Journal of Geoscience and Environment Protection, 2017, 5, 12-23
http://www.scirp.org/journal/gep
ISSN Online: 2327-4344
ISSN Print: 2327-4336

Rainbow Trout (*Oncorhynchus mykiss*) Cage Culture: Preliminary Observations of Surface Sediment's Chemical Parameters and Phosphorus Release in Gokcekaya Reservoir, Turkey

Seda Karakoca, Akasya Topcu*

Agricultural Faculty, Department of Aquaculture and Fisheries Engineering, Ankara University, Ankara, Turkey
Email: *atopcu@ankara.edu.tr

How to cite this paper: Karakoca, S. and Topcu, A. (2017) Rainbow Trout (*Oncorhynchus mykiss*) Cage Culture: Preliminary Observations of Surface Sediment's Chemical Parameters and Phosphorus Release in Gokcekaya Reservoir, Turkey. *Journal of Geoscience and Environment Protection*, **5**, 12-23.
https://doi.org/10.4236/gep.2017.54002

Received: March 21, 2017
Accepted: April 16, 2017
Published: April 19, 2017

Abstract

This research was conducted in Gokcekaya Reservoir, which is located on the Sakarya River (Ankara, Turkey). Sediment samples were obtained before and after culture periods at a rainbow trout (*Oncorhynchus mykiss*) farm with a capacity of 950 $t \cdot y^{-1}$. Total phosphorus (TP: 8.80 ± 0.50 and 9.10% ± 0.20%), total nitrogen (TN: 17.0 ± 0.20 and 17.05% ± 0.10%), organic matter (OM: 14.40 ± 0.40 and 14.60% ± 0.20%), redox potential (327.00 ± 0.08 and 170.00 ± 4.08 mV), water content (97.68 ± 0.28 and 96.38% ± 0.41%) and total organic carbon (TOC: 11.30 ± 0.10 and 13.40% ± 0.10%) were measured before and after the culture period, respectively. The mean rank order of sediment heavy metal was evaluated as Fe > Mn > Ni > Zn > Cr > Cu. The soluble reactive phosphorus (SRP) concentrations in the sediment pore water were 2.52 ± 0.14 and 7.75 ± 1.18 $\mu g \cdot L^{-1}$; ammonium (NH_3) was measured as 1.13 ± 0.09 and 1.18 ± 0.06 $\mu g \cdot L^{-1}$; nitrite (NO_2) was 8.83 ± 0.23, 12.75 ± 0.22 $\mu g \cdot L^{-1}$; nitrate (NO_3) was elevated at 0.14 ± 0.07 and 0.24 ± 0.02 $\mu g \cdot L^{-1}$, and positive phosphorus release remained at low levels: 3.35 $\mu g \cdot m^{-2} d^{-1}$ (before the culture period, September 2011) and 11.04 $\mu g \cdot m^{-2} d^{-1}$ (after the culture period, April 2012). The data on the sediment and the sediment pore water of the rainbow trout culture in Gokcekaya Reservoir shows that the cage culture in its present condition has no negative effect on sediment quality.

Keywords

Cage Culture, Gokcekaya Reservoir, Phosphorus Release, Rainbow Trout, Sediment

1. Introduction

Lakes and reservoirs generally have a slower and a weaker flow rate with a lower water exchange capacity in comparison with marine environments. Therefore, the effect of wastes, uneaten feed and the feces of fish, emerging from inland aquaculture net cages may be greater than the effect of those originating from marine cages. For this reason, the environmental impact of net cage activities in inland waters must be investigated in terms of sustainability [1]. Intensive cage aquaculture in inland waters may sometimes result in an increase in nutrient levels of the water due to the enrichment of the nitrogen-phosphorus load, organic matter or particulate nutritive elements. Sediment plays a key role in the phosphorus cycle as a source of or trap for phosphorus; consequently, because of its importance in the eutrophication process of lakes [2].

The potential impacts of cage aquaculture on the receiving water and sediment can be listed as follows: algal bloom, increase in organic nutrients in the sediment, alteration of the physical structure of some organisms, drainage, and disturbance of the hydrologic and hydrobiologic regimes. Parallel to the enrichment of organic matter, cage culture waste increases the nutrient level in the sediment [3].

