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The Impact of Rainbow Trout Farm Effluents on Water Quality of Karasu Stream, Turkey

Serap Pulatsu[1,*], Ferit Rad[2], Gülten Köksal[1], Fikri Aydın[1], A. Çağlan Karasu Benli[1], Akasya Topçu[1]
[1]University of Ankara, Agriculture Faculty, Fisheries Dept., Ankara, Turkey.
[2]University of Mersin, Fisheries Faculty, Aquaculture Dept., Mersin, Turkey.

* Corresponding Author: Tel.: +90. 312 317 05 50; Fax: +90. 312 318 52 98;
E-mail: spulatsu@agri.ankara.edu.tr

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Abstract

The aim of this study was to assess the potential impact of trout farm effluents on water quality of Karasu stream (Bozüyük-Turkey) where a ring of five trout farms are localized and to estimate the phosphorus load of the farms. Monthly samples were taken from upstream (1. station) and the last trout farm effluents (downstream- 2. station) for 11 months. Trout farms had a significant impact on dissolved oxygen (DO), biological oxygen demand (BOD_5), NO_2-N, NO_3-N and total phosphorus (TP) concentrations of Karasu stream ($P<0.05$). Changes in pH, total suspended solids (TSS) and ammonia-nitrogen (NH_3-N) concentrations were insignificant ($P>0.05$). During the study period, measured values of the last trout farm effluents were within the effluent limits for trout farming in different countries. The total annual phosphorus load of trout farms on Karasu stream was estimated as 12,205 kg. On average production of 1 ton of trout production resulted in load of 9.38 kg of phosphorus. The average phosphorus load of 1 ton of feed used was estimated as 8.09 kg.

Key Words: Rainbow trout (*Oncorhynchus mykiss*), trout farm effluents, water quality, phosphorus load

Introduction

Worldwide harvest of aquatic products by fisheries is currently close to its maximum sustainable level of productivity. Aquaculture is therefore the only means of promoting production to meet the increasing demand for aquatic products (FAO, 2002). Aquaculture is also an important instrument for promotion of economic growth in developing countries and rural areas because it creates jobs, business and income. Nevertheless, in order to compensate for the negative environmental impact of aquaculture, due attention must be paid to methods of production and the environmental consequences of the production process implemented. The environmental impact of aquaculture varies and includes conflicts between the needs of different users of its products, alteration of the hydrological regime, introduction of exotic species to the wild, and pollution of water resources (Midlen and Redding, 1998; Read *et al*., 2001). According to Boyd (2003), pollution of water resources by pond effluents is probably the most common complaint, and this concern has attracted the greatest amount of official attention in most nations. In flow-through aquaculture systems like raceways and tanks, effluents are discharged to the environment with enhanced concentrations of nutrients and solids. Such effluents may have a serious negative impact on the quality of the receiving water when discharged untreated (Forenshell, 2001; Miller and Semmens, 2002; Schulz *et al*., 2003). With increased interest in implementing environmentally friendly and sustainable fish farming practices, the aquaculture industry has been focusing in recent years on ways to reduce waste through waste management and effective feed management. Governments have also been focusing on appropriate environmental safeguards including regulatory, control, and monitoring procedures to minimize the potential adverse impact of aquaculture (Midlen and Redding, 1998; Forenshell, 2001; Henderson and Davies, 2000; Read *et al*., 2001; Bergheim and Brinker, 2003). Characterization of fish farm effluents and quantification of the environmental impact of aquaculture provides the information and the data base for decision-makers to formulate the necessary environmental safeguard regulations and for the fish farmers themselves to develop and adopt their own waste management systems.

The Farming of rainbow trout (*Oncorhynchus mykiss*) in flow-through systems that use raceways is common practice in Turkey's aquaculture sector. Currently, 758 land-based farms are involved in production of portion-size trout, with a production volume of around 33,700 mt, which corresponds to 55% of Turkey's total volume of aquaculture production in 2002 (MARA, 2001; SIS, 2003). The potential impact of trout farm effluents on water resources is not well studied in Turkey. Therefore, procedures for regulating, controlling, and monitoring the environmental impact of fish farms are not well established. The lack of site-specific data on the effluent quality of farms and on their impact on receiving streams and rivers is a major constraint on the establishment of such regulatory measures and adaptation of appropriate waste management systems.

