E-ISSN 2602-4292

Istanbul University Center for
Research and Practice in Natural Riches

Turkish Journal of Bioscience and Collections

VOLUME 9 ISSUE 1 YEAR 2025

E-ISSN: 2602-4292

DOZEM
İSTANBUL ÜNİVERSİTESİ
DOĞAL ZENGİNLİKLERİ ARAŞTIRMA VE UYGULAMA MERKEZİ
1997

Istanbul University, Center for Research and Practice in Natural Riches

Turkish Journal of Bioscience and Collections

Volume 9 • Issue 1 • Year 2025

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Indexing & Abstracting

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Publisher
Istanbul Universtiy Press
İstanbul Üniversitesi Merkez Kampüsü, 34452 Beyazıt/Fatih, İstanbul, Türkiye
+90 (212) 440 00 00
iupress@istanbul.edu.tr
https://iupress.istanbul.edu.tr/

Publication Type
Periodical

Statements and opinions expressed in papers published in this journal are the responsibility of the authors alone.

The publication language of the journal is English.

This is a scholarly, international, peer-reviewed and open-access journal published biannual times a year in February and August.

Editorial Management

Editorial Advisory Board

İSTANBUL UNIVERSITY PRESS
Turkish Journal of Bioscience and Collections
Volume: 9 • Issue: 1 • Year: 2025

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Turkish Journal of Bioscience and Collections,
TJBC 2025, 9 (1): 1–6

https://doi.org/10.26650/tjbc.1588328

Submitted 19.11.2024
Revision Requested 27.11.2024
Last Revision Received 13.01.2025
Accepted 13.01.2025
Published Online 13.02.2025

Turkish Journal of Bioscience and Collections

Research Article

Open Access

The Silent City Hunters: Exploring Shrews through Stray Cats (*Felis catus*) in Urban Ecosystems in Jordan

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Abstract

Objective: This study investigates the predatory behaviours of stray cats (*Felis catus*) in Amman City, Jordan, from April 2021 to August 2024. Stray cats are significant contributors to wildlife mortality and serve as inadvertent tools for biodiversity monitoring. By analysing prey brought by these cats, the research highlights the interactions and distributions of small mammals in urban settings. The research aims to provide insights into the abundance and distribution of shrew species in urban landscapes and explore the potential role of stray cats as contributors to biodiversity monitoring.

Materials and Methods: The study was conducted in Dair Ghbar, a residential area with agricultural patches, using opportunistic documentation of prey items presented by stray cats. Over 41 months, a total of 20 specimens were identified, including Pygmy White-toothed Shrews (*Suncus etruscus*, 16 specimens), smaller white-toothed Shrews (*Crocidura suaveolens*, 4 specimens), and house mice (*Mus musculus*). Fisher's Exact Test assessed differences in predation rates, with $p = 0.081$.

Results: Temporal trends revealed peak predation in 2021 and 2022, with seasonal patterns indicating higher captures in warmer months. Predation rates showed no significant difference between the two shrew species, but *S. etruscus* was predominant, highlighting its adaptability to urban habitats. Seasonal variation is likely to correlate with the reproductive and activity cycles of small mammals.

Conclusion: This study underscores the dual role of stray cats as ecological disruptors and biodiversity monitors. The predominance of shrews, which are sensitive to habitat fragmentation, underscores the ecological value of urban green spaces. Despite urbanisation, these areas serve as crucial refuges for biodiversity. Stray cats provide cost-effective insights into elusive species like shrews but also pose threats to urban biodiversity. Future research should incorporate larger datasets and complementary methods to balance conservation strategies with urban ecological dynamics.

Keywords *Crocidura suaveolens* · *Felis catus* · *Suncus etruscus* · Predation · Urban areas

Citation: Eid, E. (2025). The Silent City Hunters: Exploring Shrews through Stray Cats (*Felis catus*) in Urban Ecosystems in Jordan. *Turkish Journal of Bioscience and Collections*, *9*(1), 1-6. https://doi.org/10.26650/tjbc.1588328

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Introduction

Stray cats (*Felis catus*) thrive in diverse environments because of their adaptability, supplemental human feeding, and minimal dependence on free water (Baker *et al.*, 2005; Bradshaw *et al.*, 2013). Their predatory behaviour, however, has raised ecological concerns because they are significant contributors to wildlife mortality, particularly in urban and suburban areas where their densities are unnaturally high (Sims *et al.*, 2008; Turner & Bateson, 2000). Estimates suggest that domestic cats kill millions of small vertebrates annually, including mammals, birds, and reptiles, impacting species already vulnerable due to urbanisation and habitat loss (Loss *et al.*, 2013; Mead, 2000). This impact is not limited to urban areas; for instance, a stray cat in the Dibeen Forest Reserve, Jordan, was observed capturing a Persian squirrel (*Sciurus anomalus*) shortly after its release into the wild (Ehab Eid, personal observation). Notably, studies in Great Britain revealed that cats could account for up to 30% of house sparrow (*Passer domesticus*) mortality in certain areas (Churcher & Lawton, 1987), while similar predation patterns have been observed across Europe, North America, and Oceania (Blancher, 2013; Doherty *et al.*, 2016).

Despite their significant ecological impact, domestic cats can also serve as valuable tools for ecological monitoring. Cats often present prey items as "gifts" to their caregivers, providing insight into local biodiversity, especially for elusive or understudied species (Thomas *et al.*, 2012; Woods *et al.*, 2003). This phenomenon has been explored in various contexts, such as understanding the prey composition of free-ranging cats in urban areas (Baker *et al.*, 2005; Thomas *et al.*, 2014) and assessing their impacts on specific taxa like bats and shrews (Oedin *et al.*, 2021; Vergnes *et al.*, 2013). Bats are essential for maintaining ecosystem balance through their roles in pest control, pollination, and seed dispersal, making them indispensable for sustaining agricultural productivity and natural ecosystems (Kunz & Parsons, 2011). Similarly, shrews play a significant role in forest ecosystems by regulating insect populations and enhancing soil health through their burrowing activities (Nistreanu, 2019). Their presence serves as an indicator of a healthy environment due to their sensitivity to habitat changes and pollution (Nistreanu, 2019). While mitigation measures to reduce predation have faced public resistance, studies emphasise the importance of involving cat owners in conservation strategies to balance ecological concerns with domestic pet welfare (McDonald *et al.*, 2015).

In this study, we document the predatory behaviours of stray cats in Amman City, Jordan, focusing on shrews brought home as gifts. Shrews, known for their sensitivity to habitat fragmentation and their role in controlling invertebrate populations, are integral to many ecosystems but are often overlooked in urban ecological research (Churchfield, 1990; Vergnes *et al.*, 2013). By analysing the prey brought by stray cats, this research aims to provide insights into the distribution and abundance of shrew species in an urban landscape, highlighting the potential of stray cats as inadvertent contributors to biodiversity studies.

Materials and Methods

Study Area

Dair Ghbar, a well-known residential area in southwestern Amman City, Jordan, includes patches of vacant agricultural lands in the southern sections of its residential zones (Figure 1). Fertile red and yellow Mediterranean soils characterise this area, supporting forest formations and diverse shrubland as part of Jordan's Mediterranean biogeographical zone. The climate features hot, dry summers and mild, wet winters, with annual temperatures ranging from 5°C to 30°C and irregular rainfall varying between 300 and 600 mm (Taifour *et al.*, 2022).

The identification of the Lesser White-toothed Shrew (*Crocidura suaveolens*) and the Pygmy White-toothed Shrew (*Suncus etruscus*) relied on distinct morphological and anatomical traits. *Crocidura suaveolens* was identified by its comparatively larger body size and tail length, comprising 70%–80% of its body length (Amr, 2012; Harrison & Bates, 1991). Additionally, differences in fur colouration provided further differentiation, with *C. suaveolens* displaying a greyish-brown dorsal side and a lighter ventral side, in contrast to the more uniform greyish colouration of *S. etruscus* (Amr, 2012; Harrison & Bates, 1991).

