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Research Article

# Effects of Salinity on Growth Performance and Blood Parameters of Butter Catfish, *Ompok bimaculatus*

**Md. Asaduzzaman[1], Mohammad Amzad Hossain[1], Sohel Mian[1], Mohammed Mahbub Iqbal[1]**

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## ABSTRACT

The study was conducted in laboratory conditions to evaluate the effects of salinity on growth, survival, and blood chemistry of butter catfish, *Ompok bimaculatus* fingerlings. The fry, initially sized as 7.01 cm length and 1.69 g weight, were assigned in four different salinity treatments i.e., 0 ppt ($T_C$), 2 ppt ($T_1$), 4 ppt ($T_2$) and 8 ppt ($T_3$) with three replications, with 21 fry in each replication as well. Fish were fed commercial catfish diets with 43% protein and 8% lipid at 5% body weight three times a day for 90 days. The control ($T_C$) treatment showed the significantly highest growth performance among treatments, ($p<0.05$). The $T_3$ treatment group showed a lethal parameter and all fish died within 72 hours of exposure to it. The survival rate was recorded as 90.47% for $T_c$, 71.43% for $T_1$ and 47.61% for $T_2$ treatment. The mean weight and length gain 6.17 g and 4.93 cm observed in $T_1$ followed by 4.59 g and 3.06 cm in $T_2$ treatment. The specific growth rate (SGR) (%) mean weight gain, length gain, average daily weight gain, average daily length gain and percentage length gain were (%) found to be significantly higher in Tc in comparison to those in the salinity treated groups ($p<0.05$). Significantly higher hemoglobin and WBC were observed in $T_c$ among treatments and had the lowest value recorded in $T_1$ and $T_2$. There were no significant changes between RBC counts among treatments.

**Keywords:** Salinity, growth performance, blood parameters, *Ompok bimaculatus*

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## INTRODUCTION

Being an aquatic animal, fishes largely depend on water quality for their physiological performance (Paul et al., 2019). The alarming rate of global warming leads to extreme exchanges in water temperature which directly or indirectly affect the aquatic resources drastically (Baum et al., 2005; Burel et al., 1996). This effect has driven the increase of saline water intrusion to freshwater and many freshwater fish are being affected (Kang'ombe & Brown, 2008). Any changes in the optimal dilutions of salinity impose minor imbalance on the homeostasis of fish, which might be manifested by a set of physiological responses factors (Enayati et al., 2013). However, inadequate research has been done to define the salinity originated stress and growth performance in butter catfish.

Freshwater aquaculture has witnessed the broadening adoption of various endemic catfish into the culture due to a lucrative commercial return (Debnath et al., 2016). Commercial freshwater aquaculture has expanded rapidly in the past two decades by putting various indigenous catfish into the culture as they have promising growth, high profitability, and better consumer acceptance (Jayasankar, 2018). There are a number of catfish that are known to have numerous potential for freshwater aquaculture, among them butter catfish, *O. bimaculatus*, which is an indigenous common silurid fish of southeast Asian countries (Dhar et al., 2019;

Mishra et al., 2018) and has gained importance due to its premium nutritional value, taste, less intermuscular spines, and high market price (Hossen et al., 2021; Chowdhury et al., 2020; Jabed et al., 2020). However, in recent times, this species is declining in nature driven by the loss of its wild habitat, indiscriminate use of pesticide and pollutants, hampering of breeding activities, and over exploitation of mature fish without consideration of the sex (Hossain et al., 2017; Malakar et al., 2012; Rawat, 2018). Therefore, it has been categorized as a "threatened" group since 2015 (IUCN Bangladesh, 2015). So, it is extremely important to save the fish from extinction through the use of a suitable cultural practice. Although, several tactics of successful induced breeding for this fish has been established (Banik & Malla, 2015; Purkayastha et al., 2012; Rawat, 2018), it has not received much interest in commercial farming as there is a low larval survival rate which has created a shortage in t seed supply. It is an urgent necessity to work out the facts involving the low larval survival rate which is associated with their cannibalistic behavior, insufficient larval food supply, stocking density, environment borne stress, and rearing conditions.

Hemoglobin, RBC, WBC, cortisol, plasma glucose and hematocrit are considered essential indicators of the blood chemistry used to indicate the healthiness of fish (Dowidar et al., 2018; Soltan et al., 2016; Souza & Bonilla-Rodriguez, 2007). Therefore, salinity and dietary food can be used as functional nutrients to ameliorate the hematological parameters as well as to improve overall physiological condition in fish. This research was conducted to evaluate the salinity that affects fish growth and survival. With increasing salinity, fish fall into stress which is related to the physiology of the body and ultimately affects its function as well as blood parameters. For these reasons, its growth and survival decline. This research was planned to study the salinity, growth, survival, and blood parameters which are related to one another.

## MATERIALS AND METHODS

### Designing the experiments

The fingerlings of *O. bimaculatus* were collected from a private fish hatchery and acclimatized for 14 days in an aquarium before commencing the trial. Homogeneous sized, healthy fingerlings were selected for this experiment. A total of 252 fish, comprising an initial mean body weight of 1.69 g, were randomly distributed to 12 prepared glass aquariums accommodating 21 fish per aquarium (Table 1). Fish were fed 5% of their total body weight three times a day in the morning, afternoon, and night. The water was partially supplemented to compensate for evaporation loss, and fecal matter and other debris were removed regularly.

**Table 1.** Layout of the experiment.

| Treatment | % Feed fed of body weight | Replication | No. of fingerling released |
|---|---|---|---|
| $T_c$(0ppt) | 5 | $R_1, R_2, R_3$ | 21 |
| $T_1$(2ppt) | 5 | $R_1, R_2, R_3$ | 21 |
| $T_2$(4ppt) | 5 | $R_1, R_2, R_3$ | 21 |
| $T_3$(8ppt) | 5 | $R_1, R_2, R_3$ | 21 |

Water quality influences such as temperature, dissolved oxygen, $NH_3$ and pH were determined at the beginning of the experiment and measured twice per week during the feeding trial.

A 90-day trial with different salinity treatment (Table 1) was allocated for fingerling of *O. bimaculatus* reared by using commercial pabda fish feed. The nutritional composition of the diet consisted of protein 43%, carbohydrate 20%, ash 12%, lipid 8%, fiber and minerals 3% each and moisture 11%. The total dimensions of each aquarium was 0.762 m ×0.381 m × 0.381m and each was cleaned properly with disinfectants and cleaning agents. Then, they were dried and filled to 2/3 parts of its volume with clean tap water. A variable amount of NaCl was added to the water to adjust salinity to 2 ppt, 4 ppt and 8 ppt, and justified with a Refractometer as well. The control aquaria were maintained to 0 ppt i.e., without salt. Each aquarium was facilitated with an aerator with a filtration facility for proper oxygen supply.

### Sampling fish and water quality properties

Sampling was performed fortnightly to determine the growth of fish. Weight was assessed with a digital electric balance (CAMRY digital, Model EK 3052, Bangladesh) and length was measured by a steel scale. Length and weight of all fish in each tank were measured month-wise during the study period. The value of temperature, pH and salinity were measured using SI digital DO meter, model 58, while $NH_3$ was analyzed by using kit (Hanna Ammonia Test Kit HI-3824, Romania).

### Collection and analysis of blood chemistry

At the end of the 90 day trial, 10 fish from each replicate were randomly selected for blood collection through caudal puncture with heparinized syringes to perform the complete blood count (CBC) test. Fish were starved for 24 hours prior to the final sampling. All the fish were sedated with eugenol (4-allylmethoxyphenol, Wako Pure Chemical Ind., Osaka, Japan), 50 mg $L^{-1}$. Ten fish from each replicate were used for blood collection using 1 mL heparinized syringes (Jimi syringes and medical devices Ltd, Bangladesh) from the caudal vein. Following the collection of blood samples, CBC was performed in the central laboratory of Veterinary, Animal and Biomedical Sciences faculty, Sylhet Agricultural University, Sylhet, Bangladesh by using CBC analyzer.

### Growth analysis tools

Major growth biometrics were calculated using the formulas described by (Htun-Han, 1978), (Pechsiri & Yakupitiyage, 2005) and (Panase & Mengumphan, 2015).

Weight gain of fish (%) = (Final weight -Initial weight / Initial weight) 100

The specific growth rate, $\text{SGR}\ (\%) = \frac{lnW2-lnW1}{T2-T1} \times 100$, Where $W_1$= the initial body weight (gm) at a time, $W_2$= the final body weight (gm) at a time, $T_2$-$T_1$= Duration in days

$$\text{Average daily weight gain} = \frac{Mean\ value\ of\ final\ weight - Mean\ value\ of\ initial\ weight}{Duration\ of\ experiment\ in\ days}$$

$$\text{Average daily length gain} = \frac{Mean\ value\ of\ final\ length - Mean\ value\ of\ initial\ length}{Duration\ of\ experiment\ in\ days}$$

The Fulton's condition factor value, $K=(W*100)/L^3$

**Statistical analysis**
The result of fish growth performance was evaluated by using a one-way analysis of ANOVA and Duncan's multiple Range were analyzed using SPSS program version IBM 26.0.

## RESULTS AND DISCUSSION

The readings for pH, ammonia, dissolved oxygen, and temperature of the aquarium water were observed as presented in Table 2. The standard dissolved oxygen (DO) concentrations in the experimental tanks ranged from 5.49 to 5.68 mg/L during the entire experimental phase. Maximum pH was recorded 7.25 and lowest 7.01 The values of above parameters were found uniform for all treatment groups.

Water temperature is one of the parameters that directly affects fish growth and other biological activities (Burel et al., 1996; Rem et al., 2020). The water temperature above or below optimal thermal limits (25-32℃) reduced the feed intake and growth performance in tropical fish culture (Cho et al., 2015; Fatma & Ahmed, 2020). Low temperature drives the animals toward decreased metabolic rate, thus growth (Makori et al., 2017). Catfish reared in 31℃ water temperature exhibited maximum growth compared to the ambient, 29℃ and 33℃ water temperature (Rem et al., 2020). The temperature observed in current work was found within the optimal range for animals' growth. The DO level >5 ppm is crucial to sustain fish production (Bhatnagar & Devi, 2013). The optimal pH range for the suitable growth and development of butter catfish ranges between 6.0-8.0 (Riede, 2004), and levels during the experimental period were satisfactory. Fish were found dead at pH levels lower than 4 and higher than 11(Boyd & Lichtkoppler, 1979). The maximum limit of ammonia for aquatic organisms was between 0.01-0.02 mg/L (Bhatnagar & Singh, 2010; Santhosh, 2017). From the above information it is evident that the indicated water quality parameters in the present study were suitable for the butter catfish culture.

The highest mean weight gain was 10.62±0.56 g as observed in the $T_C$ group compared to $T_1$ and $T_2$ (Table 3). The $T_3$ treatment group's environment was lethal, and fish died within 72 hours after release into the aquarium. Again, the lowest weight gains of 4.59±59 g were recorded in the T2 treatment group. In comparison to the control group, a significant rise in weight gain ($p<0.05$) was observed in $T_c$ and $T_1$. Significant increases in percentage weight gain (PWG) follows the same trend as well ($p<0.05$). Specific growth rate was highest in $T_c$ as 2.29±0.29, no significant differences were observed between $T_1$ and $T_2$. Lowest specific growth rate was found for $T_1$ treatment 1.48±0.24, ($p<0.05$) (table 3). The highest mean length gain was observed in $T_c$ was 6±0.46 cm, which is significantly higher among treatments, ($p<0.05$; Table 3). Among the treatments, $T_2$ showed the significantly lowest length gain in contrast to the $T_c$ and $T_1$, ($p<0.05$). The percentage of length gain follows the same trends. The PLG (%) 44.00±9.69 and 69.6±7.25 were observed in $T_2$ and $T_1$ treatment groups, respectively. Among the treatments, no significance differences were found between $T_1$ and $T_2$ groups, whereas significant increases were observed in $T_c$ ($p<0.05$).

The growth performance revealed that the $T_c$ and $T_1$ treatment groups demonstrated better growth performance than that of

**Table 2.** Mean value of water quality parameters.

| Parameters | Tc (0ppt) | T1 (2ppt) | T2 (4ppt) | T3 (8ppt) |
|---|---|---|---|---|
| Temperature (°C) | 29.3±1.56$^a$ | 29.6±1.42$^a$ | 28.9±1.39$^a$ | 29.11±1.52$^a$ |
| pH | 7.13±0.41$^a$ | 7.19±0.38$^a$ | 7.01±0.59$^a$ | 7.25±0.45$^a$ |
| $NH_3$ (mg/l) | 0.028±0.09a | 0.018±0.08$^a$ | 0.011±0.09$^a$ | 0.021±0.09$^a$ |
| Dissolved Oxygen (mg/l) | 5.65±0.011$^a$ | 5.55±0.018$^a$ | 5.49±0.016$^a$ | 5.68±0.06$^a$ |

**Table 3.** Growth parameters of butter catfish of 90 days treatments.

| Parameters | Tc (0 ppt.) | T1 (2 ppt.) | T2 (4 ppt.) | T3 (8ppt) |
|---|---|---|---|---|
| Mean Initial Weight (g) | 1.59±0.38$^a$ | 1.78±0.32$^a$ | 1.69±0.35$^a$ | Lethal treatment |
| Mean Final Weight (g) | 12.20±0.53$^a$ | 7.95±0.30$^b$ | 6.28±0.47$^c$ | |
| Mean Weight Gain | 10.62±0.56$^a$ | 6.17±0.41$^b$ | 4.59±0.59$^c$ | |
| % Weight Gain | 709.42±193.95$^a$ | 360.38±87.50$^b$ | 286.32±83.23$^b$ | |
| SGR % | 2.29±0.26$^a$ | 1.44±0.2$^b$ | 1.48±0.24$^b$ | |
| Mean Initial Length | 6.89±0.5$^a$ | 7.11±0.34$^a$ | 6.99±0.42$^a$ | |
| Mean Final Length | 12.9±0.5$^a$ | 12.04±0.36$^b$ | 8.24±0.46$^c$ | |
| Mean Length Gain | 6±0.46$^a$ | 4.93±0.37$^b$ | 3.06±0.58$^c$ | |
| % Length Gain | 150.11±11.5$^a$ | 69.6±7.25$^b$ | 44.00±9.69$^c$ | |
| ADWG (g) | 0.12±00$^a$ | 0.07±00$^b$ | 0.05±00$^c$ | |
| ADLG (cm) | 0.07±00$^a$ | 0.05±00$^b$ | 0.03±00$^c$ | |
| Survival rate | 90.47±7.12$^a$ | 71.43±9.2$^b$ | 47.61±10.08$^c$ | |

Here, SGR= Specific growth rate, ADWG= Average daily weight gain, ADLG= Average daily length gain. *Values are means ± SD of triplicate groups. Within a row, means with the same letters are not significantly different ($p>0.05$). *Means in the column with different superscripts are significantly different ($P < 0.05$)

the $T_2$ treatment. On the other hand, the $T_2$ treatment showed the lowest growth performance compared to the control group. A negative association between the increasing salinity and survival rate of seabream fish has already been documented by (Tandler et al., 1995). The study noted that as the nurturing salinity decreased from 40 to 25 ppt, the survival increased from 5.3 to 18.6%. As high salinity increases, the fish metabolic rate falls into a stress condition, so the fish started growing more slowly (Dubey et al., 2016; Sakthivel et al., 2013). An extreme increase in salinity level might be lethal for fish (Tietze, 2016). The metabolic rate rises due to a gradual increase in the salinity range because freshwater fish can not tolerate saline water easily. The lethal salinity level for black bream was 60 ppt (Partridge & Jenkins, 2002). Most fry of *Ompok pabda* were dead after 24 hour exposure to 2.5 ppt saline (Alam et al., 2020). Grass carp, *Ctenopharyngodon* has been reported to experience cardiac arrest associated with an ion imbalance following a long-term high concentration level of salinity (Enayati et al., 2013). A level of salinity above 11‰ was found to be lethal for larvae (Gbulubo & Erondu, 1998), while >8ppt causes larval deformity and delayed hatching in African catfish (*Clarias gariepinus*) (Borode et al., 2002). Fish grew more on high food rations, but the growth and water content of the specimens declined with increasing salinity. The best growth performance observed in 0 ppt means freshwater was a freshwater fish. When saline water was added, the fish fell into stress and its growth ultimately declined. Overall, results show that without salt water the butter catfish grew very well depending on its food consumption rate.

The highest mean hemoglobin was found 3.45±0.13 g/dL in $T_c$ followed by 3.11±0.08 g/dL and 2.87±0.15 g/dL in $T_1$ and $T_2$ treatments, respectively (figure 1A). There are significant differences found in $T_c$, $T_1$ and $T_2$, (P<0.05), with significant increases of hemoglobin found in $T_c$ as compared to the $T_1$ and $T_2$. The highest number of WBC was found in $T_c$ 53950±387.3 count/cumm which is significantly higher among treatments and followed by $T_1$ and $T_2$ 53125±263.99 count/cumm and 45275±403.11 count/cumm, respectively (figure 1B). The maximum red blood cell (RBC) count was observed in $T_c$ 1.56±0.01 m/µl which is followed by 1.49±0.03 m/µl and 1.10±0.07 m/µl in $T_1$ and $T_2$, respectively (figure 1A). Significant decreases of RBC were observed in $T_1$ and $T_2$.

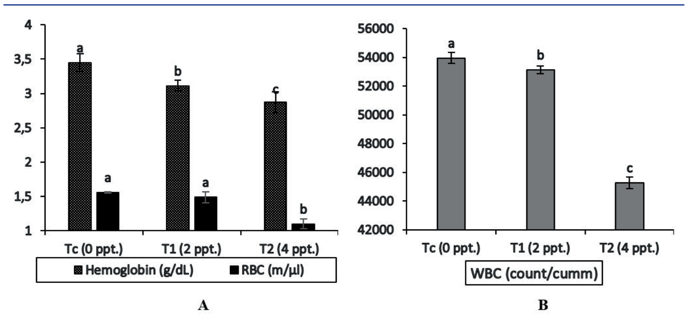


**Figure 1**. (a, b) The blood parameters of Butter catfish at different treatments (*WBC= White blood Cell, RBC= Red Blood Cell *Values are means±SD of triplicate groups. Different superscripts are significantly different at p<0.05).

A blood parameter reading is important in determining fish stressors and health factors (Hasan et al., 2021; Javed et al., 2016; Pandey, 1977). Fish growth observed in $T_c$ treatment was greater than other treatment groups. As the fish of $T_c$ treatment showed maximum growth performance, their blood parameters were also more satisfactory than any other treatment investigated in the present experiment. There were significant differences among treatments at p<0.05, $T_c$ showed increased WBC in comparison to $T_1$ and $T_2$ showed decreased WBC in contrast to the control group. From this point, the count of WBC decreases with the increase of salinities. Hasan, (2016) experimented with *Cyprinus carpio*, and found a higher level of WBC at up to 10 ppt, but at 15 ppt it was drastically decreased. A drastic increase in the salinity level was found to negatively affect the hematological parameters in *Cyprinus carpio* (Mubarik et al., 2019; Salati et al., 2011). However, Tra catfish (*Pangasianodon hypophthalmus*) were able to acclimate to the salinity changes by modifying their RBC and Hb concentrations (Phuc et al., 2017). The $T_c$ treatments fish showed maximum growth performance and satisfactory WBC count. There is a correlation between the hemoglobin quantity and RBC count (Souza & Bonilla-Rodriguez, 2007).

## CONCLUSION

The results of the current experiment clarified that salinity has a negative effect on growth as decreased performance was observed in all weight/length parameters (mean, final, %) with the increase in salinity. In the above findings, it can be concluded that the water without salinity is most suitable for the growth performance, survival, and blood parameters of butter catfish. Further experiments should be designed to find a way to maintain the water salinity in aquaculture for maximizing the growth performance of fish.

**Conflict of Interest:** The authors declare that there are no conflicts of interest.

**Ethical Approval:** The design of this study was approved with regional, institutional, and national animal ethics clearance through the documentation from Sylhet Agricultural University Research System (SAURES), Bangladesh.

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**Author Contributions:** This manuscript covers the MS thesis works of the first author, he performed laboratory works and prepared reports. The second authors were responsible for instructing in laboratory assays and preparing and writing manuscripts for publication. The main concept and methodology were generated and academically supervised by the third and fourth author.

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Research Article

# A Record of Fish Anomaly from the Sea of Marmara, Turkiye: European Hake (*Merluccius merluccius* Linnaeus, 1758) Missing the Right Eye

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## ABSTRACT

Abnormalities of shape, color or body deformities such as lack of swim bladders or any parts of the body are an unexplained issue for many fish species. There is a gap of knowledge regarding their causes. Generally, it is an important problem in the rearing technique in aquaculture management due to the high economic consequences. The morphological abnormalities occur in marine fishes as well. Missing dorsal spines or rays, scale disorientation, jaw deformities, eye deformations and the lack of some parts of the body are within the context of abnormality. In the present study, the body abnormality observed in a specimen of European hake (*Merluccius merluccius* Linnaeus, 1758) missing its right eye which was caught by a fisherman in the Marmara Sea on 13 October 2020, and its causes are reported and discussed. Further studies are needed to correlate the wild fish anomalies caused by pollution.

**Keywords:** Anomaly, European hake, Abnormality, Izmit bay, Sea of Marmara

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## INTRODUCTION

Morphological deformities are substitute indicators of the results of habitat degradation on fish populations (Sindermann, 1979). An anomaly in fishes could be one of the results of marine pollution, and heavy metals may be considered as the main causative agent of many fish anomalies (Jawad and Ibrahim, 2021). Those abnormalities are irreversible deviations, whether natural or caused, from the ordinary morphology of wild fish. The predominant morphological abnormalities in fish can be grouped into five primary classes including: skeleton, body form, scales, pigmentation and swim bladder (Divanach et al., 1996). The abnormalities are not unusual issues in aquaculture, where the purpose is to supply a great number of fish in keeping with purchaser demand (Daoulas et al., 1991; Boglione et al., 1993). Above all, anomalies within the elaborate opercular are also regular in different fish species (Valentine, 1975; Hilomen-Garcia, 1997). Morphological and structural abnormalities can arise and have a negative effect on the biological features which include respiration by physical damage to the gills and causes fungi infection, parasites and microorganisms (Bruno & Poppe, 1996; Galeotti et al., 2000).

This paper describes the physical body abnormality observed in the European hake (*Merluccius merluccius* Linnaeus, 1758) of an individual without its right eye obtained from the Bay of Izmit, in the Marmara Sea on 13 October 2020.

## MATERIAL AND METHODS

The specimen of European hake (*M. merluccius*) obtained from Izmit Bay (in the eastern part of the Marmara Sea), was caught with the commercial bottom gill-nets used by the fishermen in the region on 13 October 2020 at the depth of 70 meters (Figure 1). As soon as the fish was captured and the decision of the abnormality of the fish was determined, a fisherman put the specimen into a deep freezer and brought it to the Istanbul University Faculty of Aquatic Sciences laboratory to be examined and the body measurements were recorded to the nearest millimeters with a caliper.

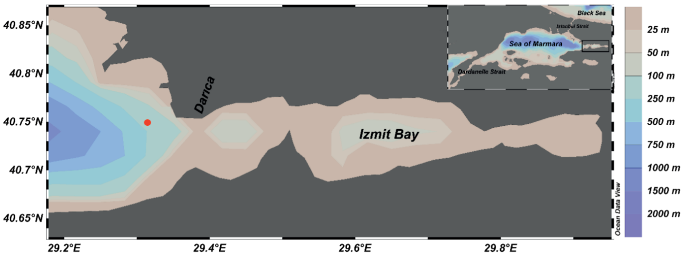


**Figure 1**. Geographical location of the capture of European hake in Izmit Bay (Sea of Marmara).

The Marmara Sea is 240 km in length and 70 km in width and has an area of 11,500 km². The Marmara Sea is under the effect of waters of the Mediterranean and Black Seas. The waters coming from the Black Sea form the upper layer of the Marmara Sea, and the waters from the Mediterranean Sea represent the lower layer. The waters originating from the Black Sea and Mediterranean Sea are separated inside the Marmara Sea via an interface layer at a depth of about 25 m. (Beşiktepe et al.,1994). It has a rich dynamic structure concerning the pelagic and demersal fish species population. Being between the two different seas, the Black Sea and Mediterranean Sea, the Marmara Sea is a completely unique environment for the fish species harboring, feeding, and breeding habitat (Kocataş et al., 1993).

Izmit Bay is located along the northeastern part of the Marmara Sea. About two million people stay nearby Izmit Bay, especially in three massive metropolitan areas consisting of Izmit, Yalova, and Tuzla.

## RESULTS AND DISCUSSION

Abnormality was recorded in one specimen of European hake in Izmit Bay. The European hake specimen was obtained from Izmit bay (Sea of Marmara), captured by fishermen during a gill-net fishery. The specimen had a normal body shape, but the right eye was missing with no injury (Figure 2). The total body length was 38.6 cm and the total weight was 492.59 g (Table 1).

**Figure 2**. The abnormal specimen of European hake (*Merluccius merluccius* Linnaeus, 1758).

**Table 1**. Morphometric characteristics of the *M. merluccius* specimen from the Sea of Marmara (Izmit Bay) (all measurements are in mm)

| **Total Length** | **386.24** | **TL%** |
|---|---|---|
| SL | 352.54 | 91.2 |
| Ld | 218.87 | 56.6 |
| La | 168.56 | 43.6 |
| Lp | 54.56 | 14.1 |
| Lv | 51.37 | 13.3 |
| Lpd | 109.06 | 28.2 |
| Lpa | 170.15 | 44 |
| Lpv | 86.48 | 22.3 |
| Lpp | 101.32 | 26.2 |
| T | 66.18 | 17.1 |
| Tpc | 16.87 | 4.3 |
| Lc | 52.28 | 13.5 |
| Head length | 104.48 | 27 |
| | | **HL%** |
| O | 17.41 | 16.6 |
| O (cornea) | 7.68 | 7.3 |
| Po | 33.46 | 32 |
| Olo | 55.48 | 53.1 |

TL: Total Length, SL: Standard Length, W: Total weight, G: Gender, GW: Gonad weight, HL: Head length, Ld: Dorsal fin length, La: Anal fin length, Lp: Pectoral fin length, Lv: Ventral fin length, Lpd: Predorsal distance, Lpa: Preanal distance, Lpv: Preventral distance, Lpp: Prepectoral distance, T: Max body height, Tpc: Min body height, O: Eye diameter, O (cornea): Cornea diameter, Po: Preocular distance, Olo: Postocular distance

This is the first report of European hake abnormalities in wild fish populations from the Marmara Sea. Fish anomalies have been ascribed to multiple factors like currents (Hilger, 1992; Divanach et al., 1997; Cerezo et al., 2005), temperature variations, pH, salinity fluctuation, and low dissolved oxygen (Milton, 1971; Turner & Farley, 1971; Gluth & Hanke, 1983; Boglione et al., 2013), high CO$^2$ concentration in water (Martens et al., 2006), pollutants like chlorinated hydrocarbons, organophosphates, pesticides, and heavy metals (Kessabi et al., 2009; Lin Sun et al., 2009)

There are few papers in the literature about the causes of different deformities in wild fish anomalies (Divananch et al., 1996; Aritaki & Seikai, 2004; Jonsson & Jonssoln, 2006; Sanchez et al., 2011). There are some fish anomaly cases in different regions reported as albinism (Baruah, 1968; Jawad & İbrahim, 2017), melanism (Atz et al., 1963; Berland, 1967; Marcoux, 1966), hermaphroditism (Bullough, 1940; Arme, 1965; Ciechomski & Christiansen, 1968; Millikan & Pattie, 1970), deformations in the vertebrae (Cavaliere, 1965; Hoff, 1970; Boglione et al., 2006; Jawad & Akyol, 2018), deformations of the fins (Hase, 1935; Bennet, 1964; Easwaran, 1968), and malpigmentation (Cerim et al., 2016).

Abnormalities, especially in the Mediterranean fish mariculture, are an important object with many factors, and are generally due to gaps in knowledge about their development (Divanach et al., 1996). Generally, the abnormalities arise as various gross skeletal abnormalities for sea bass fish species and may cause dysfunction in calcium metabolism (Valentine, 1975).

A guide has been prepared in order to investigate the anomalies of fishes that are exposed to environmental pollutants or the other effects reported by Smith et al. (2002). In the guide, the anomalies, which are observed in the fish eyes, were noted as opaque or cloudy eye, exophthalmia, missing eye, third eye, hemorrhagic eye, emboli, or gas bubbles in the eye. The congenital absence of the eye has previously been noted in the species *Silurus glanis* (Necrasov & Adascalitei, 1970) and *Merluccius merluccius* (Brian, 1952).

The skeletal anomalies and meristic counts of the three mullet species (*Chelon ramada*, *Chelon labrosus*, and *Mugil cephalus*) have been reported from the Adriatic Sea. However, no anomaly has been found for the *Chelon auratus* species in the same region. It has been reported that the three mullet species mentioned above are more sensitive to environmental conditions and that there may be differences in sensitivity to the effects of pollutants between species belonging to the same family. (Boglione et al., 2006). A similar situation has been observed among Gobiidae species (Da Cunha and Antunes, 1999). Three anomaly cases have previously been noted for the Merlucciidae family. The hermaphroditism anomalies have been observed for *Merluccius hubbsi* species in the Buenos Aires coasts in South America (Ciechomski & Christiansen, 1968) and *Merluccius productus* species off the coast of Washington in the Pacific Ocean (Millikan & Pattie 1970) and one eye anomaly has been observed in *Merluccius merluccius* on the coast of Italy (Brian, 1952) and pug head deformity in the Aegean Sea (Jawad et al., 2018). The authors state that the anomalies in wild fish may be caused by pollution (Bengtsson, 1979; Bengtsson et al, 1985; Carls et al., 1990; Kingsford and Gray, 1996; Haaparanta et al., 1997; Kirchhoff et al., 1999).

Researchers have reported egg malformations in polluted waters of the North Sea (Cameron and Westernhagen, 1997), Baltic Sea (Westernhagen et al., 1988), Australian Coastal Waters (Klumpp & Westernhagen, 1995), Chilean Waters (Llanos-Rivera et al., 2013), Western Coasts of the Atlantic (Longwell et al., 1992) and the Marmara Sea (Mavruk et al. 2015).

As a result, water inputs such as discharge points in the Sea of Marmara, litter transportation via basins, and high levels of nutrients and organic matter cause eutrophication. Eventually, there is a lack of oxygen in the region, especially in the summer and autumn periods. In addition, plankton and jellyfish blooms, red-tide and mucilage events can be encountered throughout the year (Okyar et al., 2015; TÜBİTAK MAM, 2017). Mucilage, which was first observed in 2007 and then every year to date, is composed by secreting organic compounds due to the high nitrogen and phosphate input in the Marmara Sea. (Aktan ve diğ., 2008a; Tüfekçi ve diğ., 2010; Balkis-Özdelice ve diğ., 2021). Izmit Bay has smaller industry regions such as Darica, Golcuk, Hereke, Ipras, and Karamursel. Izmit Bay comprises one of the most heavily industrialized regions of northwestern Turkiye, with large petrochemical and chemical plants in its surrounding centers. There are also heavy steel industries, textile and related industries, leather tanning and processing plants, and automotive industries in nearby Izmit. Also, the water circulation in the Gulf of Izmit is low, and the living organisms in this region, which are under the influence of pollution due to intense industry, are adversely affected.

