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ARAŞTIRMA MAKALESİ **RESEARCH PAPER**

Condition factor and meat yield of invasive zebra mussels (*Dreissena polymorpha*) in Lake Çıldır, Karakaya, and Keban Reservoirs in Turkey

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Abstract: This study presents a comprehensive view of the condition factor and meat yield of *Dreissena polymorpha* in Çıldır Lake, Keban, and Karakaya reservoirs. A diverse sample of 472 *D. polymorpha* (154 from Çıldır Lake, 169 from Karakaya Reservoir, and 149 from Keban Reservoir) was collected. The condition factor of zebra mussels in the Keban reservoir was the highest, with an average of 46.88, followed by zebra mussels in the Karakaya reservoir with 46.33. The zebra mussel in Çıldır Lake showed the lowest value, averaging 20.77. The fresh meat yield of zebra mussels in Çıldır Lake was lower than the fresh meat yields of zebra mussels in the Keban and Karakaya reservoirs. However, dry meat yield was higher. The dry meat yields of zebra mussels in all three reservoirs were found to vary significantly ($P<0.05$).

Keywords: Condition index, çıldır lake, *Dreissena polymorpha*, karakaya reservoir, keban reservoir, meat yield.

Türkiye'deki Çıldır Gölü, Karakaya ve Keban baraj Göllerindeki Istilacı Zebra Midyelerin (*Dreissena polymorpha*) Kondisyon Faktörü ve Et Verimi

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Öz: Bu çalışmada Çıldır gölü, Keban ve Karakaya baraj göllerindeki *Dreissena polymorpha*'nın vücut kondisyonu ve et verimi araştırılmıştır. Çıldır Gölünden 154, Karakaya baraj gölünden 169 ve Keban baraj gölünden 149 toplamda 472 adet *D. Polymorpha* örneklenmiştir. Keban baraj gölündeki zebra midyelerin kondisyon indeksinin 46.88 ortalama ile en yüksek olduğu, bunu 46.33 ile Karakaya baraj gölündeki zebra midyelerin takip ettiği tespit edilmiştir. Çıldır Gölü'ndeki zebra midyenin ise 20,77 ortalama ile en düşük değeri göstermiştir. Çıldır Gölü'ndeki Zebra midyelerin yaş et verimi Keban ve Karakaya rezervuarlarındaki Zebra midyelerin yaş et verimlerine kıyasla daha düşüktü. Bununla birlikte, kuru et verimi daha yüksekti. Ayrıca, her üç göldeki Zebra midyelerin kuru et verimlerinin önemli ölçüde değiştiği bulunmuştur ($P<0.05$).

Anahtar kelimeler: Çıldır gölü, *Dreissena polymorpha*, et verimi, karakaya baraj gölü, keban baraj gölü, kondisyon indeksi.

INTRODUCTION

German scientist Peter Simon Pallas was the first to identify and name *Dreissena polymorpha* (Pallas, 1771) in the Volga, Dnieper, and Ural rivers. This mussel species is considered one of the most significant invasive freshwater creatures globally (Bobat et al., 2004). Although its natural distribution area is defined as the Black Sea and Caspian Sea Basin, including Turkey, it is believed to have spread to other continents (Altınayar et al., 2001; Son, 2007). *D. polymorpha* was studied in the Northern Dvina River basin, revealing the first record of populations in the Yuras, Lyavlya, and Solombalka Rivers (Travina et al., 2020). Much research has focused on this mussel species, especially in Europe, since the last century, and it spread to North America in 1988 (Sprung & Borcherding, 1991).

The reported longevity of *D. polymorpha* ranges from 2 to 19 years, and it is not clear how much of this variation is due to biological variability and environmental conditions and how much is due to the methods used to assess age and longevity (Karatayev et al., 2006). Vaate (1991) found that the *D. polymorpha* population in the IJsselmeer Lake region reached sexual maturity at over one year of age.

