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Effects of environmental deterioration on Northeast Anatolia Trout (*Salmo spp*.) Populations

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ABSTRACT

In this study, the possible effects of overfishing pressure on local Salmonid populations and the critical environmental changes that have occurred in the wild habitats that have been deteriorating since the beginning of the 21st century were investigated in Northeast Anatolia. In the research, methods including quantitative and qualitative impact assessments were used to determine environmental changes and anthropogenic effects. In addition to numerical data, observations of the stream and its surroundings were recorded.

As a result, it has been determined that the natural trout populations, distributed in the limited habitats in the middle and upper parts of the studied rivers, have decreased considerably, especially since the number of individuals who have reached breeding age has reduced to a high level. It has been determined that the habitats in localities where the research was conducted have been under great pressure, since the end of the 20th century, due to infrastructure works, urbanization, and illegal fishing. It has been determined that the local trout populations, distributed in the limited habitats in the middle and upper basins of the studied rivers, are quite damaged. The number of individuals that have reached the breeding age has decreased significantly.

Keywords: Northeast Anatolia basin, *Salmo labrax*, Local trout populations, Overfishing, Habitat degradation

Introduction

The Black Sea salmon (*Salmo labrax,* Pallas 1814) inhabits the northern Black Sea coasts and inflowing rivers. There are anadromous, lacustrine, and resident river populations. This fish is a close relative of the brown trout. While it is the only native species of Salmonids present in the northern Black Sea basin, it may hybridize with (introduced) brown trout in the major rivers (Freyhof, 2013). Marine populations are currently found very rarely. But the resident river stocks are doing well (Froese & Pauly, 2019), just slightly better than marine populations. However, it is included in the Red List in European waters, and the IUCN status of the Caucasian and North-eastern Anatolian trout populations is NE (Nearly Extinct) (Mikeladze et al., 2021).

Today, it has been demonstrated by many studies that wild trout populations are exposed to great pressure as a result of natural ways and human activities (fishing, changing the living environment, pollution, etc.) (Crowx, 2002; Kratzer & Warren, 2003¸Zengin et al., 2017; Kirn, 2017; Şengül et al., 2018; Kalaç et al., 2019). *S. labrax* species shows a natural distribution in the Eastern Black Sea Region Rivers. This species prefers cold and fast-flowing streams. Adults migrate to the upper parts of the river to spawn, while young individuals migrate downstream to find more food and transfer to the sea. This situation then continues in reverse (Aksungur et al., 2011).

Regarding river potential, Northeast Anatolia is one of Turkey's most important geographical areas. Although the flow rate of the streams in the region is low, the flows periodically enter an increasing trend during precipitation periods (Zengin et al., 2017). After the 2000s, the rivers in the region were considered the most important potential resource in the policies to eliminate the energy deficit in Turkey. They started to be used intensively (Erdoğan, 2010r).

Local populations of Salmonid species with the same lineage group (Danube) show some morphological, ecological, and genetic differences, spread in the inland waters of Northeast Anatolia in Turkey (Çiftçi et al., 2007). *S. trutta* is represented by four subspecies in Türkiye (Berg, 1948; Balık & Geldiay, 1996). These are *Salmo abanticus,* Tortonese, 1954 is distributed in Lake Abant, *Salmo caspius,* Kessler 1877 is in the Caspian Sea region, *Salmo labrax,* Pallas 1814 is in the Black Sea region and *Salmo macrostigma,* Dumerill 1858 is in the Mediterranean region (Polat et al., 2011). However, according to recent genetic studies (Bernatchez et al., 2001; Bardakçı et al., 2006; Kalaycı et al., 2018), it has been stated that there is no molecular level difference between a large number of morphologically different trout populations in Turkey, which are considered different subspecies.

Despite the genetic findings, this taxonomic situation is still widely used (Solomon, 2000; Tabak et al., 2001; Kurtoğlu, 2002). *Salmo platycephalus* (Anatolian trout) is a trout species found only in the central south of Turkey, especially in the Seyhan River system. It was scientifically described for the first time in 1968 by a scientist named R. J. Behnke. The largest ones can reach 50 cm in length (Behnke, 1968). According to the findings obtained from the genetic studies carried out by Kalaycı et al. (2018) on the taxonomic differentiation of trout populations distributed in Turkish waters, they reported that Abant, Caspian, Black Sea, and Anatolian trout, which live in Turkish waters and are named according to the geographical regions where they have lived until today, are only an ecotype and each is an ecotype of *S. trutta,* which comes from the Danube lineage.

In this study, the possible effects of significant environmental changes in the natural habitats of the local populations of Salmonid species distributed in the Northeast Anatolian zoogeography of Turkey have deteriorated since the beginning of the 21st century on these populations were investigated.

Material and Methods

Trabzon Central Fisheries Research Institute carried out this study in consecutive periods with data from three different studies. The periods in which these projects and field studies are carried out are as follows; (1) "A Study on the Evaluation of Aquatic Ecosystems in and around Lake Çıldır in terms of Fisheries Management" carried out between 2011-2012 (Zengin et al., 2013). (2) "Investigation of Long-Term Cumulative Effects on the Ecosystem in the Solaklı Basin with an inSTREAM Agent-Based Model" conducted between 2015-2016 (Şengül et al., 2018), and (3) It was started in 2017 but canceled after two periods of fieldwork; "Studies on the Development of Black Sea Trout Fishing Populations on the Main Tributary and Tributaries of the Barhal Stream" (Çakmak et al., 2017).