In Gokcekaya Reservoir, a decision support system for the development of a sustainable cage aquaculture programme—for short, CADS_TOOL—was used at a rainbow trout cage farm with a 950 ton·year^{-1} capacity by [4]. The objective of this study was to determine the preliminary data and to evaluate the difference in the data gathered from the pre-culture and post-culture periods on diffusional phosphorus release from the sediment into the overlying water, some physiochemical parameters in the sediment and sediment pore water, as well as heavy metal concentrations in the sediment in Gokcekaya Reservoir, which hosts a newly-introduced rainbow trout cage farm with a production capacity of 950 t·y^{-1}.

2. Materials and Methods

2.1. Study Site

Gökçekaya Reservoir is located at 40˚03'46"N latitude, 31˚08/09'01"E longitude, and is 383 m above sea level. It was constructed on the Sakarya River between 1967 and 1972 in order to generate hydroelectrical energy. The water from Gokcekaya Reservoir empties into Yenice Reservoir. The region's mean temperature has been measured as 28.6˚C in summer and −1.3˚C in winter, with an annual mean temperature of 12.3˚C. Gökçekaya Reservoir, in a steeply sloped valley, runs parallel to the Sundiken Mountains and is surrounded by brown forest soil. Gokcekaya Reservoir's surface area and lake volume are 20 km^2 and 910 hm^3, respectively. The lake has a mean depth of 115 m and a mean width of 50 km [5] [6]. The present research was conducted at a cage fish farm producing portion sized rainbow trout (*Onchorynchus mykiss*), with a capacity of 950 t·y^{-1} between the years of 2011-2012 (before production period-after production period). During the growth period of *Onchorynchus mykiss*, extruded feed was used with 90% dry matter and 0.8% phosphorus content. In this study, the mean fish weight was measured at 0.3

kg with a survival rate of 80%; the feed conversion ratio (FCR) was 0.8; and the phosphorus retention of the fish was determined at 0.2%. Some hydromorphological parameters of Gokcekaya Reservoir are presented in Table 1.

2.2. Sampling and *in Situ* Analyses

Sediment samples were collected using an Eckman Birge grab beneath the selected cage farm station with a mean depth of 110 ± 3 m, then transferred to the laboratory in polyethylene bottles preserved in darkness to block the effect of sunlight. Sediment redox potential was estimated *in situ* with a pH-meter compatible with a redox potential sampling probe. The dissolved oxygen of the water was measured using an oxygen meter at the site.

2.3. Estimation of Sediment Analyses

Sediment samples were air-dried for a period of 20 days, homogenized by grinding, and finally passed through a 1.0 mm sieve for texture analyses in laboratory conditions. Organic matter (%) was determined by the loss of weight during ignition at 550˚C for 2 hours [7]. The water content of the sediment samples was determined by considering the difference between the samples before and after drying at 110˚C for 16 hours, according to [8]. The total organic carbon in the sediment samples was evaluated with an Organic Carbon Analyzer Unit, while total nitrogen values were determined by using a Total Nitrogen Analyzer Unit. The total phosphorus of the dried sediments was analyzed spectrophotometrically after digestion in a mixture of oxidizing acids with reference to [7]. Potential phosphorus release from the sediment into the lake water by molecular diffusion was calculated by Berner (1980) [9].

Flux = $\varphi.D.Q^{-2}$. dc/dx. 86,400 in which flux = SRP flux across the sediment-water interface (in $mg \cdot m^{-2} \cdot d^{-1}$).

φ = the water content by volume (dimensionless); D = molecular diffusion coefficient (varies according to temperature); Q^2 = tortuosity term ($\varphi^{-0.8}$); dc/dx = the SRP gradients across the sediment-water interface ($mg \cdot m^{-4}$); 86,400 = the factor to convert s to d.

Surficial sediment samples for Fe, Cr, Cu, Mn, Ni, Pb and Zn were dried at 60˚C for 24 hours, then sieved and measured after wet digestion with an atomic absorption spectrophotometer (Perkin-Elmer 2380) operating in the flame mode. The exchangeable fraction of metals was determined after extraction with a hydrofluoric/perchloric/sulfuric acid mixture. Detection of these metals was

Table 1. Hydromorphological parameters of Gokcekaya Reservoir.

Parameters	Gokcekaya Reservoir
Total outflow (106 $m^3 \cdot y^{-1}$)	1982
Farm length (m)	0.94
Cage raws	2
Cage volume (m^3)	2261

performed using the F-AAS technique [7].

