October 2024

INTERNATIONAL STUDIES AND EVALATIONS IN THE FIELD OF

AQUACULTURE

EDITOR

PROF. DR. AYSEL ŞAHAN

SERÜVEN YAYINEVI

Genel Yayın Yönetmeni / Editor in Chief • C. Cansın Selin Temana

Kapak & İç Tasarım / Cover & Interior Design • Serüven Yayınevi

Birinci Basım / First Edition • © Ekim 2024

ISBN • 978-625-6172-45-6

Serüven Yayınevi / Serüven Publishing
Türkiye Adres / Turkey Address: Kızılay Mah. Fevzi Çakmak 1. Sokak
Ümit Apt No: 22/A Çankaya/ANKARA
Telefon / Phone: 05437675765
web: www.seruvenyayinevi.com
e-mail: seruvenyayinevi@gmail.com

Baskı & Cilt / Printing & Volume
Sertifika / Certificate No: 47083

INTERNATIONAL STUDIES AND EVALUATIONS IN THE FIELD OF AQUACULTURE

October 2024

Editors

PROF. DR. AYSEL ŞAHAN

CONTENTS

Chapter 1

NITROGEN DYNAMICS AND ITS IMPORTANCE AT THE SEDIMENT-WATER INTERFACE IN LAKE ECOSYSTEMS: EFFECTS AND OUTCOMES*

Seda KARAKOCA ATLIĞ[1]

Akasya TOPÇU[2]

İlknur MERİÇ TURGUT[3]

* A part of this study is based on the PhD thesis titled "Nitrogen Dynamics of Sediment - Water Interface and the Effective Factors in Mogan Lake" by Seda KARAKOCA ATLIĞ (Ankara - 2023).

1 Ankara Üniversitesi Ziraat Fakültesi Su Ürünleri Mühendisliği Bölümü, 06100, Ankara, Türkiye , ID: https://orcid.org/0000-0003-4589-7803

2 Ankara Üniversitesi Ziraat Fakültesi Su Ürünleri Mühendisliği Bölümü, 06100, Ankara, Türkiye , ID: https://orcid.org/0000-0002-5229-4181

3 Ankara Üniversitesi Ziraat Fakültesi Su Ürünleri Mühendisliği Bölümü, 06100, Ankara, Türkiye , ID: https://orcid.org/0000-0001-7404-5680

1. Overview of Nitrogen in Aquatic Ecosystems

Lake ecosystems are complex realms and important biological hotspots in aquatic ecosystems. One of the critical components of these ecosystems is the sediment-water interface, which plays a vital role in the cycling and dynamics of nutrients, particularly nitrogen. Nitrogen is a key element for aquatic life, influencing primary productivity, species composition, and overall ecosystem health. Understanding the dynamics of nitrogen at the sediment-water interface is essential for managing and preserving lake ecosystems. This interface acts as a zone of intense microbial activity, where various forms of nitrogen are transformed through processes such as nitrification, denitrification, and ammonification. These processes regulate the availability of nitrogen in the water column, thereby affecting the growth of aquatic organisms and the quality of water. Consequently, studying the nitrogen dynamics at the sediment-water interface provides insights into nutrient cycling and helps in the development of strategies for the effective management of lake ecosystems.

Sediment refers to all solid inorganic and organic materials that can be transported by erosive processes and deposited afterwards. The composition of a lake or reservoir's sediment depends on geography, land cover, and the type of soil in its upstream catchment area. Over time, these solid particles accumulate in sediment layers, reducing the lake's volume and potentially harming the ecosystem and all life forms within, on, and around the lake.

Sediment can act as either a source or a trap in the process of nutrient release back into the water. There are several accepted methods for analyzing the fractions of nitrogen and phosphorus in sediments, including:

1. Nitrate-nitrogen (NO_3-N)
2. Ammonium-nitrogen (NH_4-N)
3. Phosphate-phosphorus (PO_4-P) (Kelsey, 2015).

Amonium adsorption is generally associated with the organic matter content of sediment; organic-rich sediments retain nitrogen by absorbing it within their structures. Nitrogen release in wetlands occurs through sedimentation of various nitrogen forms and their re-suspension. As ammonium is a positively charged ion, it adsorbs onto particles in the sediment. The level of adsorbed ammonium is in equilibrium with the ammonium concentration in the water, and any changes in water chemistry can result in its release into the water (Delince, 1992; Hakanson and Jansson, 2002).

Eutrophication can cause odor and taste problems in aquatic ecosystems and lead to significant issues by reducing dissolved oxygen levels, which can severely affect lake ecology. In this context, the concentrations of nutrients such as nitrogen and phosphorus in lakes and reservoirs provide insights into the health of the water body and form a good basis for management decisions. In eutrophic lakes, it has long been known that nitrogen cycling processes in sediment greatly affect water quality and sediment characteristics (Bruesewitz *et al*., 2012; Yao *et al*., 2018).

With the increase in human activities, there has been a worldwide loss of underwater macrophytes and an increase in underwater turbidity (Jeppesen *et al*., 1998; Scheffer, 1998; Körner, 2002; Wang *et al*., 2014). Excessive phosphorus input is speculated as the underlying cause of this phenomenon (Scheffer, 1998; Carpenter, 2003; Sand-Jensen *et al*., 2008), but the role of nitrogen (N) in the recession of macrophytes has recently drawn attention (Moss, 2001; Jeppesen *et al*., 2007; Moss *et al*., 2013).

According to Farshay and Dodson (2011), information on the effect of underwater plant cover on nitrogen cycling processes and associated microorganisms in sediment, which are closely related to the efficiency of lake ecosystems in removing nitrogen from the environment and their self-cleansing capacity, is limited (Yao *et al*., 2018).

2. Nitrogen Cycling in the Sediment-Water Interface: Role of Key Factors

Nitrogen is transferred from sediment to overlying water through diffusion, sediment resuspension, and bioturbation and is absorbed by plants as ammonium. The diffusion of dissolved NH4-nitrogen into the water at the sediment-water interface is the most important pathway for nitrogen release, potentially leading to ammonium release and the water becoming eutrophic and it is a complex transition involving nitrification, denitrification, and ammonification processes. The release of nutrients from sediment to water is considered an important process in nutrient balance for many aquatic systems (Hale, 1975; Gardner *et al*., 2006; Gardner and McCarty, 2009). In shallow and eutrophic lakes, hydrodynamics can induce the distribution of nutrient release in sediment. Factors such as water depth, types of nutrients, water temperature, pH, concentration gradient, redox potential, and organisms present in the environment also influence the salinity affected by hydrodynamics (Wu *et al*., 2019).

Interactions at the sediment-water interface play a critical role in dissolved and particulate organic nitrogen mineralization processes (including ammonification, nitrification, and denitrification) in aquatic ecosystems. Within these interactions, nutrient immobilization in sediment, regeneration rates, and some physicochemical and metabolic processes are involved. At this stage, dissolved oxygen concentration, redox potential, and pH levels in overlying sediment water are effective. Generally, ammonium acts as a source and nitrate as a trap in sediment nitrogen. The source of ammonium in sediment pore water is generally associated with two important biological processes: bacterial decomposition of organic matter and metabolic waste produced by benthic organisms. Ammonium release in aquatic environments is governed by various factors such as sediment type, oxidation of organic matter, temperature, and dissolved oxygen concentration.

Temperature is one of the most important environmental variables governing microbial denitrification and anaerobic conditions in sediment (Batty *et al.*, 2017). Nitrous oxide in greenhouse gases is produced during denitrification, but information on anaerobic ammonium oxidation and how these pathways respond to global warming is still limited.

- ***Case studies***

Baiyangdian Lake in China was the subject of a comprehensive study on nitrogen distribution and ammonia release in sediment, where water and sediment samples were collected from a rapidly urbanizing area (Zhu *et al.*, 2019). The mean concentrations of ammonium (NH_4±N), NO_3-N, and TP in water samples were analyzed as 0.36, 0.12, and 2.22 mg/l, respectively. Nitrogen concentrations in the water gradually increased from the northern to the southern part of the lake. About 90% of sediment samples from sampling areas were found to comply with the moderately or heavily polluted class (1000-2000 mg/kg) as defined by the U.S. Environmental Protection Agency TN pollution standards. The release of NH_4±N from sediment to water in the lake was determined to range from 5.35 to 48.76 mg/m^2/day.

Hou *et al.* (2013) investigated the impact of environmental factors on nutrient release in the sediment of Daihai, a shallow lake, located in northwest China. Nutrients in the lake indirectly affected nitrogen and phosphorus release. The researchers reported that light increased algal biomass and reduced nitrogen and phosphorus concentrations in the water, thereby indirectly inhibiting nutrient release. They also noted that high pH promoted release. Nitrate, due to its high solubility in water, is one of the most common groundwater pollutants on a global scale and poses a serious threat to human health, contributing to eutrophication. Among various treatment technologies for nitrate removal, adsorption studies have yielded satisfactory results, particularly with mineral-based and/or surface-modified adsorbents.

Szogi *et al.* (2003) investigated the combined effects of ammonium-nitrogen concentration in sediment pore water and nitrogen loading values in an artificial wetland used for the disposal of animal farm wastewater, which contained high nitrogen content. They reported that the high level of ammonium-nitrogen (>200 mg/l) detected in sediment pore water could adversely affect the long-term functionality of the artificial wetland system.

Monthly and seasonal changes in nitrogen in lake water and sediment pore water were monitored in the shallow eutrophic Chaohu Lake in China. Nitrate nitrogen was found to be the dominant nitrogen form in overlying sediment water, while ammonium was dominant in sediment pore water. This suggests the occurrence of strong oxidative nutrient degradation at the sediment-water interface. The positive correlation between ammonium release and temperature indicates the relationship between increasing temperature and intensified ammonification and nitrate reduction. Ammonium release increases with water temperature, algae biomass, and chlorophyll concentrations, while it decreases with increasing dissolved oxygen levels. This study concluded that there is a negative correlation between ammonium concentration in sediment and dissolved oxygen concentration; the increasing ammonium release is not only due to the increasing level of organic matter ammonification in sediment but also due to the decrease in the rate of nitrification associated with low dissolved oxygen levels (Zhang *et al.* 2008).

Zhong *et al.* (2021) investigated the long-term effects of nitrogen loading in eutrophic Taihu Lake in Meiling Bay using sediment screening method at the sediment-water interface (SWI). This study suggested methods to reduce organic matter and total nitrogen in sediment, including nitrogen mineralization, nitrogen fixation, denitrification, and anaerobic ammonia oxidation (anammox). Additionally, the enrichment of sediment with organic matter and nitrogen accelerated nitrogen cycling processes at the sediment-water interface. Sediment screening method studies provided benefits such as increasing the redox potential at the sediment-water interface with a reduction in organic matter and total nitrogen content in surface sediment. Thus, the study demonstrated that sediment screening method practices are both advantageous and disadvantageous in controlling internal nitrogen loading in shallow lakes. While these practices help reduce inorganic nitrogen flux at the sediment-water interface and facilitate nitrogen removal through denitrification and anammox, measures to prevent particle input and retention are also necessary.

Müller *et al.* (2021) conducted research to identify differences in nitrogen removal efficiency between the eutrophic Baldegg Lake and the oligotrophic Sarnen Lake in Switzerland. The researchers found a significant connection between annual nitrogen loading and removal rates in eutrophic lakes, and there was a statistically significant correlation between nitrate concentration in overlying sediment water and nitrogen removal. Nitrogen release showed significant seasonal variations in eutrophic Baldegg Lake but not in oligotrophic Sarnen Lake. According to the researchers, the increase in seasonal nitrogen removal rates was associated with seasonal oxygen release values at the sediment-water interface in eutrophic lakes. The increased oxygen levels were reported to enhance sediment mineralization, indirectly promoting denitrification activity.

Lee *et al.* (2019) conducted a modeling study based on a three-way hydrodynamic and transport model to determine the effect of internal nutrient loading from sediment on water quality in Euiam Lake, South Korea. While NH_4 release in the lake was generally positive, indicating a large amount of nitrate transported to the sediment, NO_3 release was negative, suggesting that sediment-water nitrification, which transports a small amount of ammonia to overlying sediment water, is dominant.

Wu *et al.* (2019) conducted a study on the spatial distribution of nitrogen and phosphorus in the sediment of Taihu Lake from a hydrodynamic transport perspective. They found that hydrodynamics play a significant role in nutrient dynamics in lakes with large surface areas, shallow depths, and eutrophic conditions. In their study, field observations of nitrogen and phosphorus in Taihu Lake sediment were compared with hydrodynamic transport perspectives based on numerical simulations and long-term ecological data analysis. During the field study, six sediment samples were collected (0-1 cm, 1-2 cm, 2-3 cm, 3-4 cm, 4-6 cm, and 6-10 cm depths). The total nitrogen (TN) content in sediment ranged from 319.4 to 3123.8 mg kg^{-1}, with the highest rates observed in Zhushan, Meiliang, and East Taihu Bay. It was found that most dissolved nitrogen is found in surface water and is horizontally transported to areas with weak biomass levels by lake currents. Enrichment from horizontally transported nitrogen led to changes in hydrodynamic regulation through nitrogen release from sediment via bioaccumulation. The phosphorus (TP) content in sediment varied between 382.6 and 1314.1 mg kg^{-1}, with high phosphorus areas located near river mouths. Unlike nitrogen, phosphorus enrichment occurred mainly through physical means in sediment, and accumulation was chemical. Surface waves had a weaker effect on phosphorus transport to overlying water compared to nitrogen. Parameters such as total organic carbon (TOC), ammonia (NH_3), nitrite (NO_2), water content, and dry weight were calculated in sediment samples. The TOC content ranged from 1.28% to 3.52%, with an average of 1.87%, and the N ratio ranged from 0.7 to 6.7 with an average of 2.6. Higher values were observed in the western and southeastern regions of the lake. Dissolved nitrogen was transported by lake currents, while phosphorus was mainly accumulated in sediment through physicochemical processes, and nitrogen exchange depended on sediment depth, coinciding with seasonal cyanobacterial blooms.

Maslukah *et al.* (2018) emphasize the significance of nitrogen and phosphorus release from sediment to water of Wiso and Serang Rivers in Indonesia. The mechanism of release varies based on concentration differences between sediment pore water and overlying water, relying on diffusion processes. Effective factors influencing the control of nutrient release include sediment particle size, distribution, water depth, salinity, pH, and dissolved oxygen, among other environmental parameters. The research concluded that there was no significant difference in nitrogen release between the two regions.

Tan *et al.* (2020) demonstrated in their study that warming directly triggered N_2O production during denitrification in subtropical sediment and that the reaction rate for N_2O production was higher with warming. Moreover, they showed that nitrogen release from sediment could be suppressed at high temperatures, indicating that denitrifying factors are thermotolerant. This study contributed to the literature regarding the response of nitrogen accumulation in sediment to climate change. The anthropogenic production of reactive nitrogen has increased tenfold over the past century, correlating with population growth and its potential to impact aquatic ecosystems. The impact of anthropogenic nitrogen on ecosystems and biogeochemical cycles has become the second most serious environmental problem globally. Concurrently, it is predicted that climate change will be a significant driver of species extinction and biodiversity loss in the coming century, with species with low thermotolerance being the most likely groups affected by global warming. Studies indicate that sediment denitrification in most aquatic ecosystems is temperature-dependent. In a study by Tan *et al.* (2020) conducted on sediment samples collected from various shallow water systems in the subtropical region of southern China, the effects of temperature on nitrogen release from sediment were investigated, with seasonal comparisons made between six stations during summer and winter. It was reported that N_2O production, a byproduct of denitrification, increased in both seasons. An optimal temperature range of 16-24°C was deemed acceptable for nitrogen release in sediment, while temperatures of 30-37°C were considered critical (Batty *et al.*, 2017).

Yao *et al.* (2018) conducted a seasonal and spatial investigation of potential nitrification, denitrification, and N_2O production rates in sediment cages for fish farming in Honghu Lake. They used five functional gene markers to assess microbial abundance during the nitrification and denitrification processes in sediment. Results indicated that sediment without vegetation supported denitrification rates, while the presence of floating aquatic plants had no significant effect on denitrification and N_2O production. The highest nitrification was observed in September, and the highest denitrification in December. The results suggested that vegetation restoration in eutrophic lakes improved water quality but did not have a positive effect on nitrogen removal efficiency or microbial presence in sediment. This research highlighted the need for lake management practices to focus on preventing external nutrient inputs to reduce nitrogen levels in eutrophic lakes.

3. External and Internal Nitrogen Sources in Lake Ecosystems

Excessive nitrogen flux can easily pass into sediment and accumulate, converting sediment into a potential nitrogen source. Accumulation of nitrogen in sediment, exacerbated by activities such as livestock and poultry farming discharges, can negatively affect benthic species distribution and also lead to year-round eutrophication if external nutrient input is controlled. In a study, average NH_4 and TN concentrations in water were found to be 0.36 mg/l and 2.22 mg/l, respectively. The total nitrogen concentration was higher compared to lakes in eastern China and was categorized as "poor level" according to Chinese Water Quality Standards. Considering TN concentrations in sediment samples from the lake, they could be classified as belonging to the "moderately polluted" class according to the U.S. Environmental Protection Agency standards. Levels of NH_3-N and NH_4-N in sediment pore water negatively affected benthic biodiversity in most sampling areas. Therefore, focusing on the effects of nitrogen on benthic species is crucial. Data on nitrogen forms in lake water and sediment concentrations provide a basis for future studies aimed at controlling lake water quality. It has been suggested that efforts should focus on implementing lake restoration measures to remove nitrogen from the environment or prevent NH_4±N release from sediment.

In China, over 90% of lakes are eutrophic due to high levels of nitrogen and phosphorus content (Yang *et al.*, 2013). High nitrogen concentrations in lakes can lead to eutrophication, resulting in hypoxic or anoxic conditions due to the decomposition of phytoplankton and algae (Bhatnagar and Sillanpää, 2011; Liu *et al.*, 2012; Davis *et al.*, 2015). Elevated nitrogen levels in water can easily be transferred to sediment under suitable conditions, becoming a potential nitrogen source as it accumulates in the sediment (Wu *et al.*, 2001; Ni and Wang, 2015). Sediment plays significant roles in physicochemical and biological processes involved in the nitrogen cycle (Li *et al.*, 2012). The release of nitrogen from sediment to water also affects nitrogen concentration in water, and if external nutrient loading is controlled, it can lead to year-round eutrophication of the lake (Xie *et al.*, 2003; Jin *et al.*, 2006). Among nutrient salts, nitrogen is the main pollutant in sediment in Baiyangdian Lake (Shu *et al.*, 2010). Nitrogen in sediment and water is mainly incorporated into the system as ammonium NH_4±N released from sediment to overlying water through diffusion, resuspension of sediment, and bioaccumulation by plants (Hu *et al.*, 2001). The diffusion of dissolved NH_4±N into the water at the sediment-water interface is an important pathway for the release of internally derived nitrogen, and as the potential for NH_4±N release increases, the risk of water eutrophication also increases accordingly.

Low ammonium nitrogen concentrations indicate nitrogen balance in the nitrogen cycle, where microbial committees, including nitrification, denitrification, and anaerobic oxidation of ammonia, are stable.

- ***Case studies***

The input of nitrogen into Lake Victoria through biological nitrogen fixation has been studied, characterizing the lake basin climate into two different seasons: a dry period from June to September and two wet periods from October to February (lightly rainy) and March to May (heavy rainy). Lake Victoria, the second-largest freshwater lake globally, is heavily impacted by anthropogenic activities and intensifies among countries surrounding its coastal waters. The source of nutrients in sediment and the importance of nitrogen fixation were investigated by Shayo and Limbu (2018). Sediment samples were collected by scuba diving from three bays of the lake (Magu, Mwanza, Kayenze bays), and nitrogen fixation rates were measured using the acetylene reduction technique. Lake Victoria is highly affected by urban/industrial waste discharges, surface runoff, and agricultural activities conducted in the coastal areas and nearby catchment areas. Wastewaters from urban areas and industries are often discharged into the environment without treatment, thus acting as primary nutrient sources and leading to eutrophication in surface waters of the lake (Nyenje *et al.*, 2010). This study suggested that anthropogenic activities could be significant sources of nutrient enrichment in sediment and surface waters.

Three different depths of water samples were taken at depths of 0.5 m, 5 m, and 10 m to determine the vertial distributions of nitrogen releases. The study revealed significant differences in NO_3 flux concentrations between three different regions at the sediment-water interface. In Kayenze Bay, where anthropogenic input is high, the NO_3 ratio is high ($p<0.001$). While differences among the three sampling regions were significantly detected in terms of NH_4±N release, total nitrogen concentrations also showed significant differences in all three regions. The differences observed in the concentrations of NO_3, NH_4, and TN released from sediment among the regions indicated the lake's susceptibility to anthropogenic activities. It was noted that sediments in Mwanza and Magu bays, heavily impacted by human activities, are rich in nutrients, while Kayenze Bay, which is away from human activities, remains relatively unaffected compared to the other two sampling areas. It was reported that agriculture and livestock activities were the main sources of nitrogen contribution to the lake, accounting for 69% to 85% of the primary nitrogen release. The results of this study support the notion that internal nutrient loads in lakes may have a significant impact on nutrient levels in lakes experiencing high external nutrient loads (Shayo and Limbu 2018).

In a study by Zhang *et al.* (2015), spatio-temporal distribution was investigated and results demonstrated that urbanization around the lake resulting in high nutrient input. The overall low nitrate concentration in the lake was attributed to microbial denitrification. In this study, seasonal changes remarkably in nitrogen and changes in nitrate were noted, but no significant seasonal changes were observed in either. Seasonal changes in the sediment-water interface in Chaohu Lake were linked to mineralization processes.

Ezzati *et al.* (2020) reported that phosphorus input from agricultural activities triggers eutrophication in water sources. In light of this information, in Ireland, the main objective within the framework of the Nitrate Directive is to regulate the use of phosphorus fertilizers on farms in terms of exposure to nutrient loads in aquatic systems and sediment losses. The parameter EPC^0 is often used in freshwater systems to determine the sediment's ability to absorb/desorb phosphorus. These measurements are conducted to determine whether sediment samples are a source or a sink of phosphorus. If the measured EPC^0 in the sediment is higher than the DRP (dissolved reactive phosphorus) value in the water, phosphorus release can occur to establish equilibrium in terms of concentration. Conversely, if the sediment's EPC^0 value is lower than the DRP value in the water, phosphorus adsorption from water to sediment is triggered to maintain the concentration level in the solution.

4. Effective Bio-factors in Nitrogen Cycle Influencing Euthrophication

Aquatic macrophytes play a crucial role in regulating the eutrophication status of lakes and rivers. Many plants utilize nitrogen and phosphorus in water for growth and nutrition. Nutrient elements reach these aquatic systems either internally (via release from sediment-water interface) or externally (due to agricultural and urban activities). There are three main mechanisms through which nitrogen affects underwater plants such as macrophytes in aquatic systems:

i- By promoting growth and shading phytoplankton,

ii- Shading periphyton,

iii- Applying toxic stress through oxidative stress in plant metabolism, inhibiting photosynthesis, leading to growth suppression and resulting in chlorosis in leaves.

Nitrogen release from anoxic sediment to the water column was investigated through microcosm experiments. Mesocosm experiments and field studies in shallow lakes in Denmark have shown that when the total nitrogen concentration exceeds 1.2-2 mg/l, the risk of overall loss of submerged macrophytes significantly increases (Sagrario *et al.*, 2005). It was noted in the study that the total phosphorus concentration exceeded 0.1-0.2 mg/l.