In various studies, it has been reported that they have a density of 30,000-100,000 individuals/m^2 on the material they attach to and cause the death of freshwater mussels as a result of infestation (Baker & Hornbach, 2000; Marszewska et al., 2019; Vrtílek & Reichard, 2012). This infestation leads to food competition, oxygen deprivation, and a loss of condition in the mussels it clings to. *D. polymorpha* spread by clinging to piers, marine vessels, stones, rocks, and other organisms, creating mechanical obstacles like blockages in irrigation canals and hydroelectric power plants and reducing water flow rates (Ercan et al., 2013). Fighting against this species has become necessary due to the economic losses it causes (Gaygusuz et al., 2007). *D. polymorpha* is not commercially exploited but is a crucial component of food webs in river ecosystems, desalinated lagoons, and bays, such as Taganrog Bay in the Sea of Azov (Travina et al., 2020).

Analyzing the distribution of heavy metals in different *D. polymorpha* populations can help assess water pollution and concentration and evaluate the food reserve for fish and birds in these water bodies (Lebedeva & Panasjuk, 2011). *D. polymorpha*'s role in the food chain positively impacts many species' nutrition, growth, and population structure. However, its high adaptation to environmental conditions and rapid reproduction adversely affect other reservoir species in reservoirs. Therefore, controlling *D. polymorpha* has become essential (Berber et al., 2018). Kutluyer et al., (2013) suggested using crayfish, natural enemies of *D. polymorpha*, for its biological control in natural environments.

Biological characteristics such as weight-length relationships (WLR) and condition factor (CF) are crucial for marine biologists, fisheries managers, and ecological studies. These parameters help estimate the condition, food and nutrition, life history, reproductive activity, and spawning of certain aquatic organisms (Stergiou & Moutopoulos, 2001). Weight-length models offer an efficient method for determining invertebrate biomass (Hawkins et al., 1997).

Schernewski et al., (2019) suggested in a scenario for Oder (Szczecin) Lagoon that Zebra mussels could replace blue mussels, as they have similar nutritional content and composition. They found similar water content (84-89%) and crude ash content (1.3%) between mussel species and proposed their use in protein-rich animal feed rations. Completed and ongoing trials in the Baltic Sea area suggest that Zebra mussels can be used for fertilizer, feed, and biogas production (Zaiko & Cahill, 2012). The meat content in zebra mussels averages 16% of dry weight, with individuals one year or younger showing a higher percentage (up to 40% of dry weight).

This study aimed to determine the condition factor and meat yield of *Dreissena polymorpha* in three lakes in eastern Turkey: Çıldır Lake, Karakaya Reservoir, and Keban Reservoir.

MATERIAL AND METHOD

The study utilized zebra mussels (*Dreissena polymorpha*) collected from Çıldır Lake, Keban, and Karakaya reservoirs (Figure 1 and 2).

Figure 1. *Dreissena polymorpha.*

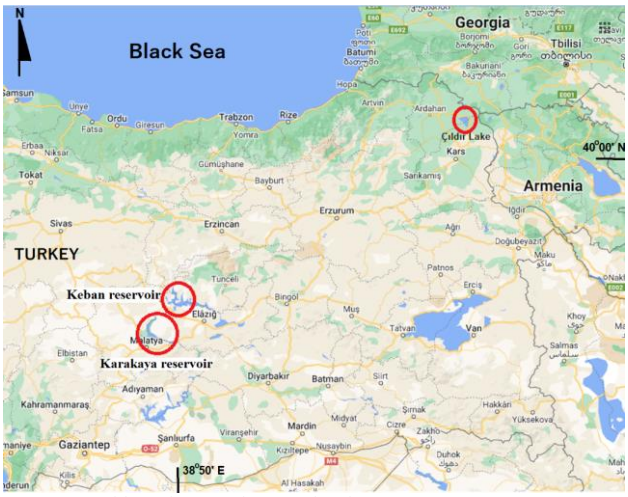

Figure 2. Çıldır Lake, Karakaya and Keban reservoirs.