Sampling Studies

Within the scope of the research, the samples of the trout populations in the river were carried out with the same standard sampling method using the 'electroshock' device. In addition, gillnets with different mesh sizes were used in the trout samplings in the Çıldır Lake. The locations where the research was carried out are shown in Figure 1. There are two ecotypes

of Caucasian trout in the Çıldır basin. These are the river ecotype and the lake (anadromous) ecotype. The height distribution of individuals in the lake ecotype is more significant than those in streams (Zengin et al., 2013). Caucasian trout migrate to some important streams (Doğruyol, Gülyüzü, and Gölebakan Streams) that discharge into the lake in the late spring and summer periods for spawning migration and migrate back to Çıldır Lake in late autumn and winter periods to feed (Zengin et al., 2013).

In the study, sub-locations, sampling periods, and the total number of samples related to the sampling studies carried out in each aquatic resource are shown in Table 1. Studies on all three aquatic resources are shown in Figures 2, 3, 4, and 5.

Table 1. Research stations, sampling periods, and total sample numbers

Research area	Stations	Sampling periods	Number of samples
Ardahan-Çıldır Lake and Streams	Lake Akçakale Stream Doğruyol Stream Çanaksu Stream Çıngıl Stream Gülyüzü Stream Gölebakan Stream Arpaçay/HEP Discharge	July 2011 September 2011 June 2011	99
Trabzon-Çaykara-Solaklı Stream	Haldizen Branch Karaçam Branch	August 2015 December 2015 April 2016 October 206	96
Artvin-Yusufeli-Barhal River	Barhal Main Branch Bıçakçılar Stream Altıparmak Stream	April 2017 July 2017	75

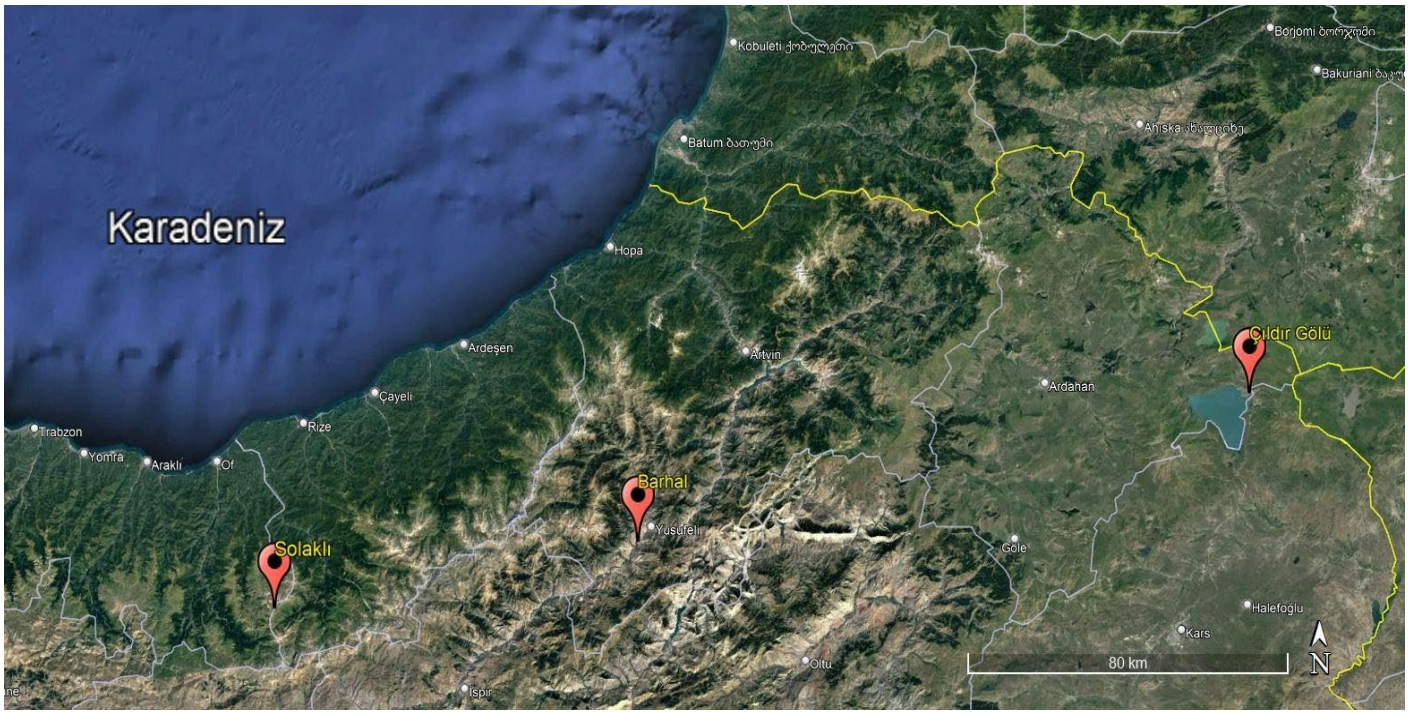

Figure 1. Aquatic areas in the Northeast Anatolia Region where the studies were carried out; Çıldır Lake (Ardahan, Arpaçay), Barhal Stream (Artvin, Yusufeli), and Solaklı Stream (Çaykara, Trabzon)