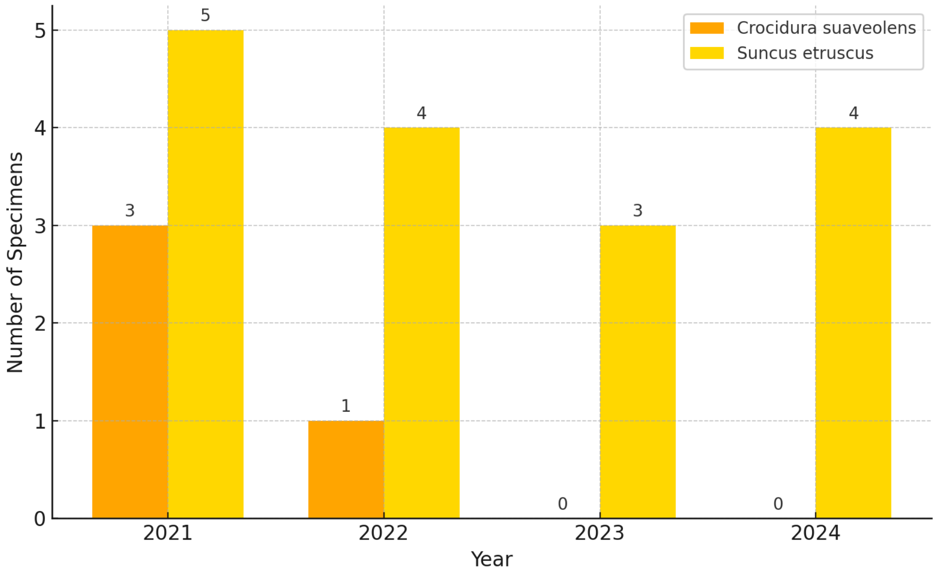
Opportunistic Documentation

This study, conducted over 41 months from April 2021 to August 2024, used an opportunistic method to record wild species brought as prey by stray cats in an urban environment. Each specimen presented by a cat was documented, including the date and species identification. This systematic approach offers a cost-effective and non-invasive way

Figure 1
Study area at Dair Ghbar.

Figure 2

Yearly trends in documented shrew specimens.



to monitor urban wildlife and examine ecological interactions in densely human-populated areas.

Results

Over the study period, 20 specimens were documented as prey brought by stray cats in an urban setting, showing temporal variation in occurrences. Most specimens were recorded during 2021 (8 specimens) and 2022 (5 specimens), with fewer observed in 2023 (3 specimens) and 2024 (4 specimens). In 2021, eight specimens were documented, with peaks in July (2 specimens), while the remaining records were distributed across April, May, June, and August. In 2022, five specimens were recorded, occurring in February, April, June, August, and September. In 2023, three specimens were documented, one each in March, April, and May. In 2024, four specimens were recorded, with occurrences in May, June, and August (Figure 2).

Of the specimens identified, four were Lesser White-toothed Shrews (*C. suaveolens*), recorded as follows: two in July 2021, one in June 2021, and one in February 2022. The remaining 16 specimens were identified as Pygmy White-toothed Shrews (*S. etruscus*) distributed across all study years (Figure 3). Additionally, four specimens of the house mouse (*M. musculus*) were documented.

Fisher's Exact Test was used due to the small sample size and sparse data, providing accurate probability estimates. The test resulted in a *p*-value of 0.081, indicating no statistically significant difference in the number of specimens recorded for the two species (*C. suaveolens*: 4 specimens; *S. etruscus*: 16 specimens) ($p > 0.05$). The observed variation is likely due to chance rather than a significant ecological or behavioural difference. However, the small sample size limits the statistical power of the analysis, requiring cautious interpretation. Further research with larger datasets is essential to validate these findings.

Figure 3

Photos of the species were collected (right: Suncus etruscus, left: Crocidura suaveolens).

Discussion

This study emphasises the dual role of stray cats as biodiversity monitors and ecological disruptors, providing insights into species interactions in urban areas like Dair Ghbar in Amman City. The predominance of *S. etruscus* (16 specimens) underscores its abundance and accessibility in urban environments. Although classified as the Least Concern in Jordan (Eid *et al*., 2020), shrews are sensitive to habitat fragmentation and environmental changes, making their urban presence significant. Differences in predation rates between *S. etruscus* and *C. suaveolens* (4 specimens) may reflect variations in behaviour, habitat use, or population size. Studies in Europe similarly highlight shrews as the common prey of domestic cats in fragmented urban habitats (Krauze-Gryz *et al*., 2016; Vergnes *et al*., 2013), suggesting cats utilise these microhabitats as refugia for small mammals.

The temporal patterns observed in this study, with higher predation in 2021 and 2022 and fewer records in 2023 and 2024, may reflect fluctuations in shrew populations or changes in cat hunting behaviours. Seasonal variation in prey captures, with higher numbers recorded during warmer months, is consistent with studies from Poland and the UK, where seasonal changes influence prey availability and activity in temperature and food resources (Baker *et al*., 2005; Krauze-Gryz *et al*., 2016). This seasonal trend likely corresponds to the reproductive cycles and activity peaks of small mammals during these periods.

Statistical analysis revealed no significant difference in the predation rates between the two shrew species ($p = 0.081$), indicating that the observed differences are likely incidental rather than indicative of ecological or behavioural distinctions. However, the small sample size limits the robustness of this finding, emphasising the need for larger datasets to validate these patterns and draw more definitive conclusions.

The role of domestic cats in global wildlife mortality is well-documented (Doherty *et al*., 2016; Loss *et al*., 2013). Nonetheless, this study highlights their utility in biodiversity monitoring, particularly for elusive species such as shrews that are otherwise challenging to survey. Opportunistic documentation of prey items offers insights into the presence and distribution of these species, aligning with the findings of Thomas *et al*. (2012), who emphasised the value of domestic cats in biodiversity studies, especially in urban environments.

Seasonal variation in prey composition may also reflect fluctuations in shrew availability linked to their reproductive cycles and environmental factors. Urban green spaces play a critical role in supporting such species by serving as ecological corridors that mitigate the effects of habitat fragmentation (Vergnes *et al*., 2013). Despite extensive urbanisation in Dair Ghbar, the continued presence of shrews underscores their resilience and highlights the importance of conserving and enhancing urban green spaces.

This study highlights the dual role of urban green spaces as vital habitats for small mammals and refuges for biodiversity while underscoring the mounting ecological pressures they face. Stray cats in urban areas, although offering valuable insights into local biodiversity, significantly contribute to their decline, which is already under severe threat from urbanisation. Their growing populations place additional strain on fragile ecosystems. To address this, immediate and practical actions are needed, such as public awareness campaigns to discourage feeding stray cats near sensitive areas, improved waste management to limit their food sources, and expanded research to better understand their ecological impacts. Such efforts can help mitigate the effects of stray cats and promote the preservation of urban biodiversity in Amman.

Peer Review: Externally peer-reviewed.
Ethics Approval: No specific ethical approval was necessary, and no ethical contraventions occurred in this report.
Conflict of Interest: The author has no conflict of interest to declare.
Grant Support: The author declared that this study has received no financial support.

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Turkish Journal of Bioscience and Collections,
TJBC 2025, 9 (1): 7–18

https://doi.org/10.26650/tjbc.1624479

Submitted 21.01.2025
Revision Requested 10.02.2025
Last Revision Received 02.03.2025
Accepted 03.03.2025
Published Online 12.03.2025

Turkish Journal of Bioscience and Collections

Research Article

Open Access

Antimicrobial Activity of Essential Oils for Potential Use as Wound Dressing Material Additives

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Abstract

Objective: The use of natural products in wound care has a long history, with herbal extracts and aromatic oils offering therapeutic benefits such as antimicrobial and antioxidant properties. This study investigated the antimicrobial efficacy of essential oils (tea tree, thyme, and cinnamon) incorporated into non-woven, hypoallergenic, and sterile wound dressings.

Materials and Methods: The antimicrobial activity of tea tree, thyme, and cinnamon oils was evaluated using minimum inhibitory concentration (MIC) and minimum bactericidal/fungicidal concentration (MBC/MFC) tests. After application of the MBC doses determined in our study to the wound dressing and gauze, the samples were evaluated using a stepwise qualitative to quantitative experimental design to assess the static and cidal effects.

Results: Tea tree oil showed the highest MIC/MBC values (1-3 mg/mL), while thyme and cinnamon oils showed efficacy at lower concentrations (0.25 mg/mL) against *Staphylococcus aureus* and *Escherichia coli*. In addition, the essential oils showed significant antifungal activity against *Candida albicans* at lower concentrations than bacteria. The impregnated dressings exhibited strong antimicrobial properties with a 99.99% (4 log) reduction in microbial growth, confirming the potential of essential oils as viable, biocompatible alternatives to traditional chemical agents in wound healing applications.

Conclusion: These findings highlight the benefits of natural essential oils in improving wound care while minimising the risk of toxicity and resistance associated with chemical treatments. In conclusion, based on the results of our study, wound dressings with natural essential oils used to reduce the risk of infection and indirectly promote wound healing can reduce healing time and improve patient quality of life in a cost-effective care setting.