In shallow and eutrophic lakes, the formation of eutrophication and the proliferation of cyanobacteria pose a significant threat to the ecological health and sustainable ecosystem development of many lakes worldwide, irrespective of geography (Bunting *et al.*, 2007; Yamamoto, 2011; Stone, 2011; O'Neil *et al.*, 2012; Cozar *et al.*, 2012; Higgins *et al.*, 2017; Matisoff *et al.*, 2017; Payton *et al.*, 2017; Wu *et al.*, 2019). Sediment biogeochemistry constitutes a major component of the elemental cycling; in shallow systems like these, around 30% of the organically produced matter through photosynthesis accumulates in sediment and is subsequently released back into the water. Oxygen consumption in the circulation of organic matter leads to either the source or trap of nutrient elements in the water column. Some of the organic matter is re-mineralized via denitrification, facilitating the formation of biologically unused nitrogen gas. Denitrification in coastal waters is crucial for nitrogen removal. Under low oxygen conditions, nitrification-denitrification in sediment is inhibited, and re-mineralized nitrogen transitions to NH_4 form, readily available for primary producers' use, thus exacerbating eutrophication (Laurent *et al.*, 2016).

During seasons of algal blooms, dissolved inorganic nitrogen decreases, limiting nitrogen utilization in the water. Experimental studies have shown that algal blooms can be significantly reduced, and nitrogen deficiency may vary across different layers, affecting key mechanisms. While assimilation serves as a way to reduce nitrogen in the upper layers of the water, denitrification plays a significant role at the sediment-water interface and in surface sediment. Stable nitrogen isotope experiments have demonstrated that nitrate reduction at the sediment-water interface is hindered by the Microcystis population density, while denitrification rates are triggered by the formation of dark and oxygen-deprived conditions during Microcystis blooms. Nitrogen dynamics in eutrophic lakes vary seasonally, with nitrogen limitation typically occurring in summer and autumn. The results of this study demonstrated that ideal conditions for denitrification occur at the sediment-water interface and in surface sediment during algal bloom periods, facilitating nitrogen reduction (Shen *et al.*, 2020).

- ***Case studies***

Enrich *et al.* (2016) emphasize the significant role of aerobic organic matter mineralization regulation concerning oxygen consumption and substrate availability in controlling nitrogen dynamics in coastal tropical ecosystems. The presence of microbial activity in sediment contributes to the regulation of oxygen consumption and nitrogen concentration due to organic matter assimilation, impacting nitrogen transformation rates. The study suggests that nitrogen is a limiting factor in the examined field samples, with NO_3 concentration being the regulatory primary factor.

Mu *et al.* (2007) investigated nitrogen, phosphorus, and silicon exchange at the sediment-water interface in Bohai Bay, Tianjin coast. The concentration of dissolved oxygen in the sediment-water interface reflects the redox potential, affecting the transition of ammonium, nitrate, and nitrite nitrogen. Nitrification occurs easily under oxygenated conditions, leading to an increase in nitrate nitrogen concentration in sediment and subsequent release from sediment to overlying water. Under anoxic conditions, denitrification occurs while restricting nitrification, resulting in a decrease in nitrate nitrogen and an increase in NO and N_2 molecules. Redox conditions in coastal sediments affect the adsorption of ammonium nitrogen, with increased desorption and ammonium nitrogen release under anoxic conditions.

In New Zealand, seasonal variations in sediment release rates of SRP and ammonium were studied in Rotorua Lake, a large shallow polymictic lake with benthic ring incubation. The high amount of ammonium release during the summer period was found to be associated with the high organic matter content of the sediment. While the high nutrient element release in this lake has been attributed to high external nutrient loading for many years, the high level of organic matter in the sediment and the anoxic nature of the sediment have also been found to be effective factors. It is thought that the significant reduction in external nutrient loading could provide a breakthrough in the nutrient accumulation cycle (Burger *et al.*, 2007).

5. Concluding remarks

Nitrogen dynamics at the sediment-water interface are complex and have significant implications for lake ecosystems. In the context of eutrophication studies in stagnant aquatic systems, both the importance of sediment and its role on nutrient dynamics at the sediment-water interface is a key actor in eutrophication scenario.

In wetlands, the sedimentation and resuspension of N types determine the direction of nitrogen dynamics. While the accumulation of organic nitrogen in the sediment reduces the availability of nitrogen for aquatic organisms, the release of nitrogen from biomass through decomposition provides nutrients reusable. Sediments can serve as both a sink and a source of ammonium. Sediments can release nutrients into the overlying water, contributing to eutrophication and impacting water quality. The release of ammonium in aquatic environments is governed by various factors such as sediment type, organic matter oxidation, temperature, and dissolved oxygen concentration.

Nitrogen dynamics change seasonally, with nitrogen limitation typically occurring in wet/anoxic and dry/oxic periods in eutrophic lakes. The components of the nitrogen cycle, nitrification, and denitrification events are temperature-dependent, and during periods of high temperature, the denitrification of nitrate to gaseous forms of nitrogen (N_2 and N_2O) and ammonium leads to a decrease in nitrate levels in sediment pore water. The nitrogen mobility has a direct interaction with the lake mobility in case of static condition, the ammonia nitrogen release was mainly through molecular diffusion where as in disturbance conditions, the change in hydrodynamics had more influence on ammonia nitrogen release. This issue can be analysed as the stronger disturbance leads to greater amount of release.

The internal and external factors such as climate change, land use change, and water pollution and the integrity of the sediment can alter the functioning of the sedimentary nitrogen cycle. Coping with the challenges of various pollution inputs by sustainable applications and effective management strategies, conservation of lake ecosystems could be enabled.

REFERENCES

Battye, W., Aneja, V. P. & Schlesinger, W. H. 2017. Is nitrogen the next carbon?. Earth's Future 5, 894-904.

Bhatnagar, A. and Sillanpaa M. A. 2011. Review of emerging adsorbents for nitrate removal from water. Chemical Engineering Journal, 168, 493-504.

Bruesewitz, D. A., Tank, J. L., Hamilton, S. K. 2012. Incorporating spatial variation of nitrification and denitrification rates into whole-lake nitrogen Dynamics. J. Geophys. Res. Biogeosci. 117, G00N07.

Bunting, L., Leavitt, P.R., Gibson, C.E., Mcgee, E.J., Hall, V.A. 2007. Degradation of water quality in lough neagh, Northern Ireland, by diffuse nitrogen flux from a phosphorus-rich catchment. Limnol. Oceanogr. 52 (1), 354–369.

Burger D. F., Hamilton, D. P., Pilditch, C. A., Gibbs, M. M. 2007. Benthic nutrient fluxes in a eutrophic, polymictic lake. Hydrobiologia (2007) 584:13–25 DOI 10.1007/s10750-007-0582-0.

Carpenter, S.R., 2003. Regime shifts in Lake Ecosystems: pattern and variation excellence in Ecology Series, vol. 15, Ecology Institute, Oldendorf/Luhe, Germany, p. 199.

Cózar, A., Bruno, M., Bergamino, N., Úbeda, B., Bracchini, L., Dattilo, A.M., Loiselle, S.A. 2012. Basin-scale control on the phytoplankton biomass in Lake Victoria, Africa. PLoS One 7 (1), e29962. https://doi.org/10.1371/journal.pone.0029962.

Davis, T.W., Bullerjahn, G.S., Tuttle, T., Mckay, R.M., Watson, S.B. 2015. Effects of increasing nitrogen and phosphorus concentrations on phytoplankton community growth and toxicity during *Planktothrix* blooms in Sandusky Bay, Lake Erie. Environmental Science & Technology, Vol:49, pages: 7197-7207.

Delince, G. 1992. The Ecology of the fish pond ecosystem. Kluwer Aademic Publishers, Netherlves, Pp: 230.

Enrich-Prast, A., Figueiredo, V., Assis Esteves, F., Nielsen, P. L. 2016. Controls of sediment nitrogen dynamics in tropical coastal lagoons. Plos One, 11Ezzati, G., Fenton, O., Healy, M.G., Christianson, L., Feyereisen, G.W., Thornton, S., Chen, Q., Fan, B., Ding, J., Daly, K. 2020. Impact of P inputs on source-sink P dynamics of sediment along an agricultural ditch network. Journal of Environmental Management, 257;109988.

Farshay, K. J., Dodson, S. I. 2011. Macrophyte presence is an indicator of enhanced denitrification and nitrification in sediments of temperate restored agricultural stream. Hydrobiologia, 668, 21-34.

Gardner, W. S. & McCarthy, M. J. 2009. Nitrogen dynamics at the sediment-water interface in shallow, sub-tropical Florida Bay: why denitrification efficiency may decrease with increased eutrophication. Biogeochemistry 95, 185-198.

Gardner, W. S., McCarthy, M. J., An, S., Sobolev, D., Sell, K. S. & Brock, D. (2006). Nitrogen fixation and dissimilatory nitrate reduction to ammonium (DNRA) support nitrogen Dynamics in Texas estuariaes. Limnol. Oceanogr. 51, 558-568.

Hakanson, L. and Jansson, M. 2002. Principles of lake sedimentology. The Blackburn Pres. New Jersey, USA, Pp: 316.

Hale, S. S. 1975. The role of benthic communities in the nitrogen and phoshorus cycles of an estuary. Recent Adv. Estuar. Res. 1, 291-308.

Higgins, S.N., Paterson, M.J., Hecky, R.E., Schindler, D.W., Venkiteswaran, J.J., Findlay, D.L. 2017. Biological nitrogen fixation prevents the response of a eutrophic lake to reduced loading of nitrogen: evidence from a 46-year wholelake experiment. Ecosystems, 1–13 https://doi.org/10.1007/s10021-017-0204-2.

Hou, D., He, J., Lü, C., Sun, Y., Zhang, F. and Otgonbayar, K. 2013. Effects of Environmental Factors on Nutrients Release at Sediment-Water Interface and Assessment of Trophic Status for a Typical Shallow Lake, Northwest China. The Scientific World Journal, Volume:2013, ID716342, 16 pages.

Hu, W., Lo, W., Chua, H., Sin, S., Yu, P. 2001. Nutrient release and sediment oxygen demand in a eutrophic land-locked embayment in Hong Kong. Environmental International, 26, 369–375.

Jeppensen, E., Sondergaord, M., Christoffersen, K. 1998. The stucturing role of submersed macrophytes in lakes. Ecological Studies, 689-714.

Jin, X., Wang, S., Pang, Y., Wu, F.C., 2006. Phosphorus fractions and the effect of pH on the phosphorus release of the sediments from different trophic areas in Taihu Lake, China. Environtal Pollution, 139, 288–295.

Kelsey L. B. 2015. Analysis of nitrogen and phodphorus nutrients in lake sediment. Senior Honors Projects, 2010-2015.

Körner, S. 2002. Loss of submerged macrophytes in shallow lakes in north-eastern Germany. International Review of Hydrobiology, 87 (4), pp. 375-384.

Laurent, A., Fennel, K., Wilson, R., Lehrter, J., Devereux, R. 2016. Parameterization of biogeochemical sediment-water fluxes using in situ measurements and a diagenetic model. Biogeoscinces, 13, 77-94.

Lee, H. W., Lee, Y. S., Kim, J., Lim, K. J. and Choi, J. H. 2019. Contribution of internal nutrients loading on the water quality of a reservoir. Water, 11, 1409; doi:10.3390/w11071409.

Li, H., Wang, Y., Shi, L., Mi, J., Song, D., Pan, X. 2012. Distribution and Fractions of Phosphorus and Nitrogen in Surface Sediments from Dianchi Lake, China. International Journal of Environmetal Research 6(1):195-208.

Liu, C. C., Kroeze, A.Y., Hoekstra, W. 2012. Gerbens-LeenesPast and future trends in grey water footprints of anthropogenic nitrogen and phosphorus inputs to major world rivers. Ecological Indicators, 18, pp. 42-49.

Liu, J., Cao, L., Dou, S. 2019. Trophic transfer, biomagnification and risk assessments of four common heavy metals in the food web of Laizhau Bay, the Bohai Sea. Science of The Total environment. Volume 670, pages: 508-522.

Maslukah, L., Wulandari, Y. S., Prasetyawan, I. B., Zainuri, M. 2018. Distributions and fluxes of nitrogen and phosphorus nutrients in porewater sediments in the Estuary of Jepara Indonesia. Journal of Ecological Engineering, Volume 20, Issue 2, February.

Matisoff, G., Watson, S.B., Guo, J., Duewiger, A., Steely, R. 2017. Sediment and nutrient distribution and resuspension in Lake Winnipeg. Science Total Environmental, 575, 173–186.

Moss, B. 2001. The Broads: The People's Wetland. The New Naturalist, Harper Collins Publishers, London.

Moss, B., Jeppesen, E., Søndergaard, M., Lauridsen, T.L., Liu, Z. 2013. Nitrogen, macrophytes, shallow lakes and nutrient limitation: Resolution of a current controversy?. Hydrobiologia, 7-10 (1), pp. 3-21.

Mu, D., Yuan, D., Feng, H., Xing, F., Teo, F. Y., Li, S. 2007. Nutrient fluxes across sediment-water interface in Bohai Bay Coastal Zone, China. Marine Pollution Bulletin 114:705-714.

Müller, B., Thoma, R., Baumann, K. B. L., Callbeck, C. M., Schubert, C. J. 2021. Nitrogen removal processes in lakes of diferent trophic states from on-site measurements and historic data. Aquatic Sciences, 83:37.

Ni, Z., Wang, S. 2015 Historical accumulation and environmental risk of nitrogen and phosphorus in sediments of Erhai Lake, Southwest China. Ecological Engineering, Volume: 79, pages: 42-53.

Nyenje, P. M., Foppen, J. W., Uhlenbrook, S., Kulabako, R. & Muwanga, A. 2010. Eutrophication and nutrient release in urban areas of sub-Saharan Africa- A review. Sci. Total Environ. 408, 447-455.

O'Neil, J.M., Davis, T.W., Burford,M.A., Gobler, C.J. 2012. The rise of harmful cyanobacteria blooms: the potential roles of eutrophication and climate change. Harmful Algae 14, 313–334.

Payton, A., Roberts, K.,Watson, S., Peek, S., Chuang, P.C., Defforey, D., Kendall, C. 2017. Internal loading of phosphate in Lake Erie Central Basin. Sci. Total Environ. 579, 1356–1365.

Sagrario, G. M., Jeppesen, M. A. E., Gomà, J.M., Søndergaard, M., Jensen, J.P., Lauridsen, T., Landkildehus, F. 2005. Does high nitrogen loading prevent clear-water conditions in shallow lakes at moderately high phosphorus concentrations?. Freshwater Biology, 50 (1) pp. 27-41.

Sand-Jensen, K., Pedersen, N. L., Thorsgaard, I., Moeslund, B., Borum, J., Brodersen, K. P. 2008. 100 years of vegetation decline and recovery in Lake Fure, Denmark. Journal of Ecology, 96 (2), pp. 260-271.

Scheffer, M. 1998. Ecology of Shallow Lakes. Kluwer Academic Publishers, Dordrecht.

Shayo, S., Limbu, M. S. 2018. Nutrient release from the sediments and biological nitrogen fixation; advancing sources of eutrophication in Lake Victoria, Tanzania. Lakes & Reservoirs Research & Management. 23 (4) 2-20.

Shen, Y., Huang, Y., Hu, J., Li, P., Zhang, C., Li, L., Xu, P. 2020. The nitrogen reduction in eutrophic water column driven bu Microcystis Bloom. Journal of Hazardous Materials. 385:121578.

Shu, L., Yangle, J. X. 2010. In Effect of the pH value on the nitrogen and phosphorus release from the sediment Baiyangdian J. Anhui Agric. Sci., 38, pp. 20859-20862.

Stone, R. 2011. China aims to turn tide against toxic lake pollution. Science 333, 1210–1211.

Szogi, A. A., Hunt, P. G. and Humenik, F. J. 2003. Nitrogen distribution in soils of constructed wetlands treating Lagoon Wastewater. Soil Science Society America Journal, 67: 1943-1951.

Tan, E., Zou, W., Zheng, Z., Yan, X., Du, M., Hsu, T., Tian, L., Middelburg, J. J., Trull, W. T. and Kao, S. 2020. Warming stimulates sediment denitrification at the expense of anaerobic ammonium oxidation. Natura Climate Excgange, Vol:10, page: 349-355.

Wang, H. J., Wang, H. Z., Liang, X.M., Wu, S. K. 2014. Total phosphorus thresholds for regime shifts are nearly equal in subtropical and temperate shallow lakes with moderate depths and areas. Freshw. Biol., 59 (12), pp. 1659-1671.

Wu, F., Qing, H., Wan, G. 2001. Regeneration of N, P and Si, N. near the sediment/water interface of lakes from Southwestern China Plateau. Water Research, volume: 35, pp: 1334-1337.

Wu, T., Qui, B., Brookes, J. D., Yan, W., Ji, X., Feng, J. 2019. Spatial distribution of sediment nitrogen and phosphorus in Lake Taihu from a hydrodynamics-induced transpart perspective. Science of the Total Environment, 650, 1554-1564.

Xie, L., Xie, P., Tang, H., 2003. Enhancement of dissolved phosphorus release from sediment to lake water by Microcystis blooms — an enclosure experiment in a hyper-eutrophic, subtropical Chinese lake. Environental Pollution, 122, 391–399.

Yamamoto, Y. 2011. Indirect impact of bluegill Lepomismacrochirus on the development of cyanobacterial blooms in Lake Biwa, Japan. J. Freshw. Ecol. 26, 323–335.

Yang, L., Lei, K., Meng, W., Fu, G., Yan, W. 2013. Temporal and spatial changes in nutrients and chlorophyll-α in a shallow lake, Lake Chaohu, China: an 11-year investigation. Journal Environmental Science, 25, pp:1117-1123.

Yao, L., Chen, C., Liu, G., Liu, W. 2018. Sediment nitrogen cycling ratesand microbial abudance along a submerged vegetation gradient in a eutrophic lake. Science of the Total Environment, 616-617, 899-997.

Zhang, M., Xu, J., Xie, P. 2008. Nitrogen Dynamics in large shallow eutrophic Lake Chaohu, China. Environtal Geology, Volume 55, pages:1-8.

Zhang, Z., Gao, J.,Gao, Y. 2015. The influences of land use changes on the value of ecosystem services in Chaohu Lake Basin, China. Environmental Earth Sciences. Volume: 74, pages 385-395.

Zhong, J., Wen, S., Zhang, Lu., Wang, J., Liu, C., Yu, J., Zhang, Lei, Fan, C. 2021. Nitrogen budget at sediment–water interface altered by sediment dredging and settling particles: Benefits and drawbacks in managing eutrophication. Journal of Hazardous Materials, Volume: 406, 124491.

Zhu, Y., Jin, X., Tang, W., Meng, X., Shan, B. 2019. Comprehensive analysis of nitrogen distributions and ammonia nitrogen release fluxes in the sediments of Baiyangdian Lake, China. Journal of Environmental Sciences, Volume: 76, pages: 319-328.

Chapter 2

VARIATIONS OF MERISTIC TRAITS IN REGARDING TO LENGTH-WEIGHT RELATIONSHIP FOR *Cyprinion macrostomus* (HECKEL, 1843) AND *Alburnus mossulensis* (HECKEL, 1843) IN THE MIDDLE EUPHRATES BASIN (ADIYAMAN, TÜRKIYE)

Cemil KARA[1]

Mehmet Fatih CAN[2]

1 Prof. Dr. Cemil KARA, Karadeniz Technical University,
Faculty of Science, Department of Biology, Trabzon, Türkiye
ORCID: 0000-0002-2593-9140
2 Prof. Dr. Mehmet Fatih CAN, İskenderunTechnical University,
Faculty of Marine Science and Technology, Hatay, Türkiye
ORCID: 0000-0002-3866-2419

1. Introduction

Findings regarding the length-weight relationship are very important in terms of fish biology and fisheries management. The length-weight relationship parameters (a and b) allow the weight of the fish to be estimated from its length, the condition index to be calculated, and the morphology and life processes of populations in different habitats to be compared (İlhan and İlhan, 2018; Saylar et al., 2020). Determining the morphometric and meristic characteristics of fish in different water systems within the scope of their biological characteristics is important for ichthyofauna. In order to reveal the ichthyofauna in a wetland, the biological characteristics of all fish species must be known and periodic monitoring studies must be carried out. Determining the morphometric and meristic characteristics and the length-weight relationships within the scope of their biological characteristics will be important for ichthyofauna in different water systems. These measurements also form the basis for explaining the evolutionary relationships and taxonomy of fish (Gül et al., 2017).

The distribution center of the *Cyprinion* genus is the southern regions of western Asia. Some species are reported to be in Syria, Arabia, Mesopotamia, Iran, the desert regions of India, Pakistan and Afghanistan (Kuru, 1975; Dağlı, 2013). There are two species of the *Cyprinion* genus in the inland waters of Türkiye, *Cyprinion macrostomum* and *Cyprinion kais* (Geldiay and Balık, 2009; Çiçek et al., 2015). *C. macrostomum* is a natural and endemic species of the Tigris-Euphrates basins and is distributed up to the upper Euphrates basin (Banarescu and Strachil, 1995; Coad, 1996; Geldiay and Balık, 2009). It is stated that *C. macrostomum* individuals in Topardıç Creek and Kangal fish hot spring (Sivas) pools have adapted up to 35 celsius (Metin and Akpınar, 2000; Daştan et al., 2012; Duman and Şahan, 2014). According to Fricke et al. (2007), the conservation status of *C. macrostomum* in Türkiye is in the endangered species group. Yılmaz et al. (2015) revealed some biochemical blood parameters of *C. macrostomum* in Adıyaman region, Kara and Güneş (2015) revealed the distribution and some morphometric characteristics of this species in streams and lakes of Adıyaman region; Uçkun and Gökçe (2015) revealed the growth and reproduction characteristics of *C. macrostomum* and *C. kais* in Karakaya dam lake (Euphrates River). In addition, there are also studies on the genetic diversity (Daştan et al. 2012), reproductive biology (Faghani and Mousavi, 2018), and some morphological features (Dağlı, 2013) of *C. macrostomus* in Türkiye.

The genus *Alburnus* has 39 species in Europe and Asia (Falahatkar et. al., 2015). There are 27 species of the genus *Alburnus* in Türkiye, 18 of which are endemic (Mangıt and Yerli, 2018; Çiçek et al., 2018; Bayçelebi, 2020), and Türkiye is a speciation center for this genus (Özuluğ and Freyhof, 2007). *A. mossulensis* is distributed in the upper branches of the Tigris-Euphrates, Türkiye, Iran and Hormuz Basins (Esmaeili et al. 2010, 2015; Keivany et al. 2016; Kuru, 1979; Bogutskaya, 1997; Coad, 2010). The distribution of *A. mossulensis* in Türkiye is the Eastern and Southeastern Anatolia regions, especially the Tigris and Euphrates river systems (Geliday and Balık, 2007). In the Atatürk Dam Lake, it is a commercially important fish species (Bayhan and Gocer, 2012).

In this chapter, variations of meristic traits in regarding to length-weight relationship for *Cyprinion macrostomus* (Heckel, 1843) and *Alburnus mossulensis* (Heckel, 1843) in the middle Euphrates Basin (Adıyaman, Türkiye) are presented.

2. Material and Methods

2.1. Sampling, sampling area, and fish species:

Fish samples were captured using electroshock from different branches of the Middle Euphrates River (in the Adıyaman region: May 2012- October 2013, Figure 1). Measurements were made on 83 individuals of the *C. macrostomus* species and 24 individuals of the *A. mossulensis* species. The specimen measured in this study were provided from a research project that was supported by the Adıyaman University Scientific Research Projects (BAP) Coordination Unit, Project No. 2012/001, and was carried out with the legal consent of the Ministry of Food, Agriculture, and Livestock, General Directorate of Fisheries and Aquaculture (permission date 05.04.2012; permission number: 01515).

