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Review Article

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Fish Fauna and Fishery Evaluation of Sapanca Lake

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Abstract

Scientific data on fish communities in Türkiye's lakes and rivers, particularly long-term studies with continuity, remain scarce. However, Sapanca Lake is an exception due to its strategic location in the Marmara Region, which has attracted significant research interest in its limnology, fish fauna, and fisheries. This review synthesises historical and contemporary changes in the fish communities of Sapanca Lake, integrating scientific articles, theses, books, and reports. The lake has undergone notable shifts in species composition, with some native species (*Abramis brama, Alburnoides bipunctatus, Anguilla anguilla, Carassius carassius, Leuciscus aspius, Perca fluviatilis, Ponticola syrman, Salmo labrax*) disappearing, while others (*Gambusia holbrooki, Gobio sakaryaensis, Leucaspius delineatus, Phoxinus strandjae*) have recently been recorded. These changes are attributed to eutrophication, habitat degradation, overfishing, and the introduction of non-native species. Some non-native species, such as *G. holbrooki*, have established themselves in vegetated areas and slow-flowing streams, raising concerns about their potential effects on the lake's biodiversity and food web. The review also highlights the role of fisheries regulations in shaping the lake's ecological dynamics. Commercial fishing was banned in the late 1990s, and in 2003, the lake was designated as a drinking water basin, further restricting fishing activities. However, illegal fishing persists, posing ongoing threats to fish populations. Meanwhile, cyprinid species have become dominant, likely benefiting from the lake's shifting trophic state and reduced predation pressure. Given these findings, the study underscores the urgent need for improved monitoring, conservation strategies, and adaptive management to mitigate further biodiversity loss and preserve the lake's ecological integrity. Future efforts should prioritise long-term ecological assessments, targeted control of invasive species, and sustainable fisheries management to maintain the resilience of Sapanca Lake's fish communities.

Keywords Aquatic life · Inland fisheries · Limnology · Long-term data · Stock management

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Introduction

Sapanca Lake was closed to commercial fishing in the late 1990s (Resmi Gazete, 1997) and was declared a drinking water basin in 2003 (Marka, 2011). For many years, the lake held significant importance in the field of fisheries and remains one of the most prominent lakes in the Marmara Region for recreational fishing (İlhan *et al.*, 2024). Today, the lake serves as a vital source of both drinking and utility water, while also being a subject of numerous studies by domestic and international researchers on its fish and fisheries. The first information on the fish of Sapanca Lake was provided by Deveciyan (2006) in his book *"Türkiye'de Balık ve Balıkçılık"* (*Fish and Fisheries in Turkey*), based on his observations of fish brought to the Istanbul Fish Market. This book, originally published in Ottoman Turkish in 1915, was later translated into French as *"Pêche et Pêcheries en Turquie"* in 1926 and reprinted in modern Turkish in 2006. Kosswig & Battalgil (1943) provided insights into the fish of Sapanca Lake in their article *"The Zoogeographic Importance of Turkish Freshwater Fish"*. Numann (1958, 1961) conducted comprehensive studies on the limnology and fisheries of Lake Sapanca, compiled fish species lists, and provided the first data on the biology and population structures of economically important species in his research, *"Limnological and Fisheries Investigations in Various Anatolian Lakes"* and *"Die Anatolischen Seen und ihre fischereiliche Bewirtschaftung"* (*Anatolian Lakes and Fisheries Management*). Ladiges (1960) compiled information on the fish of Lake Sapanca by combining his own findings with data from various sources. Among the subsequent studies, Ongan (1982) listed the fish species in the lake in his report titled "Development of Inland Water Resources and Inventory of Water Bodies in the Southern Marmara Region" and identified the dominant species based on information obtained from local fishermen. Rahe & Worthmann (1986) provided important information about the fish fauna of Sapanca Lake, the biology of some species, and fishing activities within the scope of the "Marmara Region Inland Fisheries Development Project". After a period of stagnation in fish and fisheries research on Sapanca Lake, the Faculty of Aquatic Sciences at Istanbul University resumed fisheries biology studies in 2000. Research in the early 2000s primarily focused on the biology and population dynamics of common cyprinid species, including *Blicca bjoerkna*, *Vimba vimba*, *Rutilus rutilus*, and *Scardinius erythrophthalmus* (Gürsoy, 2001; Okgerman, 2002; Tarkan, 2002). These studies resulted in multiple publications and a doctoral dissertation investigating the growth and reproductive biology of *V. vimba* and *B. bjoerkna* (Gürsoy *et al.*, 2005a, 2005b; Hamalosmanoğlu, 2003; Karabatak & Okgerman, 2002; Okgerman, 2005; Okgerman & Oral, 2004, 2005). Subsequent research expanded to include the population characteristics of economically significant species such as *Esox lucius*, alongside dominant cyprinids like *R. rutilus* and *S. erythrophthalmus* (Gürsoy *et al.*, 2005a, 2005b; Okgerman, 2005; Okgerman & Oral, 2004, 2005). Since then, biological and taxonomic studies on the lake's fish have steadily increased, covering additional species (Gaygusuz *et al.*, 2006, 2007a; İlhan *et al.*, 2024; Karakuş *et al.*, 2018; Lappalainen & Tarkan, 2007; Tarkan, 2006, 2007; Tarkan *et al.*, 2006a, 2007a, 2007b, 2008a, 2018, 2019; Saç *et al.*, 2019; Saç & Özuluğ, 2015; Top *et al.*, 2018, 2019).

This study aims to analyse changes in fisheries and fish species diversity in Sapanca Lake from past to present, examining the underlying causes of these changes. Additionally, it evaluates the impacts of these changes on the general biology and ecology of the fish, offering recommendations for managing fisheries in the lake. This review study utilised reports, scientific theses, articles, and books obtained from university libraries, personal collections, and open-access sources such as Google Scholar, the Web of Science Core Collection, and the National Thesis Centre of the Turkish Higher Education Council (YÖK).

Study Area

Sapanca Lake (Figure 1), with a maximum depth of 55 metres (Albay *et al.*, 2003), lies in a tectonic depression extending parallel to Lake İznik and continuing from the Gulf of İzmit to the Adapazarı Plain. Most of the streams feeding the lake originate from the Samanlı Mountains to the south, while those to the north typically dry up during the summer months (Ergüven, 1989).

The region experienced active tectonic activity from the Late Cretaceous to the Eocene (Emre *et al.*, 1998). These processes resulted in the formation of the North Anatolian Fault Zone, encompassing the current Gulf of İzmit, Sapanca, and Adapazarı depressions. During the Quaternary, regional tectonic movements persisted, and the ancient Sakarya River, along with other streams, discharged into the Gulf of İzmit via the Adapazarı Plain and Sapanca Lake (Emre *et al.*, 1998). Over time, alluvial materials carried by the Sakarya River and other streams were deposited in the region between the Sapanca Lake and

Figure 1
Sapanca Lake, Türkiye (Google Maps, 2025).

the Gulf of İzmit. Regional subsidence and uplift caused by ongoing tectonic movements redirected the flow of the Sakarya River and other streams from the Sapanca and Adapazarı depressions towards the north, carving a new course leading to the Black Sea. Under these new fluvial conditions, alluvial deposits from the Sakarya River and other streams filled the Adapazarı depression, thereby isolating it from the Sapanca Lake. Geological evidence indicates that the Sakarya River once had a connection to the Sea of Marmara via the Sapanca Lake. Today, the lake indirectly connects to the Black Sea through its outflow via Çark Stream into the Sakarya River. The geological processes involved in the formation of Sapanca Lake have significantly contributed to its rich fish biodiversity.