Moreover, the lack of regulatory measures in licensing procedures and site selection permits the establishment of a string of 2–5 farms on the same stream or river where the potential impact of farm effluents could be additive and problems of jurisdiction could arise due to conflict between users.

This study was therefore initiated to assess the potential impact of trout farm effluents on the water quality of receiving waters and to estimate the potential phosphorous load of trout farming. The study was carried out in Bozüyük/Bilecik, where a string of five trout farms was situated along on the same water source (the Karasu stream) and constituted a real case for assessment of the potential additive impact of farm effluents on receiving waters.

Materials and Methods

Description of the Study Area

This study was carried out in Karasu stream (Province of Bilecik, district of Bozüyük), which is a mountain spring with minimum and maximum flow rates of 1,025 L/s and 2,500 L/s, respectively. Due to the topography of the area, Karasu stream flows at a high velocity through a narrow bed. There is no industrial or domestic sewage that discharges to the stream. A string of five successive rainbow trout (*Oncorhynchus mykiss*) farms is located on the bank of Karasu stream. The additive impact of farm effluents can be observed where effluent water of upstream farms is discharged into the feeding water of the downstream farms (Figure 1; Farm A, B_1, B_2, C and D). Sites B_1 and B_2 were operated by the same company.

Historically, farm B_2 was the first enterprise established on the Karasu stream, followed by farms C, D, B_1 and A. Theoretical (Project) capacities, actual production figures and distances of farms from the spring are given in Table 1.

Sampling Procedures

Monthly samples were taken from two stations. Station I was located 1,500 m upstream from the abstraction point of Farm A to measure the normal conditions of the stream. Station II was located 100 m downstream of the discharge point of the last farm (Farm D) to assess the additive impact of farm effluents on the water quality of the receiving water. Sampling took place from March 2001 to February 2002. Samples were taken in duplicate at the same hour of the day throughout the study. Water samples were collected from the stream's surface only and analyzed within 24 h.

Table 1. Theoretical capacities (mt/year), actual production figures and distances of farms from water source

Farm	Theoretical capacity (mt/year)	Production (mt)	Distance from water source (m)
A	256	40	1 500
B_1	900	1 000	1 500
B_2	600		4 225
C	120	200	6 825
D	52	60	8 225
Total	1 928	1 300	-

