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RESEARCH ARTICLE

The effects of aquaculture activities on species composition and diversity of native freshwater fish populations

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Abstract – The rapid development of the aquaculture industry in recent years and the increase in the intensity of production has raised questions regarding potential environmental impacts. Understanding intra- and interspecific relationships between native and cultured species is important for sustainable use of natural resources. This study investigated the spatial and temporal effects of a fish farm constructed next to a river on the relative abundance and diversity of natural fish populations. Sampling was conducted at three stations, upstream and down stream from a trout farm and at a control site, on Kocabas stream in Çanakkale (Turkey) monthly between August 2015 and July 2016. There was no significant difference among the three stations in fish diversity. However, a remarkable seasonal and spatial variation in the composition and relative proportion of the indigenous fish assemblage were observed among the three stations. In conclusion, the fish farm might have influenced species composition and relative abundances particularly at the downstream station.

Keywords: Fish farm / aquatic ecology / stream ecology / fish assemblages / Kocabas Stream

1 Introduction

Freshwater ecosystems contain stream coastal systems, surface-underground waters and the ecotones between them (Ward and Tockner, 2001). Species diversity is shaped by ecological and evolutionary factors such as evolutionary speed, interspecific interactions, geographic region, environmental energy, productivity and environmental damage (Currie, 1991; Willig et al., 2003; Krebs, 2009) and also physicochemical conditions such as salinity, temperature, light, dissolved gases and nutrients (Geist, 2011). In freshwater habitats fishes are generally the most abundant group within vertebrates. Freshwater fish tend to be isolated by geology or behavior, which in evolutionary times leads to different populations and subspecies. Other factors affecting this process are also derived from the evolutionary history of the individual taxonomy and the distribution of geographical factors such as mountains and rivers (Allan and Flecker, 1993).

Factors threatening river diversity can be grouped under five headings: water quality, overexploitation, flow alterations, habitat degradation and introduced alien species (Allan and Flecker, 1993; Naiman and Turner, 2000; Malmquist and Rundle, 2002; Postel et al., 2003; Dudgeon et al., 2006; Geist, 2011). In addition, anthropogenic activities (dam construction, land use change and also aquaculture) may have negative impacts on diversity (Geist, 2011). During recent years, aquaculture production has advanced concerning water quality, disease control, and enriched feed, and generated stock improvements by selective breeding, hybridization, and molecular genetic technologies (Stickney, 1994). Even if aquaculture has several positive effects on diversity, the negative effects are debated, for instance escaped fish. Cultured species introduced to the wild may cause environmental or genetic hazards (Stokstad, 2002; Maury-Brachet et al., 2008). They may have detrimental impacts such as disease and parasite transmission to the wild (Beveridge, 1990) or habitat invasion (Diana, 2009). Ecological effects can also occur with increasing predation pressure on native fauna depending on escaped fish abundance (Goldberg et al., 2001). Other adverse ecological effects may occur, including organic pollution, eutrophication, nutrient enrichment and waste contamination. In addition to these impacts, algal blooms, oxygen insufficiency, decrease in water quality and habitat damage may arise as a result of chemical pollution (Boesch et al., 2001; Aubin, 2006; Miranda et al., 2016).The output resulting from aquaculture activities is primarily suspended solid matter composed of uneaten food and feces (Holmer,