Keywords Aromatic oils · Bioactive compounds · Infection control · Natural antimicrobial agents · Phytochemicals

Citation: Karakuş, B. & Şanlı, N. Ö. (2025). Antimicrobial activity of essential oils for potential use as wound dressing material additives. *Turkish Journal of Bioscience and Collections*, *9*(1), 7-18. https://doi.org/10.26650/tjbc.1624479

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Introduction

Essential oils are volatile and aromatic compounds derived from the secondary metabolism of plants. They are produced in glandular trichomes located in various leaves and stems as a result of the plant's interaction with its natural environment (Hili, 1997). The application of these oils as antimicrobial agents has been advocated for many years. Notably, there is a growing trend towards traditional therapeutic methods to obtain alternative and more effective products, driven by the increasing reliance on synthetic and/or semi-synthetic antimicrobial agents, which has contributed to the emergence of antimicrobial resistance (Goel *et al.*, 2016).

It is well-established that microorganisms within the skin flora, which facilitate interaction with the external environment, can become opportunistic pathogens due to various factors, including an increase in their population, changes in their location, or alterations in the conditions to which they are exposed (Çitil *et al.*, 2015). When the integrity of the skin is compromised, wounds create an entry point for infections. This is particularly concerning for individuals with weakened immune systems or impaired blood circulation, such as cancer patients or those with diabetes, as wound healing can be significantly prolonged in these populations. Rapid healing of wounds and restoration of skin integrity are essential. It is well-documented that mechanical barriers, such as wound dressings and gauze, are insufficient on their own, as they cannot effectively prevent the passage of bacteria (Türsen, 2013). The objective is to isolate chronic wound infections, which can develop into skin lesions or ulcers, from the external environment using barriers such as alginates, hydrocolloids, and films (Türsen, 2013). Furthermore, it is crucial to protect the environment from infectious agents. By incorporating antimicrobial properties into the wound dressings, the duration of treatment can be reduced. The first synthetic dressings, made from polyurethane film, were developed in the late 1960s, with additional forms emerging in the 1980s (Türsen, 2013).

According to the classification established by the U.S. Food and Drug Administration (FDA, 1999), wound dressings can be categorised into four types: i) non-resorbable passive dressings, such as gauze and tulle; ii) occlusive dressings, including film, hydrocolloid, and foam; iii) absorbent, hydrophilic dressings, such as alginates and hydrofibers; and iv) hydrogel dressings. These dressings can be enhanced through the incorporation of antimicrobial agents, growth factors, live cell cultures, keratin, collagen, and other substances to create bioengineered products (Dumville, 2012; Türsen, 2013). Commonly used antimicrobial agents include chlorhexidine acetate, silver, bismuth, and iodine. Additionally, two types of medical honey recommended by the FDA for direct application in wound care may also be utilized. In immunocompromised individuals, the use of natural antimicrobial agents in dressings is considered more beneficial than chemical agents due to their ability to reduce the risk of secondary systemic infections, their natural composition, patient comfort, sustainability, and lower cost. The chosen antimicrobial agent must be non-toxic to patients, should not induce antimicrobial resistance in the bacteria at the site of application, and must be effective against infectious agents (Nychas *et al.*, 2003; Koire *et al.*, 2024; Tüfekyapan *et al.*, 2025). Among these natural chemical agents, thyme oil (*Thymus vulgaris* L.) from the *Lamiaceae* family exhibits antimicrobial activity through its active compounds, thymol and carvacrol, which affect cell permeability and disrupt membrane integrity (Borugă *et al.*, 2014). Another natural oil, tea tree oil (from the *Myrtaceae* family, *Melaleuca alternifolia*), possesses properties due to its monoterpenoid components, which compromise pathogen cell membrane integrity and inhibit membrane-bound enzymes, rendering the microorganisms ineffective (Andrew *et al.*, 1980; Uribe *et al.*, 1985; Sikkema *et al.*, 1995). Cinnamon oil, derived from *Cinnamomum zeylanicum* (*Lauraceae* family), exhibits antimicrobial effects and demonstrates effects against various microorganisms due to its components, including pyrimidine analogs, echinocandins, triazoles, eugenol, and cinnamaldehyde (Raharivelomanana, 1989; Mishra, 2008; Lopez, 2005). Cinnamaldehyde, an electronegative molecule found in cinnamon, exerts its antimicrobial effect by reacting with nitrogen-containing biomolecules such as proteins and nucleic acids. Furthermore, it has been reported that cinnamon extracts and oils inhibit bacteria by disrupting bacterial growth cell membranes, ATPases, and exhibiting anti-quorum sensing effects (Vasconcelos, 2018).

The disadvantages of chemical agents applied to wound dressings, such as skin discolouration, irritation, induction of bacterial resistance and cytotoxic effects on host tissues, have led to the use of natural products. Due to the need for biocompatible alternatives to traditional chemical agents in wound healing applications, we aimed to evaluate the antimicrobial efficacy of essential aromatic oils by direct application to non-woven, hypoallergenic, flexible and adhesive, sterile and additive-free film occlusive wound dressings and non-resorbable gauze dressings. In our study, the inhibitory and microbicidal effects of thyme, tea tree and cinnamon oils were determined under *in vitro* conditions, and the antimicrobial activity of the essential oils on the gauze and hydrogel dressings was evaluated by adapting the standard methods used to evaluate the antimicrobial activity of textile products.

Materials and Methods

Preparation of the test microorganisms

In this study, the bacteria *Staphylococcus aureus* ATCC 6538 and *Escherichia coli* ATCC 8739, along with the yeast *Candida albicans* ATCC 10231, were used. *Melaleuca alternifolia* (tea tree), *Thymus vulgaris* L. (thyme oil), *Cinnamomum cassia* (cinnamon oil), and commercially available wound care dressings (non-antimicrobial) were utilised.

The microbial strains used in the experiments were stored at −86°C in a phosphate buffer and glycerol suspension. For experimental purposes, the frozen bacteria were revived by inoculating them onto Nutrient Agar (NA, Oxoid) and incubating at 37°C for 24 h. The cultured bacteria were then diluted in 1/500 Nutrient Broth (NB, Oxoid) to achieve a final concentration of 1-2×10^5 colony-forming units (CFU)/mL, starting from an initial density of 1-2×10^8 CFU/mL, as measured by a densitometer in sterile phosphate buffer (BioSan, Letonia).

Candida albicans was revived by inoculating Tryptic Soy Agar (TSA, Oxoid) and incubating at 30°C for 24 to 48 h. After the following incubation period, a turbidimetric suspension was prepared in Tryptic Soy Broth (TSB, Oxoid) and Sabouraud Dextrose Broth (SDB, Oxoid) to achieve a final concentration of 10^7 CFU/mL.

Evaluation of the Antimicrobial Activity of Tested Essential Oils Under in vitro Conditions

The antimicrobial activity of the selected essential oils in the suspension form was initially determined using the microdilution method. Subsequently, the active oils were applied to the wound dressings, and their antibacterial activities were assessed using standard testing methods.

Determination of the MIC and the MBC/MFC of the Tested Essential Oils

According to the guidelines of the Clinical and Laboratory Standards Institute (CLSI, 2015; Aydoğdu *et al.*, 2023), microdilution tests were performed by adding 100 µl of bacterial suspension to wells containing different concentrations of the selected essential oils to obtain a final concentration of approximately 5×10^5 CFU/mL bacterial suspension in the wells. After an incubation period of 24 h at 37°C, the first well in which no bacterial growth was observed in the oil/bacterial suspension series was identified as the MIC. To determine the MBC and MFC values, 10 µl samples from the wells with no bacterial or fungal growth were plated onto Mueller Hinton Agar (MHA; Oxoid) Petri dishes and incubated at 37°C for an additional 24 h. The lowest concentration at which no colony formation occurred was recorded as the MBC/MFC dose. The MIC, MBC, and MFC tests were performed in triplicate alongside the positive and negative controls. A quaternary ammonium compound known to have antimicrobial activity against the test organisms was used as a positive control and sterile phosphate buffer used to dilute the bacteria was used as a negative control.

Determination of the Antimicrobial Activity of the Tested Oils Applied to Wound Dressing and Gauze

The antimicrobial activity against *S. aureus*, *E. coli* and *C. albicans* was evaluated through a stepwise approach that included both qualitative and quantitative tests, using positive and negative controls as follows:

i) AATTC (Association of Textile, Appareal&Materials Professionals) Test Method 147 (Parallel Streak Method)

ii) EN ISO 20645 Determination of Antibacterial Activity - Agar Diffusion Plate Test

iii) AATCC 100 Test Method for the Determination of the Antibacterial Activity of Textile Materials

Assessment of the antimicrobial activity according to AATTC Test Method 147 (Parallel Streak Method)

The method used in this test was designed for the qualitative assessment of bacteriostatic, fungistatic, and antimicrobial activity in the samples.