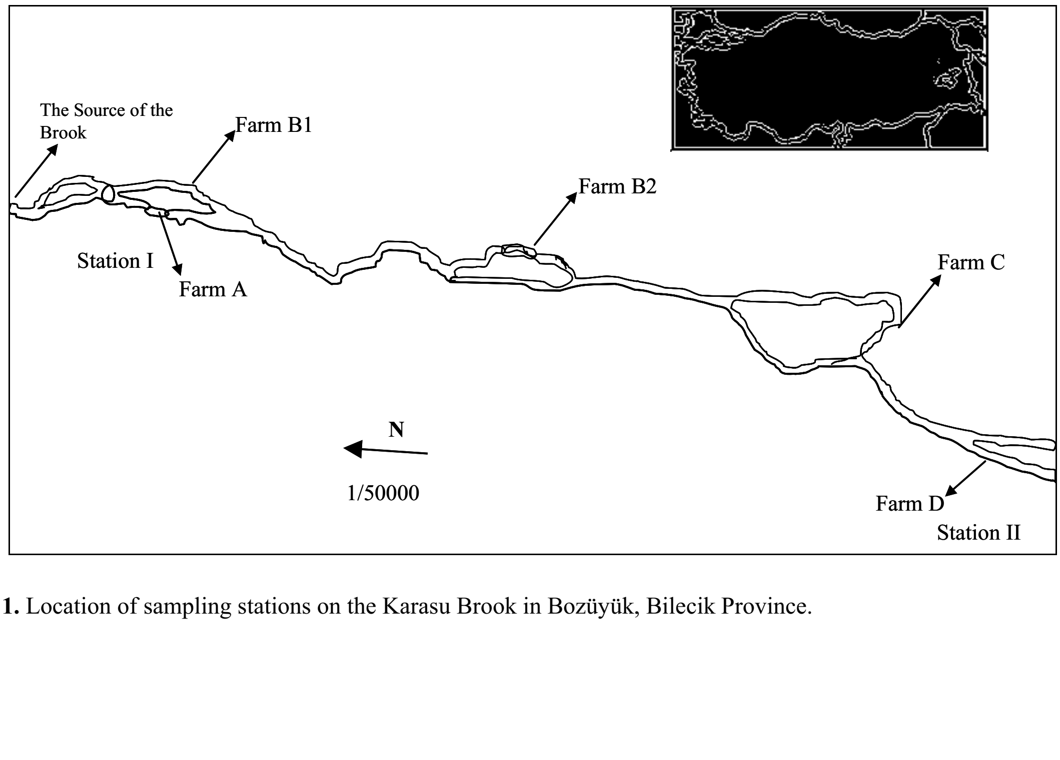

Figure 1. Location of sampling stations on the Karasu Brook in Bozüyük, Bilecik Province.

Analytical Methods

Measured physico-chemical water quality parameters were temperature, total suspended solids (TSS), pH, BOD_5, ammonia- nitrogen (NH_3-N), nitrite-nitrogen (NO_2-N), nitrate-nitrogen (NO_3-N) and total phosphorus (TP). Temperature, pH and dissolved oxygen were measured *in situ* using YSI 51B oxygenmeter and WTW pH 330 pH meter. The other analyses were conducted according to standard methods (Anonymous, 1975; Foy and Rosell, 1991). All measurements were replicated four times.

Monthly data were converted to mean values (±standard error) for comparison. Mean values of each parameter measured upstream and downstream were compared using the Independent Samples-t test, adjusted to 95% confidence limits. SPSS program version 10.0 was used for statistical analysis.

The phosphorus load of farms in 2001 was estimated based on each farm's production figure, feed conversion ratio (FCR), total feed consumption and phosphorous content of the feed used, according to Boyd and Queiroz (2001). Phosphorus load was estimated in terms of kg P/farm, kg P/ton feed used and kg P/ton fish produced.

Results

Data on water quality parameters of Karasu, upstream and downstream the trout farms are given in Table 2. Trout farms had a significant impact on dissolved oxygen (DO), biological oxygen demand (BOD), NO_2-N, NO_3-N and total phosphorus (TP) concentrations of the Karasu stream ($P>0.05$). Meanwhile, changes in pH, total suspended solids (TSS) and ammonia-nitrogen (NH_3-N) concentrations were insignificant ($P<0.05$).

Mean upstream and downstream DO concentrations of Karasu were measured to be 10.84±1.27 and 9.04±0.62 mg/L, respectively. This reduction in DO concentration, due to consumption on the trout farms, was found to be statistically significant.

The impact of trout farm effluents on the pH of the receiving water was not significant and there was only a minor elevation in pH (0.04) downstream of the farms. On the other hand, the impact of trout farm effluents on the BOD of the receiving water was significant, and the BOD of the Karasu stream was found to have increased by 2.15 mg/L following the discharge of farm wastewaters. The mean value of BOD increased from 1.01±0.89 mg/L upstream to 3.16±1.23 mg/L downstream the trout farms.

The mean concentration of total suspended solids upstream of the trout farms was measured to be 0.25±0.22 mg/L. Total suspended solids mean concentration downstream of the farms increased to 0.60±0.64 mg/L due to discharge of effluents into the stream. Nevertheless, this increase in the concentration of total suspended solids was not statistically significant.