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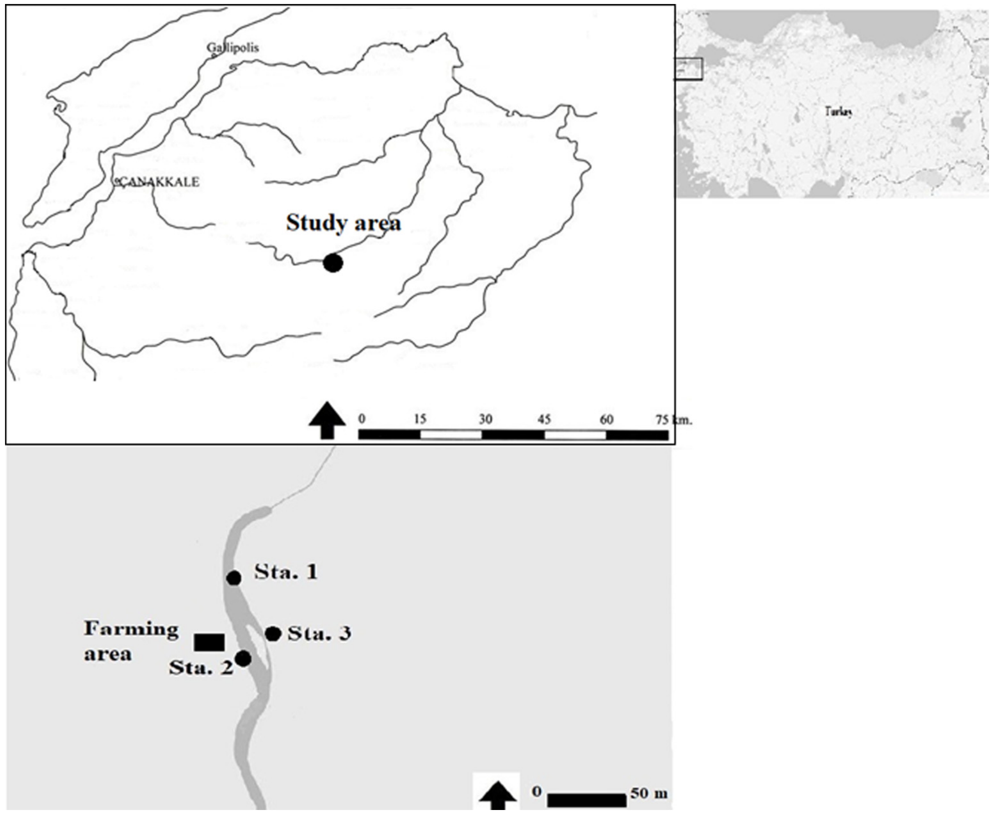

Fig 1. The study area with the three sampling stations. Flow direction is from station 1 to station 2.

1991; Iwama, 1991) which is considered to cause damage to the natural environment (Troell and Norberg, 1998; Naylor et al., 2000). Many studies have shown how the products of fish farms affected negatively sediment chemistry and community dynamics of benthic fauna (Holmer, 1991; Findlay and Watling, 1997; Hargrave et al., 1997; Pergent et al., 1999; Pearson and Black, 2000; La Rosa et al., 2001; Mirto et al., 2002) but also the phytoplankton community (Miranda et al., 2016). Studies on the ecological effects of aquaculture activities have generally focused on water quality and benthic composition (Demir et al., 2001; Wilding et al., 2012). Demir et al. (2001) investigated the effect of a *O. mykiss* farm on the dam reservoir on plankton and benthos abundance. Among the stations identified, higher phytoplankton, zooplankton and benthos abundance was found at stations closest to the aquaculture unit. Wilding et al. (2012) examined the effect of trout farms on macrobenthos with a camera system. At the end of the study, solid wastes were determined by a benthic flux model, which showed that macrobenthic organisms near the farm were negatively affected. There are some studies on the effects of aquaculture activities on biodiversity and abundance, particularly in marine areas (Carss 1990; Dempster et al., 2002, 2004; Machias et al., 2004; Morrisey et al., 2006; Krkosek et al., 2007; Diana, 2009). However, there are limited studies on the impact of aquaculture activities in freshwater ecosystems (Arthur et al., 2010; Miranda et al., 2016). The fish diversity in freshwater ecosystems is more sensitive compared to marine ecosystems and the change and modifications in the freshwater are much more striking than in terrestrial ecosystems (Sala et al., 2000; Ekmekçi et al., 2013). The consequences of fish farms on stream fish fauna particularly in terms of change in diversity and abundance have so far not been evaluated quantitatively.

Diversity loss is both a measure of environmental change and an indicator of ecosystem integrity and because of this it is considered one of the most serious ecological problems resulting from human activities (Secretariat of the Convention on Biological Diversity, 2006). In the present study we assessed the impacts of aquaculture activities on the abundance and diversity of native fish communities in Kocabas Stream, Canakkale, Turkey. We conducted field studies to determine species richness and abundance of native fish communities around a fish farm and for a control site situated on the branch of the river without any fish farms. We aimed to develop scientific understanding and gain insights for new management strategies to eliminate potential problems of aquaculture.