## CONCLUSION

In the present study, the anomaly of the absence of the right eye of the European hake specimen obtained from the Marmara Sea was observed and this anomaly is thought to most likely have been caused by pollution. It may also have been caused by a fishing activity such as angling, in which the hook of a handline used in the region could have hooked the eye of the fish in its early stages of life, or it also may have been caused by fish competition in the early stages of the fish's life, or by genetic factors. It is suggested that pollution may have caused the absence of the right eye of the fish because there was no visible injury on the right side of the specimen, and also because of another anomaly reported in the Marmara Sea: the presence of individuals with abnormal development (conjoined twins) belonging to *Trachurus mediterraneus* (Mavruk et al., 2015). Changes in the ecosystem of the Marmara Sea as a result of anthropogenic effects may cause anomalies in wild fish species. Further studies are needed in order to understand fish anomalies which are caused by environmental pollutants.

**Conflict of interests:** The authors declare that they have no conflict of interest.

**Ethics committee approval:** This study does not need any ethical approval.

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Research Article

# The Seasonal Distribution of Molluscan (Bivalvia and Gastropoda) Biodiversity in Riva Stream (Istanbul)

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## ABSTRACT

Mollusk samples were collected between March 2018 and January 2019 through seasonal sampling at five stations [Riva (ST1), Kuzdere (ST2), Kanlıdere (ST3), Atdosun (ST4), Değirmendere (ST5)] of Riva Stream (Istanbul). In the study, 7,073 individuals, 7 taxa [1 species belonging to Prosobranchia (*Bithynia* sp.), 3 species belonging to Pulmonata (*Planorbis planorbis* (Linnaeus, 1758), *Physella acuta* (Draparnaud, 1805) and *Gyraulus albus* (O. F. Müller, 1774) and 3 species belonging to Bivalvia [*Pisidium casertanum* (Poli 1791), *Pisidium amnicum* (Muller, 1774) and *Sphaerium corneum* (Linnaeus, 1758)] were determined. Considering the dominance (%) of taxa, *Bithynia* sp. was determined as the most dominant species among all stations (5,479 individuals (77.46%)). During sampling, various environmental variables [depth (cm), width (cm), flow rate (m/s), water temperature ($^{O}$C), dissolved oxygen (%), pH, conductivity (µS/cm), salinity (ppm), $NH_4$-N (mg/L), $NO_3$-N (mg/L), $NO_2$-N (mg/L), $PO_4$-P (mg/L), TP (mg/L) and TSS (g/L)] were measured. The relationship between environmental variables and taxa was determined using Canonical Correspondence Analysis (CCA) using the Past Statistics Program, version 4.02. The clustering relationship between the five sampling stations and the unweighted pair group method (UPGMA) with arithmetic mean was shown.

**Keywords:** Gastropoda, Bivalvia, water quality, biodiversity, environmental variables

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## INTRODUCTION

Molluscs are a common macrobenthic invertebrate group of freshwater ecosystems (rivers, lakes, streams, shallow water etc.). They play significant roles in food webs and ecosystem equilibriums such as biofiltration, nutrient cycling and storage (Vaughn, 2017). Bivalves and gastropods are used as indicator organisms for biological monitoring and in hazard and risk assessment (Goldberg, 1986; Borcherding and Volpers, 1994).

Riva Stream, which is located on the Anatolian side of Istanbul, is a freshwater basin having a length of 70 km. The stream is borne from Gebze, flows into the Black Sea through Beykoz and has approximately 859 km$^2$ of drainage basin. In this study, five stations were selected including one main channel station [Riva (ST1)] and the other stations [ST2 (Kuzdere); ST3 (Kanlıdere); ST4 (Atdosun) and ST5 (Değirmendere)] were at the tributary (Table 1; Figure 1).

The aim of this study is to determine the molluscan fauna of Riva Stream for the first time and observe the environmental variables through biological monitoring.

## MATERIAL AND METHODS

The field research was carried out between March 2018 and January 2019 at five stations (Riva, Kuzdere, Kanlıdere, Atdosun, Değirmendere). All samples were collected using a kicking method by a D-frame hand net which has a 0.5 mm mesh size. A 1 m$^2$ area was selected on the field and samples were collected against the direction of the river's flow. The benthos

**Table 1.** The sampling stations' coordinates.

| No | Station | Coordinates |
|---|---|---|
| ST1 | Riva | N41°12'45.88"<br>E29°13'31.22" |
| ST2 | Kuzdere | N41°10'57.64"<br>E29°13'59.15" |
| ST3 | Kanlıdere | N41°07'08.30"<br>E29°16'09.80" |
| ST4 | Atdosun | N41°10'25.00"<br>E29°16'17.60" |
| ST5 | Değirmendere | N41°07'58.30"<br>E29°16'55.50" |

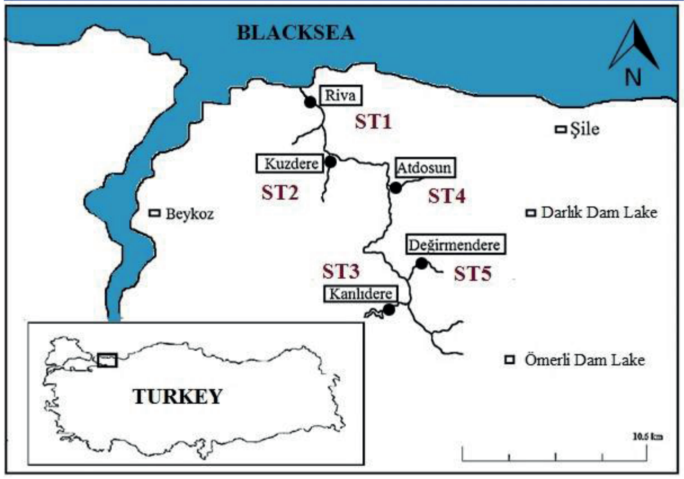


**Figure 1.** Study area.

material was fixed with ethyl alcohol in the field, eliminated via measured sieves under high-pressure water and preserved in 75% ethyl alcohol in the laboratory. Mollusks were identified at the species level by using the guidelines outlined by Schutt (1965), Macan (1969; 1977), Glöer (2002) and Oscoz (2011).

Dominance values and frequency of taxa were calculated according to individual number [D = (NA/Nn)*100] and [F = (Na/Nn)*100] D: Dominancy, F: Frequency, NA: Individual number of "A" taxon, Na: Sampling number of "A" taxon, Nn: All sampling/individual numbers) (Kocataş, 2008).

Some environmental variables (depth (cm), width (cm), flow rate (m/s), water temperature (°C), dissolved oxygen (%), pH, conductivity (µS/cm), salinity (ppm)) were measured with multiparameter devices during sampling. Various chemical parameter values ($NO_3$-N (mg/L), $NO_2$-N (mg/L), $PO_4$-P (mg/L), TP (mg/L) and TSS (g/L) were analyzed according to the standard method (Boyd and Tucker, 1992). For measurements of $NH_4$-N (mg/L) SM 4500 $NH_3$ B, the F test method was followed.

The relationship between environmental variables and taxa was determined using Canonical Correspondence Analysis (CCA) via the Past Statistics Program, version 4.02. The clustering relationship between the five sampling stations by season and the unweighted pair group method (UPGMA) with arithmetic mean was shown.

## RESULTS AND DISCUSSION

***Biological Results:*** In this study, 7,073 individuals were examined in total, and it was found that 1 species belongs to Prosobranchia (*Bithynia* sp.), 3 species belong to Pulmonata (*Planorbis planorbis* (Linnaeus, 1758), *Physella acuta* (Draparnaud, 1805) and *Gyraulus albus* (O. F. Müller, 1774) and 3 species belong to Bivalvia [*Pisidium casertanum* (Poli 1791), *Pisidium amnicum* (Muller, 1774) and *Sphaerium corneum* (Linnaeus, 1758)] (Figure 2).

Considering the dominance (%) of taxa, *Bithynia* sp. was determined as the most dominant taxon with 77.46%, while *P. casertanum* (10.80%) and *P. acuta* (9.12%) were the second and third dominant taxa (Figure 3).

It was determined that the highest number of individuals at ST3 for all seasons and ST2 in Summer had a higher number of individuals from other stations. With 1,901 individuals, the ST3 Autumn season especially was the sampling with the highest number of individuals. While there were no bivalves at ST1 (all seasons), ST2 (Summer) and ST4 (Winter), ST1 had no mollusks in both Spring and Autumn.

According to the frequency (%) of taxa, *P. acuta* was determined as 65%, *P. casertanum and Bithynia* sp. as 60%, and *S. corneum* as 10%.

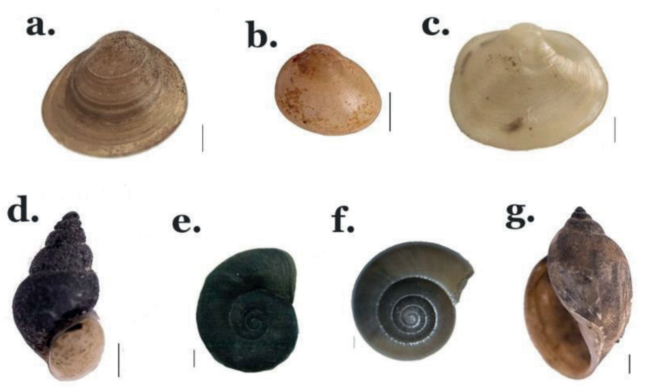


**Figure 2.** Mollusca diversity of Riva Stream [a- *P.amnicum*; b- *P. casertanum*; c- *S. corneum*; d- *Bithynia* sp.; e- *P. planorbis*; f- *G. albus*; g- *P. acuta*. Scale bars: 1 mm].

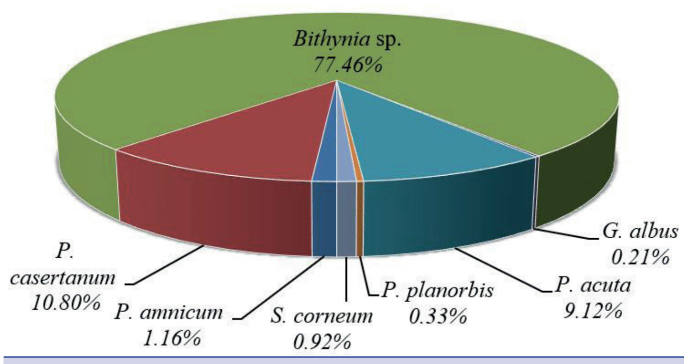


**Figure 3.** The dominance (%) of taxa.

In this study, 911 individuals belonging to 3 genera and 3 species were determined: *Pisidium amnicum* (Müller, 1774), *P. casertanum* (Poli, 1791), *Sphaerium corneum* (Linnaeus, 1758) of Bivalvia. *P. amnicum* was collected from ST2 (2 individuals), ST3 (54 individuals) and ST4 (26 individuals) in various seasons. *S. corneum*, with 65 individuals, was only collected from ST5 in Summer and Autumn. There were 435 individuals of *P. casertanum* collected from ST3 in all seasons except Winter and 279 individuals collected from ST4 in the same seasons. Twelve individuals were determined at ST2 except in Summer and 38 individuals at ST5 except in Autumn. The species identified are located within the range of distribution (Koşal Şahin and Yıldırım 2007; Kılıçaslan and Özbek, 2010; Koşal Şahin, 2013; Gürlek et al., 2019).

Of Gastropoda, 6,162 individuals belonging to 4 taxa of 3 families were determined (*Bithynia* sp., *Planorbis planorbis* (Linnaeus, 1758), *Gyraulus albus* (Müller, 1774), *Physa acuta* (Draparnaud, 1805). *Bithynia* sp. was determined as the taxon which has the highest number of individuals among all stations (5,479 individuals (77.46%)). The highest number of individuals belonging to the species was found at ST3 with 4,532 individuals. It was followed by ST2 with 933 individuals. The sum of individuals collected from ST2 and ST3, constitutes 99.7% of the total number of individuals of the species. While very few individuals were found at the other stations, there were no species found at ST5. Likewise, *G. albus* was collected from all stations except ST4. The highest number of individuals (6 individuals) belonging to this species was found at ST1. *P. planorbis* was found at ST2 (8 individuals) in all seasons except Summer, while 1 individual at ST3 was found only in Summer. The species were found at ST5 (14 individuals) in all seasons. It was observed that the stations with the highest number of *P. acuta* were found at ST4 (411 individuals) and ST5 (214 individuals). It is known that individuals belonging to this species live on plants and ground mud in shallow waters in the region where vegetation is rich (Özvarol et al., 2004). *Physa* is one of the most tolerant genera to low oxygen conditions (Hawkes, 1997; Kırkağaç and Köksal, 2005). While other species identified are located within the range of distribution (Ertan et al., 1996; Özbek et al., 2004; Yıldırım, 2004; Koşal Şahin et al., 2017; Gürlek et al., 2019), *G. albus* was recorded for the first time in Istanbul.

*Environmental variables:* According to the average of physico-chemical values, depth values were between 20 and 47 cm and the width values were between 174 and 6,749 cm. It was seen that ST1 was quite wide compared to other stations. FR was between 0 and 0.85 m/s and the sampling site of ST1 was stagnant, while other stations were more rapid. Water temperature results were between 12.6 and 14.9°C. DO values were between 5.81 and 9.46 mg/L. Considering the Criteria of Regulation on the Management of Surface Water Quality (2021), all stations ex-

**Table 2.** The individual number of taxa and the dominance (%) and frequency (%) in total.

| | | *P. amnicum* | *P. casertanum* | *S. corneum* | *Bithynia sp.* | *P. planorbis* | *G. albus* | *P. acuta* |
|---|---|---|---|---|---|---|---|---|
| **ST1** | Spring | - | - | - | - | - | - | - |
| | Summer | - | - | - | - | - | 1 | 5 |
| | Autumn | - | - | - | - | - | - | - |
| | Winter | - | - | - | 8 | - | 5 | - |
| **ST2** | Spring | 1 | 5 | - | 112 | 4 | - | 1 |
| | Summer | - | - | - | 658 | - | - | - |
| | Autumn | - | 1 | - | 145 | 3 | 1 | - |
| | Winter | 1 | 6 | - | 18 | 1 | 4 | 9 |
| **ST3** | Spring | - | 3 | - | 606 | - | - | 1 |
| | Summer | 41 | 203 | - | 944 | 1 | - | 4 |
| | Autumn | - | 229 | - | 1672 | - | - | - |
| | Winter | 13 | - | - | 1310 | - | 1 | - |
| **ST4** | Spring | 7 | 24 | - | 2 | - | - | 3 |
| | Summer | 19 | 48 | - | - | - | - | 216 |
| | Autumn | - | 207 | - | 3 | - | - | 158 |
| | Winter | - | - | - | 1 | - | - | 34 |
| **ST5** | Spring | - | 5 | - | - | 2 | 2 | 51 |
| | Summer | - | 19 | 13 | - | 6 | - | 92 |
| | Autumn | - | - | 52 | - | 5 | - | 50 |
| | Winter | - | 14 | - | - | 1 | 1 | 21 |
| **N total** | | 82 | 764 | 65 | 5479 | 23 | 15 | 645 |
| **% Dominancy** | | 1.16 | 10.80 | 0.92 | 77.46 | 0.33 | 0.21 | 9.12 |
| **% Frequency** | | 30 | 60 | 10 | 60 | 40 | 35 | 65 |

**Table 3.** The average of environmental variables of Riva Stream (Istanbul).

| | Depth (cm) | Width (cm) | FR (m/s) | Water Temperature (°C) | Dissolved Oxygen (mg/L) | pH | Conductivity (µS/cm) | Salinity (ppm) | $NH_4$-N (mg/L) | $NO_3$-N (mg/L) | $NO_2$-N (mg/L) | $PO_4$-P (mg/L) | TP (mg/L) | TSS (g/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **ST1** | 33 | 6749 | 0.0 | 14.9 | 5.81 | 7.86 | 1900 | 1.31 | 4.99 | 0.425 | 0.083 | 0.187 | 0.367 | 2.08 |
| **ST2** | 20 | 303 | 0.55 | 13.9 | 8.5 | 7.91 | 442.5 | 0.09 | <0.5 | 0.417 | 0.031 | 0.023 | 0.112 | 0.31 |
| **ST3** | 27 | 319 | 0.85 | 12.6 | 9.01 | 8 | 130 | 0.04 | 0.71 | 0.263 | 0.013 | 0.035 | 0.087 | 0.17 |
| **ST4** | 24 | 174 | 0.24 | 13.2 | 9.46 | 8.08 | 220 | 0.34 | <0.5 | 0.240 | 0.018 | 0.049 | 0.135 | 0.19 |
| **ST5** | 47 | 449 | 0.08 | 14.6 | 8.11 | 7.73 | 630 | 0.24 | <0.5 | 0.536 | 0.08 | 0.174 | 0.32 | 0.51 |

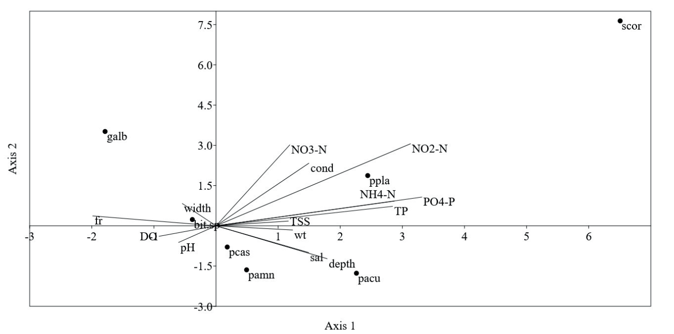


**Figure 4**. CCA triplot *(Abbrv.: pamn: P. amnicum, pcas: P. casertanum, bit.sp: Bithynia sp., galb: G. albus, pacu: P. acuta, ppla: P. planorbis, scor: S. corneum, wt: water temperature, sal: salinity, TSS: suspended solid, cond: conductivity, fr: flow rate).*

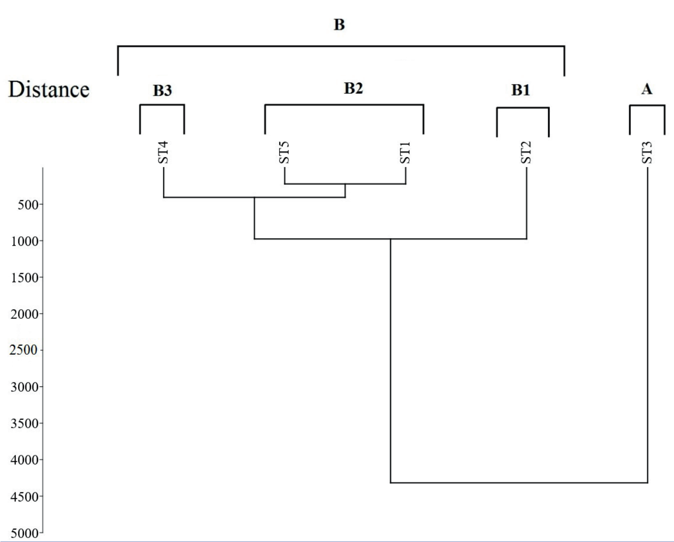


**Figure 5**. UPGMA Cluster Analysis based on mollusk diversity.

cept ST1 were Class I (>8), while ST1 was determined as Class III (<6) in terms of DO. pH values were between 7.73 and 8.08 and measured within the specified range. Conductivity values were between 130 and 1,900 µS/cm; according to the Criteria of Regulation on the Management of Surface Water Quality (2021), ST1 and ST2 were determined as Class III. The salinity values were between 0.04 and 1.31 ppm. ST1 is the main branch of Riva Stream and the closest station to the sea. Therefore, it was found to be the station with the highest salinity value. $NH_4$-N values were between <0.5 and 4.99 mg/L; $NO_3$-N was between 0.240 and 0.536 mg/L; $NO_2$-N was between 0.013 and 0.083 mg/L.

The highest $NH_4$-N and $NO_2$-N values were measured at ST1, while the highest $NO_3$-N value was at ST5. According to the Criteria of Regulation on the Management of Surface Water Quality (2021), ST1 was determined as Class III in terms of $NH_4$-N, while ST2, ST4 and ST5 were measured as <0.5 mg/L.

$PO_4$-P values were between 0.023 and 0.187 mg/L and TP between 0.087 and 0.367 mg/L. According to the Criteria of Regulation on the Management of Surface Water Quality (2021), ST1 and ST5 were Class III in terms of $PO_4$-P and TP values, while the other stations were Class I in terms of $PO_4$-P and Class II in terms of TP.

TSS values were between 0.17 and 2.08 g/L. ST1 had the highest value as 2.08, and ST5 was determined as the second highest station. Selected environmental variables are shown in Table 3.

**Statistical results:** The relationship between individual mollusk numbers and environmental variables was determined by Canonical Correspondence Analysis (CCA) (Figure 4). In the CCA triplot shown, lines represent environmental variables and dots represent taxa. Eigen values of the first two axes were used for drawing the CCA triplot. Two axes, 51.79% (1st Axis) and 25.51% (2nd Axis), explain a total of 77.3%. When the CCA triplot was examined, the species distributed parallel to the second axis and the water temperature value was closest to the second axis. According to this analysis, *Bithynia* sp. and flow rate appear to be closely related.

In addition, the similarity comparison of the stations according to the taxa found in Riva Stream stations was made (Figure 5). As a result of the UPGMA analysis, it is seen that the stream is divided into two sections (A-B) according to taxa. The third station in A was immediately separated from the B group according to the biological composition type they have. Three separate groupings are distinguished within group B (B1-B2-B3). Within the scope of similarity, ST1 and ST5 were identified as two similar stations.

## CONCLUSION

During the study area visits and according to the variables, it is seen that the stream is contaminated due to high levels of urbanization and domestic waste pressure. Increased measures are required to protect biodiversity and improve the water quality of Riva Stream.

**Conflict of interests:** There are no conflicts of interest to declare.

**Ethics committee approval:** Ethics committee approval is not required.

**Financial disclosure:** -

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Research Article

# Freshwater Amphipod Species of Western Anatolia, Marmara and Turkish Thrace Regions

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## ABSTRACT

To determine the Amphipoda (Crustacea) fauna of the inland waters of Western Anatolia, Marmara and the Turkish Thrace Region, field studies were conducted between May 2014 and March 2019. Seven field studies were conducted. Samplings were conducted at 291 localities and amphipod specimens were found at 127 of them. As a result, 11 amphipod species (*Echinogammarus stocki* G. Karaman, 1970, *Gammarus aequicauda* (G. Karaman, 1970), *Gammarus anatoliensis* Schellenberg, 1937, *Gammarus arduus* G. Karaman, 1975, *Gammarus balcanicus* Schäferna, 1923, *Gammarus dorsosetosus* Mateus & Mateus, 1990, *Gammarus gonensis* Özbek, 2016, *Gammarus komareki* Schäferna, 1923, *Gammarus lacustris* G.O. Sars, 1863, *Gammarus pulex* pulex (Linnaeus, 1758), *Gammarus uludagi* G.S. Karaman, 1975) were determined. The new records can be listed as: *E. stocki* for Ekinanbarı, *G. anatoliensis* for Uşak, *G. arduus* for Bolu and Düzce, *G. balcanicus* for Kocaeli and Sakarya, *G. dorsosetosus* for Bolu, *G. gonensis* for Istanbul and Manisa, *G. komareki* for Düzce and Kocaeli, *G. lacustris* for Istanbul, *G. pulex* pulex for Bolu, Kırklareli, Kocaeli, Sakarya and Uşak, and *G. uludagi* for Aydın, Bilecik, Sakarya and Yalova provinces. The observed morphological features and the detailed drawings of the determined taxa are presented. Additionally, a map showing the distribution of the obtained species is also given.

**Keywords:** Inland-water, river, Peracarida, benthos, Malacostraca

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## INTRODUCTION

The order Amphipoda constitutes 30% of the Malacostraca class, with more than 30,000 species worldwide. The number of marine, freshwater, brackish and terrestrial species (except Amphipoda with 22 species) is 10,247 worldwide (Horton et al., 2021). The taxonomy of the order Amphipoda has been finalized consisting of six suborders by the study of Lowry and Myers (2017). All of the amphipod species reported from the inland waters of Turkiye belong to the suborder Senticaudata.

The pioneering study on the freshwater amphipod species of Turkiye was reported by Vávra (1905) who described *Gammarus argeaus* from the Erciyes Mountains. After this initial study, many studies have been reported. The last study regarding the inland water amphipods of Turkiye was on the identification of *Rhipidogammarus gordankaramani* Özbek & Sket 2019 which was reported in Antalya.

In the present study, it is aimed to determine the Amphipoda fauna of the inland waters of Western Anatolia, Marmara and the Turkish Thrace Region.

## MATERIAL AND METHODS

Seven field studies were conducted between May 2014 and March 2019 at 291 localities and amphipod specimens were found at 127 of them (Figure 1).

Samples were fixed in 96% ethyl alcohol in the field and then sorted in the laboratory using a

Leica EZ4 stereomicroscope and then kept in 96% ethyl alcohol. During the field study, altitudes, and geographical coordinates of the sampling localities were also noted (Table 1). Temporary slides of mature male specimens were prepared using pure glycerol. The photographs of the extremities were taken with a digital camera (Kameram21) attached to a microscope (Nikon Eclipse 80i) and processed with image processing programs. A digitizer board (Wacom CTE-440) connected to a PC and its standard pen were used to draw illustrations on a transparent layer of the original photo of each extremity. Coleman (2003, 2006, 2009) was followed while drawing illustrations. Scale bars were marked using a micrometric slide for each magnification ratio of the microscope.

Karaman and Pinkster (1977a, 1977b, 1987), Bellan-Santini et al. (1982), Özbek (2011) and Pinkster (1993) were followed for the taxonomic identification.

The collected samples are stored in the laboratory of the Faculty of Science and Letters of Eskisehir Osmangazi University, Eskisehir, Turkiye.


**Figure 1**. Distribution of the determined amphipod species species (◆*Echinogammarus stocki*, ✇*Gammarus aequicauda*, ■*Gammarus anatoliensis*, ⊗*Gammarus arduus*, ⊠*Gammarus balcanicus*, ☐*Gammarus dorsosetosus*, ❀*Gammarus gonensis*, ☯*Gammarus komareki*, ⊙*Gammarus lacustris*, ☼*Gammarus pulex pulex*, ⓘ*Gammarus uludagi*).

## RESULTS AND DISCUSSION

A total of 11 gammaridean taxa [Echinogammarus stocki G. Karaman, 1970, *Gammarus aequicauda* (G. Karaman, 1970), *Gammarus anatoliensis* Schellenberg, 1937, *Gammarus arduus* G. Karaman, 1975, *Gammarus balcanicus* Schäferna, 1923, *Gammarus dorsosetosus* Mateus & Mateus, 1990, *Gammarus gonensis* Özbek, 2016, *Gammarus komareki* Schäferna, 1923, *Gammarus lacustris* G.O. Sars, 1863, *Gammarus pulex pulex* (Linnaeus, 1758), *Gammarus uludagi* G.S. Karaman, 1975] were recorded.

*G. arduus* was the most common species and sampled at 33 localities. *G. komareki*, *G. pulex pulex*, and *G. uludagi* were observed at 22, 21, and 18 localities, respectively. The distribution of the determined taxa and the information of the stations are presented (Figure 1, Table 2). The observed morphological features of the determined taxa are as follows:

*E. stocki:* A small species. The maximum body length is about 11mm in adults. The antenna I reach half of the body and peduncle segments bear long setae along the posterior margins; the main and accessory flagellum consists of 20 and 4-5 segments, respectively. The fourth and fifth peduncle segments of antenna II bear 7-8 groups of long setae along the posterior margin, and the length of these setae are more than twice as long as the diameter of the segments on which they are implanted. Calceoli is absent. The mandibular palp has the characteristic C-setae. Endopodite of uropod III elongated and prominently as long as 1/5 of the exopodite and its length is three times as long as the wide. Exopodite with many plumose setae on both margins. Telson lobes are deeply cleft and about twice as long as their width.

*Examined material:* St. 2: 2 ♀♀, 2 ♂♂, 17.v.2014; St. 3: 30 ♀♀, 30 ♂♂, 17.v.2014.

*G. aequicauda:* The maximum body length is about 14-15 mm in adults. The main and accessory flagellum of antenna I consist of 28 and 6 segments, respectively. The fourth and fifth peduncle segments of antenna II bear many groups of long curled and simple setae on the posterior margins. Calceoli is absent. The third segment of the mandibular palp bears 2 groups of A-setae, 1 group of B-setae, 26 D-setae, and 4 E-setae. Gnathopod I is smaller than gnathopod II; propodus of the gnathopods I-II elongated and pyriform with a flask-shaped medial palmar spine. Pereiopods V-VII with long setae on the anterior margin. The basis of the pereiopod V-VI with 3-4 and 7-8 short setae on the postero-interior surface. Rami of the uropod III bears many plumose and simple setae. Telson lobes are very deeply cleft and about three times as long as their width. Each lobe with 2 groups of spines and setae on the outer margin, and 3 spines and 6-7 long setae on the terminal; setae longer than spines.

Examined material: St. 2: 43 ♀♀, 62 ♂♂, 17.v.2014; St. 3: 8 ♂♂, 17.v.2014; St. 125: 16 ♀♀, 12 ♂♂, 20.xii.2018; St. 126: 1 ♂♂, 20.xii.2018.