Middle Euphrates River is considered the most important river in Adıyaman province. It is 180 km long within the province and forms a border with Şanlıurfa and Diyarbakır provinces. Kahta, Kalburcu and Göksu are the main tributaries of the Euphrates River. Its length is 45.5 km. Göksu Stream emerges from the Kahramanmaraş province and passes through Erkenek, Tut and Akdere. After receiving the Sofraz water, it flows into the Euphrates River west of Gümüşkaya. Its length within the province is 90 km. Sofraz Stream emerges from the Toklu Village of Besni district and mixes with Göksu Stream near Akdere after taking Keysun Suyu near Hacıhalil Village. Its length within the province is 51 km. Ziyaret Stream originates from the waters of Cebel and Zey Villages and flows into the Atatürk Reservoir near İpekli Village (Kara and Can, 2023).

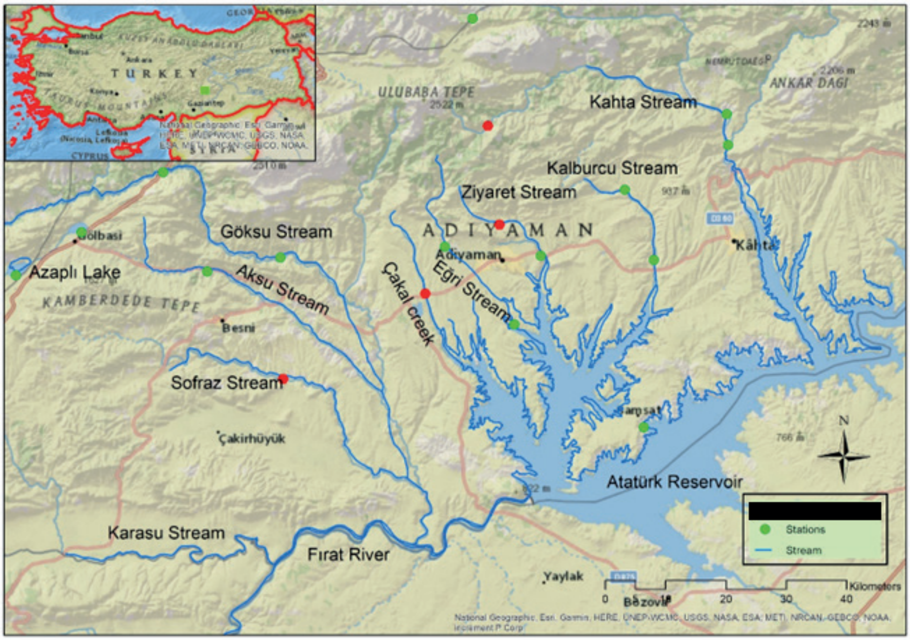

Figure 1. Map of sampling area from a research project that was supported by the Adıyaman University Scientific Research Projects (BAP) Coordination Unit, Project No. 2012/001.

C. macrostomum individuals have high bodies and large scales. The mouth is in a ventral position, the lower and upper lips are thick. There is a pair of very short barbs around the mouth. The posterior edge of the longest bony ray of the dorsal fin is highly serrated. The caudal fin is deeply forked and the tips of the tail lobes are pointed (Figure 2).

Figure 2. C. macrostomum specimen (Total length: 7.13 cm, Ziyaret Stream, Adıyaman).

Alburnus mossulensis is known by locals as the "freshwater silver fish". Its body is long and thin and slightly flattened from the sides. Their length is around 10-12 cm. Their bodies are grayish white. Fins are usually colorless. The mouth is lower positioned and has no whiskers (Figure3). This species is found in both lentic and lotic environments.

Figure 3. A. mossulensis specimen (Total length:8.05 cm, Sofraz Stream, Besni, Adıyaman).

2.2. Measurement and data analysis

Caught fishes were brought to the laboratory in plastic containers containing 4% formaldehyde. Each sample was measured for fork length (±1 mm) and total weight (±1 g). The length-weight equation $W = a\ L^b$ was used to estimate the relationship between the weight (g) and fork length (cm). In the formula, 'a' and "b" represent the intercept and slope of the relationship, respectively. When applying this formula on sampled fish, b may deviate from the "ideal value" of 3 that represents an isometric growth, less than 3, fish become slimmer with increasing length, and growth will be negatively allometric. When b is greater than 3.0, fish become heavier showing a positive allometric growth and reflecting optimum conditions for growth. Confidence intervals were used to verify if b for each fish species is statistically significantly different from the isometric growth (b = 3). The coefficient of determination (R-square) was used to assess the relationship strength between length and weight (Jisr et. al., 2018). Data was analyzed using R version 4.1.0. (R Core Team, 2022) and Jamovi version 2.4 (The Jamovi project, 2023).

3. Results

3.1.Length-Weight Relationship

The b (± se) coefficient in the length-weight relationship is 2.99± 0.06 (confidence limit: 2.87-3.11, R-squared= 0.9635) and 3.24± 0.10 (confidence limit: 3.03-3.45, R squared=0.9426) for *C. macrostomus* and *A. mossulensis* species, respectively (Figure 4, 5). It is seen that the growth is isometric for the *C. macrostomus* species and positive allometric for the *A. mossulensis*.

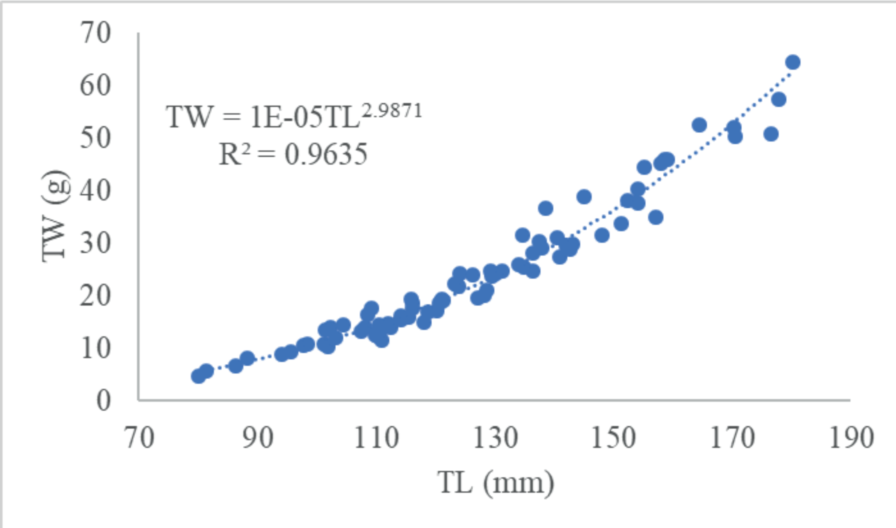

Figure 4. Length-weight relationship for C. macrostomus.

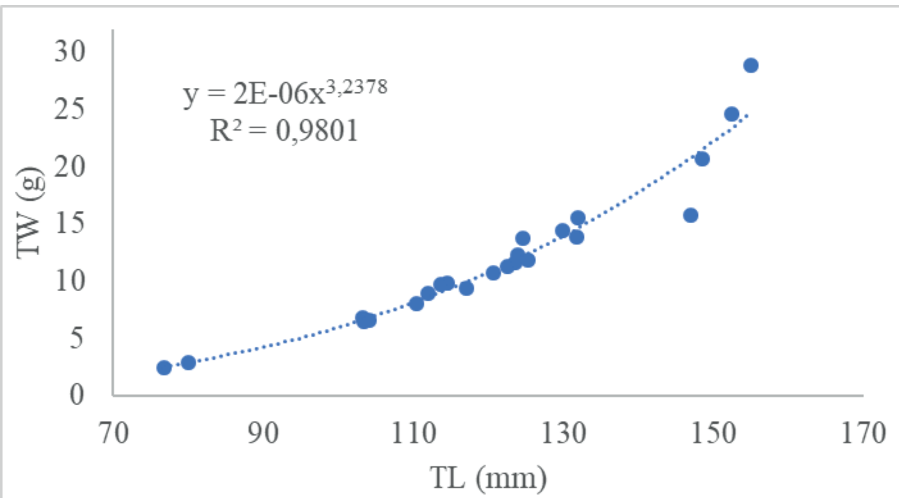

Figure 5. Length-weight relationship for A. mossulensis.

3.2. Metric Variations

3.2.1. Metric Variations for *Alburnus mossulensis*

For this species, inter-individual variations were observed in the number of linea lateral scales, the number of caudal fin spine rays, and the number of anal, ventral and pectoral fin rays. The most variation (13 categories) among individuals of this species was observed in the number of linea lateral scales (between 63-89) and it was determined that the 72-scale category was the most represented category with 22 percent. It was observed that the individual containing 84 scales in the lateral line was the largest individual in terms of length and weight (Table1, Figure 6.

Table 1. Some descriptive statistics of variations in meristic traits of sampled individuals for A. mossulensis and C. macrostomus species.

A. mossulensis				*C. macrostomus*			
Category	N (N%)	TL±sd	TW±sd		N (N%)	TL±sd	TW±sd
Linea letaral				Category		Linea letaral	
63	1 (4%)	80.1±0.00	2.9±0.00	41	23(28%)	123±22.8	22±11.6
65	1 (4%)	76.8±0.00	2.5±0.00	40	12(15%)	125±22.4	23.3±11.3
70	3(13%)	123±25.7	13.7±9.53	39	2(2%)	92.3±8.56	8.65±2.9
72	5 (22%)	130±12.1	13.1±2.39	42	25(30%)	123±17.5	21.1±9.76
73	2 (9%)	122±2.27	11.5±1.13	43	14(17%)	150±22.1	38.5±15.6
74	2 (9%)	104±0.50	6.55±0.07	38	5(6%)	112±12.5	16.5±4.78
75	3(13%)	135±12.7	15.9±4.57	36	1(6%)	114±0.00	16.1±0.00
82	1(4%)	125±0.00	13.8±0.00				
84	1(4%)	155±0.00	28.8±0.00				
85	1(4%)	110±0.00	8.1±0.00	Number of dorsal fin bony rays			
87	1(4%)	123±0.00	11.3±0.00	4	63(77%)	123±21	21.8±10.7
88	1(4%)	117±0.00	9.4±0.00	3	19(23%)	138±26.4	31.2±17.6
89	1(4%)	112±0.00	8.9±0.00				
Number of caudal fin bony rays				Number of dorsal fin soft rays			
5	2(9%)	78.4±2.32	2.7±0.30	15	61(74%)	126±23.9	23.8±13.9
8	21(91%)	125±15.6	12.9±5.79	14	4(5%)	110±22.6	15.7±8.99
				5	14(17%)	131±17.3	26.5±10.3
Number of anal fin soft rays				13	3(4%)	140±24.2	27.5±11.8
10	4(17%)	116±5.46	9.43±1.36				
11	10(43%)	127±15.4	13.8±6.01	Number of anal fin soft rays			
12	9(39%)	116±27	11.1±7.60	7	71(87%)	129±23	25.3±13.50
				8	11(13%)	109±14.2	15.7±5.56
Number of venal fin soft rays							
7	2(9%)	78.4±2.32	2.7±0.30	Number of pectoral fin soft rays			
8	21(91%)	125±15.6	12.9±5.79	12	26(45%)	128±18.4	23.8±10.5
				13	37(32%)	120±22.3	20.5±10.8
Number of pectoral fin bony rays				14	19(23%)	138±26.4	31.2±17.6
13	2(9%)	78.4±2.32	2.7±0.28				
14	2(9%)	140±21.6	21.3±10.6				
15	19(83%)	123±14.7	12±4.72				

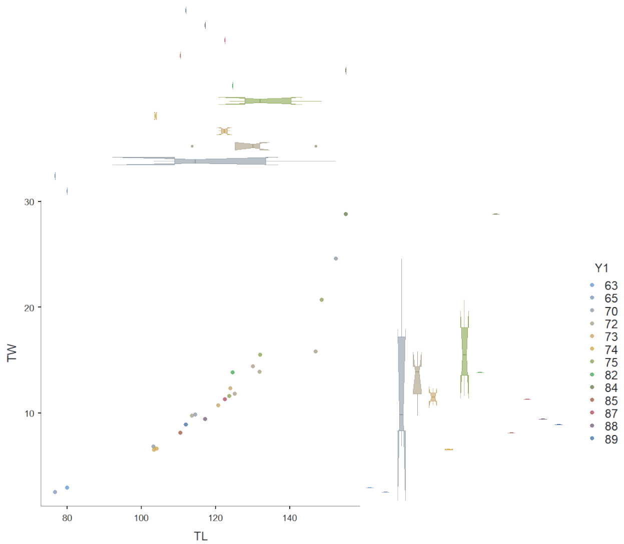

Figure 6. Distribution of A. mossulensis individuals according to their categories in terms of the number of linea lateral scales within the scope of length-weight relationship.

Two categories (5 and 8) were observed in the number of caudal fin spine rays, it was determined that the number of individuals with 8 rays constituted 91 % of the sampled individuals, and individuals with 5 spine rays had lower average values in terms of length and weight (Table1, Figure 7).

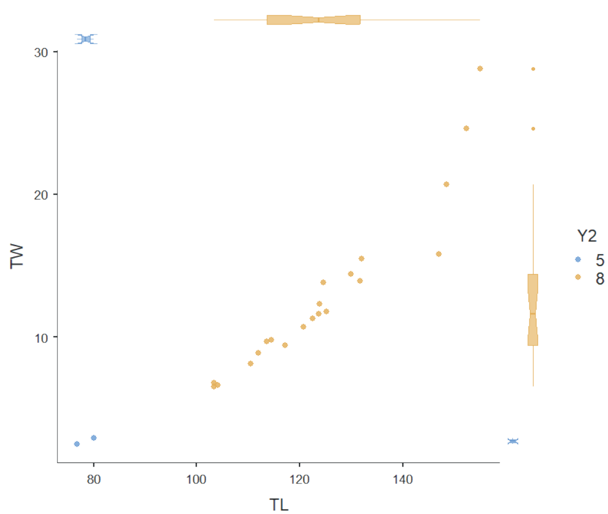

Figure 7. Distribution of A. mossulensis individuals according to their categories in terms of the number of caudal fin spine ray within the scope of length-weight relationship.

A. mossulensis individual were into 3 categories in the number of anal fin soft ray (10, 11 and12), and the average length and weight of individuals with the 11-ray category were higher than that of other categories (Table1, Figure 8).

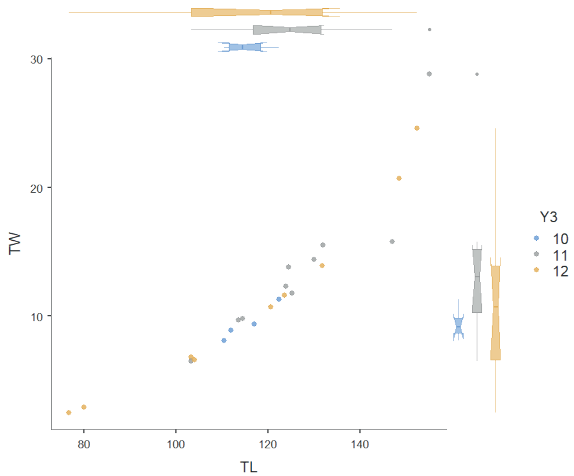

Figure 8. Distribution of A. mossulensis individuals according to their categories in terms of the number of anal fin soft ray within the scope of length-weight relationship.

Two ventral soft ray categories with 7 (9 %) and 8 (91 %) were determined in the sampled individuals, and it was observed that individuals with 8 rays were larger in average length and weight (Table 1, Figure 9).

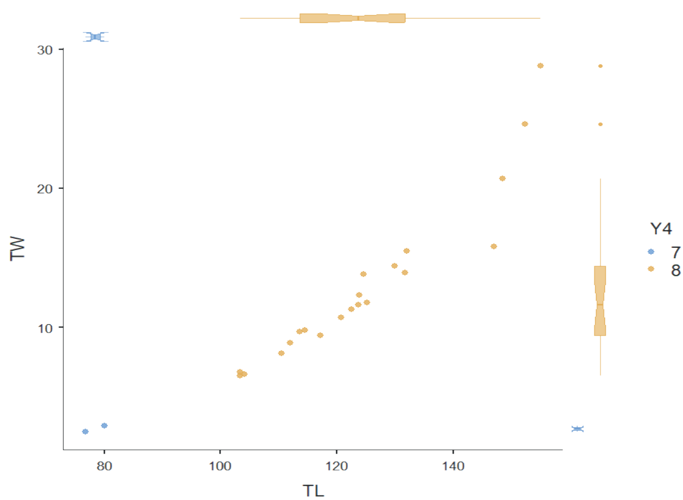

Figure 9. Distribution of A. mossulensis individuals according to their categories in terms of the number of ventral fin soft ray within the scope of length-weight relationship.

Three categories were determined in terms of the number of soft pectoral rays (13, 14 and 15). Individuals with 15 rays constituted 82 percent, and individuals with 14 rays were larger in length and weight (Table 1, Figure 10).

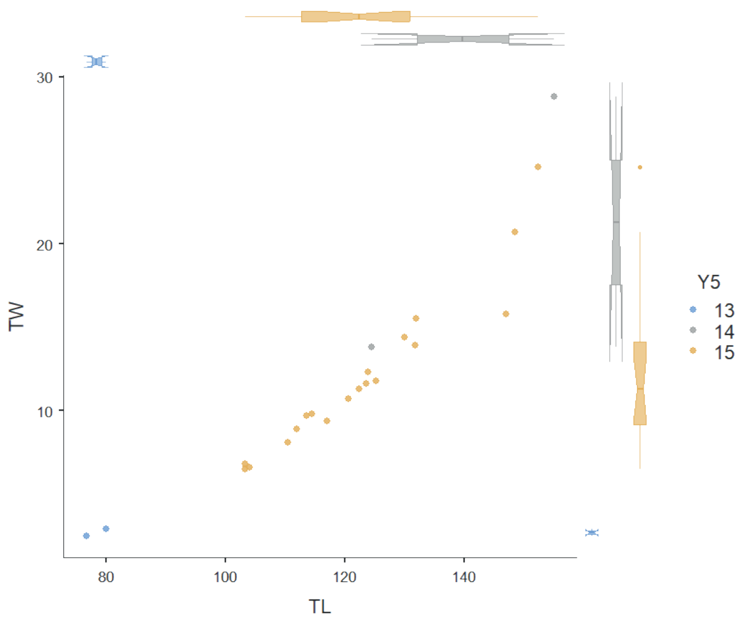

Figure 10. Distribution of A. mossulensis individuals according to their categories in terms of the number of pectoral fin soft rays within the scope of length-weight relationship

3.2.2. Metric Variations for *Cyprinion macrostomus*

For the *C. macrostomus*, variations were observed in the number of linea lateral scales, dorsal fin, spine and soft ray numbers, and anal and pectoral fin soft ray numbers. Eight categories were determined in terms of the number of linea lateral scales of *C. macrostomus* individuals, and the group with 42 scales was represented at the highest percent with 30 %, and the individuals with the highest average length and weight were in the group with 43 scales, and the lowest individuals were in the group with 39 scales (Table 1, Figure11).

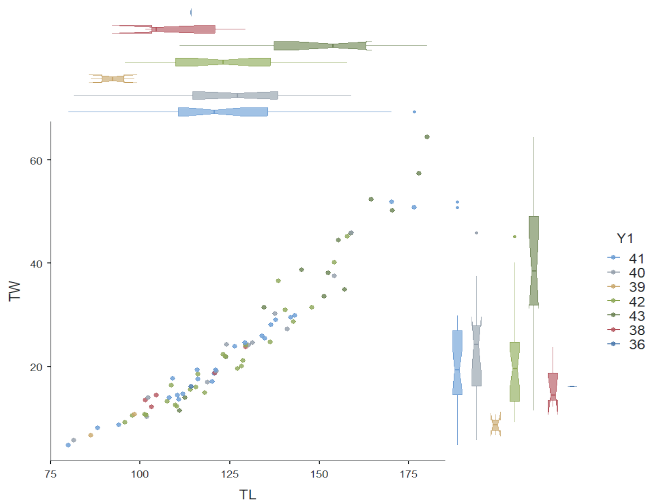

Figure 11. Distribution of C. macrostomus individuals according to their categories in terms of the number of linea lateral scales within the scope of length-weight relationship.

It was determined that the sampled individuals were in 2 categories (3 and 4) in terms of the number of dorsal fin spine rays (individuals with 4 rays were represented by 77 %), and individuals with 3 rays had a higher average value both length and weight (Table 1, Figure 12).

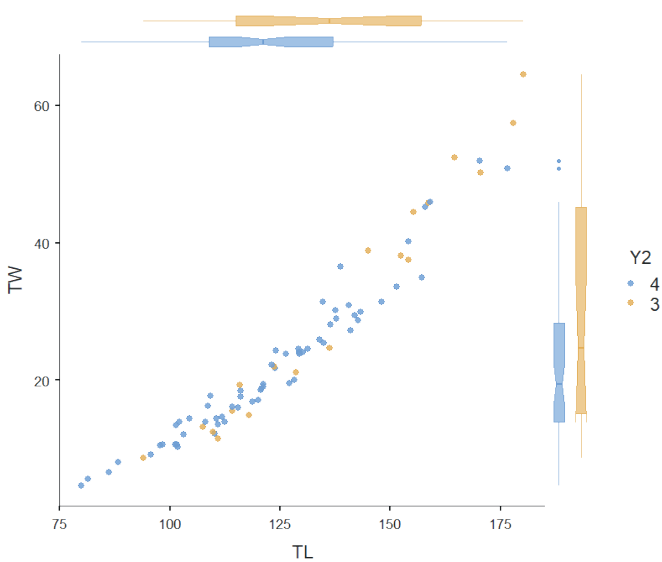

Figure 12. Distribution of C. macrostomus individuals according to their categories in terms of the number of dorsal fin spine rays within the scope of length-weight relationship.

It was determined that there were 4 categories in terms of the number of dorsal fin soft rays (3,13,14,15). Among them the number of individuals with 15 rays was higher (74 %), but individuals with 13 rays were larger in length and weight (Table 1, Figure 13).

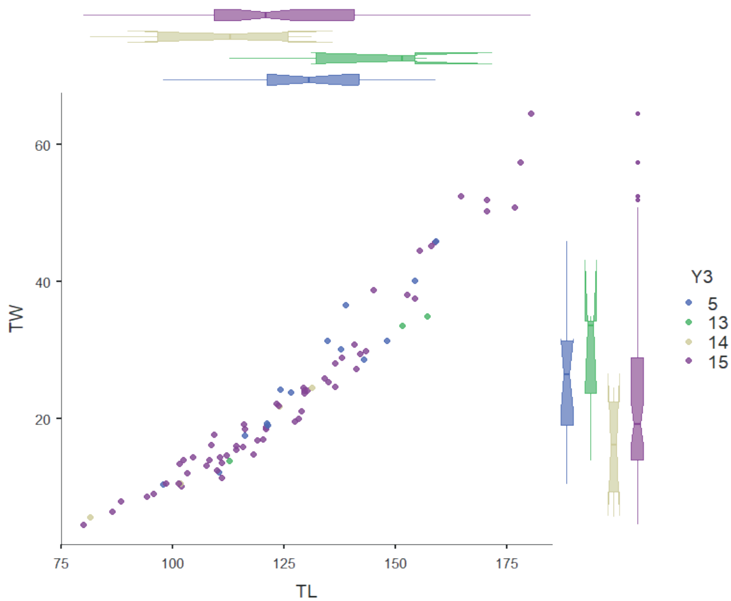

Figure 13. Distribution of C. macrostomus individuals according to their categories in terms of the number of dorsal fin soft rays within the scope of length-weight relationship.