Fish and Fisheries in Sapanca Lake

Historical Changes in the Fish Composition of Sapanca Lake

Deveciyan (2006) documented the first records of fish species inhabiting Sapanca Lake in 1915. In his book based on fish brought to the Istanbul Fish Market, he recorded species such as *Tinca tinca*, *E. lucius*, *S. erythrophthalmus R. rutilus*, *Perca fluviatilis,* and *Silurus glanis* from Sapanca Lake (Table 1). Subsequently, Kosswig & Battalgil (1943) reported 21 fish species based on specimens from the lake in the collection of the Istanbul Zoological Institute. The presence of *Salmo trutta macrostigma* (SL: 16.49 cm), mentioned in this study, was only found 65 years later in streams flowing into Sapanca Lake (Tarkan *et al*., 2008a). Currently, the valid species *Salmo macrostigma* is recognised as inhabiting Algeria and does not occur in Turkey's inland waters (Delling & Doadrio, 2005; Kottelat, 1997; Turan *et al*., 2011, 2014). Genetic studies on *Salmo* populations in Türkiye have revealed new endemic species distinct from this trout species (Küçük *et al*., 2024; Turan *et al*., 2014). Research on streams flowing into the Black Sea identified *S. trutta labrax* and *S. t. macrostigma* as the endemic *S. coruhensis* and *S. rizeensis* (Turan *et al*., 2009). Recently, the species identified as *S. t. macrostigma* in streams flowing into Sapanca Lake was reclassified as *S. coruhensis* (Turan *et al*., 2024) (Figure 2). Numann (1958) compiled unpublished data from Kosswig's limnological study of Sapanca Lake in 1952 and reported 28 fish species (Table 1). The species *Alvonus brunner* lacks scientific documentation, and its inclusion in the study is presumed to be a typographical error. Similarly, *Varicorhinus tri* was not recorded in later studies or the global literature (Table 1). Ladiges (1960) later documented 13 fish species, including *Chondrostoma knerii*, which was later identified as *Chondrostoma nasus* (Ladiges, 1966) and subsequently renamed *Chondrostoma angorense* (Elvira, 1987, 1997). Tarkan *et al*. (2007b) confirmed the existence of *Chondrostoma angorense* from Sapanca Lake in 2006. Ongan (1982) reported 27 species, including three goby species (*Neogobius fluviatilis*, *Pomatoschistus caucasicus kosswigi*, and *Proterorhinus marmoratus*), not noted by Numann (1958). Rahe & Worthmann (1986) expanded this list to 33 species by adding *Alburnoides bipunctatus*, *Atherina boyeri*, *Clupeonella abrau muhlisi*, *Neogobius syrman*, and *Oncorhynchus mykiss*, the latter likely introduced from local fish farms, along with several other species. Synonyms in the literature, such as *Atherina mochon* and

Figure 2
Salmo coruhensis in the Mahmudiye Stream (Original).

A. boyeri, were clarified, with the latter accepted as the valid species.

The first detailed study after Rahe & Worthmann (1986) was conducted by Karabatak & Orgerman (2002), who reported 15 fish species (Table 1). Subsequently, a more comprehensive study by Okgerman *et al.* (2006) indicated that 20 fish species were present in the lake, along with the detection of two non-native species, *Carassius gibelio* and *Lepomis gibbosus*. Apart from these two species, the reported species were those previously known to inhabit the lake. However, in the study by Okgerman *et al.* (2006) conducted between 2000 and 2004, the following species were not found in the lake: *Abramis brama*, *Alburnus alburnus*, *A. bipunctatus*, *Anguilla anguilla*, *Lampetra fluviatilis*, *N. syrman*, *Oxynoemacheilus angorae*, *P. fluviatilis*, *Petroleuciscus borysthenicus*, *P. c. kosswigi*, *P. marmoratus*, and *S. abaster*. The most recent study on the fish fauna of Lake Sapanca was conducted in 2007, and no comprehensive ichthyofaunal studies were found until 2024 (Tarkan, 2007; Özuluğ *et al.*, 2007; İlhan *et al.*, 2024). Another study focused solely on the fish fauna of the streams flowing into the lake, where 12 species were identified (Tarkan, 2007). Among these, *Phoxinus phoxinus* and *Gambusia holbrooki* (SL: 1.98 cm) were new records for the lake basin (Özuluğ *et al.*, 2007). Later, the species *P. phoxinus* was identified as *Phoxinus strandjae* (Saç & Özuluğ, 2015). Additionally, following Ergüven (1989), specimens of a *Lampetra* species were recorded for the first time in Yanık Dere in 2007 (Özuluğ *et al.*, 2007). However, species identification was not possible due to the absence of adult individuals. However, recent molecular-based studies have revealed that the species present in Lake Sapanca is *Lampetra lanceolata*, not *L. fluviatilis* (Geiger *et al.,* 2014). The discovery of new species in the streams flowing into Lake Sapanca is related to the fact that very few studies have been conducted on these streams until now. Comprehensive studies conducted on the streams flowing into Lake Sapanca reveal that species, especially those whose habitats are streams, are easily detected. Similarly, individuals of rainbow trout caught in these streams are likely to have escaped from the numerous trout farms in the surrounding areas (Tarkan, 2007).

In a study by, Özuluğ & Freyhof (2007) identified a species previously referred to as *Chalcalburnus chalcoides* in the lake as the endemic *Alburnus istanbulensis*. This discovery showed that the species recorded by Ladiges (1960) as *A. albidus* should actually be *A. istanbulensis*. Additionally, the endemic species *Gobio sakaryaensis* was first recorded in the Maşukiye Stream, one of the significant rivers flowing into Lake Sapanca (Saç *et al.*, 2019). In a recent publication, the presence of 26 fish species in the Lake Sapanca basin was reported, and the first record of *Leucaspius delineatus* from the lake was noted (İlhan *et al.,* 2024). Individuals of these species have been found in the areas where the Maden (Eşme), Balıkhane, Yanık and Kurtköy streams meet the lake. When we examined the changes in the fish fauna of Lake Sapanca, we observed notable shifts in species richness over time. Initially, the species richness was reported as 28 species, which later increased to 35 species. However, considering the findings from recent studies and our field observations, it can be concluded that there are currently 27 native and 2 non-native species present in the lake (Table 1, 2).

When evaluating studies conducted from the past to the present in Lake Sapanca, it was observed that the following species have been found in the lake and the streams flowing into it: *A. istanbulensis*, *A. boyeri*, *Babka gymnotrachelus*, *B. bjoerkna*, *Cobitis emrei*, *Cyprinus carpio*, *E. lucius*, *L. delineatus*, *N. fluviatilis*, *N. melanostomus*, *P. borysthenicus*, *P. strandjae*, *Proterorhinus semilunaris*, *Rhodeus amarus*, *R. rutilus*, *S. erythrophthalmus*, *S. glanis*, *Squalius pursakensis*, *Tinca tinca*, and *V. vimba* (Table 1). The currently recorded fish species are listed in Table 2. Among these, *Alosa maeotica*, *C. angorense*, *Clupeonella cultriventris*, *G. sakaryaensis*, *L. lanceolata*, *S. coruhensis*, and *S. abaster* are considered to be under threat. Notably, no individuals of *C. angorense* and *L. lanceolata* have been encountered in our sampling efforts since 2007. Therefore, further detailed research is needed to determine the current status of *C. angorense* and *L. lanceolata*. However, the following species are no longer found in Lake Sapanca: *A. brama*, *A. bipunctatus*, *A. anguilla*, *Carassius carassius*, *Leuciscus aspius*, *N. syrman*, *O. angorae*, *P. fluviatilis*, and *S. labrax*.