Wound dressing samples, both with and without the application of an antimicrobial agent (control), were prepared as rectangular pieces measuring 25×50 mm using sterile forceps, scissors, scalpels, and moulds.

The suspensions of the test microorganisms were prepared separately by adding 1.0±0.1 mL of a 24h liquid culture to 9.0±0.1 mL of sterile phosphate buffer in sterile test tubes. For inoculation, one drop of the test microorganism's suspension, obtained using a 4 mm diameter inoculating loop, was applied in five parallel lines on the surface of sterile agar plates. The lines were arranged to be approximately 60 mm long, with 10 mm spacing between them, and centred in the Petri dish. No additional sample collection was performed using the loop during the line inoculation, and care was taken to avoid any damage or tearing of the agar surface.

The sterile samples, both with and without the application of antimicrobial agents, were positioned perpendicular to the five inoculation lines to ensure complete contact between the samples and the bacterial lines. To prevent the samples from curling during incubation and from losing contact with the test microorganisms, sterile glass covers were placed over them. The Petri dishes were incubated at 37±2°C for 18-24 hours. At the end of the incubation period, the Petri plates were assessed for the presence or absence of a zone of inhibition, specifically noting any interruptions in the bacterial inoculum lines and clear zones of growth inhibition around the edges of the samples.

The inhibition zone along the inoculum line on one side of the tested sample was calculated using the following formula:

$W = \frac{T-D}{2}$, where: W=Inhibition zone, in mm; T=Total of the sample and inhibition zone, in mm; D=The test sample, in mm.

According to the AATCC 147 standard, the size of the inhibition zone cannot be used for the quantitative evaluation of antimicrobial activity. The absence of microorganism colonies in the contact area under the sample is regarded as acceptable antimicrobial activity (AATCC 147, 2004; Kimiran Erdem & Sanli Yurudu, 2008).

Assessment of the antimicrobial activity according to EN ISO 20645

A semi-quantitative test method (EN ISO 20645:2004) was employed to validate the antimicrobial activity of the samples. Antimicrobial oil-treated and untreated control samples were prepared in a circular shape with a diameter of 25±5 mm using sterile forceps, scissors, a scalpel, and moulds. Since the samples were tested between two layers of agar, both sides could be evaluated. The lower layer was free of bacteria, while the upper layer was inoculated with the selected microorganism.

The Petri dish and its sterility were checked. For the upper layer, 1 mL of the microorganism suspension (1×10^8 CFU/mL) was added to the melted and cooled nutrient agar (at 45°C). The selected microorganism was inoculated into this upper layer. The test samples were placed in the lower layer using sterile forceps, and 5 mL of agar containing the test microorganism was poured over the samples. After the agar solidified, the Petri dishes were incubated at 37±2°C for 18-24 hours.

Non-sterile samples, both with and without the application of antimicrobial agents, were evaluated in parallel in triplicate.

At the end of the incubation period, the Petri plates were evaluated for the presence or absence of a zone of inhibition surrounding the edges of the sample, as well as any growth beneath the sample.

The inhibition zone surrounding the tested sample was calculated using the following formula:

$(H =)\frac{(D-d)}{(2)}$, where: H=Inhibition zone, in mm; D=Total of the sample and inhibition zone, in mm; d=Diameter of the test sample, in mm.

After measuring the inhibition zone, the samples were carefully removed using sterile forceps, and the presence or absence of growth beneath each sample was assessed. The evaluation was conducted in accordance with Table 1.

Table 1

Evaluation of the zone of inhibition according to the EN ISO 20645 standard.

Inhibition Zone (mm)	Growth[a]	Evaluation
> 1	None	
1-0	None	Good Effect
0	None	
0	Weak	Limited Effect
0	Moderate	Ineffective
0	Intense	

[a]: Growth under the sample

Measurement of Antimicrobial Efficacy in accordance with the AATCC 100 Test Method

The reduction in the microorganism count in the samples was assessed using a quantitative testing method based on the AATCC 100 standard (AATCC 100, 2019).

Both antimicrobial oil-treated and untreated control samples were prepared in a circular shape with a diameter of 4.8±0.1 cm using sterile forceps, scissors, scalpels, and moulds. Before testing, the number of samples capable of absorbing 1 mL of inoculum was determined. It was found that 1 mL of the bacterial suspension could be absorbed by one pair of double-layered gauze and a single-layer wound dressing sample. The samples were then impregnated with 1 mL of bacterial suspension at a concentration of 1-2×10^7 CFU/mL, which was added to separate sterile containers with screw caps.

After a contact time of 24 h, a neutralising solution was added to the wound dressing and gauze samples that had absorbed the test inoculum to stop the activity of the antimicrobial compounds. A neutralising solution consisting of 3% Tween 80 and 0.3% lecithin in a liquid medium was used. At the end of each contact period, the bottles were vortexed, and serial dilutions were performed. From each dilution tube, 0.1 mL was taken and spread onto Petri dishes containing nutrient agar, which were then incubated at 37°C for 18-24 hours. After the incubation period, the colonies that formed were counted.

The reduction in colony counts was calculated using the following formula:

$\mathrm{R} = \frac{(\mathrm{C-A})}{(\mathrm{C})}(\times 100)$, where: R=Percentage reduction; A=Colony count obtained from antimicrobial oil-treated samples after 24 h of contact; C=Colony count obtained from untreated samples at time 0 (approximately 1 minute after measurement).

According to the AATCC 100 standard, the acceptable kill rate percentage's lower and upper limits are established by the involved parties. Additionally, the standard indicates that a deviation of up to 18% may occur between different analytical laboratories, while a variation of up to 8% can be observed within analyses conducted by the same individual.

Statistical analysis

Comparisons of differences in CFU between the control group and those treated with essential oils were analysed using Student's t-test. $P < .05$ was considered statistically significant.

Results

Determination of the MIC and the MBC/MFC of the Tested Essential Oils Against the Test Microorganisms

The MIC and MBC/MFC of the tested essential oils against the selected test microorganisms are demonstrated in Table 2. The MIC/MBC/MFC results revealed that the essential oils exhibited varying sensitivities against the tested microbial strains. As indicated in Figure 1 and Table 1, the antimicrobial activities of the oils were positively correlated with their concentrations for the tested bacterial strains.

The most effective inhibition was observed against *C. albicans*, followed by *E. coli* and *S. aureus* (Table 2). The lowest MIC and MBC concentrations were determined at a concentration of 0.25 mg/mL for thyme oil against *S. aureus* and *E. coli* and cinnamon oil against *E. coli*.

Table 2

The MIC and the MBC/MFC values of the tested essential oils against test microorganisms (mg/mL).

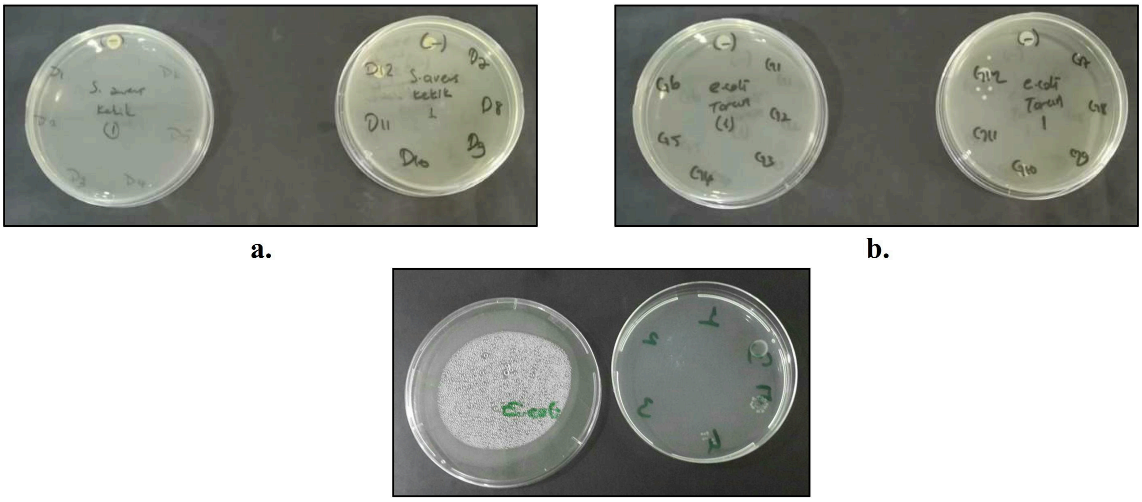
Test microorganisms	Oils	MIC	MBC
S. aureus	Tea Tree Oil	1	3
	Thyme Oil	0.25	0.25
	Cinnamon Oil	0.625	0.625
E. coli	Tea Tree Oil	1	2
	Thyme Oil	0.25	0.25
	Cinnamon Oil	0.25	0.25
C. albicans	Tea Tree Oil	1	2
	Thyme Oil	0.31	0.31
	Cinnamon Oil	0.31	0.31

Determination of the Antimicrobial Activity of the Tested Oils Applied to Wound Dressing and Gauze

The antimicrobial activity of the wound dressing and gauze samples impregnated with essential oils was evaluated using qualitative (AATCC 147), semi-quantitative (EN ISO 20645) and quantitative (AATCC 100) methods.