Figure 2. Samplings of Lake Çıldır were made with gillnets with different mesh sizes (July 2011)

Figure 3. Trout samplings from the streams discharging into Çıldır Lake (July 2011)

Figure 4. Trout sampling studies at stations in Trabzon, Çaykara-Solaklı Stream Karaçam and Uzungöl/Taşkıran tributaries (April 2016)

Figure 5. Sampling studies on the Altıparmak tributary of Barhal Stream (July 2017)

Biometric Studies

On fish samples, respectively, biometric measurements (mm total length, body weight measurements sensitive of 0.01 g and gonad weights), sex determinations, and laboratory studies for macroscopic determination of gonad development stages were performed (Holden & Raitt, 1974) (Figures 6, Figures 7). For age estimation, otoliths, an indicator of growth, were fixed and estimated from age rings under the electronic microscope (Jensen & Johnsen, 1982). With the data obtained, the analysis of parameters such as length-weight-sex-age-laying maturity, length-frequency, age-frequency distributions, and distribution of individuals who have reached sexual maturity will reveal the structure of the trout populations in each location, where made current structure of fish populations. Many reference points will reveal the effect of internal (natural) and external (environmental effects, anthropogenic, etc.) factors, such as whether the population has decreased or is it able to maintain itself at the optimum level. The most valuable and direct method that provides rational information to the researcher is to take the length and age distributions of the individuals in the population as a reference (Sparre et al., 1989).

Figure 6. Biometric studies on trout samples from Barhal Stream

Figure 7. Biometric measurements and determination of sex and gonad development stages on trout samples (Trabzon Central Fisheries Research Institute, Biology Laboratory)

Habitat Studies

Primary data of the study; retrospective, long-term hydrological data on rivers and water structures in the pilot regions, habitat observations, and ongoing investigations on stream beds. In the study, methods including quantitative and qualitative impact assessments were used for the determination of environmental changes and anthropogenic effects. In addition to numerical data, observations of the stream and its surroundings were recorded. Parameters related to environmental factors were divided into categories and standardized by giving a quantitative score/value to the variable under each category. The results were analysed and evaluated proportionally (Rosenthal et al., 2015).

The basic parameters listed below were considered for aquatic habitat analysis (Paffett et al., 2018; Rosenthal et al., 2015). These are, respectively, historical changes in the river flow regime, the structural features of the river bed, the past topographic and current state of the river, the settlement characteristics of the river basin, the depth, width, slope, bends/curves of the river bed, bottom profile, substrate type, and size, structure of the shore banks, islets, river reclamation/flood embankments type, erosion levels, in-river and coastal vegetation, creek basin land/soil use, hydrological structures and other activities (reservoirs, water sequestration), wastewater discharges, pollution status and levels, solid waste landfill, quarries, mining, bridge and road crossings, recreation areas, urbanization.

With all these collected data, answers to the following questions were sought. Does the previous and current evidence prove the migration of native trout across streams? Can species/ecotype detection be done safely? Are the proportions of the species known? Where are the spawning grounds? Where were the juveniles/fry seen on the stream? Is there evidence of their longest-distance migration on the river? Regarding hydrology/water quality, is there a smooth spring/summer flow? Is the depth in spawning areas sufficient? What is the average particle size in sediment transport? Is the water quality suitable for the upper streams as they are historically and currently potentially spawning areas for the species, or has it

changed? Are there any analytical plans to reduce the pollutants directly released into the stream? Can measures be taken to reduce the impact of new Hydroelectric Plants Power (HEPPs), which are implemented and planned on rivers, the river water regime, and the aquatic ecosystem/fish migration? (Gessner et al, 2000; Paffett et al., 2018).

Results and Discussion

State of Populations

Lake Çıldır: The length distribution of the *Salmo caspius* population sampled from the lake ecosystem was determined as 23.7-41.2 (31.2) cm, and the length distribution of the population sampled from the streams discharged into the lake was determined as 8.8-27.5 (10.3) cm (Figure 8). The first sexual maturity length of the population is 13.7 cm. When this size criterion is taken as a reference, 58.3% of the individuals distributed in the river environment consist of individuals who have not yet reached sexual maturity (Figure 9). Considering the age distribution, their populations mainly consist of smolt and young individuals (54.3%) in the 1st and 2nd age groups (Figure 10). Although individuals belonging to the 'lake ecotype' are biometrically larger, the age distribution of individuals belonging to the 'river ecotype' was found to be relatively higher. It is estimated that this growth difference is due to the fact that the feeding dynamics of the lake have a richer potential than the river. However, for both environments, overfishing pressure caused the populations to decline.