Table 1

The fish species reported to have occurred in Lake Sapanca according to various researchers (arranged by species families) (modified from Özuluğ et al., 2007)

Species	1	2	3	4	5	6	7	8	9	10
Anguilla anguilla			+		+	+				
*Atherina boyeri**		+	+		+	+	+	+	+	+
Lepomis gibbosus								+		
*Alosa maeotica**		+	+		+	+	+	+	+	+
*Clupeonella cultriventris**						+		+	+	+
*Cobitis emrei**			+		+	+		+	+	+
Abramis brama			+	+	+	+				
Alburnoides bipunctatus						+				
Alburnus albidus		+		+						
Alburnus alburnus			+		+	+				
*Alburnus istanbulensis**		+	+	+	+	+		+	+	+
Alvonus brunner ?			+							
Blicca bjoerkna		+	+	+	+	+	+	+	+	+
Carassius carassius			+	+	+	+	+			
Carassius gibelio								+		
*Chondrostoma angorense**				+						+
Cyprinus carpio		+	+	+	+	+	+	+	+	+
Gobio sakaryaensis									+	+
Leucaspius delineatus									+	+
Leuciscus aspius		+	+	+	+	+	+			
*Petroleuciscus borysthenicus**		+	+	+	+	+			+	+
*Phoxinus strandjae**									+	+
*Rhodeus amarus**		+	+	+	+	+	+	+	+	+
Rutilus rutilus	+	+	+	+	+	+	+	+	+	+
Scardinius erythrophthalmus	+	+	+	+	+	+	+	+	+	+
*Squalius pursakensis**			+		+	+	+	+	+	+
Tinca tinca	+					+	+	+	+	+
Varicorhinus tri ?			+							
Vimba vimba		+	+	+	+	+	+	+	+	+
Esox lucius	+	+	+		+	+	+	+	+	+
*Babka gymnotrachelus**		+	+		+	+		+	+	+
*Knipowitschia caucasica**		+			+	+				
*Neogobius fluviatilis**		+	+		+			+	+	+
*Neogobius melanostomus**		+	+		+	+		+	+	+
*Ponticola syrman**						+				
*Proterorhinus semilunaris**		+			+	+			+	+
*Oxynoemacheilus angorae**			+		+	+				
Perca fluviatilis	+	+	+		+	+				
*Lampetra lanceolata**										+
Gambusia holbrooki									+	+
*Oncorhynchus mykiss**						+	+	+	+	+

Species	1	2	3	4	5	6	7	8	9	10
Salmo labrax			+							
*Salmo coruhensis**		+								+
Silurus glanis	+		+		+	+	+	+	+	+
Syngnathus abaster			+		+	+			+	+
Syngnathus tenuirostris						+				
Syngnathus nigrolineatus		+				+				
Number of Species	6	21	28	13	27	33	15	21	26	29

1 = Deveciyan (2006); **2** = Kosswig & Battalgil (1943); **3** = Numann (1958); **4** = Ladiges (1960); **5** = Ongan (1982); **6** = Rahe & Worthmann (1986); **7** = Karabatak & Okgerman (2002); **8** = Okgerman *et al.,* (2006); **9** = İlhan *et al., (*2024); **10** = Present study. To avoid confusion in fish names, the names have been provided based on the most recent literature (Fricke *et al.,* 2024; Froese & Pauly, 2024). Species names follow Fricke *et al.* (2024), and Froese and Pauly (2024). (*)The species whose names have been updated are; *Atherina mochon = Atherina boyeri*; *Caspialosa maeotica = Alosa maeotica*; *Aspius aspius = Leuciscus aspius*; *Cobitis taenia = Cobitis emrei*; *Chalcalburnus chalcoides sapancae = Alburnus istanbulensis*; *Chondrostoma knerii = Chondrostoma angorense*; *Clupeonella muhlisi = Clupeonella cultriventris*; *Leuciscus borysthenicus = Petroleuciscus borysthenicus*; *Leuciscus cephalus = Squalius pursakensis*; *Rhodeus sericeus = Rhodeus amarus*; *Vimba vimba tenella = Vimba vimba*; *Gobius lacteus = Neogobius fluviatilis*; *Salmo gairdnerii = Oncorhynchus mykiss*; *Meogobius gymnotrachelus = Babka gymnotrachelus*; *Gobius melanostomus = Neogobius melanostomus*; *Gobius syrman = Ponticola syrman*; *Bubyr caucasicus kosswigi, Pomatoschistus caucasicus kosswigi = Knipowitschia caucasica*; *Lampetra fluviatilis = Lampetra lanceolata*; *Salmo trutta macrostigma = Salmo coruhensis*; *Phoxinus phoxinus = Phoxinus strandjae*; *Nemacheilus angorae = Oxynoemacheilus angorae.*

Carassius gibelio, *G. holbrooki*, *L. gibbosus*, and *O. mykiss* are non-native species that entered the lake due to human activities. After being recorded in earlier studies (Karabatak & Okgerman 2002; Okgerman *et al*., 2006; Rahe & Worthmann, 1986), *C. gibelio* and *L. gibbosus* have not been encountered in the Sapanca Lake basin in subsequent studies.

The decreases in the populations of certain species caused by overfishing and the destruction of breeding areas (Figure 3) can be evidenced by changes in the abundance and size of the fish. For example, according to Ongan (1982), one of the most economically important fish species in the lake, *E. lucius*, was the most caught commercial fish species at 31.25%, followed by *C. carpio* at 25%. This was followed by the non-economic species S. *erythrophthalmus* at 18.75%. Another economic species, *S. glanis*, was next at 12.5%. Other fish species accounted for 12.5% of the catch. In Karabatak & Okgerman (2002), it was observed that these proportions shifted in favour of non-economic species. *Esox lucius* was represented by 7.37%, *C. carpio* by 1.10%, and *S. glanis* by 0.52%, while non-economic species like *S. erythrophthalmus* were the most abundant at 24.4%, followed by *B. bjoerkna* at 22.98% and *R. rutilus* at 21.71%. According to İlhan *et al*. (2024), the most abundant species were *R. amarus*, *B. bjoerkna*, *C. cultriventris*, *A. boyeri*, *N. fluviatilis*, *R. rutilus*, *S. erythrophthalmus*, and *V. vimba*. The differences between the two studies may be due to the different mesh sizes used in the nets: 5-55 mm in İlhan *et al*. (2024) and 22-50 mm in Karabatak & Okgerman (2002).

The significant reductions in the stocks of economic fish, especially pike, could be a result of the intense fishing pressure on these species. For instance, the overfishing of pike during the breeding season (February to April), combined with the capture of immature individuals, may have led to a significant decrease in *E. lucius* stocks. Rahe & Worthmann (1986) reported that there was a poor exploitation situation for *E. lucius*, which had been overexploited. *Cyprinus carpio*, another economic fish, was heavily fished during its spawning period in reed beds, and *S. glanis* was also heavily fished, with many small individuals being caught, leading to a sharp decline in their populations. While Numann (1958) reported that there were *C. carpio* weighing 10 kg and 83 cm long, Karabatak & Okgerman (2002) reported that the largest *C. carpio* was only 1.3 kg and 45.5 cm long. This suggests that large *C. carpio* individuals have significantly decreased and their sizes have drastically reduced due to overfishing. İlhan *et al*. (2024) also reported that they encountered few individuals of *C. carpio*, *E. lucius*, and *S. glanis*.

Table 2

The current fish fauna of Lake Sapanca.