2.4. Estimation of Sediment Pore Water Analyses

For 24 hours, sediment samples of 1600 g were centrifuged for 20 min at 3000 rpm to obtain pore water. The supernatants of the pore water were filtered through Whatman GF/C filters and then analyzed for soluble reactive phosphorus by the ascorbic acid method [10]; the pH of the pore water was measured after centrifugation but prior to filtration.

The Nesslerisation method was applied to the water samples to determine the concentration of ammoniac nitrogen (NH_3-N), calculated colorimetrically using the Nessler reactive reagent at a wavelength of 420 nm. Nitrite nitrogen (NO_2-N) concentrations were determined by diazotizing with sulfanilamide and coupling with N-1-naphthylethylenediamine dihydrochloride to form a color azo dye; then a colorimetric measurement was performed by spectrophotometer at 520 nm. In the nitrate nitrogen (NO_3-N) analysis, after the reaction between the nitrate ions and brucine, the absorbance of the yellow color was determined spectrophotometrically [10].

2.5. Statistical Analyses

Statistical analyses were performed using Minitab and MStat software for Windows. ANOVA and T-test were used to evaluate the differences between sampling periods in the sediment and sediment pore water parameters [11].

3. Results

During the research period, the sampling station's mean depth and Secchi depth were measured as 110 ± 3 m and 40 ± 2 cm, respectively. As for dissolved oxygen concentrations, the minimum value was 13.35 ± 0.13 $mg \cdot L^{-1}$ before the production period in September, whereas the maximum concentration (18.13 ± 0.17 $mg \cdot L^{-1}$) was elevated after the production period in April.

In the results of the T-test, which was conducted taking into account the data on all the chemical parameters of the sediment, the interaction between the pre- and post-production periods was determined. In this research, the sediment consisted mainly of silt, and the sediment texture was composed of 23.08% sand, 45.22% silt and 20.01% clay before the cage culture period (September), and 15.43% sand, 55.16% silt and 27.45% clay after the cage culture period (April).

During this research, the maximum water content of the sediment was established at 97.68 ± 0.28% (September), whereas the minimum content was found to be 96.38 ± 0.41% in April; the difference between the values was found to be statistically significant ($p < 0.05$) (**Table 2**). The sediment had redox potentials of 327.00 ± 008 mV and 170.00 ± 4.08 mV, respectively for the uncultured and cultured periods, a statistically significant difference ($p < 0.05$) (**Table 2**). The minimum and maximum values for the sediment organic material were evaluated at 14.40 ± 0.40 (September) and 14.6 ± 0.20 (April), respectively (**Table 2**). The difference between the organic material values was not found to be statistically significant ($p > 0.05$). The lowest (11.30 ± 0.10; September) and the highest (13.40 ± 0.10; April) total organic carbon values in the sediment were found to be statistically significant ($p < 0.05$) (Table 2). The values for the concentrations of sediment total nitrogen and total phosphorus are presented in Table 2. Sediment total phosphorus concentrations were 8.80 ± 0.50% (September; before the culture period) and 9.10% ± 0.20% (April; after the culture period), showing a statistically significant difference ($p < 0.05$). However, the difference in sediment total nitrogen values (%) (17.00 ± 0.10 - 17.05 ± 0.20) was not found to be statistically significant ($p > 0.05$) (Table 2).

In Gokcekaya Reservoir, the diffusional potential release of phosphorus from the sediment to the lake water by molecular diffusion (flux) remained at low levels: 3.35 $\mu g \cdot m^{-2} \cdot d^{-1}$ (before the culture period; September 2011), and 11.04 $\mu g \cdot m^{-2} \cdot d^{-1}$ (after the culture period; April 2012).

In this research, we investigated heavy metal concentrations (Fe, Cr, Cu, Mn, Ni, Pb and Zn) that might have accumulated in the sediment beneath the cage farm in Gokcekaya Reservoir as an outcome of aquaculture activities, such as uneaten feed, feces, metabolic excretion, antifoulants and detritus material. Significant differences were determined in all heavy metal concentrations between the periods (pre- and post-culture periods) (Table 3). Correlation coefficients

Table 2. Difference in sediment parameters according to period (before culture: September and after culture: April) (Mean value ± Standard deviation, n = 4).