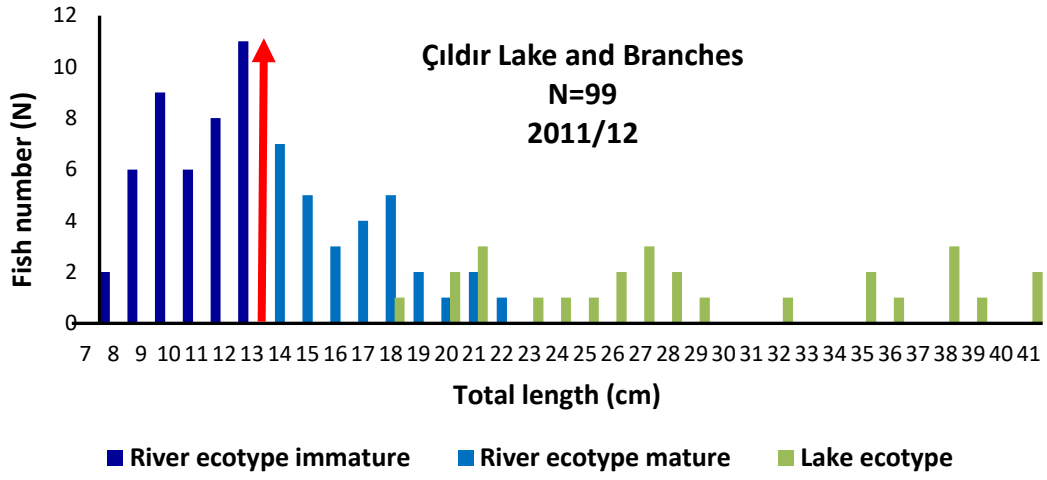

Figure 8. Çıldır lake; length-frequency distributions of river and lake ecotypes

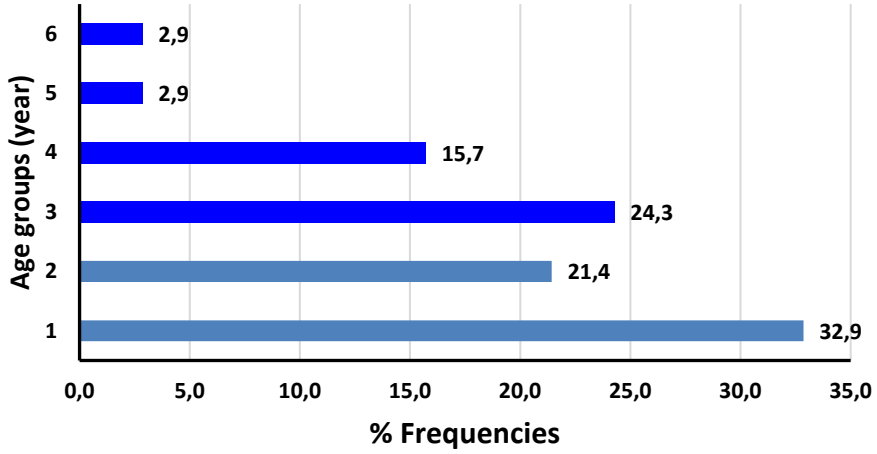

Figure 9. Distribution of age groups of *Salmo caspius* populations in Lake Çıldır

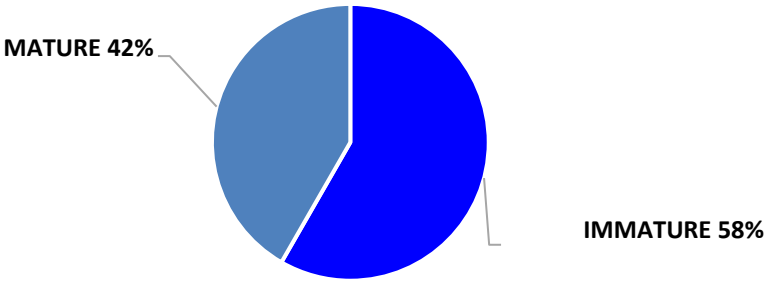

Figure 10. Sexual maturity distributions of *Salmo caspius* populations in the streams discharged to Lake Çıldır

Solaklı Stream: While the length distribution of *Salmo labrax* individuals sampled from the upper tributaries of the Solaklı Stream varied between 6.9-23.2 (13.2) cm, it was observed that the population disappeared completely in the main branch extending to the downstream of the creek in the center of Çaykara district (Figure 11). The age distribution of the Solaklı population ranges from 0 to 3. When the first sexual maturity size of *S. labrax* is taken as a criterion, 35.4% of the Solaklı population consists of adults, and 64.6% are juveniles/young individuals (Figure 12). Considering the first sexual maturity length of the population (13.7 cm), the majority of the individuals distributed in the river consist of individuals who have not reached sexual maturity yet. Considering the age distribution, their populations mostly comprise smolt and young individuals (65.7%) in 0 and 1 age groups (Figure 13). The findings reveal that the trout population living in this habitat has been overexploited. Urbanization along the Solaklı valley, tourism activities in Uzungöl, wastewater discharges, sand-gravel intakes, recreation in the riverbeds, and opening 14 HEPPs and regulators on the main and side branches of the same river have had an impact on this attrition, mainly since the 2000s.