Zebra mussels (*Dreissena polymorpha*) collected from Çıldır Lake, Keban and Karakaya reservoirs were used in the study (Figure 2). Zebra mussels were sampled from Çıldır Lake in August 2019, Keban in August 2021 and Karakaya Reservoir in September 2021. Zebra mussel sampling could not be carried out in other months of the year due to transport difficulties, health problems and COVID-19 pandemic restrictions. Zebra mussels were

sampled from three locations in Çıldır Lake, Karakaya, and Keban reservoirs. Care was taken to have at least 50 zebra mussels in each sampling. Çıldır Lake is at 41º03' 23" N and 43º14'39" E coordinates and is 1900 m above sea level. The lake's average temperature varies between -8 ºC and 6 ºC (Anonymous 2023; Bağcı et al., 2023). The sampling points (1, 2, and 3) of the zebra mussel in Çıldır Lake are shown in Figure 3: 1 (41° 03' 54" N; 43° 08' 25" E), 2 (41° 03' 58" N; 43° 19' 12" E), and 3 (40° 58' 30" N; 43° 15' 12" E).

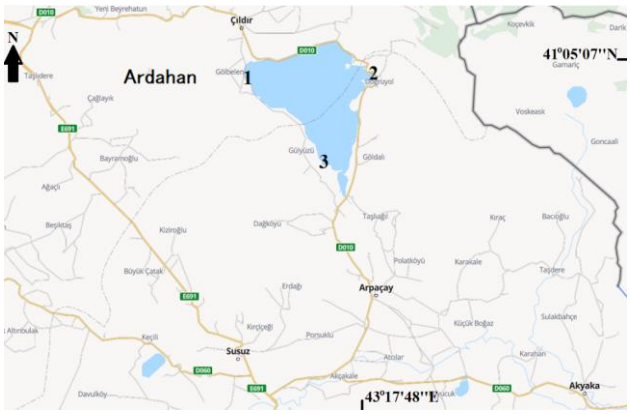

Figure 3. Zebra mussel sampling points (1, 2 and 3) in Çıldır Lake.

Karakaya reservoir is located in Malatya province, between longitudes 38° 30' East and 40°21' East and latitudes 38° 17' North and 39° 11' North (Figure 2). The reservoir was a lake with a size of 268 km^2 and an elevation of 670 to 920 meters above sea level. The maximum depth of the reservoir is 36 m, and the average temperature ranges between 7 ºC and 29.7 ºC (Ayekin et al., 2018). The sampling points (1, 2 and 3) of zebra mussels from Karakaya reservoir are shown in Figure 4: **1** (38º 38′19″ N, 38º 20′ 49″ E), **2** (38º 27′ 11″ N; 38º 27′ 42″E) and **3** (38º24′47″ N; 38º45′08″ E).

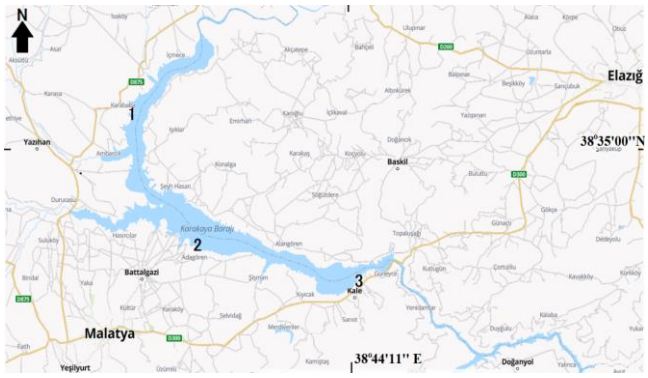

Figure 4. Zebra mussel sampling points (1, 2 and 3) in the Karakaya reservoir.

Keban reservoir is located in Elazığ province, between latitudes 39°06'37" N and 38°35'28" N and longitudes 38º38′29″ E and 39º49′32″ E (Figure 2). The reservoir area is 64.100 hectares, and the average temperature varies between 20.1 ºC and 27.5 ºC. The lake is also used for aquaculture and electricity generation (Anonymous, 2024; Topal, 2019). The sampling points (1, 2 and 3) of zebra mussels from Keban reservoir are shown in Figure 5: **1** (38º55′57″ N; 38º43′24″ E), **2** (38º52′05″N; 38º57′25″ E) and **3** (35º50′46″ N: 39º17′20″ E).