There were two anal fin soft ray number categories (7 with 87 %, and 8 with 13 %), and individuals with 7 rays were found to be larger on average length and weight (Table 1, Figure 14).

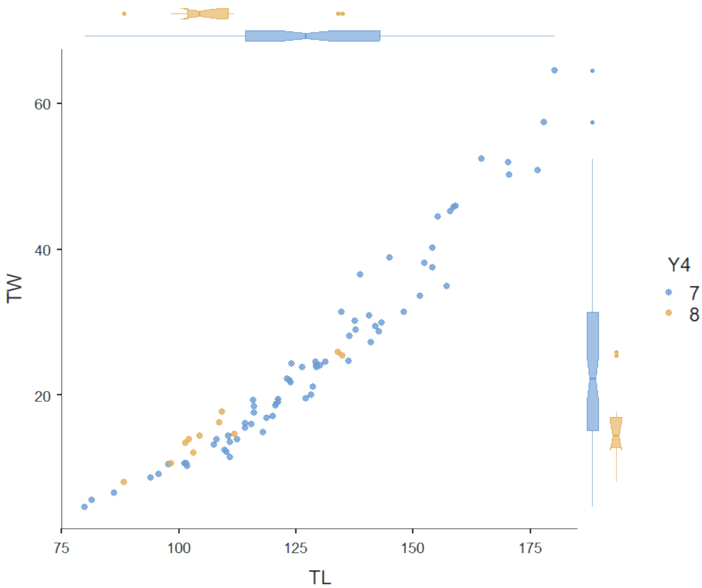

Figure 14. Distribution of C. macrostomus individuals according to their categories in terms of the number of anal fin soft rays within the scope of length-weight relationship.

There are 3 categories (12.,13.,14) in terms of the number of pectoral fin soft rays, and it was determined that individuals with 13 rays were most represented by 45 %, and individuals with 14 rays were larger in terms of average height and weight (Table 1, Figure 15).

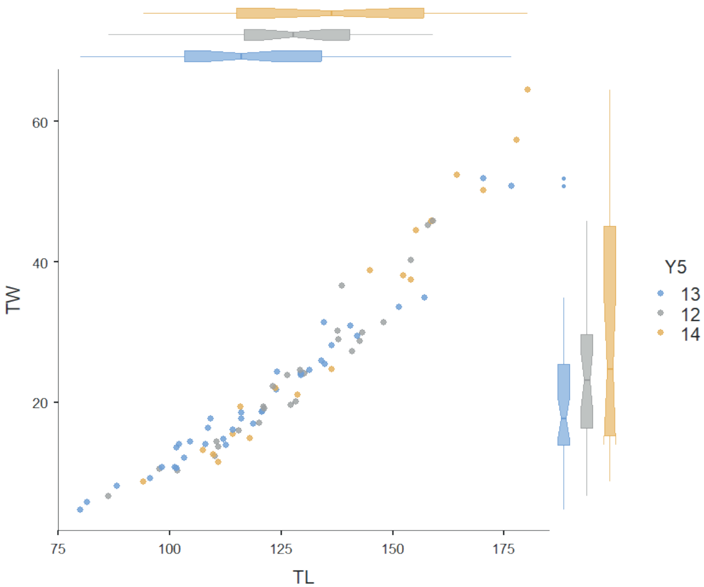

Figure 15. Distribution of A. mossulensis individuals according to their categories in terms of the number of pectoral fin soft rays within the scope of length-weight relationship.

4. Discussion

The b value in the length-weight relationship of fish not only gives information about the environmental conditions, but also gives information about the body shape of the fish. It is stated that in a fish population, if b=3 there is isometric growth, if b>3 there is positive allometric growth, and if b<3 there is negative allometric growth (Avşar, 1998). Growth in fish; it is thought that factors such as physical and chemical properties of water systems, genetic structure of the population, interspecific competition and hunting pressure may be effective. Table 2. shows the findings regarding the length-weight relationship of different researchers for *C. macrostomus* and *A. mossulensis* species.

The b (± se) coefficient in the length-weight relationship was 2.99± 0.06 (confidence limit:2.87-3.11, R-squared =0.98) and 3.24± 0.10 (confidence limit: 3.03-3.45, R- squared = 0.97) for *C. macrostomus* and *A. mossulensis* species, respectively. It could be said that the regional conditions are suitable for the populations of both species. However, it is reported that this value varies depending on many conditions such as the number of samples, fishing season, characteristics of the aquatic ecosystem, gonadosomatic index value and nutrition (Bagenal and Tesch, 1978).

As is known, body measurements in fish are widely used in characterizing stocks, fisheries biology and taxonomy. It has been reported by various researchers that changes in morphological characters are reflected in the phenotype, but changes in meristic characters are transferred to the genotype, thus morphometric characters reflect more phenotypic characteristics of the fish, while meristic characters reflect genotypic characteristics (Coşkun, 2019). It has been emphasized that the variations observed between meristic characteristics in different populations of the same fish species in various freshwater systems may be a result of differences in the biotic and abiotic conditions of the habitats where the fish live (Gül et.al., 2017).

Table 2. Findings on length-weight relationship by different researchers for both species.

Author	**Study area**	**Species**	**Sex**	**N**	**a**	**b**	**R^2**
Bibak et.al. (2013)	Dalaki River, Iran	*C. macrostomus*			0.015	3.129	0.98
Bibak et.al. (2013)	Shahpur River, Iran	*C. macrostomus*			0.027	2.935	0.99
Alkan Uçkun and Gökçe (2015)	Karakaya Dam Lake (Euphrates River), Turkey	*C. macrostomus*	♀ ♂ ♀+♂	83 70 153	1,32 0.607 0,72	2.95 2.86 2.92	0,88 0.93 0.87
Alkan Uçkun and Gökçe (2015)	Karakaya Dam Lake (Euphrates River), Turkey	*C. kais*	♀ ♂ ♀+♂	59 55 114	0.549 0.354 0.417	3.01 3.04 3.02	0.91 0.95 0.93
Present study			♀+♂	83		2.99	0.963
		A.mossulensis					
Parmaksız et al (2018)			♀ ♂ ♀+♂			3.295 3.211 3.269	0.959 0.948 0.956
Özcan et al.(2021).	Pülümür Nehri, Tunceli	*A.mossulensis*	♀	304	0,0105	2,86	0,92
			♂	213	0,0160	2,70	0,93
			♀+♂	517	0,0126	2,79	0,92
Başusta (2000)	Keban Baraj Gölü	*A.mossulensis*	♀ ♂		0,000004 0,00003	3,126 3,144	
Türkmen and Akyurt, (2000)	Karasu Irmağı	*A.mossulensis*	♀ ♂		0,008 0,01	3,082 2,828	
Başusta and Çiçek, (2006)	Atatürk Baraj Gölü	*A.mossulensis*	♀+♂		0,00395	3,313	
Özcan, (2019)	Murat River	*A.mossulensis*	♀ ♂		0,0131 0,0125	2,80 2,82	

Fazli et al.(2019)	Azad Dam Reservoir, İran	♀+♂	522	0.0003	2.743	0.8983
Present study	River Euphrates, Adıyaman region	♀+♂	24		3.24	0.9426

5. Brief overview

In this chapter, variations of meristic traits in regarding to length-weight relationship for *Cyprinion macrostomu*s (Heckel, 1843) and *Alburnus mossulensis* (Heckel, 1843) in the Middle Euphrates Basin (Adıyaman, Türkiye) are presented. Fish samples were caught from streams and lakes in Adıyaman region (Türkiye). The coefficient b (± se) for length-weight relationships was estimated as 2.99± 0.06 (confidence limit: 2.87-3.11, R-squared= 0.98) and 3.24± 0.10 (confidence limit: 3.03-3.45, R-squared= 0.97) for *C. macrostomus* and *A. mossulensis*, respectively. Variations were observed in the number of linea lateral scales, the number of spine and soft rays in dorsal fins, and the number of soft rays in anal and pectoral fins among individuals of *C. macrostomus*. The highest meristic variation for this species was determined in the number of linea lateral scales (7 categories), and among the categories of scale numbers in the linea lateral, it was determined that the 42 scale number categories were represented the most with 77%. Among *A. mossulensis* individuals, variations were observed in the number of linea lateral scales, the number of caudal fin bony rays, and the number of anal, ventral and pectoral fin rays. The highest variation (13 categories) for this species was observed in the number of Linea lateral scales, and it was determined that the 72-scale category was the most represented category with 22%.

References

Avşar, D. (1998). Balıkçılık biyolojisi ve populasyon dinamiği. Ders Kitabı No: 5. Baki Kitap ve Yayınevi. Adana. 303s.

Alkan Uçkun, A. and Gökçe, D. (2015). Growth and reproduction of *Cyprinion macrostomus* (Heckel, 1843) and *Cyprinion kais* (Heckel, 1843) populations in Karakaya Dam Lake (Euphrates River), Turkey, Turk J Zool. 39: 685-692, TÜBİTAK. DOI:10.3906/zoo-1307-5.

Bagenal, T. B. & Tesch, F. W. (1978). Age and growth. In: Methods for assessment of fish production in freshwaters, (Bagenal, T.B., Ed), Blackwell Science Publication, Oxford, UK.pp. 101-136.

Bayçelebi, E. (2020). Distribution and diversity of fish from Seyhan, Ceyhan and Orontes River Systems. Zoosyst Evol. 96(2):747–767. doi:10.3897/zse.96.55837.

Banarescu, P.M ve Herzig-Straschil, B. (1995). A revision of the species of the *Cyprinion macrostomus* group (Pisces: Cyprinidae), 411-420,Ann. Naturhist. Mus. Wien.

Bayhan, Y. K. and Gocer, M. (2012). The fisheries in Ataturk Dam Lake (Adiyaman) and technical features of the fishing gears being used. J. Fish. Sci., 6: 232-242.

Bogutskaya, N. G. (1997). Contribution to the knowledge of leuciscine fishes of Asia Minor. Part-II. An annotated Biology of mossul bleak *Alburnus mossulensis* 42 check-list of leuciscine fishes (Leuciscinae, Cyprinidae) of Turkey with descriptions of a new species and two new subspecies. Mitt. Hamb. Zool. Mus. Inst., 94: 161-186.

Bibak, M., Hosseini, S. A.and Izadpanahi, G. R.(2013). Length-Weight Relationship of *Cyprinion macrostomus*, (Heckel, 1843) in Dalaki River and Shahpur River in South of Iran, World Journal of Fish and Marine Sciences 5 (3):263-265. DOI: 10.5829/idosi.wjfms.2013.05.03.66185.

Başusta, A. (2000). Keban Baraj Gölü'nde yaşayan Acanthobrama marmid, Chalcalburnus mossulensis ve Chondrostoma regium balıklarında büyüme ve kan hücrelerindeki değişimlerin incelenmesi. Doktora Tezi, Fırat Üniversitesi Fen Bilimleri Enstitüsü, Elazığ, 70s.

Başusta, N. & Çiçek, E. (2006). Length-weight relationships for some teleost fishes caught in Atatürk Dam Lake in southeastern Anatolia, Turkey. Journal of Applied Ichthyology. 22, 279-280. DOI: 10.1111/j.1439-0426.2006.00778.x

Çoşkun, T. (2019). Gümüş Balığı, *Atherina hepsetus* Linnaeus, 1758'in Marmara Denizi Popülasyonu Üzerine Morfometrik Bir Araştırma (Master's thesis, Ordu Üniversitesi Fen Bilimleri Enstitüsü, Türkiye), 62 s.

Coad, B. W. (2010). Freshwater fishes of Iraq. Pensoft Publishers, Sofia-Moscow, 294 pp.

Coad, B. W. (1996). Zoogeography of the fishes of the Tigris-Euphrates Basin, Zoology in the Middle East, 13:51-70.

Çiçek, E, Birecikligil, S. and Fricke, R. (2015). Freshwater fishes of Turkey: a revised and updated annotated checklist, Biharean Biologist; 9 (2): 141-157; http://biozoojournals.ro/bihbiol/index.html.

Çiçek E, Fricke R, Sungur S, Eagderi S. (2018). Endemic freshwater fishes of Turkey. FishTaxa. 3(4):1-39.

Dağlı, M. (2013). *Barbus lacerta* Heckel, 1843 ve *Cyprinion macrostomum* Heckel, 1843'un Morfolojik Özellikleri, Düzce Üniversitesi Bilim ve Teknoloji Dergisi, 1: 88–95, Düzce.

Daştan D. S., Bardakci, F., Değerli, N. (2012). Genetic Diversity of *Cyprinion macrostomus* Heckel, 1843 (Teleostei: Cyprinidae) in Anatolia Turkish Journal of Fisheries and Aquatic Sciences 12: 651-659, DOI: 10.4194/1303-2712-v12_3_13.

Duman, S. Şahan A. (2014). Kangal (Sivas) Balıklı Çermik Termal Kaplıcası ile Topardıç Deresi'nde (Sivas) Yaşayan Benekli Sezen *Cyprinion macrostomus* (Heckel, 1843)'de Bazı Hematolojik Parametreler ve Non-Spesifik İmmün Yanıtın Belirlenmesi, Yunus Araştırma Bülteni, 4:21-28.

Esmaeili, H.R. Coad, B.W. Gholamifard, A. Nazari, N. Teimori, A. (2010). Annotated checklist of the freshwater fishes of Iran. Zoosystematica Rossica;19: 361-386.

Esmaeili, H.R. Babai, S. Gholamifard, A. Pazira, A. Gholamhosseini, A. & Coad, B.W. (2015). Fishes of the Persis region of Iran: an updated checklist and Ichthyogeography. Iranian Journal of Ichthyology 3: 201-223.

Falahatkar, B., Amlashi, A.S., Eagderi, S., Mousavi-Sabet, H. (2015). Review on the Caspian Shemaya, *Alburnus chalcoides* (Güldenstädt, 1772). International Journal of Aquatic Biology 3(5), 323-330.

Faghani, L. H. Mousavi, S, H. (2018). Reproductive biology of lotak, *Cyprinion macrostomum* Heckel, 1843 (Pisces: Cyprinidae), from the Tigris River drainage, sayfa. 288-299, DOI: 10.22092/IJFS.2018.115479.

Fricke, R. Bilecenoğlu, Sarı, M. H. (2007). Stuttgarter Beiträge zur Naturkunde. Serie A (Biologie) No: 706: 1-174.

Fazli, H., Daryanabard G.R. Janbaz A., Naderi M., Mirzaei, R., Hosseinpour, H., Vahedi N. (2019). Age and growth of *Alburnus mossulensis* Heckel, 1843 in Azad Dam Reservoir and Komasi River in Kordestan Province, Iran. Iranian Journal of Fisheries Sciences, 18(4) 672-683, DOI: 10.22092/ijfs.2018.117745.

Geldiay, R., Balık, S. (2007). "Türkiye Tatlısu Balıkları", Ege Üniversitesi, Su Ürünleri Fakültesi Yayınları No: 46, V. Baskı, 638s.

Geldiay, R. ve Balık, S. (2009). Türkiye Tatlısu Balıkları, Ege Üniversitesi Su Ürünleri Fakültesi Yayınları, No:46, 644 sayfa, İzmir.

Gül, G., Yılmaz, M., Saylar, Ö., Benzer, S. & Gül, A. (2017). Mogan Gölü (Ankara, Türkiye) Sazan (*Cyprinus carpio*) Populasyonunun Morfometrik, Meristik Özellikleri ve Boy-Ağırlık İlişkisi. Süleyman Demirel Üniversitesi Eğirdir Su Ürünleri Fakültesi Dergisi, 13(2), 163-172.

İlhan, A., & İlhan, D. (2018). Marmara Gölü (Manisa) ve Homa Lagünü (İzmir)'nden yakalanan Gümüş Balığı (Atherina boyeri Risso, 1810)'nın boy-ağırlık ilişkisi ve kondisyonu. *Karadeniz Fen Bilimleri Dergisi*, *8*(1), 25-34.

Kara, C. Güneş, H. (2015). Adıyaman Bölgesi akarsu ve göllerinde *Cyprinion macrostomus ,* (Heckel, 1843) bireylerinin dağılımı ve bazı morfometrik özellikleri, Yunus Araştırma Bülteni. 4:13-19, doi: 10.17693/yunus.48659.

Kara, C and Can, M. F. (2023). Spatial Variation in Growth for *Garra rufa* (Heckel, 1843): A Case study on Three River Systems, Academic Research and Reviews in Agriculture, Forestry and Aquaculture Sciences, Sayfa, 143-153. ISBN: 978-625-6517-64-6.

Keivany, Y. Nasri, M. Abbasi, K. & Abdoli, A. (2016). Atlas of Inland Water Fishes of Iran. Iran Department of Environment Press. In press.

Kuru, M. (1975). Dicle-Fırat, Kura-Aras, Van Gölü ve Karadeniz Havzası Tatlısularında Yaşayan Balıkların (Pisces) Sistematik ve Zoocoğrafik Yönden İncelenmesi, Doçentlik Tezi, Atatürk Üniversitesi, Erzurum-Türkiye,

Kuru, M. (1979). The freshwater fish of South-Eastern Turkey-2 (Euphrates-Tigris system). Hacettepe Bull. Nat. Sci. Eng., 7(8): 105-114.

Mangıt F, Yerli S.V. (2018). Systematic evaluation of the genus Alburnus (Cyprinidae) with description of a new species. Hydrobiologia. 807:297–312. doi:10.1007/s10750-017-3405-y

Metin, K. ve Akpınar, M. A. 2000. *Cyprinion macrostomus* (Heckel, 1843)'un Gonadlarında Total Lipid ve Yağ Asidi Miktarının Mevsimsel Değişimi, Turk. J. Biol., 627634, TÜBİTAK.

Özcan, E. İ. & Serdar, O. (2021). Length-Weight Relationships and Condition Factor of Alburnus mossulensis Heckel, 1843 Population in the Pülümür River (Tunceli-Turkey). J. Anatolian Env. and Anim. Sciences, 6(4), 614-620, DOI: https://doi.org/10.35229/jaes.976636

Özcan, E.I. (2019). Artificial neural networks (a new statistical approach) method in length-weight relationships of Alburnus mossulensis in Murat River (Palu-Elazığ) Turkey. Applied Ecology and Environmental Research, 17(5), 10253-10266. DOI: 10.15666/aeer/1705_1025310266.

Özuluğ, M and Freyhof, J. (2007). *Alburnus demiri*, a new species of bleak from Western Anatolia, Turkey (Teleostei: Cyprinidae). Ichthyol Explor Fresh. 18:307-312.

Parmaksız, A., Oymak, A., , Doğan, N. Ve Ünlü, E. (2018). Select biological characteristics of the mossul bleak *Alburnus mossulensis* Heckel, 1843 (Actinopterygii: Cyprinidae) in the Ataturk Dam Lake, Turkey, Indian J. Fish., 65(4): 36-43, DOI: 10.21077/ijf.2018.65.4.75624-04.

Saylar, O ., Ata, B. & Firidin, B. (2020). Ankara Asartepe Baraj Gölü'nde Yaşayan *Oxynoemachellus angorae* (Steindachner, 1897)' nın Bazı Popülasyon Özellikleri. Anadolu Çev. ve Hay. Dergisi, 5(4), 711-716.

Türkmen, M. & Akyurt, İ. (2000). Karasu Irmağı'nın Aşkale mevkiinden yakalanan gümüş balığı (Chalcalburnus mossulensis, Heckel 1843)'nın populasyon yapısı ve büyüme özellikleri. Turkish Journal of Biology, 24, 95-111.

Uçkun, A.A. and Gökçe, D. (2015) "Growth and reproduction of *Cyprinion macrostomus* (Heckel, 1843) and *Cyprinion kais* (Heckel, 1843) populations in Karakaya Dam Lake (Euphrates River), Turkey," Turkish Journal of Zoology: Vol. 39: No. 4, Article 20. https://doi.org/10.3906/zoo-1307-5.

Unlu, E. (2014). Fisheries and aquaculture in the Euphrates and Tigris River in Turkey. Report of the Expert Meeting on the Review of Fisheries and Aquaculture Activities in the Tigris Euphrates Basin, Erbil, Iraq, 11-12 November 2012. FAO Fisheries and Aquaculture Report No: 1079. Food and Agricultural Organisation, Rome.

Yılmaz S., Kara C., Güneş, H., Gürlek, M. E., Küçükkaya Y (2015). Adıyaman Bölgesindeki (*Cyprinion macrostomus,* Heckel, 1843)'un Bazı Biyokimyasal Kan Parametrelerinin Referans Aralıklarının Belirlenmesi, Adıyaman Üniversitesi Fen Bilimleri Dergisi 4 (2), sayfa 68-81, Adıyaman.

Chapter 3

AGE DETERMINATION IN OSTEICHTHYES AND CHONDRICHTHYES

Omar Abdulazeez Abdulkareem SHWANI[1]

Serap SALER[2]

1 Fırat University Fisheries Faculty Elazıg-Türkiye
2 Fırat University Fisheries Faculty Elazıg-Türkiye

1. Introduction

Age information is crucial for estimating growth rates, mortality rates, and productivity in fisheries and ecology. A range of methods are used to determine the age of fish, including tag-recapture experiments, which mark and recapture fish in order to assess population dynamics, and radiochemical decay rates, which provide precise age estimates. The most commonly used method is incremental counting of features such as otoliths, scales, fin rays, and bones. Otoliths are selected for their unique growth rings. These age data enable the understanding of population dynamics, the identification of sustainable crops and the management of environmental assessments, This additionally encourages effective supervision of fisheries and efforts to conserve (Campana, 2001).

Fish can mature in different ways. While recapture tags are considered the most accurate method of age determination in natural environments, their widespread use in fisheries is limited by time and cost. Another method is length-frequency data analysis, which is effective for species that reproduce annually but does not provide an age range for individual fish. The anatomical technique involves the examination of annual rings on bony structures such as scales, otoliths, surgical bones, vertebrae and fin rays. Age is calculated by comparing readings from different readers and structures. Assessing the precision of the chosen bone structure and accounting for aging imperfections are important considerations when selecting a method, as the most reliable technique may vary depending on the piece (Polat et al., 2001).

It can be difficult to determine the age of Chondrichthyes, because, unlike telo fishes, they lack otoliths or ordinary scales. Therefore, in the aging studies of chondricht, a number of techniques were used, such as: B. caudal spines, radiography, eye lens weight, spinal spines, and frequency of tooth replacement. In contrast, the majority of studies on chondrichtyan aging rely on a cyclical increase in spinal centers. The age-defining technique is used by researchers studying fish biology, ecology and population dynamics in the Osteichthyes and Chondrichthyes orders. With an accurate assessment of the age of fish, scientists and resource managers can make informed decisions that ensure long-term sustainability and maintenance of aquatic ecosystems (Başusta et al., 2017).

2. The Significance of Fish Ageing

Assessing the health of a population depends on the age of fish, which can be determined using calcified structures such as fin rays, otoliths, and scales. Age and growth statistics are essential for comprehending demographics, such as longevity, recruitment age, and mortality, according to Panfili et al. (2002). A broad age profile is indicative of a healthy population; an absence of older fish could be a sign of excessive harvesting, while a lack of younger fish could be a sign of problems with recruitment.Research on overfished populations focuses on sustainable resource extraction, with age data crucial to stock evaluations. According to some scientist correct age-length data is crucial for efficient management and conservation, particularly in situations where stock numbers are low, as these studies seek to assess stock conditions against historical benchmarks and management aims (Vitale et al., 2019).

3. **What are Chondrichthyes and Osteichthyes?**

Fish are divided into two main taxonomic groups: the Osteichthyes and the chondrichthyans, which correspond to the cartilaginous and bony fishes. Taken together, these two species account for nearly all known fish species on Earth. The total number of bony and cartilaginous fish species is about 28,000.