Figure 1

Representative photographs of the determination of the MBC values for the tested oils; a) thyme oil against S. aureus, b) cinnamon oil against E. coli, c) tea tree oil against E. coli.



Assessment of the antimicrobial activity according to AATTC Test Method 147 (Parallel Streak Method)

The qualitative AATCC 147 test method results showing the bacteriostatic effect are shown in Tables 3, 4, and 5.

As shown in Figures 2 and 3, according to the results of the AATCC 147 test, all oils evaluated, except tea tree oil, formed inhibition zones against representative pathogens. In accordance with the AATCC 147 standard, the absence of growth in the contact area of the antimicrobial-treated samples was considered to have a good antimicrobial effect (Figures 2 and 3; Tables 3, 4 and 5).

Table 3

The results of the antimicrobial activity of essential oil-impregnated wound dressings and gauze against S. aureus ATCC 6538 using the parallel streak method.

Sample	T¹ WD/G	T-D¹ WD/G	(T-D/2)¹ WD/G	Growth WD/G
Tea Tree Oil	-/-	-/-	-/-	No/No
	-/-	-/-	-/-	No/No
	-/-	-/-	-/-	No/No
	43.50/47.00	18.50/22.00	9.25/11.00	No/No
	45.00/53.00	20.00/28.00	10.00/14.00	No/No
Thyme Oil	60.00/60.00	35.00/35.00	17.50/17.50	No/No
	60.00/60.00	35.00/35.00	17.50/17.50	No/No
	60.00/60.00	35.00/35.00	17.50/17.50	No/No
	60.00/60.00	35.00/35.00	17.50/17.50	No/No
	60.00/60.00	35.00/35.00	17.50/17.50	No/No
Cinnamon Oil	37.50/37.50	12.50/12.50	6.25/6.25	No/No
	42.50/45.00	20.00/20.00	10.00/10.00	No/No
	42.50/54.00	27.00/27.00	13.50/13.50	No/No
	42.50/56.50	24.50/24.50	15.75/15.75	No/No
	42.50/58.50	33.50/33.50	16.75/16.75	No/No

¹mm, D = 25 mm, WD: wound dressing, G: gauze. Growth was vigorous around the control samples, and no inhibition of growth was observed in their vicinity.

Figure 2

Representative photographs of the results of the antimicrobial activity of the essential oil-impregnated wound dressing and gauze against S. aureus ATCC 6538 using the parallel streak method.

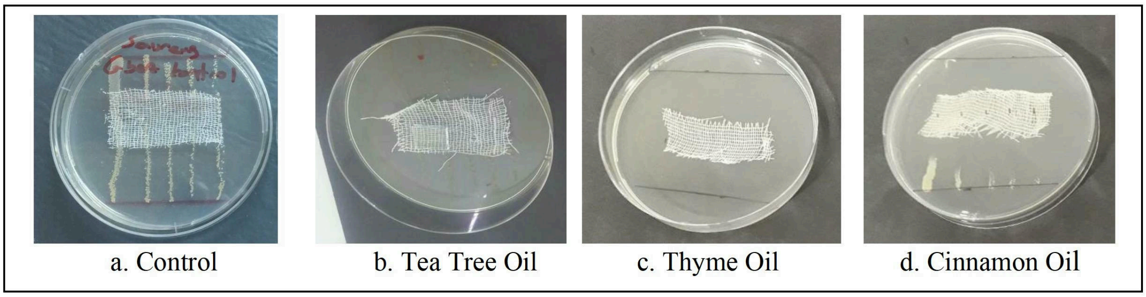


Figure 3

Representative photographs of the results of the antimicrobial activity of the essential oil-impregnated wound dressing and gauze against E. coli ATCC 25922 using the parallel streak method.

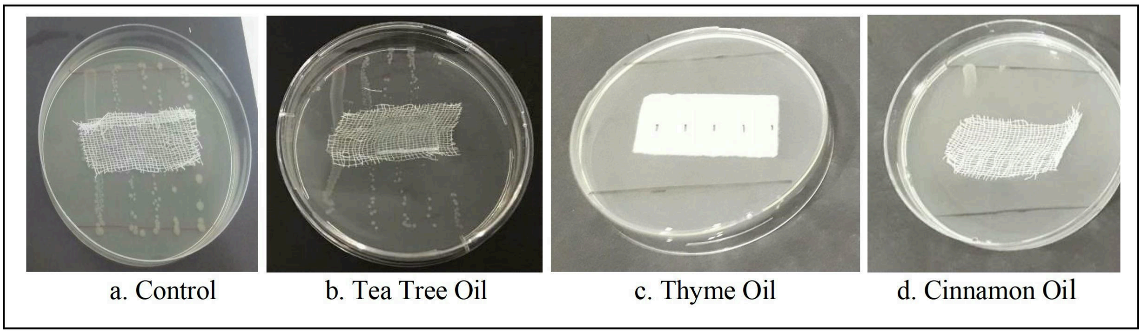


Table 4

The results of the antimicrobial activity of the essential oil-impregnated wound dressings and gauze against E. coli ATCC 25922 using the parallel streak method.

Sample	T[1] WD/G	T-D[1] WD/G	(T-D/2)[1] WD/G	Growth WD/G
Tea Tree Oil	-/-	-/-	-/-	No/No
	-/-	-/-	-/-	No/No
	-/-	-/-	-/-	No/No
	-/-	-/-	-/-	No/No
	45.00/46.00	20.00/21.00	10.00/10.50	No/No
Thyme Oil	60.00/60.00	35.00/35.00	17.50/17.50	No/No
	60.00/60.00	35.00/35.00	17.50/17.50	No/No
	60.00/60.00	35.00/35.00	17.50/17.50	No/No
	60.00/60.00	35.00/35.00	17.50/17.50	No/No
	60.00/60.00	35.00/35.00	17.50/17.50	No/No
Cinnamon Oil	37.50/37.50	12.50/12.50	6.25/6.25	No/No
	58.00/58.00	33.00/33.00	16.50/16.50	No/No
	60.00/60.00	35.00/35.00	17.50/17.50	No/No
	60.00/60.00	35.00/35.00	17.50/17.50	No/No
	60.00/60.00	35.00/35.00	17.50/17.50	No/No

[1]mm, D = 25 mm, WD: wound dressing, G: gauze. Growth was vigorous around the control samples, and no inhibition of growth was observed in their vicinity.

Table 5

The results of the antimicrobial activity of essential oil-impregnated wound dressings and gauze against C. albicans ATCC 10231 using the parallel streak method.

Sample	T[1] WD/G	T-D[1] WD/G	(T-D/2)[1] WD/G	Growth WD/G
Tea Tree Oil	-/-	-/-	-/-	No/No
	-/-	-/-	-/-	No/No
	-/-	-/-	-/-	No/No
	-/-	-/-	-/-	No/No
	51.00/52.00	26.00/27.00	13.00/13.50	No/No
Thyme Oil	60.00/60.00	35.00/35.00	17.50/17.50	No/No
	60.00/60.00	35.00/35.00	17.50/17.50	No/No
	60.00/60.00	35.00/35.00	17.50/17.50	No/No
	60.00/60.00	35.00/35.00	17.50/17.50	No/No
	60.00/60.00	35.00/35.00	17.50/17.50	No/No
Cinnamon Oil	34.50/37.50	12.50/12.50	6.25/6.25	No/No
	42.50/44.00	17.50/19.00	8.75/9.50	No/No
	60.00/60.00	35.00/35.00	17.50/17.50	No/No
	60.00/60.00	35.00/35.00	17.50/17.50	No/No
	60.00/60.00	35.00/35.00	17.50/17.50	No/No

[1]mm, D = 25 mm, WD: wound dressing, G: gauze. Growth was vigorous around the control samples, and no inhibition of growth was observed in their vicinity.