*G. anatoliensis:* The maximum body length is about 14-15mm in adults. Within the *Gammarus balcanicus*-group, it can be easily distinguished from the others by the elevated and crenulated dorsoposterior margins of the metasomal segments. Addition-

**Table 1.** Taxonomic status, abbreviations (Abbr.) and newly recorded provinces of the determined taxa.

| | Taxonomic status | Abbr. | Newly recorded locality |
|---|---|---|---|
| Gammaridae Leach, 1814 | Genus: *Echinogammarus* Stebbing, 1899 | | |
| | *E. stocki* G. Karaman, 1970 | *E.s.* | Ekinanbarı |
| | Genus: *Gammarus* Fabricius, 1775 | | |
| | *G. aequicauda* (Martynov, 1931) | *G.ae.* | -- |
| | *G. anatoliensis* Schellenberg, 1937 | *G.an.* | Uşak |
| | *G. arduus* G. Karaman, 1975 | *G.ar.* | Bolu and Düzce |
| | *G. balcanicus* Schäferna, 1923 | *G.b.* | Kocaeli and Sakarya |
| | *G. dorsosetosus* Mateus & Mateus, 1990 | *G.d.* | Bolu |
| | *G. gonensis* Özbek, 2016 | *G.g.* | Istanbul and Manisa |
| | *G. komareki* Schäferna, 1923 | *G.k.* | Düzce and Kocaeli |
| | *G. lacustris* G.O. Sars, 1863 | *G.l.* | Istanbul |
| | *G. pulex pulex* (Linnaeus, 1758) | *G.p.p.* | Bolu, Kırklareli, Kocaeli, Sakarya and Uşak |
| | *G. uludagi* G.S. Karaman, 1975 | *G.u.* | Aydın, Bilecik, Sakarya and Yalova |

**Table 2.** The names, localities, sampling dates, geographical locations, and altitudes of the stations.

| No | Locality | Date | Latitude | Longitude | Taxon |
|---|---|---|---|---|---|
| 1 | Fountain (Paşa Valley) | 12.05.2014 | 37°56′34.0″N | 27°53′31.8″E | *G.u.* |
| 2 | Ekinanbarı Spring | 17.05.2014 | 37°14′42.58″N | 27°41′9.09″E | *E.s., G.ae.* |
| 3 | Bafa Lake | 17.05.2014 | 37°28′37.13″N | 27°29′8.28″E | *E.s., G.ae.* |
| 4 | Hona Creek | 23.05.2015 | 38°14′28.40″N | 27°14′0.84″E | *G.u.* |
| 5 | Karasu Spring | 25.07.2015 | 39°50′28.90″N | 29°58′38.73″E | *G.b.* |
| 6 | Mezit Creek-1 | 25.07.2015 | 39°54′49.48″N | 29°48′54.57″E | *G.b.* |
| 7 | Mezit Creek-2 | 25.07.2015 | 39°54′55.71″N | 29°49′7.25″E | *G.b.* |
| 8 | Creek (Berçin) | 25.07.2015 | 39°47′18.96″N | 29°35′40.63″E | *G.b., G.p.p.* |
| 9 | Sorkun Creek | 26.07.2015 | 39°34′13.23″N | 29°27′10.86″E | *G.p.p.* |
| 10 | Creek (Harmancık) | 26.07.2015 | 39°40′28.84″N | 29° 9′0.70″E | *G.b., G.p.p.* |
| 11 | Fountain | 26.07.2015 | 39°35′26.64″N | 27°29′25.22″E | *G.u.* |
| 12 | Creek (Dereiçi) | 27.07.2015 | 39°41′11.83″N | 27°9′51.93″E | *G.u.* |
| 13 | Creek (Hanlar) | 27.07.2015 | 39°43′27.49″N | 27°11′0.61″E | *G.u.* |
| 14 | Fountain (Hanlar) | 27.07.2015 | 39°43′9.95″N | 27°10′60.00″E | *G.u.* |
| 15 | Fountain (Huriyeoğulları) | 27.07.2015 | 39°40′18.01″N | 27°6′42.31″E | *G.u.* |
| 16 | Fountain (Talimalanı) | 27.07.2015 | 39°40′16.57″N | 27°5′52.54″E | *G.u.* |
| 17 | Hasanboğuldu Creek-1 | 27.07.2015 | 39°38′42.05″N | 26°55′6.62″E | *G.u.* |
| 18 | Hasanboğuldu Creek-2 | 27.07.2015 | 39°38′47.01″N | 26°55′4.78″E | *G.u.* |
| 19 | Pınarbaşı Creek | 30.07.2015 | 39°37′15.10″N | 26°52′49.86″E | *G.u.* |
| 20 | Bıçkı Creek | 30.07.2015 | 39°45′20.34″N | 26°48′17.07″E | *G.u.* |
| 21 | Ayazma Creek | 30.07.2015 | 39°44′46.90″N | 26°50′35.03″E | *G.u.* |
| 22 | Kocaköy Creek | 31.07.2015 | 39°56′17.26″N | 27°13′54.72″E | *G.g.* |
| 23 | Kaz Creek | 31.07.2015 | 39°58′53.66″N | 27°7′22.62″E | *G.u.* |
| 24 | Fındıklı Creek-1 | 31.07.2015 | 40°24′29.76″N | 26°34′6.56″E | *G.ar.* |
| 25 | Fındıklı Creek-2 | 31.07.2015 | 40°25′6.98″N | 26°33′46.82″E | *G.ar.* |
| 26 | Burgaz Creek-1 | 1.08.2015 | 40°24′54.65″N | 26°30′38.75″E | *G.ar.* |
| 27 | Burgaz Creek-2 | 1.08.2015 | 40°24′55.05″N | 26°30′39.28″E | *G.ar.* |
| 28 | Gölcük Creek | 1.08.2015 | 40°41′31.22″N | 27°5′47.02″E | *G.ar.* |
| 29 | Fountain (Hasan Engin) | 2.08.2015 | 40°42′21.08″N | 26°34′0.98″E | *G.ar.* |
| 30 | Fountain (Erikli) | 2.08.2015 | 40°38′17.99″N | 26°27′24.08″E | *G.ar.* |
| 31 | Babadere Creek | 2.08.2015 | 40°39′25.52″N | 26°32′57.66″E | *G.k.* |
| 32 | Dere-1 (Hasköy) | 2.08.2015 | 40°39′55.49″N | 26°19′2.88″E | *G.ar.* |
| 33 | Ova Creek | 2.08.2015 | 40°40′25.32″N | 26°11′16.75″E | *G.ar.* |

**Table 2.** Continue.

| No | Locality | Date | Latitude | Longitude | Taxon |
|---|---|---|---|---|---|
| 34 | Fountain (Hacı Hüseyin) | 3.08.2015 | 40°53′45.95″N | 26°22′3.71″E | *G.ar.* |
| 35 | Fountain (H. Seyit Kâhya) | 3.08.2015 | 40°53′45.68″N | 26°22′3.90″E | *G.ar.* |
| 36 | Fountain (Sultan) | 3.08.2015 | 41°1′43.83″N | 26°26′56.51″E | *G.ar.* |
| 37 | Balabancık Creek | 3.08.2015 | 41°1′57.94″N | 26°24′36.97″E | *G.ar.* |
| 38 | Fountain (Uzunköprü) | 3.08.2015 | 41°16′26.39″N | 26°39′44.88″E | *G.ar.* |
| 39 | Bölükler Creek | 3.08.2015 | 41°10′29.46″N | 26°40′3.40″E | *G.k.* |
| 40 | Fountain | 3.08.2015 | 41°17′52.27″N | 26°57′7.73″E | *G.ar.* |
| 41 | Fountain-1 (Danişment) | 3.08.2015 | 41°18′14.14″N | 26°54′2.21″E | *G.ar.* |
| 42 | Fountain-2 (Danişment) | 4.08.2015 | 41°18′25.93″N | 26°54′9.89″E | *G.ar.* |
| 43 | Fountain (Akarca) | 4.08.2015 | 41°20′2.88″N | 26°55′20.23″E | *G.ar.* |
| 44 | Kaynarca Creek | 4.08.2015 | 41°33′2.16″N | 27°25′44.24″E | *G.ar.* |
| 45 | Fountain (Sofuhalil) | 4.08.2015 | 41°26′38.24″N | 27°9′22.33″E | *G.ar.* |
| 46 | Çilingir Creek-2 | 4.08.2015 | 41°26′39.95″N | 27°9′16.44″E | *G.ar.* |
| 47 | Fountain(Menekşesofular) | 5.08.2015 | 41°45′42.36″N | 26°38′37.00″E | *G.ar.* |
| 48 | Sofular Creek | 5.08.2015 | 41°45′43.03″N | 26°38′35.86″E | *G.ar.* |
| 49 | Sinanköy Creek | 5.08.2015 | 41°44′16.29″N | 26°39′52.99″E | *G.k.* |
| 50 | Karayusuf Creek | 5.08.2015 | 41°43′53.89″N | 26°41′39.67″E | *G.ar.* |
| 51 | Fountain (Demirhanlı) | 5.08.2015 | 41°41′55.66″N | 26°44′2.00″E | *G.k.* |
| 52 | Fountain (Özmen Ailesi) | 5.08.2015 | 41°43′58.18″N | 26°50′52.46″E | *G.ar.* |
| 53 | Fountain (Bostanlı) | 5.08.2015 | 41°36′37.50″N | 26°58′16.91″E | *G.ar.* |
| 54 | Fountain (Hazinedar) | 5.08.2015 | 41°33′45.41″N | 27°0′22.42″E | *G.ar.* |
| 55 | İnece Creek-2 | 5.08.2015 | 41°33′39.96″N | 27°0′51.59″E | *G.k.* |
| 56 | Fountain (Çaydere) | 6.08.2015 | 41°42′6.52″N | 27°30′41.63″E | *G.ar.* |
| 57 | Fountain (Gendarmerie Tower) | 6.08.2015 | 41°46′7.71″N | 27°41′0.73″E | *G.k.* |
| 58 | Velika Creek | 6.08.2015 | 41°46′55.45″N | 27°42′26.07″E | *G.p.p.* |
| 59 | Asker Creek | 6.08.2015 | 41°51′7.86″N | 27°48′24.55″E | *G.k.* |
| 60 | Değirmen Creek | 6.08.2015 | 41°49′18.09″N | 27°45′4.25″E | *G.p.p.* |
| 61 | Fountain-2 (Sergen) | 6.08.2015 | 41°41′19.10″N | 27°42′33.41″E | *G.ar.* |
| 62 | Fountain (Okçular) | 7.08.2015 | 41°33′14.82″N | 27°49′29.08″E | *G.ar.* |
| 63 | Kazan Creek | 7.08.2015 | 41°37′51.54″N | 27°53′4.20″E | *G.ar., G.k.* |
| 64 | Kömürköy Spring | 7.08.2015 | 41°38′13.10″N | 27°53′33.97″E | *G.k.* |
| 65 | Pabuç Creek | 7.08.2015 | 41°41′6.01″N | 27°52′58.25″E | *G.k.* |
| 66 | Dere (Kışlacık) | 7.08.2015 | 41°40′50.65″N | 27°57′17.80″E | *G.k.* |
| 67 | Kızılcaali Creek | 9.08.2015 | 41°13′58.72″N | 28°33′19.17″E | *G.l.* |
| 68 | Sofular Creek | 9.08.2015 | 41°10′26.41″N | 29°29′24.97″E | *G.k.* |
| 69 | Dere (Kızılcaköy) | 9.08.2015 | 41°9′16.14″N | 29°32′37.80″E | *G.p.p.* |
| 70 | Kızılca Spring | 9.08.2015 | 41°9′15.66″N | 29°32′37.77″E | *G.p.p.* |
| 71 | Ballıkaya Creek | 10.08.2015 | 40°50′21.70″N | 29°31′2.21″E | *G.b.* |
| 72 | Oruçoğlu Creek | 11.08.2015 | 41°3′54.89″N | 29°28′26.88″E | *G.k.* |
| 73 | Übeyli Dere | 11.08.2015 | 41°5′58.00″N | 29°46′56.20″E | *G.g.* |
| 74 | Taşlıgeçit Creek | 11.08.2015 | 41°6′16.85″N | 30°28′34.40″E | *G.p.p.* |
| 75 | Kiraz Stream | 12.08.2015 | 40°42′5.52″N | 29°59′40.90″E | *G.p.p.* |
| 76 | Kazan Dere | 12.08.2015 | 40°38′22.03″N | 29°57′37.37″E | *G.k.* |
| 77 | Armutlu Creek-3 | 13.08.2015 | 40°32′44.61″N | 28°50′30.68″E | *G.g.* |
| 78 | Fountain (Selimiye) | 13.08.2015 | 40°30′51.86″N | 28°58′55.44″E | *G.g.* |
| 79 | Soğukdere Creek-1 | 13.08.2015 | 40°31′17.71″N | 28°59′11.82″E | *G.u.* |
| 80 | Soğukdere Creek-2 | 13.08.2015 | 40°31′17.08″N | 28°59′11.29″E | *G.p.p.* |
| 81 | Boğaz Creek | 14.08.2015 | 40°14′58.02″N | 29°42′53.54″E | *G.p.p., G.d.* |
| 82 | Papatya Creek (Göksu Stream) | 14.08.2015 | 40°14′34.27″N | 29°44′22.95″E | *G.p.p.* |
| 83 | Fountain (Pelitözü) | 14.08.2015 | 40°10′37.23″N | 29°57′27.46″E | *G.p.p.* |
| 84 | Hamsu Creek-1 (Çakırpınar) | 14.08.2015 | 40°8′40.66″N | 29°57′47.67″E | *G.p.p.* |

**Table 2.** Continue.

| No | Locality | Date | Latitude | Longitude | Taxon |
|---|---|---|---|---|---|
| 85 | Hamsu Creek-2 (Selöz) | 15.08.2015 | 40°7′51.45″N | 29°55′49.31″E | *G.p.p.* |
| 86 | Hamsu Creek-3 (Ulupınar) | 15.08.2015 | 40°7′15.06″N | 29°53′15.29″E | *G.p.p.* |
| 87 | Fountain (Ulupınar) | 15.08.2015 | 40°6′39.34″N | 29°52′59.33″E | *G.p.p.* |
| 88 | Fountain (Karadede) | 15.08.2015 | 40°5′12.68″N | 29°50′49.86″E | *G.p.p.* |
| 89 | Günyurdu Creek | 15.08.2015 | 40°4′32.17″N | 29°50′27.55″E | *G.p.p.* |
| 90 | Fountain (Büyükelmalı) | 15.08.2015 | 40° 3′9.11″N | 29°48′25.90″E | *G.u.* |
| 91 | Fountain (Küplü Bridge) | 5.12.2015 | 40°00′36.118″N | 30°39′54.38″E | *G.an.* |
| 92 | Küplü Creek (Mayıslar) | 5.12.2015 | 40°01′29.168″N | 30°39′16.609″E | *G.an.* |
| 93 | Sorgun Creek | 5.12.2015 | 40°20′24.34″N | 31°14′22.44″E | *G.p.p.* |
| 94 | Mudurnu Stream-1 | 5.12.2015 | 40°31′26.641″N | 31°14′33.935″E | *G.p.p.* |
| 95 | Dere-1 (Uğurköy) | 6.12.2015 | 40°44′3.294″N | 31°12′51.735″E | *G.k.* |
| 96 | Dere-2 (Uğurköy) | 6.12.2015 | 40°44′16.807″N | 31°12′28.224″E | *G.ar.* |
| 97 | Creek (Gelenöz) | 6.12.2015 | 40°55′57.80″N | 31°19′38.43″E | *G.k.* |
| 98 | Creek (Ahmetçiler) | 6.12.2015 | 40°58′33.194″N | 31°26′5.346″E | *G.k.* |
| 99 | Creek (Tıraşlar) | 6.12.2015 | 41°00′37.326″N | 31°24′52.136″E | *G.k.* |
| 100 | Edilli Creek | 8.12.2015 | 41°4′15.00″N | 31°4′18.05″E | *G.k.* |
| 101 | Karaburun Creek | 8.12.2015 | 41°4′12.32″N | 31°1′0.14″E | *G.k.* |
| 102 | Akçay Stream | 8.12.2015 | 40°34′54.58″N | 30°45′19.88″E | *G.u.* |
| 103 | Fountain (Çamyurdu) | 8.12.2015 | 40°35′32.50″N | 30°56′16.35″E | *G.b.* |
| 104 | Çağşak Creek | 9.12.2015 | 40°33′2.03″N | 31°0′17.27″E | *G.p.p.* |
| 105 | Fountain (Tosunlar) | 9.12.2015 | 40°33′1.99″N | 31°0′17.74″E | *G.p.p.* |
| 106 | Gök Dere-1 (Çavuşdere) | 9.12.2015 | 40°30′7.26″N | 31°2′45.90″E | *G.p.p.* |
| 107 | Gök Dere-2 (Yeşilyazı) | 9.12.2015 | 40°27′20.19″N | 30°58′11.10″E | *G.ar.* |
| 108 | Gök Dere-3 (Sünnet) | 9.12.2015 | 40°26′31.63″N | 30°57′38.21″E | *G.p.p.* |
| 109 | Hebirler Creek | 9.12.2015 | 40°18′49.69″N | 30°51′22.56″E | *G.p.p.* |
| 110 | Gelinkaya Creek | 25.04.2016 | 39°18′56.44″N | 29°58′39.10″E | *G.p.p.* |
| 111 | Fountain (Yaylaköy) | 25.04.2016 | 39°5′22.39″N | 29°28′15.68″E | *G.u.* |
| 112 | Fountain (Akçaalan) | 25.04.2016 | 39°4′13.56″N | 29°24′11.96″E | *G.u.* |
| 113 | Fountain (Aşağıyoncaağaç) | 25.04.2016 | 39°13′54.39″N | 29°14′47.00″E | *G.u.* |
| 114 | Creek (Emet) | 25.04.2016 | 39°20′14.72″N | 29°17′31.51″E | *G.g.* |
| 115 | Fountain (Oysu) | 26.04.2016 | 38°58′1.80″N | 29°54′54.70″E | *G.g.* |
| 116 | Fountain (Saraycık) | 26.04.2016 | 38°59′4.10″N | 29°50′53.30″E | *G.an.* |
| 117 | Banaz Stream-1 | 27.04.2016 | 38°22′0.87″N | 29°19′40.89″E | *G.an.* |
| 118 | Creek (Kıranyer) | 28.04.2016 | 37°48′19.30″N | 28°48′37.80″E | *G.u.* |
| 119 | Bozüyük Pınarbaşı Creek | 29.04.2016 | 37°17′44.68″N | 28°7′39.24″E | *G.b.* |
| 120 | Banaz Stream-2 | 12.05.2016 | 38°32′58.12″N | 29°37′26.00″E | *G.p.p.* |
| 121 | Hamam Creek | 12.05.2016 | 38°46′43.20″N | 29°49′11.90″E | *G.p.p.* |
| 122 | Dere (Zafertepeçalköy) | 12.05.2016 | 38°56′46.60″N | 30°5′20.30″E | *G.an.* |
| 123 | Çitalan Creek | 17.04.2018 | 39°24′5.30″N | 27°36′26.20″E | *G.g.* |
| 124 | Yağcılı Creek | 18.04.2018 | 39°14′15.07″N | 27°31′56.03″E | *G.g.* |
| 125 | Karina Lagoon | 20.12.2018 | 37°37′13.18″N | 27°11′54.00″E | *G.ae.* |
| 126 | Tuzburgazı Spring | 20.12.2018 | 37°37′15.88″N | 27°11′54.46″E | *G.ae.* |
| 127 | Creek (Soğanlı) | 16.03.2019 | 38°32′7.20″N | 28°26′8.92″E | *G.p.p.* |

ally, the basis of the pereiopod VII bears few setae on the posteroventral side. The main and accessory flagellum of antenna I consist of 21-25 and 3-4 segments, respectively. The flagellum of antenna II consists of 11-13 segments; with few flag-like brush setae on the posterior margins. Calceoli can be present or absent. The third segment of the mandibular palp bears 1 group of A-setae, 1 group of B-setae, 23-25 D-setae, and 4-5 E-setae. C-setae is absent. Pereiopod III and IV have a weak setation. Pereiopods V-VII bears the only spine on the anterior margin in segments 3-6, the setae is usually absent, if there is any, it is shorter than the spines. Rami of the uropod III is weakly armed. Telson lobes are cleft and more than twice their width. Each lobe has 2-3 spines and 4-5 setae on the terminal and usually 2 plumose setae on the lateral margin.

*Examined material:* St. 91: 5 ♀♀, 10 ♂♂, 5.xii.2015; St. 92: 9 ♀♀, 18 ♂♂, 5.xii.2015; St. 115: 28 ♀♀, 34 ♂♂, 26.iv.2016; St. 116: 6 ♀♀, 7 ♂♂, 26.iv.2016; St. 117: 26 ♀♀, 40♂♂, 27.iv.2016 St. 121: 2 ♂♂, 12.v.2016; St. 122: 5 ♂♂, 12.v.2016.

*G. arduus:* The body length is 14-15 mm in adults. Within the *Gammarus pulex*-group, it can be easily distinguished from the others by the antenna II that has a slender flagellum, and the epimeral plate II bears densely setae on the outer surface and distal margin, and especially basis of the pereiopod VI-VII bear setae on the postero-ventral side. Sometimes segments of the metasome II and III bear setae on the dorsal margin. Peduncles of the antenna I have a weak setation like flagellum. The main and accessory flagellum consists of 26-30 and 3-5 segments, respectively. Calceoli is absent. The third segment of mandibular palp bears 1 group of A-setae, 2 groups of B-setae, 25-27 D-setae, and 4-6 E-setae. C-setae is absent. Pereiopod III and IV are slender and have short dactylus. Epimeral plates I-III can be slightly pointed on the posterodistal corner. Epimeral plate II with numerous setae on the outer surface. The Rami of uropod III has many simple and plumose setae. The telson lobes are deeply cleft and about 3 times their width.

*Examined material:* St. 24: 28 ♀♀, 29 ♂♂, 31.vii.2015; St. 25: 52 ♀♀, 52 ♂♂, 31.vii.2015; St. 26: 49 ♀♀, 57 ♂♂, 1.viii.2015; St. 27: 29 ♀♀, 32 ♂♂, 1.viii.2015; St. 28: 37 ♀♀, 37 ♂♂, 1.viii.2015; St. 29: 21 ♀♀, 26 ♂♂, 2.viii.2015; St. 30: 43 ♀♀, 84 ♂♂, 2.viii.2015; St. 32: 15 ♀♀, 21 ♂♂, 2.viii.2015; St. 33: 44 ♀♀, 58 ♂♂, 2.viii.2015; St. 34: 29 ♀♀, 54 ♂♂, 3.viii.2015; St. 35: 14 ♀♀, 35 ♂♂, 3.viii.2015; St. 36: 23 ♀♀, 66 ♂♂, 3.viii.2015; St. 37: 82 ♀♀, 144 ♂♂, 3.viii.2015; St. 38: 5 ♀♀, 28 ♂♂, 3.viii.2015; St. 40: 61 ♀♀, 68 ♂♂, 3.viii.2015; St. 41: 43 ♀♀, 68 ♂♂, 3.vii.2015; St. 42: 46 ♀♀, 57 ♂♂, 4.viii.2015; St. 43: 21 ♀♀, 29 ♂♂, 4.viii.2015; St. 44: 61 ♀♀, 64 ♂♂, 4.viii.2015; St. 45: 32 ♀♀, 65 ♂♂, 4.viii.2015; St. 46: 60 ♀♀, 83 ♂♂, 4.viii.2015; St. 47: 10 ♀♀, 24 ♂♂, 5.viii.2015; St. 48: 14 ♀♀, 11 ♂♂, 5.viii.2015; St. 50: 28 ♀♀, 124 ♂♂, 5.viii.2015; St. 52: 23 ♀♀, 49 ♂♂, 5.viii.2015; St. 53: 1 ♀♀, 2 ♂♂, 5.viii.2015; St. 54: 18 ♀♀, 37 ♂♂, 5.viii.2015; St. 56: 20 ♀♀, 33 ♂♂, 6.viii.2015; St. 61: 18 ♀♀, 28 ♂♂, 6.viii.2015; St. 62: 13 ♀♀, 46 ♂♂, 7.viii.2015; St. 63: 12 ♂♂, 7.viii.2015; St. 96: 10 ♀♀, 55 ♂♂, 6.xii.2015; St. 107: 6 ♀♀, 22 ♂♂, 9.xii.2015.

*G. balcanicus:* The maximum body length is about 12-13mm in adults, a relatively small species. The antenna II is slender and has fewer setae. The pereiopods III-IV bear a few short setae, the pereiopods V-VII bear almost no seta, if any seta is present, it is always shorter than the spines. Epimeral plates I-III can be slightly pointed on the posterodistal corner and bear the only spine. The antenna I has a weak setation; the main and accessory flagellum consists of 21-25 and 3-4 segments, respectively. Antenna II bears short and fewer setae. The flagellum consists of 10-14 segments; the length of the setae is shorter than the diameter of the segments on which they are implanted. Calceoli can be present or absent. The third segment of the mandibular palp bears 2 groups of A-setae, 1 group of B-setae, 22-26 D-setae, and 4-5 long E-setae. C-setae is absent. Gnathopod I and II bear a small numerous of setae. The rami of uropod III bears only simple setae on both margins; there are no plumose setae. The telson lobes are deeply cleft and about 2 times their width.

*Examined material:* St. 5: 18 ♀♀, 47♂♂, 25.vii.2015; St. 6: 1 ♀, 1 ♂, 25.vii.2015; St. 7: 10 ♀♀, 22 ♂♂, 25.vii.2015; St. 8: 21 ♀♀, 17 ♂♂, 25.vii.2015; St. 10: 20 ♀♀, 29 ♂♂, 26.vii.2015; St. 71: 36 ♀♀, 29 ♂♂, 10.viii.2015; St. 82: 10 ♀♀, 11 ♂♂, 14.viii.2015; St. 102: 6 ♂♂, 8.xii.2015; St. 103: 29 ♀♀, 42 ♂♂, 8.xii.2015; St. 119: 49 ♀♀, 62 ♂♂, 29.iv.2016.

*G. dorsosetosus:* The body is smooth and its length is up to 10-11mm in adults. Within the *Gammarus balcanicus*-group, it can be easily distinguished from the others by the presence of long setae on the dorsoposterior margin of the metasome segments, which is a distinguishing morphological character for these species. The antenna I has a weak setation and the main and accessory flagellum consists of 20-23 and 2 segments, respectively. Antenna II bears fewer setae. The flagellum consists of 11 segments. Calceoli is absent. The third segment of mandibular palp bears one group of A-setae, one group of B-setae, 23-24 D-setae, and 4-5 E-setae. C-setae is absent. The lengths of pereiopod V-VII are almost the same, the length of the basis is 1.5 times their width, but the pereiopod V is relatively quadrangular in form and slightly longer than the width. The endopodite of the uropod III is about as long as 3/5 of the exopodite; the rami bear some plumose setae. The telson lobes are cleft and about 2.5 times their width.

*Examined material:* St. 81: 5 ♀♀, 16 ♂♂, 14.viii.2015; St. 84 : 7 ♀♀, 18 ♂♂, 14.viii.2015; St. 85 : 10 ♀♀, 8 ♂♂, 15.viii.2015; St. 86 : 2 ♀♀, 11 ♂♂, 15.viii.2015; St. 93: 2 ♂♂, 5.xii.2015.

*G. gonensis:* The body is smooth, medium to large, and up to 13-14 mm in adults. It belongs to the *Gammarus pulex*-group and is similar to *Gammarus uludagi* except for bearing many setae along the anterior margins of pereiopods 5-7, bearing less setose on the peduncle segments of the antenna II, bearing more setae on the propodus of the gnathopod II and having longer antenna I. The main and accessory flagellum of antenna I consist of 30 and 4 segments, respectively. Peduncles and flagellum have a weak setation. The flagellum of antenna II consists of 11 slightly swollen segments. Calceoli present on the segments 1-7. The third segment of the mandibular palp bears 1 group of A-setae, 2 groups of B-setae, 29 D-setae, and 6 E-setae. C-setae is absent. Endopodite of the uropod III is about as long as 3/4 of the exopodite with numerous plumose setae on both margins. The telson lobes are deeply cleft and about 2.5 times their width.

*Examined material:* St. 22: 28 ♀♀, 40♂♂, 31.vii.2015; St. 73: 13 ♀♀, 11 ♂♂, 11.viii.2015; St. 77 : 5 ♀♀, 13 ♂♂, 13.viii.2015; St. 78 : 6 ♀♀, 41 ♂♂, 13.viii.2015; St. 114: 24 ♀♀, 41 ♂♂, 25.iv.2016; St. 115: 5 ♀♀, 11 ♂♂, 26.iv.2016; St. 123: 18 ♀♀, 15 ♂♂, 17.iv.2018; St. 124: 19 ♀♀, 23 ♂♂, 18.iv.2018.

*G. komareki:* The body is smooth, medium to large, and up to 15mm in adults. It belongs to the *Gammarus pulex*-group and the most distinguishing morphological character is that the peduncles and flagellum of the antenna II have a very densely and long setation. The antenna I has a weak setation. There is Metasome III with some spinules on the dorsoposterior margin. The antenna I is long and as long as 2/3 of the total body length. Peduncles and flagellum have a weak setation. The main and accessory flagellum consists of 35-38 and 4-5 segments, respectively. The second and third peduncles and flagellum segments of the antenna II have a very dense, long and curled setation. The transverse rows of setae of the flagellum are 3 times the diameter of the segment on which they are implanted. The flagellum consists of 13 slightly swollen segments. Calceoli is absent. The third segment of the mandibular palp bears 1 group of A-setae, 1-2 groups of B-setae, 35 D-setae, and 4-6 E-setae. C-setae is absent. The endopodite of the uropod III is about as long as 3/4 of the exopodite; rami with some spines and numerous plumose setae on both margins. The telson lobes are deeply cleft and about as long as twice their width.

*Examined material:* St. 31: 37 ♀♀, 55 ♂♂, 2.viii.2015; St. 32: 47 ♀♀, 44 ♂♂, 2.viii.2015; St. 35: 36 ♀♀, 33 ♂♂, 3.viii.2015; St. 39: 55 ♀♀, 46 ♂♂, 3.viii.2015; St. 49: 42 ♀♀, 70 ♂♂, 5.viii.2015; St. 51: 8 ♀♀, 18 ♂♂, 5.viii.2015; St. 55: 27 ♀♀, 49 ♂♂, 5.viii.2015; St. 57: 6 ♀♀, 9 ♂♂, 6.viii.2015; St. 59: 26 ♀♀, 12 ♂♂, 6.viii.2015; St. 63: 13 ♀♀, 7 ♂♂, 7.viii.2015; St. 64: 9 ♀♀, 49 ♂♂, 7.viii.2015; St. 65: 56 ♀♀, 58 ♂♂, 7.viii.2015; St. 66: 30 ♀♀, 85 ♂♂, 7.viii.2015; St. 68: 32 ♀♀, 84 ♂♂, 9.viii.2015; St. 72: 9 ♀♀, 54 ♂♂, 11.viii.2015; St. 76: 2 ♀♀, 2 ♂♂, 12.viii.2015; St. 95: 31 ♀♀, 63 ♂♂, 6.xii.2015; St. 97: 26 ♀♀, 34 ♂♂, 6.xii.2015; St. 98: 8 ♀♀, 40 ♂♂, 6.xii.2015 ;St. 99: 6 ♀♀, 6 ♂♂, 6.xii.2015; St. 100: 13 ♀♀, 21 ♂♂, 8.xii.2015; St. 101: 3 ♀♀, 8 ♂♂, 8.xii.2015.

*G. lacustris:* The body is smooth and large and up to 24mm in adults. It belongs to the *Gammarus pulex*-group and is similar to *Gammarus pulex pulex* except for bearing not flag-like brush setae, it has relatively short and slender antennae, has more sharply pointed Epimeral plates, and slender dactylus. Metasome II and III with some spinules on the dorsoposterior margin. The antenna I is relatively short and slightly exceeds 1/3 of the total body length. The Peduncles and flagellum have a weak setation. The main and accessory flagellum consists of 27 and 3-4 segments, respectively. The fourth and fifth peduncles of the antenna II are almost equal in length with few setae, implanted in 3-4 longitudinal rows. Calceoli is present. There is no calceoli in some periods of the year as given information in the literature. The third segment of the mandibular palp bears 1 group of A-setae, 1 group of B-setae, 27 D-setae, and 4 E-setae. C-setae is absent. Endopodite of the uropod III reaches about 3/4 of the exopodite; rami with numerous plumose setae. The telson lobes are cleft and about as long as three their width.

*Examined material:* St. 67: 40 ♀♀, 73 ♂♂, 9.viii.2015.

*G. pulex pulex:* The body is smooth and large and is up to 25-30mm in adults. The Antenna II with a swollen compressed flagellum bears flag-like brush setae on the posterior margin; the swollen and compressed flagellum consists of 11-12 segments; each segment bears a transverse row of setae; Peduncles and flagellum of antenna I have a weak setation. The main and accessory flagellum consists of 25 and 5 segments, respectively. Calceoli is absent or present. The third segment of the mandibular palp bears 1 group of A-setae, 1 group of B-setae, 28 D-setae, and 5 E-setae. C-setae is absent. Pereiopods III-IV with long and curled setae. Rami of uropod III has a dense setation. The telson lobes are deeply cleft and about as long as three their width.