Sharks, rays, and skates are examples of cartilaginous fish, whereas hagfish and lampreys are examples of agnatha or jawless fish. (A fourth class, the armored fish Placoderms, is now extinct, and most experts include the spiny sharks Acanthodes under the Osteichthyes classification.

Chondrichthyes: These species belong to the class of cartilaginous fishes called chondrichthyes, and their skeletons are primarily composed of cartilage .Chondrichthyes are jawed vertebrates that have paired fins, paired nares, scales, and a series-chambered heart. The Chondrichthyes family of marine animals includes about the 10 cm (3.9 in) finless sleeping ray and the 10 m (32 ft.) whale shark.

- Sharks, chimaeras, skates, and rays are all members of the class Chondrichthyes. Since their skeletons are composed of cartilage rather than bone, they are categorized as jawed vertebrates. The two subclasses that comprise the class are **Holocephali** (chimaeras) and **Elasmobranchii** (sharks, rays, skates, and sawfish).

Osteichthyes: Osteichthyes, a complex superclass of vertebrates that is commonly referred to as "bony fish," have skeletons mostly made of bone tissue. of contrast, the majority of the skeletons of the Chondrichthyes are made of cartilage. The Osteichthyes order, which has 28,000 species and 45 orders dispersed through 435 families, is home to the majority of fish species. Right now, it is the largest class of vertebrates.

- The Osteichthyes fishes with bony skeletons comprises the **Sarcopterygii** (coelacanth and lungfishes) and the **Actinopterygii,** the latter of which includes the largest class of vertebrates, the Teleostei.

- **Some Examples of Osteichthyes and Chondrichthyes**
- **steichthyes:**(Salmon,Tuna,Trout,Perch,Cod,Angelfish,Barramundi, Mackerel, Sardines, Guppies, Catfish, Piranha, Grouper, Herring, Bass, Aquarium Bony Fishes,Bony,Ray-finned Fish,Fish with Lobe-fins,Lungfishes etc…)

Chondrichthyes:

(Sharks,Rays ,Skates,Sawfish,Chimaeras, Dogfish,Sawfishes,Chimaeras etc…)

4. Age Determination in Osteichthyes (Bony fish)

4.1.Otoliths

The majority of fish have their ages determined using the sagittal otolith. It is found in the inner ear's sacculus. Depending on the kind of fish, there are many ways to cut into its head and remove it. It also depends on whether the fish are going to be sold later, in which case there needs to be as little damage done to the fish as possible.

4.1.1.Taking sample of otoliths

Otoliths from "roundfish," such as gadoids, can be removed using a variety of techniques. The most basic is to make a longitudinal cut acrossthe head, just behind the eyes, deep enough into the skull to allow the head to be broken open (Figure 1). acrossthe head, just behind the eyes, deep enough into the skull to allow the head to be broken open.

Figure 1. Otolith extraction (URL 1, 2024).

For smaller fish, a knife or scalpel can be used; however, for larger fish, a standard metal kacksaw facilitates a rapid and simple process. While the proper technique is quickly learned, an untrained worker can easily cut too deeply and injure the otoliths. An further technique is to elevate the cranium.

This is a less likely way to damage the otoliths, but it is more challenging, especially with larger fish. It is feasible to remove the otoliths from under the gill or from the roof of the mouth if doing so is necessary without appearing to harm the fish.

4.1.2. Preparation of otoliths

The simplest method, which works for most species, is to clean the otoliths well before storing them dry in paper envelopes or plastic bags that are the right size and are stacked in boxes with labels. The best liquid should be used and small sample tubes of the right size should be used if it is important to keep the otoliths fresh. It is possible to use creosote, alcohol, glycerine, or a combination of the two, although caution must be exercised to prevent damage to or loss of the otolith's ring structure from improper storage. Using formalin is not suggested. It is a good idea to frequently assess the liquid's effect on the otolith's appearance, regardless of the choice for the storage medium. The clarity of the ring structure may gradually deteriorate after a brief time of storage, even though in certain situations it may make the rings easier to read. Mounting a succession of small otoliths, such those from sandeels or mackerel, in resin on a microscope slide makes handling and storing them convenient.

4.1.3. The structure of the otolith

Otoliths are three-dimensional in nature structures, as was previously mentioned, but their growth rates are not always uniform across all dimensions. If the otolith exhibits any pattern at all, it will consist of several concentric shells with various radii.

The two types of zones or rings must never be referred to as "light" and "dark". This only creates confusion, because the method of illuminating the otolith determines whether a zone appears as dark or light ring (Figure 2). The terms "summer zones" and "winter zones" should also be avoided. It is also best to avoid the term annuli unless it is certain that the rings or zones are annual.

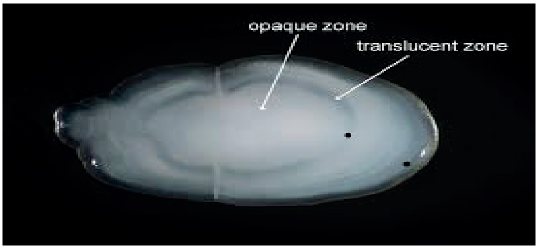

Figure 2. Showing (light and dark) zone of otolith (URL, 2, 2024).

4.1.4. Viewing the fresh otolith

The ring structure may become clearest as soon as the fish's otoliths are removed. If that's the case, then it would be best to read them at that time. It can be the only moment that certain species are readable.

4.1.5.Viewing the whole otolith

Otoliths can be viewed in several ways, the simplest being to illuminate it from above while immersed in a clear liquid (e.g. water) and against a dark background. This method works well for thin, clear otoliths with challenging rings. Narrow outer rings, on the other hand, can be blurry and only become visible in cross section when the fish's growth slows. Before determining age, it is important to look for these narrow rings in cross section to avoid age determination. While grinding the otolith surface may increase transparency, not all rings on the underside may still be visible, requiring a cross-section to accurately determine age.

4.1.6. Preparing a cross-section of an otolith

One can examine longitudinal, transverse, or diagonal incisions while examining otoliths in cross-section. All methods of age determination must be taken into account. Cutting through the center of the nucleus is essential, as skipping it can result in misunderstandings. If the incision goes into the nucleus, an incorrect identification of the first ring could lead to an overestimation of age. Another piece that can cause confusion is one that only displays the tip of the nucleus, altering the ring's form. Correct evaluation requires a clear visualization of the nucleus and rings, which is best achieved when the slice goes through the center of the nucleus (Vitale et al., 2019).

4.1.7. The burning technique of otolith

Some fish, including soles (Solea solea), have otolith rings that are hidden from view without assistance. Others, such as plaice (*Pleuronectes platessa*) and turbot (*Psetta marina*), can have shattered or narrow outer rings that are hard to see. A cross-section can be made more visible by slowly burning it over a low flame until a black ring forms. Removing the core from the flame after it has darkened; if needed, you can return it to the flame to continue burning (Figure 3). After that, arrange the otolith on plasticine so that it may be easily seen under a microscope.

Figure 3. *Burning of otolith (URL, 2, 2024).*

It is often helpful to use a range of viewing approaches, such as showing the otolith whole, lighted from above against a dark background, and sectioned burned or unburned. Sometimes, queries arising from the first technique can be addressed by using the alternative procedure on the second otolith of the pair (Christensen, 1964).

4.2. Scales

Scales cover the body's exoskeleton, providing protection. Scale structure is helpful for broad group classification. Thus, among fish, higher teleosts have cycloid and ctenoid scales, whereas placoid scales are indicative of Chondrichthyes, early bony fish have ganoid scales, and fish with placoid scales are those seen in primitive fish. The scales can be helpful in classifying families and orders at times. since of this, siluroid fishes may be identified from cyprinoids since they lack scales. Scales are a valuable resource for learning about fossilised fish and for categorising edible middens of extinct humans. Scales are helpful for researching piscivorous species' habits of consumption. Numerous species are identified in taxonomic studies by counting the scales around the body and along the lateral line. Fish scales, such as cycloid and etenoid, are very useful in determining the age and growth rate of fish. The lines of growth on the scale show that many species have seasonal growth. It is possible to determine the number of times a fish has spawned by looking for spawning marks on its scales, which are visible in some species like Salmo. Scales change in proportion to the fish as it grows (Khan and Khan, 2009).

- **Scale method fish scale showing growth rings (Figure 4)**

1. The focus, which is chosen initially, shows the beginning size of a scale as it develops.

2. New structures are added, fulfilling their functions as ages of scale. The grooves and circuli are representations of growth action.

3. They also exhibit osteoblastic action, which results in the secretion and deposition of material around the focal point. In this way, a number of these circuli and grooves are produced each year.

4. Ichthylepidin, an original bone material, deposits on circuli, increasing their height; this process is reliant on mineralization.

5. Although anuli grow slowly throughout a year, they dramatically improve in many fish during the winter and are added to the fish as it grows each year.

6. Because of this, annuli can be used as year markers on a scale and are very useful for estimating the age of fish. The annuli are particularly noticeable at the front of the scale (Ilieş et al., 2014)

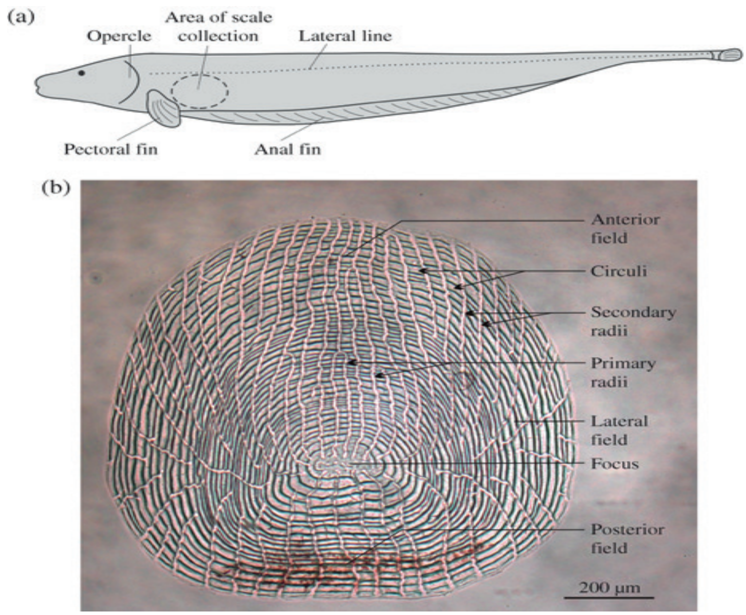

Figure 4. Scale sampling. (a) Schematic drawing of *Apteronotus leptorhynchus*, illustrating the location from whichthe scales were collected. (b) Typical body scale of *A. leptorhynchus* from the pectoral region (Ilies et al. 2014).

4.2.1. Scale preparation and reading techniques

In the area of the pectoral fin tip, above the lateral line, scales were removed. After removing mucus and extraneous materials by washing the scales in tap water and rubbing them in between the finger tips, the scales were cleaned, dried, and examined as dry mounts. If the scales are large, they can be dipped in a mild solution (1%) of potassium hydroxide (KOH) for 5 to 10 minutes, followed by washing with tap water and allowed to dry in the air. Using a compound microscope, small scales were placed between two glass slides and examined (Khan and Khan, 2009).

4.2.3. The structure of the scale

Scales are structures that are nearly two-dimensional. A number of sclerites that extend from the scale's centre in a regular structure create the anterior section. Should they fail to do so and show confusion or irregularities, it is highly likely that the scale is a replacement item and should not be utilised for determining an individual's age. As already mentioned, the term "annuli" should not be used because it accepts that the rings are annual. The structural discontinuities used for age determination are caused by irregularities in the pattern of the sclerites; they may be slightly distorted or they may be slightly closer spaced than the majority of the sclerites. Typically, the discontinuities are narrow and are called "rings." As a result, the scale displays another image to the otoliths (Nakamura et al., 1998).

4.3. Vertebrae

According to reports, in Nile perch skeletons, vertebrae are the most trusted component for determining age (Polat et al., 2001).compared different bony parts of north Atlantic flounder, Pleuronectes flesus luscus (Pallas) for determining age and found that the most dependable structure with the least amount of ageing error was the vertebrae. In Burbot, Lota lota, otoliths and vertebrae provided comparable age estimations (Linnaeus). When comparing vertebrae, otoliths, and scales for ageing the autumn season chum salmon, Oncorhynchus keta (Walbaum), sectioning otoliths and vertebrae improved the ability to identify opaque zones in otoliths and understand growth checks in vertebrae, and produced higher age estimates than those obtained from whole vertebrae and otoliths. The golden snapper, Lutjanus johnii (Bloch). The researcher came to the conclusion that although vertebrae required 20 times more time to process and read than scales, they were the most precise and accurate of the three structures studied due to their high degree of accuracy. Hardly have vertebrae used in research on fish age estimation when the fish has clear development signs in other ageing components that cause minimal or no damage on the fish. The rings on the vertebral centra in the current study were not specially clear and had a number of tiny marks unrelated to cyclic situations, which corroborates with the observations made by (Khan and Khan, 2009).

4.3.1. Vertebrae preparation and reading techniques

Vertebrae (4th to 10th) were removed and placed in boiling water for 10–15 min to clear the attached muscles. Vertebrae were then dried for 2 weeks to count annual rings (Figure 5). Vertebrae were examined by shining a fiber-optic light near the bottom of the structure to illuminate annuli under dissecting microscope (Khan and Khan, 2009).

Figure 5. *Washing and cleaning of Vertebrae (Rashid, 2017).*

4.4. Opercular

The hard, bony plates called opercula (operculum singular) serve as a protective covering for the gills of bony fish (Figure 6). Their otoliths are so little that they are among the most prevalent ways to age. it has to cut the fish's bone in order to remove the opercula. After the bone is removed, all associated flesh must be cleansed off of it and accomplish this by carefully removing the flesh with a tooth brush after boiling the skeletal framework. It is ready to be aged once the operculum is clean.

Figure 6. *Showing opercular for age determination (Rashid, 2017).*

4.4.1 Opercular bone preparation and reading techniques

The opercular bone were detached with the help of scalpel and dipped in boiling water for few minutes to remove extraneous tissue. A bristled brush was used to remove tissue that boiling water did not loosen. Cleaned opercular bones were dried at room temperature and examined under transmitted fluorescent light with naked eye (Phelps et al., 2007).

5. Age determination in Chondrichthyes

5.1. Vertebrae

Chondrichthyes have been aged using whole vertebral centra, as well as transverse and sagittally (i.e., longitudinally) sectioned centra (Figure 7). When lit from below, transverse sectioning will keep bands on opposite halves from hiding from one another. The age of older animals can still be difficult to determine, though, because bands at the outer edge of vertebrae grow more tightly packed. Also, if transverse sections or complete centra are used for ageing, the bands can accidentally be aggregated and tallied together, leading to an underestimation of age. Therefore, unless it can be proven beyond a reasonable doubt that complete centra from a given species can consistently yield comparable ages, sagittally sectioned vertebrae should be utilised for ageing (Campana, 2001).

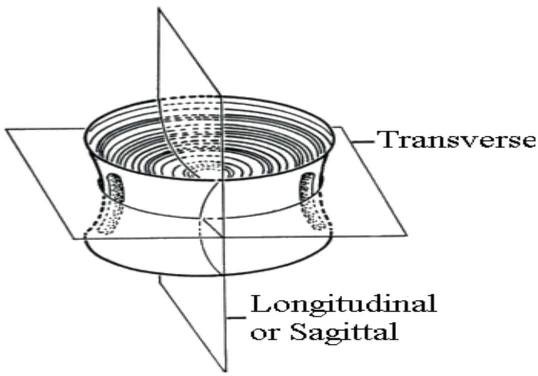

Figure 7. *The two sectioning planes that can be used on vertebral centra (Goldman et al. 2012).*

5.1.1. Taking Samples

The location of the ageing samples' collection in the vertebral column can statistically significantly affect the number of steps. Therefore, for age studies, it is essential to use the larger, more anterior (thoracic) centra because smaller centra from the caudal area might not have all of the bands. This highlights the significance of standardising the vertebral sample region for all ageing studies, enabling more accurate comparisons between populations as well as precise, valid comparisons among individuals within a community .Centra devoid of tissue are necessary for all ageing processes; nonetheless, multiple centra should retain their neural arches (Khan and Khan, 2009).

5.1.2. Whole Vertebrae

For some species, accurate age determination can be achieved by examining their united vertebrae. Unlike otoliths, which grow proportionally with body size, older, sexually mature elasmobranchs show limited vertebral growth. This limited growth is typically observed in vertebral parts but is much harder to assess in complete vertebrae. In contrast, intact vertebrae are reliable for determining the age of young, rapidly developing species, such as the blue shark (Prionace glauca) (MacNeil and Campana, 2002) (Figure 8). Whole vertebrae need to be dried and free of any attached tissue in order to age. Growth bands in bigger species are frequently apparent to the unaided eye, although age determination is more precise when using a digital camera or a low magnification dissecting microscope. For this, a standard digital camera on a pedestal works great. Sufficient lighting is essential; utilizing low-angle, oblique lighting from both sides of a fiber optic light source improves contrast. When taking pictures, it's crucial to make sure that all growth axes are in the same focal plane or, for precision, to take multiple pictures at various focal planes (Campana, 2014).

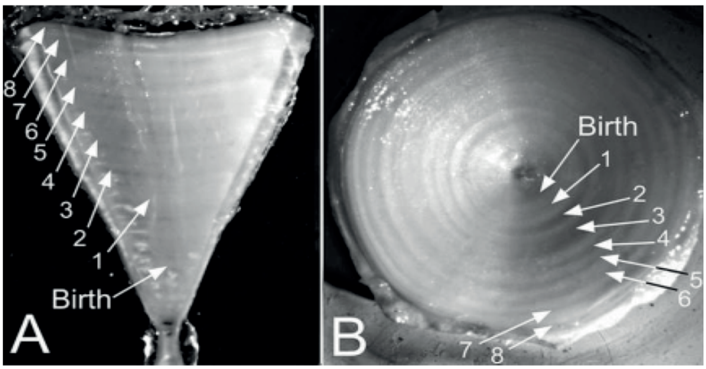

Figure *8. Comparison of annual growth bands visible in a single Prionace glauca vertebraafter sectioning (A) and as viewed whole (B); annual growth bands are indicated (Campana, 2014).*

5.2 . Spines

Fin spines can be used to determine age because they have annual growth bands, similar to those of the spiny dogfish (Squalus acanthias). First dorsal spines, which frequently wear down and cause underestimations, are preferable to second dorsal spines. Spine wear can be compensated for by correction factors. Without needing a lot of preparing, treatments like longitudinal cuts or wet sanding can help reveal growth bands. Age determination in several chimaeras and squaloids has also been achieved using cross-sectioned dorsal spines, providing valuable information on their life histories.

5.2.1. Sample collection

Dorsal fin spine and vertebrae dissection. A) A downward incision is made posterior to the dorsal fi n spine, followed by B) a horizontal incision ventral to the vertebral column, and finally C) an upward incision is made to simultaneously remove the spine and a portion of vertebral column. D) Excess tissue is removed from the spine and vertebrae to produce E) a single sample ready to be frozen until further processing in the laboratory is possible (Figure 9).

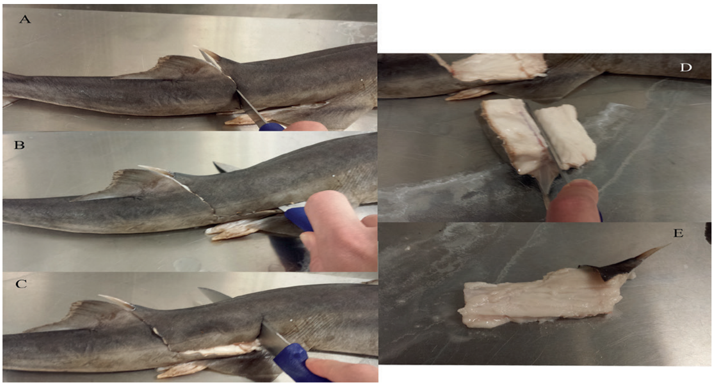

Figure 9. *Taking sample of dorsal fin spine (Tribuzio et al., 2016)*.

5.5.2. Specimen Preparation

5.2.2.1. Dorsal Fin Spines

Spines can be prepared for age determination using a variety of methods and equipments. To prevent tissue degeneration of the vertebrae prior to processing, it is desirable to separate the frozen spines and vertebrae and keep the vertebrae for further processing, as detailed in the following section. This should be done with the structures frozen or partially frozen. To help remove tissue from the spine, it must be heated carefully so as not to harm the foundation structure or the spine's enamel. It is advised to process beneath a fume hood or in a well-ventilated location because heating will produce a strong odour.

6. Conclusion

Age determination in chondrichthyans (cartilage fish) and o Osteichthyes (bony fish) presents particular challenges due to their anatomical features. In chondrichthyans, They lack development rings, therefore age is ascertained indirectly by more advanced techniques like size measurement or spine inspection. Despite these challenges, contemporary techniques such as genetic analysis and high-resolution imaging are crucial. Understanding the age structure of fish is essential to ensure the preservation and long-term viability of fisheries, which underlines the need for interdisciplinary cooperation in marine science.

REFERENCES

Başusta, N., Sefa Ayhan Demirhan, Erdoğan Çiçek, A. B. (2017). Assessment of Some of the Feeding Aspects and Reproduction of S. undosquamis Distributed in the İskenderun Bay. *Turkish Journal of Fisheries and Aquatic Sciences*, *17*(1), 41–49. https://doi.org/10.4194/1303-2712-v17

Campana, S. E. (2001). Accuracy, precision and quality control in age determination, including a review of the use and abuse of age validation methods. *Journal of Fish Biology*, *59*(2), 197–242. https://doi.org/10.1006/jfbi.2001.1668

Campana, S. E. (2014). *Age determination of elasmobranches with special reference to mediterranean species: a technical manual* (Issue 94). STUDIES AND REVIEWS.

Christensen, J. M. (1964). Burning of otoliths, a technique for age determination of-Burning of otoliths, a technique for age determination of soles and other fish soles and other fish. *ICES Journal of Marine Science*, *29*(1), 73–81. https://doi.org/10.1093/icesjms/29.1.73

Goldman K., Cailliet G. M., Natanson, L. J. Andrew, A. H. (2012). Assesing the age and growth of Chondrichthyan Fishes, *Biology of Sharks and Their Relatives*, 14, 423-451

Ilieş, I., Traniello, I. M., Sîrbulescu, R. F., and Zupanc, G. K. H. (2014). Determination of relative age using growth increments of scales as a minimally invasive method in the tropical freshwater Apteronotus leptorhynchus. *Journal of Fish Biology*, *84*(5), 1312–1325. https://doi.org/10.1111/jfb.12354

Khan, M. A. and Khan, S. (2009). Comparison of age estimates from scale, opercular bone, otolith, vertebrae and dorsal fin ray in Labeo rohita (HaKhan, M. A., and Khan, S. (2009). Comparison of age estimates from scale, opercular bone, otolith, vertebrae and dorsal fin ray in Labeo rohita. *Fisheries Research*, *100* (3), 255–259. https://doi.org/10.1016/j.fishres.2009.08.005

MacNeil, M. A., and Campana, S. E. (2002). Comparison of whole and sectioned vertebrae for determining the age of young blue shark (Prionace glauca). *Journal of Northwest Atlantic Fishery Science*, *22*(December 2002), 77–82. https://doi.org/10.2960/j.v30.a5

Nakamura, T., Maruyama, T., and Watanabe, S. (1998). Validity of Age Determination in the Fluvial Japanese Charr Salvelinus leucomaenis by Scale Reading. *Fisheries Science*, *64*(3), 385–387. https://doi.org/10.2331/fishsci.64.385

Panfili, J., Pontual, H., Troadec, H., Wright, P.J. (2002). *Manual of fish sclerochronology*. Brest, France: Ifremer-lRD coedition, 464 p.