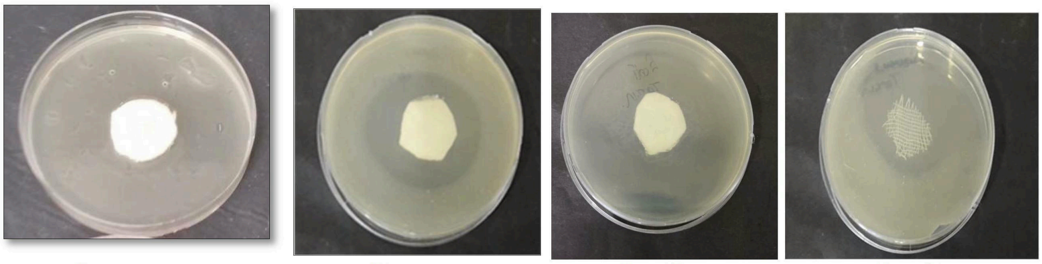
Table 6

The results of the antimicrobial activity of wound dressings and gauze impregnated with essential oils according to the standard test ISO 20645.

	Samples	***S. aureus*** **ATCC 6538**	***E. coli*** **ATCC 25922**	***C. albicans*** **ATCC 10231**
Tea Tree Oil	Wound Dressing	0 mm and no growth under the sample	0 mm and no growth under the sample	0 mm and no growth under the sample
	Gauze	0 mm and no growth under the sample	0 mm and no growth under the sample	0 mm and no growth under the sample
	Negative Control	0 mm and intense growth	0 mm and intense growth	0 mm and intense growth
Thyme Oil	Wound Dressing	30.8 mm and no growth under the sample	33.2 mm and no growth under the sample	42.5 mm and no growth under the sample
	Gauze	35 mm and no growth under the sample	33 mm and no growth under the sample	42.5 mm and no growth under the sample
	Negative Control	0 mm and intense growth	0 mm and intense growth	0 mm and intense growth
Cinnamon Oil	Wound Dressing	14 mm and no growth under the sample	21,2 mm and no growth under the sample	42.5 mm and no growth under the sample
	Gauze	50 mm and no growth under the product	17 mm and no growth under the sample	42.5 mm and no growth under the sample
	Negative Control	0 mm and intense growth	0 mm and intense growth	0 mm and intense growth

Figure 4

Representative photographs of the results of the antimicrobial activity of the essential oil-impregnated wound dressing and gauze using the ISO 20645 standard method.



S. aureus control | *S.* aureus- thyme oil impregnated wound dressing | *E. coli* control | *E. coli*- cinnamon oil impregnated gauze

EN ISO 20645 (Determination of Antibacterial Activity-Agar Diffusion Plate Test)

The results and representative photographs of the oil-impregnated wound care samples according to the EN ISO 20645 standard method are shown in Table 6 and Figure 4 (Table 6, Figure 4).

In accordance with the provisions stipulated in the EN ISO 20645 standard, the efficacy of the essential oil-impregnated wound care samples was demonstrated to be effective against the bacteria under investigation. This was evidenced by the absence of bacterial growth beneath the samples (Tables 3, 5, and Figure 4).

Measurement of Antimicrobial Efficacy in accordance with the AATCC 100 Test Method

The results of the evaluation of the antimicrobial activity of the essential oil-impregnated wound care products according to the AATCC 100 method are shown in Table 7.

Wound care samples impregnated with essential oils showed strong antimicrobial activity with a reduction in test microorganisms of more than 4 log, 99.99% (Table 7).

Discussion

Since ancient times, people have utilised linen, cotton, and gauze to dress wounds, along with various natural herbal products, including aromatic oils, to prevent infections (Simões *et al.*, 2018). Many scientific studies have shown that extracts obtained from plants' roots, leaves, or flowers can have a therapeutic effect due to compounds such as alkaloids, flavonoids, glycosides, and terpenes (Akpınar *et al.*, 2024; Türsen, 2013). Extracts can increase collagen synthesis, stimulate fibroblasts, support epithelization, and provide antioxidant and antimicrobial effects (Toroğlu & Çenet, 2013). Among the herbal products studied, aromatic oils are primarily preferred due to their advantages, such as being non-toxic to tissues, easily accessible, and cost-effective (Seow *et al.*, 2014). Treatments that were once developed through trial and error are now validated through standardised antimicrobial activity and cytotoxicity tests conducted in laboratories. These advancements provide a range of contemporary products with applications in bioengineering.

While it was once preferred to keep wounds dry, research conducted over the past 50 years has demonstrated that a moist environment facilitates the clearance of debris and the elimination of bacteria. This is attributed to the presence of fluids and electrolytes as well as epithelial growth factors, matrix metalloproteinase enzymes, macrophages, and neutrophils. In addition to protecting against contamination, enhancing patient comfort, and facilitating wound monitoring through their transparency, wound dressings can serve multiple purposes by incorporating unique properties, such as an antimicrobial effect achieved through various chemical compounds (Thiruvoth, 2015; Türsen, 2013).

Chemical compounds often preferred in wound dressings include silver, silver products, polyhexamethylene biguanide, cadoxemer iodine or polyacrylate used to reduce the risk of superficial infection in chronic wounds. Of these, silver in particular is effective against a wide range of resistant microorganisms, but it has been found to have a negative effect on *in vitro* skin cultures, and its effect on healthy tissue is unknown. Chlorhexidine, betadine, acetic acid, hydrogen peroxide, scarlet red dye and bacitracin are used to prevent superficial infections. Antimicrobials are known to have local effects such as pain and rash and

Table 7

Results of the antimicrobial activity of tea tree oil-impregnated wound care products using the AATCC 100 method.

Microorganisms	Materials	Bacteria count**	% Percentage of reduction
	WD-tea tree oil	< 100**	> 99.99978
	WD-thyme oil	< 100**	> 99.99978
	WD-cinnamon oil	< 100**	> 99.99978
***S. aureus* ATCC 6538**	G-tea tree oil	< 100**	> 99.99978
	G- thyme oil		> 99.99978
	G- cinnamon oil	< 100**	> 99.99978
	Control	2.55x10^5 (0.h)	4.60x10^7 (24.h)
	WD-tea tree oil	< 100**	> 99.9988
	WD-thyme oil	< 100**	> 99.9988
	WD-cinnamon oil	< 100**	> 99.9988
***E. coli* ATCC 25922**	G-tea tree oil	< 100**	> 99.9988
	G- thyme oil	< 100**	> 99.9988
	G- cinnamon oil	< 100**	> 99.9988
	Control	2.14x10^5 (0.h)	8.90 x10^6
	WD-tea tree oil	< 100**	> 99.9962
	WD-thyme oil	< 100**	> 99.9962
	WD-cinnamon oil	< 100**	> 99.9962
***C. albicans* ATCC 10231**	G-tea tree oil	< 100**	> 99.9962
	G- thyme oil	< 100**	> 99.9962
	G- cinnamon oil	< 100**	> 99.9962
	Control	2.44x10^5 (0.h)	2.70 x10^6

**Bacteria counts after 24 h of exposure

**A colony count of 0 in the Petri dish was accepted as a 100 colony count due to the dilution factor.

cytotoxic effects on cells necessary for the wound healing process such as epithelial cells, fibroblasts, endothelial and inflammatory cells and others; systemic effects such as causing toxicity in the kidneys, liver and other organs as a result of absorption of these substances into the systemic circulation. It is well known that iodine and silver compounds cause skin discolouration and irritation with prolonged use; antiseptics have a broader spectrum and higher cytotoxicity in host tissues than antibiotics, while antibiotics are more likely to develop bacterial resistance (Borda *et al.*, 2016; Punjataewakupt *et al.*, 2019). Therefore, considering the biocompatibility of natural products against the disadvantages of chemicals, natural products are preferred. In our study, taking all these factors into account, the essential aromatic oils tested were applied directly to non-woven, hypoallergenic, flexible and adhesive, sterile and additive-free film occlusive wound dressings and non-resorbable gauze. The dressings tested in the study were preferred because they did not contain any interfering substances.

Choosing the optimal concentration of antimicrobial is important both to adequately control infection and to avoid toxicity from antimicrobial administration. The concentration of antimicrobial required to inhibit the growth of a pathogen was determined with MIC and MBC tests. According to our MIC and MBC test results, the highest MIC/MBC (MFC) concentrations (1-3 mg/mL) were obtained with tea tree oil; the lowest MIC and MBC concentrations were obtained at a concentration of 0.25 mg/mL for thyme oil against *S. aureus* and *E. coli* bacteria and for cinnamon oil against *E. coli* bacteria. Tea tree oil and cinnamon oil were effective against the fungus *C. albicans* at lower concentrations than bacteria. The MIC and MBC values obtained for oils are consistent with the results evaluated for similar microorganisms (Costa *et al.*, 2021; Gao *et al.*, 2020; Shi *et al.*, 2016; Yasin *et al.*, 2021).