*Examined material:* St. 8: 21 ♀♀, 17 ♂♂, 25.vii.2015; St. 9: 15 ♀♀, 39 ♂♂, 26.vii.2015; St. 10: 9 ♀♀, 17 ♂♂, 26.vii.2015; St. 58 : 45 ♀♀, 50 ♂♂, 6.viii.2015; St. 60: 45 ♀♀, 67 ♂♂, 6.viii.2015; St. 69: 21 ♀♀, 43 ♂♂, 9.viii.2015; St. 70: 7 ♀♀, 22 ♂♂, 9.viii.2015; St. 74: 10 ♀♀, 30 ♂♂, 11.viii.2015; St. 75: 13 ♀♀, 28 ♂♂, 12.viii.2015; St. 80: 16 ♀♀, 20 ♂♂, 13.viii.2015; St. 81: 7 ♀♀, 4 ♂♂, 14.viii.2015; St. 83: 1 ♀, 1 ♂♂, 14.viii.2015; St. 84: 9 ♀♀, 8 ♂♂, 14.viii.2015; St. 85: 10 ♀♀, 25 ♂♂, 15.viii.2015; St. 86: 4 ♀♀, 27 ♂♂, 15.viii.2015; St. 87: 10 ♀♀, 27 ♂♂, 15.viii.2015; St. 88: 4 ♀♀, 6 ♂♂, 15.viii.2015; St. 89: 17 ♀♀, 29 ♂♂, 15.viii.2015; St. 93: 25 ♀♀, 35 ♂♂, 5.xii.2015; St. 94: 13 ♀♀, 14 ♂♂, 5.xii.2015; St. 104: 16 ♀♀, 37 ♂♂, 9.xii.2015; St. 105: 8 ♀♀, 23 ♂♂, 9.xii.2015; St. 106: 17 ♀♀, 40 ♂♂, 9.xii.2015; St. 108: 30 ♀♀, 55 ♂♂, 9.xii.2015; St. 109: 7 ♀♀, 11 ♂♂, 9.xii.2015; St. 110: 17 ♀♀, 23 ♂♂, 25.iv.2016; St. 116: 15 ♀♀, 17 ♂♂, 26.iv.2016; St. 120: 8 ♀♀, 30 ♂♂, 12.v.2016; St. 121: 17 ♀♀, 18 ♂♂, 12.v.2016; St. 122: 17 ♀♀, 23 ♂♂, 12.v.2016; St. 127: 3 ♀♀, 1 ♂, 16.iii.2019.

*G. uludagi:* The body smooth and medium-large is 13mm in adults. It is very similar to *G. fossarum* and *G. gonensis* at first sight, but it has flag-like brush setae on the flagellum of the antenna II and long setae on the peduncle segments. The fourth and fifth peduncles are almost equal in length and bear 4-5 groups of long setae with transverse rows on the posterior margin and these setae are about as long as or longer than the diameter of the segments on which are implanted. The swollen and compressed flagellum of antenna II consists of 11-12 segments; each segment bears a transverse row of setae. With a very characteristic feature, the telson lobes are deeply cleft and longer than twice their width. Each lobe has 2-3 groups of setae and 2 short plumose setae on the outer lateral margin, 2-3 groups of setae on the inner lateral margin, and additionally to 1 spine and 4-5 setae on the terminal; these setae are about as long as or longer than the length of the lobes. Peduncles and flagellum of antenna I have a weak setation. The main and accessory flagellum consists of 32 and 6 segments, respectively. Calceoli is absent. The third segment of the mandibular palp bears 1 group of A-setae, 1 group of B-setae, 27 D-setae, and 6 E-setae. C-setae is absent. Endopodite of the uropod III is about as long as 3/5 of the exopodite; The rami bear simple setae on both margins.

*Examined material*: St. 1: 18 ♀♀, 20 ♂♂, 12.v.2014; St. 4 : 27 ♀♀, 42 ♂♂, 23.v.2015; St. 11: 26 ♀♀, 23 ♂♂, 26.vii.2015; St. 12: 19 ♀♀, 41 ♂♂, 27.vii.2015; St. 13: 16 ♀♀, 71 ♂♂, 27.vii.2015; St. 14: 26 ♀♀, 42 ♂♂, 27.vii.2015; St. 15: 21 ♀♀, 43 ♂♂, 27.vii.2015; St. 16: 7 ♀♀, 59 ♂♂, 27.vii.2015; St. 17: 22 ♀♀, 20 ♂♂, 27.vii.2015; St. 18: 22 ♀♀, 11 ♂♂, 27.vii.2015; St. 19: 55 ♀♀, 48 ♂♂, 30.vii.2015; St. 20: 26 ♀♀, 55 ♂♂, 30.vii.2015; St. 21: 49 ♀♀, 53 ♂♂, 30.vii.2015; St. 23: 31 ♀♀, 51 ♂♂, 31.vii.2015, St. 79: 6 ♀♀, 6 ♂♂, 13.viii.2015; St. 90: 5 ♀♀, 9 ♂♂, 15.viii.2015; St. 102: 3 ♀♀, 14 ♂♂, 8.xii.2015; St. 111: 13 ♀♀, 33 ♂♂, 25.iv.2016; St. 112: 14 ♀♀, 27 ♂♂, 25.iv.2016; St. 113: 13 ♀♀, 39 ♂♂, 25.iv.2016; St. 118 : 30 ♀♀, 40 ♂♂, 28.iv.2016.

**Diagnostic key**

1. a) Endopodite of the uropod III is less than 1/4 of the length of the exopodite …..(*Echinogammarus*) ……......................... ....... *Echinogammarus stocki* G. Karaman, 1970

   b) Endopodite of the uropod III is longer than 1/4 of the length of the exopodite ……......…..(*Gammarus*) ….......….. 2

2. a) Eyes elongated, kidney-shaped………….. *Gammarus aequicauda* (Martynov, 1931)

   b) The eyes are round or oval ............................................... 3

3. a) Posterior margins of the pereiopod III-IV poorly setose…..........(*Gammarus balcanicus*-group)...........................4

   b) Pereiopod III-IV with numerous long setae…….. (*Gammarus pulex*-group) …… 6

4. a) Inner surface of basal segment of the pereiopod VII with setae..………… *Gammarus anatoliensis* Schellenberg, 1937

   b) Inner surface of basal segment of the pereiopod VII without setae ……........…… 5

5. a) Metasome segments with a few long setae on dorsoposterior margins……..…....………………........…… *Gammarus dorsosetosus* Mateus & Mateus, 1990

   b) Metasome segments without long setae on dorsoposterior margins ………………..… ……….…………..………....... …...…...………… *Gammarus balcanicus* Schäferna, 1923

6. a) Inner surface of basal segment of the pereiopod VI-VII with setae …………………... ………………………………………………...…… *Gammarus arduus* G. Karaman, 1975

   b) Inner surface of basal segment of the pereiopod VI-VII without setae …......……..... 7

7. a) Peduncle and flagellum segments of antenna II densely set with brushes of very long setae …………....………………………..…..…..……… *Gammarus komareki* Schäferna, 1923

   b) Peduncle and flagellum segments of antenna II with shorter setae ………………..…. 8

8. a) Inner surface of palm of the gnathopod II with many long curled setae …...…....…. 9

   b) Inner surface of palm of the gnathopod II without curled setae ……...…………..... 10

9. a) Peduncles of the antenna II bear long setae (as long as or longer than the diameter of the segments) …………..…….…………….....……… *Gammarus uludagi* G.S. Karaman, 1975

   b) Peduncles of the antenna II with short setae …….. *Gammarus gonensis* Özbek, 2016

10. a) Flagellar segments of antenna II swollen bearing flag like setae. Epimeral plate II-III with rectangular to weekly pointed ……...……..… *Gammarus pulex pulex* (Linnaeus, 1758)

    b) Flagellar segments of antenna II without flag like setae. Epimeral plate II-III with sharply pointed posteroinferior corners …...……...…… *Gammarus lacustris* G.O. Sars, 1863

*E. stocki* is one of the most difficult species to find because it inhabits a very narrow zone on the verge of freshwater and brackish or marine waters as stated in the literature (Pinkster, 1993). The type locality of the species is a salt spring in Cres Island (Karaman, 1970). In Turkiye, it was firstly recorded from the Bafa Lake by Karaman (1971). Then, several recordings were reported from the lake (Geldiay et al., 1977; Kocataş & Katağan, 1978; Bellan-Santini et al., 1982; Ustaoğlu et al., 1998; Sarı et al., 2001). In this study, the species was reported from a spring in the Ekinanbarı village for the first time. The species was previously confused with *E. acarinatus*, then Karaman (1970) eliminated this confusion when he revealed the presence of C-seta in the mandibular palp which is an important character distinguishing it from the other *Echinogammarus* species. Although it was stated that the sample from France has setae on the anterior margin of the epimeral plate I and the ventral margins of the epimeral plates II-III (Pinkster, 1993), these setae were absent in our samples (Figure 2).

The type locality of *G. aequicauda* is Donuzlav Lake in Crimea. In Turkiye, it was firstly recorded from a brackish water pool in Mersin province by Stock (1967). The species is abundant, especially in Western Anatolia (from Çanakkale to Muğla provinces) and there are several records from Mersin and Antalya in the Mediterranean, Sinop and Samsun in the Black Sea, Çanakkale, Edirne and Istanbul in Thrace region (Altınsaçlı et al., 2017; Akbulut et al., 2002, 2009*a*, 2009b; Balık et al., 2006; Bat et al., 2000; Karaman, 2003, Kocataş & Katağan, 1978; Mateus & Mateus, 1990; Özbek 2011; Özbek & Ustaoğlu, 1998, Özbek et al., 2015, 2016; Sarı et al., 2001; Ustaoğlu et al., 1998, 2000). It was also reported from the Gökçeada Island (Aegean Sea) (Özbek & Özkan, 2017). Considering the morphological features of *G. aequicauda* given in the literature, the brackish water forms reported from Crimea and Mersin look similar, while the freshwater form from southern France has weaker setation than the others (Stock, 1967). The samples we studied are similar to those recorded from the Mersin province in terms of the length of the base of pereiopods V-VII. On the other hand, the present specimens differ from those reported from southern France in terms of the length of the basal segments of pereiopods V-VII and the setation of the anterior margins of the mentioned segments (Figure 2).

The type locality of *G. anatoliensis* is a torrent in Akşehir, Konya (Schellenberg, 1937). It is an endemic species of Turkiye. *G. anatoliensis* is widespread in the Lake District Region of Turkiye, but it was also recorded from the Marmara, the Black Sea, the Aegean, and the Mediterranean regions of Turkiye (Karaman & Pinkster, 1987, Özbek & Ustaoğlu, 2005, 2008, 2011; Özbek et al., 2009; Ekinci & Miroğlu 2016; İpek et al., 2017). In the present study, the species was recorded from the Uşak province for the first time. *G. anatoliensis* was detected at 7 localities in our study. The present specimens are almost identical with Karaman and Pinkster's (1987) description, but some variations were also observed (such as the absence of calceoli).

The type locality of *G. arduus* is a fountain in Malkara, Tekirdağ (Karaman 1975) in Turkiye. The species was also recorded from the Ordu and Samsun provinces in the Black Sea Region of Turkiye (Chertoprud & Palatov, 2017; Gözal, 2004; Karaman & Pinkster, 1977; Mateus & Mateus, 1990; Karaman, 2003; Özbek et al., 2017;

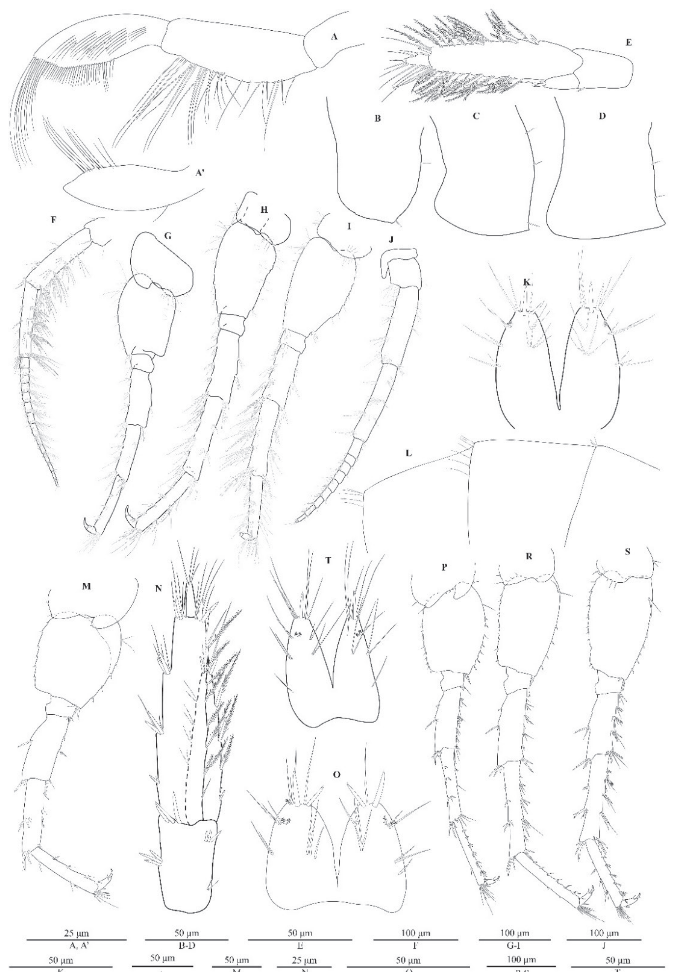

**Figure 2**. Some extremities (original) of *E. stocki* (A-E) (St.2), *G. aequicauda* (F-I) (St.2), *G. arduus* (J-K) (St.62), *G. dorsosetosus* (L-N) (St.93), *G. komareki* (O-S) (St.31), *G. lacustris* (T) (St.67). Male. A: mandibular palp; A': inner surface of the third segment of mandibular palp; B: epimeral plate I; C: epimeral plate II; D: epimeral plate III; E: uropod III; F: antenna II; G: pereiopod V; H: pereiopod VI; I: pereiopod VII; J: antenna II; K: telson; L: metasoma somites I-III; M: pereiopod V; N: uropod III; O: telson; P: pereiopod V; R: pereiopod VI; S: pereiopod VII; T: telson.

Özkan, 2009; Yeşilmen & Kırgız, 1996). In this study, the species was reported from Bolu and Düzce provinces for the first time. The specimens examined in this study have no calceoli.

The type locality of *G. balcanicus* is a spring in Kolašin, Montenegro (Schäferna, 1923). In Turkiye, it was first recorded from the Erciyes Mountain by S. Karaman (1934). Then, it was reported from several localities from the Strandja Mountains in Thrace to Bayburt in the Black Sea region, from İzmir in the Aegean to Hatay on the Mediterranean coast and to Van in eastern Anatolia (Akbulut et al., 2009b; Akbaba & Boyacı, 2015; Aygen & Balık, 2005; Balık et al., 2006; Baytaşoğlu & Gözler, 2018; Chertoprud & Palatov, 2017; Ekinci & Miroğlu, 2016; İpek & Şirin, 2009; İpek et al., 2017; Karaman, 2003, Karaman & Pinkster, 1987; Öntürk & İpek, 2018; Özbek & Ustaoğlu, 2005, 2008, 2011; Özbek et al., 2004, 2009; Ustaoğlu et al., 2004, 2008). In this study, the species was recorded from the Kocaeli and Sakarya provinces for the first time.

Karaman and Pinkster (1987) showed that the species has calceoli on the flagellum of the antenna II, but they mentioned that it is a variable character. Calceoli is also absent in our samples. The wide distribution of the species and its presence in various environments indicate the high tolerance of the species, as mentioned by Karaman and Pinkster (1987).

The type locality of *G. dorsosetosus* is the Amanos Mountains, Hatay province (Mateus & Mateus, 1990), and it is an endemic species for Turkiye. The species was also reported from the Burdur and Karaman provinces (Özbek & Topkara, 2007). In this study, the first record of the species from the Bolu province is documented. The slightly elevated metasome segments and the presence of long setae on the dorsoposterior margins are the characteristic features of the species (Figure 2). Mateus and Mateus (1990) did not provide detailed drawings of this species. However, Özbek and Topkara (2007) gave detailed drawings of the morphological characteristics of this species.

The type locality of *Gammarus gonensis* is the Gönen Stream in Balıkesir (Özbek 2016). It was also recorded from Çanakkale, and Tekirdağ (Özbek et al., 2017), Kütahya (İpek et al., 2017) provinces. In this study, the species was firstly recorded from the Istanbul (in Thrace), and Manisa provinces. *G. gonensis* is similar to the *G. uludagi* however, it can be easily distinguished from *G. uludagi* by the absence of long setae on the peduncle segments of antenna II, and by the presence of densely and curved setae on the inner surface of the propodus of the gnathopod II. In our study, the species was determined as a result of sampling made among the stones on the ground of streams with vegetation as Özbek (2016) stated.

The type locality of *G. komareki* is in Belovo Village near Pazarzik, Bulgaria (Schäferna, 1923). In Turkiye, it was firstly recorded by Karaman (1975) from a fountain in Malkara, Tekirdağ. Although it is mostly located in Thrace in our country, it has records from the Marmara and Black Sea regions in Anatolia (Akbulut et al., 2009b; Aslan et al., 2018; Chertoprud & Palatov, 2017; Ekinci & Miroğlu, 2016; Gözal, 2004; Karaman, 1975, 2003; Mateus & Mateus, 1990; Odabaşı et al., 2016; Özbek, 2008, 2011; Özbek & Özkan, 2017; Özbek et al., 2017; Yeşilmen & Kırgız, 1996). By the present study, the species was recorded for the first time from the Düzce and Kocaeli provinces. In the samples we examined, the telson lobes were wider and P5-7 were without long setae on the anterior margins. We omitted it as it is a variation (Figure 2).

The type locality of *G. lacustris* is Scandinavia (Sars, 1863) was firstly recorded in Turkiye by Tareen (1974) from the Gölcük Lake in İzmir. Despite the presence of several records of the species from Anatolia (Karaman, 1975, 2003; Özbek & Ustaoğlu, 2005, 2011; Özbek & Ustaoğlu, 1998; Özbek et al., 2007), it was firstly recorded from the Thrace Region of Turkiye in the present study. The samples we examined have setae on the telson lobes that were absent in Karaman and Pinkster's (1977a) report (Figure 2). Considering the previous studies, the setation of the telson in the samples in Lake Dimon and Venerocolo in Italy and especially in Lake Lame and the Lake District Region (Turkiye) is similar to our samples (Ruffo 1951; Özbek & Ustaoğlu, 2005).

The type locality of *G. pulex pulex* is in Öland Island, Sweden (Linnaeus, 1758). *G. pulex pulex*, which gives its name to the *G. pulex*-group and is a typical representative of the group, is one of the members of the genus *Gammarus* with the greatest distribution in the world. It has a wide distribution in Turkiye (Karaman, 1975; Karaman & Pinkster, 1977; Bat et al., 2000; Akbulut et al., 2002, 2009b; Ekinci & Miroğlu, 2016; Özbek & Ustaoğlu, 2005; Özbek et al., 2017). In our study, it was identified from the provinces of Kırklareli in Thrace, and Kocaeli, Sakarya, and Uşak in Western Anatolia for the first time except for the regions previously identified.

The type locality of *G. uludagi* is the Uludağ Mountain in Bursa (Karaman, 1975). It is an endemic species of Turkiye. Also, several records were given from the western parts of Anatolia, the island of Lesbos on the Anatolian coast, and the Black Sea Region of Turkiye (Akbulut et al., 2009b; Karaman, 1975; Karaman & Pinkster, 1977; Özbek & Ustaoğlu, 1998; Özbek et al., 2015, 2017; Şirin et al., 2009). In the present study, it was firstly recorded from a fountain in the Pasha Plateau on the Aydın Mountains, and Bilecik, and a stream in Sakarya.

## CONCLUSION

In this study, in which amphipod species are distributed in Western Anatolia, Marmara and Thrace regions of Turkiye were investigated, a total of 11 species were determined. This study, which aims to support the discovery of Turkish freshwater amphipod biodiversity, can be a resource for native amphipod researchers. It is obvious that rivers and lakes are under adverse conditions due to human pressure and global climate change. Several species living in Turkish rivers and lakes under the threat of pollution and frost are adversely affected by these changes, and some of them are completely eliminated. Under these conditions, the detection of biodiversity and the protection of our biological richness are of great importance. The authors believe that biodiversity studies should be supported and their numbers should be increased. Afterwards, sustainable management strategies can be developed.

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Research Article

# A Theoretical Approach to Determine the Total Resistance on Different Trawl Gears Used in Turkiye

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## ABSTRACT

The study aims to theoretically determine the total resistance forces acting on bottom trawls used in the commercial trawl fishery around the Turkish Peninsula. For this purpose, a total of 14 (2 for Black Sea, 2 for Sea of Marmara, 6 for Aegean Sea and 4 Mediterranean Sea) trawl gears were examined during the study representing all types of the bottom trawl fishery (e.g., fish targeted, shrimp targeted and mix) in Turkiye. The calculation of the hydrodynamic forces of the gears was based on the determination of each gear component; net, floaters, sweep, door, warp and the friction force caused by footrope, sweep and door. The total resistance of trawl gears was calculated according to different towing speeds and warp lengths. Average resistance values of the examined nets with a 500 m warp length indicated that the frictional force of the trawl door composed more than 41.3% of the total resistance, followed by net (39.4%), both doors (6.3%), footrope friction (6.1%), sweep frictions (3.1%) and the rest belonged to sweeps, warps and floaters (totally 3.8%). It was determined that resistance caused by friction including sweeps, footrope and doors constituted more than 50% of the total resistance. Among the examined gears, the greatest resistance values were determined for the 600 meshes tailored-traditional Mediterranean type trawl gear.

**Keywords:** Bottom trawl, total resistance, friction, hydrodynamic

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## INTRODUCTION

Trawls are one of the most important commercial fishing gears and account for almost a quarter of the global landed marine catch (Amoroso et al., 2018; Cashion et al., 2018). The target catch of trawl fishery is both demersal and pelagic species located in the water column. The gears are constituted by a set of the net, warp wire, trawl doors, sweeps, floaters, and sinkers. These elements should work well-matched with each other for good fishing performance. On the other hand, sea trials in order to understand the performance of these complex structures are expensive (Winger, DeLouche, & Legge, 2006). Therefore, mostly trawl performance studies were investigated by flume tank tests (Ferro, van Marlen, & Hansen, 1996; Balash, 2012), numerical modelling (Tsukrov, Eroshkin, Fredriksson, Swift, & Çelikkol B, 2003; Lee, Lee, Cha, Kim, & Lee, 2005; Priour, 2009; Tang, Dong, Xu, Zhao, & Bi, 2017) analytical modelling (Park, 2007), software simulation (Lee et al., 2005; Priour, 2013). Numerical modelling and simulation, in particular, are becoming popular methods of evaluating trawl designs and assessing their performance during the early stages of gear development (Fiorentini, Sala, Hansen, Cosimi, & Palumbo, 2004).

The Turkish Peninsula is surrounded by different physicochemical and geological features which create particular species diversity and the catch composition of commercial fishery shows variety in each sea (Bilecenoğlu, Kaya, Cihangir, & Çiçek, 2014). More than 90% of demersal fishes are landed by the trawl fishery in Turkiye (Soykan, Akgül, & Kınacıgil, 2016). Trawls have a variety in size and types which are complex in their design, material choice, and construction. There are many scientific studies conducted on trawls, but most of them focused on selectivity (both size and species) (Aydın, Tokaç, Ulaş, Maktay, & Şensurat, 2011; Özbilgin, Tokaç, & Kaykaç, 2012; Tokaç, Herrmann, Aydın, Kaykaç, Ünlüler, & Gökce, 2014), discard characteristics (Soykan et al., 2016; Soykan, Bakır, & Kınacıgil, 2019), survival ratios (Düzbastılar et al., 2010) and other aspects of the demersal trawl fishery in Turkiye (Stewart, 2002). On the other hand, scientific interest in resistance and other hydrodynamic effects is very limited and scarce in Turkiye. Only Düzbastılar, Tosunoğlu, & Kaykaç (2003) calculated the resistance values of conventional and tailored demersal trawl nets. On the other hand, choosing the right size trawl according to the power of the vessel including the other components of the gear such as doors and footrope is crucial for fuel consumption and catch efficiency.

The study aims to be a theoretical approach to determine hydrodynamic effects on different trawl gears used in Turkiye's commercial trawl fishery. The present work is the first theoretical study on the hydrodynamic forces on various types of bottom trawls considering the friction force and resistance of floaters for Turkiye.

## MATERIAL AND METHODS

### Trawl gears

Resistance forces on trawl nets were well described by Fridman (1973) and Düzbastılar et al. (2003). Due to the lack of gear standardization in the Turkish trawl fishery, almost each trawler has its own trawl net design although there are some restrictions, especially on mesh size at the codend. Bottom trawls investigated for theoretical evaluation here have been used in commercial fishing around Turkiye; the Black Sea, Sea of Marmara, Aegean Sea and the Mediterranean Sea. A total of 14 trawl nets (2 for the Black sea, 2 for the Sea of Marmara, 6 for the Aegean Sea and 4 for the Mediterranean Sea) were examined during the study, and those were the representatives of each type of the bottom trawl fishery (e.g., fish targeted, shrimp targeted and mix) in Turkiye. The nets emphasized in this study were chosen from published scientific papers around Turkish territorial waters (Table 1).

Total hydrodynamic resistance ($R_T$) was calculated by adding the resistance of each gear component; net, floaters, sweep, door, warp and the friction force caused by the footrope, sweep and door with the following formulae:

$$R_T = R_N + 2R_D + 2(R_S+R_W)+ nR_F + F_F$$

$R_T$: Total resistance (N)

$R_N$: Net resistance (N)

$R_D$: Door resistance (N)

$R_S$: Sweep resistance (N)

$R_W$: Warp resistance (N)

n: Number of floaters

$R_F$: Floater resistance (N)

Friction forces consist of friction of the footrope, sweep and doors

$$F_F= F_{FF}+F_{FS} +F_{FD}$$

$F_F$= Friction forces

$F_{FF}$= Friction by footrope

$F_{FS}$= Friction by sweep

$F_{FD}$= Friction by doors

**Table 1.** General specifications of trawl nets evaluated in the study.

| Code | Trawls types | Target species | Region | Literature |
|---|---|---|---|---|
| BS1 | 800 meshes | Fish | Black Sea | Özdemir et al., 2014 |
| BS2 | 900 meshes tailored | Fish | Black Sea (Samsun) | Kaykaç et al., 2017 |
| SM1 | 500 meshes traditional | Shrimp, fish | Sea of Marmara (Bandırma -Erdek) | Zengin et al., 2004 |
| SM2 | 260 meshes tailored | Shrimp fish | Sea of Marmara (Tekirdağ-Şarköy, Hoşköy, Barbaros) | Zengin et al., 2004 |
| AS1 | 900 meshes tailored | Fish | Aegean Sea (İzmir) | Tosunoğlu & Aydın, 2007 |
| AS2 | 1200 meshes tailored | Shrimp, fish | Aegean Sea (İzmir) | Tosunoğlu & Aydın, 2007 |
| AS3 | 1100 meshes tailored | Shrimp, fish | Aegean Sea (İzmir) | Aydın & Tosunoğlu, 2009 |
| AS4 | 600 meshes tailored | Fish | Aegean Sea (Foça) | Tokaç et al., 2010 |
| AS5 | 700 meshes traditional | Fish | Aegean Sea (Çanakkale) | Tokaç et al., 2010 |
| AS6 | 600 meshes traditional | Fish | Aegean (Bodrum) | Tokaç et al., 2010 |
| MS1 | 650 meshes traditional | Shrimps, fish | Mediterranean (İskenderun Bay) | Demirci et al., 2008 |
| MS2 | 600 meshes tailored | Shrimp | Mediterranean (Iskenderun Bay) | Demirci et al., 2008 |
| MS3 | 500 meshes tailored-traditional | Fish | Mediterranean (Iskenderun Bay) | Demirci et al., 2008 |
| MS4 | 600 meshes tailored-traditional | Fish, shrimps | Mediterranean (Mersin Bay) | Özbilgin et al., 2018 |

## Hydrodynamic resistance of trawl net

Trawl net sections in various sizes are composed of different materials. To estimate the hydrodynamic resistance forces, technical parameters such as rope diameter d (mm), the mesh length l (mm) and their ratio to each other (d/l) were taken from the technical plans. Metric characteristics of each section of the trawl nets were given in Table 2.