Familia	Scientific name	Status
Acheilognathidae	*Rhodeus amarus* (Bloch, 1782)	Native
Atherinidae	*Atherina boyeri* Risso, 1810	Native
Clupeidae	*Alosa maeotica* (Grimm, 1901)	Native
	Clupeonella cultriventris (Nordmann, 1840)	Native
Cobitidae	*Cobitis emrei* Freyhof, Bayçelebi & Gieger, 2018	Endemic to the Sapanca Lake
Cyprinidae	*Cyprinus carpio* Linnaeus, 1758	Native
Esocidae	*Esox lucius* Linnaeus, 1758	Native
Gobiidae	*Babka gymnotrachelus* (Kessler, 1857)	Native
	Neogobius melanostomus (Pallas, 1814)	Native
	Neogobius fluviatilis (Pallas, 1814)	Native
	Proterorhinus semilunaris (Heckel, 1837)	Native
Gobionidae	*Gobio sakaryaensis* Turan, Ekmekçi, Luskova & Mendel, 2012	Endemic to Türkiye
Leuciscidae	*Alburnus istanbulensis* Battalgil, 1941	Endemic to Türkiye
	Blicca bjoerkna (Linnaeus, 1758)	Native
	Chondrostoma angorense Elvira, 1987	Endemic to Türkiye
	Leucaspius delineatus (Heckel, 1843)	Native
	Petroleuciscus borysthenicus (Kessler, 1859)	Native
	Phoxinus strandjae Drensky, 1926	Native
	Rutilus rutilus (Linnaeus, 1758)	Native
	Scardinius erythrophthalmus (Linnaeus, 1758)	Native
	Squalius pursakensis (Hankó, 1925)	Native
	Vimba vimba (Linnaeus, 1758)	Native
Petromyzontidae	*Lampetra lanceolata* Kux & Steiner, 1972	Endemic to Türkiye
Poeciliidae	*Gambusia holbrooki* Girard, 1859	Non-Native
Salmonidae	*Oncorhynchus mykiss* (Walbaum, 1792)	Non-Native
	Salmo coruhensis Turan, Kottelat & Engin 2010	Endemic to Türkiye
Siluridae	*Silurus glanis* Linnaeus, 1758	Native
Syngnathidae	*Syngnathus abaster* Risso, 1827	Native
Tincidae	*Tinca tinca* (Linnaeus, 1758)	Native

In the recent findings, migratory species like *A. anguilla* and *S. labrax*, as well as marine-origin species like *S. abaster*, are believed to have left the lake, likely due to habitat degradation and pollution, particularly in the streams feeding into the lake and in the Çark Stream, which is the outflow of the lake. In recent field studies conducted by us, we have rarely encountered *S. abaster* individuals. İlhan *et al.* (2024) also reported encountering a few *S. abaster* individuals but noted that their numbers have drastically decreased, and they are thought to be on the brink of disappearing from the lake. In our examinations of streams, we observed that overfishing is a significant factor affecting *S. coruhensis*, which is believed by locals to be beneficial for stomach ailments and is known for its excellent taste. In addition, due to habitat destruction caused by streambed alterations and increasing pollution, these fish are now rarely found in streams (Tarkan *et al.*, 2008a).

Non-native Fish Species in Sapanca Lake

Carassius gibelio, *G. holbrooki*, and *L. gibbosus*, thought to have entered the lake in recent years, are considered among the most dangerous invasive fish species (Özuluğ *et al.*, 2007; Şaşı & Balık, 2003). Individuals of *G. holbrooki* have been observed in the reed-covered and macrophyte-dominated areas of the lake, as well as in the slow-flowing

Figure 3

Fish habitat destruction in the Sapanca Lake basin.

Destruction of the habitat of the *Salmo coruhensis* in the Mahmudiye Stream (Original).

Destruction of the habitat of the *Salmo coruhensis* in the Mahmudiye Stream (Original).

Quarry near Yanık Creek and the dumping of debris into the fish habitat (Original).

Domestic waste in Istanbul Creek and its impact on fish habitats (Original).

sections of streams. This species, introduced into many freshwater systems in Turkey for malaria control (Geldiay & Balık, 2009; Öztürk & İkiz, 2004), can exert predation pressure on native species, leading to ecological consequences (Özuluğ *et al*., 2007).

In Okgerman *et al*. (2006), individuals of *C. gibelio* and *L. gibbosus* were observed in fishermen's nets. However, İlhan *et al*. (2024) did not encounter these two species in their research. Similarly, our field studies in the Sapanca Lake Basin did not detect either species. This finding is significant for the lake, as previous studies have demonstrated that *C. gibelio* can rapidly establish dense populations, compete with other species for food and habitat, and negatively impact their populations (Gaygusuz *et al*., 2007b). In addition, its gynogenetic reproduction provides a reproductive advantage over other species, enabling it to exploit a wide range of food resources, grow rapidly in its early years, and reach sexual maturity earlier than other cyprinids (Tarkan *et al*., 2012a; 2012b). Moreover, studies conducted in other regions have shown that *C. gibelio*, due to its benthic feeding habits, exerts pressure on benthic fauna and contributes to the release of nutrient elements, leading to long-term water quality problems in lakes (Paulovits *et al*., 1998; Ruppert *et al*., 2017). Similar issues are likely to arise in Lake Sapanca in the coming years because of fish stocking activities conducted by public institutions. Therefore, a comprehensive action plan and monitoring strategy should be developed to manage these species. Such efforts could help identify the presence of *C. gibelio* in the lake and, if found, prevent it from forming a significant population that could negatively impact other fish species, thereby minimising its harmful effects. Regarding the other reported non-native species, *L. gibbosus*, information is currently limited to observational data (Okgerman *et al*., 2006). Consequently, it is challenging to assess its current impact on other fish species in the lake. Our field studies did not detect *L. gibbosus* in fishing gear or among catches by recreational anglers. This lack of data underscores the need for further research to evaluate its potential ecological effects in Lake Sapanca.

Current Situation of Fishing in Lake Sapanca

Deveciyan (2006) provided the first information about fishing in Lake Sapanca. According to Deveciyan (2006), fishing was carried out with a 450-meter-long seine, and 50 tons of fish were caught annually. It was argued that this amount was low and that this situation was due to the fishermen's underexploration. In Numann's (1958) observational study, it was stated that, at that time, Lake Sapanca was not leased, and only some villagers fished using gillnets. Due to these data deficiencies, it was also mentioned that it would not be possible to obtain exact numerical values regarding the lake's actual production and fishing possibilities. In this context, Numann (1958) stated that a product of 8.3 kg per hectare would be considered normal for an oligotrophic lake and that obtaining more products from this lake would not be possible, and furthermore, fishing had almost come to a halt by that time.

Until 1974, there were no fisheries cooperative or union operating in Lake Sapanca. Organised fishing activities in this lake began in 1974 with the establishment of a cooperative focused on crayfish *Pontastacus leptodactylus* fishing (Sapanca Aşağı Dereköy S.S. Fisheries Cooperative). It was stated that this cooperative had 66 passive and 44 active members (Rahe & Worthmann, 1986). Almost all the fishermen conducted their activities using 22 fishing boats with motors of 4 to 8 horsepower. The crew of the boats consisted of two people: the boat owner and a paid worker or family member. *Pontastacus leptodactylus* were collected using baskets, with fish heads used as bait. It was stated that in addition to crayfish fishing, the cooperative members also worked in agriculture. It was also mentioned that commercial fishing in Sapanca Lake was carried out by a few individuals who were not members of the cooperative, using cast and seine nets.