Following the application of the MBC doses determined in our study to the wound dressing and gauze, the samples were evaluated using a qualitative to quantitative experimental set-up with a stepwise approach to assess the static and cidal effects. Qualitative and semi-quantitative tests showed that all essential oils had good antimicrobial activity, including those that did not form a zone (tea tree oil), and this effect was confirmed by the standard qualitative method. The wound dressing samples impregnated with essential oils were found to have strong antimicrobial activity with a 99.99% reduction of more than 4 logs of test microorganisms by qualitative assessment. The results of the present study indicate that the essential oils tested have significant ($p<0.05$) antimicrobial activity, strengthening the potential use of these substances as antimicrobials in the future.

It is known that in various studies in the literature, one or two of these oils have been applied with chemical agents that may have stabilising and/or synergistic effects on the wound dressing and evaluated using various standard antimicrobial activity tests (Behary *et al.*, 2020; Besen, 2019; Cremar *et al.*, 2018; Gheorghita *et al.*, 2022; Rieger *et al.*, 2014). In our study, unlike other studies, three different essential oils were applied to sterile gauze and wound dressing without any other additive and their antimicrobial activity was evaluated using a stepwise qualitative to quantitative experimental design. This study has demonstrated the potential of natural essential oils to provide an effective solution by demonstrating an antimicrobial effect when applied to wound dressing material through *in vitro* treated dressing tests.

Conclusion

In conclusion, based on the results of our study, wound dressings with natural essential oils applied to reduce the risk of infection and indirectly promote wound healing can reduce healing time and improve patient quality of life in a cost-effective care setting.

Ethics Approval: No specific ethical approval was necessary, and no ethical contraventions occurred in this report.

Peer Review: Externally peer-reviewed.

Author Contributions: Conception/Design of Study- N.Ö.Ş.; Data Acquisition- N.Ö.Ş., B.K.; Data Analysis/ Interpretation- N.Ö.Ş., B.K.; Drafting Manuscript- N.Ö.Ş., B.K.; Critical Revision of Manuscript- N.Ö.Ş.; Final Approval and Accountability- N.Ö.Ş.; Technical or Material Support- N.Ö.Ş., B.K.; Supervision- N.Ö.Ş.

Acknowledgements: This study was carried out by Beyza Karakus under the supervision of Nazmiye Ozlem Sanli as a graduate thesis of IU Faculty of Science, Higher Education Council (YÖK) Basic Sciences Programmes (TEBIP).

Conflict of Interest: The authors have no conflict of interest to declare.

Financial Disclosure: The authors declared that this study has received no financial support.

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Istanbul University Press

Turkish Journal of Bioscience and Collections,
TJBC 2025, 9 (1): 19–38

https://doi.org/10.26650/tjbc.1618060

Submitted 11.01.2025
Revision Requested 04.02.2025
Last Revision Received 20.02.2025
Accepted 20.02.2025
Published Online 04.03.2025

Turkish Journal of Bioscience and Collections

Review Article

Open Access

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

Citation: Gaygusuz, Ö., Tarkan, A. S. & Gürsoy Gaygusuz, Ç. (2025). Fish Fauna and Fishery Evaluation of Sapanca Lake. *Turkish Journal of Bioscience and Collections*, *9*(1), 19-38. https://doi.org/10.26650/tjbc.1618060

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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.

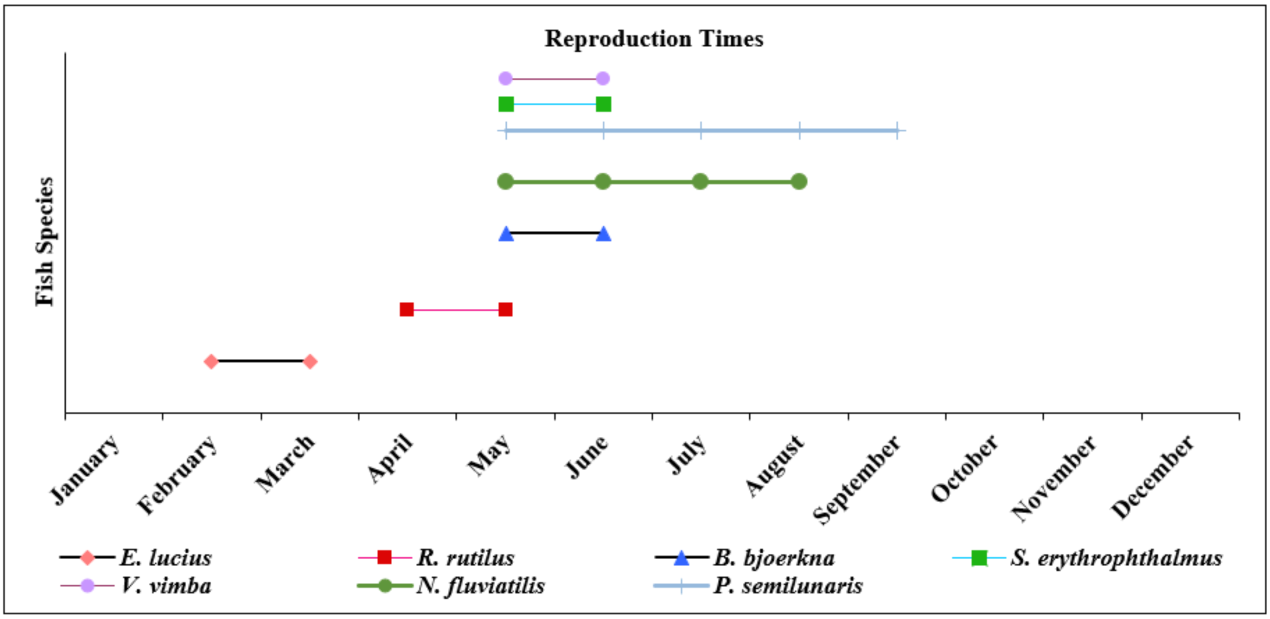
Since this period, comprehensive fisheries biology studies have been initiated in the lake in 2000, and their results began to be published after 2001. Gürsoy (2001) reported that *V. vimba* spawn in June, reach sexual maturity at age 3, and produce between 3545 and 14988 eggs, *whereas B. bjoerkna* 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.

Acknowledgements: We would like to express our gratitude to Dr. Müfit Özuluğ, who provided literature support during the preparation of this manuscript, listened to our questions with great attention and interest, and was always helpful; to Dr. Derya Akdemir and Dr. M. Didem Demircan for their contributions and constructive criticism. We express our gratitude to the late Adnan Sümer, to whom we can never fully repay, who has been helping us since we started our research in Lake Sapanca, working with us day and night, through the heat of summer and the cold of winter, always finding practical solutions in our difficult moments, and whom we lost unexpectedly in 2016. He will always live in our hearts and memories. May he rest in peace, and we salute him with respect. This study is dedicated to the cherished memory of Adnan Sümer.

Ethics Approval: No specific ethical approval was necessary, and no ethical contraventions occurred in this report.

Peer-review: Externally peer-reviewed.

Author Contributions: Conception/Design of study: Ö.G, A.S.T, Ç.G.G.; Data Acquisition: Ö.G, A.S.T, Ç.G.G.; Data Analysis/Interpretation: Ö.G, A.S.T, Ç.G.G.; Drafting Manuscript: Ö.G, A.S.T, Ç.G.G.

Conflict of Interest: The authors have no conflict of interest to declare.

Financial Disclosure: The authors declared that this study has received no financial support.

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İSTANBUL UNIVERSITY PRESS

Turkish Journal of Bioscience and Collections,
TJBC 2025, 9 (1): 39–42

https://doi.org/10.26650/tjbc.1631271

Submitted 01.02.2025
Revision Requested 08.02.2025
Last Revision Received 09.02.2025
Accepted 10.02.2025
Published Online 18.02.2025

Turkish Journal of Bioscience and Collections

Short Communication

Open Access

Occurrence of the Non-Native Pumpkinseed *Lepomis gibbosus* in a Reservoir of the Karamenderes Basin (Çanakkale, Türkiye)

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Abstract This study reports the recent discovery of the pumpkinseed *Lepomis gibbosus* in the Bayramiç Reservoir, which is located in the Karamenderes Basin (NW Türkiye). A total of five specimens were captured with a portable electrofishing unit. Total length (TL) and body weight (W) measurements were recorded with an accuracy of 0.1 cm and 0.01 g, respectively. The length and weight ranges of the specimens were 41–88 mm and 7.2–14.3 g, respectively. The presence of this non-native species in the study area could be attributed to either natural expansion or multiple (deliberate/indeliberate) introductions.