Resistance of the net ($R_n$) was calculated by the following formulas according to Nomura & Yamazaki (1975);

$$R_n = 25 \times \frac{d}{l} \times \lambda^2 \times v^2$$

$R_n$ = Resistance of the net

$\frac{d}{l}$ = ratio between the diameter of net line and mesh length (mm)

λ = Length of the headrope (m)

ν = Towing speed ($ms^{-1}$)

## Frictional resistance of footrope

The length, material and diameter of the footrope differed in each net (Table 3). Footrope weight in water was calculated with the following formulas:

**Table 2.** Metric characteristics of bottom trawl nets.

| | P | M | d | l | d/l | N | RxN | L | B | h | a | A |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BS1 | 1 | 1672 | 1.72 | 100 | 0.01720 | 2 | 0.03440 | 100 | 180 | 120 | 57.79 | 115.58 |
| Mean d/l=0.025238 | 2 | 1672 | 1.72 | 100 | 0.01720 | 2 | 0.03440 | 100 | 180 | 120 | 57.79 | 115.58 |
| | 3 | 836 | 0.86 | 40 | 0.02150 | 2 | 0.04300 | 400 | 400 | 225 | 61.92 | 123.84 |
| | 4 | | 3 | 50 | 0.06000 | 1 | 0.06000 | 60 | 10 | 90 | 9.45 | 9.45 |
| | 5 | 836 | 0.86 | 40 | 0.02150 | 2 | 0.04300 | 400 | 400 | 225 | 61.92 | 123.84 |
| | 6 | | 3 | 50 | 0.06000 | 1 | 0.06000 | 60 | 10 | 90 | 9.45 | 9.45 |
| | 7 | 836 | 0.86 | 40 | 0.02150 | 2 | 0.04300 | 600 | 600 | 180 | 74.30 | 148.61 |
| | 8 | 836 | 0.86 | 40 | 0.02150 | 2 | 0.04300 | 400 | 400 | 150 | 41.28 | 82.56 |
| | 9 | 836 | 0.86 | 40 | 0.02150 | 2 | 0.04300 | 300 | 300 | 180 | 37.15 | 74.30 |
| BS2 | 1 | 1078 | 1.17 | 100 | 0.01170 | 2 | 0.02340 | 25 | 50 | 25 | 2.19 | 4.39 |
| Mean d/l=0.01989 | 2 | 1078 | 1.17 | 100 | 0.01170 | 2 | 0.02340 | 25 | 50 | 25 | 2.19 | 4.39 |
| | 3 | 1078 | 1.17 | 100 | 0.01170 | 2 | 0.02340 | 50 | 75 | 75 | 10.97 | 21.94 |
| | 4 | 1078 | 1.17 | 100 | 0.01170 | 2 | 0.02340 | 50 | 50 | 75 | 8.78 | 17.55 |
| | 5 | 923 | 1.08 | 44 | 0.02455 | 2 | 0.04909 | 150 | 187.5 | 75 | 12.03 | 24.06 |
| | 6 | 923 | 1.08 | 44 | 0.02455 | 2 | 0.04909 | 75 | 150 | 150 | 16.04 | 32.08 |
| | 7 | 923 | 1.08 | 44 | 0.02455 | 1 | 0.02455 | 525 | 450 | 175 | 81.08 | 81.08 |
| | 8 | 923 | 1.08 | 44 | 0.02455 | 1 | 0.02455 | 450 | 350 | 100 | 38.02 | 38.02 |
| | 9 | 923 | 1.08 | 44 | 0.02455 | 1 | 0.02455 | 450 | 350 | 100 | 38.02 | 38.02 |
| | 10 | 923 | 1.08 | 40 | 0.02700 | 2 | 0.05400 | 385 | 150 | 235 | 54.31 | 108.63 |
| | 11 | 1078 | 1.17 | 40 | 0.02925 | 2 | 0.05850 | 150 | 150 | 200 | 28.08 | 56.16 |
| SM1 | 1 | 1030 | 1.20 | 80 | 0.01500 | 2 | 0.03000 | 15 | 15 | 24 | 0.69 | 1.38 |
| Mean d/l=0.13318 | 2 | 1030 | 1.20 | 80 | 0.01500 | 2 | 0.03000 | 15 | 15 | 24 | 0.69 | 1.38 |
| | 3 | 1030 | 1.20 | 80 | 0.01500 | 2 | 0.03000 | 25 | 25 | 32 | 1.54 | 3.07 |
| | 4 | 1030 | 1.20 | 80 | 0.01500 | 2 | 0.03000 | 25 | 25 | 32 | 1.54 | 3.07 |
| | 5 | 256 | 0.54 | 80 | 0.00675 | 2 | 0.01350 | 150 | 150 | 110 | 14.26 | 28.51 |
| | 6 | 256 | 0.54 | 80 | 0.00675 | 2 | 0.01350 | 150 | 150 | 110 | 14.26 | 28.51 |
| | 7 | 256 | 0.54 | 80 | 0.00675 | 2 | 0.01350 | 45 | 1 | 56 | 1.11 | 2.23 |
| | 8 | 256 | 0.54 | 80 | 0.00675 | 2 | 0.01350 | 45 | 1 | 28 | 0.56 | 1.11 |
| | 9 | 308 | 0.60 | 80 | 0.00750 | 2 | 0.01500 | 100 | 100 | 110 | 10.56 | 21.12 |
| | 10 | 462 | 0.74 | 20 | 0.03700 | 2 | 0.07400 | 75 | 70 | 120 | 2.58 | 5.15 |
| | 11 | 1030 | 1.20 | 80 | 0.01500 | 2 | 0.03000 | 50 | 50 | 25 | 2.40 | 4.80 |
| SM2 | 1 | 925 | 1.08 | 80 | 0.01350 | 2 | 0.02700 | 1 | 9 | 20 | 0.17 | 0.35 |
| Mean d/l=0.020488 | 2 | 925 | 1.08 | 80 | 0.01350 | 2 | 0.02700 | 1 | 9 | 20 | 0.17 | 0.35 |
| | 3 | 642 | 0.89 | 60 | 0.01483 | 2 | 0.02967 | 12 | 40 | 92 | 2.55 | 5.11 |
| | 4 | 642 | 0.89 | 60 | 0.01483 | 2 | 0.02967 | 12 | 40 | 92 | 2.55 | 5.11 |
| | 5 | 308 | 0.60 | 24 | 0.02500 | 1 | 0.02500 | 110 | 1 | 125 | 2.00 | 2.00 |
| | 6 | 308 | 0.60 | 24 | 0.02500 | 2 | 0.05000 | 110 | 130 | 125 | 4.32 | 8.64 |
| | 7 | 308 | 0.60 | 24 | 0.02500 | 2 | 0.05000 | 110 | 130 | 125 | 4.32 | 8.64 |
| | 8 | 308 | 0.60 | 24 | 0.02500 | 2 | 0.05000 | 260 | 192 | 167 | 10.87 | 21.74 |
| | 9 | 308 | 0.60 | 24 | 0.02500 | 2 | 0.05000 | 192 | 175 | 146 | 7.72 | 15.43 |
| | 10 | 308 | 0.60 | 24 | 0.02500 | 2 | 0.05000 | 175 | 77 | 167 | 6.06 | 12.12 |
| | 11 | 308 | 0.60 | 28 | 0.02143 | 1 | 0.02143 | 66 | 66 | 100 | 2.22 | 2.22 |

**Table 2.** Continue.

| | P | M | d | l | d/l | N | RxN | L | B | h | a | A |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AS1 | 1 | 923 | 1.26 | 110 | 0.01145 | 2 | 0.02291 | 5 | 50 | 45 | 3.43 | 6.86 |
| | 2 | 923 | 1.26 | 110 | 0.01145 | 2 | 0.02291 | 5 | 50 | 45 | 3.43 | 6.86 |
| | 3 | 923 | 1.26 | 110 | 0.01145 | 2 | 0.02291 | 75 | 100 | 75 | 18.19 | 36.38 |
| | 4 | 923 | 1.26 | 110 | 0.01145 | 2 | 0.02291 | 50 | 50 | 75 | 10.40 | 20.79 |
| Mean d/l=0.020386 | 5 | 692 | 1.09 | 46 | 0.02370 | 2 | 0.04739 | 200 | 250 | 32,5 | 7.33 | 14.67 |
| | 6 | 692 | 1.09 | 46 | 0.02370 | 2 | 0.04739 | 100 | 100 | 100 | 10.03 | 20.06 |
| | 7 | 692 | 1.09 | 46 | 0.02370 | 2 | 0.04739 | 285 | 200 | 167,5 | 40.73 | 81.46 |
| | 8 | 692 | 1.09 | 46 | 0.02370 | 2 | 0.04739 | 100 | 150 | 32,5 | 4.07 | 8.15 |
| | 9 | 692 | 1.09 | 46 | 0.02370 | 2 | 0.04739 | 185 | 150 | 67,5 | 11.34 | 22.68 |
| | 10 | 692 | 1.09 | 46 | 0.02370 | 2 | 0.04739 | 350 | 250 | 100 | 30.08 | 60.17 |
| | 11 | 692 | 1.09 | 46 | 0.02370 | 2 | 0.04739 | 250 | 150 | 100 | 20.06 | 40.11 |
| | 12 | 692 | 1.09 | 46 | 0.02370 | 2 | 0.04739 | 150 | 150 | 100 | 15.04 | 30.08 |
| | 13 | | 3.50 | 90 | 0.03889 | 1 | 0.03889 | 70 | 70 | 50 | 22.05 | 22.05 |
| AS2 | 1 | 923 | 1.26 | 110 | 0.01145 | 2 | 0.02291 | 5 | 50 | 45 | 3.43 | 6.86 |
| | 2 | 923 | 1.26 | 110 | 0.01145 | 2 | 0.02291 | 5 | 50 | 45 | 3.43 | 6.86 |
| | 3 | 923 | 1.26 | 110 | 0.01145 | 2 | 0.02291 | 66,5 | 100 | 100 | 2308 | 46.15 |
| | 4 | 923 | 1.26 | 110 | 0.01145 | 2 | 0.02291 | 50 | 50 | 100 | 13.86 | 27.72 |
| Mean d/l=0.019756 | 5 | 692 | 1.09 | 46 | 0.02370 | 2 | 0.04739 | 200 | 250 | 100 | 22.56 | 45.13 |
| | 6 | 692 | 1.09 | 46 | 0.02370 | 2 | 0.04739 | 350 | 300 | 100 | 32.59 | 65.18 |
| | 7 | 692 | 1.09 | 46 | 0.02370 | 2 | 0.04739 | 100 | 200 | 200 | 30.08 | 60.17 |
| | 8 | 692 | 1.09 | 46 | 0.02370 | 2 | 0.04739 | 600 | 400 | 200 | 100.28 | 200.56 |
| | 9 | 692 | 1.09 | 46 | 0.02370 | 2 | 0.04739 | 400 | 200 | 200 | 60.17 | 120.34 |
| | 10 | 692 | 1.09 | 46 | 0.02370 | 2 | 0.04739 | 200 | 200 | 200 | 40.11 | 80.22 |
| | 11 | | 3.50 | 90 | 0.03889 | 1 | 0.03889 | 70 | 70 | 100 | 44.10 | 44.10 |
| AS3 | 1 | 692 | 1.09 | 95 | 0.01147 | 2 | 0.02295 | 5 | 50 | 45 | 2.56 | 5.13 |
| | 2 | 692 | 1.09 | 95 | 0.01147 | 2 | 0.02295 | 5 | 50 | 45 | 2.56 | 5.13 |
| | 3 | 692 | 1.09 | 95 | 0.01147 | 2 | 0.02295 | 66,5 | 100 | 100 | 17.24 | 34.48 |
| | 4 | 692 | 1.09 | 95 | 0.01147 | 2 | 0.02295 | 50 | 50 | 100 | 10.36 | 20.71 |
| Mean d/l=0.019664 | 5 | 615 | 1.02 | 44 | 0.02318 | 2 | 0.04636 | 200 | 225 | 75 | 14.31 | 28.61 |
| | 6 | 615 | 1.02 | 44 | 0.02318 | 2 | 0.04636 | 325 | 275 | 100 | 26.93 | 53.86 |
| | 7 | 615 | 1.02 | 44 | 0.02318 | 2 | 0.04636 | 100 | 175 | 175 | 21.60 | 43.20 |
| | 8 | 615 | 1.02 | 44 | 0.02318 | 2 | 0.04636 | 550 | 150 | 400 | 125.66 | 251.33 |
| | 9 | 615 | 1.02 | 44 | 0.02318 | 2 | 0.04636 | 150 | 150 | 200 | 26.93 | 53.86 |
| | 10 | | 5.00 | 100 | 0.05000 | 1 | 0.05000 | 70 | 70 | 75 | 52.50 | 52.50 |
| AS4 | 1 | | 3,00 | 110 | 0.02727 | 2 | 0.05455 | 50 | 100 | 50 | 24.75 | 49.50 |
| | 2 | | 3.00 | 64 | 0.04688 | 2 | 0.09375 | 1 | 50 | 50 | 4.90 | 9.79 |
| | 3 | | 3.00 | 64 | 0.04688 | 2 | 0.09375 | 100 | 150 | 50 | 24.00 | 48.00 |
| | 4 | | 3.00 | 56 | 0.05357 | 1 | 0.05357 | 250 | 200 | 100 | 75.60 | 75.60 |
| | 5 | | 3.00 | 28 | 0.10714 | 1 | 0.10714 | 200 | 1 | 200 | 33.77 | 33.77 |
| Mean d/l=0.05706 | 6 | | 3.00 | 56 | 0.05357 | 2 | 0.10714 | 100 | 100 | 100 | 33.60 | 67.20 |
| | 7 | | 3.00 | 28 | 0.10714 | 2 | 0.21429 | 100 | 100 | 200 | 33.60 | 67.20 |
| | 8 | | 3.00 | 44 | 0.06818 | 2 | 0.13636 | 100 | 100 | 150 | 39.60 | 79.20 |
| | 9 | | 3.00 | 64 | 0.04688 | 1 | 0.04688 | 10 | 50 | 80 | 9.22 | 9.22 |
| | 10 | | 3.00 | 64 | 0.04688 | 1 | 0.04688 | 10 | 50 | 80 | 9.22 | 9.22 |
| | 11 | | 3.00 | 64 | 0.04688 | 1 | 0.04688 | 50 | 60 | 7 | 1.48 | 1.48 |
| | 12 | | 3.00 | 64 | 0.04688 | 1 | 0,04688 | 50 | 60 | 7 | 1.48 | 1.48 |
| | 13 | | 3.00 | 56 | 0.05357 | 1 | 0,05357 | 200 | 100 | 100 | 50.40 | 50.40 |
| | 14 | | 3.00 | 48 | 0.06250 | 1 | 0,06250 | 100 | 1 | 100 | 14.54 | 14.54 |
| | 15 | | 3,00 | 88 | 0.03409 | 1 | 0,03409 | 50 | 50 | 30 | 7.92 | 7.92 |

**Table 2.** Continue.

| | P | M | d | l | d/l | N | RxN | L | B | h | a | A |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AS5 | 1 | | 5.25 | 100 | 0.05250 | 2 | 0.10500 | 35 | 110 | 108 | 82.22 | 164.43 |
| Mean d/l=0.038943 | 2 | | 5.25 | 100 | 0.05250 | 2 | 0.10500 | 35 | 110 | 108 | 82.22 | 164.43 |
| | 3 | | 0.54 | 100 | 0.00540 | 2 | 0.01080 | 150 | 150 | 107 | 17.33 | 34.67 |
| | 4 | | 0.54 | 100 | 0.00540 | 2 | 0.01080 | 150 | 150 | 107 | 17.33 | 34.67 |
| | 5 | | 2.50 | 100 | 0.02500 | 2 | 0.05000 | 43 | 15 | 45 | 6.53 | 13.05 |
| | 6 | | 2.50 | 100 | 0.02500 | 2 | 0.05000 | 43 | 15 | 54 | 7.83 | 15.66 |
| | 7 | | 2.50 | 80 | 0.03125 | 2 | 0.06250 | 20 | 20 | 123 | 9.84 | 19.68 |
| | 8 | | 2.50 | 80 | 0.03125 | 2 | 0.06250 | 20 | 20 | 123 | 9.84 | 19.68 |
| | 9 | | 3.00 | 44 | 0.06818 | 2 | 0.13636 | 250 | 250 | 163 | 107.58 | 215.16 |
| | 10 | | 3.00 | 44 | 0.06818 | 2 | 0.13636 | 200 | 200 | 163 | 86.06 | 172.13 |
| | 11 | | 3.00 | 44 | 0.06818 | 2 | 0.13636 | 100 | 100 | 163 | 43.03 | 86.06 |
| | 12 | | 3.00 | 100 | 0.03000 | 1 | 0.03000 | 90 | 90 | 72 | 38.88 | 38.88 |
| AS6 | 1 | | 3.60 | 100 | 0.03600 | 2 | 0.07200 | 100 | 100 | 90 | 64.80 | 129.60 |
| Mean d/l=0.048395 | 2 | | 3.60 | 100 | 0.03600 | 2 | 0.07200 | 100 | 100 | 90 | 64.80 | 129.60 |
| | 3 | | 3.00 | 80 | 0.03750 | 2 | 0.07500 | 20 | 20 | 112 | 10.75 | 21.50 |
| | 4 | | 3.00 | 80 | 0.03750 | 2 | 0.07500 | 20 | 20 | 112 | 10.75 | 21.50 |
| | 5 | | 3.00 | 80 | 0.03750 | 2 | 0.07500 | 20 | 20 | 112 | 10.75 | 21.50 |
| | 6 | | 3.00 | 80 | 0.03750 | 2 | 0.07500 | 30 | 30 | 112 | 16.13 | 32.26 |
| | 7 | | 3.60 | 100 | 0.03600 | 2 | 0.07200 | 150 | 150 | 90 | 97.20 | 194.40 |
| | 8 | | 3.60 | 100 | 0.03600 | 2 | 0.07200 | 150 | 150 | 90 | 97.20 | 194.40 |
| | 9 | | 2.50 | 80 | 0.03125 | 2 | 0.06250 | 45 | 10 | 56 | 6.16 | 12.32 |
| | 10 | | 3.00 | 80 | 0.03750 | 2 | 0.07500 | 50 | 15 | 67 | 10.45 | 20.90 |
| | 11 | | 4.00 | 44 | 0.09091 | 2 | 0.18182 | 250 | 250 | 122 | 107.36 | 214.72 |
| | 12 | | 4.00 | 44 | 0.09091 | 2 | 0.18182 | 200 | 200 | 102 | 71.81 | 143.62 |
| | 13 | | 4.00 | 44 | 0.09091 | 2 | 0.18182 | 100 | 100 | 143 | 50.34 | 100.67 |
| | 14 | | 3.00 | 84 | 0.03571 | 1 | 0.03571 | 100 | 100 | 74 | 37.30 | 37.30 |
| MS1 | 1 | 1430 | 1,40 | 44 | 0.03182 | 2 | 0.06364 | 65 | 135 | 245 | 3.02 | 6.04 |
| Mean d/l=0.030825 | 2 | 1430 | 1.40 | 44 | 0.03182 | 2 | 0.06364 | 65 | 135 | 245 | 3.02 | 6.04 |
| | 3 | 1430 | 1.40 | 44 | 0.03182 | 2 | 0.06364 | 160 | 160 | 62 | 1.22 | 2.44 |
| | 4 | 1430 | 1.40 | 44 | 0.03182 | 2 | 0.06364 | 30 | 30 | 62 | 0.23 | 0.46 |
| | 5 | 1430 | 1.40 | 44 | 0.03182 | 2 | 0.06364 | 130 | 130 | 30 | 0.48 | 0.96 |
| | 6 | 1430 | 1.40 | 44 | 0.03182 | 2 | 0.06364 | 160 | 160 | 62 | 1.22 | 2.44 |
| | 7 | 1430 | 1.40 | 44 | 0.03182 | 2 | 0.06364 | 30 | 30 | 62 | 0.23 | 0.46 |
| | 8 | 1430 | 1.40 | 44 | 0.03182 | 2 | 0.06364 | 1 | 25 | 25 | 0.04 | 0.08 |
| | 9 | 1430 | 1.40 | 44 | 0.03182 | 2 | 0.06364 | 1 | 30 | 30 | 0.06 | 0.11 |
| | 10 | 1430 | 1.40 | 44 | 0.03182 | 2 | 0.06364 | 325 | 325 | 100 | 4.00 | 8.01 |
| | 11 | 1430 | 1.40 | 44 | 0.03182 | 2 | 0.06364 | 275 | 275 | 100 | 3.39 | 6.78 |
| | 12 | 1430 | 1.40 | 44 | 0.03182 | 2 | 0.06364 | 225 | 225 | 100 | 2.77 | 5.54 |
| | 13 | 1430 | 1.40 | 44 | 0.03182 | 2 | 0.06364 | 175 | 175 | 100 | 2.16 | 4.31 |
| | 14 | 1570 | 1.72 | 96 | 0.01792 | 2 | 0.03583 | 70 | 70 | 140 | 3.24 | 6.47 |
| MS2 | 1 | 1430 | 1,40 | 50 | 0,02800 | 2 | 0,05600 | 1 | 133 | 300 | 28,14 | 56,28 |
| Mean d/l= 0.03163 | 2 | 1430 | 1,40 | 50 | 0,02800 | 2 | 0,05600 | 1 | 110 | 300 | 23,31 | 46,62 |
| | 3 | 1430 | 1,40 | 50 | 0,02800 | 2 | 0,05600 | 143 | 143 | 40 | 8,01 | 16,02 |
| | 4 | 1430 | 1,40 | 50 | 0,02800 | 2 | 0,05600 | 76 | 76 | 320 | 34,05 | 68,10 |
| | 5 | 1430 | 1,40 | 36 | 0,03889 | 2 | 0,07778 | 360 | 100 | 200 | 46,37 | 92,74 |
| | 6 | 1430 | 1,40 | 36 | 0,03889 | 2 | 0,07778 | 100 | 100 | 200 | 20,16 | 40,32 |
| MS3 | 1 | | 4.00 | 96 | 0.04167 | 2 | 0.08333 | 17.5 | 112.5 | 131 | 65.40 | 130.79 |
| Mean d/ l=0.03026 | 2 | | 4.00 | 96 | 0.04167 | 2 | 0.08333 | 17.5 | 112.5 | 131 | 65.40 | 130.79 |
| | 3 | 1430 | 1.40 | 44 | 0.03182 | 2 | 0.06364 | 125 | 125 | 163 | 25.10 | 50.20 |
| | 4 | 1430 | 1.40 | 44 | 0.03182 | 2 | 0.06364 | 125 | 125 | 163 | 25.10 | 50.20 |
| | 5 | 1570 | 1.73 | 96 | 0.01802 | 2 | 0.03604 | 10 | 10 | 65 | 2.16 | 4.32 |

**Table 2.** Continue.

| | P | M | d | l | d/l | N | RxN | L | B | h | a | A |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean d/l=0.03026 | 6 | 1570 | 1.73 | 96 | 0.01802 | 2 | 0.03604 | 10 | 10 | 65 | 2.16 | 4.32 |
| | 7 | | 4.00 | 96 | 0.04167 | 2 | 0.08333 | 35 | 15 | 47 | 9.02 | 18.05 |
| | 8 | 1570 | 1.73 | 96 | 0.01802 | 2 | 0.03604 | 10 | 10 | 38 | 1.26 | 2.52 |
| | 9 | 1430 | 1.40 | 44 | 0.03182 | 2 | 0.06364 | 250 | 250 | 61 | 18.79 | 37.58 |
| | 10 | 1430 | 1.40 | 44 | 0.03182 | 2 | 0.06364 | 200 | 200 | 41 | 10.10 | 20.20 |
| | 11 | 1430 | 1.40 | 44 | 0.03182 | 2 | 0.06364 | 150 | 150 | 245 | 45.28 | 90.55 |
| | 12 | 1570 | 1.73 | 88 | 0.01966 | 1 | 0.01966 | 70 | 70 | 120 | 25.58 | 25.58 |
| MS4 | 1 | 1280 | 1.30 | 100 | 0.01300 | 2 | 0.02600 | 68 | 68 | 54.5 | 9.64 | 19.27 |
| Mean d/l=0.1276 | 2 | 1280 | 7.50 | 44 | 0.17045 | 2 | 0.34091 | 5 | 50 | 63.6 | 11.54 | 23.09 |
| | 3 | 1280 | 7.50 | 44 | 0.17045 | 2 | 0.34091 | 125 | 125 | 163 | 134.48 | 268.95 |
| | 4 | 1280 | 7.50 | 44 | 0.17045 | 2 | 0.34091 | 50 | 5 | 129.5 | 23.50 | 47.01 |
| | 5 | 1280 | 7.50 | 44 | 0.17045 | 1 | 0.17045 | 100 | 5 | 129.5 | 44.87 | 44.87 |
| | 6 | 1280 | 1.30 | 100 | 0.01300 | 2 | 0.02600 | 68 | 68 | 54.5 | 9.64 | 19.27 |
| | 7 | 1280 | 7.50 | 44 | 0.17045 | 2 | 0.34091 | 100 | 100 | 63.6 | 41.98 | 83.95 |
| | 8 | 1280 | 7.50 | 44 | 0.17045 | 2 | 0.34091 | 5 | 50 | 63.6 | 11.54 | 23.09 |
| | 9 | 1280 | 7.50 | 44 | 0.17045 | 2 | 0.34091 | 100 | 100 | 180 | 118.80 | 237.60 |
| | 10 | 1280 | 7.50 | 44 | 0.17045 | 1 | 0.17045 | 200 | 10 | 180 | 124.74 | 124.74 |
| | 11 | 1280 | 3.50 | 44 | 0.07955 | 1 | 0.07955 | 300 | 300 | 94 | 86.86 | 86.86 |
| | 12 | 1280 | 3.00 | 88 | 0.03409 | 1 | 0.03409 | 60 | 60 | 68.1 | 21.57 | 21.57 |

(S: Sections, M: Material T: Rtex values (twine thickness), d: Diameter (mm) of twine, l: Mesh size (mm), N: Number of each section, L: Number of meshes on the upper edge, B: Number of meshes on the lower edge, h: Number of longitudinal meshes, a: Twine surface area of each section ($m^2$), A: Total twine surface area ($m^2$) PA: Polyamide, PE: Polyethylene, PP: Polypropylene

$F_B =$ x g x V

$F = m \times g$

$F_{Net} = F - F_B$

Where;

$F_B$= Buoyant force (N)

$\rho$ = Density of sea water, 1.026 ($kgm^{-3}$)

g= acceleration of gravity ($ms^{-2}$)

V= Volume of body submerged in fluid ($m^3$)

In order to increase the impact of ground contact, additional weights have been applied on the footrope. Kaykaç, Zengin, Özcan-Akpınar, & Tosunoğlu (2014) stated the additional weight for Black Sea trawlers to be 100-150 kg. Considering this, a mean value of 1226.3 N (125 kg) additional weight was taken for Black Sea and Sea of Marmara. Özbilgin et al. (2018), reported that the average value of the additional weights on the footrope used in the Mediterranean as 1304.3 N (133 kg). Thus, we accepted this value in calculations for the Mediterranean. Due to lack of literature regarding additional weight on the footrope for the Aegean Sea, a total of 1471.5 N (150 kg) additional weight was accounted (personal communication with Aydın Kuruca, a net manufacturer and skipper). Total weight of footropes was calculated by adding the weights of footrope itself and the additional weight taking the floatation force of the material into account.

### Hydrodynamic resistance of floaters

Floaters used in trawls are made of plastic materials, spherical shape ranging in different thickness values according to depth

**Table 3.** Parameters for calculating the total weight of footrope with respect to specifications of each net.

| Net | Material | Diameter (mm) | Weight (kg) per 100 m | Length (m) | Weight in the air (kg) |
|---|---|---|---|---|---|
| BS1 | PP | 28 | 35.4 | 33.2 | 11.8 |
| BS2 | PP | 32 | 46.3 | 35.4 | 16.4 |
| SM1 | PP | 28 | 35.4 | 22.0 | 7.8 |
| SM2 | PP | 28 | 35.4 | 18.6 | 6.6 |
| AS1 | PP | 20 | 18.1 | 38.5 | 7.0 |
| AS2 | PP+PP | 20+10 | 18.1+4.5 | 52.2 | 11.7 |
| AS3 | PP+PP | 20+10 | 18.1+4.5 | 45.0 | 10.1 |
| AS4 | PA | 30 | 55.5 | 29.6 | 16.4 |
| AS5 | COMB | 18 | 48.8 | 32.0 | 15.6 |
| AS6 | COMB | 36 | 60.3 | 28.5 | 17.2 |
| MS1 | PP | 32 | 46.3 | 35.1 | 16.3 |
| MS2 | PP | 28 | 48.4 | 35.8 | 17.3 |
| MS3 | PA | 32 | 63.2 | 39.7 | 25.0 |
| MS4 | PA | 28 | 106 | 20.3 | 21.5 |

PP: Polypropylene, PA: Polyamide, COMB: Combination

and pressure. The hydrodynamic resistance of floaters ($R_F$) was calculated by using Newton's model;

$$R_F = \frac{C_{Df}}{2} \times \rho \times v^2 \times S_f$$

Where $C_{Df}$ is the drag coefficient for a sphere, with a value of 0.47 (Fridman, 1969),= density of sea water (1.026 g/cm$^{-3}$). Calculation of the floater's surface area ($S_f$) was considered as the sphere's projected area, the diametral circle (Pereira, 2012). Number of floaters during a trawl operation differs according to area and the target species. Mostly, a diameter of 20 cm spherical floaters were used around the Turkish Peninsula. While the number of those were taken to be 6 for the Black Sea and the Sea of Marmara, 10 for the Aegean Sea and the Mediterranean, based on the literature survey and the interviews with the skippers in each region (personal communication with Mustafa Kuraca and İsmail Öksüz who are the owner and the skipper of trawlers).

### Resistance of sweep, door and warp

Auxiliary equipment such as sweep, doors and warp were kept constant in order to calculate hydrodynamic effects. Those were determined for different depths and towing speeds. Sweep was made of combined material (Polypropylene and lead) with a diameter of 32 mm, and it was assumed to be 200 m long in each gear. Weight per meter of the sweep was 8.83 N (0.9 kg) (personal communication with the rope manufacturer). Trawl doors (otter boards), evaluated in the study, have a rectangular shape, wooden material, surrounded by an iron frame, a surface area of 1,71 m$^2$ and a weight of 1.57 kN (160 kg), and the warp was made of steel wire with a diameter of 10 mm. Resistances of the sweep, ($R_s$), the warp ($R_w$) and door ($R_d$) were calculated by the following formulas according to Nomura & Yamazaki (1975);

$$R_{S=}C_{Ds}/2 \times \rho \times d_s \times L_s \times v^2$$

$R_S$ = Resistance of sweep

$C_{Ds}$=Resistance coefficient of sweep

$\rho$ = Density of seawater (1.026 g/cm$^{-3}$)

$d_s$= Diameter of sweep

$L_s$= Length of the sweep

$$R_{W=}C_{Dw}/2 \times \rho \times d_w \times L_w \times v^2$$

$R_W$ = Resistance of warp,

$C_{Dw}$=Resistance coefficient of warp

$\rho$ = Density of seawater (1.026 g/cm$^{-3}$)

$d_w$= Diameter of warp

$L_w$= Length of the warp

$$R_D = \frac{C_{Dd}}{2} \times \rho \times v^2 \times S_d$$

$R_D$=Resistance of the door

$C_{Dd}$= Estimated drag coefficient of trawl door (hydrodynamic resistance coefficient)

$S_d$= Surface area of the door (m$^2$)

### Friction force

Friction force that acts in the opposite direction of the tow (between structural elements of trawl gear such as door, sweep and footrope and sea floor) were also calculated. The sliding friction depends on the weight of the equipment in water and the seabed conditions (Sala, 2013). The footrope weight is considered as the overall weight (including the additional weights) depending on the material of the footrope in each net (Sala, 2013). Polypropylene material which has a lower density than sea water tends to float, the footrope, therefore, its weight in the water was subtracted during the calculation of overall weight. The weight of footropes made of other materials is assumed as the overall weight used to sink the line as recommended by Sala (2013). The effective otter board weight is the weight in water. The difference between the doors' weight in water and air is related to the used material (Sala, 2013). The weight of the otter board in water is usually around 87% of the weight in the air when the otter board is constructed with solid steel, while it is 60% when wood is preferred (Sala, 2013). Expression of the friction force is given by the following equation (Sala, 2013):

$$F_{fr} = k.N$$

Where $F_{fr}$ is the friction force, k is the friction coefficient on the element and the contact surface and N is the reaction on the contact surface. Although there are different values for the friction coefficient according to the sediment type (Fridman, 1969; Sala, 2013), ground effect coefficients were taken as 0.61, 0.80 and 1.20, for door, footrope and sweep, respectively (Sala, 2013).

## RESULTS AND DISCUSSION

The hydrodynamic resistance of 14 different trawl gears used around Turkiye was determined theoretically. Net, floater, sweep, door, warp resistances and friction forces (occurred by footrope, sweeps and doors) of each gear was separately calculated according to different depths and towing speeds.

### Hydrodynamic resistance of the nets

Among the investigated nets, the greatest total twine surface area belonged to the AS6 with a value of 1136.3 m$^2$ and the smallest to MS1 with 50.1 m$^2$ (Figure 1).

Hydrodynamic resistance force of the trawl nets varied from 1.7 kN (SM2) to 12 kN (MS4) (Table 4). The resistance of the nets be-

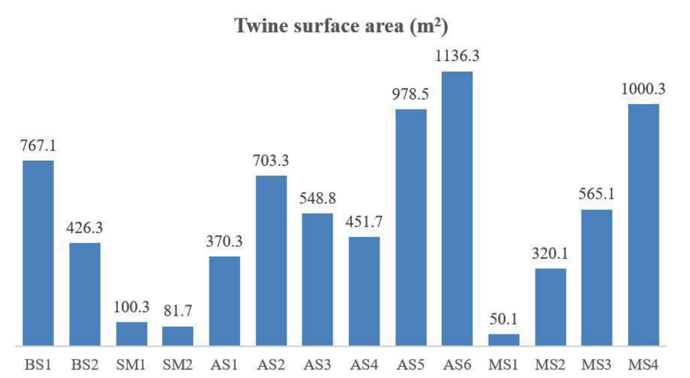


**Figure 1**. Total twine surface area of examined nets.

came bigger by the increasing the towing speed and the maximum value was determined to be 39.1 kN (MS4) (Figure 2).