Parameters	Months	
	September	April
Redox potential (mV)	$327.00 \pm 0.08^{b*}$	170.00 ± 4.08^{a}
Water content (%)	97.68 ± 0.28^{b}	96.38 ± 0.41^{a}
TP (%)	8.80 ± 0.50^{a}	9.10 ± 0.20^{b}
TN (%)	17.00 ± 0.20^{a}	17.05 ± 0.10^{a}
TOC (%)	11.30 ± 0.10^{a}	13.40 ± 0.10^{b}
OM (%)	14.40 ± 0.40^{a}	14.60 ± 0.20^{a}

*Means in the same row with different subscripts differ statistically significantly ($p < 0.05$).

Table 3. Heavy metal concentrations ($\mu g \cdot g^{-1}$ DW) in the sediment of the study area (Mean value ± Standard deviation, n = 4).

Parameters	Months	
	September	April
Fe	$88.780 \pm 4.650^{a*}$	166.510 ± 9.150^{b}
Cr	0.212 ± 0.012^{a}	0.437 ± 0.031^{b}
Cu	0.169 ± 0.008^{a}	0.304 ± 0.012^{b}
Mn	2.796 ± 0.119^{a}	5.414 ± 0.210^{b}
Ni	0.258 ± 0.010^{a}	0.493 ± 0.025^{b}
Pb	0.066 ± 0.003^{a}	0.100 ± 0.002^{b}
Zn	0.262 ± 0.015^{a}	0.491 ± 0.034^{b}

*Means in the same row with different subscripts differ statistically significantly ($p < 0.05$).

Scientific Research Publishing

between heavy metal concentrations (Fe, Cr, Cu, Mn, Ni, Pb and Zn) and sdiment chemical parameters of the study area were given in Table 4.

Data on the sediment pore water of Gokcekaya Reservoir are given in Table 5. Pore water pH values were 7.69 ± 0.04 (September) and 7.77 ± 0.01 (April). The highest concentration of SRP in the pore water was recorded as 7.75 ± 1.18 $\mu g \cdot L^{-1}$ in April, whereas the lowest value was measured at 2.52 ± 0.14 $\mu g \cdot L^{-1}$ in September. Ammonia concentration reached its maximum value (1.18 ± 0.06 $\mu g \cdot L^{-1}$) in the pore water in April, whereas the lowest value (1.13 ± 0.09 $\mu g \cdot L^{-1}$) was determined in October. The lowest nitrite (8.83 ± 0.23 $\mu g \cdot L^{-1}$) and nitrate (0.14 ± 0.07 $\mu g \cdot L^{-1}$) concentrations in the sediment pore water were found in September (Table 5). Meanwhile, changes in SRP, nitrite and nitrate concentrations were found to be statistically significant ($p < 0.05$), whereas differences in ammonia values were determined to be insignificant.

Table 4. Correlation coefficient between heavy metal concentrations (Fe, Cr, Cu, Mn, Ni, Pb and Zn) and sediment chemical parameters of the study area (n = 8).

	Zn	Pb	Ni	Mn	Cu	Cr	Fe	TOC	OM	TN	TF
TF	0.880**	0.899**	0.914**	0.919**	0.913**	0.897**	0.896**	0.961**	−0.266[a]	0.303[a]	-
TN	−0.035[a]	−0.102[a]	−0.020[a]	−0.042[a]	−0.066[a]	−0.016[a]	−0.046[a]	0.072[a]	−0.162[a]	-	
OM	−0.097[a]	−0.145[a]	−0.137[a]	−0.152[a]	−0.135[a]	−0.112[a]	−0.119[a]	−0.147[a]	-		
TOC	0.955**	0.974**	0.977**	0.982**	0.974**	0.964**	0.968**	-			
Fe	0.998**	0.993**	0.999**	0.996**	0.998**	0.999**	-				
Cr	0.999**	0.987**	0.998**	0.992**	0.995**	-					
Cu	0.993**	0.998**	0.999**	0.999**	-						
Mn	0.988**	0.998**	0.998**	-							
Ni	0.995**	0.994**	-								
Pb	0.984**	-									
Zn	-										

[a]Cannot be computed because at least one of the variables is constant. **Correlation is significant at the 0.01 level (2-tailed).

Table 5. Difference between periods (before culture: September and after culture: April) in sediment pore water SRP, ammonia, nitrite and nitrate (Mean value ± Standard deviation, n = 4).