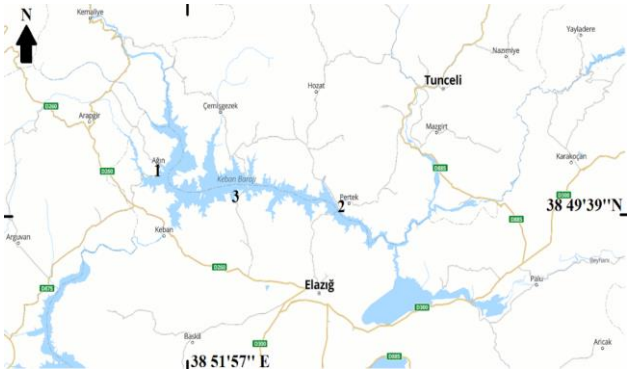

Figure 5. Zebra mussel sampling points (1, 2 and 3) in the Keban reservoir.

The study used mussels (*Dreissena polymorpha*) collected from Çıldır Lake, Keban, and Karakaya reservoirs (Figure 2). No distinction was made between males and females when evaluating the samples. In population analyses, the condition factor can be used to compare two or more stocks where environmental conditions are the same or different, to determine the time and duration of sexual maturity in stocks, and to monitor monthly and seasonal changes in the feeding activity of living things. In bivalve molluscs, the condition factor varies with the ratio between the amount of meat and the amount of shell. It is accepted as a measure that reflects the proportional change of meat to the whole mass (Şahin, 1999).

The $CF = {}^{W}/_{L^3}\, x100$ formula Ricker, (1975) specified was used to calculate the mussels' condition factor (C.F), considering the shell length and total weight values.

Where W = Body weight (g), L = Shell length (cm)

The condition factor of mussels, expressed as the filling ratio of the shell cavity with meat, was determined. After the length and live weight values of 50 mussels were taken, their live volumes were measured. With the help of a scalpel, the meat inside the shell was removed by entering through the foot cavity and cutting the adductor muscle. After weighing the fresh meat and shell, volume measurements were made.

In determining meat yield (MY):

MY(%) Fresh Meat Yield = (Fresh meat weight/ Live weight)x 100

DMY (%) Dry Meat Yield = (Dry meat weight/Live weight)x100 (Okumuş, 1993) formulas were used.

Data distributions were tested for normality using Shapiro-Wilk tests, and Tukey tests were applied to determine the difference between the condition factors and fresh and dry meat yields of zebra mussels in different reservoirs and lakes.

RESULTS AND DISCUSSION

The length and body weight values of 50 mussels from each of 472 *D. polymorpha* sampled from Çıldır Lake, Karakaya, and Keban reservoirs were recorded, and their body volumes were measured. The zebra mussels collected from Çıldır Lake had an average length of 2.78 cm ± 0.50, ranging from 1.12 cm to 4.13 cm, and an average weight of 3.6 g ± 1.35, ranging from 0.2 g to 9.8 g. In the Karakaya reservoir, the average length was 2.23 cm ± 0.61, ranging from 0.46 cm to 3.45 cm, and the average weight was 1.85 g ± 0.18, ranging from 0.013 g to 3.818 g. In the Keban reservoir, the average length was 2.19 cm ± 0.72, ranging from 0.38 cm to 3.32 cm, and the average weight was 1.43 g ± 0.716, ranging from 0.019 g to 4.128 g. The meat inside the shell was removed by cutting the adductor muscle with a scalpel, and measurements of the fresh meat and shell weights were taken. Volume measurements were then recorded. Comparing the volume-based condition factors of zebra mussels sampled from 3 different points of Çıldır Lake, Karakaya, and Keban reservoirs, it was found that the condition factor of zebra mussels in the Keban reservoir was the highest, with an average of 46.88, followed by the zebra mussels in Karakaya reservoir with 46.33. The zebra mussel in Çıldır Lake showed the lowest value, averaging 20.77. Similar differences were found in dry and fresh index values. After examining the dry and fresh meat yields of zebra mussel from Çıldır Lake, Keban, and Karakaya reservoirs, it was discovered that the fresh meat yield of zebra mussels in Çıldır Lake was lower compared to the fresh meat yields of zebra mussels in Keban and Karakaya reservoirs. However, the dry meat yield was higher, as indicated in Table 1. Additionally, it was found that the dry meat yields of zebra mussels in all three lakes varied significantly ($P<0.05$).