There was an increase in the mean concentration of NH_3-N downstream of the trout farms, from 0.038±0.032 mg/L to 0.114±0.12 mg/L. While trout farm effluents did not have a significant effect on NH_3-N concentration of the Karasu stream, their impact on NO_2-N and NO_3-N concentrations were statistically significant. NO_2-N and NO_3-N concentrations increased from 0.019±0.054 and 0.581±0.33 mg/L upstream to 0.108±0.074 and 1.035±0.56 mg/L downstream, respectively.

The impact of trout farming activities on the TP concentration of the receiving water also turned out to be significant. The concentration of TP rose from

Table 2. Water quality parameters of Karasu, upstream and downstream the trout farms (mg/L, excluding pH)

	Parameter	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Jan	Feb	Mean
UPSTREAM	Temp.	13.00	12.50	13.00	14.50	14.00	16.00	13.00	14.00	13.00	11.50	12.00	13.32
	DO	12.30	13.50	11.98	10.49	9.09	10.30	9.78	10.0	10.41	10.90	10.50	10.84
	PH	7.80	7.97	8.24	7.90	8.80	7.50	7.50	7.50	7.50	7.50	7.20	7.76
	BOD_5	1.07	0.69	2.71	1.41	2.00	0.45	1.96	0.13	0.23	0.06	0.45	1.01
	TSS	0.03	0.11	0.11	0.13	0.15	0.66	0.04	0.24	0.40	0.25	0.66	0.25
	NH_3-N	0.021	0.062	0.081	0.101	0.034	0.044	0.039	0.012	0.016	0.002	0.005	0.038
	NO_2-N	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.011	0.184	0.001	0.001	0.019
	NO_3-N	0.701	0.516	0.666	0.738	0.862	1.185	0.660	0.018	0.018	0.493	0.536	0.581
	TP	0.055	0.044	0.013	0.021	0.104	0.081	0.068	0.098	0.108	0.110	0.057	0.069
DOWNSTREAM	Temp.	14.00	14.00	15.00	15.00	14.20	19.00	14.00	12.00	14.00	12.00	13.00	14.20
	DO	9.02	8.75	9.13	8.91	8.94	8.83	9.26	7.80	9.52	9.40	10.40	9.09
	PH	8.03	8.04	8.19	8.25	8.01	7.77	7.83	7.78	7.78	7.80	6.91	7.89
	BOD_5	4.40	1.73	4.99	3.09	3.96	3.94	4.13	2.70	2.84	1.12	1.87	3.16
	TSS	0.17	0.27	0.31	0.31	2.46	0.42	0.68	0.33	0.86	0.34	0.42	0.60
	NH_3-N	0.188	0.236	0.105	0.406	0.134	0.066	0.046	0.020	0.022	0.010	0.025	0.114
	NO_2-N	0.128	0.087	0.019	0.044	0.094	0.217	0.198	0.101	0.220	0.027	0.052	0.108
	NO_3-N	1.063	1.675	1.248	1.263	1.624	1.865	0.940	0.220	0.194	0.729	0.566	1.035
	TP	0.064	0.106	0.060	0.084	0.149	0.098	0.112	0.171	0.184	0.116	0.149	0.117