Barhal Stream: The length distribution of the *Salmo macrostigma* population sampled on the upstream branches of the Barhal Stream, which constitutes the main branch of the Çoruh River, was found to be between 6.4-27.2 (16.8) cm (Figure 14), and the age distribution was between 0-6 (Figure 15). Considering the first maturity length of the population (13.7 cm), 35.7% of the fish distributed in the river environment consist of individuals who have not reached sexual maturity yet (Figure 16). The fact that the adult populations in this region are 65.3% higher than the other two localities indicates that the trout populations in the region are less overexploited. The reason for this is that the trout populations in the upper branches of the Barhal Stream are in a safer environment due to environmental factors and less separation of their habitats, compared to many aquatic environments of Türkiye. However, the Yusufeli Dam, which was recently built on the main branch of the Barhal Stream, poses a significant risk to these populations' breeding and feeding migration. As a result, it is likely that natural trout populations, which spread in limited habitats in the middle and upper parts of the studied rivers, will be damaged by this because there is no 'fish passage' planned on the HEPP system that the fish can use between the downstream and the upstream for breeding and feeding migration.

Environmental Impacts

The common results of multiple environmental parameter analyses conducted on stream habitats are shown in Figure 17. According to the findings, the effects of environmental impacts gathered under three main categories on aquatic habitats (Çıldır lake and its side streams, Barhal Stream and Solaklı Stream) are respectively; pollution 65%, hydrological changes 52%, biological effects 35%. Among these essential factors, the most important impact is eutrophication, solid waste storage, and nutrient discharges; in other words, it constitutes a group of urban, industrial, and agricultural wastes. On the other hand, the rate of hydrological impacts is still moderate, and this rate is around 50%. In this group, the effect of HEPPs established on riverbeds is prominent. In addition, the destruction of the structure of the riverbed is also essential. Below the medium level, the most negligible impact is excessive fishing pressure from biological origin, illegal fishing, and exotic species invasions.

At the beginning of environmental impacts, the effect of the Hydroelectric Power Plants, which started to operate at an increasing rate in the Eastern Black Sea Region since the beginning of the 2000s, has created significant risk for trout populations (Zengin et al., 2017). As a result of insufficient compensation of water, invertebrate and vertebrate fauna are adversely affected, as well as habitat loss in the stream bed. Depending on the increase in water temperature in summer

and the relative decrease in flow rate, algae colonization may occur in the localities from the tailwater discharge point to the downstream in HEPPs. These negative factors disrupted the water flow regime in the river system and the water quality, causing a rapid decrease in fish populations living in the region's rivers. On the other hand, due to the embankment in front of the reservoir (dam lake) of the HEPPs, the biological contact between the lower and upper sections is cut off. The temperature of the water accumulating in the reservoir rises. Due to the decay of organic materials accumulated in the reservoir, oxygen in the water decreases, and toxic gas accumulation increases. The flow of water in the stream decreases, especially in the summer months, and the amount of confirmed life in water cannot be fully achieved.

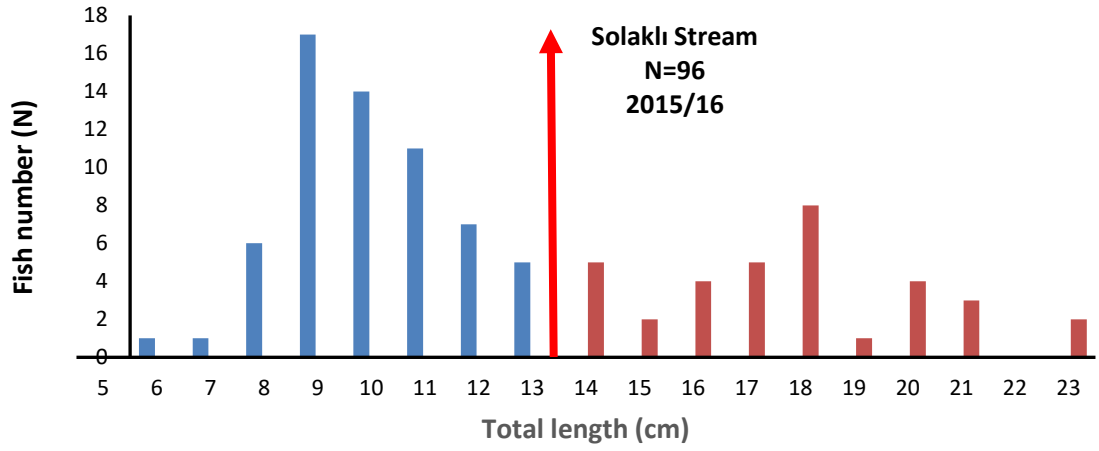

Figure 11. Length-frequency distributions of the *Salmo labrax* populations of Solaklı Stream