2 Materials and methods

Kocabas Stream is located in the southwestern part of the Marmara region (Fig. 1). It arises from the northeastern part of the Biga district of Çanakkale, results from three main tributaries and reaches the Sea of Marmara south of Karabiga (Tanatmıs and Narin, 2004). Mean depth is 50 cm (DSI, 2000) and total length 80 km (Kayabasi and Gokceoglu, 2012). This water resource is used as irrigation water for agricultural activities and also drinking water for animals (Yayintas et al., 2007). In addition, aquaculture activities are also carried out in fish farms established on it.

Sampling was carried out at three stations near a rainbow trout farm built next to Kocabas between August 2015 and July 2016. The aquaculture activity involves taking water from the stream and feeding back wastewater. The annual aquaculture potential of the farm is 60 tons of rainbow trout. One station was selected upstream (Sta 1; 365 m, 39° 45′ 37.20″ N and 27° 7′ 35.13″ E) and one downstream (Sta 2; 360 m, 39° 45′ 54.75″ N and 27° 7′ 33.09″ E) from the fish farm. The third station was a control station (Sta 3; 357 m, 39° 45′ 39.67″ N and 27° 7′ 18.80″ E) situated on the branch of the stream without fish farms.

At each station the study area was about 1.5 km long and 2 m wide. In monthly sampling periods, each station was sampled once using electrofishing with SAMUS 725G. Physicochemical parameters (temperature, pH, dissolved oxygen, electrical conductivity) were measured by a WTW Multiparameter Prob twice at each station; the two values were averaged for analysis. Fish samples were brought to the laboratory maintaining the cold chain. They were identified to species level and the number of species and individuals was recorded.

3 Data analysis

To evaluate the impacts of aquaculture on fish communities, the number of species per station (S) was first calculated, followed by the Shannon-Wiener diversity (H') and evenness indices, which standardized the sample size in terms of abundance and number of species, in order to establish the relation of the number of species to the total abundance. The relative abundance of each species was calculated with the following formula (Tramer, 1969); p_i = total abundance of species$_i$/ total abundance of all species.

The Shannon-Wiener Diversity Index H' and Evenness E were calculated using (Shannon 1948);

$$\mathrm{H}' = -\Sigma \mathrm{p_i} \ln \mathrm{p_i}$$

$$\mathrm{E} = \mathrm{H}'/\ln(\mathrm{S})$$

Differences between relative abundances of each species caught monthly at the three stations were tested using non-parametric Kruskal-Wallis tests. The pairwise differences among upstream-downstream, upstream-control and downstream-control stations were determined with non-parametric ranked based Mann-Whitney U tests. The spatial variations in diversity and evenness among station were also compared with Kruskal-Wallis tests. Correlations between species abundances among stations were calculated with Spearman's rho. A 0.05 alpha level was used for all tests. Spatial and seasonal differences of physicochemical parameters were tested with two-way ANOVA. The homogeneity of variances of each parameter was tested by Levene's test and non-homogeneous variable were transformed before ANOVA.

4 Results

Temperature values ranged between 8.8 °C (November) and 20.2 °C (August), pH values between 6.87 (September) and 8.34 (August), electrical conductivity values between 134 µScm^{-1} (April) and 289.5 µScm^{-1} (March), and dissolved oxygen values varied between 6.9 mgL^{-1} (October) and 10.72 mgL^{-1} (March). Dissolved oxygen values were highest during winter months when temperatures were generally lowest. These measurements are compatible with the literature (Hacıoglu and Dülger, 2009; Akbulut et al., 2014).We recorded four freshwater fish species during field sampling; sea trout *Salmo cf. macrostigma* (Dumeril 1958), minnow *Phoxinus phoxinus* (Linnaeus 1758), Marmara barbel *Barbus oligolepis* (Battalgil 1941) and European chub *Squalius cii* (Richardson 1857). Averaged across months, the relative abundance of *P. phoxinus* was highest with 46.3%, followed by *S. cf. macrostigma* with 22.3%, *S. cii* 16.7% and *B. oligolepis* 14.7%. Thus *P. phoxinus* was the dominant species in the stream.