Ongan (1982) stated that based on the figures provided by the fishermen, approximately 16 tons of fish were caught from the lake annually, which corresponds to a very low amount of 3.44 kg per hectare. The most important aquatic product from Lake Sapanca was *P. leptodactylus*. According to the official records of the cooperative, Ongan (1982) reported that in 1980, approximately 55 tons of *P. leptodactylus* were caught, although in earlier years, the amount was higher. It was also reported that the average annual *P. leptodactylus* yield from Sapanca Lake was around 60-70 tons, which corresponds to 11.82 kg per hectare, categorising it as a low-yield lake (Ongan, 1982). Rahe and Worthmann (1986) stated that there were only two economically valuable species in the lake (*P. leptodactylus* and *E. lucius*), and only *P. leptodactylus* was considered significant. They mentioned that other species such as *R. rutilus*, *S. erythrophthalmus*, and *T. tinca* had no market value, and these species were only caught by illegal fishermen for their personal consumption. These researchers also reported a continuous decrease in the size and weight of *P. leptodactylus* caught between 1978 and 1984, despite the introduction of new *P. leptodactylus* baskets in 1984, which had been expected to increase the catch. According to their report, the number of *P. leptodactylus* required to make 1 kg in 1978 was 15, whereas in 1984, it had increased to between 30 and 40. Similarly, there was a decrease in the total catches and unit catches in 1981. Despite the anticipated increase in catch following the introduction of new *P. leptodactylus* baskets in 1984, the actual catch declined from 58 to 52 tons. Based on the decreasing age groups of the *P. leptodactylus*, it was concluded that the exploitation rate of the population was extremely high, indicating that the population had been poorly exploited (Rahe & Worthmann, 1986). Similarly, the other economically valuable species, *E. lucius*, was also considered to have been over-exploited. It was assumed that the *E. lucius* stock had also been severely overfished, and the cause of overfishing was attributed not to the excessive number of fish caught but to the selective fishing of mature stocks. Rahe & Worthmann (1986) also calculated that fish species with lower market value, such as *S. erythrophthalmus*, *R. rutilus*, *T. tinca*, and *A. istanbulensis*, which are important mainly due to their size rather than their flavour yielded a total of 21.3 kg per hectare from the use of extension nets.

Currently, there are no active fisheries cooperative in the lake. The only cooperative ever established in the lake, which focused on *P. leptodactylus*, was affected by *the P. leptodactylus* plague (*Aphanomyces astaci* Schikora, 1906) that emerged in the early 1980s in many lakes across Türkiye, causing a significant decline in *P. leptodactylus* populations (Baran & Soylu, 1989). Therefore, the only cooperative operating in Lake Sapanca was closed. To date, no fish stocks suitable for marketing according to European standards have developed in the Sapanca Lake other than *E. lucius* and *P. leptodactylus*. For this reason,

Figure 4
The regulated state of Balıkhane Stream, one of the important spawning areas for Esox lucius (Original).

no cooperative has been established other than the short-lived Sapanca Aşağı Dereköy S. S. Fisheries Cooperative. Today, years of unregulated and excessive fishing of *E. lucius* have significantly depleted its stock, making it a rare catch. Approximately 40 years ago, Rahe & Worthmann (1986) pointed out that *E. lucius* were heavily overfished during their spawning season between February and April, and that the population was severely exploited. Furthermore, the species' spawning habitats have been visibly destroyed (Figure 4), particularly due to pollution and excessive fluctuations in water levels, which has worsened the situation of the species in the lake.

Since the Rahe & Worthmann (1986) report, overfishing has continued in an uncontrolled manner by amateur and commercial fishers using gillnets and trap nets, which has further decreased the *E. lucius* population. The most significant problem here is the disregard for fishing bans during the fish's reproductive periods, preventing them from reproducing at least once before being caught, and fishing them before reaching sexual maturity. In Lake Sapanca, the average first reproductive size of *E. lucius* is 33 cm (Rahe & Worthmann, 1986), which leads to continued and intense fishing pressure on the species. This is a considerable threat to the *E. lucius* population in the lake, as these fish are caught before having a chance to reproduce, and thus, the continuity and regeneration of the population are hindered. A similar situation applies to *C. carpio*, an economic species although less abundant in the lake. These relatively larger fish are targeted during their reproductive periods with various fishing methods, including firearms, in reed beds and among macrophytes. Non-economic species that start reproducing at smaller sizes are less affected by human and natural predation pressures. These species have increased in number, particularly due to the decline of natural predators like *E. lucius*.

Records of fishing activities in the Sapanca Lake are limited, based primarily on observations and insufficient information from fishers. In 2003, the lake was declared a drinking water basin (Marka, 2011), and a ban on fishing using gasoline- or diesel-powered boats was implemented year-round. While this restriction appears to have a positive effect on the fish species in the lake, field observations indicate that illegal fishing continues. The fishing activities in the Sapanca Lake need to be reassessed and restructured based on scientific principles. This requires a collaborative effort involving government agencies, universities, municipalities, Non-governmental organisation, and both commercial and recreational fishers. A collective decision must be made to ensure the sustainability of the lake's fish populations.

Biological and Ecological Characteristics of Fish

Biological and ecological studies on fish living in Sapanca Lake have generally focused on the dominant species in the lake. In recent years, these studies have intensified, with the participation of species whose biological characteristics had not been previously studied in the lake. Numann (1958) provided the first biological data on some fish in the Sapanca Lake. He observed a *C. carpio* weighing 10 kg and measuring 83 cm in length, and stated that *E. lucius* can reach a weight of 15 kg. Rahe & Worthmann (1986) provided information on the growth of economically important species in the lake, such as *E. lucius* and *P. leptodactylus*. In addition, the age and growth parameters of the dominant cyprinid species in the lake, including *S. erythrophthalmus*, *R. rutilus*, *V. vimba*, and *A. maeotica*, have been reported in previous studies conducted in the lake. The von Bertalanffy growth model parameters, including asymptotic length (L_∞), Brody growth coefficient (K), and theoretical age at length zero (t_0), were documented from these studies (Table 3). When the growth values of *E. lucius* were compared with data from other countries, it was noted that *E. lucius* in Sapanca Lake grew better than in other regions (Rahe & Worthmann, 1986). This was attributed to the reduced competition for food due to the intense fishing pressure on *E. lucius*. In this study, it was also reported that *E. lucius* in Sapanca Lake reached sexual maturity at the age of 3, with individuals of this age being 33 cm long and weighing approximately 400 grammes. As for *P. leptodactylus*, infinite size calculations showed that male individuals could reach a length of 12.8 cm and a weight of 67.5 g, while female individuals could reach a maximum weight of 57.1 g and a length of 11.8 cm.

