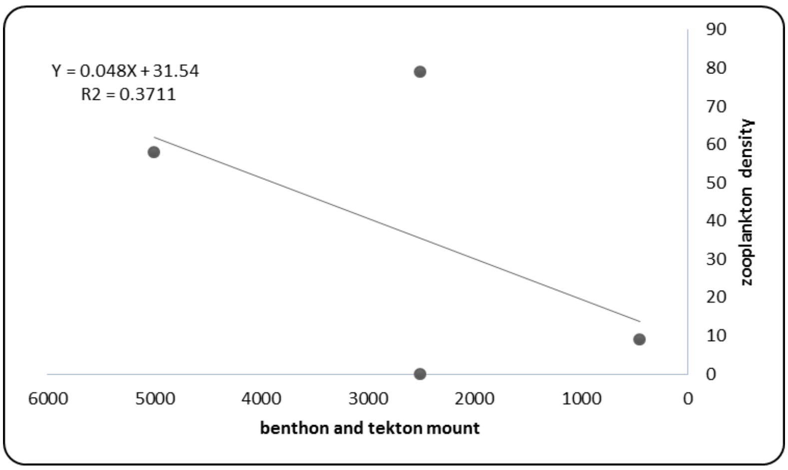

Figure 3c: Relationship between zooplankton density and benthos and tekton amount in autumn.

D) Winter

According to the correlation coefficient (R = 0.2830), the correlation between the density of zooplankton with tekton and benthos, in winter is weak and in a reverse direction. In other words, in winter in all six ecosystems, increase in zooplankton density resulted in a decrease in tekton and benthos density, and according to the slope of the graph the reduction process was weaker than in autumn.

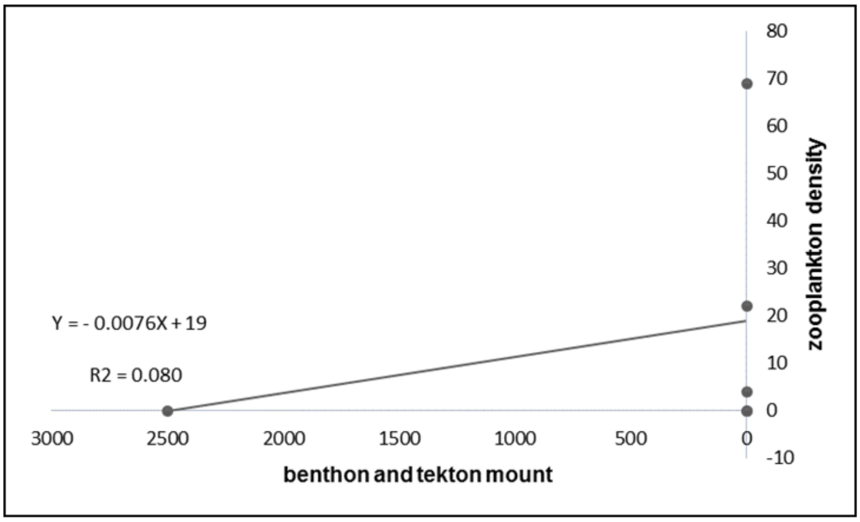

Figure 3d: Relationship between zooplankton density and benthos and tekton mount in winter.

Discussion

Rain is the main component of precipitation in the watershed and snow is usually rare. The irrigated lands lie along the headwaters. During agricultural season water from Bahmanzad and Rahimi Rivers flows to agricultural lands and due to the relatively high slope of the grounds accumulates at the end of the patches and then overflows to the same river. As a result several different chemical components get washed out towards the headwaters. This caused high levels of ionic concentrations in the headwaters, especially for calcium. Due to high calcium concentrations, the headwaters were considered as hard waters. High hardness was also reported in Siahrod and Haraz Rivers which were exposed to industrial and agricultural pollution (Brooks, 1969). In these rivers the concentration of sodium ions were higher than that of magnesium. Therefore in addition to calcium and magnesium salts, the sodium salts especially sodium chloride were also important in headwaters. On a world scale, the cationic and anionic composition of rivers have been reported as $Ca^{2+} > Mg^{2+} > Na^{+} > K^{+}$ and $HCO_3^{-} > CO_3^{2-} > SO_4^{2-} > Cl^{-}$, respectively (Barica, 1990).

In the watershed the ionic composition mentioned above changed significantly. The composition of $Ca^{2+} > Na^{+} > Mg^{2+} > K^{+}$ in volcanic watershed and $Cl^{-} > SO_4^{2-} > CO_3^{2-}$ in very soft waters was dominant. In rivers with watersheds containing marine deposits and exposed to agricultural and industrial pollution the ionic composition changed to Cl^{-}>HCO_3^{-} >SO_4^{2-} and Na^{+} >Mg^{2+}>Ca^{2+}>K^{+} (Wildish *et al*.,1988). Similarly in the headwaters of the Hanna River, the watershed properties, climatic conditions and agricultural pollution identified the ionic composition of the water.

The measured mean of 5.1 mgL^{-1} of carbonate concentration in the reservoir was significantly lower than the reported mean of 11 mgL^{-1} in Parishan Lake (Esteky, 1997). This amount was even lower than the average of 14 mg\L reported for a lake in North America (Awadallah and Mollas, 1996).