Although there was no difference with regard to relative abundance of *S. cf. macrostigma* (x^2 = 2.4; df = 2; P>0.05) among stations, the relative abundances of the other three species differed significantly among stations ($x^2_{P.\ phoxinus}$ = 6.6; df = 2; $P_{P.\ phoxinus} < 0.05$; $x^2_{B.\ oligolepis}$ = 11.1; df = 2; $P_{B.\ oligolepis} < 0.05$; $x^2_{S.\ cii}$ = 8.7; df = 2; $P_{S.\ cii} < 0.05$). The relative abundances of *P. phoxinus* at the upstream and control stations were higher compared to the downstream station in the Kocabas Stream; both pairwise comparisons were statistically significant (upstream-downstream: Z = 2.3; $P < 0.05$; downstream-control: Z = 2.2; $P < 0.05$). In contrast, the relative abundance of *B. oligolepis* was higher at the downstream station compared to the other two stations; both pairwise comparisons were significant (upstream-control: Z = 2.4, $P < 0.05$; downstream-control: Z = 3.1, $P < 0.05$). *S. cii* was also more abundant at the downstream station; only upstream and downstream stations were significantly different (Z = 2.9; $P < 0.05$).

The monthly species compositions are shown in Figure 2. While *P. phoxinus* was the dominant species almost in all months at the upstream and control stations, at the downstream station the dominance this species was limited to December to June (Fig. 2). There were two peaks in spring and fall in the abundance of *P. phoxinus* at the upstream and control stations. The fall peak of this species was weak at the downstream station. *S. cf. macrostigma* was not or little encountered between December and March at all stations. At the upstream station, the relative abundance of *S. cf. macrostigma* reached 40% in November and December and was much lower in the other months. At the downstream station, the highest relative abundance was found in August (nearly 60%). At the control station the highest relative abundances were found in summer and autumn. *B. oligolepis* was mainly caught at the upstream and downstream stations. The relative abundance of this species was higher in summer and early autumn (September) at both stations. The last species, *S. cii*'s, was relatively rare at the upstream station and not caught during winter and spring sampling periods. Its relative abundance at the downstream and control station was higher compared to the upstream station (Fig. 2).

Shannon-Wiener diversity and Evenness were not statistically different between stations ($P > 0.05$). They both varied seasonally, with lowest values found in February, March and April at all stations (Fig. 3). This decline was particularly pronounced at the first station and the control station was the

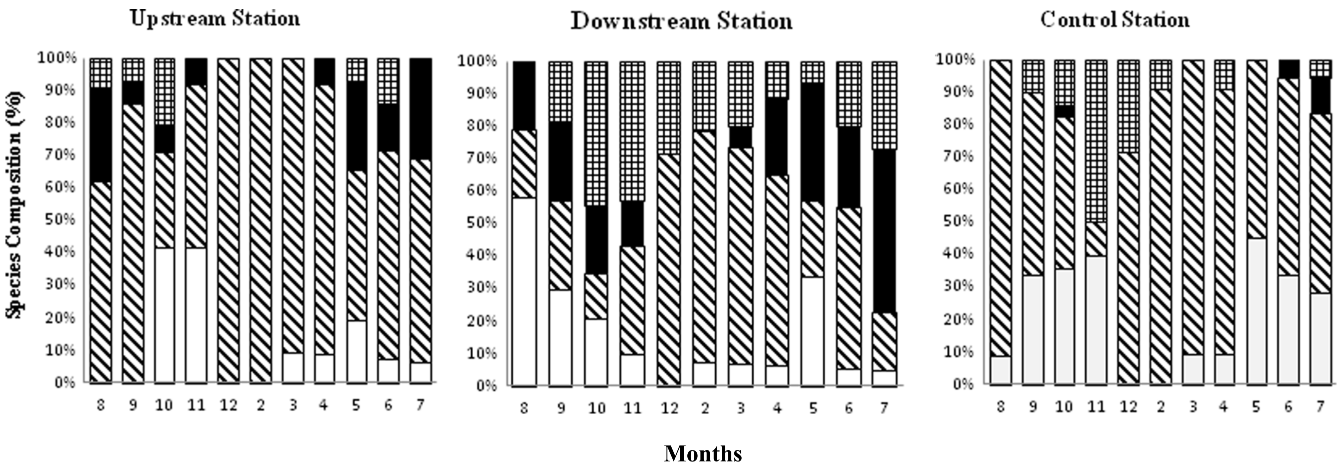

Fig. 2. Monthly species composition at three sampling stations on Kocabas Stream near a fish farm (White: *S. cf. macrostigma*, Striped: *P. phoxinus*, Black: *B. oligolepis*, Squared*: S. cii*).