**Table 4.** Calculating the resistance force of trawl nets depending on Nomura and Yamazaki (1975).

| Net type | d/l | λ (m) | λ² (m²) | Rn (kg) | Rn (N) |
|---|---|---|---|---|---|
| BS1 | 0.025238 | 28.4 | 806.56 | 508.899 | 4992.3 |
| BS2 | 0.01989 | 29.9 | 894.01 | 444.5465 | 4361.0 |
| SM1 | 0.13318 | 16 | 256 | 852.352 | 8361.5 |
| SM2 | 0.020488 | 18.6 | 345.96 | 177.2007 | 1738.3 |
| AS1 | 0.020386 | 29.5 | 870.25 | 443.5229 | 4350.9 |
| AS2 | 0.019756 | 43.2 | 1866.24 | 921.7359 | 9042.2 |
| AS3 | 0.019664 | 36.5 | 1332.25 | 654.9341 | 6424.9 |
| AS4 | 0.05706 | 18.6 | 345.96 | 493.5119 | 4841.3 |
| AS5 | 0.038943 | 27.2 | 739.84 | 720.2897 | 7066.0 |
| AS6 | 0.048395 | 22.98 | 528.0804 | 638.9113 | 6267.7 |
| MS1 | 0.030825 | 32 | 1024 | 789.12 | 7741.2 |
| MS2 | 0.03163 | 31.8 | 1011.24 | 799.638 | 7844.4 |
| MS3 | 0.03026 | 32.1 | 1030.41 | 779.5052 | 7646.9 |
| MS4 | 0.1276 | 19.64 | 385.7296 | 1230.477 | 12070.9 |

$R_n$: Resistance of the net, d/l: the ratio between the diameter of net line and mesh length (mm), λ: Length of the headrope (m), v: Towing speed ($ms^{-1}$).

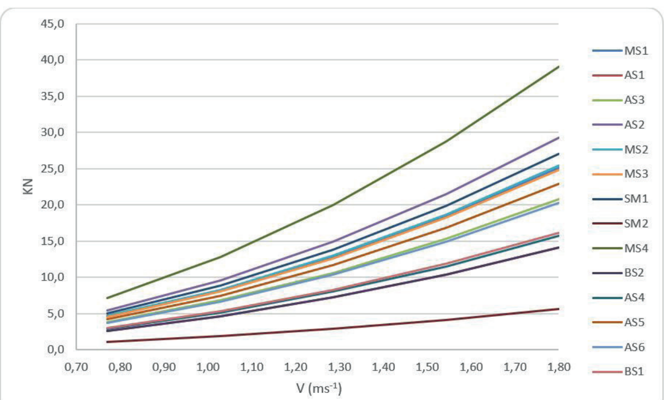


**Figure 2.** Resistance force of examined trawl nets according to different towing speeds.

### Hydrodynamic resistance of Floaters

The resistance force of a 20 cm diameter spherical plastic floater ranged between 4.53 and 24.64 N under different towing speeds (Figure 3). The flotation resistance force for the Black Sea (BS1 and BS2) and the Sea of Marmara (SM1 and SM2) was 147.84 N for the Aegean (AS1-AS2-AS3-AS4-AS5 and AS6) and the Mediterranean Sea (MS1-MS2-MS3-MS4) was 264.4 N (Table 5).

### Hydrodynamic resistance of sweeps

The resistance coefficient of the sweep was 0.04 at a constant flow angle of 10° (Düzbastılar et al.; 2003). The diameter and the length of the sweep are 0.032 m and 200 m, respectively, and these values were taken to be standard measures for all of the examined nets. The resistance value of one sweep varied between 78.5 N and 427.5 N at different speeds (Figure 3).

### Hydrodynamic resistance of trawl doors

Doors are basic elements for trawl operations, generating the horizontal opening in the net mouth through the arrangement of the corresponding warps. The resistance force of doors primarily depends on surface area and the towing speed. Hydrodynamic resistance of the trawl door varied in a wide range from 314 N to 1713 N (Figure 3). It is worth noting that a 2.3 times increase in the vessel speed resulted in a 5.5 times increase in the hydrodynamic resistance force.

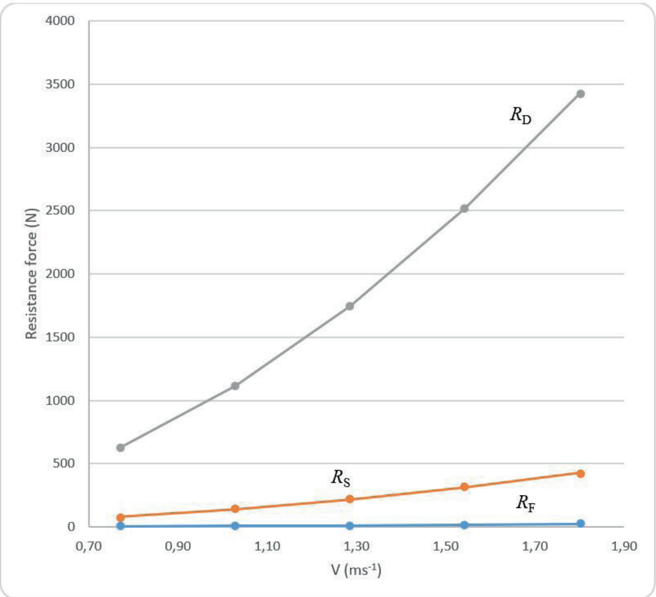


**Figure 3.** Resistance force of a 20 cm diameter (D) spherical floater, 200 m long sweep and trawl doors according to different speeds ($R_F$; Resistance of floater, $R_S$; Resistance of sweep, $R_D$; Resistance of door.

### Hydrodynamic resistance of warps

It is necessary that the angle between the warp and water surface should be definite to calculate warp resistance. The angle between the warp and the water surface ranged from 11° to 24° and the resistance coefficient of one of the warp is 0.1 at an angle of 20° (Düzbastılar et al., 2003). The resistance force of a 1m steel cable, therefore, ranged from 0.3 N to 1.7 N at different speeds (Figure 4). The length of the warps differed according to the depth of the trawl operation. The attitude of Turkish fishermen, in general, is to apply the length of warp between 3 and 5 times the operating depth. Therefore, resistance forces of a warp with different measures were shown in Figure 3 and varied between 766 N and 4174 N with different towing speeds.

### Frictional resistance

In general, footrope, sweeps and doors are in contact with the sea bottom which creates frictional resistance. The frictional resistance of these elements was calculated separately.

**Table 5.** Cumulative hydrodynamic resistance forces of the floaters according to net type and towing speed.

| Net type | Area | # | Towing speed ($ms^{-1}$) | | | | |
|---|---|---|---|---|---|---|---|
| | | | 0.77 | 1.03 | 1.29 | 1.54 | 1.80 |
| | | | | | Rf (N) | | |
| BS1-BS2 | Black Sea | 6 | 27.18 | 48.3 | 75.42 | 108.6 | 147.84 |
| SM1-SM2 | Sea of Marmara | 6 | 27.18 | 48.3 | 75.42 | 108.6 | 147.84 |
| AS1-AS2-AS3-AS4-AS5-AS6 | Aegean Sea | 10 | 45.3 | 80.5 | 125.7 | 181.0 | 246.4 |
| MS1-MS2-MS3-MS4 | Mediterranean Sea | 10 | 45.3 | 80.5 | 125.7 | 181.0 | 246.4 |

#; the number of floaters in each type of net, Rf: Resistance force of the floater in N

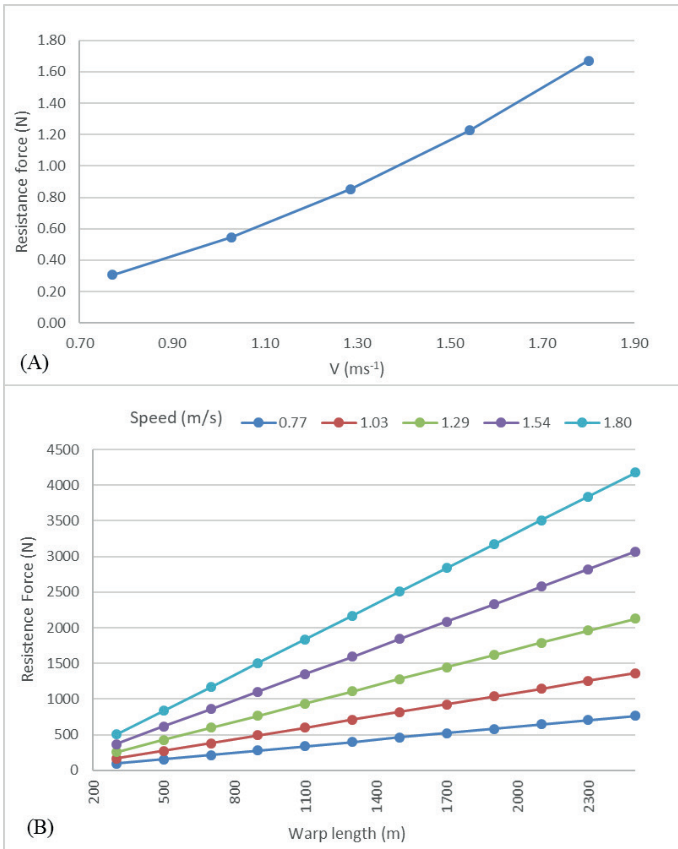


**Figure 4**. Resistance force of a 1 m long warp according to different speeds (A) and Resistance force (N) of one of the warps according to different speed and warp length (B).

**Footrope friction**

In order to determine footrope friction, the total weight of the footrope (additional weight and footrope weight together) in water was calculated. Estimated friction force caused by the footrope ranged between 835.5 N (BS2) and 1063.9 N (AS6) (Table 6).

**Sweep friction**

The weight of the sweep in water was calculated to be 545.4 N (55.6 kg). The friction coefficient between sweep and sand was assumed to be 0.80 (Sala, 2013). Therefore; friction force caused by the sweep was determined as 436.3 N resulting in 872.6 N of total friction.

**Doors friction**

A wooden material trawl door weighed 1569.6 N (160 kg) in the air corresponding to 941.8 N (96 kg) weight in the water. Ninety-six kg weight equals 941.7 N which is also the normal force (N). The friction coefficient was assumed to be 0.61, therefore friction force between one door and the sediment was calculated as 5744.3 N. Total amount of friction force created by both doors was determined to be 11488.6 N.

Consequently, the total amount of friction created by sweeps and doors which were kept constant for all type nets was estimated to be 12361.2 N

**Total resistance of the examined trawl gears**

The total resistance force of 14 trawl nets was calculated for different towing speeds according to 1 m long warp lengths. The greatest total resistance for 1 m warp length belonged to N9, while the lowest value was detected for N8 (Table 7).

Warp length/depth ratio is generally preferred between 3:1 and 5:1 by Turkish skippers. If we assume a number of bottom trawl operations at depths of 150-250-400-500 meters, they correspond to a warp length of more or less 500, 1100, 1700 and 2500 m, respectively. Based on this assumption, theoretical total resistance force values varied between 15.4 and 63.1 kN (Figure 5).

In this study, we have determined the hydrodynamic effects on different trawl gears used in Turkish territorial waters based on theoretical assumptions. Each section of a trawl net has different contributions on the total resistance. Average resistance values of the examined nets with 500 m warp length showed that door frictions composed more than 41.3% of the total resistance, followed by net (39.4%), doors (6.3%), footrope friction (6.1%), sweep frictions (3.1%) and the rest belonged to sweeps, warps and floaters (totally 3.8%). It was determined that resistance caused by friction including sweeps, footrope and doors constituted more than 50% of the total resistance. Among the examined nets, the greatest resistance values were determined for MS4. While a total of 37.7 kN resistance value was determined for MS4 under a towing speed of 2.5 knots and 500 m warp

**Table 6.** Total weight of footrope in seawater.

| Net | Additional weight (kg) | | Footrope weight (kg) | | Total weight in water | | Friction force |
|---|---|---|---|---|---|---|---|
| | Weight in air | Weight in seawater | W in air | W in water | kg | N | N |
| BS1 | 125 | 108.6 | 11.8 | -1.5 | 107.1 | 1050.2 | 840.2 |
| BS2 | 125 | 108.6 | 16.4 | -2.1 | 106.5 | 1044.3 | 835.5 |
| SM1 | 125 | 108.6 | 7.8 | -1.0 | 107.6 | 1055.1 | 844.1 |
| SM2 | 125 | 108.6 | 6.6 | -0.8 | 107.8 | 1057.1 | 845.7 |
| AS1 | 150 | 130.3 | 7.0 | -0.9 | 129.4 | 1269.1 | 1015.3 |
| AS2 | 150 | 130.3 | 11.7 | -1.5 | 128.8 | 1263.2 | 1010.6 |
| AS3 | 150 | 130.3 | 10.1 | -1.3 | 129.0 | 1265.2 | 1012.2 |
| AS4 | 150 | 130.3 | 16.4 | 1.7 | 132.0 | 1294.6 | 1035.7 |
| AS5 | 150 | 130.3 | 15.6 | 5.0 | 135.3 | 1327.0 | 1061.6 |
| AS6 | 150 | 130.3 | 17.2 | 5.3 | 135.6 | 1329.9 | 1063.9 |
| MS1 | 133 | 115.5 | 16.3 | -2.1 | 113.4 | 1112.5 | 890.0 |
| MS2 | 133 | 115.5 | 17.3 | -2.2 | 113.3 | 1111.5 | 889.2 |
| MS3 | 133 | 115.5 | 25.0 | 2.5 | 118.0 | 1157.6 | 926.1 |
| MS4 | 133 | 115.5 | 21.5 | 2.2 | 117.7 | 1154.7 | 923.8 |

Additional weight indicates the amount of iron (=7.8 $gcm^{-3}$) chains equipped to the footrope, - sign indicates a buoyant or floating force.

**Table 7.** Total resistance force of examined trawl gears based on 1m long warp length.

| | Net | | Door | Sweep | Warp | Resistance of floaters | | | Friction | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | V | $R_N$ | $2R_D$ | $2R_S$ | $2R_W$ | $R_F$ | n | $R_{FT}$ | $F_{FF}$ | $F_S$ | $F_D$ | $F_T$ | $R_T$ |
| | 0.77 | 2972.8 | 629.3 | 157 | 0.61 | 4.53 | | 27.2 | 840.2 | 872.6 | 11488.6 | 13201.4 | 16988.3 |
| | 1.03 | 5284.9 | 1118.8 | 279.1 | 1.09 | 8.05 | | 48.3 | 840.2 | 872.6 | 11488.6 | 13201.4 | 19933.6 |
| BS1 | 1.29 | 8257.7 | 1748.1 | 436.2 | 1.7 | 12.57 | 6 | 75.4 | 840.2 | 872.6 | 11488.6 | 13201.4 | 23720.5 |
| | 1.54 | 11891 | 2517.2 | 628.1 | 2.45 | 18.1 | | 108.6 | 840.2 | 872.6 | 11488.6 | 13201.4 | 28348.8 |
| | 1.8 | 16185 | 3426.2 | 854.9 | 3.34 | 24.64 | | 147.8 | 840.2 | 872.6 | 11488.6 | 13201.4 | 33818.7 |
| | 0.77 | 2596.8 | 629.3 | 157 | 0.61 | 4.53 | | 27.2 | 835.5 | 872.6 | 11488.6 | 13196.7 | 16607.6 |
| | 1.03 | 4616.6 | 1118.8 | 279.1 | 1.09 | 8.05 | | 48.3 | 835.5 | 872.6 | 11488.6 | 13196.7 | 19260.6 |
| BS2 | 1.29 | 7213.5 | 1748.1 | 436.2 | 1.7 | 12.57 | 6 | 75.4 | 835.5 | 872.6 | 11488.6 | 13196.7 | 22671.6 |
| | 1.54 | 10387.4 | 2517.2 | 628.1 | 2.45 | 18.1 | | 108.6 | 835.5 | 872.6 | 11488.6 | 13196.7 | 26840.5 |
| | 1.8 | 14138.4 | 3426.2 | 854.9 | 3.34 | 24.64 | | 147.8 | 835.5 | 872.6 | 11488.6 | 13196.7 | 31767.4 |
| | 0.77 | 4979.1 | 629.3 | 157 | 0.61 | 4.53 | | 27.2 | 844.1 | 872.6 | 11488.6 | 13205.3 | 18998.5 |
| | 1.03 | 8851.7 | 1118.8 | 279.1 | 1.09 | 8.05 | | 48.3 | 844.1 | 872.6 | 11488.6 | 13205.3 | 23504.3 |
| SM1 | 1.29 | 13830.7 | 1748.1 | 436.2 | 1.7 | 12.57 | 6 | 75.4 | 844.1 | 872.6 | 11488.6 | 13205.3 | 29297.4 |
| | 1.54 | 19916.2 | 2517.2 | 628.1 | 2.45 | 18.1 | | 108.6 | 844.1 | 872.6 | 11488.6 | 13205.3 | 36377.9 |
| | 1.8 | 27108.2 | 3426.2 | 854.9 | 3.34 | 24.64 | | 147.8 | 844.1 | 872.6 | 11488.6 | 13205.3 | 44745.8 |
| | 0.77 | 1035.1 | 629.3 | 157 | 0.61 | 4.53 | | 27.2 | 845.7 | 872.6 | 11488.6 | 13206.9 | 15056.1 |
| | 1.03 | 1840.2 | 1118.8 | 279.1 | 1.09 | 8.05 | | 48.3 | 845.7 | 872.6 | 11488.6 | 13206.9 | 16494.4 |
| SM2 | 1.29 | 2875.4 | 1748.1 | 436.2 | 1.7 | 12.57 | 6 | 75.4 | 845.7 | 872.6 | 11488.6 | 13206.9 | 18343.7 |
| | 1.54 | 4140.5 | 2517.2 | 628.1 | 2.45 | 18.1 | | 108.6 | 845.7 | 872.6 | 11488.6 | 13206.9 | 20603.8 |
| | 1.8 | 5635.7 | 3426.2 | 854.9 | 3.34 | 24.64 | | 147.8 | 845.7 | 872.6 | 11488.6 | 13206.9 | 23274.9 |

**Table 7.** Continue.

| | Net | | Door | Sweep | Warp | Resistance of floaters | | | Friction | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | V | $R_N$ | $2R_D$ | $2R_S$ | $2R_W$ | $R_F$ | n | $R_{FT}$ | $F_{FF}$ | $F_S$ | $F_D$ | $F_T$ | $R_T$ |
| AS1 | 0.77 | 2590.9 | 629.3 | 157 | 0.61 | 4.53 | 10 | 45.3 | 1015.3 | 872.6 | 11488.6 | 13376.5 | 16799.6 |
| | 1.03 | 4606 | 1118.8 | 279.1 | 1.09 | 8.05 | | 80.5 | 1015.3 | 872.6 | 11488.6 | 13376.5 | 19462.0 |
| | 1.29 | 7196.8 | 1748.1 | 436.2 | 1.7 | 12.57 | | 125.7 | 1015.3 | 872.6 | 11488.6 | 13376.5 | 22885.0 |
| | 1.54 | 10363.5 | 2517.2 | 628.1 | 2.45 | 18.1 | | 181.0 | 1015.3 | 872.6 | 11488.6 | 13376.5 | 27068.8 |
| | 1.8 | 14105.8 | 3426.2 | 854.9 | 3.34 | 24.64 | | 246.4 | 1015.3 | 872.6 | 11488.6 | 13376.5 | 32013.1 |
| AS2 | 0.77 | 5384.4 | 629.3 | 157 | 0.61 | 4.53 | 10 | 45.3 | 1010.6 | 872.6 | 11488.6 | 13371.8 | 19588.4 |
| | 1.03 | 9572.2 | 1118.8 | 279.1 | 1.09 | 8.05 | | 80.5 | 1010.6 | 872.6 | 11488.6 | 13371.8 | 24423.5 |
| | 1.29 | 14956.6 | 1748.1 | 436.2 | 1.7 | 12.57 | | 125.7 | 1010.6 | 872.6 | 11488.6 | 13371.8 | 30640.1 |
| | 1.54 | 21537.5 | 2517.2 | 628.1 | 2.45 | 18.1 | | 181.0 | 1010.6 | 872.6 | 11488.6 | 13371.8 | 38238.1 |
| | 1.8 | 29314.9 | 3426.2 | 854.9 | 3.34 | 24.64 | | 246.4 | 1010.6 | 872.6 | 11488.6 | 13371.8 | 47217.5 |
| AS3 | 0.77 | 3825.8 | 629.3 | 157 | 0.61 | 4.53 | 10 | 45.3 | 1012.2 | 872.6 | 11488.6 | 13373.4 | 18031.4 |
| | 1.03 | 6801.5 | 1118.8 | 279.1 | 1.09 | 8.05 | | 80.5 | 1012.2 | 872.6 | 11488.6 | 13373.4 | 21654.4 |
| | 1.29 | 10627.3 | 1748.1 | 436.2 | 1.7 | 12.57 | | 125.7 | 1012.2 | 872.6 | 11488.6 | 13373.4 | 26312.4 |
| | 1.54 | 15303.3 | 2517.2 | 628.1 | 2.45 | 18.1 | | 181.0 | 1012.2 | 872.6 | 11488.6 | 13373.4 | 32005.5 |
| | 1.8 | 20829.5 | 3426.2 | 854.9 | 3.34 | 24.64 | | 246.4 | 1012.2 | 872.6 | 11488.6 | 13373.4 | 38733.7 |
| AS4 | 0.77 | 2882.9 | 629.3 | 157 | 0.61 | 4.53 | 10 | 45.3 | 1035.7 | 872.6 | 11488.6 | 13396.9 | 17112.0 |
| | 1.03 | 5125.1 | 1118.8 | 279.1 | 1.09 | 8.05 | | 80.5 | 1035.7 | 872.6 | 11488.6 | 13396.9 | 20001.5 |
| | 1.29 | 8008 | 1748.1 | 436.2 | 1.7 | 12.57 | | 125.7 | 1035.7 | 872.6 | 11488.6 | 13396.9 | 23716.6 |
| | 1.54 | 11531.5 | 2517.2 | 628.1 | 2.45 | 18.1 | | 181.0 | 1035.7 | 872.6 | 11488.6 | 13396.9 | 28257.2 |
| | 1.8 | 15695.7 | 3426.2 | 854.9 | 3.34 | 24.64 | | 246.4 | 1035.7 | 872.6 | 11488.6 | 13396.9 | 33623.4 |
| AS5 | 0.77 | 4207.6 | 629.3 | 157 | 0.61 | 4.53 | 10 | 45.3 | 1061.6 | 872.6 | 11488.6 | 13422.8 | 18462.6 |
| | 1.03 | 7480.2 | 1118.8 | 279.1 | 1.09 | 8.05 | | 80.5 | 1061.6 | 872.6 | 11488.6 | 13422.8 | 22382.5 |
| | 1.29 | 11687.8 | 1748.1 | 436.2 | 1.7 | 12.57 | | 125.7 | 1061.6 | 872.6 | 11488.6 | 13422.8 | 27422.3 |
| | 1.54 | 16830.4 | 2517.2 | 628.1 | 2.45 | 18.1 | | 181.0 | 1061.6 | 872.6 | 11488.6 | 13422.8 | 33582.0 |
| | 1.8 | 22908.1 | 3426.2 | 854.9 | 3.34 | 24.64 | | 246.4 | 1061.6 | 872.6 | 11488.6 | 13422.8 | 40861.7 |
| AS6 | 0.77 | 3732.2 | 629.3 | 157 | 0.61 | 4.53 | 10 | 45.3 | 1063.9 | 872.6 | 11488.6 | 13425.1 | 17989.5 |
| | 1.03 | 6635.1 | 1118.8 | 279.1 | 1.09 | 8.05 | | 80.5 | 1063.9 | 872.6 | 11488.6 | 13425.1 | 21539.7 |
| | 1.29 | 10367.3 | 1748.1 | 436.2 | 1.7 | 12.57 | | 125.7 | 1063.9 | 872.6 | 11488.6 | 13425.1 | 26104.1 |
| | 1.54 | 14928.9 | 2517.2 | 628.1 | 2.45 | 18.1 | | 181.0 | 1063.9 | 872.6 | 11488.6 | 13425.1 | 31682.8 |
| | 1.8 | 20320 | 3426.2 | 854.9 | 3.34 | 24.64 | | 246.4 | 1063.9 | 872.6 | 11488.6 | 13425.1 | 38275.9 |
| MS1 | 0.77 | 4609.7 | 629.3 | 157 | 0.61 | 4.53 | 10 | 45.3 | 890 | 872.6 | 11488.6 | 13251.2 | 18693.1 |
| | 1.03 | 8195 | 1118.8 | 279.1 | 1.09 | 8.05 | | 80.5 | 890 | 872.6 | 11488.6 | 13251.2 | 22925.7 |
| | 1.29 | 12804.7 | 1748.1 | 436.2 | 1.7 | 12.57 | | 125.7 | 890 | 872.6 | 11488.6 | 13251.2 | 28367.6 |
| | 1.54 | 18438.8 | 2517.2 | 628.1 | 2.45 | 18.1 | | 181.0 | 890 | 872.6 | 11488.6 | 13251.2 | 35018.8 |
| | 1.8 | 25097.2 | 3426.2 | 854.9 | 3.34 | 24.64 | | 246.4 | 890 | 872.6 | 11488.6 | 13251.2 | 42879.2 |
| MS2 | 0.77 | 4671.1 | 629.3 | 157 | 0.61 | 4.53 | 10 | 45.3 | 889.2 | 872.6 | 11488.6 | 13250.4 | 18753.7 |
| | 1.03 | 8304.2 | 1118.8 | 279.1 | 1.09 | 8.05 | | 80.5 | 889.2 | 872.6 | 11488.6 | 13250.4 | 23034.1 |
| | 1.29 | 12975.4 | 1748.1 | 436.2 | 1.7 | 12.57 | | 125.7 | 889.2 | 872.6 | 11488.6 | 13250.4 | 28537.5 |
| | 1.54 | 18684.5 | 2517.2 | 628.1 | 2.45 | 18.1 | | 181.0 | 889.2 | 872.6 | 11488.6 | 13250.4 | 35263.7 |
| | 1.8 | 25431.7 | 3426.2 | 854.9 | 3.34 | 24.64 | | 246.4 | 889.2 | 872.6 | 11488.6 | 13250.4 | 43212.9 |

**Table 7.** Continue.

| | | Net | Door | Sweep | Warp | Resistance of floaters | | | Friction | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | V | $R_N$ | $2R_D$ | $2R_S$ | $2R_W$ | $R_F$ | n | $R_{FT}$ | $F_{FF}$ | $F_S$ | $F_D$ | $F_T$ | $R_T$ |
| MS3 | 0.77 | 4553.5 | 629.3 | 157 | 0.61 | 4.53 | 10 | 45.3 | 926.1 | 872.6 | 11488.6 | 13287.3 | 18673.0 |
| | 1.03 | 8095.2 | 1118.8 | 279.1 | 1.09 | 8.05 | | 80.5 | 926.1 | 872.6 | 11488.6 | 13287.3 | 22862.0 |
| | 1.29 | 12648.7 | 1748.1 | 436.2 | 1.7 | 12.57 | | 125.7 | 926.1 | 872.6 | 11488.6 | 13287.3 | 28247.7 |
| | 1.54 | 18214.1 | 2517.2 | 628.1 | 2.45 | 18.1 | | 181.0 | 926.1 | 872.6 | 11488.6 | 13287.3 | 34830.2 |
| | 1.8 | 24791.4 | 3426.2 | 854.9 | 3.34 | 24.64 | | 246.4 | 926.1 | 872.6 | 11488.6 | 13287.3 | 42609.5 |
| MS4 | 0.77 | 7187.9 | 629.3 | 157 | 0.61 | 4.53 | 10 | 45.3 | 923.8 | 872.6 | 11488.6 | 13285 | 21305.1 |
| | 1.03 | 12778.5 | 1118.8 | 279.1 | 1.09 | 8.05 | | 80.5 | 923.8 | 872.6 | 11488.6 | 13285 | 27543.0 |
| | 1.29 | 19966.4 | 1748.1 | 436.2 | 1.7 | 12.57 | | 125.7 | 923.8 | 872.6 | 11488.6 | 13285 | 35563.1 |
| | 1.54 | 28751.6 | 2517.2 | 628.1 | 2.45 | 18.1 | | 181.0 | 923.8 | 872.6 | 11488.6 | 13285 | 45365.4 |
| | 1.8 | 39134.1 | 3426.2 | 854.9 | 3.34 | 24.64 | | 246.4 | 923.8 | 872.6 | 11488.6 | 13285 | 56949.9 |

V: Towing speed (knot), $R_N$: resistance of net, $R_D$: resistance of door, $R_S$: resistance of sweep, $R_W$: resistance of warp, $R_F$: resistance of floater, n: number of floaters, $R_{FT}$: Total resistance of floaters, $F_{FF}$: footrope friction, $F_{FS}$: sweep friction, $F_{FD}$: door friction, $F_T$: total friction, $R_T$: total resistance

length, the other nets had lower values. The main reasons for this case could be due to the twine diameter (see Table 2) of the net and the additional weight of the footrope which directly affected the footrope friction. On the other hand, the second and third greatest resistance values were determined for AS2, MS2, respectively. MS4, AS2, MS2 were all traditional nets, indicating that traditional type nets composed more resistance than tailored ones in general.

Although the total twine surface area of AS6 is greater than MS1, AS2, MS2, MS3, SM1, MS4 and AS5, only the net resistance of those gears is bigger than that of AS6. This is due to the material of the filament, twine diameter, mesh size and length of the headrope. Düzbastılar et al. (2003), revealed the resistance values of conventional and tailored demersal trawl nets with various trawling speed and operation depth based on theoretical calculations. The authors calculated the total resistance of conventional and tailored trawl gears to be 7.5 and 6.9 kN, respectively at 100 m depth with a towing speed of 1.29 $ms^{-1}$ (2.5 knot). Considerable differences between the two studies are attributable to the magnitude of the nets, twine diameter and more importantly the impact of friction which was omitted by Düzbastılar et al. (2003).