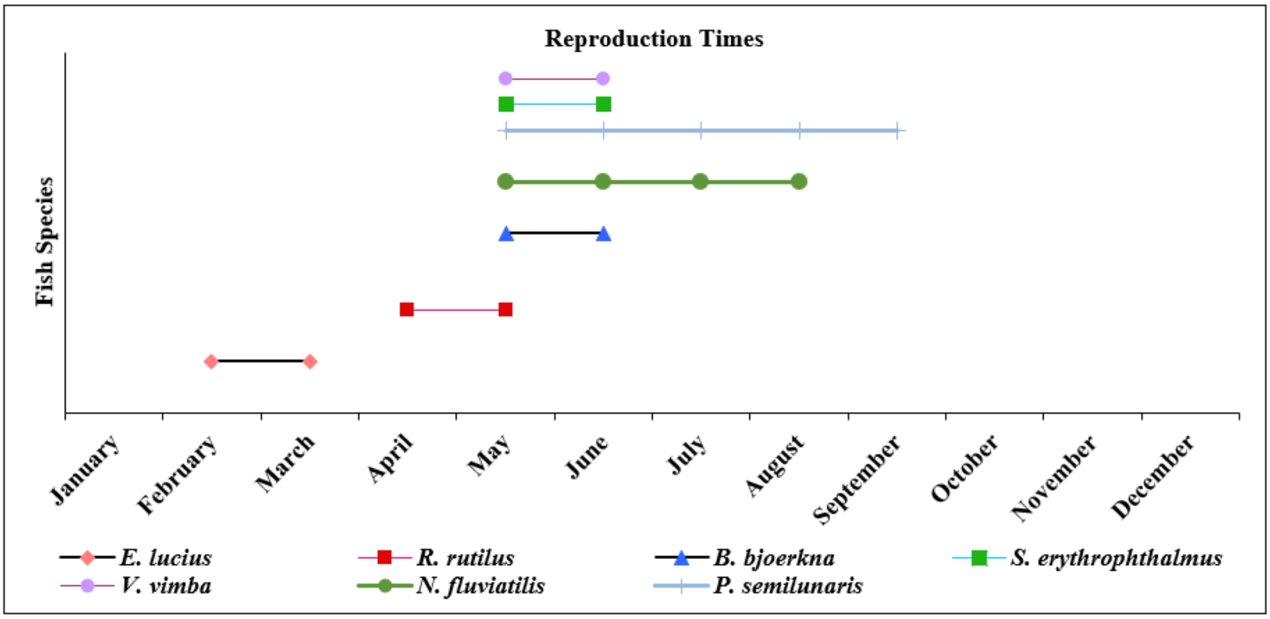
Since this period, comprehensive fisheries biology studies have been initiated in the lake in 2000, and their results began to be published after 2001. Gürsoy (2001) reported that *V. vimba* spawn in June, reach sexual maturity at age 3, and produce between 3545 and 14988 eggs, *whereas B. bjoerkna* spawn in May, reach sexual maturity at age 3, and produce between 2642 and 47978 eggs. A detailed comparative paper on the reproductive ecology of *S. erythrophthalmus* and *R. rutilus* was published in 2006 (Tarkan, 2006). In this study, it was found that *S. erythrophthalmus* spawns between April and May, when water temperatures range from 13–18ºC, both sexes reach sexual maturity at age 3, and the number of eggs varies between 7829 and 95387. *Rutilus rutilus*, on the other hand, spawns between May and June, when water temperatures range from 17.5–23.5ºC, reaches sexual maturity in the first year of life, and the number of eggs varies between 1807 and 35629 (Tarkan, 2006). Okgerman (2002) investigated the food preferences of the two most commonly caught species in the lake, *S. erythrophthalmus* and *R. rutilus*, and the temporal changes in these preferences. It was found that both species in the lake had a herbivorous feeding regime, with food preferences consisting of macrophytes, filamentous algae, molluscs, and other food sources (fish extremities and eggs, Oligochaeta, Chironomidae, Trichoptera, Nematoda, crayfish larvae and extremities, zooplankton, and phytoplankton). The food preferences of both fish species showed seasonal changes, and among these food groups, algae and macrophytes were found to be the dominant food groups, although they varied between seasons. Okgerman & Oral (2004) presented some biological characteristics of *R. rutilus* caught between 2000 and 2001. According to the results of this study, both females and males exhibited equal growth in terms of the length-weight relationship. According to the infinite growth equations, the infinite growth lengths were found to be 31.876 cm for males and 47.195 cm for females.

Some methodological studies on the age determination of *S. erythrophthalmus* and *R. rutilus* were published by Gürsoy *et al.* (2005a; 2005b), and studies on the biological characteristics of *R. rutilus*, *E. lucius*, and *V. vimba* were published by Okgerman (2005), Okgerman & Oral (2005), and Okgerman *et al.* (2005). In Okgerman's (2005) study, seasonal changes in the length-weight relationships and condition of *R. rutilus* were examined; it was found that these relationships and conditions did not show significant seasonal or gender-based variations. Additionally, from the coefficients of the length-weight relationship, it was concluded that the fish grew better in terms of weight than length, and the nutritional status in Sapanca Lake was considered good. These findings were supported by the relatively high condition values obtained. In another study by the same researchers (Okgerman & Oral, 2005), *E. lucius*, one of the economic fish species in the lake, was studied between 2000 and 2001, and some population characteristics were examined. In their study, the length-weight relationship showed equal growth, and the spawning period was determined to be between the end of February and the beginning of April, with water temperatures ranging from 9.3°C to 13.7°C. In a study by Okgerman *et al.* (2005) on *V. vimba*, it was found that weight growth was better than length growth in both sexes, with infinite lengths of 19.352 cm for males and 22.693 cm for females. The condition factor was reported to be highest in April for both sexes, and spawning occurred between April and June. In Tarkan *et al.* (2006a), the length-weight relationships of 11 species from Lake Sapanca were examined. Tarkan *et al.* (2006a), the length-weight equations were provided in a list, and some preliminary information on the fish's condition and nutrition was reported. In another study that included fish from Sapanca Lake, conversion formulas for different length types (standard, fork, and total length) were provided (Gaygusuz *et al.*, 2006).

In a 2007 study on *S. erythrophthalmus*, the reproductive characteristics of the populations in Sapanca Lake and in the northern latitudes where they are distributed were compared in relation to latitude, and the results were evaluated in terms of changes in reproductive traits (Lappalainen & Tarkan, 2007). According to a study on two *Neogobius* species (*N. fluviatilis, N. melanostomus*) in the lake, it was determined that these species primarily feed on *D. polymorpha* (Gaygusuz *et al.*, 2007a). In the results of

Figure 5

Reproduction periods of some fish species in the Sapanca Lake.



this study, these two goby species exerted considerable pressure on *D. polymorpha*, showing that they fed heavily on them (Gaygusuz *et al.*, 2007a). In the same year, Tarkan *et al.* (2007a) conducted a methodological study on predator-prey relationships in Lake Sapanca, based on measurements taken from the bones of some of the lake's fish. Later, in 2009, a study was conducted on the length-weight relationships of six fish species living in the streams flowing into Lake Sapanca (Tarkan *et al.*, 2009). Subsequently, fish biology studies, which had decreased for a short period, were revived with studies on the growth and feeding characteristics of the goby fish species found in the lake basin. Despite being ecologically important, these species are often overlooked due to their lack of economic value, and research has focused on two dominant species in the lake basin, *N. fluviatilis* and *P. semilunaris* (Karakuş *et al.*, 2018; Tarkan *et al.*, 2018, 2019; Tepeköy *et al.*, 2013; 2014; Top *et al.*, 2018, 2019). Although many studies have been conducted on the invasive populations of both species outside their natural distribution areas, few studies have been conducted within their natural range. In this context, the growth, reproduction, feeding, habitat selection, and genetic diversity of both species have been explored. The results indicate that the bio-ecological characteristics of both species show significant seasonal variations between lakes, with the *N. fluviatilis* and *P. semilunaris* populations in Lake Sapanca growing relatively slower, producing fewer but larger eggs, and preferring zooplankton, macroinvertebrates, and detritus as their main food sources. *Proterorhinus semilunaris* prefers clear waters, large stones, and rocky habitats, whereas *N. fluviatilis* prefers turbid waters and areas near plant cover with woody materials. The growth and reproduction study results of the fish species living in Lake Sapanca have been compiled in Table 3. The reproductive periods of some fish species are shown in Figure 5.

Cyprinid species generally exhibit slow growth characteristics. In Sapanca Lake, the growth rates of cyprinid species (*S. erythrophthalmus* and *R. rutilus*) were observed to be faster than some populations in other regions, but slower than others. Unfortunately, studies on the growth of these fish in Türkiye's other inland water sources are quite limited, although there has been an increase in such studies in recent years. The growth studies conducted in Sapanca Lake show significant similarities with those conducted in Türkiye. However, the growth rates of fish in Lake Sapanca showed significant differences when compared with populations in northern latitudes worldwide (Lappalainen & Tarkan, 2007; Lappalainen *et al.*, 2008; Tarkan & Vilizzi, 2015).