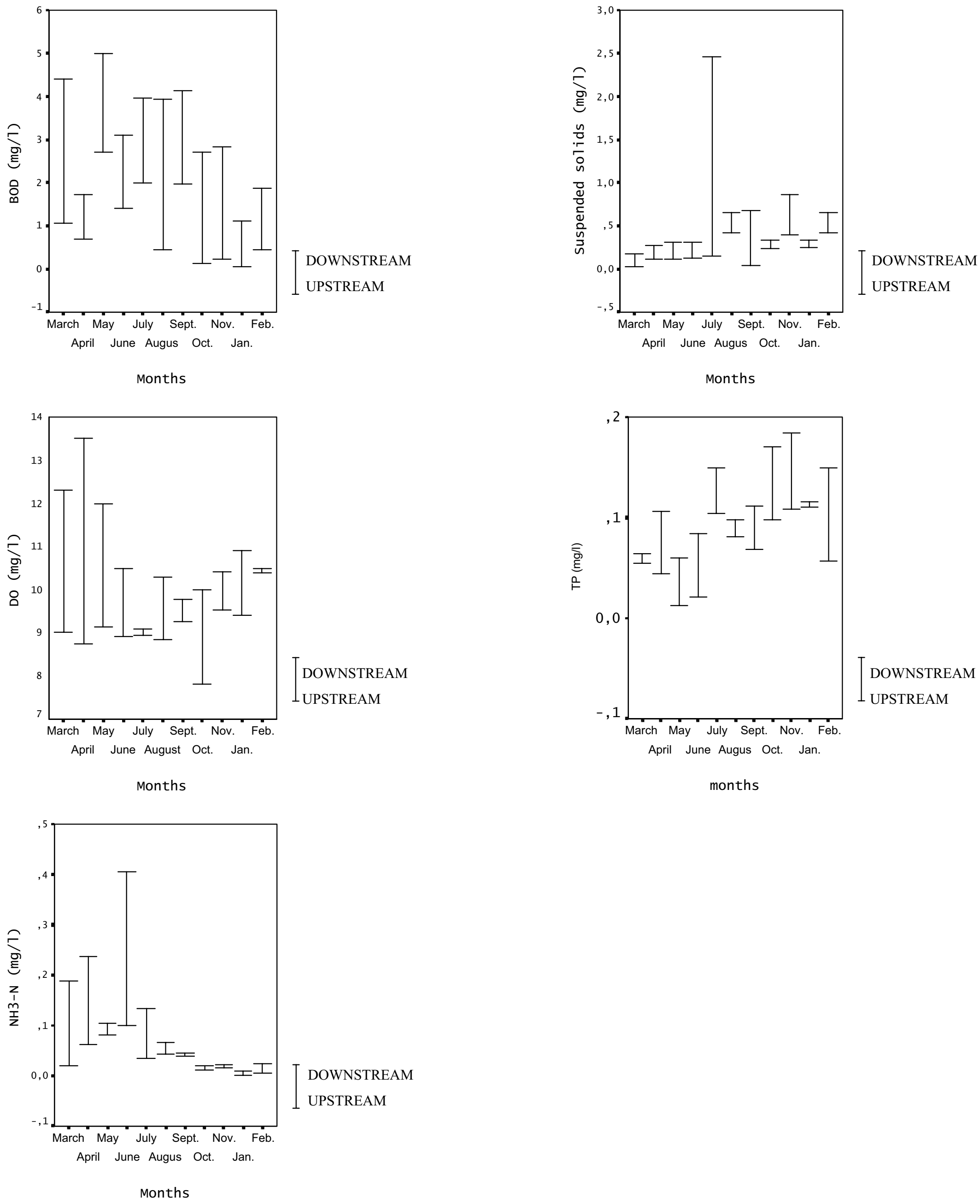

Figure 2. Monthly changes in some water quality parameters of Karasu stream.

0.069±0.034 mg/L above the trout farms to 0.117±0.041 mg/L downstream of the trout farms. Monthly changes in water quality parameters of Karasu stream are also presented in Figure 1.

Estimated Phosphorus Load of Trout Farms

Estimations of individual and total phosphorus load of the trout farms are given in Table 3. Phosphorus loads were estimated in terms of kg P/farm, kg P/ton feed used and kg P/ton fish produced. In 2001, a total of 1,300 tons of rainbow trout was produced along the Karasu stream using 1,570 tons of feed. The impact of this production on the stream was estimated to be 12,205 kg phosphorus. The average phosphorus load of 1 ton of feed used was estimated to be 8.09 kg. On average, production of 1 ton of trout resulted in the discharge of 9.38 kg of phosphorus into the Karasu stream.