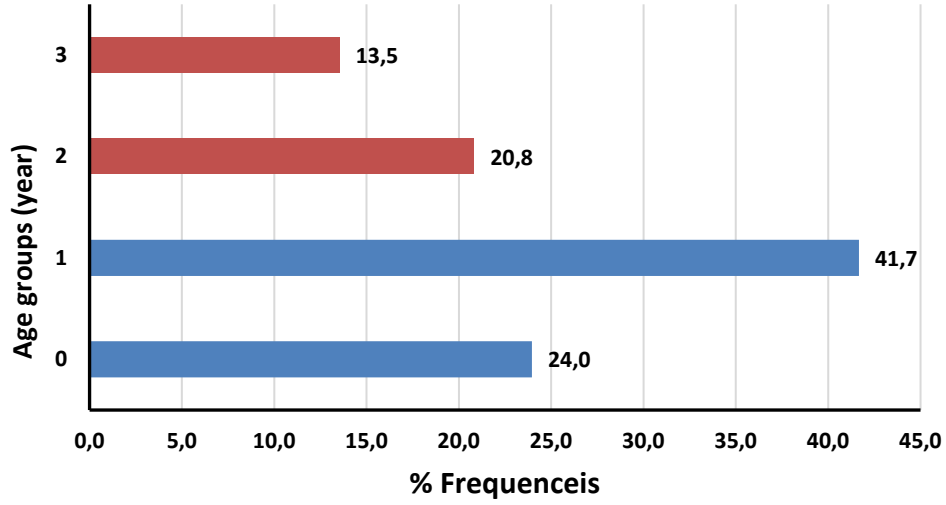

Figure 12. Distribution of age groups of *Salmo labrax* populations of Solaklı Stream

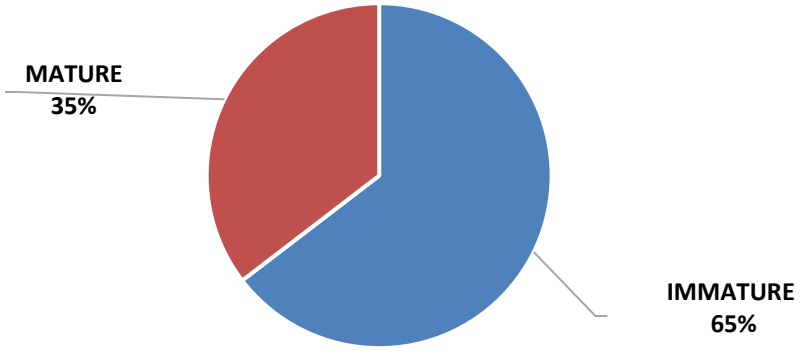

Figure 13. Sexual maturity length distributions of Solaklı *Salmo labrax* populations

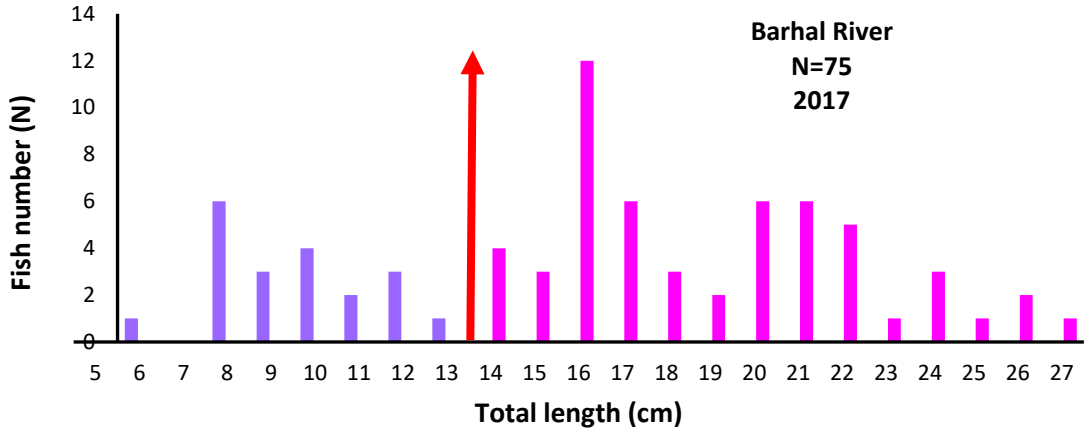

Figure 14. Length-frequency distributions of Barhal Stream *Salmo macrostigma* populations

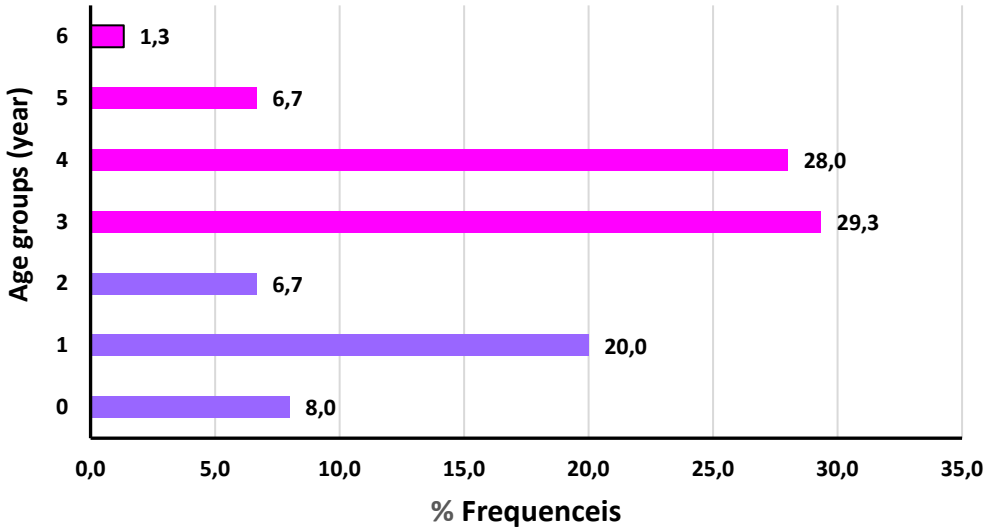

Figure 15. Distribution of age groups of *Salmo macrostigma* populations of Solaklı Stream