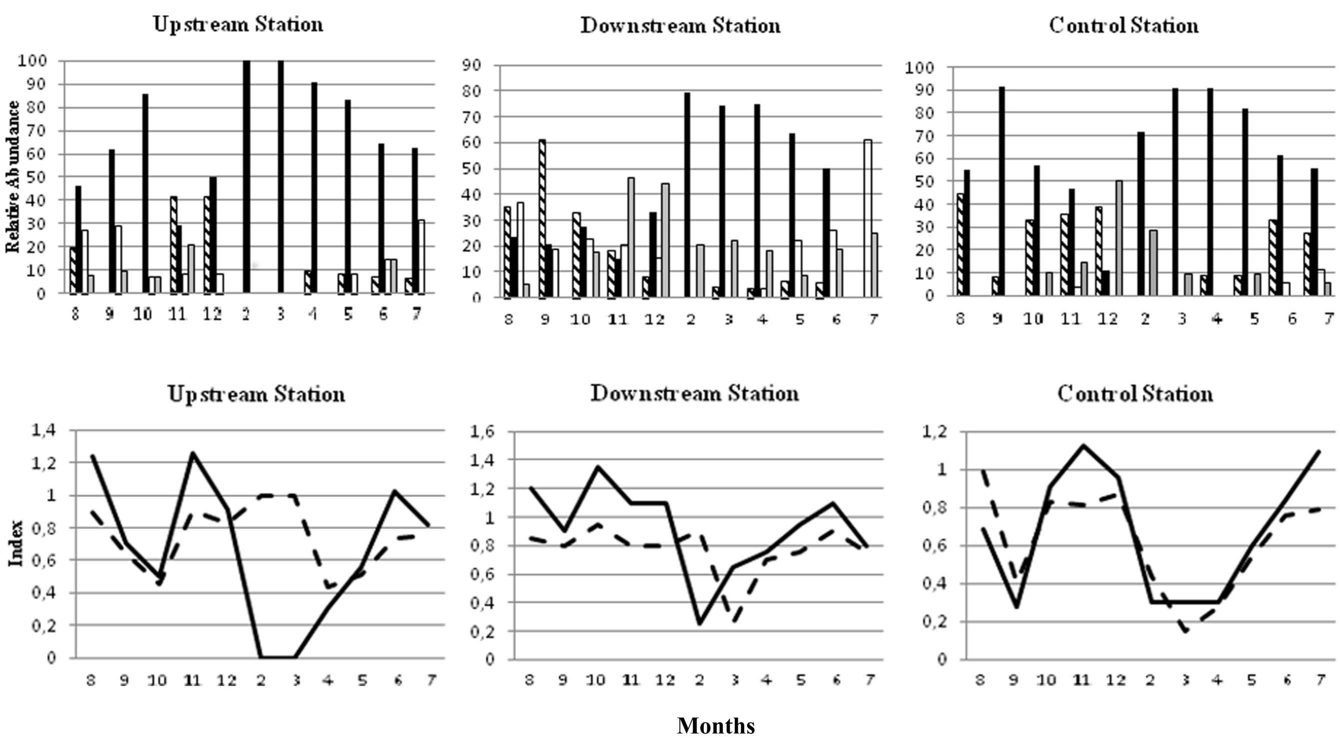

Fig. 3. Shannon-Wiener biodiversity Index (H') and Evenness (E) values for species collected monthly from upper, lower and control sites. Continuous line H'; dotted line: E.

least affected. In general, indices for the upstream and control stations were more similar.

Monthly variations in relative abundance of *P. phoxinus* were significantly negatively correlated with the other three species at the station upstream from the fish farm (Table 1). At the control station they were only significantly negatively correlated with *S. cf. macrostigma* and no correlations were found for the downstream station. None of the other species were correlated at any of the stations.