Parameters months		
	September	April
pH	7.69 ± 0.04[a]*	7.77 ± 0.01[a]
SRP ($\mu g \cdot L^{-1}$)	2.52 ± 0.14[a]	7.75 ± 1.18[b]
NH_3 ($mg \cdot L^{-1}$)	1.13 ± 0.09[a]	1.18 ± 0.06[a]
NO_2 ($\mu g \cdot L^{-1}$)	8.83 ± 0.23[a]	12.75 ± 0.22[b]
NO_3 ($mg \cdot L^{-1}$)	0.14 ± 0.07[a]	0.24 ± 0.02[b]

*Means in the same row with different subscripts differ statistically significantly ($p < 0.05$).

4. Discussion

Nutrients tend to accumulate in the sediment under cage fish farms over a long time period, and especially the surface sediment is a source or a trap in which excess nutrients may lead to eutrophication; this matter should be studied in detail. Gokcekaya Reservoir has just been introduced to rainbow trout cage farming and has a production period of six months. Physio-chemical parameters of the sediment as well as heavy metals and sediment pore water data were determined for this cage farm before and after the production period.

Sediment organic material, total carbon, total nitrogen and total phosphorus in a low-capacity (20 $t\cdot y^{-1}$) cage farm in Kesikkopru Reservoir to quantify the effect of cage farms on sediment quality was evaluated by [12]. Total phosphorus concentration, organic material and total nitrogen values increased 2.6- , 1.08- and 1.3-fold, respectively. In Gokcekaya Reservoir with a rainbow trout cage culture production capacity of 950 $t\cdot y^{-1}$ over a 6-month production period, sediment total phosphorus and organic material values showed 1.03- and 1.01-fold increases; however, the total nitrogen value did not display statistically significant variation. Even if the capacity of this study is higher than the other study, the data were approximate; the probable reason for this is the fact that the research area is a newly-introduced cage culture.

During the research period in Gokcekaya Reservoir the minimum SRP concentration of the sediment porewater was 2.52 ± 0.14 $\mu g\cdot L^{-1}$ in the pre-production period, whereas the maximum SRP value was estimated as 7.75 ± 1.18 $\mu g\cdot L^{-1}$ in the post-production period. These SRP values are closer to [13]'s findings regarding the values encountered in oligotrophic aquatic systems. Pore water SRP values of <0.1 $mg\cdot L^{-1}$ pointed to the oligotrophy of the aquatic system was determined by [14]. The results regarding SRP values in this study are <0.1 $mg\cdot L^{-1}$; this shows that the trophic state of Gokcekaya Reservoir is oligotrophic. Moreover, considering that Gokcekaya Reservoir is new to cage farm fish production, it can easily be said that the cages do not have a negative effect on the sediment at present.

Sediments are the main components of limnological studies and are generally used in determining the trophic levels of lakes. During our study, Gokcekaya Reservoir's potential phosphorus release from the sediment to the lake water by molecular diffusion (flux) was estimated at 3.35 $\mu g\cdot m^{-2}\cdot d^{-1}$ in September 2011 (before the culture period) and 11.04 $\mu g\cdot m^{-2}\cdot d^{-1}$ in April 2012 (after the culture period). The estimated phosphorus release for the post-production period showed an increase when compared with the pre-production period. The phosphorus-release rates estimated in this study were considerably lower than the rates measured in shallow eutrophic aquatic environments by [15] [16]. Furthermore, the findings from this study support a positive relationship between clear water conditions and increased phosphorus retention. The phosphorus release season from the sediment into the reservoir water column was similar to the results of [17], which reported that the phosphorus retention was lower in the cold season in comparison with the warmer one.

The main variables affecting water quality in aquacultural areas are listed as total phosphorus, total nitrogen, total carbon, organic material and redox potential in the sediment. The effect of a cage farm with a capacity of 14 $t \cdot y^{-1}$ on an aquatic ecosystem in oligotrophic Passage Lake was investigated by [18]. In that study, the reason for the high measurements for organic material, pH, phosphorus and redox potential of the cages compared to the control station can be explained by the local effect of the cages. In Gokcekaya Reservoir, the sediment total phosphorus, total organic carbon and redox potential showed a statistically significant increase after the production period compared to the data from before the production period. There was no statistical variation in total nitrogen although organic waste released from cage fish farms is generally nitrogen-rich. This is because there was no pre-existing nutrient load originating from fish cage culture in the area.

The C/N ratio ranges between 4.5 - 8.5 in nutrient rich aquatic systems [19]. The C/N ratio in Gokcekaya Reservoir was estimated at 0.67 in September (pre-production) and 0.79 in April (post-production). These values are lower than those specified by [19], confirming the oligotrophic status of Gokcekaya Reservoir.