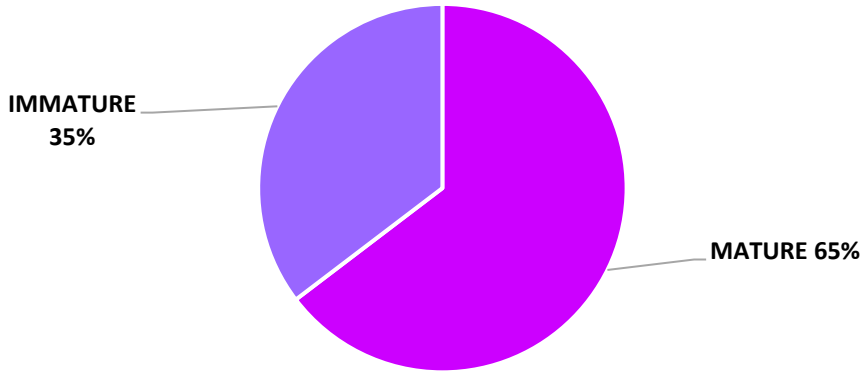

Figure 16. Sexual maturity length distributions of Barhal Stream *Salmo macrostigma* populations

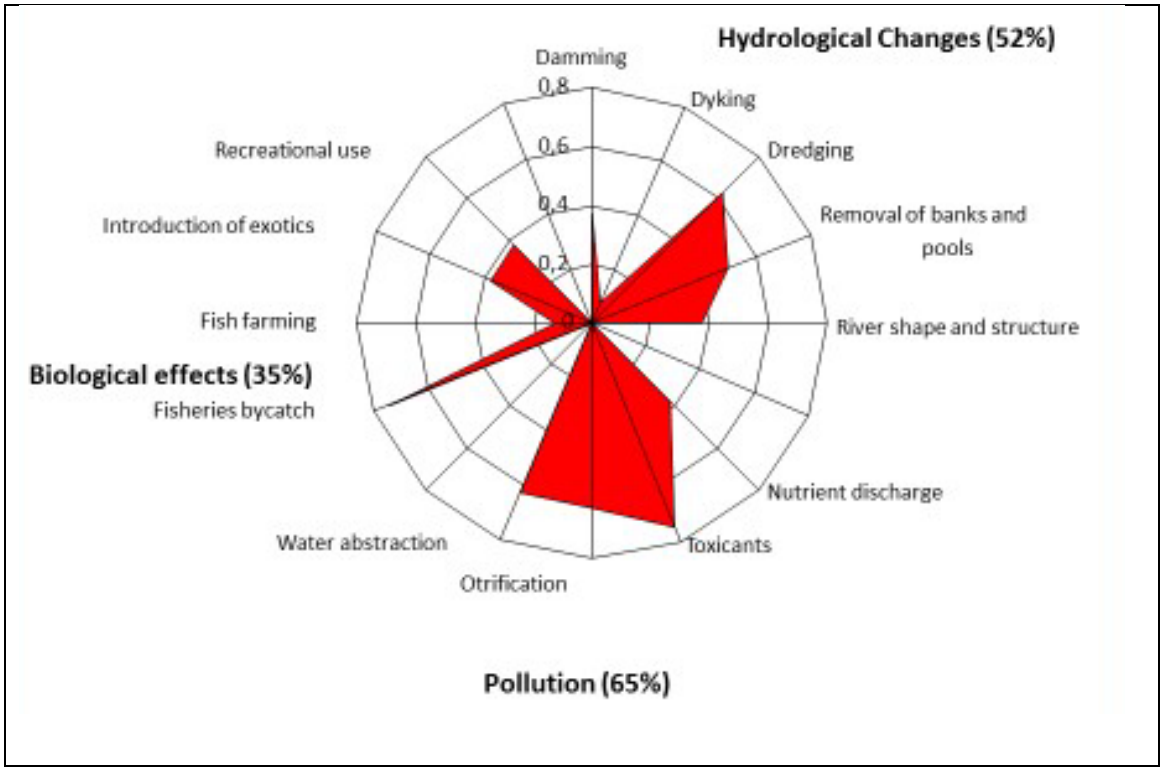

Figure 17. Categorical distribution of possible effects of environmental degradation on trout populations in Northeast Anatolia (Relative index values)

One of the most important risks in the creek's downstream regions is the riverbed's recreational activities carried out by the sand and gravel quarries and the local administrations. During and after these studies, the historical and natural structures of the stream and stream beds are completely changed. Trout individuals dispersed in downstream regions need a safe habitat for both feeding and breeding migration. Although there is no significant problem in this respect in the upper/upstream sections of the stream, where the breeding migration occurs to a large extent, the deterioration was observed relatively in the discharge/closer areas of the stream. In addition, due to the deterioration in these parts of the stream, Stream edge and inland aquatic vegetation could not develop. As a result of erosion/flooding, clay-shaft deposits have accumulated on the riverbank. The deposition has evolved into permanent substrate layers over time. The aquatic habitats in the shallow/marginal regions of the stream, where the current is stagnant, form the living areas of

all living creatures, aquatic insects, their adults, eggs, and larvae that feed the benthic macrofauna in the aquatic ecosystem, and therefore fish. For these reasons, stream modifications (such as retaining walls, road construction, and bridge) should be made within the framework of a certain plan.