Water quality parameters measured in each sampling area are presented in Figure 4. Temperature and electrical conductivity did not significantly differ among stations ($Ftemp = 0.09$, $df = 2$, $P > 0.05$; $Fec = 0.3$, $df = 2$, $P > 0.05$), while seasonal differences were statistically significant ($Ft = 29.5$, $df = 3$, $P < 0.05$; $Fec = 8.6$, $df = 3$, $P < 0.05$). PH and dissolved oxygen values were also similar ($Fph = 0.2$, $df = 2$, $P > 0.05$; $Fdo = 0.3$, $df = 2$, $P > 0.05$) and differed seasonally ($Fph = 0.7$, $df = 3$, $P > 0.05$; $Fdo = 0.4$, $df = 3$, $P > 0.05$).

5 Discussion

Studying fish survival and mobility contributes to understanding the long-term effects of environmental or

Table 1. Correlation test results (Spearman's rho) for monthly relative species abundances at three sampling stations on Kocabas Stream near a fish farm ($n = 11$ months).

	upstream (Sta 1)	downstream (Sta 2)	control (Sta 3)
S.cf. macrostigma -P. phoxinus	**−0.67** *	−0.55	**−0.84** *
S.cf. macrostigma -B. oligolepis	0.16	0.14	0.25
S.cf. macrostigma -S.cii	0.16	−0.22	0.04
phoxinus- B. oligolepis	**−0.72** *	−0.45	−0.36
P phoxinus- S.cii	**−0.59** *	−0.24	−0.46
B.oligolepis- S.cii	0.42	−0.12	−0.15