The reason for low resistance in N8 and high resistance in MS4 is attributable to twine diameter. Almost all sections of the MS4 were rigged by PE Ø 0,25 3*10 material which resulted in thicker twines. The bigger the twine is, the more the net resists. The use of smaller diameter twines and change in the twine materials of trawl netting are reported to be other methods in order to achieve reduced drag. This situation was confirmed by Verhulst & Jochems (1993). Researchers, conducting a series of experimental fishing operations by replacing polyamide ropes with ropes made of resistant Dyneema SK 60 in the front part of a large Dutch pelagic trawl, reported that it was possible to achieve ~10% higher towing speed for the same engine power with the new type of rope. They also noted that the mouth area of the net increased by 25%, apart from the increased towing speed. Other methods used for achieving reduced drag are the use of smaller diameter twines and change in the twine materials of trawl netting. Verhulst & Jochems (1993) conducted a series of experimental fishing operations by replacing polyamide ropes with ropes made of resistant Dyneema SK 60 in the front part of a large Dutch pelagic trawl. The results show that it is possible to achieve ~a 10% higher towing speed for the same engine power with the new type of rope. It was reported that the door can comprise 30-35% of the total drag of the trawl gear and thus 30-35% of the fuel usage (Bankston, 1988). Nearly 50% of the total resistance (door frictions 41.3% and resistances of doors 6.3%) was obtained by doors and their interactions with the ground in our study. Therefore, doors are one of the most important elements of the trawl fishery in terms of hydrodynamic impacts.

Despite the increasing length over all (LOA) and engine power of trawlers and improved net structures, almost the same door design and structure have been used in the Turkish demersal trawl fishery for many years (Aydın & Düzbastılar, 2011). In this study, each trawl door resistance varied in a wide range from 314 N to 1713 N. There are other types of doors creating less resistance values (SEAFISH, IFREMER & DIFTA 1995). Such types should be theoretically examined and observed during trawl operations in the Turkish demersal trawl fishery to reduce the resistance, thus, the fuel consumption.

It is possible to calculate the resistance values of whole trawl gear in different sizes and properties by theoretical resistance calculations. While most of the previous studies took into account the design of the gear, the water speed, and the bottom contact (Ward &Ferro, 1993; Ferro et al., 1996; Sala, De Carlo, Buglioni, & Lucchetti, 2011; Park, 2007; Lee et al., 2005; Tsukrov et al., 2003; Priour, 2013) but there are few studies on catch effect (O'Neill, Knudsen, Wileman, & McKay, 2005.; Priour & Hermann, 2005). Detailed investigation of catch weight influence

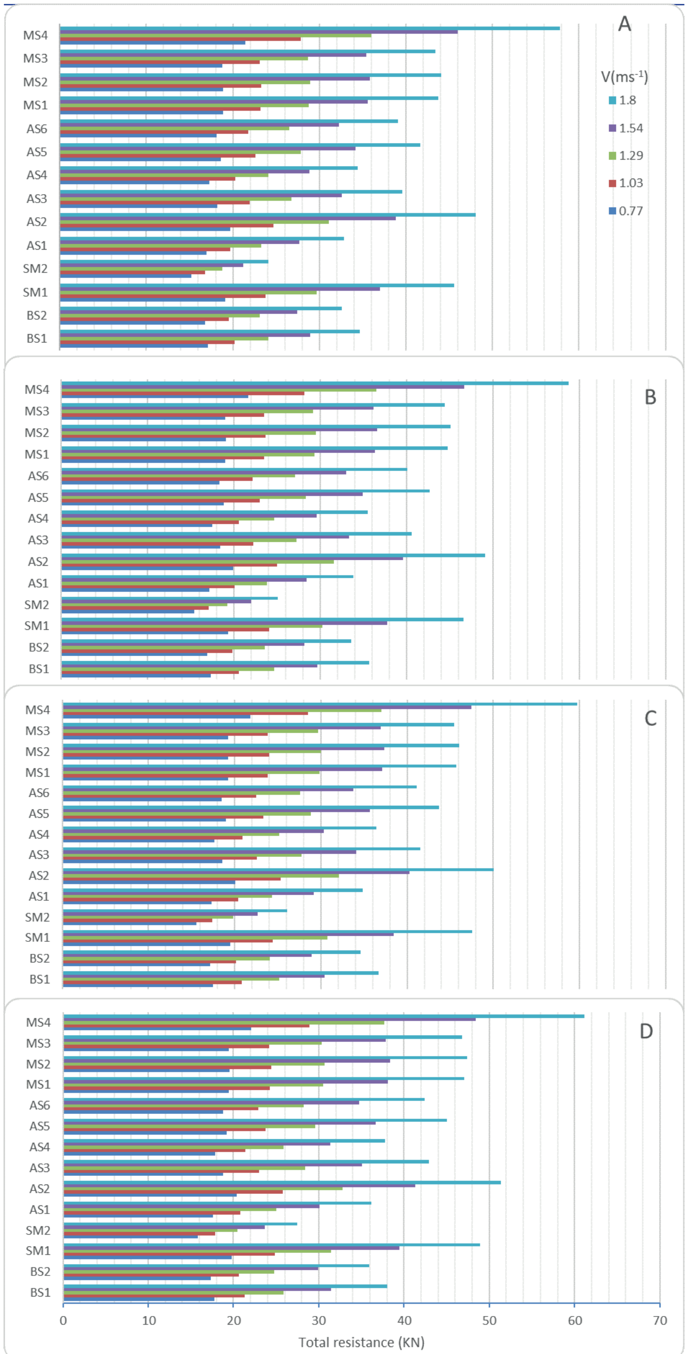


**Figure 5**. Total resistance values (kN) of the examined trawl gears according to four different warp lengths ((A) 500 m, (B) 1100 m, (C)1700 m, (D) 2500 m).

on trawl behavior based on sea trials was carried out by Daniel & Amelia (2015) and they stated that besides the catch weight, catch volume is also very important because the density of fish is not exactly the density of water, and this difference could slightly affect the volume of the catch. Therefore, biological factors must be added into the calculations in order to make factual estimations in further studies. It is also very important to measure the tension on the warp with suitable force gauges for accurate determination of the total resistance of the trawl gear. Although Düzbastılar et al. (2003), reported total resistance of traditional and tailored bottom trawl nets, they excluded the effect of bottom contact and floater resistance from their calculations. Moreover, our study, parallel with that of Düzbastılar et al (2003), is missing the influence of catch weight on trawl behavior. At this point, as mentioned by Daniel &Amelia (2015), taking the catch mass and volume into account becomes very important in order to reflect or at least to reliably simulate the actual response of the gear.

## CONCLUSION

Different types of trawl nets have been operated in the Turkish demersal trawl fishery according to the target species. Hydrodynamic resistance of the most common ones was theoretically estimated in the study. The greatest contributions to total resistance were composed of door friction, net and doors, respectively. Twine thickness and additional weights on the footrope were also determined to be major parameters directly affecting the net resistance. The present work is considered to inspire further studies on mathematical modelling of bottom trawl gears and, thus, comprehensive projects which contribute to the trawling efficiency will be performed.

**Conflict of interests:** The authors have no conflicts of interest to declare.

**Ethics committee approval:** This study was conducted in accordance with ethics committee procedures of animal experiments.

**Financial disclosure: -**

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**Disclosure: -**

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Research Article

# Egg and Larval Growth Performance of Brown Trout (*Salmo trutta sp.*) in Commercial Farm Conditions

**Serhat Engin[1], Özgür Altan[1]**

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## ABSTRACT

The aim of this study is to determine the egg and larval growth performance of brown trout (*Salmo trutta sp.*) at a constant high water temperature under commercial farm conditions. Eggs were taken from 450 female broodstocks with an average weight of 5.09±0.29 kg. The eggs placed in the incubators were observed on the 14th day and kept at a constant temperature of 12.5°C. Then larvae began to hatch on the 29th day and all the eggs were fully hatched by the 31st day. The incubation period was determined as 350 days /°C. In the study, an average survival rate was determined as 21.07%±5.16% until the end of the larval stage. A significant relationship was found between the rate of eggs that hatched and the survival rate after the larval period had ended ($p<0.05$). After 120 days of larval feeding, larvae weighing 0.15 g reached 9.26±1.13 g. During this period, the feed conversion rate (FCR) and specific growth rate (SGR) values were determined as 1.21±0.09 and 1.23±0.72 respectively.

**Keywords:** *Salmo trutta sp.*, egg, larvae, growth

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## INTRODUCTION

The *Salmonidae* family has many species of commercial, cultural and environmental value. According to the International Union for Conservation of Nature - Red List of Threatened Species, thirteen species in the family are listed as "endangered", "critically endangered" or "vulnerable" (IUCN 2020). Overfishing, water pollution and wrong water management policies are the main reasons for the decreasing natural populations of the fish. Aquaculture is one of the most widely used methods to increase natural populations after endangered species have adapted to culture conditions (Cabrita et al. 2009).

Salmo trutta sp., also known as Brown (*Salmo trutta sp.* Dumeril, 1858), Mediterranean or Anatolian trout, were studied and recorded at many locations throughout a wide area of Turkiye (Kocaman et al. 2004). Hesthagen & Johnsen (1989) observed that the effects of larvae stocking time in habitats on growth rates were negligible. For this reason, breeding these species in culture conditions will increase the survival rate of larvae.

Freshwater fish species may be even more vulnerable to global climate change as they have limited dispersal abilities within the hydrographic networks in which they currently live. In this context, an important scientific issue is to predict how fish populations will cope with future temperature changes in their natural habitats (Buisson et al. 2008, 2009). Environmental temperature is an important abiotic factor affecting physiological functions in aquatic vertebrates, and many aspects of fish embryonic development are strongly affected by temperature (Mueller et al. 2011). As the temperature increases, embryonic development also increases (Mueller et al. 2015).

Some information about the embryonic development and larval rearing of different trout species has been provided to date (Grande & Andersen, 1990; Killeen et al. 1999; Halacka, 1995; Bascinar & Okumus, 2004), but this information seems to be limited in the case of brown trout. Moreover, it is seen that the information about the relationship between water temperature, egg hatching and larval development is mostly limited to the information related to fish in the natural environment (Réalis-Doyelle et al. 2016, 2018).

The aim of this study is to provide information on brown trout in terms of egg hatching, survival rate and larval growth performance in a commercial farm environment and to increase the production success based on these new results.

## MATERIALS and METHODS

### Broodstock stocking and feeding

Brown trout broodstocks used in the experiment, which are expected to be fed up to an average live weight of 5.09 0.29 kg, were first taken into the maturation process in the commercial net cage farm which is located in Keban Dam Lake. Fish were placed in net cages and the volume was kept as 5 kg/cubic meter. The water temperature in which the broodstock was located was 12.5 ± 0.5 °C. Fish were fed twice a day at 2% of their average body weight with feed purchased from a commercial fish feed factory, with nutrient contents given in Table 1. After the maturation period of about 3 months, a total of 500 broodstocks were selected randomly and transferred to the hatchery of the farm. Eggs were taken from 450 female broodstocks with an average weight of 5.09 ± 0.29 kg. The fish were fed at 1% of their average weight for one month, gonad development and egg maturation were continuously controlled and feeding was stopped two days before spawning. The fish, whose eggs were determined to be mature, were gradually spawned within 15 days.

**Table 1.** Proximate composition of the experimental diet (% dry matter) for trout.

| Essential Nutrient | Commercial Feed I (350-500 µ) | Commercial Feed II (800µ - 1 mm) |
|---|---|---|
| Dry Matter (max) | 88 | 88 |
| Crude Protein (% - Least) | 50 | 44 |
| Crude Cellulose (% - Most) | 1.3 | 2.5 |
| Crude Ash (% - Most) | 12 | 12 |
| Crude Fat (% - Least) | 15 | 18 |
| Digestible energy (kcal/kg) | 4360 | 4000 |
| **Vitamins** | | |
| Vit. $B_2$ (mg / kg) | 25 | 25 |
| Pantothenic acid (mg / kg) | 20 | 20 |
| Vit. $B_1$ (mg / kg) | 10 | 10 |
| Vit. $B_{12}$ (mg / kg) | 0.02 | 0.02 |
| Niacin (mg / kg) | 200 | 200 |
| Biotin (mg / kg) | 0.5 | 0.5 |
| Folic acid (mg / kg) | 5 | 5 |
| Colin (mg / kg) | 1.500 | 1.000 |
| Vit. A (IU / kg ) | 12.500 | 12.500 |
| Vit. E (IU / kg) | 250 | 250 |
| Vit. D3 (IU / kg) | 2.500 | 2.500 |
| Vit. C (mg / kg) | 250 | 200 |
| Vit. $K_3$ (mg / kg) | 5 | 5 |

### Incubation, Hatching and Larval Feeding

Sperm and eggs were obtained from brown trout provided by the Keban Trout Co. Inc. which is located in Keban Dam Lake, Elazig-Turkiye. Prior to milt extraction, males were anesthetized using 0.2 g/l MS-222. Milt was obtained by abdominal massage and collected from the urogenital papilla using a jug, taking special care to avoid urine and faeces contamination. Females were anesthetized with the same method and eggs were obtained by stripping (female male ratio 1:2). The eggs were stocked with 5000 pieces in each incubator. A total of 4,244,400 eggs were used throughout the study. No manipulation was applied to the eggs that were expected to pass to the observation stage, only 150 ml of formaldehyde was applied to each incubator twice a day to prevent fungal growth. Dead eggs were counted daily and removed from the incubators. The larvae with yolk sac were transferred into 3x1x0.5 m larvae tanks. The first feeding was made with the starter feeds in the form of powder and the content of which is given in Table 2 and given to the fish just before the consumption of the yolk sac. The live weight development of the larvae was measured with a 0.001 g precision digital electronic balance (made by Mettler Toledo), and 100 larvae were randomly selected from each experimental group for this measurement.

**Table 2.** Nutritional composition of starter feed.

| | |
|---|---|
| Brut Energy | 4.900 max. |
| Fat | 12 |
| Protein | 48 |
| Digestible energy | 4.360 |
| DP/DE (mg/kj) | 29.50 |

Water quality parameters were measured between 7:00 am and 8:00 am on each sampling day. Water temperature, dissolved oxygen and pH were measured and recorded daily with YSI multi-parametric instrument.

The study was carried out for four months under commercial production conditions. The larvae were fed 8 times a day with extruded trout larvae feed which was produced by Camli Fish Feed Company, Izmir Turkiye. The nutrient content of the feed was "48% crude protein, 12% crude fat, and 1.5% crude fiber and 4360 kcal/kg digestible energy".

Growth performance indicators were calculated using the following formulae according to (Ricker, 1975):

Specific growth rate (SGR,%day-1)= ln (final weight in grams) – ln (initial weight in grams) x100) / t (in days).

Mean daily weight gain (MDWG) = 100 x [(Total final weight – Total initial weight)/Days of experiment]

Survival (%) = 100 x (Total number of harvested fish / Total number of initial stock)

### Statistical analysis

The mean and standard deviation values were calculated using Microsoft Excel 2020 version. For the statistical analysis, data from the replicates of each group were pooled for one-way ANOVA analysis and differences at the 5% level were considered significant.

## RESULTS AND DISCUSSION

The eggs of Salmo trutta sp. were incubated at 13 ± 0.3 ° C; dissolved oxygen 7 ± 0.8 mg/lt $O_2$ and pH between 7 ± 0.5 were measured.

This study on the larval growth of brown trout consisted of 2 stages. First, the broodstock were fed for a total of 7 months. 450 female and 226 male broodstocks were used in the study and a total of 400,000 g eggs were obtained from 2280 kg female broodstocks. The eggs placed in the incubators were observed on the 14th day at a constant temperature of 12.5 °C and the larvae began to hatch on the 29th day and all the eggs were fully hatched by the 31st day. The incubation period was determined as 350 days / °C. The weight of the eggs obtained from spawning was measured as 0.095 ± 0.005g. The average weight of female broodstocks throughout the experiment, unfertilized eggs, losses in incubators during the larval period were also calculated and noted (Table 3).

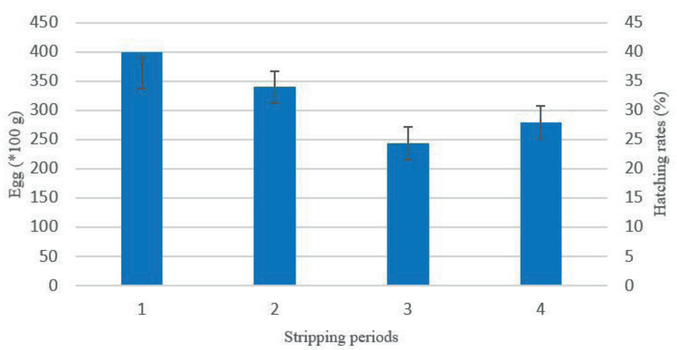


**Figure 1**. Number of brown trout egg according to spawning period and hatchery success.

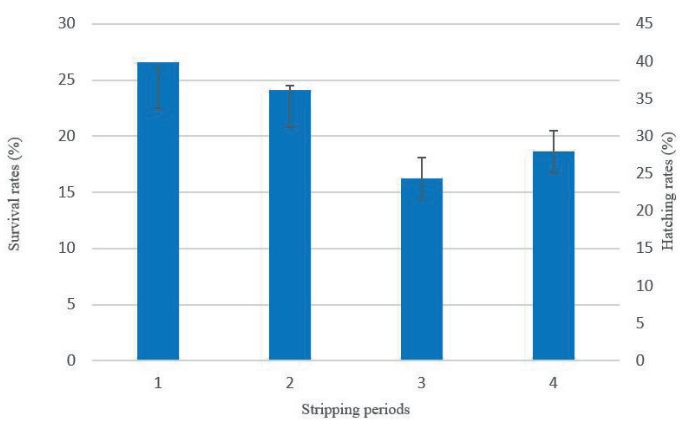


**Figure 2**. Comparison of hatching rate (%) and larval survival rate (%).

According to the data obtained, the average hatching success was determined as 30.7 ± 5.52% in a study carried out at constant temperature in a commercial enterprise (figure 1).

Figure 1. Figure 1. Number of brown trout egg according to spawning period and hatchery success

During this period, feeding was done 8 times a day until the larvae were satiated. During the experiment, a total of 4,244,400 eggs and 856,280 fish were obtained with an average survival rate of 21.07% ± 5.16% until the end of the larval stage. A significant relationship was found between the rate at which eggs hatched and the survival rate after the larval period ($p<0.05$). (Figure 2). Larval feeding was studied over a period of four months. The mean FCR and SGR values during the study were 1.21 ± 0.09 and 1.23 ± 0.72, respectively. The variation of these values according to the months is given in Figure 3.

From the 12th day following their hatching, the fish were first fed with larvae starter feed with a size of 300 microns. In direct proportion to the size of the fish, 500 and 800 micron sized powder feeds were used. The content of the feed used had 48% crude protein and 12% crude fat content. Larvae weighing 0.15 g were fed in the larvae tanks for 3 months and reached a weight of 3.7 g at the end of the feeding. During this period, fish weighing about 3.7 g were fed in concrete ponds (fry rearing ponds) for one month. At the end, the mean fish weight was determined as 9.26±1.13 g.

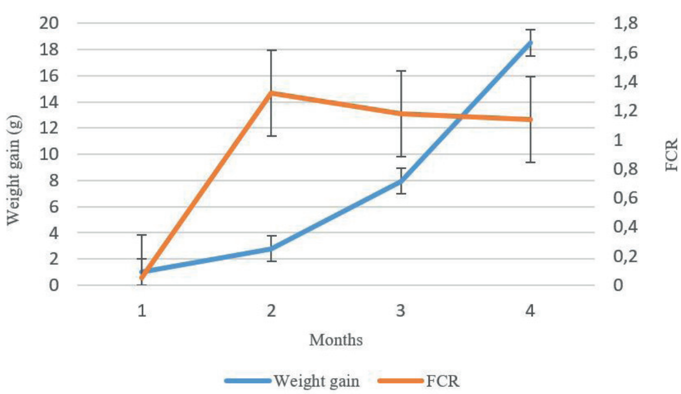


**Figure 3**. *Salmo trutta sp.* larva feeding on a monthly basis FCR -Weight gain.

**Table 3.** Number of eggs and hatchery success of brown trout.

| Spawning | Number of spawned female broodstock | Obtained number of eggs | Harvesting losses (%) | Number of live eggs | Incubation losses (%) | Hatchery success (%) |
|---|---|---|---|---|---|---|
| 1 | 50 | 40.000 | 38.2 | 24.720 | 41 | 36.46 |
| 2 | 150 | 135.000 | 37 | 85.050 | 46 | 34.02 |
| 3 | 150 | 140.000 | 39 | 85.400 | 60 | 24.40 |
| 4 | 100 | 85.000 | 36.5 | 53.975 | 56 | 27.94 |

This study reveals the egg hatching rate and larval survival rate of brown trout in a commercial farm at 12.5 ± 0.5 °C. These results allow us to gain insight into the larval growth performance of brown trout at constant water temperature in the commercial setting Bascinar and Okumus (2004) reported that factors such as genetic status and broodstock pond water temperature are among the factors controlling the duration of the early developmental stages of fish embryos and larvae. The degree-day value in embryonic development is lower in cold water than in hot water (Grande and Andersen, 1990; Bascinar and Okumus, 2004). The first eye pigmentation time of various trout species is 30-33 days at degree-day for Salmo trutta (Killeen et al., 1999), 220 days at degree-day (Gjerdem and Gunnes, 1978), 195 days at degrees (Grande and Andersen, 1990), and 245 days for *Salvelinus fontinalis*. Alp et al., (2010) observed that Brown trout eggs were incubated at 7.23°C for 244 degree-day (35 days) and at 387 days (56 days), whereas at 8.21°C they were observed for 261 degree-day (31 days). The authors also reported that they hatched at 413 degree-day (50 days). In addition, the effect of temperature on the hatching time of brown trout was investigated in different geographical regions (Spain, [Ojanguren and Braña, 2003], Austria, [Lahnsteiner, 2012], the United States [Embody, 1934], the United Kingdom and [Wood, 1931] The consensus of these researchers revealed a negative curvilinear relationship between egg hatching time and temperature, especially at water temperatures of 6°C, 8°C and 10°C.

In this study, Brown trout eggs reached the eye stage at 12.5°C on the 14th day and all the eggs were hatched by the 31st day. Compared to previous studies, the result of this study shows that the eye period and opening of brown trout eggs is much more advanced. It can be said that this difference is due to the high water temperature.

Doyelle et al., (2016), in their study with Brown trout, found the larval survival rate at low water temperature (6-8°C) to be 75%, and similar results were also revealed in the study by Lahnsteiner, 2012. In this study, the larval survival rate was approximately 30%. This difference was caused by the higher incubation temperature and higher stocking rates in the commercial fish farm environment than in the experimental conditions.

## CONCLUSION

This study is probably one of the first studies on egg production, hatching and larval survival of commercial brown trout at a constant high hatchery temperature. After incubation, larval feeding for 90 days followed by 30 days of fry feeding was carried out commercially for this species. In the study, the highest live weight gain was determined in the period when the fish were kept in concrete ponds. In the light of the biological data obtained from this study, it is seen that the production success of brown trout under culture conditions changes depending on hatching temperature and larval feeding regime. More detailed research is needed in suitable habitats for rootstock supply, larval breeding and breeding for the protection of natural stocks.

**Conflict of interests:** Authors declare that there is no conflict of interest regarding the publication of this paper.

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Research Article

# Seasonal Distribution of Ephemeroptera (Insecta) Fauna and Relationship Among Physicochemical Parameters in the Ceyhan Basin

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## ABSTRACT

This study was carried out in 20 different localities in the spring, summer and autumn periods in 2019 in order to determine the Ephemeroptera fauna of the Ceyhan Basin and to reveal its relationship with some physicochemical parameters. As a result, 971 specimens were examined and 17 species belonging to six families were identified. There is no data on the given taxa in the Ceyhan basin so all taxa are new records for the Ceyhan Basin. According to the Shannon-Wiener (H) diversity index, the highest and lowest diversity values were determined, respectively, in the spring at stations 7th (1.456) and 6th (0.173), in the summer at stations 20th (1.311) and 13th (0.341), and in the autumn at stations 15th (1.102) and 8th (0.457). According to Evenness (E) values, the most homogeneous stations are the 3rd (0.963), 7th (0.973) and 1st (0.945) stations in the same seasonal order, and the stations with the least homogeneity are the 16th (0.529), 16th (0.659) and 8th (0.527) stations. According to cluster analyses, the highest similarities were observed between stations 3rd and 5th in addition to stations 9th,14th,17th,18th and 19th with 100% percentage. Based on the physicochemical parameters measured in accordance with the Surface Water Quality Regulation, the water quality classes of the stations were in high quality water (Class I) and less contaminated (Class II) water. Canonical correspondence analysis was applied to reveal the relationships between Ephemeroptera taxa and physicochemical parameters.

**Keywords:** Ephemeroptera, Ceyhan Basin, diversity, water quality, fauna

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## INTRODUCTION

Recently, overexploitation of water resources and deterioration of existing water quality are now being caused by a fast population increase, and environmental pressures on aquatic systems due to increasing industrial and agricultural activities (Gelgeç, 2012; Zhang et al., 2019). For this reason, the protection, improvement and sustainable use of water, which is a renewable natural resource, is one of the most important and priority problems (Kalyoncu et. al., 2008; Çiçek & Birecikligil, 2015).

In Turkiye, which is relatively rich in terms of fresh water potential, changes occur in aquatic ecosystems as a result of the negative effects caused by anthropogenic pressures. Accordingly, many groups of organisms react to disturbances in their habitats. As a result, there is a decrease in population densities, changes in habitats and even the extinction of certain species. Thus, changes occur in the species composition of the ecosystem. Depending on these changes in communities, it is possible to evaluate water quality. It is possible to determine the quality of the existing aquatic environment as a result of determining the reactions of aquatic organisms to changes. Biological monitoring is defined as the evaluation of environmental changes caused by human activities according to biological responses in order to evaluate an ecosystem and to identify deviations in its natural structure. (Kazancı et al., 1997). Water quality is an indicator of the physical, chemical and biological properties of water. In studies to determine water quality lotic waters, physicochemical components are not always sufficient because they only reveal the situation at the time of measurement. In this context, biological monitoring is a unifying method in identifying physical, chemical and biological problems, as it more accurately reveals the destructions that occur in sensitive ecosystems. With this method, taxa that can be used as bioindicators (biological indicator) are determined together with the fauna of the studied region. For this reason, physicochemical data should be used together with biological data to evaluate medium and long-term contamination in water quality determination (Uyanık & Cebe, 2017).

Benthic invertebrates in river ecosystems show a great diversity in taxonomic, structural and functional aspects, and each of these living groups has different ecological characteristics (Allan, 1995). Benthic macroinvertebrates are one of the most widely used organism groups in water quality assessment studies because they are sensitive to different chemical and physical conditions. Therefore, the composition of macroinvertebrate species sampled from a water body provides important information for determining the quality of that water body (Hellawell, 1986; Aksoy, 2019).

Ephemeroptera is the most important group among benthic macroinvertebrates with its high species diversity and population density. This order is used as important biological indicators in water quality determination studies, as they are low tolerant to the presence of any pollutant in water bodies and contain many sensitive species against pollution (Özyurt & Tanatmış, 2008; Aksoy, 2019). Ephemeroptera fauna of Turkiye is represented by 34 genera, 138 species and five subspecies belonging to 14 families (Kazancı & Türkmen, 2012, 2016; Salur et al., 2016). In our country, the studies of this order were mostly carried out in the North-West Anatolia region (Tanatmış, 1999, 2000, 2002, 2004a, 2004b, 2007; Kazancı, 2001a, 2001b, 2009; Narin & Tanatmış, 2004; Kazancı & Türkmen, 2008; Tanatmış & Ertorun, 2006, 2008; Türkmen & Özkan, 2011; Türkmen & Kazancı, 2011; Aydınlı, 2013; Küçüker, 2019). There are a very limited number of studies in the remaining parts of Turkiye (Türkmen & Kazancı, 2015; Özgül Uzun, 2018; Bakioğlu, 2019), and in the Seyhan, Ceyhan and Eastern Mediterranean basins, where the rivers flowing into the North-eastern Mediterranean are located, no detailed study has been found so far, except for a few individual studies (Kara & Çömlekçioğlu, 2004; Yıldırım, 2006; Ayas & Kara, 2014).

This study was carried out to reveal the seasonal Ephemeroptera fauna of the Ceyhan Basin and to evaluate the water quality with the help of these parameters by determining the relationships between the identified taxa and the physicochemical parameters in their distribution areas.

## MATERIAL AND METHODS

The Ceyhan Basin includes the Ceyhan River originating from the Elbistan district of Kahramanmaraş and the large and small streams that join it, and empties into the sea in the Iskenderun Bay. Field studies were carried out once in the spring, summer and autumn periods at 20 stations determined in 2019. The stations representing the study area and the information about the stations are given in Table 1 and Figure 1.

Sampling and physicochemical parameter measurements of water samples were taken into 1-liter polyethylene containers from the middle of each stream and analyzed in a laboratory environment according to TS EN ISO 5667-3 and TS ISO 5667-6 standards (dissolved oxygen, salinity, total nitrogen, organic nitrogen, alkalinity). Temperature, pH, electrical conductivity were measured and recorded during field studies with the HACH LANGE HQ 40-D portable multiparameter meter.

Benthic macroinvertebrate sampling was carried out by applying 2-3 minutes of kicking method at a distance of 100 m along the stream, with the help of a dip net with a 500 μm mesh, taking into account the different ecological regions of each stream. The obtained benthos samples were transported to Nevşehir Hacı Bektaş Veli University Hydrobiology Research Laboratory in plastic bottles containing 4% formaldehyde solution. The benthos transferred to the laboratory was passed through sieves with different mesh openings and living material was collected with the help of forceps and roughly divided into systematic groups under a LEICA EZ-4D brand stereo microscope. Then, using LEICA DM-500 brand light microscope, they were identified at family, genus and species level. Kazancı (1985); Kluge (1988, 1994, 1997); Tanatmış (1993); Bauernfeind (1994, 1995); Haybach (1999); Bauernfeind & Soldan (2012); Türkmen and Kazancı (2013) were used in the identification of the species.

In the evaluation of biological data; dominance and frequency values of Ephemeroptera order according to stations were calculated by using individual numbers (Kocataş, 1997). The species diversity in the stations according to the detected species was revealed by SHE analysis via BİÇEB software (Özkan et al., 2020), and the similarities depending on the distinction between stations were revealed by two-way cluster analysis using Past-3 and PC-ORD software. In order to eliminate the multicollinearity problem between the physicochemical parameters and to select the appropriate parameters and to determine the relationship between the variables, the multicollinearty test and Pearson correlation analysis were performed using the ECOM-2.01 package program, respectively. The relationship between the determined taxa and physicochemical variables was revealed by Canonical CorrespondenceAnalysis (CCA) using the CANOCO-4.5 software. In addition, the water quality classes of the stations were interpreted based on some physicochemical parameters measured according to the Surface Water Quality Regulation (YSKY, 2021).

## RESULTS AND DISCUSSION

The R-squared ($R^2$) and variance inflation factor (VIF) of the multicollinearity test are presented in Table 2. According to this; The evaluations were continued by eliminating the variables (salinity, organic nitrogen and alkalinity) that had $R^2$>0.9 and VIF>10 values and were calculated close to these values due to their close relationship with each other.