The condition factors, fresh and dry meat yields of zebra mussels sampled from different lakes were tested by the Shapiro-Wilk test and found to be normally distributed ($P>0.05$), and the variance was equal ($P>0.05$). One-way ANOVA tested the difference between zebra mussels sampled from different lakes. Tukey post-hoc was applied, and it was found that there was a difference between the condition factor and fresh and dry meat yield of mussels sampled from different lakes ($P<0.05$). Accordingly, the condition index values of zebra mussels sampled from Çıldır Lake differed from those of the Karakaya and Keban reservoirs. Fresh and dry meat yield of zebra mussels differed in all two reservoirs and one lake. These differences were thought to be due to the habitat conditions (water temperature, nutrients, etc.) in which zebra mussels were found.

Table 1. Meat yield of *Dreissena polymorpha* in Çıldır Lake, Karakaya and Keban reservoirs.

Sapling area	CF (volume)	CF (Dry)	CF (weight)	Meat yield (Fresh)	Meat yield (Dry)
Çıldır Lake (SP1)	21.28	18.34	26.98	16.46	11.57
Çıldır Lake (SP2)	19.61	18.87	29.81	16.00	11.57
Çıldır Lake (SP3)	21.43	18.61	32.66	15.16	11.57
Mean	20.77	18.61	29.82	15.87	11.57
Karakaya reservoir (SP1)	47.30	8.24	52.65	28.15	4.42
Karakaya reservoir (SP2)	46.67	7.81	49.53	26.86	4.20
Karakaya reservoir (SP3)	46.67	7.61	54.61	28.16	4.24
Mean	46.88	7.89	52.26	27.73	4.29
Keban reservoir (SP1)	40.00	2.51	42.56	24.95	2.25
Keban reservoir (SP2)	44.44	2.68	40.81	25.06	2.26
Keban reservoir (SP3)	54.55	2.92	45.07	26.84	2.42
Mean	46.33	2.71	42.82	25.62	2.31

More research is needed on zebra mussels' meat yield and condition factors. It has been observed that studies on zebra mussels focus mainly on their bio-accumulative properties, biochemistry, heavy metal retention capacity, effects on the nutrition and growth of other organisms in their environment, etc. (Pourang, 2021; Wong, 2020; McLaughlin & Aldridge., 2013; Rahnama et al., 2011). There is a study on the population dynamics of zebra mussels in an artificial reservoir in western Greece (Conides et al., 1995). For these reasons, our study can be considered as one of the few studies on zebra mussel condition factors and meat yield. A study on population parameters and economic valuation of freshwater mussels in Lake Çıldır showed significant monthly variation in *A. cygnea* condition factor values. The maximum condition factor value was CF=16.28±1.56 in July, and the minimum value was CF=13.92±0.55 in October (Başçınar, 2003). In a different region, it was reported that the condition factor of *Parresia corrugata*, a freshwater bivalve in Kempula River, India, showed remarkable fluctuations. The highest condition index value was reached in April, and the lowest in January. The reason for the fluctuations in the condition factor was shown as reproductive activity (Ramesha et al., 2009). A study on the population dynamics of *Parresia cylindrica* in freshwater in the Western Ghats region of India determined that the monthly average value of the condition factor varied between 5.07 and 11.97. High fitness values were found between March and May, and low values were found in October and February (Shettigar & Thippeswamy, 2023). In a study conducted on the growth indices and reproductive pattern of the freshwater mussel *Lamellidens marginalis* (Lamarck, 1819) in the northwestern district of Bangladesh, the highest condition factor was observed in June (23.35) and the lowest in November (10.44). The condition factor was reported to increase in April and June but significantly decrease in June and August (Nahar, 2020).