The effect of trout cage culture on the sediment and pore water during two production periods was examined by [20]. In the first production cycle, total nitrogen in the pore water increased, and at the end of the period, NH_3 and pH values showed a remarkable rise. Furthermore, the increases in TOC, TN and TP were limited to beneath the center of the cage; however, by the end of the second production, the effect had spread. The authors observed high variability in sediment TN measurements and a lower-magnitude increase than in TOC and TP. The most remarkable effect of cage fish culture on freshwater and sediment is the increase in the nutrient level. The effect on the sediment of a cage culture with a production capacity of 450 $t \cdot y^{-1}$ (cage production started in 1986) in Alicura Reservoir was examined by [21]. Comparing sediment TP and TN concentrations, the increase in TP was found to be higher than TN, similar to [20]. In Gokcekaya Reservoir, the increase in sediment TP exceeded that of sediment TN; this finding is compatible with [20]. The reason for this is that TN was lost from the sediment in the form of soluble ammonia and gaseous nitrogen at a higher rate than the loss of TOC and TP.

Lake Kariba, one of the artificial lakes on the border between Zambia and Zimbabwe, has undergone dramatic ecological changes since its formation. The fate of fish farm waste with regard to sediment bio-chemical parameters between 1991-1994 was investigated by [22]. In that study, there was a cage site and two control sites (at 300 m east and west of the cages). According to the compiled data comprising values for the sediment and sediment pore water, the maximum values were found in April at the end of the production period. Sediment carbon, nitrogen and phosphorus concentrations rose to their maximum values at the end of the production period, and they claimed that cage fish production had a localised effect on the sediment in comparison with the control stations. In

Gokcekaya Reservoir, sediment phosphorus concentrations were measured at 8.80% (before production) and 9.10% (after production). There was a slight increase in organic carbon (from 11.30% to 13.40%) as well, whereas the total nitrogen level remained at 17.00% throughout the production period. The data might be explained by taking into consideration that Gokcekaya Reservoir has an oligotrophic character and was only introduced to cage fish farming immediately before the study period.

The nutrient contents of the sediment reflect cage fish farm waste inputs. Sediment quality parameters of rainbow trout fish farms with capacities of 50 $t \cdot y^{-1}$ and 150 $t \cdot y^{-1}$ in Lago Moreno (70-meter depth) and Alicura Reservoir, Argentina was determined by [21]. The Alicura Reservoir sediment parameters were detected as 1.7% (TP) and 0.4% (TN). Lago Moreno's sediment values were not significantly different from Alicura Reservoir's. In Gokcekaya Reservoir, sediment phosphorus concentrations rose from 8.80% to 9.10%, a statistically significant difference. Gokcekaya Reservoir's sediment phosphorus value was slightly higher than Alicura Reservoir's data although Gokcekaya Reservoir, a new area for cage fish farming, had a 6.3-fold lower production capacity. In this context, a monitoring programme should be implemented in Gokcekaya Reservoir.

Sediment TOC concentrations showed a significant increase in the post-culture period compared with the pre-culture period; sediment heavy metal concentrations showed a similar increase during the culture period. Iron in the sediment as an essential component of clay minerals is a major element in lakes. The concentration of heavy metal in the surface sediment had the trend Fe > Mn > Zn > Ni > Cr > Cu > Pb. The descending order of heavy metal concentrations in this study is compatible with [23]'s data. In our study, Zn and Pb concentrations were determined at 0.262 ± 0.015 - 0.491 ± 0.034 $\mu g \cdot g^{-1}$ DW and 0.066 ± 0.003 - 0.100 ± 0.002 $\mu g \cdot g^{-1}$ DW, respectively. These findings did not exceed the hazardous levels for aquatic organisms according to [24]. The pollution index of the sediment called the Schaanning Pollution Index and developed by Schaanning MT (1994), can be determined by using Zn and Cu concentration ranges in relation to pH levels [25]. Gokcekaya Reservoir's pH (8.85 and 9.12) was >7.7, and the sediment Zn and Cu concentrations were also <5. According to the Schaanning Pollution Index (1994), these values correspond with the degree of "No Pollution" in Gokcekaya Reservoir's sediment in its present situation.