Table 3

Fish Species with Identified Population Parameters in Lake Sapanca

Species	a	b	Length (cm) Min.-Max.	L_∞	K	t_0	Fecundity	Lm	La
A. maeotica [1] ♂♀	-	-	-	58.20	0.150	−0.200	-	-	-
A. maeotica [8] ♂♀	0.0053	3.15	13.2-32.0 (TL)	-	-	-	-	-	-
C. emrei [10] ♂♀	0.0083	3.19	5.3-7.3 (SL)	-	-	-	-	-	-
C. carpio [3]	-	-	16.2-45.5 (TL)	-	-	-	-	-	-
C. carpio [8] ♂♀	0.0311	2.79	16.8-45.5 (TL)	-	-	-	-	-	-
E. lucius [1] ♂♀	-	-	-	97.30	0.160	0.450	-	33.0	3
E. lucius [3] ♂♀	-	-	23.0-57.6 (TL)	-	-	-	-	-	-
E. lucius [5] ♂♀	0.0056	3.0250	23.0-49.9 (TL)	-	-	-	-	-	-
E. lucius [5] ♀	0.0045	3.0854	-	-	-	-	-	-	-
E. lucius [5] ♂	0.0045	2.9497	-	-	-	-	-	-	-
E. lucius [8] ♂♀	0.0030	3.21	26.3-57.6 (TL)	-	-	-	-	-	-
B. gymnotrachelus [10] ♂♀	0.0549	2.44	5.3-6.1 (SL)	-	-	-	-	-	-
N. melanostomus [8] ♂♀	0.0142	3.00	10.5-18.4 (TL)	-	-	-	-	-	-
N. fluviatilis [12] ♂♀	0.00001	2.907	3.1-10.7 (TL)	25.49	0.060	−1.590♀	170.44±51.15	3.0♀	40 mm (TL)
P. semilunaris [10] ♂♀	0.0305	2.85	1.8-4.9 (SL)	-	-	-	-	-	-
P. semilunaris [11] ♂♀	0.0090	3.153	2.0-7.2 (TL)	-	-	-	148.83±52	3.54♀	49 mm (TL)
A. istanbulensis [8] ♂♀	0.0017	3.56	16.8-27.6 (TL)	-	-	-	-	-	-
B. bjoerkna [1] ♂♀	-	-	-	36.60	0.210	0.280	-	-	-
B. bjoerkna [2] ♀	-	-	-	-	-	-	2642-47978	12.4	3
B. bjoerkna [2] ♂	-	-	-	-	-	-	-	12.3	3
B. bjoerkna [8] ♂♀	0.0072	3.18	12.0-21.20 (TL)	-	-	-	-	-	-
P. strandjae [9] ♂♀	-	-	3.96-5.58 (SL)	-	-	-	-	-	-
P. strandjae [10] ♂♀	0.0150	3.23	1.9-5.9 (SL)	-	-	-	-	-	-
R. rutilus [1] ♂♀	-	-	-	57.90	0.100	−0.290	-	-	-
R. rutilus [4] ♂	0.0148	2.9336	-	31.87	0.195	−0.034	-	-	-
R. rutilus [4] ♀	0.0130	2.972	-	47.19	0.109	−0.056	-	-	-
R. rutilus [7] ♂	-	-	-	-	-	-	-	12.26	3
R. rutilus [7] ♀	-	-	-	-	-	-	1807-35629	14.98	3
R. rutilus [8] ♂♀	0.0072	3.17	6.0-38.1 (TL)	-	-	-	-	-	-
S. erythrophthalmus [1] ♂♀	-	-	-	52.60	0.160	0.230	-	-	-
S. erythrophthalmus [7] ♂	-	-	-	-	-	-	-	7.12	1
S. erythrophthalmus [7] ♀	-	-	-	-	-	-	7829-95387	8.1	1
S. erythrophthalmus [8] ♂♀	0.0116	3.02	7.2-29.1 (TL)	-	-	-	-	-	-
V. vimba [2] ♀	-	-	-	-	-	-	3545-14988	18.7	3
V. vimba [2] ♂	-	-	-	-	-	-	-	17.6	3
V. vimba [6] ♂	-	-	-	19.352	-	-	-	-	-
V. vimba [6] ♀	-	-	-	22.693	-	-	-	-	-
V. vimba [8] ♂♀	0.0055	3.20	15.8-26.2 (TL)	-	-	-	-	-	-
P. borysthenicus [10] ♂♀	0.0136	3.35	5.1-9.1 (SL)	-	-	-	-	-	-
G. holbrooki [10] ♂♀	0.0252	2.68	1.4-3.5 (SL)	-	-	-	-	-	-

S. glanis [3] ♂♀	-	-	30.0-58.2 (TL)	-	-	-	-	-	-
S. glanis [8] ♂♀	0.0096	2.90	29.6-53.0 (TL)	-	-	-	-	-	-
T. tinca [3] ♂♀	-	-	12.6-35.0 (TL)	-	-	-	-	-	-
T. tinca [8] ♂♀	0.0071	3.25	13.1-35.0 (TL)	-	-	-	-	-	-

1- Rahe & Worthman (1986); 2- Gürsoy (2001); 3- Karabatak & Okgerman (2002); 4- Okgerman & Oral (2004); 5- Okgerman & Oral (2005); 6- Okgerman *et al.* (2005); 7- Tarkan (2006); 8- Tarkan *et al.* (2006a); 9- Özuluğ *et al.* (2007); 10- Tarkan *et al.* (2009); 11- Top *et al.* (2018). 12- Karakuş *et al.* (2018).

L_∞: Asymptotic Length; K: Brody Condition Factor; t_0: Length at Age 0; Fecundity: Egg Production; Lm: Length at Sexual Maturity; La: Age at Sexual Maturity, TL: Total Length; SL: Standart Length.

We suggest that this difference is due to the geographical location of the Sapanca Lake. A fish's growth characteristics vary from one population to another, and the most influential factor in this variation is the location of the populations. When examining the global distribution of species as a whole, it is observed that in areas near the centre of the distribution range, intra-species and population-related changes are effective on the population structure, whereas in areas closer to the boundaries of the distribution range, inter-species and environmental variables unrelated to the population become more influential. The fish studied in Sapanca Lake are located near the southern boundaries of the regions where these species are distributed globally. The positive effect of optimal temperature on fish growth is well known (Mooij *et al*., 1994; Müller & Meng, 1986). For most of the cyprinids in the Sapanca Lake, the optimal temperatures are found in latitudes that form the centre of their distribution ranges. For example, the distribution centre of *S. erythrophthalmus* is between 44º and 49º North latitude (Lappalainen & Tarkan, 2007) and Lake Sapanca is located at 40º North latitude.

Apart from cyprinids, the only economic species for which growth characteristics have been studied is *E. lucius*. Rahe & Worthmann (1986) reported that the abundance of *E. lucius* in the lake decreased due to overfishing, and as a result, the reduced food competition allowed for better growth of *E. lucius* in Sapanca Lake. However, in Okgerman *et al.* (2005), although the issue of overfishing was highlighted, no explanatory comment was made regarding the growth of *E. lucius*. Over the years, the *E. lucius* population in the lake has significantly declined, and its presence in the lake today is even under threat. Considering that the remaining population is under environmental stress due to the degradation of the lake's water quality and fishing pressure, it seems unlikely that *E. lucius* would show good growth performance.