Phelps, Q. E., Edwards, K. R., and Willis, D. W. (2007). Precision of Five Structures for Estimating Age of Common Carp. *North American Journal of Fisheries Management*, *27*(1), 103–105. https://doi.org/10.1577/m06-045.1

Polat, N., Bostanci, D., and Yilmaz, S. (2001). Comparable Age Determination in Different Bony Structures of Pleuronectes flesus luscus Pallas, 1811 Inhabiting the Black Sea. *Turk. J. Zool.*, *25*, 441–446.

Rashid, R. F. (2017). Determınatıon of most relıable bony structure for ageıng of aspıus vorax ınhabıtıng karakaya dam lake (malatya-turkey). *Angewandte Chemie International Edition, 6(11), 951–952.*, 5–24. http://repo.iain-tulungagung.ac.id/5510/5/BAB 2.pdf

Tribuzio, C. A., Matta, M. E., Gburski, C., Atkins, N., and Bubley, W. (2016). Dorsal Fin Spines As described, accurate age estimation of spiny dogfish spines is difficult because the spines are external to the body and are often broken or worn, resulting in "missing" annuli, the number of which must be estimated using regression me. *Marine Fisheries Review*, *78*(1–2), 1–13. https://doi.org/10.7755/MFR.78.1–2.1

Vitale, F., Clausen, L. W., and Chonchuir, G. N. (2019). Handbook of fish age estimation protocols and validation methods. ICES Cooperative Research Report No. 346. In *ICES Cooperative Research Report No. 348* (Issue April). https://doi.org/10.17895/ices.pub.5221

URL 1, 2024. https://fishbio.com/fish-ears/

URL 2, 2024. https://www.fisheries.noaa.gov/

Chapter 4

PARASITE DIVERSITY OF FISHES IN TÜRKİYE –

IX. MINOR TAXA

Ahmet ÖZER[1]

1 Prof. Dr., Sinop University, Faculty of Fisheries and Aquatic Sciences, 57000, Sinop, Türkiye, aozer@sinop.edu.tr, ORCID: 0000-0002-2890-6766

1. INTRODUCTION

Fish parasitic Annelida primarily refers to certain species of leeches (class Hirudinea) that parasitize fish. They have a worldwide distribution in marine and freshwater environments and attach to their hosts, feeding on blood and body fluids. They can potentially affect the health of fish in a variety of ways and the most common way is their vector role of other infectious agents in host-parasite interactions. While freshwater leeches, such as *Piscicola geometra*, are most abundant in temperate lakes, ponds, and streams worldwide, marine ones are most abundant on primarily demersal fishes in polar to temperate regions such as *Trachelobdella lubrica* (Williams et al. 1994; Burreson, 2006, Kaygorodova and Matveenko, 2023).

Euglenozoa is a monophyletic group of flagellated protists that encompasses free-living, symbiotic, and parasitic species. This phylum is divided into three distinct lineages: euglenids, kinetoplastids, and diplonemids. Each lineage exhibits different life strategies and unique morphologies, but they share several common characteristics (Berman, 2012; Kostygov et al. 2021). Fish euglenoid parasites are parasitic members of the Euglenozoa group that infect fish. These parasites, such as *Ichthyobodo, Trypanosoma*, and *Cryptobia*, typically belong to the subgroup Kinetoplastida, which includes species that can cause diseases in various aquatic hosts (Simpson et al. 2006; Tikhonenkov et al. 2021).

Myzozoa is a diverse and complex group of single-celled eukaryotic organisms within the Alveolata superphylum which includes several important and well-known subgroups such as dinoflagellates, apicomplexans, and certain parasitic protozoans (Cavalier-Smith et al. 2004). Members of Dinoflagellates, such as *Amyloodinium ocellatum*, and Apicomplexans, such as *Eimeria sardinae*, are among the most known parasites (Noga and Levy, 2006; Bachvaroff et al. 2014; Özer et al. 2014; Gomez and Gast, 2018). Dinoflagellates mainly inhabit aquatic environments, including both marine and freshwater ecosystems. In contrast, apicomplexans are obligate parasites equipped with specialized structures that allow them to invade and feed on host cells (Frenal and Soldati-Favre, 2009).

Members of the phylum Microsporidia are important parasites that impact fish health, affecting both wild and aquaculture populations. These microorganisms are notable for their ability to infect a wide range of hosts, including fish. Several microsporidian species infect fish, including *Pleistophora, Glugea, Nosema*, and *Loma* (Lom, 2002; Stentiford et al. 2013).

Metamonada is a group of unicellular, flagellated protists. Notable genera that infect fish include *Spironucleus* and *Hexamita,* and some members, such as *Hexamita* spp, are known to infect fish, leading to various health issues. They can infect a wide range of freshwater and marine fish species, including salmonids, cichlids, and ornamental fish (Post, 1987).

Mollusca is a diverse phylum that includes snails, clams, squids, and octopuses (Brusca et al. 2016). They inhabit a wide range of environments, from deep oceans to freshwater bodies and terrestrial habitats (Haszprunar and Wanninger, 2012). Some mollusks, such as glochidia (larval stage of freshwater mussels, can act as parasites on fish by attaching to the gills or fins of fish, where they encyst and develop before detaching and settling into the substrate to grow into adult mussels (Rock et al. 2022).

Choanozoa are an important component of marine and freshwater environments. While choanoflagellates themselves do not directly interact with fish in significant ways (e.g., as parasites or pathogens), they are part of the broader plankton community that serves as a primary food source for many fish, especially in their larval stages (Fonseca et al. 2023). Outbreaks of disease caused by Sphaerothecum destruens have been documented in both wild and farmed salmonid fish along the West Coast of the USA, and it has also been identified as a factor in the decline of endemic fish species in Türkiye (Harrel et al. 1986; Ercan et al. 2015)

Research on fish parasites from the phyla Annelida, Euglenozoa, Myzozoa, Microsporidia, Metamonada, Mollusca, and Choanozoa in both freshwater and marine environments in Türkiye has resulted in numerous papers and several checklists (Öktener, 2003, 2005, 2014; Özer, 2019, 2020, 2022; Özer et al., 2014, 2015; Özer and Öztürk, 2017). Özer (2021) published the first comprehensive checklist book detailing host-parasite and parasite-host relationships based on all prior reports in Türkiye. This chapter on the parasites belonging to minor taxa of fish in Türkiye is derived from the data presented in this recent book, which compiles all individual publications on each nematode parasite species..

2. MINOR PARASITIC TAXA DIVERSITY OF FISHES IN TÜRKİYE

According to Özer (2021), in addition to the members of the main parasitic taxa, 46 parasite species belonging to phyla Annelida, Euglenozoa, Myzozoa, Microsporidia, Metamonada, Mollusca, and Choanozoa have also been reported from marine, freshwater, and brackish water fish species in Türkiye corresponding with 6% of the whole parasite species reported from fishes in Türkiye (Figure 1). The numbers and percentages of all parasites belonging to phylum mentioned above are provided in Figure 1.

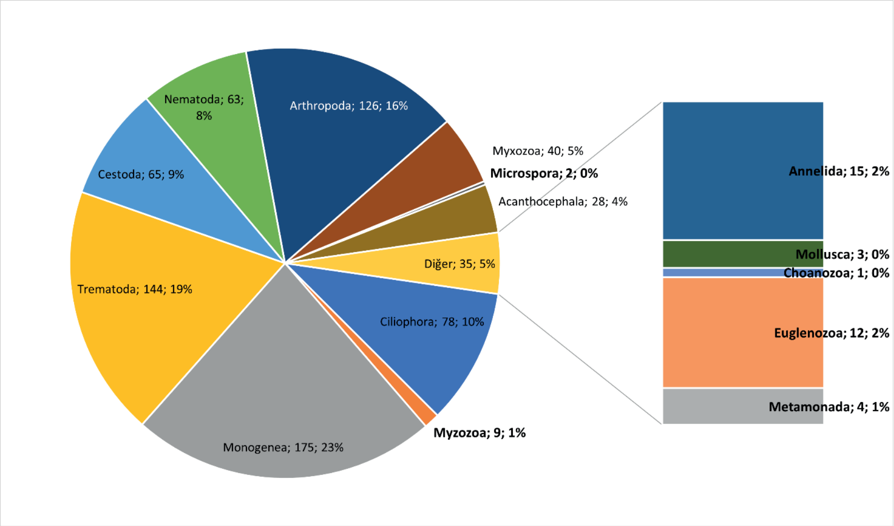

Figure 1. *Total number and percentage of minor parasite taxa reported from fishes in Türkiye*

The numbers of the parasite species of the phyla Annelida and Euglenozoa were higher than those of others as can be seen in Figures 2, 3. Of the reported 46 parasite species, details are also provided in Figure 3.

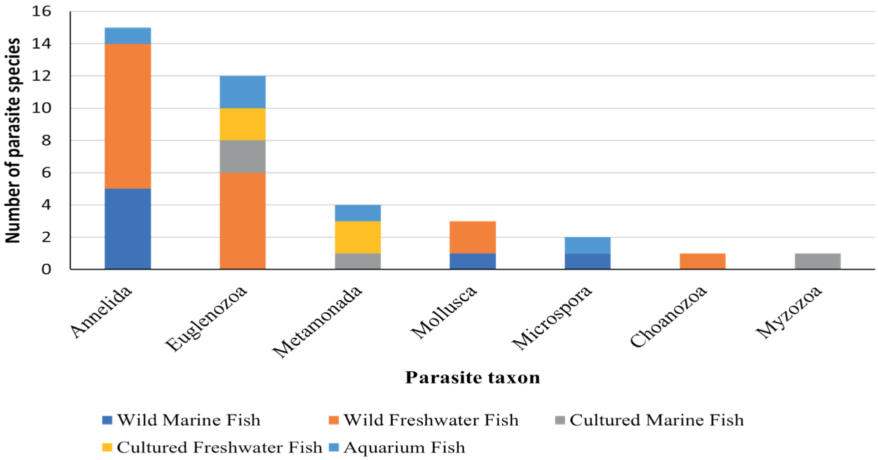

Figure 2. *The total number of minor parasite taxa species reported from marine, freshwater, and aquarium fishes in Türkiye*

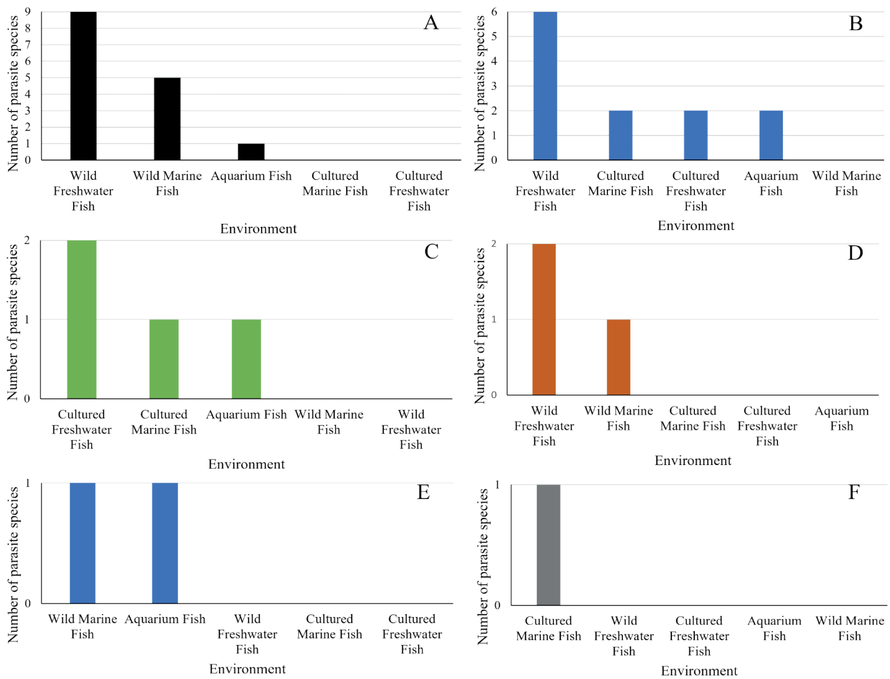

Figure 3. *The number of minor parasite taxa species reported from marine, freshwater, and aquarium fishes in Türkiye. A) Annelida, B) Euglenozoa, C) Metamonada, D) Mollusca, E) Microspora, F) Myzozoa*

3. MINOR PARASITIC TAXA DIVERSITY OF MARINE FISHES

3.1. Wild marine fishes

Among the seven minor parasitic taxa, four included at least one parasite species (Figure 4). Annelida had the highest number of parasite species in marine environments, with seven species, while Microspora, Mollusca, and Myzozoa each had only one species, as shown in Figure 4. Özer (2021) noted that the only Mollusc and Microspora species reported were from the Sea of Marmara (*Glochidia* larvae from *Mugil cephalus*) and the Black Sea (*Loma* sp. from *Mullus barbatus*), respectively. There are no reports of any Euglenozoa, Choanozoa, or Metamonada species.

Figure 5A illustrates that the thornback ray (*Raja clavata*) served as the host for two parasitic annelid species, while five other fish species were each infected by only one annelid species. Considering the annelid species infecting marine host fishes, *Trachelobdella lubrica* was the most frequently reported, found in six different marine host species. This was followed by Pontobdella muricata, which infected five host species, *Stibarobdella moorei* with three hosts, and *S. macrothela* with one host, as shown in Figure 5B.

3.2. Cultured marine fishes

Fish culture in marine environments in Türkiye is growing fast and cultured species are mainly European seabass *Dicentarchus labrax* and gilthead seabream *Sparus aurata* along with some other alternate species such as common dentex *Dentex dentex*. Reports on parasites from cultured fishes are from the members of the families Euglenozoa and Myzozoa (Figure 6) along with Metamonada.

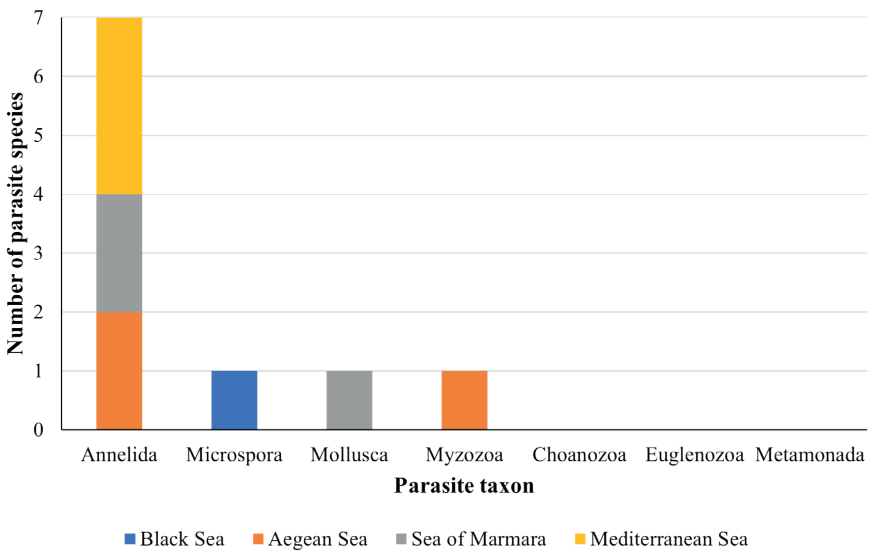

Figure 4. *The number of minor parasite taxa species reported from wild marine fish species inhabited the surrounding seas of Türkiye*

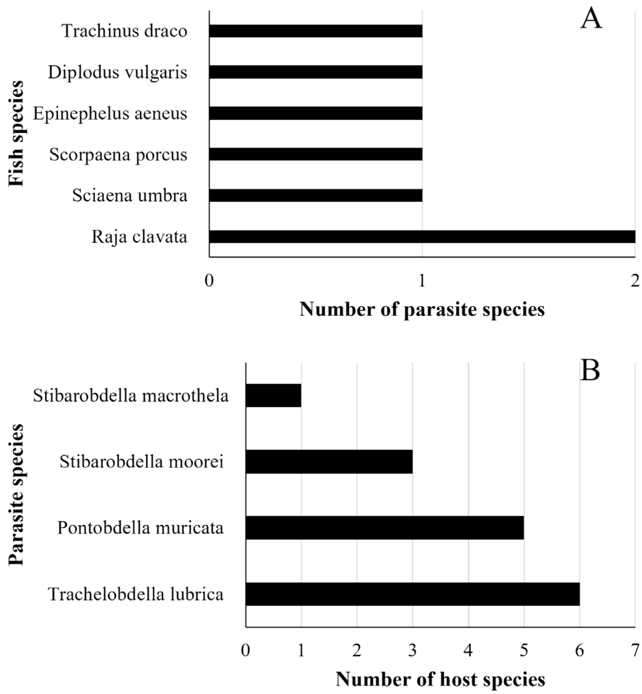

Figure 5. *A) The number of wild marine host fish species infected by the members of the phylum Annelida in Türkiye, B) The number of Annelida species infecting the wild marine host fishes in Türkiye*

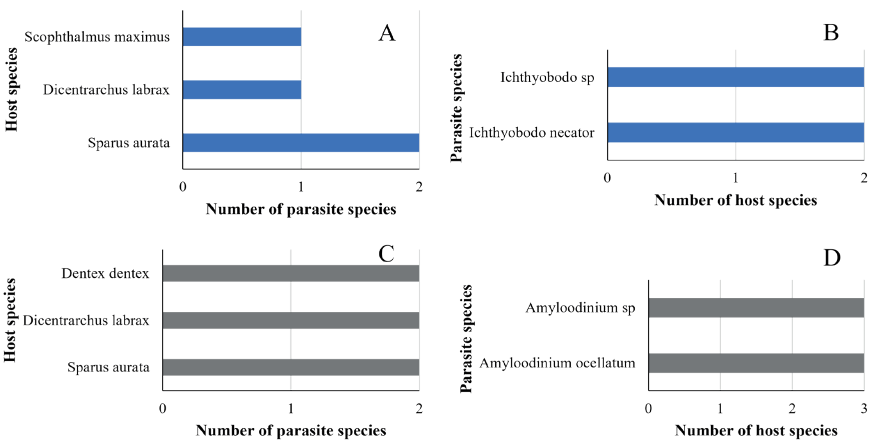

Figure 6. *A) The number of cultured marine host fish species infected by the members of the phylum Euglenozoa (A), the number of Euglenozoa species infecting the wild marine host fishes in Türkiye (B), the number of cultured marine host fish species infected by the members of the phylum Myzozoa (C), the number of Myzozoa species infecting the wild marine host fishes in Türkiye (D).*

Rainbow trout *Oncorhynchus mykiss* from culture cages in the Black Sea was also reported to be infected by 1 myzozoan parasite species *Spironucleus salmonicida*.

4. MINOR PARASITIC TAXA DIVERSITY OF FRESHWATER FISHES

4.1. Wild freshwater fish

Out of the seven minor parasitic taxa, four included at least one parasite species (Figure 7). Annelida had the largest number of parasite species in marine environments, with eight species, while Mollusca had only two species, as illustrated in Figures 7 and 8. Özer (2021) also reported only one member of the phylum Choanozoa, *Sphaerothecum destruens* from *Pseudorasbora parva* while there is no report for any Microspora, Myzozoa, and Metamonada species.

Figure 7A shows the number of annelid species infesting wild freshwater fish hosts and that northern pike *Esox Lucius,* common carp *Cyprinus carpio,* and common roach *Rutilus rutilus* were the hosts for 4, 3, and 2 annelid species, respectively, followed by other 10 fish species infected by only one annelid species. When the Annelid species infecting freshwater host fishes are considered, *Piscicola geometra* was the highest reported species from 13 different host species, and the rest were from 2, and 1 host species (Figure 7B).

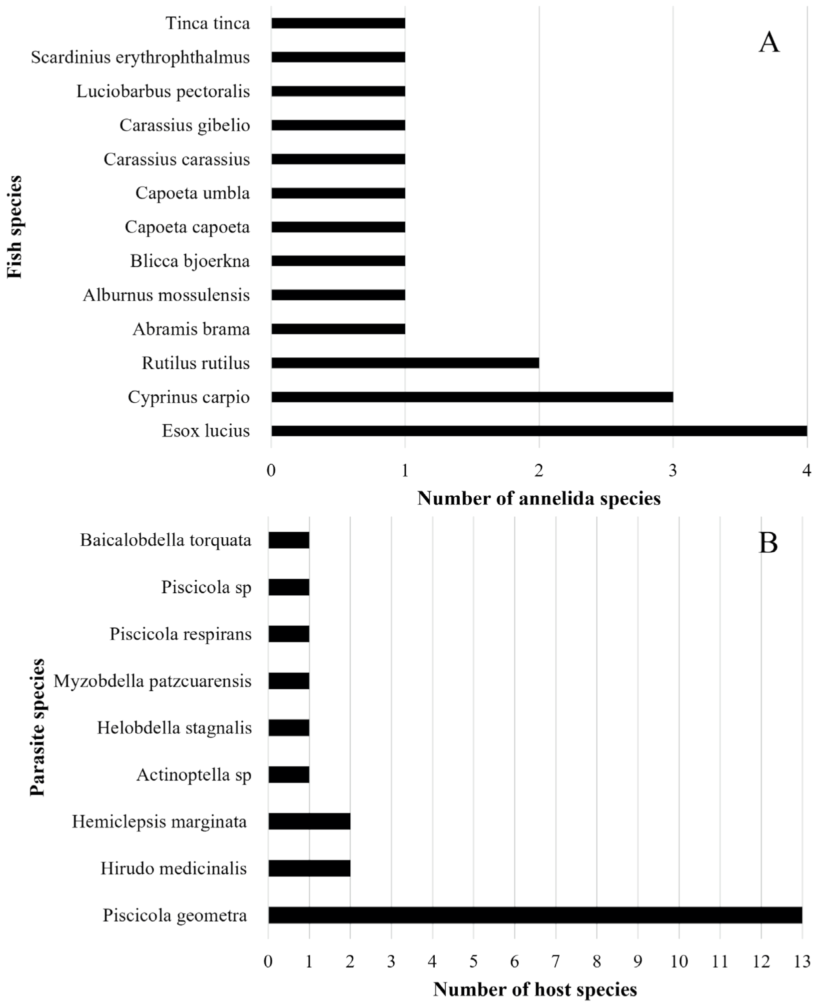

Figure 7. *A) The number of wild freshwater host fish species infected by the members of the phylum Annelida in Türkiye, B) The number of Annelida species infecting the wild freshwater host fishes in Türkiye*

Figure 8A displays the number of mollusk species infesting wild freshwater fish hosts. It shows that white bream (*Blicca bjoerkna*), common roach (*Rutilus rutilus*), rudd (*Scardinius erythrophthalmus*), and tench (*Tinca tinca*) each served as hosts for two mollusk species, while 14 other fish species were infected by only one mollusk species. When the Annelid species infecting freshwater host fishes are considered, *Piscicola geometra* was the highest reported species from 13 different host species, and the rest were from 2, and 1 host species (Figure 7B).