Organic matter in colloidal form plays an important role in the exchange capacity of sediments, whereas in the presence of iron, organic matter adsorbs greater amounts of phosphates as these carry negative surface charges [26]. In Gokcekaya Reservoir, surface sediment Fe and Zn, generally used in commercial fish diets, were found in low concentrations compared to the guidelines recommended by the Canadian Council of Ministers of the Environment [24]. Additionally, copper is commonly used in antifouling chemicals for the treatment of cage nets. The highest copper concentration (0.304 $\mu g \cdot g^{-1}$ DW) determined in this study was lower than the recommended highest value (35.7 $\mu g \cdot g^{-1}$ DW); therefore, there no toxicity risk exists for aquatic organisms in Gokcekaya Reservoir.

The interrelation between organic matter, total nitrogen and sediment heavy metals in our study could not be computed because at least one of these variables must remain constant. Total phosphorus, total organic carbon and sediment heavy metals displayed higher correlation coefficients in general ($p < 0.01$) (Table 4). The positive high correlations refer to the accumulation of these materials originating from fish feed and feces, which play a key role in changes of the sediment conditions under cages.

5. Conclusion

In aquatic environments, the determination of the effects of fish farming on water-sediment parameters is obligatory from an ecological perspective. In this sense, sediment and sediment pore water parameters should be monitored to promote sustainable and environmentally-friendly fish farming. The aim of this study in Gokcekaya Reservoir was to establish reference data for sediment and sediment pore water physio-chemical parameters and sediment diffusional phosphorus flux with some sediment heavy metal concentrations. In this study, our attention is especially drawn to the very low internal phosphorus flux; however, this value has a tendency to increase when the pre- and post-culture periods are compared. It seems that cage culture activity does not currently pose any danger in the reservoir. Gokcekaya Reservoir was classified as an oligotrophic environment, taking into account the pore water SRP and ammonium values. Our results showed that concentrations of heavy metals in the sediment were not high enough to effect aquatic life negatively. Considering the primary data, it can be concluded that cage fish farming in Gokcekaya Reservoir does not pose the hazard to the lake's nutrient level in its current state; however, a long-term monitoring programme must be adopted particularly with respect to the sediments of the reservoir.

References

[1] Kelly, L.A. and Elberizon, I.R. (2001) Fresh Water Finfish Cage Culture. In: Black, K.D., Ed., *Environmental Impacts of Aquaculture*, Sheffield Academic Press, Sheffield, 1-32.

[2] Topçu, A. and Pulatsü, S. (2004) Göl ve Göletlerin Ötrofikasyonunda Sedimentin Rolü. *Ulusal Su Günleri Türk Sucul Yaşam Dergisi*, İzmir. (In Turkish)

[3] Pulatsü, S. and Topçu, A. (2014) Su Kirlenmesi ve Kontrolü (Genişletilmiş 2. Baskı). *Ankara Üniversitesi Ziraat Fakültesi Yayın* No. 1617, Ders Kitabı: 569. 384 s., Ankara. (In Turkish)

[4] Özdal, B. and Pulatsü, S. (2012) Using of the Computer Software for the Sustainable Rainbow Trout Cage Culture: A Case Study in Gökçekaya Reservoir (Ankara/Turkey). *Ege Journal of Fisheries and Aquatic Sciences*, **29**, 49-54.

[5] Akın, S., Atıcı, T. and Katırcıoğlu, H. (2008) Physicochemical, Toxicological and Ecological Analysis of Gökçekaya Reservoir. *African Journal of Biotechnology*, **7**, 444-449.

[6] Akın, B.S., Atıcı, T., Katırcıoğlu, H. and Keskin, F. (2011) Investigation of Water Quality on Gökçekaya Reservoir Using Multivariate Statistical Analysis, in

Eskişehir, Turkey. *Environmental Earth Sciences*, **63**, 1251-1261.

[7] Kacar, B. (1995) Bitki ve Toprağın Kimyasal Analizleri 3: Toprak Analizleri. Ankara Üniversitesi Ziraat Fakültesi Eğitim Araştırma ve Geliştirme Vakfı Yayınları, No. 3, 705 s. (In Turkish)

[8] Shrestha, M.K. and Lin, C.K. (1996) Determination of Phosphorus Saturation Level in Relation to Clay Content in Formulated Pond Muds. *Aquacultural Engineering*, **15**, 441-459.

[9] Shaw, J.F.H. and Prepas, E.E. (1990) Relationships between Phosphorus in Shallow Sediments and in the Trophogenic Zone of Seven Alberta Lakes. *Water Resources*, **24**, 551-556.