Keywords Non-indigenous species · Bayramiç · reservoir · introduction · freshwater fish

Citation: Kaya, Y., Gökmenoğlu, T., Telci, T., Kurt, E. & Ağdamar, S. (2025). Occurrence of the Non-Native Pumpkinseed *Lepomis gibbosus* in a Reservoir of the Karamenderes Basin (Çanakkale, Türkiye). *Turkish Journal of Bioscience and Collections*, *9*(1), 39-42. https://doi.org/10.26650/tjbc.1631271

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Introduction

Pumpkinseed (*Lepomis gibbosus*), a carnivorous benthopelagic fish native to North America, became widely established as an invasive species in Europe by the late 19th century, as documented by early studies (Copp & Fox, 2007; Lever, 1977; Wheeler & Maitland, 1973). In Türkiye, the pumpkinseed first recorded by Erk'akan (1983) in the Thrace Region (Northern Marmara). Subsequent reports have expanded its known distribution, particularly across the Aegean Region, with contributions from multiple researchers over decades (Ağdamar *et al.*, 2015; Baran & Ongan, 1988; Bay, 2010; Dirican, 2001; İlhan *et al.*, 2020; Keskin *et al.*, 2013; Koca *et al.*, 2005; Özcan, 2007; Özuluğ *et al.*, 2019; Reis *et al.*, 2018; Türker *et al.*, 2022).

This study reports the presence of *L. gibbosus* in the Bayramiç Reservoir, a waterbody hydrologically connected to the Karamenderes Stream.

Materials and Methods

Study area

With an average length of 109 km, the Karamenderes Stream is the longest river in the Biga Peninsula, situated within Çanakkale Province, northwestern Türkiye (Baba *et al.*, 2007). Originating from the northern slopes of Mount İda (Kazdağı), the stream follows a meandering path through three primary geomorphological zones - the Evciler Depression (upper basin), the Ezine-Bayramiç Plain (middle basin), and the Karamenderes Delta (lower basin)- before discharging into the Dardanelles (Akbulut *et al.*, 2009). Constructed between 1986 and 1996 for irrigation, the Bayramiç Reservoir features an earth-filled structure with a total body volume of 4.0 hm³. The reservoir stands 55.5 meters high from its foundation and has a total storage capacity of 86.5 hm³ (Akbulut *et al.*, 2006).

Figure 1

Map (Modified from Partal & Yalçın Özdilek, 2017) and images of the study area (Photograph by Sevan Ağdamar).

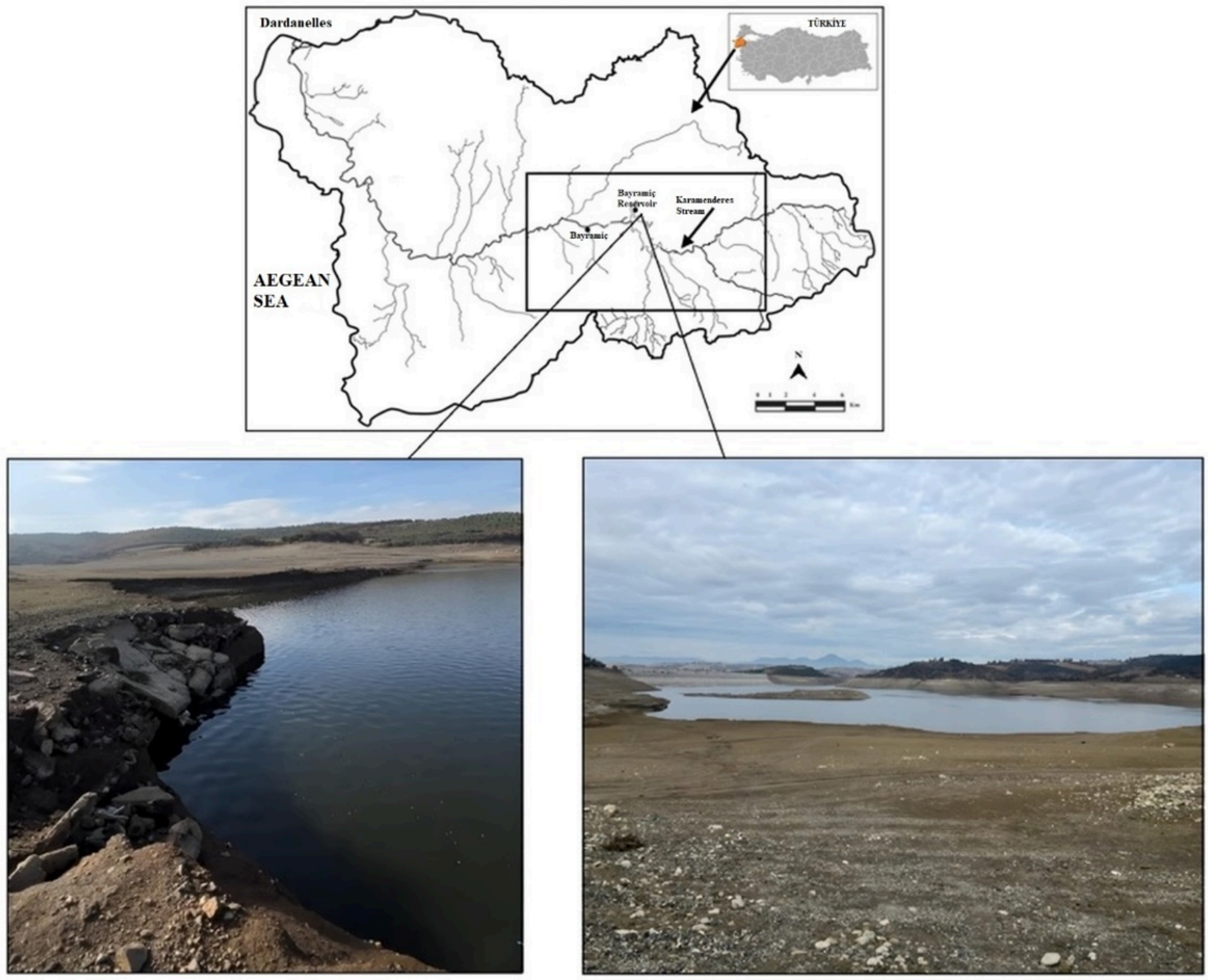

Table 1

Fish data on the sampling location of the pumpkinseed in the Bayramiç Reservoir.

Species	Number of specimens	Length range (TL, mm)	Weight range (W, g)	Coordinate
Lepomis gibbosus	5	41–88	7.2–14.3	39.814180° N, 26.673390° E

Figure 2

The specimen of pumpkinseed caught in the Bayramiç Reservoir, Çanakkale, Türkiye on December 27, 2024 (Photograph by Sevan Ağdamar).

Sampling

The samplings were performed in the Bayramiç Reservoir (Çanakkale, Türkiye) between December 2024 and January 2025 (Figure 1). The specimens were collected using a portable electrofishing device, SAMUS 1000 (Figure 2). Total length (TL) and body weight (W) were measured to the nearest 0.1 cm and 0.01 g, respectively. After examination, the specimens were released back to their habitat. Fish data on the sampling site are listed in Table 1.

Results and Discussion

Because of the field surveys carried out in the study area, five specimens of *L. gibbosus* were collected. The length and weight ranges of the specimens were 41-88 mm and 7.2-14.3 g, respectively (Table 1).

Consequently, this study marks the first documented occurrence of the pumpkinseed within the reservoir system of the Karamenderes Basin. There are several possible scenarios that could explain how this species appeared in the reservoir. In Türkiye, the spread of non-native freshwater fish species has been facilitated by multiple introductions as well as the involvement of local fishermen (Aydın *et al.*, 2011). Given the connection between the Bayramiç Reservoir and the Karamenderes Stream, it is hypothesised that this non-native species may have entered the area through natural dispersal mechanisms or intentional/unintentional introductions. It is advised that thorough on-site studies be carried out in all waterbodies connected to the Karamenderes Stream to evaluate the dispersal of non-native species and their possible effects on the ecosystem.

Peer Review: Externally peer-reviewed.

Ethics Approval: No specific ethical approval was necessary, and no ethical contraventions occurred in this report.

Author Contributions: Conception/Design of study: S.A.; Data Collection: S.A., Y.A., T.G., T.T., E.K.; Data Analysis/Interpretation: S.A.; Drafting/Writing Manuscript: S.A.

Conflict of Interest: The author has no conflict of interest to declare.

Grant Support: This study was supported by the TÜBİTAK (Project Code: 2209-A, Project ID: 1919B012332891)

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