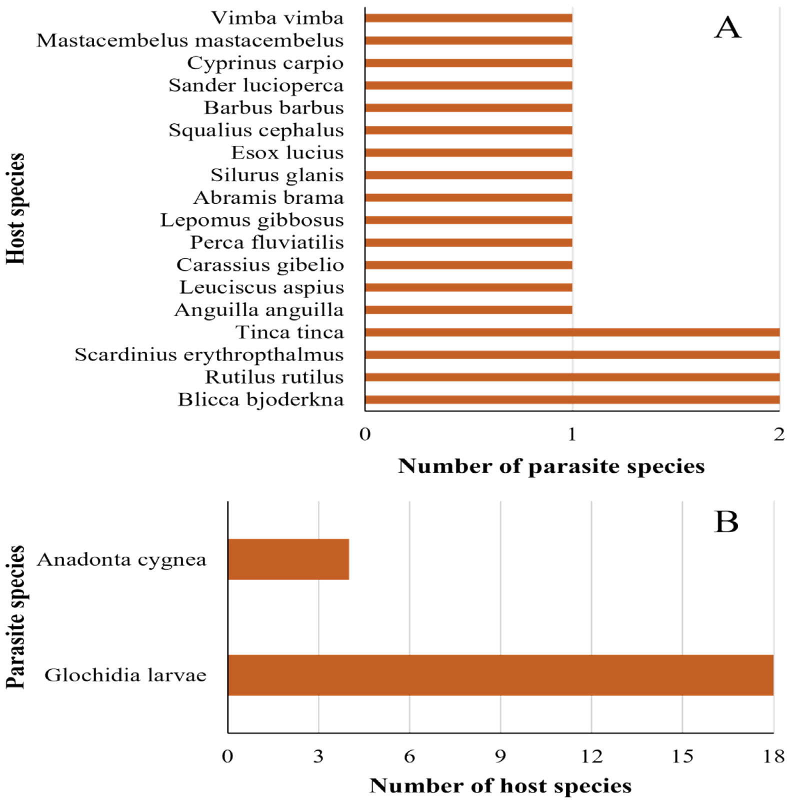

Figure 8. *A) The number of wild freshwater host fish species infected by the members of the phylum Mollusca in Türkiye, B) The number of Mollusca species infecting the wild freshwater host fishes in Türkiye*

4.2. Cultured freshwater fish

Of the 7 minor parasitic taxa, only 2, one of which was named Euglenozoa, were represented by 1 parasite species each (Figure 9). Özer (2021) also reported only one member of the phylum Metamonada, *Hexamita salmonis* from *Oncorhynchus mykiss* while there is no report for any Annelida, Mollusca, Microspora, Myzozoa, and Choanozoa species.

Rainbow trout *Oncorhynchus mykiss* is the most intensively cultured commercial freshwater species in different types of freshwater environments such as rivers, streams, and lakes either in concrete pools or cages in Türkiye. Figure 9 shows the number of Euglenozoa species infesting wild freshwater fish hosts, and 2 salmonid species were the hosts for 1 euglenozoid species, even though one other species reported in genus level belongs to the species level identified parasite.

5. MINOR PARASITIC TAXA DIVERSITY OF AQUARIUM FISHES

According to Özer (2021), a total of 32 ornamental fish species have been reported in Türkiye, and among them, only 9 and 2 have been reported to be infested by the members of Euglenozoa (Figure 10) and Metamonada, respectively. Among them, *Carassius auratus, Carassius* sp, and *Poecilia reticulata* were reported to host only 2 and the others had only one euglenozoid parasite species (Figure 10). On the other hand, *Hexamita* sp, a member of the phylum Metamonada, was reported from *Pterophyllum scalare* and *Carassius auratus* (Özer, 2021).

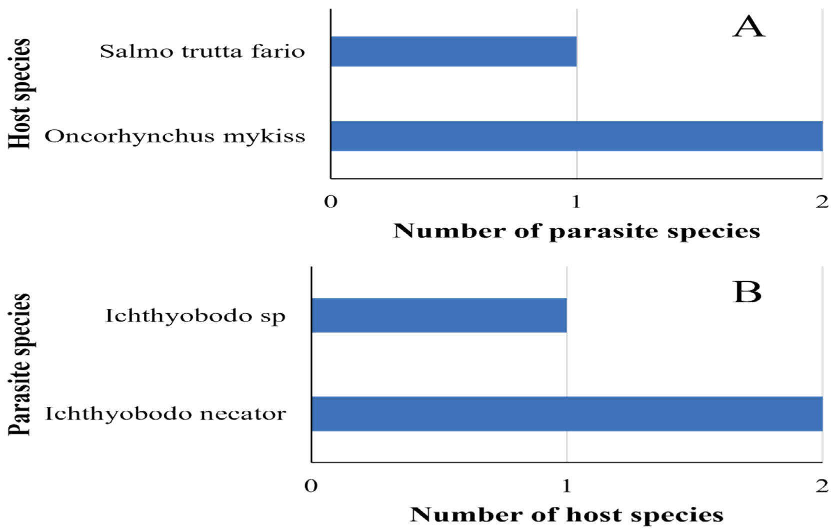

Figure 9. *A) The number of cultured freshwater host fish species infected by the members of the phylum Euglenozoa in Türkiye, B) The number of Euglenozoa species infecting the cultured freshwater host fishes in Türkiye*

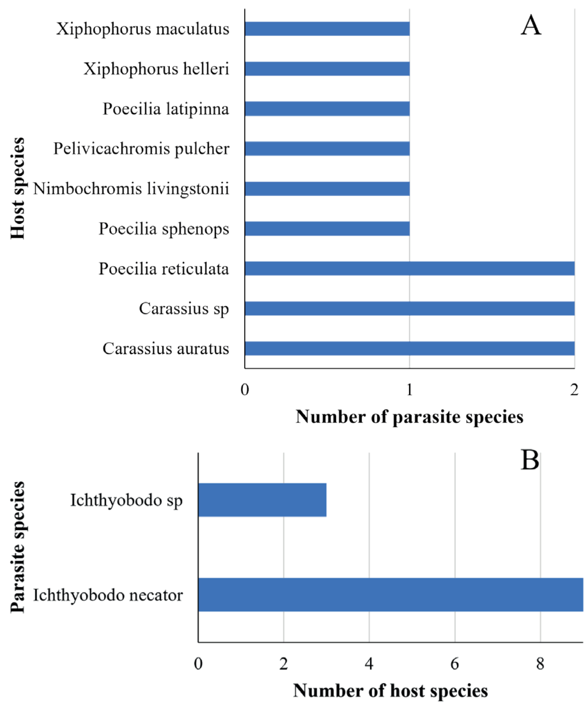

Figure 10. *A) The number of aquarium fish host species infected by the members of the phylum Euglenozoa in Türkiye, B) The number of Euglenozoa species infesting aquarium host fishes in Türkiye*

6. CONCLUSION

The ornamental fish sector is one of the most attractive and growing ones among other fisheries-related sectors. This chapter provided current knowledge on the minor taxa parasites belonging to phyla Annelida, Euglenozoa, Myzozoa, Microsporidia, Metamonada, Mollusca, and Choanozoa of wild, cultured, and ornamental fish hosts in Türkiye based on the comprehensive work conducted by Özer (2021). Members of these parasitic taxa corresponded with 6% of the whole parasite species reported from fishes in Türkiye with a total of 46 parasite species. Wild marine and wild freshwater host fishes had more diverse parasite species than those of cultured and ornamental hosts (Özer, 2021) and these numbers are very low when considering the reported 561 marine and 401 freshwater fish species in Türkiye by Froese & Pauly (2022). It is not known what the actual number of parasite species belonging to the above-mentioned taxa infecting host fishes in marine and inland waters of Türkiye, in the future, however, more studies will yield more numbers of parasite species along with their expanded number of host species.

References

Bachvaroff, T.R., Gornik, S.G., Concepcion, G.T., Waller, R.F., Mendez, G.S., Lippmeier, J.C., Delwiche, C.F. (2014). Dinoflagellate phylogeny revisited: using ribosomal proteins to resolve deep branching dinoflagellate clades. Mol Phylogenet Evol. 70: 314-22.

Berman, J.J. (2012). Taxonomic Guide to Infectious Diseases.http://dx.doi.org/10.1016/B978-0-12-415895-5.00017-9

Brusca, R.C., Lindberg, D.R., Ponder, W.F. (2016). Phylum Mollusca. In: Brusca RC, Moore W, Shuster SM (eds) Invertebrates. Sinauer Associates, Sunderland, pp 453–530

Burreson, E.M. 1995. Phylum Annelida: Hirudinea as vectors and disease agents. In: Fish Diseases and Disorders, Vol. 1: Protozoan and Metazoan Infections. P.T.K. Woo (Ed.): 599-629. CAB International. Oxford.

Cavalier-Smith, T., Chao, E.E. (2004). Protalveolate phylogeny and systematics and the origins of Sporozoa and dinoflagellates (phylum Myzozoa nom. Nov.). Eur J Protistol, 40:185-212.

Ercan, D., Andreou, D., Sana, S., et al. (2015). Evidence of threat to European economy and biodiversity following the introduction of an alien pathogen on the fungal-animal boundary. Emerg Microbes Infect, 4: e52.

Fonseca, C., Mendonça Filho, J.G., Reolid, M., Duarte, L.V., Oliveira, A.D., Sousa, J.T., Lézin, C., (2023). First putative occurrence in the fossil record of choanoflagellates, the sister group of Metazoa. Scientific Reports 13: 1242.

Frenal, K., Soldati-Favre, D. (2009). Role of the Parasite and Host Cytoskeleton in Apicomplexa Parasitism. Cell Host & Microbe, 5(6): 602-611.

Froese, R., Pauly, D. (2022). *FishBase.* World Wide Web electronic publication. www.fishbase.org, version (02/2022).

Gomes, F., Gast, R.J. (2018). Dinoflagellates *Amyloodinium* and *Ichthyodinium* (Dinophyceae), parasites of marine fishes in the South Atlantic Ocean. Diseases of Aquatic Organisms, 131: 27-37.

Harrell, L.W., Elston, R.A., Scott, T.M., et al. (1986). A significant new systemic disease of net-pen reared chinook salmon (*Oncorhynchus tshawytscha* brood stock. Aquaculture, 55: 249–262.

Haszprunar, G., Wanninger, A. (2012). Molluscs. Current Biology, 510-514. https://doi.org/10.1016/j.cub.2012.05.039

Kaygorodova, I., Matveenko, E. (2023). Diversity of the *Piscicola* species (Hirudinea, Piscicolidae) in the Eastern Palaearctic with a description of three new species and notes on their biogeography. Diversity, 15(1): 98. https://doi.org/10.3390/d15010098

Kostygov, A.Y., Karnkowska, A., Votýpka, J., Tashyreva, D., Maciszewski, K., Yurchenko, V., Lukeš, J. (2021). Euglenozoa: taxonomy, diversity and ecology, symbioses and viruses. Open Biol. 11(3): 200407. doi: 10.1098/rsob.200407

Lom, J. (2002). A catalogue of described genera and species of microsporidians parasitic in fish. Systematic Parasitology, 53(2):81-99.

Mattiucci, S., Cipriani, P., Levsen, A., Paoletti, M., Nascetti, G. (2018). Molecular epidemiology of Anisakis and anisakiasis: an ecological and evolutionary road map. Adv Parasitol. 99: 93–263.

Noga, E.J., Levy, M.G. (2006). *Phylum Dinoflagellata*. In: Woo, P. T. K. (Ed.), Fish diseases and disorders, Protozoan and metazoan Infections (pp. 16‑45). Oxford, UK.

Öktener, A. (2003). Checklist of metazoon parasites recorded in freshwater fish from Turkey. Zootaxa, 394: 1-28.

Öktener, A. (2005): A checklist of parasitic helminths reported from sixtyfive species of marine fish from Turkey including two new records of monogeneans. Zootaxa 1063: 33-52

Öktener, A. (2014). Revision of parasitic helminths reported in freshwater fish from Turkey with new records. Transylv. Rev. Syst. Ecol. Res. 16: 1–56.

Özer, A. (2019). *Invasive, Endemic Localized Fishes and Their Parasites*, 177 pp, İdeal Kültür Yayıncılık (In Turkish)

Özer, A. (2020). *Marine Fishes and Parasites*. İdeal Kültür Yayıncılık, 280 pp, (In Turkish)

Özer, A. (2021). *Checklist of Marine Freshwater and Aquarium Fish in Turkey*. Turkish Marine Research Foundation (TÜDAV), 311 pp, Publication No: 62.

Özer, A. (2022). Parasite Biodiversity of Marine, Freshwater and Aquarium Fishes in Turkey. (Editors; Akar, T., Daşdemir, İ., Cengizler, İ.), Current Research in Agriculture, Forestry and Aquaculture, Gece Kitaplığı, pp. 127-143.

Özer, A., & Öztürk T. (2017). Parasite Diversity of the Black Sea Fishes in Turkish Coastal Areas. (Eds: Sezgin, M., Bat, L., Ürkmez, D., Arıcı, E., Öztürk, B.), *In: Black Sea Marine Environment; The Turkish Shelf,* Turkish Marine Research Foundation (TÜDAV) Publication No: 46, pp. 289-309.

Özer, A., Öztürk, T., Yurakhno, V., Kornyychuk, Y.M. (2014). First report of *Eimeria sardinae* (Apicomplexa: Coccidia) near Turkish coast of the Black Sea. Ege Journal of Fisheries and Aquatic Sciences, 31(3): 151-153.

Özer, A., Öztürk, T., Kornyychuk, Y., Yurakhno, V. (2015). Comparative analysis of parasite fauna of whiting, *Merlangius merlangus* L., 1758, collected from northern and southern zones of the Black Sea. Turkish Journal of Fisheries and Aquatic Sciences 15: 285-294.

Post, G. (1987). Textbook of Fish Health. T.F.H. Publications, Inc.. Neptune City, New Jersey. Pp. 165-169.

Rock, S.L., Watz, J., Nilsson, P.A., Österling, M. (2022). Effects of parasitic freshwater mussels on their host fishes: a review. Parasitology 149, 1958–1975.

Simpson, A,G.B., Stevens, J.R., Lukes, J. (2006). The evolution and diversity of kinetoplastid flagellates. Trends in Parasitology, 22(4): 168-174.

Stentiford, G.D., Feist, S.W., Stone, D.M., Bateman, K.S., Dunn, A.M. (2013). Microsporidia: diverse, dynamic, and emergent pathogens in aquatic systems. Trends in parasitology, 29(11): 567-578.

Tikhonenkov, D.V., Gawryluk, R.M.R., Mylnikov, A.P., Keeling, P.J. (2021) First finding of free-living representatives of Prokinetoplastina and their nuclear and mitochondrial genomes. Sci Rep. 11(1): 2946. doi: 10.1038/s41598-021-82369-z.

Williams, E.H., Bunkley-Williams, L., Burreson, E.M. (1994). Some new record of marine and freshwater leeches from Caribbean, southeastern U.S.A., Eastern Pacific, and Okinawan animals. Journal of the Helminthological Society of Washington, 61: 133-138.

Chapter 5

PHOSPHORUS LOAD ESTIMATION USING AN EXPORT COEFFICIENTS IN LAKE MOGAN WATERSHED

Serap PULATSÜ[1]

1 Ankara University, Faculty of Agriculture Department of Fisheries and Aquaculture, 06100, Ankara, Türkiye, ID: https://orcid.org/0000-0001-5277-417X, spulatsu@agri.ankara.edu.tr

Introduction

The exacerbation of the eutrophication problem in lakes is mainly due to increases in point and non-point inputs of nitrogen (N) and phosphorus (P) in lake water, and in recent years climate change has also triggered eutrophication. To improve and protect the quality of water resources, it is crucial to identify and control non-point source pollutants, which, along with point source pollutants, have a significant impact on water and watershed pollution. After the effective control of point source pollution through various methods (such as the treatment of urban sewage and industrial wastewater), the contribution of non-point source pollutants (from agricultural activities, atmospheric deposition, and rural populations) in lake watersheds has become the primary cause of water quality deterioration (Ma and Wang 2015; Wang et al. 2015). In this context, the arrival of nitrogen and phosphorus to receiving waters through irrigation or precipitation-runoff results in various dimensions of eutrophication in lakes (Ma et al. 2011; Chen et al. 2013). In estimating diffuse pollution loads, the following methods are used: a) using GIS or satellite maps to determine area values, b) conducting regular measurements in the receiving environment, c) using models, and d) utilizing existing area data (Biçer 2011).

Water pollution loads are primarily estimated through the mechanism model (MM) and the export coefficient model (ECM). Hydrological and water quality mechanism models such as SWAT, SWMM, STORM, HSPF, ANSWERS, CREAMS, EPDC, AGNPS, and GLEAMS are used to: 1) simulate and predict pollution loads, 2) analyze the temporal and spatial characteristics of pollution, 3) identify major pollution source areas and pathways, and 4) assess the impact of pollution loads on water bodies (Yang et al. 2020, 2022). In principle, hydrological models provide the necessary tools for managing river basins. These models enable the simulation of the effects of potential pollution management strategies, climate change impacts, and land use changes on water quality and quantity. However, compared to complex mechanistic models and regression models, the ECM has been recognized as viable and acceptable for modeling non-point source (NPS) pollution (Ding et al. 2010).

The export coefficient model (ECM) was initially developed in North America to estimate nutrient export from watersheds and nutrient inputs to lakes and rivers (Reckhow and Simpson 1980; Johnes 1996). The export coefficients describe the rates at which nutrients are lost from each source to the surface drainage network and are often obtained from the literature and some field studies (Johnes 1996). The reliability of the ECM in modeling nutrient pollution at the watershed scale has been demonstrated by various studies (Ma and Wang 2015; Wu et al. 2015; Ma et al. 2016). It has also been reported that the ECM method, which requires less data input and uses fewer parameters compared to deterministic models, is simpler than process-based models (Ma et al. 2011). It has been reported that the ECM method does not simulate complex processes such as nutrient generation, transport, and transformation, but it possesses acceptable accuracy on a large scale and is particularly useful in areas with limited observed data (Wu et al. 2015; Li and Zhang 2019).

Early studies using the ECM predicted nutrient export solely as a function of different land use types such as cultivated land, pasture, and forested areas. In contrast, some later studies have also considered factors from non-point sources—such as livestock activities, rural households, and atmospheric deposition—as well as point sources—such as sewage treatment facilities and industrial wastewater discharges. Moreover, these studies have shown that agriculture, residential population, and livestock are generally the main sources of nitrogen (N) and phosphorus (P) in watersheds, and that different watersheds have different dominant sources. Additionally, some researchers have modified the ECM by incorporating influential factors such as precipitation and land use, and have tested the suitability of the enhanced model through empirical studies (Ding et al. 2010; Wang et al. 2015). Beyond revealing past nutrient emission models, the ECM has also been used to simulate future nutrient pollution scenarios under different watershed management scenarios.

Eutrophication of lakes is a significant water quality issue that poses major environmental, economic, and social threats. Since phosphorus is a limiting nutrient in freshwater systems, controlling phosphorus inputs is crucial for preventing eutrophication in freshwater lakes. Understanding phosphorus export and loading from different regions and sources within a lake watershed is important for developing policies aimed at preserving lake water quality and managing the watershed environment sustainably.

The rapid and uncontrolled growth of the Gölbaşı district in Ankara has led to intense pollution pressure on Mogan and Eymir Lakes, which are key attractions within the district. In Mogan Lake (Ankara), which is an eutrophic and shallow lake, extensive eutrophication-focused studies have been conducted for years, and management activities in the lake and its watershed, especially since the 2000s, have also gained momentum. Important components of eutrophication reduction practices for the lake include efforts to reduce external nutrient loadings and sediment removal (dredging) activities. Following these activities, some recent studies have also been conducted in the lake (Topçu and Pulatsü 2017; Küçükosmanoğlu and Filazi 2020; Binici et al., 2021; Topçu and Atlığ 2023).

In the Mogan Lake Basin, studies have been conducted in recent years utilizing various hydrological and water quality models. Özcan et al. (2016) employed the deterministic distributed watershed model SWAT, along with nonlinear optimization models, in the semi-arid region of the Mogan Lake

Basin. Özcan et al. (2017a, b) evaluated the effectiveness of agricultural BMPs in the basin using the SWAT Model again, and they suggested that the calibrated SWAT model could provide useful information for comparing the effects of different management practices on widespread pollution and water quality in the basin.

This study focuses on estimating the phosphorus load from point and various non-point sources in the Mogan Lake Basin using the export coefficient model (ECM). In this context, potential export coefficients based on findings from studies conducted in different receiving environments in Turkey and in the Mogan Lake Basin were used. The study's findings have been compared with the results of the Dillon-Rigler (1975) Model applied to the lake approximately 30 years ago. It is intended that the methodologies presented in the study will contribute to the decision-making process for controlling pollution in the lake basin.

Material and Method

Material

The Mogan and Eymir Lakes basin is an ecological system with a very delicate balance, characterized by its water resources, topography, soil and terrain structure, climate features, and living organisms. To protect the lakes, an area of 245 km², including the Gölbaşı district center and 10 settlements, was designated as a Special Environmental Protection Area by a Council of Ministers decision on October 22, 1990. All planning and oversight authority for this area was transferred to the Special Environmental Protection Agency (Directorate General for the Protection of Natural Assets). Mogan Lake is a natural reservoir lake formed behind alluvial barriers at the lower end of a generally flat to moderately rugged basin. Its surface area is approximately 5.6 km². The lake drains into Eymir Lake, located 2 km to the south, which has a 1.25 km² area and is situated 5 meters lower in elevation. Eymir Lake features a wetland transition zone both underground and on the surface (Anonymous 2024a). In the Mogan Lake Basin, there are also the Ikizce (Topaklı) and Dikilitaş reservoirs, constructed for irrigation purposes.

Method

In this study, the main diffuse (non-point) and point source phosphorus inputs in the basin were considered in estimating the total phosphorus load reaching Lake Mogan.

- Estimation of diffuse phosphorus loads

The non-point sources of phosphorus in the basin have been classified as land use, agricultural activities (fertilization), livestock activities, and septic effluents. Atmospheric deposition, which is also a non-point source, has been disregarded. As is known, the sources of diffuse pollution loads from atmospheric transport and air pollution include industrial activities, fossil fuels used for heating in residential areas, and exhaust gases from motor vehicles. These pollutants not only cause air pollution but also contaminate water sources in the basin through rain. Due to atmospheric accumulation, phosphorus loads do not generally form from emissions related to heating, industrial activities, or traffic. In studies conducted on a basin scale in Turkey, NOx and NH_3 parameters have been evaluated as pollutants in terms of atmospheric accumulation when estimating diffuse loads (Anonymous 2024b).

The values used for the different sources considered in the study are explained below (Table 1). The general form of the model is as follows, in accordance with the principles outlined by Johnes (1996) and Hou et al. (2017):

$$L_{TP} = \sum_{i=1}^{m} E_{ij} \times A_i \qquad (1)$$

L_{TP} = TP load (kg/year)

i = The land use type with a total of m species

E_{ij} = The export coefficient of pollutants j in land use type i (kg/km^2),

the excretion coefficient of each livestock and poultry of type i (kg/year),

or the export coefficient per person (kg/year)

A_i = The area of land use type i in the catchment

The phosphorus load calculated according to Equation (1) corresponds to the amount of phosphorus in the soil resulting from activities from different sources. Subsequently, it is necessary to determine the extent to which the estimated phosphorus load reaches the receiving environment. For this purpose, possible attainment values provided in the literature for each phosphorus source have been accepted.

Diffuse loads from land use: All pollutants entering the receiving environment as distributed pollutants arrive through surface runoff, and to estimate these loads, information on land types and their areas is required. The five different land use types (water/wetland, forest, agriculture, meadow, unused land) selected for the Mogan Lake basin and their areas are presented in Table 1. For this category, the transport coefficient value of 0.25 proposed by Hou et al. (2017) has been used.

Diffuse loads from agricultural activities: : In this category, phosphorus from fertilizer use in agricultural activities has been specifically considered. Özcan et al. (2017b) reported that four types of fertilizers—urea, ammonium nitrate, ammonium sulfate, and diammonium phosphate—are used in the agricultural lands of the basin, and that fertilizers used to increase the growth of wheat are mostly nitrogen-based. They also reported that 25 kg of Diammonium phosphate (18-46-00) fertilizer is applied per decare before or during planting. Therefore, in the estimation of phosphorus loads from fertilization, the pure phosphorus content of this fertilizer has been taken into account. For losses due to leaching and surface runoff, it has been assumed that 5% of the applied phosphorus reaches the receiving environment (Tanık et al. 2010; Haksevenler and Ayaz 2021).