During the interviews with some amateur fishermen from the local people who are interested in trout fishing in the area, It has been declared that approximately 25-30 fish are still caught in a day with fishing line, especially in the upper parts where the stream bed is less physically affected (in the foothills of the Kaçkar Mountains, in the small lakes and streams in the plateau and hamlet regions). However, it has been stated that the trout populations in the creek have decreased gradually in the 40 years since the 1980s. Undoubtedly, in addition to over and illegal fishing without control, the existence of an ineffective management strategy for amateur fisheries in our country is also an important factor. For example, when the irregular catch statistics in Lake Çıldır were examined, it was determined that the trout with carnivorous characteristics in the lake was at a fishable level at the beginning of the 1990s, but then it became almost extinct. Uncontrolled fishing is carried out by fishermen who are commercially caught lake trout that enter the lake in certain periods for feeding while spawning migration is carried out to some important streams that discharge into the lake in the spring and summer periods. Today, it is mentioned that about 8-10 lake trout are caught by each fisherman in the nets along with other target species during the fishing season in Lake Çıldır (Zengin, 2019). The development of the fish populations in the lake in favor of herbivorous and omnivorous species instead of carnivores has led to a decrease in the population in the following years due to reasons such as feeding and habitat sharing (Zengin et al., 2013). In the 2000s, the introduction of an exotic and invasive species of crucian carp (*Carassius gibelio*) and crayfish (*Astacus leptodactylus*); started to put potential pressure on the native fish fauna in the lake in response to the collapse of wild stocks in the lake since the early 1990s (Zengin, 2019). In addition, as a result of the increase in the operating capacity of the Arpaçay Hydroelectric Power Plant fed from Lake Çıldır, the coastal/shallow, reed, and sensitive areas that constitute the breeding and feeding areas of the local carp have been adversely affected.

Conclusion

It has been determined that the habitats in all three localities where the research was conducted have been under great pressure, especially since the end of the 21th century, due to infrastructure works, urbanization, and illegal fishing. It has been determined that in the downstream regions of the studied rivers, the trout populations have completely disappeared with habitat loss, the local trout populations that spread in the limited habitats in the middle and upper basins are quite worn out, and the number of individuals who have reached breeding age has decreased significantly.

If serious measures are not taken at the national level for aquatic ecosystems in the ongoing process, habitat loss and wild trout populations will be at greater risk. They will gradually enter the process of extinction as they cannot maintain their basic vital activities such as breeding, migration, and feeding. One of the most important threats in this process is the existence of hydroelectric power plants planned for energy purposes on rivers.

Like the trout populations distributed in other geographical areas of Türkiye, the trout population living in the Northeast Anatolian geography has decreased gradually as the environmental conditions deteriorate and the increasing illegal fishing cannot be prevented. In general, the stocks of the trout populations in our country's waters have come to the limit of extinction for many years, especially due to the deterioration of their habitats and overfishing with the market economy implemented since the beginning of the 1980s. Today, due to the significant population decline, it has no commercial importance. Despite the collapse of their stocks and their protection in fisheries management, we have left behind the first half of the 21st century, and there have not been enough promising developments in this regard yet.

Wild trout habitats (river, lake, and marine habitats) are exposed to three major pressures today. These are mainly (1) Domestic, agricultural, and industrial wastes, (2) Changes/modifications in riverbeds, and (3) Hydroelectric Power Plant activities. All factors cause habitat loss and insufficient water flow. As a result of insufficient compensation, water, invertebrate, and vertebrate fauna are adversely affected, as well as habitat loss in the stream bed.

In this study, the relations of natural trout populations in North-eastern Anatolian rivers with the environment are evaluated; These stocks, which remained relatively stable until the 1980s, deteriorated gradually, especially from the beginning of the 20th century. Today's trout populations consist of younger and smaller individuals. Small age classes characterize the age distribution of individuals in natural breeding and feeding areas. This situation shows that the populations have decreased significantly in the last 20-30 years as a result of the disruption of the habitats in the natural trout habitats and uncontrolled fishing. The long-term viability of Northeast Anatolian wild trout river populations will require protecting and developing forested coastal areas, diverse, complex, and interconnected aquatic habitats, and maintenance and im-

provement of suitable water temperatures, natural water quality, and natural hydrology. With the impact of environmental regulatory procedures, policies, and practices of the Ministry of Agriculture and Forestry, the highest responsible and administrative unit in this regard, can positively affect the protection and development of critical habitat requirements of this important ecological fishery resource. In addition, training, social outreach, and technical assistance should be provided to private landowners and people in local settlements.

Compliance with Ethical Standards

Conflict of interest: The authors declare that they have no actual, potential, or perceived conflict of interest for this article.

Ethics committee approval: Ethics committee approval is not required.

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