In our study, the condition factors of zebra mussels sampled from different habitats are given in Table 2. The condition factor of male and female *Uni terminalis* individuals in Gölbaşı Lake (Hatay) was investigated. It was determined to be 17.79 in male individuals and 19.76 in female individuals (Şereflişan, 2021). Our study calculated the condition index averages of zebra mussels in Çıldır Lake, Keban, and Karakaya reservoirs as 29.82, 42.82, and 52.26, respectively. These differences were not considered in sample sizes, but it was understood that zebra mussels had a higher condition. A study on the meat yield and growth of *Anodonta cygnea* in Çıldır Lake found that the condition factor reached its highest value (16.70) in July and its lowest value (14.30) in October (Başçınar et al., 2009). In our study, the condition factor value of zebra mussels was relatively high in all three lakes compared to these results.

In a study conducted in Çıldır Lake, the highest meat yield of *A. cygnea* was determined as 30.7% of the wet weight for the 75-85 mm length group. When evaluated in terms of dry meat, this rate is 3%. The average edible meat weight was 0.52 g for the smallest length group (45-55 mm) and 11.21 g for the largest group (135-145 mm) (Başçınar, 2003). In another study conducted in Çıldır Lake, it was determined that the shell lengths of *A. cygnea* ranged between 49.8 and 136.8 mm, 85% of the samples ranged between 85-125 mm, 10% between 45-85 mm and 5% between 125-145 mm. The highest fresh and dry meat yield was calculated as 29.8% and 3.1% of the total weight in the 85-95 mm length group, respectively. Dry meat weight increased between May and October (Başçınar et al., 2009). In another study carried out on some bioecological characteristics and meat yield of freshwater mussels (unio *sp*.) collected from Müceldi and Karasu creeks, the average of live weight, meat weight and meat ratio (%) were found to be 17.29±1.68 g, 3.67±0.30 g, 30.63±1.21 in Müceldi creek mussels and 22.37±1.78 g, 4.36±0.38 g, 31.44±0.83 in Karasu stream mussels, respectively, 31.44±0.83 (Akyurt & Erdoğan, 2011). *Uni pictorum* from freshwater mussels in the Karasu stream in Sinop City was calculated as 21.75±0.91 (Keskinbalta & Çelik, 2020).

Although zebra mussels could not be sampled in all seasons of the year in our study, considering that the sampling coincided with the spring and summer months, the meat yield values of zebra mussels were at the highest level or above average. There is a close relationship between meat yield and mussel growth. According to our findings, fresh and dry meat yields were 15.08, 25.62 and 27.73 for Çıldır Lake, Karakaya and Keban reservoirs and 11.57, 2.31 and 4.29 for zebra mussels, respectively. The highest fresh meat yield was obtained from zebra mussels in the Keban and Karakaya reservoirs. The highest dry meat yield was found in zebra mussels obtained from Çıldır Lake. In our study, zebra mussels were sampled at the end of spring, autumn and summer, and the fresh meat yield of zebra mussels varied between 15.08-27.73%. Based on the wet meat and dry meat yield values, it can be said that zebra mussel is almost similar to the meat yield of *A. cygnea* in the studies conducted by Başçınar et al. (2003) and Başçınar et al. (2009) in Çıldır Lake. The results obtained in the study conducted by Akyurt and Erdoğan (2011) on the biological characteristics and meat yield of Unio *sp*. in Müceldi and Karasu streams were in parallel with our study results. Keskinbalta & Çelik (2020) found the meat yield of *U. pictorum* in the Sinop-Karasu stream as 21.75%. On average, the meat yield of zebra mussels in our study was higher than that of *U. pictorum*. As stated by Nahar (2020), the seasonal variation of the condition factor and meat yield index is an important parameter indicating the physiological status of freshwater mussels, the seasonal energy storage of bivalves, and the seasonal variation associated with reproductive activity.

CONCLUSION

This study determined that the condition factor and meat yield of zebra mussels (*Dreissena polymorpha*) were higher than those of many mussel species. As a result, it is evaluated that zebra mussels can be used as animal feed, in the preparation of feed rations, and as a bioindicator.

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