* p-value < 0.05

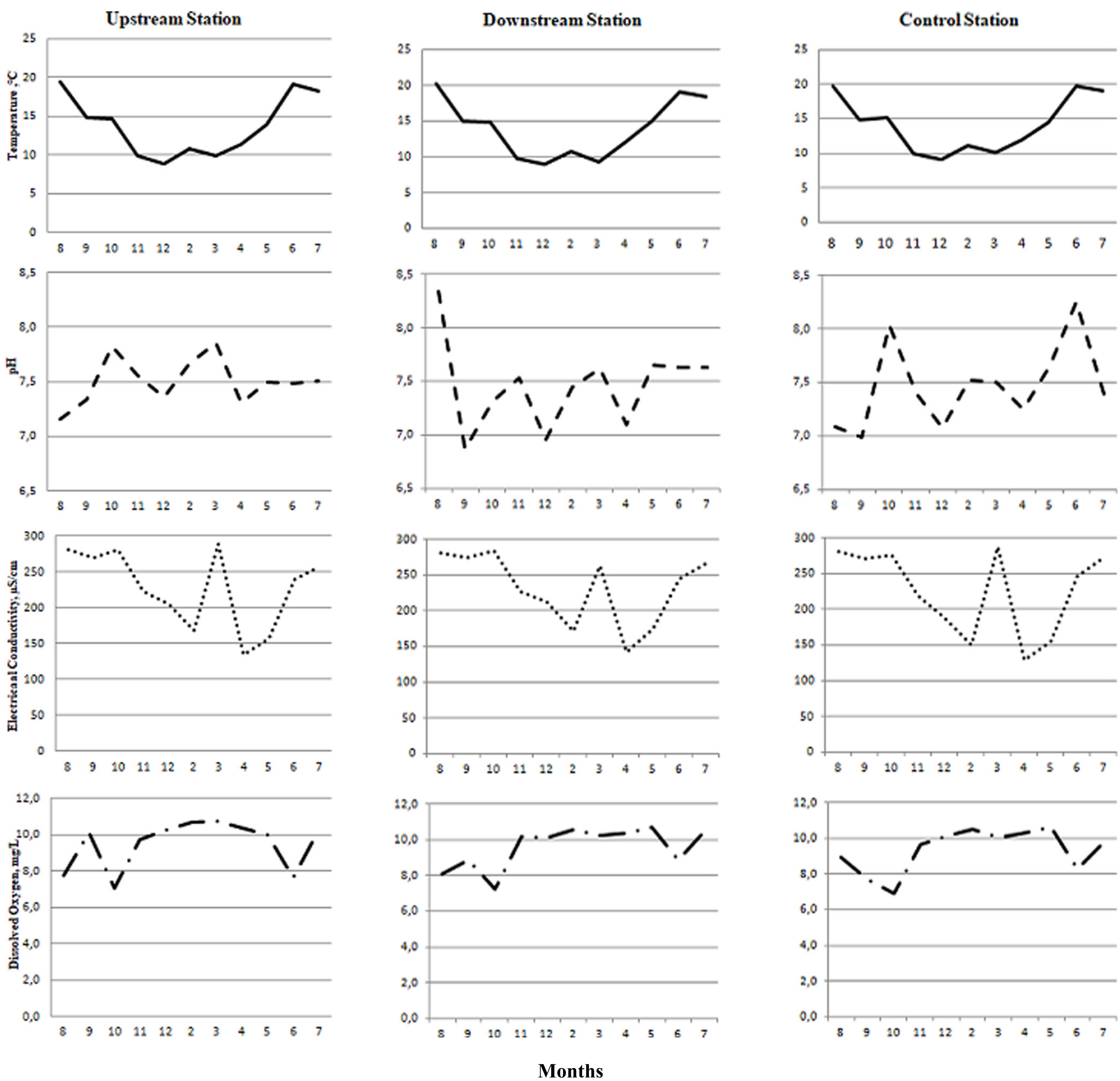

Fig. 4. Physicochemical parameters measured at the three sampling stations on Kocabas Stream near a fish farm.

anthropogenic factors and habitat conditions (Karr et al., 1986; Stephens and Farris 2004). As shown in this study, the Kocabas Stream provides suitable habitats for four fish species. For the upper trout and grayling zone, the presence of these species is an indicator of stream environmental conditions. The results of the present study on the potential effects of a rainbow trout farm on native fauna indicated no large alterations, especially with respect to the diversity of native species. However, the results suggested potential variations in the composition and relative abundance of native fish species, possibly as a consequence of the impact of the farm.

Published studies have focused on the adverse effects of fish farms such as blocking migratory routes and disturbance of ecosystem functioning by habitat modifications (Agostinho et al., 2005, 2007, 2008; Gubiani et al., 2007; JúlioJúnior et al., 2009). In this study, the fish farm did not present any physical obstacle to migration. Therefore, we studied the potential effects on diversity and its seasonal changes.

The study area was located in the trout and grayling zones (for *P. phoxinus*) of the Kocabas Stream. *B. oligolepis* and *S. cii* were found at all three sampled stations. Both species are common along the Kocabas stream (Çiçek et al., 2015) but their higher relative abundance in the trout and grayling zones (downstream station) might have been caused by a farm effect. Artificial food components scattered from the farm might be rich in fish meal and thus provide direct food for native fish species downstream from the farm. On the other hand, these scattered food components might be a source of high nutrient input throughout the stream food web and result in rich macroinvertebrates as live food, thus representing an indirect food input. Both explanations are important, particularly for the trout and grayling zone resident fish species *cf. macrostigma* and *P. phoxinus.* A detailed study is suggested on the feeding ecology of these species.

The negative correlations found between freshwater fish species relative abundances might be explained by predator-prey relationships (Cooper et al., 1990; Borgstrøm et al., 1996, 2010; Museth et al., 2007, 2010). *P. phoxinus* is a small fish species and might be potential food for the other three species. Some records exist for this species in sea trout diet (Museth et al., 2010). There might have been a shift in the diet of sea trout and other predatory fishes at the downstream station caused by changes in the availability of food resources. The results indicated that there might be competition between *S. cf. macrostigma, B. oligolepis* and *S. cii.* However, *B. oligolepis* might have had more success in collecting prey items compared to the other species and *S. cf. macrostigma* and *S. cii* might have shifted their diet from *P. phoxinus* to other food items. This hypothesis needs to be investigated further.

6 Conclusion

Aquaculture develops in many regions around the world. The results and methods of this study provide baseline information on the relative abundance and diversity of fish associated with aquaculture sites. In the study the fish farm was not an obstacle for migration of any fish species. We found that the aquaculture activity might explain higher relative abundances of some species. This finding is in accordance with Dempster et al., 2004; Machias et al., 2004; Neofitou et al., 2010; Briones et al., 2016. However, this higher relative abundance favored downstream fish species rather than *S. cf. macrostigma*. *S. cf. macrostigma* is one of the most important economic fish species in up streams and population dynamics of this species might have been affected by the aquaculture activity. This hypothesis needs to be further investigated.

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