[10] Anonymous (2012) Standard Methods for the Examination of Water and Wastewater. 22th Edition, John D., Ducas Co., USA, 1-1193.

[11] Kesici, T. and Kocabaş, Z. (2007) Biyoistatistik. Ankara Üniversitesi Eczacılık Fakültesi Yayın No. 94, Ankara. (In Turkish)

[12] Alpaslan, A. and Pulatsü, S. (2008) The Effect of Rainbow Trout (*Oncorhynchus mykiss* Walbaum, 1792) Cage Culture on Sediment Quality in Kesikköprü Reservoir, Turkey. *Turkish Journal of Fisheries and Aquatic Science*, **8**, 65-70.

[13] Enell, M. and Löfgren, S. (1988) Phosphorus in Interstitial Water: Methods and Dynamics. *Hydrobiologia*, **170**, 103-132. https://doi.org/10.1007/BF00024901

[14] Temporetti, P., Beamud, G. and Pedrozo, F. (2014) The Trophic State of Patagonian Argentinean Lakes and its Relationship with Depth Distribution in Sediment Phosphorus. *International Journal of Environmental Research*, **8**, 671-686.

[15] Istvanovics, V. (1988) Seasonal Variation of Phosphorus Release from the Sediments of Shallow Lake Balaton (Hungary). *Water Research*, **22**, 1473-1481.

[16] Sondergaard, M., Jensen, J.P. and Jeppesen, E. (2003) Role of Sediment and Internal Loading of Phosphorus in Shallow Lakes. *Hydrobiologia*, **506**, 135-145. https://doi.org/10.1023/B:HYDR.0000008611.12704.dd

[17] Sondergaard, M., Jensen, J.P. and Jeppesen, E. (1999) Internal Phosphorus Loading in Shallow Danish Lakes. *Hydrobiologia*, **408**, 145-152. https://doi.org/10.1023/A:1017063431437

[18] Cornel, G.E. and Whoriskey, F.G. (1993) The Effects of Rainbow Trout (*Oncorhynchus mykiss*) Cage Culture on the Water Quality, Zooplankton, Benthos and Sediments of Lac du Passage, Quebec. *Aquaculture*, **109**, 101-117.

[19] McKindsey, W.C., Archambault, P., Callier, M.D. and Can, F.O. (2011) Influence of Suspended and Off-bottom Mussel Culture on the Sea Bottom and Benthic Habitats: A Review. *Journal of Zoology*, **89**, 622-646.

[20] Rooney, C.R. and Podemski, C.L. (2010) Freshwater Rainbow Trout (*Oncorhynchus mykiss*) Farming Affects Sediment and Pore-Water Chemistry. *Marine and Freshwater Research*, **61**, 513-526. https://doi.org/10.1071/MF09097

[21] Temporetti, P.F., Alonso, M.F., Baffico, G., Diaz, M.M., Lopez, W., Pedrozo, F.L. and Vigliano, P.H. (2001) Trophic State, Fish Community and Intensive Production of Salmonids in Alicura Reservoir (Patagonia, Argentina). *Lakes & Reservoirs: Research and Management*, **6**, 259-267. https://doi.org/10.1046/j.1440-1770.2001.00142.x

[22] Troell, M. and Berg, H. (1997) Cage Fish Farming in the Tropical Lake Kariba, Zimbabwe: Impact and Biogeochemical Change in Sediment. *Aquaculture*, **28**, 527-544.

[23] Saeed, S.M. and Shaker, I.S. (2008) Assessment of Heavy Metals Pollution in Water and Sediments and Their Effect on *Oreochromis niloticus* in the Northern Delta Lakes, Egypt. *The 8th International Symposium on Tilapia in Aquaculture*, 475-489.

[24] CCME (1995) Protocol for the Derivation of Canadian Sediment Quality Guidelines for the Production of Aquatic Life. Ottawa.

[25] Jaysankar, D., Kimio, F., Kozo, I. and Kei, O. (2009) Occurrence of Heavy Metals in the Sediments of Uranouchi Inlet, Kochi Prefecture, Japan. *Fisheries Science*, **75**, 413-423.

[26] Delince, G. (1992) The Ecology of the Fish Pond Ecosystem. Kluwer Academic Publishers, The Netherlands, 230. https://doi.org/10.1007/978-94-017-3292-5