Discussion

There was a reduction in the DO concentration of the Karasu stream as a result of the trout farming activities. The DO concentration of the Karasu stream was lower below the trout farms throughout the study. However; the pattern of reduction revealed a monthly cyclic variation. This variation was attributed to differences in fish biomass and feeding levels during the different months. Higher fish biomass and intensive feeding increased the DO need of a farm and resulted in higher DO intake from the feeding water (Midlen and Redding, 1998; Lawson, 1995). The lowest value of DO (7.80 mg/L) was observed in October, downstream of the trout farms. This value was above the minimum limits of 6.0 and 6.6 mg/L set for DO (mg/L) content of receiving waters by the States of North Carolina and Virginia (Davis, 1993). Furthermore; the lowest value of DO observed in Karasu stream still exceeded the upper limit of DO concentration (5 mg/L or more for DO) that is recommended by the Global Aquaculture Alliance (Boyd and Gautier, 2000).

The relatively high concentration of DO, even downstream of the trout farms, occurred due to mechanical aeration and oxygenation of the receiving water. The Karasu stream runs through a narrow bed with a high slope, providing aeration as well as gravitational pull. The reduction in DO concentration due to trout farming activity was therefore partly counterbalanced by gravity aeration. Similar observations were also reported by Boaventura *et al.* (1997).

Trout farm effluents did not have a significant impact on the pH of the Karasu stream. The minor elevation in pH was not statistically significant. Even the pH downstream of the trout farms was still within the acceptable limits of 6.5–9.5 proposed by different standard schemes (Lawson, 1995; Davis, 1993; Boyd and Gautier, 2000).

The change in the BOD of the Karasu stream due to output of organic matter by trout farming activities was found to be statistically significant. Increases in BOD were found to be more pronounced in summer months, most likely due to rising water temperatures and higher feeding rates applied by farms. Higher feeding rates increase the output of organic matter from farms either as uneaten feed or faeces and result in marked elevation in the BOD of receiving water (Miller and Semmens, 2002). Many standard schemes have taken the safe limits for BOD to be 3–20 mg/L (Midlen and Redding, 1998; Boyd, 2003; Davis, 1993; Clipps and Kelly, 1995). In this study, the BOD of the receiving water downstream of the trout farms was measured to be 3.16±1.23 mg/L. This value was therefore within the safe limits proposed for waters receiving trout farm effluents. The measured value of 3.16±1.23 mg/L would be expected to decrease further downstream from the trout farms, since running water has the capacity of undergo self-purification, which would result in lower BOD. Boaventura *et al.* (1997) have reported BOD's returning to the value for feeding water 2–3 km downstream from the point of effluent discharge in the Fornelo and Inha rivers in Portugal.

Total suspended solid concentrations downstream of the trout farms ranged between 0.17–0.86 mg/L throughout the year except in July. During this month, the concentration of total suspended solids was recorded as being 2.46 mg/L, corresponding to an increase of 700% compared to June. This significant rise in total suspended solids concentration might have occurred due to cleaning or harvesting activities on one of the farms. The cleaning of raceways or harvesting of fish could create a significant pollutant load for the receiving water (Midlen and Redding, 1998; Dumas and Bregheim, 2001). According TO Midlen and Redding (1998), suspended solids discharged from trout farms could rise from 1.5–11.4 mg/L in normal days to 17–8.01 mg/L on cleaning or harvest days. Nevertheless, even the highest concentration of suspended solids recorded along the Karasu stream fell within the range of limits allowed for increase in concentration of suspended solids in receiving waters (Davis, 1993; Bergheim and Cripps, 1998; Westers, 2000).

Both BOD and total suspended solid concentrations downstream the trout farms would be expected to be higher. However, significant settlement of waste materials in raceways and ponds

Table 3. Estimated phosphorus loads of the trout farms in 2001

Site	Trout Production (kg)	Feed consumption (kg)	FCR	Phosphorous content of feed (%)	Phosphorus load* kg P/farm	kg P/ton feed	kg P/ton fish
A	40,000	60,000	1.50	1.5	580	9.66	14.50
B_1	1,000,000	1,150,000	1.15	1.5	9,250	8.04	9.25
B_2							
C	200 000	240,000	1.20	1.5	2,000	8.33	10.00
D	60,000	57 000	0.95	1.5	375	6.57	6.25
Total/Average	1,300,000	1,507,000	-	-	12,205	8.09	9.38

* - Dry matter content of rainbow trout was assumed as 25% and P as 3.2% (dry matter basis)

reduces the impact of farm effluents on receiving water as far as suspended solids and BOD are concerned (DEHLG, 1995).