Diffuse loads from livestock activities: Despite the rapid reduction of agricultural lands, small and large livestock farming remains quite widespread. In addition to livestock farming, poultry farming and beekeeping are also practiced (Anonymous 2024a). The basin has 28,948 large cattle, 167,301 small ruminants, and 501,693 poultry (TURKSTAT 2024). To determine the accepted excretion coefficients for each livestock group, the average live animal weights were assumed to be 500 kg for cattle, 45 kg for small ruminants, and 2 kg for poultry. The load from livestock activities was estimated based on the principles reported by Haksevenler and Ayaz (2021) and Tırınk (2021). In this study, based on the assumption that farms use their own fertilizers by spreading them on their fields, the percentage of phosphorus reaching the receiving environment was assumed to be 5%.

Diffuse loads from septic tank leachate: Generally, rural settlements use either leaky or non-leaky septic tanks. For the Gölbaşı District, the rural population is 10,088 people, and the total number of septic tanks where the district's wastewater is stored is reported to be 27 (Anonymous 2023). The value required for leachate from wastewaters to reach the receiving environment was accepted as 0.30 as suggested by Hou et al. (2017).

- Estimation of point phosphorus load

Regarding the basin, only urban wastewater from point sources has been considered. Gölbaşı hosts numerous medium and large-scale industrial facilities. Most of these facilities, located mainly along the Konya Road and Haymana Road, are engaged in food, electronics, and construction activities. Additionally, andesite stone manufacturing facilities are located within the boundaries of Gerder Neighborhood (Anonymous 2024a). In this study, it is assumed that the industrial facility discharges, which fall under point source pollutants, are directed to the wastewater treatment plant, and thus, only a single point source of pollution is considered for the basin.

Point phosphorus load from urban wastewater: It is reported that the urban population of Gölbaşı District, one of the twenty-five districts in Ankara, was 128,856 as of 2022 (Anonymous 2023). The district, located within the boundaries of the Ankara Metropolitan Municipality, is connected to the sewer system managed by the ASKİ General Directorate. Wastewater from the district is treated at the central wastewater treatment plant located in the Tatlar area of Sincan District and then discharged into the Ankara Stream (Anonymous 2024a). The Ankara Central Wastewater Treatment Plant is the largest wastewater treatment facility in Turkey, with a capacity of 765,000 m^3/day, and it only performs carbon removal. The plant is designed as a 'Classical Activated Sludge Process'. According to Anonymous (2010), the TP (total phosphorus) value for areas with a population range of 50,000-100,000 is reported to be 1.1 g/person-day. The efficiency of phosphorus removal in the existing urban wastewater treatment plant is assumed to be 10%. The transport coefficient for the urban population connected to the wastewater treatment plant was assumed to be 1 (Hou et al. 2017).

Table 1. *Export coefficients of total phosphorus (TP) sources used for Lake Mogan watershed*

TP source	**A_i**	**Export Coefficient**	
Land use class	Area (km^2)	Unit kg/ha/year	Reference
Water/Wetland	11.74	0.36	Özcan et al. (2016), Özcan et al. (2017a)
Forest	18.62	0.42	
Agriculture	297.69	0.07	
Meadow	408.95	0.13	
Unused land	33.85	0.36	
Agricultural activities	29.52	250 kg/ha/year (DAP application)	Özcan et al. (2017a)
Livestock activities	Number	kg/animal/year	Haksevenler and Ayaz (2021), Tırınk (2021), TURKSTAT (2024)
Cattle	28.948	0.91	
Small ruminat	167.301	0.05	
Poultry	501.693	0.08	
Septic tank leachate	Population	(g/person/day)	Hou et al. (2017), Anonymous (2023), Haksevenler and Ayaz (2021)
	10.088	0.7	

Results and Discussion

In accordance with the principles provided in the Materials and Methods section, the estimated total phosphorus load values, based on Equation (1) and the load values reaching the receiving environment, are presented in Table 2. As shown in the table, the diffuse phosphorus load is 117.13 tons/year, which significantly exceeds the estimated point phosphorus load value (5.17 tons/year) in this study.

The methodology for estimating export coefficients for nutrient elements, particularly nitrogen and phosphorus, that trigger eutrophication is largely dependent on the spatial values of different land use activities, population, and unit loads related to various activities. In this study, the EC value (0.07 kg TP/ha/year) reported by Özcan et al. (2016) is specific to agricultural land within the basin. The researchers estimated the unit total nitrogen and phosphorus loads from the basin during rainy periods to be 0.46 kg TN/ha/year and 0.07 kg TP/ha/year, respectively. They also pointed out that the estimated unit nutrient loads, both at the basin scale and for different land use categories, could be used to assess common pollution control measures for similar regions with semi-arid conditions and intensive agricultural activities.

Table 2. *Estimated total phosphorus (TP) load from non-point and point sources in Lake Mogan watershed*

TP source	**Load$_{TP}$** (ton/year)
Non-point sources	
Land use class	2.46
Agricultural activities	75.26
Livestock activities	38.64
Septic tank leachate	0.77
Total diffuse load	117.13
Point source	5.17
Total phosphorus load (L_{TP})	122.30

Empirical nutrient balance models are commonly used to predict in-lake nutrient concentrations based on nutrient loading to lakes. Among the best-known empirical models are those published by Dillon and Rigler (1975) and Vollenweider (1976). These models combine nutrient budget data with information on lake morphometry and water budget. One of the lakes where the Dillon-Rigler model, based on phosphorus load estimation, has been successfully applied is Mogan Lake. Using this model, Pulatsü and Aydın (1997) determined the terrestrial load values as 126.61 kg/year for 1993 and

112.40 kg/year for 1994. In another study in the same field using the same model (Fakıoğlu and Pulatsü 2005), the terrestrial phosphorus load was estimated to be 2,668.88 kg for the year 2003. In both studies, phosphorus transport coefficients for the rivers feeding the lake in the basin (Sukesen, Yavrucak, Çölova, Başpınar) were used for estimating terrestrial load. In this study, however, a more detailed approach was taken by considering four different categories and export coefficients contributing to non-point phosphorus loads. The diffuse phosphorus load was estimated as 117.13 tons/year, providing a general quantitative approach for the basin.

In determining the artificial phosphorus load reaching the lake for the years 1992-1994, Pulatsü and Aydın (1997) used the value of 0.80 kg/capita/year reported by Dillon and Rigler (1975), as a reliable coefficient for phosphorus per household had not yet been established. They estimated the artificial phosphorus load to be 2,998 kg/year. Fakıoğlu and Pulatsü (2005), based on the average phosphorus value of 3.5 g per person per day given in the Bank of Provinces Wastewater Treatment Facility Process General Specifications, calculated the artificial phosphorus load as 8084 kg/year. In this study, however, there has been approximately a 2.5-fold increase in the district's population over the past twenty years, and the amount of phosphorus discharged per person has been determined as 5.7 tons per year, based on a value of 1.1 g/person/day according to the "Wastewater Treatment Facilities Technical Communique" (Anonymous 2010). In other words, the point source phosphorus load has been found to be lower when considering the methodological differences and estimated diffuse phosphorus load. In this context, the main factor for the relatively low level of anthropogenic phosphorus load seems to be that a significant portion of the district's point source wastewater is connected to the sewage system of the ASKİ General Directorate.

While Fakıoğlu and Pulatsü (2005) determined the total phosphorus load reaching Lake Mogan to be 10,941 kg/year, this study, which uses the ECM Model and particularly addresses diffuse sources in detail, estimates it to be 122.30 tons/year based on current data. This quantitative approach, which can describe in general terms, reflects the basin-based pressure on the lake over the past twenty years.

The most suitable scale for monitoring all effects of interventions in areas where different sectors and resource users are considered together, and threats and opportunities are evaluated in the long term, is the watershed. In Turkey, knowing the current water resources and water quality in watersheds is a prerequisite for making future projections; therefore, both at the provincial and watershed levels, quantity and quality assessments have been conducted comprehensively (Pulatsü et al. 2014). Additionally, there are studies specifically focused on agricultural and rural non-point source (NPS) pollution in Turkey (Tanık et al. 2010, 2013; Katip and Karaer 2013; Derin et al. 2019; Hacısalihoğlu and Karaer 2020; Cebe and Uysal 2024). A common point of these studies is that, considering all variables, each watershed has a unique phosphorus budget. In this context, the fundamental watershed components and load values of Lake Mogan have also shown variability.

With this study, the higher determination of agricultural diffuse pollution compared to other categories in the Lake Mogan Watershed (75.26 tons/year) supports the importance of BMPs for agricultural diffuse pollution in the watershed, as reported in studies conducted by Özcan et al. (2016, 2017a, b).

There are also recent studies in Turkey focusing on the calculation of diffuse TN (Total Nitrogen) and TP (Total Phosphorus) loads resulting from livestock activities among non-point source pollutants (Yetiş et al. 2018; Kumaş and Akyüz 2020; Tırınk 2021; Ertop et al. 2022). For the Lake Mogan Watershed, the estimated diffuse livestock load (38.64 tons/year) is lower compared to the total phosphorus loads identified in most of the aforementioned studies, but it remains the most significant category among non-point sources after agricultural activities. In this context, as reported by Ertop et al. (2022), it is important to establish an integrated database to track changes in animal numbers and pollutant diffuse loads. Additionally, Arata et al. (2022) emphasized the assumption that there is no phosphorus loss in animal shelters due to impermeable manure collection systems such as concrete floors or sludge channels, or that there is no runoff from manure storage facilities that are of sufficient size and assumed to have leakage.

In estimating the diffuse phosphorus load from septic system leachate at the watershed level, attention should be paid to whether settlements are connected to a sewage system. It has been reported that septic systems are used in some rural areas of the Lake Mogan Watershed (Anonymous 2023). Therefore, a portion of rural discharges has been considered as a diffuse source; however, due to the low population in the rural areas, the load value for this category (0.77 tons/year) is found to be relatively low compared to other categories. In addition, as reported by Tanık et al. (2010), many factors, such as soil properties, climatic conditions, the specific characteristics of fertilizers and forest components (decomposing material, topsoil, etc.), and the behavior of nutrients transported in the soil, influence the transport mechanisms in the soil.

Generally, it is anticipated that point source pollutants are relatively easier to control compared to diffuse pollutants, as their sources can be observed at the watershed level. In the facility reported as Turkey's largest wastewater treatment plant, which treats the sewage from the Gölbaşı District, a large portion of phosphorus cannot be removed. In other words, the point source phosphorus load, which is estimated to be lower compared to diffuse pollutant sources in the watershed, will continue to pose a significant threat, especially when considering urban population projections.

Conclusion

- Factors such as the increasing population, urbanization, changes in land use, sediment transport, the rise in agricultural pesticide use, and mining activities, along with climate change, have made annual changes in water and sediment quality in Lake Mogan (Ankara) inevitable. In this study of the Lake Mogan Watershed, it has been possible to approximately estimate the non-point (diffuse) and point phosphorus loads using the ECM Model.

- Watersheds will clearly exhibit a wide range of variability in nutrient export due to their specific climatological and physiographic characteristics, as well as differing agricultural and urban land uses. In this context, identifying possible regional trends in EMCs and the use of “localized” values are of particular importance.

- Based on the diffuse and point phosphorus load values in the Lake Mogan watershed, it has been demonstrated that the most significant reduction in phosphorus load can be achieved through organic farming and livestock practices. However, to identify the most realistic measures for reducing diffuse loads, more detailed investigations throughout the entire watershed will be necessary in the future.

- For reducing diffuse pollutants in the watershed, the implementation of best agricultural practices such as irrigation techniques, crop selection, timing, frequency, and amount of fertilizer applications, transitioning to organic farming that avoids pesticides and commercial fertilizers, appropriate reuse of animal waste in agriculture, and controlling non-agricultural areas play a crucial role.

- Increasing awareness among farmers about diffuse loads and educating them on best management practices are also urgent matters. There is a need for long-term protective measures to ensure the sustainability of Lake Mogan.

References

Anonymous. 2010. Atıksu Arıtma Tesisleri Teknik Usuller Tebliği. Resmî Gazete Tarihi: 20.03.2010 Resmî Gazete Sayısı: 27527. (in Turkish)

Anonymous. 2023. Ankara İli İçmesuyu, Atıksu ve Yağmursuyu Yönetimi Master Planı. ASKİ Genel Müdürlüğü, 602 s., Ankara (in Turkish)

Anonymous. 2024a. Gölbaşı Belediyesi. Stratejik Plan 2020-2024. Yayın No: 3, 76 s. Ankara. https://www.ankaragolbasi.bel.tr/uploads/stratejik-plan_v/2020-2024-stratejik-plan.pdf (in Turkish)

Anonymous. 2024b. Havza Koruma Eylem Planlarının Hazırlanması-Kızılırmak Havzası. TÜBİTAK MAM Çevre Enstitüsü. https://www.tarimorman.gov.tr/SYGM/Belgeler/Kızılırmak Havzası pdf. (in Turkish)

Arata, L., Chakrabarti, A., Ekane, N., Foged, HL., Pahmeyer, C., Rosemarin, A., Sckokai, P. 2022. Assessment of environmental and farm business impacts of phosphorus policies in two European regions. Front. Sustain. Food Syst. 6: 852887. https://doi.org/10. 10.3389/fsufs.2022.852887

Biçer, C. A. 2011. Göl Alt Havzaları Bazında Yayılı Kaynaklardan Oluşan N ve P Yükünün Tahmini: Burdur Havzası Örneği. Yüksek Lisans Tezi, İstanbul Teknik Üniversitesi, Fen Bilimleri Enstitüsü, 102s., İstanbul. (in Turkish)

Binici, A., Pulatsü, S., Bursa, N. 2021. Evaluation of sediment dredging on heavy metal concentrations in Mogan Lake's sediment (Ankara, Turkey). COMU J. Mar. Sci. Fish., 4, (2):159-167. https://doi.org/10. 46384/jmsf.987343

Cebe, K. and Uysal, O. G. 2024. Estimating of non-point pollution sources and pollution loads in Kesikköprü Reservoir Basin. NOHU J. Eng. Sci., 13(1):253-261. https://doi.org/10. 28948/ngumuh.1355285

Chen, H., Teng, Y., Wang, J. 2013. Load estimation and source apportionment of nonpoint source nitrogen and phosphorus based on integrated application of SLURP model, ECM, and RUSLE: a case study in the Jinjiang River, China. Environmental Monitoring and Assessment, 185, 2009–2021. https://doi.org/10. 1007/s10661-012-2684-z

Derin, P., Yetiş, AD., Yeşilnacar, Mİ., Yetiş, R. 2019. Mardin Merkez ve İlçeleri için Antropojenik Yayılı Kirletici Kaynaklarından Hayvansal Kirlilik Yükünün Belirlenmesi. 72. Uluslararası Katılımlı 72. Türkiye Jeoloji Kurultayı, 28 Ocak–01 Şubat 2019, Ankara, Türkiye, p. 694-698. (in Turkish)

Dillon, P.J., Rigler, F.H., 1975. A simple metod for predicting the capacity of a lake for development based on lake trophic status. J. Fish. Res. Board Can., 2(9):1519-1531.

Ding, XW., Shen, ZY., Hong, Q., Yang, ZF., Wu, X., Liu, RM. 2010. Development and test of the export coefficient model in the upper reach of the Yangtze River. J Hydrol., 383: 233–44. https://doi.org/10.1016/j.jhydrol.2009.12.039

Ertop, H., Aksoy, E., Atılgan, A., Saltuk, B. 2022. Doğu Anadolu Bölgesi Büyükbaş

Hayvansal Atıkların Yayılı Kirletici Yükü Hesabı. Akademisyen Yayınevi, Biyosistem Mühendisliği 3, Editörler: Atılgan Atılgan, Hasan Değirmenci, Çağatay Tanrıverdi, Vecdi Demircan, 39-50, Ankara. (in Turkish)

Fakıoğlu, Ö. and Pulatsü, S. 2005. Determination of external phosphorus loading in Mogan Lake (Ankara) following some restoration measures. Yüzüncü Yıl Üniversitesi, Ziraat Fakültesi Tarım Bilimleri Dergisi (J. Agric. Sci.), 15(1):63-69. (in Turkish)

Hacısalihoğlu, S. and Karaer, F. 2020. Uluabat Gölü noktasal kirletici kaynaklar ve kirlilik yükleri. Doğal Afetler ve Çevre Dergisi, 6(2):258-267. https://doi.org/10.21324/dacd.602385 (in Turkish)

Haksevenler, B. H. G. and Ayaz, S. 2021. The effect of point and diffuse pollution sources on surface water quality, A case study for Alaşehir Aiver sub-basin. GÜFBED/GUSTIJ, 11 (4): 1258-1268. https://doi.org/10.17714/gumusfenbil.882693

Hou, Y., Chen, W., Liao, Y., Luo, Y. 2017. Modelling of the estimated contributions of different sub-watersheds and sources to phosphorous export and loading from the Dongting Lake watershed, China. Environ Monit Assess., 189: 602. https://doi.org/10.1007/s10661-017-6293-8

Johnes, P. J. 1996. Evaluation and management of the impact of land use change on the nitrogen and phosphorus load delivered to surface waters: the export coefficient modelling approach. Journal of Hydrology, 183, (3–4):323–49.

Katip, A. and Karaer, F. 2013. Research on the non-point pollution loads in the Lake Uluabat Basin. Journal of Environmental Protection, 4, 29-37. https://doi.org/10.4236/jep.2013.47A004

Kumaş, K. and Akyüz, A. 2020. Analysis of pollution load originating from cattle, small ruminant and poultry: A comparative case study for Isparta, Turkey. International Journal of Energy Applications and Technologies, 7(3): 50-53. https://doi.org/10.31593/ijeat.764217

Küçükosmanoğlu, A. G. and Filazi, A. 2020. Investigation of the metal pollution sources in Lake Mogan, Ankara, Turkey. Biological Trace Element Research, 198, 269-282. https://doi.org/10.1007/s12011-020-02031-z

Li, H.Z. and Zhang, M.X. 2019. A review on the calculation of non-point source pollution loads. IOP Conf. Ser.: Earth Environ. Sci., 344 012138. https://doi.org/10.1088/1755-1315/344/1/012138.

Ma, X., Li, Y., Zhang, M., Zheng, F., Du, S. 2011. Assessment and analysis of non-point source nitrogen and phosphorus loads in the Three Gorges Reservoir Area of Hubei Province, China. Science of the Total Environment, 412-413, 154–161. https://doi.org/10.1016/j.scitotenv.2011.09.034

Ma, G., and Wang, S. 2015. Temporal and spatial distribution changing characteristics of exogenous pollution load into Dianchi Lake, Southwest of China. Environmental Earth Sciences, 74, 3781–3793. https://doi.org/10.1007/s12665-015-4721-z

Ma, X., Li, Y., Li, B., Han, W., Liu, D., Liu, X. 2016. Evaluation of nitrogen and phosphorus loads from agricultural nonpoint source in relation to water quality in Three Gorges Reservoir Area, China. Desalination and Water Treatment, 57, 20985–21002. https://doi.org/10.1080/19443994.2015.1112307

Özcan, Z., Kentel, E., Alp, E. 2016. Determination of unit nutrient loads for different land uses in wet periods through modelling and optimization for a semi-arid region. J. Hydrol., 540, 40–49. https://doi.org/10.1016/j.jhydrol.2016.05.074

Özcan, Z., Başkan, O., Düzgün, Ş., Kentel, E., Alp, E. 2017a. A pollution fate and transport model application in a semi-arid region: Is some number better than no number? Science of The Total Environment, 595, 425-440. https://doi.org/10.1016/j.scitotenv.2017.03.240

Özcan, Z., Kentel, E., Alp, E. 2017b. Evaluation of the best management practices in a semi-arid region with high agricultural activity. Agricultural Water Management, 194, 160-171. https://doi.org/10.1016/j.agwat.2017.09.007

Pulatsü, S., and Aydın, F. 1997. Water quality and phosphorus budget of Mogan Lake, Turkey. Acta Hydrochimica et Hydrobiologica, 25, 128–134.

Pulatsü, S., Topçu, A., Atay, D. 2014. Su Kirlenmesi ve Kontrolü, A.Ü. Ziraat Fakültesi, Yay. No:1617, 384s, Ankara. (in Turkish)

Reckhow, K. H. and Simpson, J. T. 1980. A procedure using modeling and error analysis for the prediction of lake phosphorus concentration from land use information. Canadian Journal of Fisheries and Aquatic Sciences, 37, 1439–1448.

Tanık, A., Yontar, B., Şeker, D.Z. 2010. Determination and control of diffuse pollutants arising from watersheds - A case study from Turkey. Fresenius Environmental Bulletin, 19 (10):2324-2333.

Tanık, A., Ozalp, D., Şeker, D.Z. 2013. Practical estimation and distribution of diffuse pollutants arising from a watershed in Turkey. Int. J. Environ. Sci. Technol., 10:221–230. https://doi.org/10.1007/s13762-012-0140-9

Topçu, A. and Pulatsü, S. 2017. Evalution of some management strategies in eutrophic Mogan lake, Turkey: phosphorus mobility in the sediment-water interface. Applied Ecology and Enviromental Research, 15(4):705-717. https://doi.org/10.15666/aeer/1504_705717

Topçu, A. and Atlığ, S. 2023. Post-dredging nitrogen dynamics at the sediment–water interface: the shallow, eutrophic Mogan Lake, Turkey. Oceanological and Hydrobiological Studies, 52,1,124-136. https://doi.org/10.26881/oahs-2023.1.10

Tırınk S. 2021. Environmental effects and diffuse pollution load calculation of animal wastes in Iğdır province and districts. BSJ Eng Sci, 4(2):43-50. https://doi.org/10.34248/bsengineering.841821

TURKSTAT 2024. Turkish Statistical Institute. https://data.tuik.gov.tr/Search/Search?text= hayvansal%20%C3%BCretim

Vollenweider, R.A., 1976. Advences in defining critical loading levels for phosphorus in lake eutrophication. Mem. Ist. Ital. Idrobiol., 33:53-83.

Wang, J., Shao, J., Wang, D., Ni, J., Xie, D. 2015. Simulation of the dissolved nitrogen and phosphorus loads in different land uses in the Three Gorges Reservoir Region-based on the improved export coefficient model. Environmental Science: Processes & Impacts, 17, 1976–1989. https://doi.org/10.1039/C5EM00380F

Wu, L., Gao, J., Ma, X., Li, D. 2015. Application of modified export coefficient method on the load estimation of non-point source nitrogen and phosphorus pollution of soil and water loss in semiarid regions. Environmental Science and Pollution Research, 22, 10647–10660. https://doi.org/10.1007/s11356-015-4242-z.

Yang, S., Zheng, M., Liu, C., Ma, Y., Wang, Q. 2020. Research Progress of Agricultural Non-point Source Pollution Models[J]. Adm. Tech. Environ. Monit., 32 (03): 8–13. https://doi.org/10.19501/j.cnki.1006-2009.20200513.006

Yang L, Zhang M, Wei J., Qi J. 2022. Pollution Load Estimation and Control Countermeasures of Zhangze Reservoir. Front. Environ. Sci. 10:874124. https://doi.org/10.3389/fenvs.2022.874124.

Yetiş, DA., Yetiş, R., Gazigil, L. 2018. Bitlis Merkez ve İlçelerinin Hayvansal Kaynaklı Kirlilik Yükü Hesabı. International Symposium on Urban Water and Wastewater Management, Denizli, s. 610-617.