The average reservoir bicarbonate concentration of 181 was more than the concentration of 30 mgL^{-1} in Parishan Lake and 93 mgL^{-1} in a lake in North America (Awadallah and Moallas, 1996). It was also higher than 152 mgL^{-1} reported for a lake in Estonia (Bergman and Peters, 1980). In all of the collected samples, chloride concentrations in headwaters were slightly higher than in the reservoir. Therefore chloride concentrations did not increase in the reservoir and its prevalence in ionic composition was a result of vast absorption and reduction of bicarbonate ions through intensive photosynthetic activities. These findings in the Hanna Reservoir do not agree with that of Rippey and Wood (1985), who postulated that evaporation is the main reason for prevalence of chloride ions in the ionic composition of many reservoirs and lakes (Bermner and Keeney, 1996).

There were no significant differences in sulfate concentrations between the headwaters and the reservoir. During the surveyed year the fluctuation of sulfate concentrations of most samples was also not significant. It is well known that in aerated aquatic ecosystems such as the Hanna Reservoir sulfate is usually not an essential pathway for energy flow and the recycling of nutrient salts (Wetzel, 1983; Wright and Shapiro, 1984).

The cationic composition of Ca^{2+}>Mg^{2+}>Na^{+} in the headwaters changed to Mg^{2+}>Ca^{2+}>Na^{+} when retained in the reservoir. Increase in photosynthetic activities and pH were the reasons for calcium carbonate precipitation and reduction. In the Hanna Reservoir white deposition of calcium carbonate covered vast populations of macrophytes in dried littoral areas; coverage of macrophytes with precipitated calcium carbonate dominated lakes (Boyd, 1998).

The Hanna Reservoir has been the site of aquaculture for 4 years. Several changes have taken place in the lake environment, presumably due to the installation of the cages. These included an oxygen depletion in the vicinity of the cages, decreased densities of Daphnia around the farm, an increased sedimentation rate below the cages and an increase in sediment pH, % organic matter and [available P] below the farm compared to the control sites. These are all common short-term impacts associated with cage farming (Beveridge, 1984; Gowen and Bradbury, 1987; Anonymous, 1988). In the Hanna Reservoir, an accumulation of NH_4 is evident in the hypolimnion at the mid lake site. At this depth (below 20 m), conditions are anoxic and thus the accumulation probably results from the decomposition of organic material and the release of ammonium from the sediments (Wetzel, 1983). Ammonium can be directly toxic to fish between 0.5 and 2.5 mgL^{-1} (Weston, 1988). Since the maximum levels in the Hanna Reservoir are considerably lower than this range in all except the deepest portions of the lake, there is little threat to farmed or indigenous fish. Furthermore, the areas of ammonium accumulation have very low concentrations of oxygen and could not support fish life. As with the phosphorus, ammonium is probably isolated in the hypolimnion since little mixing seems to occur. Consequently, ammonium is unavailable to algae and will contribute little to lake productivity (Boulanger, 1984).

The community structure and biomass of the phytoplankton are regulated mainly by nutrient availability (i.e. bottom-up dynamics) (McQueen *et al*., 1986). Cage aquaculture can disturb trophic relationships in a lake by the addition of nutrient sources for primary producers. In the Hanna Reservoir, available nutrients are probably assimilated quickly by the algae, eventually increasing their productivity. Subsequent changes in the zooplankton population estimated by these changes in the algal populations may occur. Most commonly, species abundance is altered, with less effect on species composition (Brooks, 1969). Cage farms operated in lakes managed for fisheries could be a source of "fertilizer" and thus benefit other users of the lake. Aquaculture facilities are of concern as they may affect the quality of drinking water. The water in the Hanna Reservoir meets the norms for drinking and recreation. Fecal coliform levels were below the acceptable limit of 200 organisms/ 100 mL (R. Fisher, pers. Commun.), the pH fell in the prescribed range (6.5-8.5) and nitrate levels were well below 10 mgL^{-1}. The water from the Hanna Reservoir is used for drinking, washing and swimming with no ill effects.

In the Hanna Reservoir, there was evidence of short-term, localized impacts of a rainbow trout cage farm. These included a local depletion of oxygen levels, a decreased density of daphnia in the vicinity of the cages and changes in these dements below the farm (Dewis and Freitas, 1984).

According to the strong correlation coefficient in autumn, it can be said that in terms of this test, zooplankton have had stronger nutritional value in all six ecosystems of the Hanna Reservoir, in seasons in which fish feed on these nutritional sources breeding occurs with higher efficiency.

Aquaculture of rainbow trout in the Hanna Reservoir had various effects which were short term and restricted to the area of study. Increase in the density of daphnia and reduction of oxygen levels in the district were two of the many impacts of fish farming. According to the current level of nutrients produced by rainbow trout (about 14 tons/year) there is a small likelihood of exceeding the short term buffering capacity of the Hanna Reservoir. Due to the complication of the food web relationships it is difficult to predict the long term effects of fish farming on the surrounding environment. From this research it can be concluded that by choosing appropriate oligotrophic lakes for aquaculture, good results in fish production is likely to be achieved and by regularly monitoring these sites the long term effects of aquaculture on the environment can be assessed. More studies should be done in the future to evaluate the environmental deprivation resulting from aquaculture in the Hanna Reservoir.

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