The mean concentration of NH_3-N downstream of the trout farm discharge points (0.038 mg/L) increased by 200%, reaching 0.114 mg/L. Even though this increase was not found to be statistically significant, the NH_3-N concentration of Karasu down stream trout farms exceeded the recommended limit for Salmonid farms (0.025 mg/L) (Laird and Needham, 1988). However, the NH_3-N concentration remained below the maximum allowable level of 1.0 mg/L recommended by the EEC for protection and improvement of fish in freshwater (Boaventura *et al.*, 1997). Mean NO_2-N and NO_3-N concentrations were not found to be risen significantly downstream of the trout farm effluent discharge points. Both values remained below the recommended limits. Concentration of NO_2-N was below the recommended value of 0.83 mg/L (Schwartz and Boyd, 1994) for farm effluents. NO_3-N concentration downstream from trout farms also stayed below the recommended upper limit of 16.9 mg/L for nitrate (Schwartz and Boyd, 1994).

Estimated mean loads of phosphorus per ton of feed used and per ton of fish produced in trout farms on Karasu stream exceeded the values cited in the literature (Boyd and Queiroz, 2001; Enell, 1995; Green *et al.*, 2002). According to Boyd and Queiroz (2001) and Green *et al.* (2002), on average, trout farms discharge 4.6–5.7 kg of phosphorus into receiving waters for every ton of feed used. In this study, even in the farm with efficient feed management and the lowest FCR (Farm D), the estimated phosphorus load per ton of feed used (6.57 kg P) was higher than loads reported by the aforementioned researchers. The amount of phosphorus discharged in to Karasu stream per ton of trout produced was also above the current load of Nordic farms. Phosphorus load of trout farms using Karasu stream ranged from 6.25 to 14.50 kg per ton of fish produced (Table 3). The lowest load (6.25 kg P /ton fish) was again found in farm D, which enjoyed a better FCR and lower feed consumption per ton of fish produced. Bearing in mind that the phosphorus load of Nordic trout farms per ton of fish produced was reported to be 4.8–6.0 kg (Bergheim and Cripps, 1998; Enell, 1995), the current load of trout farms on Karasu stream exceeded European standards as far as phosphorus was concerned.

The higher phosphorus loads on trout farms investigated in this study seemed to be associated with the high phosphorus content of feeds used and insufficient feed management. The phosphorus content of feed used on these farms in 2001 was 1.5%. Furthermore, with the exception of farm D, where effective feed management resulted in an FCR of 0.95, the other four farms were less successful in feed management and all had an FCR of above 1.0 (1.15–1.5). In countries where strict environmental regulations govern the operation of trout farms, phosphorus content of trout feed and FCR are not permitted to exceed 0.9–1.0% and 1.0 respectively (Bergheim and Cripps, 1998; Mac Millan *et al.*, 2003).

Conclusion

The results of this study indicated that trout farm effluents had a significant impact on the water quality of the Karasu stream with respect to dissolved oxygen (DO), biological oxygen demand (BOD), NO_2-N, NO_3-N and total phosphorus (TP) concentrations. However, effluents exceeded water quality standards for the receiving waters for none of the studied water quality parameters downstream of the points of trout farms. The phosphorus loads of the farms, both in terms of kg P/ton feed used and kg P/ton fish produced, were high and exceeded loads reported for fish farms in Nordic and North American farms. The high phosphorus loads were associated with the higher phosphorus content of trout feeds used in Turkey and with insufficient feed management. Phosphorus loads could be reduced by use of low-pollution feed and better feed management. The overall impact of trout farms effluents on the water quality of the Karasu stream could also be further reduced via better farm husbandry, improved farm design, water filtration, and the use of constructed wetlands.

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