According to studies on the egg production potential of cyprinids in Sapanca Lake, it has been surprisingly found that the egg production potential of cyprinids in this lake is quite low. The number of eggs produced by these fish is even lower than that of cyprinids in northern latitudes or regions with similar climatic conditions in Türkiye, where the conditions for reproduction are more favourable. This observation suggests that factors other than temperature may also affect egg production. One such factor, supported by previous studies, is the quality of food, which has been shown to influence egg numbers (Kuznetsov & Khalitov, 1978). Sapanca Lake, being an oligotrophic/mesooligotrophic and deep lake, is particularly poor in animal-based food sources (zooplankton, benthos) (Rahe & Worthmann, 1986; Koşal, 2002). Therefore, the cyprinids in the lake primarily feed on plant-based food sources (Okgerman, 2002). However, cyprinids benefit less from plant-based food compared to animal-based sources (Persson, 1983). This may explain why cyprinids in Lake Sapanca have lower egg numbers. Supporting this claim, a study by Titova (1965) in the southern and northern U.S.S.R. found that when *S. erythrophthalmus* feeds on plant-based food, it produces significantly fewer eggs compared to when it feeds on animal-based food.

In recent years, studies on the goby species, known for forming dense populations in streams within the basin, have compared the reproductive characteristics of *P. semilunaris* and *N. fluviatilis* to those in other large lakes in the Marmara Region and invasive populations in other areas. These species are characterised by late sexual maturity, low gonadosomatic index, long reproductive periods (May to September), low fecundity, and larger egg sizes (Table 3). These findings support the reasons outlined for cyprinids and *E. lucius*.

Studies on the feeding ecology of fish in Sapanca Lake are limited, and more comprehensive studies involving a greater variety of species are needed. Recent detailed feeding studies on the two dominant goby species in the lake can be considered important contributions. These studies, with the help of modern isotope analysis, have examined the feeding ecology of *P. semilunaris* and *N. fluviatilis*, along with the effects of zebra mussels on the diet of rudd and roach. The results indicate that, in terms of the lake's productivity and fertility, cyprinids primarily feed on plant-based food sources, whereas goby species prefer detritus, macroinvertebrates, and zooplankton. However, these studies need to be expanded to include all fish species in the lake, as well as differences in feeding patterns between day and night, feeding differences between the open and coastal areas of the lake, interspecies food competition, and food partitioning.

Conclusion

Studies conducted on the fish of Sapanca Lake to date have generally focused on the identification of fish compositions and the biology of some important and dominant fish species. The findings from these studies, as suggested in our review, can be summarised as follows: Although the productivity of Sapanca Lake has increased in recent years, it still falls within the category of low to medium productivity lakes (Akçaalan *et al.*, 2007; Morkoç *et al.*, 1998). Despite this, the lake appears to be quite rich in terms of fish species diversity. However, another characteristic feature of such lakes, the low fish yield, has also emerged in Sapanca Lake, and it has been observed that the fish in the lake do not form suitable and exploitable stocks for fishing productivity. Although no fishing cooperatives have been established to exploit the fish in the lake so far, some economically valuable fish species have failed to establish themselves in the lake (e.g., *P. fluviatilis*, *A. anguilla*, *S. labrax*), and the numbers of some others have significantly decreased (*E. lucius*, *S. glanis*, *C. carpio*). The decline or disappearance of these species from the lake may be due to natural causes, but it could also be attributed to illegal and unregulated fishing activities. Furthermore, various factors such as habitat loss/damage in the streams that feed into the lake and the Çark Stream, barriers and culverts preventing fish migration, and pollution caused by intense human pressure may have played a role.

In recent years, the increase in nutrients (Akçaalan *et al.*, 2007; Morkoç *et al.*, 1998) and the high volume of water extracted for drinking and usage purposes have led to increased productivity in the lake. This has facilitated the growth of some cyprinid species that are economically insignificant and not heavily consumed, while negatively affecting some fish species that rely on the lake's coastal areas as habitats (mainly goby species). This situation may have had a negative impact on both the fish species and fishing activities in the lake. Additionally, the increase in these fish species may have adverse effects on the lake's food chain and contribute to future water quality deterioration.

Cyprinids, due to their biology being more tolerant to environmental factors and adverse conditions, are likely to become more dominant over time in the competition for food and space with other economically valuable species. Furthermore, in recent years, ecological damage has occurred in the habitats of some important goby species due to fluctuations in water levels, which have become more frequent. These species have been observed to leave their usual habitats in the coastal regions and the areas where streams meet the lake, migrating to deeper parts of the lake. However, after heavy rainfall in the winter of 2015, they returned to their previous habitats, which had been restored (Karakuş *et al.*, 2018; Top *et al.*, 2018).

Commercial fishing in Sapanca Lake was banned in the late 1990s (Resmi Gazete, 1997). Following this ban, in 2003, the lake was declared a drinking water basin, which also prohibited all types of fishing using diesel- and gasoline-powered boats (Marka, 2011). The Ministry of Agriculture and Forestry has issued regulations on the commercial and recreational fishing of aquatic products, including restrictions on location, time, and species in the lake. However, illegal fishing continues the lake and its basin.

From our review, based on the current situation, we can make the following recommendations regarding the sustainable fisheries management of the lake:

1. Research on Biological Characteristics of Fish: The biological characteristics of the existing fish populations, especially those that are important for the lake and fisheries, as well as those whose populations are under threat, should be thoroughly studied. These characteristics include reproductive times, age and length at first sexual maturity, abundance, growth parameters, exploitation rates, feeding habits, and

intra- and interspecies interactions. This information is essential for the conservation of ecologically or economically significant fish species and for the appropriate management of fisheries in the lake.

2. Monitoring of Invasive Fish Species: Invasive fish species detected in the lake should be monitored, and their population sizes should be assessed. The effects of these species on the lake ecosystem and other fish populations should be continuously tracked and kept under control. Furthermore, *O. mykiss* individuals have been found in very small numbers in all studies conducted to date. Measures should be taken to prevent these species from escaping from aquaculture facilities into the streams, and aquaculture operators should be informed about this issue.
3. Review of Fisheries Regulations: The current fishing regulations in the lake should be reviewed. Given that the lake is a drinking water basin, the complete cessation of fishing activities is a negative situation for the local population that relies on fishing for their livelihood and consumes the caught fish. Moreover, optimum fishing pressure should be applied to the increasing numbers of cyprinids in the lake to prevent cyprinid populations from growing unchecked within the increasingly favourable lake ecosystem. This increase could indirectly or directly trigger a decline in the populations of other economically valuable fish species that are not cyprinids. However, this fishing should be conducted with great care and control. Special attention should be given to fish species with decreasing numbers, such as *E. lucius*, *S. glanis*, and *C. carpio* and overfishing should be avoided. Fishing should not occur during their reproductive periods or before they reach sexual maturity (with at least one successful reproduction allowed). Additionally, illegal fishing in the lake basin should be prevented.
4. Hydraulic Regulations in Streams: Hydraulic regulations in streams should be carried out in a way that does not destroy the living and breeding habitats of fish. Various technical structures, such as culverts, bridge piers, embankments, and concrete barriers, exist in the streams in the basin. These structures, especially those blocking the migration of species that breed in the streams and migrate to the lake, reduce their reproductive success. Functionally obsolete technical structures should be demolished, or nature-friendly solutions, such as fish ladders, should be developed to allow fish migration. Particularly, Çoruh trout (*S. coruhensis*), an important and endemic species in the streams, may have been stressed due to the rainbow trout farms established in these streams, and the escape of rainbow trout from these farms could have caused adverse effects. In addition, illegal fishing activities using traps and gillnets in the streams should be terminated.

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