According to the results of the correlation analysis applied to determine the relationship of physicochemical parameters with each other; statistically, a significant positive correlation was observed between dissolved oxygen and pH, and between total nitrogen and temperature, while a significant negative correlation

**Table 1.** Information about the sampling stations of the Ceyhan Basin.

| Code | Stream Name | Latitude | Longitude | Bottom Structure | Agriculture | Farming |
|---|---|---|---|---|---|---|
| 1 | Çatağın | 36.68033 | 38.36949 | Rock, stone and gravel | Unavailable | Available |
| 2 | Tokadun | 36.44295 | 38.07066 | Rocks, stones, gravel and coarse sand | Unavailable | Unavailable |
| 3 | Fenk | 36.51513 | 37.83089 | Rock, stone and gravel | Available | Available |
| 4 | Büyükçat | 36.40425 | 37.76909 | Stone, gravel and sand | Available | Available |
| 5 | Kirksu | 36.36456 | 37.77113 | Stone and gravel | Unavailable | Available |
| 6 | Topaktas | 36.3627 | 37.70541 | Rocks, stones, gravel and coarse sand | Available | Available |
| 7 | Hüseyin | 36.39426 | 37.06847 | Rocks, stones, gravel and coarse sand | Unavailable | Unavailable |
| 8 | Baskonus | 36.53387 | 37.25438 | Stone, gravel and coarse sand | Unavailable | Available |
| 9 | Zokur | 36.55773 | 37.34633 | Rocks, stones, gravel and coarse sand | Unavailable | Available |
| 10 | Çağırgan | 36.60487 | 37.39108 | Rocks, stones, gravel and coarse sand | Available | Available |
| 11 | Keven | 37.03649 | 37.79895 | Rock, stone and gravel | Unavailable | Unavailable |
| 12 | Karataş | 36.77581 | 37.90035 | Rocks, stones, gravel and coarse sand | Available | Available |
| 13 | Kızıldağ | 36.75949 | 37.94049 | Rock, stone and gravel | Unavailable | Available |
| 14 | Geyikbeli | 36.95934 | 37.98516 | Rocks, stones, gravel and coarse sand | Unavailable | Unavailable |
| 15 | Söğütlü | 37.63291 | 38.11674 | Rocks, stones, gravel and coarse sand | Available | Available |
| 16 | Pasaölen | 36.58571 | 38.23852 | Stone, gravel and sand | Unavailable | Available |
| 17 | Mahmut | 36.99009 | 38.4868 | Rocks, stones, gravel and coarse sand | Available | Available |
| 18 | Çamlı | 36.31581 | 37.76583 | Stone and gravel | Available | Available |
| 19 | Kuru | 36.34822 | 37.75084 | Rocks, stones, gravel and coarse sand | Available | Available |
| 20 | Kirazlı | 36.4 | 37.64492 | Rocks, stones, gravel and coarse sand | Unavailable | Available |

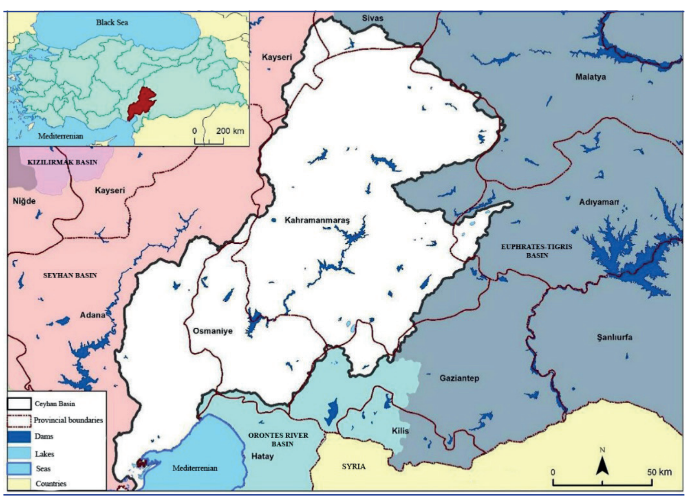


**Figure 1.** Location map of the Ceyhan Basin.

was observed between dissolved oxygen and temperature and total nitrogen ($p<0.01$) (Table 3). Seasonally, physicochemical parameters and quality classes of the stations are given together with their color coding in Table 4 (YSKY, 2021).

According to Table 4, when the water quality classes of the stations are evaluated in terms of some parameters seasonally (YSKY, 2021); In all three periods, it has been determined that all stations have first class water quality according to temperature, pH and total nitrogen. In the spring period, $17^{th}$ station in terms of dissolved oxygen and $2^{nd}$, $7^{th}$, $17^{th}$ and $19^{th}$ stations in terms of electrical conductivity have second class water quality while the other stations were determined to be of first class water quality. In the summer period; $1^{st}$, $5^{th}$, $6^{th}$, $8^{th}$, $11^{th}$, $13^{th}$, $17^{th}$, $18^{th}$, $19^{th}$ and $20^{th}$ stations in terms of dissolved oxygen, $2^{nd}$, $3^{rd}$, $4^{th}$, $7^{th}$, $9^{th}$, $17^{th}$, $18^{th}$ and $19^{th}$ stations in terms of electrical conductivity have second class water quality while the other stations were determined to be of first class water quality. In the autumn period, measurements could not be made at the $4^{th}$, $10^{th}$, $11^{th}$ and $17^{th}$ stations due to the dryness of the water, and $3^{rd}$, $5^{th}$, $7^{th}$, $9^{th}$, $12^{th}$, $14^{th}$ and $20^{th}$ stations in terms of dissolved oxygen and $2^{nd}$, $3^{rd}$, $7^{th}$ and $19^{th}$ stations in terms of electrical conductivity have second class water quality while the other stations were determined to be of first class water quality. If the final classes of the stations regarding the average values of the parameters are evaluated; while $2^{nd}$, $3^{rd}$, $4^{th}$, $7^{th}$, $17^{th}$ and $19^{th}$ stations have moderate polluted water quality, the other stations are determined to be in high quality water class. Accordingly, it can be said that all stations are in a healthy ecosystem structure and there is no element that threatens the water quality.

As a result of sampling at 20 stations in three different periods, 971 individuals were examined and 17 species belonging to six families (Baetidae, Heptageniidae, Leptophlebiidae, Ephemeridae, Ephemerellidae and Caenidae) were identified (Table 5). Considering the seasonal dominance of the species (%), the most dominant species is *B. rhodani* with the rates of 56.49%, 58.36% and 81.05% in the spring, summer and autumn periods, respectively, *E. alpicola* followed with a rate of 23.32% and 13.5% in the spring and summer periods, *E. lateralis* and *R. semicolorata* followed with a rate of 3.68% in the autumn period. Considering the frequency values (%) of the species, *B. rhodani* is the most common taxon with 90%, 85% and 65% rates in the spring, summer and autumn periods, respectively, while it was followed by *E. alpicola* with 40% and 30% rates in the spring and summer

**Table 2.** Multicollinearty test of physicochemical parameters.

| Dependent variable | R-squared | VIF |
|---|---|---|
| Temperature (°C) | 0.657 | 2.919 |
| pH | 0.295 | 1.418 |
| Electrical Conductivity (µS/cm) | 0.796 | 4.905 |
| Dissolved Oxygen (mg/L) | 0.715 | 3.503 |
| Salinity (%) | **0.929** | **14.01** |
| Total Nitrogen (mg/L) | 0.336 | 1.507 |
| Organic Nitrogen (mg/L) | **0.973** | **36.643** |
| Alkalinity (CaCO3 (mg/L)) | **0.795** | **4.877** |

**Table 3.** Pearson correlation of physicochemical variables.

| | Temperature (°C) | pH | EC (µS/cm) | DO (mg/L) | TN (mg/L) |
|---|---|---|---|---|---|
| **Temperature (°C)** | 1 | | | | |
| **pH** | -0.026 | 1 | | | |
| **EC (µS/cm)** | 0.219 | 0.054 | 1 | | |
| **DO (mg/L)** | **-0.744** | **0.369** | -0.097 | 1 | |
| **TN (mg/L)** | **0.479** | 0.005 | -0.115 | **-0.484** | 1 |

The correlation is significant at the p<0.01 level. EC: Electrical Conductivity, DO: Dissolved Oxygen, TN: Total Nitrogen

periods respectively, and *E. alpicola*, *E. lateralis* and *R. semicolorata* with the same frequency (10%) in the autumn period (Table 6). The continuous presence of *B. rhodani* in all three periods indicates that the ecological tolerance of the species is high.

In studies on ecology based on diversity calculation, Shannon-Wiener species diversity index (H) has become a more preferred index in ecology as it gives more objective results without distinguishing rare and dominant species (Gülsoy & Özkan, 2008; Özkan et al., 2020). For this reason, the SHE analysis, which is a technique in which the number of species (S), Shannon-Wiener species diversity index (H) and equality-balance (E) results were presented simultaneously. According to the data obtained from the sampled Ephemeroptera taxa and the abundance values of the individual numbers, when the general diversity status is examined regardless of the season; the species richness was highest with eight and six species at the 7th and 15th stations, then four species with the same species richness at the 1st, 8th, 10th, 12th, 16th and 20th stations and three species with the 2nd, 3rd ,5th and 13th stations was observed. The stations with the least species diversity were determined as the 4th and 6th stations with 2 species and the 9th, 11th, 14th, 17th, 18th and 19th stations with only one species.

According to the results of the SHE analysis (Table 7 and Figure 2); if the H values that express the diversity are compared; in the spring period, the highest diversity was calculated at the 7th, 20th and 15th stations with the values of 1.456, 1.199 and 1.158, respectively, and the lowest diversity was calculated as the 6th and 4th stations, with the values of 0.173 and 0.245, respectively. The highest E values expressing balance-equality were calculated at the 3rd and 13th stations with 0.963 and 0.877, respectively, and the lowest values were calculated at the 16th and 7th stations with 0.529 and 0.536 respectively. The differences in the diversity (H) values of the stations that have the same species richness but differ in terms of individual numbers, or the disproportions in the H and E values of the stations with high species richness vary according to the distribution characteristics of the taxa at the stations. Therefore, although the species richness of the 20th station and the 15th, 10th, 12th and 16th stations are the same, the higher H value of the 20th station explains the high level of balanced distribution among the species found there. As a matter of fact, it is seen that the E value, which expresses balance-equality, is higher at the 20th station. On the other hand, it has been observed that the 7th station, which has the highest species richness, has a low E value against the high H value. This is explained by the less balanced (heterogeneous) distribution of individuals in that station.

In the summer sampling period, the highest H value was calculated with 1.311, 1.210 and 1.117 at the 20th, 15th and 10th stations, respectively, and the lowest was 0.341 at the 13th station. The stations with the most balanced (homogeneous) distribution were seen as the 7th station with 0.973 according to the results of the E value expressing equality and balance, followed by the 1st and 8th stations with the same value (0.963). The stations with the least balanced distribution were determined as 16th and 12th stations with 0.659 and 0.666, respectively.

In the autumn period sampling, which was completed with the least species diversity as a result of the increase in the species eliminated from the environment due to both the drying up of the waters and the changing water parameters, the highest diversity (H) was calculated at the 15th and 16th stations with the values of 1.102 and 0.843, respectively, and the lowest diversity was calculated at the 8th station the value of 0.457. The stations with the most balanced distribution were determined as the 1st and 6th stations with the values of 0.945 and 0.877, respectively, and the stations with the least balanced distribution were determined as the 8th and 15th stations, respectively, with the values of 0.527 and 0.753.

Since they have only one species in all three seasons, no significant results could be obtained in stations with species richness of 1, and H and E values were calculated as 0 and 1, respectively (Table 7 and Figure 2). In addition, no samples could be detected at the 1st station in the spring period, the 4th in the summer period, and the 7th and 19th stations in the autumn period.

According to the distribution of the obtained taxa, the similarities between the stations were examined by the Bray-Curtis Analysis method (Figure 3). According to this; among the 20 stations, the highest similarity rate (100%) was observed between the 3rd and 5th stations and between the 9th, 14th, 17th, 18th and 19th stations. This is followed by the similarity of the 3rd and 5th sta-

**Table 4.** Physicochemical parameters of the stations.

| Quality Classes and Stations | Season | Temperature (°C) | pH | EC(μS/cm) | DO (mg/L) | TN (mg/L) |
|---|---|---|---|---|---|---|
| I (High-quality water) | - | ≤ 25 | 6-9 | < 400 | > 8 | < 3.5 |
| II (Moderate polluted water) | - | ≤ 25 | 6-9 | 1000 | 6 | 11.5 |
| III (Polluted water) | - | ≤ 25 | 6-9 | >1000 | <6 | >11.5 |
| 1 | Spring | 11.10 | 8.86 | 239.00 | 8.74 | 0.71 |
| | Summer | 19.60 | 8.58 | 252.00 | 7.52 | 2.76 |
| | Autumn | 10.80 | 8.11 | 245.00 | 8.22 | 2.22 |
| | Avg. | **13.80** | **8.52** | **245.00** | **8.16** | **1.90** |
| 2 | Spring | 12.00 | 8.51 | 436.00 | 9.46 | 0.11 |
| | Summer | 17.60 | 8.40 | 475.00 | 8.23 | 0.47 |
| | Autumn | 12.20 | 7.91 | 439.00 | 9.58 | 0.37 |
| | Avg. | **13.90** | **8.27** | **450.00** | **9.09** | **0.32** |
| 3 | Spring | 11.90 | 8.88 | 250.00 | 9.12 | 0.29 |
| | Summer | 17.20 | 8.50 | 409.00 | 8.29 | 1.20 |
| | Autumn | 16.10 | 7.92 | 434.00 | 7.84 | 0.19 |
| | Avg. | **15.10** | **8.43** | **364.00** | **8.42** | **0.56** |
| 4 | Spring | 11.10 | 8.60 | 383.00 | 10.10 | 0.1 |
| | Summer | 23.60 | 8.38 | 444.00 | 8.06 | 0.82 |
| | Autumn | - | - | - | - | - |
| | Avg. | **17.40** | **8.49** | **414.00** | **9.07** | **0.43** |
| 5 | Spring | 10.80 | 8.58 | 288.00 | 9.28 | 0.14 |
| | Summer | 14.60 | 8.34 | 338.00 | 7.76 | 0.70 |
| | Autumn | 12.40 | 7.44 | 331.00 | 7.92 | 0.44 |
| | Avg. | **12.60** | **8.12** | **319.00** | **8.32** | **0.43** |
| 6 | Spring | 11.30 | 8.61 | 399.00 | 9.42 | 0.1 |
| | Summer | 18.80 | 8.44 | 396.00 | 7.60 | 0.56 |
| | Autumn | 16.60 | 8.82 | 357.00 | 8.56 | 1.28 |
| | Avg. | **15.60** | **8.62** | **384.00** | **8.53** | **0.63** |
| 7 | Spring | 12.70 | 8.75 | 402.00 | 9.67 | 1.20 |
| | Summer | 18.00 | 8.74 | 479.00 | 8.74 | 0.38 |
| | Autumn | 16.70 | 8.36 | 465.00 | 7.91 | 0.76 |
| | Avg. | **15.80** | **8.62** | **449.00** | **8.77** | **0.78** |
| 8 | Spring | 17.70 | 8.41 | 153.00 | 8.45 | 0.17 |
| | Summer | 18.60 | 8.39 | 191.00 | 7.44 | 0.72 |
| | Autumn | 15.90 | 7.36 | 200.00 | 8.35 | 0.92 |
| | Avg. | **17.40** | **8.05** | **182.00** | **8.08** | **0.60** |
| 9 | Spring | 16.90 | 8.89 | 384.00 | 9.22 | 0.1 |
| | Summer | 19.10 | 8.91 | 415.00 | 8.63 | 0.88 |
| | Autumn | 18.10 | 8.60 | 390.00 | 7.86 | 0.45 |
| | Avg. | **18.00** | **8.80** | **396.00** | **8.57** | **0.46** |
| 10 | Spring | 15.30 | 8.51 | 259.00 | 9.29 | 0.52 |
| | Summer | 19.00 | 8.51 | 292.00 | 8.60 | 1.81 |
| | Autumn | - | - | - | - | - |
| | Avg. | **17.20** | **8.51** | **276.00** | **8.95** | **1.17** |
| 11 | Spring | 16.00 | 8.75 | 236.00 | 8.75 | 0.49 |
| | Summer | 16.90 | 8.37 | 277.00 | 7.61 | 0.62 |
| | Autumn | - | - | - | - | - |
| | Avg. | **16.50** | **8.56** | **257.00** | **8.18** | **0.56** |
| 12 | Spring | 12.20 | 8.78 | 345.00 | 9.60 | 0.19 |
| | Summer | 18.60 | 8.43 | 340.00 | 8.09 | 1.59 |
| | Autumn | 16.30 | 7.91 | 396.00 | 7.84 | 0.52 |
| | Avg. | **15.70** | **8.37** | **360.00** | **8.51** | **0.76** |

**Table 4.** Continue.

| Quality Classes and Stations | Season | Temperature (°C) | pH | EC(µS/cm) | DO (mg/L) | TN (mg/L) |
|---|---|---|---|---|---|---|
| 13 | **Spring** | 8.20 | 8.84 | 79.80 | 9.80 | 0.21 |
| | **Summer** | 16.10 | 8.40 | 91.00 | 7.58 | 1.18 |
| | **Autumn** | 16.10 | 8.40 | 290.00 | 8.03 | 0.50 |
| | **Avg.** | **13.50** | **8.55** | **154.00** | **8.47** | **0.63** |
| 14 | **Spring** | 10.40 | 8.56 | 161.00 | 9.96 | 0.17 |
| | **Summer** | 18.50 | 8.64 | 265.00 | 8.04 | 1.60 |
| | **Autumn** | 18.30 | 7.78 | 237.00 | 7.65 | 1.11 |
| | **Avg.** | **15.70** | **8.33** | **221.00** | **8.55** | **0.96** |
| 15 | **Spring** | 10.50 | 8.65 | 208.00 | 9.58 | 0.31 |
| | **Summer** | 16.30 | 8.50 | 244.00 | 8.11 | 2.18 |
| | **Autumn** | 14.20 | 7.78 | 233.00 | 8.07 | 1.17 |
| | **Avg.** | **13.70** | **8.31** | **228.00** | **8.59** | **1.22** |
| 16 | **Spring** | 9.90 | 8.50 | 245.00 | 9.75 | 0.63 |
| | **Summer** | 13.60 | 8.60 | 270.00 | 8.67 | 2.45 |
| | **Autumn** | 14.50 | 8.34 | 281.00 | 8.38 | 1.50 |
| | **Avg.** | **12.70** | **8.48** | **265.00** | **8.93** | **1.53** |
| 17 | **Spring** | 14.30 | 8.43 | 442.00 | 7.24 | 0.63 |
| | **Summer** | 17.40 | 8.76 | 506.00 | 7.44 | 1.24 |
| | **Autumn** | - | - | - | - | - |
| | **Avg.** | **15.90** | **8.60** | **474.00** | **7.34** | **0.94** |
| 18 | **Spring** | 11.60 | 8.63 | 319.00 | 9.34 | 0.13 |
| | **Summer** | 22.60 | 8.60 | 414.00 | 7.26 | 2.54 |
| | **Autumn** | 15.90 | 8.18 | 385.00 | 8.53 | 0.74 |
| | **Avg.** | **16.70** | **8.47** | **373.00** | **8.38** | **1.14** |
| 19 | **Spring** | 11.60 | 8.46 | 430.00 | 9.38 | 0.19 |
| | **Summer** | 19.40 | 8.38 | 424.00 | 7.20 | 1.42 |
| | **Autumn** | 14.50 | 7.90 | 418.00 | 8.58 | 0.35 |
| | **Avg.** | **15.20** | **8.25** | **424.00** | **8.39** | **0.65** |
| 20 | **Spring** | 11.60 | 8.54 | 397.00 | 9.60 | 0.12 |
| | **Summer** | 1860 | 8.41 | 362.00 | 7.74 | 1.49 |
| | **Autumn** | 15.30 | 7.40 | 367.00 | 7.55 | 0.32 |
| | **Avg.** | **15.20** | **8.12** | **375.00** | **8.30** | **0.64** |

EC: Electrical Conductivity, DO: Dissolved Oxygen, TN: Total Nitrogen, Avg: Average. (In the Autumn period, measurements could not be made at stations 4, 10, 11 and 17 due to the drying up of the waters.)

tions to the 10th and 16th stations with a rate of 86%. The least similarity was determined as the distance of the 15th station to the 12th and 20th stations with a rate of 20%. This was followed by the distance of the 7th station to the 9th, 14th, 17th, 18th and 19th stations and the 13th station to the 15th station, with a rate of 22%. On the other hand, it was determined that the 11th station was the most different station in the basin by being completely separated from the other stations, except for the 40% similarity to the 10th station. The reason for this is that the taxon *H. perflava* could not be detected at any station other than these two stations, and no other species other than this species were found at station 11. As a matter of fact, in the CCA graph obtained, it is seen that this species is located far from the center.

The eigen values of the first two axes were calculated as 0.208 and 0.141, respectively, in the Canonical Correspondence Analysis (CCA) applied to understand the relationship of species with physicochemical parameters. In the graph obtained, the dissolved oxygen, pH and total nitrogen variable groups and the temperature and electrical conductivity variables are located on different axes, and the most decisive variables are determined as electrical conductivity and temperature. *C. macrura* taxon is located at a distant point in the graph, since it was not observed at any station other than station 2 of the autumn period and no other taxa was encountered at this station (Figure 4).

Among the 971 individuals examined, the highest diversity belongs to the Heptageniidae family with 11 species, and the lowest diversity belongs to the Baetidae, Leptophlebiidae, Ephemeridae and Caenidae families, which are represented by a single species. While *B. rhodani* was observed as the taxon with the highest number of individuals with 602 individuals, the least number of individuals was determined in *E. affinis* and *E. assimilis* species with one individual. Considering the species diversity seasonally; 13, 11 and

**Table 5.** Distribution of the detected species by stations.

| | Stations | | | | | | | | | | Seasons | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Family and Species** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **Spr** | **Sum** | **Aut** |
| **Baetidae** | | | | | | | | | | | | | |
| *Baetis rhodani* (Pictet, 1843) | + | + | + | + | + | + | + | + | + | + | **** | **** | *** |
| **Heptageniidae** | | | | | | | | | | | | | |
| *Ecdyonurus macani* (Thomas ve Soma, 1970) | + | | | | | | + | | | | * | * | - |
| *Electrogena lateralis* (Curtis, 1834) | + | | | + | | | + | | | | * | - | * |
| *Epeorus alpicola* (Eaton, 1871) | | + | + | | + | | + | + | | + | ** | ** | * |
| *Epeorus assimilis* (Eaton, 1865) | | | | | | | + | | | | * | - | - |
| *Heptagenia coerulans* (Rostock, 1877) | | | | | | | | | | | * | * | - |
| *Heptagenia perflava* (Roctock, 1878) | | | | | | | | | | + | * | * | - |
| *Heptagenia* sp. | | | | | | | | | | | * | * | - |
| *Rhithrogena semicolorata* Curtis, 1834) | + | | + | | + | | + | | | + | ** | ** | * |
| *Ecdyonurus submontanus* (Landa, 1970) | | | | | | | | | | | - | - | * |
| *Electrogena affinis* (Eaton, 1886) | | | | | | | | + | | | - | - | * |
| *Epeorus caucasicus* (Tshernova, 1938) | | | | | | | | | | | - | - | * |
| **Leptophlebiidae** | | | | | | | | | | | | | |
| *Paraleptophlebia submarginata* (Stephens, 1835) | | | | | | + | + | | | | * | * | * |
| **Ephemeridae** | | | | | | | | | | | | | |
| *Ephemera vulgata* (Linnaeus 1758) | | | | | | | | | | | * | * | - |
| **Ephemerellidae** | | | | | | | | | | | | | |
| *Serratella ignita* (Poda, 1761) | | | | | | | + | + | | | * | * | - |
| *Ephemerella notata* (Eaton, 1887) | | | | | | | | | | | * | * | - |
| **Caenidae** | | | | | | | | | | | | | |
| *Caenis macrura* (Stephens, 1836) | | + | | | | | | | | | - | - | * |
| **Total** | **4** | **3** | **3** | **2** | **3** | **2** | **8** | **4** | **1** | **4** | | | |

| | Stations | | | | | | | | | | Seasons | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Family and Species** | **11** | **12** | **13** | **14** | **15** | **16** | **17** | **18** | **19** | **20** | **Spr** | **Sum** | **Aut** |
| **Baetidae** | | | | | | | | | | | | | |
| *Baetis rhodani* (Pictet, 1843) | | + | + | + | + | + | + | + | + | + | **** | **** | *** |
| **Heptageniidae** | | | | | | | | | | | | | |
| *Ecdyonurus macani* (Thomas ve Soma, 1970) | | | | | | + | | | | + | * | * | - |
| *Electrogena lateralis* (Curtis, 1834) | | | + | | | | | | | | * | - | * |
| *Epeorus alpicola* (Eaton, 1871) | | + | + | | | + | | | | | ** | ** | * |
| *Epeorus assimilis* (Eaton, 1865) | | | | | | | | | | | * | - | - |
| *Heptagenia coerulans* (Rostock, 1877) | | + | | | | | | | | | * | * | - |
| *Heptagenia perflava* (Brodsky, 1930) | + | | | | | | | | | | * | * | - |
| *Heptagenia* sp. | | | | | | | | | | + | * | * | - |
| *Rhithrogena semicolorata* (Curtis, 1834) | | | | | + | + | | | | | ** | ** | * |
| *Ecdyonurus submontanus* (Landa, 1970) | | | | | + | | | | | | - | - | * |
| *Electrogena affinis* (Eaton, 1886) | | | | | | | | | | | - | - | * |
| *Epeorus caucasicus* (Tshernova, 1938) | | | | | + | | | | | | - | - | * |
| **Leptophlebiidae** | | | | | | | | | | | | | |
| *Paraleptophlebia submarginata* (Stephens, 1835) | | + | | | | | | | | | * | * | * |
| **Ephemeridae** | | | | | | | | | | | | | |
| *Ephemera vulgata* (Linnaeus, 1758) | | | | | | | | | | + | * | * | - |

**Table 5.** Continue.

| | Stations | | | | | | | | | | Seasons | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Family and Species** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **Spr** | **Sum** | **Aut** |
| **Ephemerellidae** | | | | | | | | | | | | | |
| *Serratella ignita* (Poda, 1761) | | | | | + | | | | | | * | * | - |
| *Ephemerella notata* (Eaton, 1887) | | | | | + | | | | | | * | * | - |
| **Caenidae** | | | | | | | | | | | | | |
| *Caenis macrura* (Stephens, 1836) | | | | | | | | | | | - | - | * |
| **Total** | **1** | **4** | **3** | **1** | **6** | **4** | **1** | **1** | **1** | **4** | | | |

Spr: Spring, Sum: Summer, Aut: Autumn, *: Rare, **: Scarce, ***: Usually, ****: Continuous

**Table 6.** The seasonal abundance (N/m²), % dominance (D) and % frequency (F) values of the detected Ephemeroptera samples.

| | Spring | | | Summer | | | Autumn | | |
|---|---|---|---|---|---|---|---|---|---|
| **Species** | **N/m²** | **%D** | **%F** | **N/m²** | **%D** | **%F** | **N/m²** | **%D** | **%F** |
| *Baetis rhodani* | 235 | 56.49 | 90 | 213 | 58.36 | 85 | 154 | 81.05 | 65 |
| *Caenis macrura* | 0 | 0.00 | 0 | 0 | 0.00 | 0 | 6 | 3.16 | 5 |
| *Ecdyonurus macani* | 4 | 0.96 | 15 | 20 | 5.48 | 20 | 0 | 0.00 | 0 |
| *Ecdyonurus submontanus* | 0 | 0.00 | 0 | 0 | 0.00 | 0 | 6 | 3.16 | 5 |
| *Electrogena affinis* | 0 | 0.00 | 0 | 0 | 0.00 | 0 | 1 | 0.53 | 5 |
| *Electrogena lateralis* | 4 | 0.96 | 10 | 0 | 0.00 | 0 | 7 | 3.68 | 10 |
| *Epeorus alpicola* | 97 | 23.32 | 40 | 48 | 13.15 | 30 | 6 | 3.16 | 10 |
| *Epeorus assimilis* | 1 | 0.24 | 5 | 0 | 0.00 | 0 | 0 | 0.00 | 0 |
| *Epeorus caucasicus* | 0 | 0.00 | 0 | 0 | 0.00 | 0 | 2 | 1.05 | 5 |
| *Heptagenia coerulens* | 2 | 0.48 | 5 | 2 | 0.55 | 5 | 0 | 0.00 | 0 |
| *Heptagenia perflava* | 5 | 1.20 | 10 | 16 | 4.38 | 10 | 0 | 0.00 | 0 |
| *Heptagenia* sp. | 1 | 0.24 | 5 | 5 | 1.37 | 5 | 0 | 0.00 | 0 |
| *Rhithrogena semicolorata* | 41 | 9.86 | 30 | 15 | 4.11 | 25 | 7 | 3.68 | 10 |
| *Paraleptophlebia submarginata* | 5 | 1.20 | 15 | 15 | 4.11 | 10 | 1 | 0.53 | 5 |
| *Ephemera vulgata* | 3 | 0.72 | 15 | 4 | 1.10 | 5 | 0 | 0.00 | 0 |
| *Ephemerella ignita* | 12 | 2.88 | 15 | 18 | 4.93 | 10 | 0 | 0.00 | 0 |
| *Ephemerella notata* | 6 | 1.44 | 5 | 9 | 2.47 | 5 | 0 | 0.00 | 0 |
| **Total** | **416** | **100** | **-** | **365** | **100** | **-** | **190** | **100** | **-** |

nine species were identified in the spring, summer and autumn periods, respectively. When the stations are compared on a seasonal basis in terms of species diversity, the highest diversity was seen at the 7th station belonging to the spring period with eight species. This was followed by the 10th, 12th, 15th, 16th and 20th stations of the spring and summer periods and the 15th station of the autumn period with four species. Considering the abundance values of the stations, the highest Ephemeroptera community diversity was determined with 69 individuals at the 7th station of the spring period, and the lowest with a single individual at the 2nd and 14th stations of the spring period and the 18th station of the autumn period. Shannon values (H) of SHE analysis used to determine diversity support this result. *B. rhodani* taxon was observed as the most dominant species with 235, 213 and 154 individuals in the spring, summer and autumn periods, respectively, and it was also the most frequently observed taxon by being detected in 18, 17 and 13 stations, respectively.

The high diversity in the spring and summer periods can be explained by the increase in the dissolved oxygen value, which is the appropriate parameters for Ephemeroptera communities -especially the Heptageniidae family-, where diversity is high-, due to the increase in the waters together with the melting of the snow waters, and accordingly the decrease in the amount of pollution and organic matter. The fact that the diversity in the autumn period is low compared to the other seasons is the fact that no sampling can be made at the 4th, 10th, 11th and 17th stations, which have a seasonal stream regime, together with the drying of the waters. On the other hand, it is due to the decrease in available waters and the inability to observe some species (particularly, individuals belonging to the genus Heptegenia and Ephemera, which prefer habitats where the flow is fast, dissolved oxygen is abundant and the amount of organic matter is low).

When some of the physicochemical parameters measured according to the Surface Water Quality Regulation (YSKY, 2021) are exam-

**Table 7.** SHE diversity analysis values, number of species (S) and individual numbers (N) calculated based on the species and individual numbers of the stations.

| Station | S | N | H | E | Station | S | N | H | E |
|---|---|---|---|---|---|---|---|---|---|
| **1-Sum** | 3 | 14 | 1.061 | 0.963 | **11-Sum** | 1 | 12 | 0.000 | 1.000 |
| **1-Aut** | 2 | 3 | 0.637 | 0.945 | **12-Spr** | 4 | 28 | 0.855 | 0.588 |
| **2-Spr** | 1 | 1 | 0.000 | 1.000 | **12-Sum** | 4 | 30 | 0.980 | 0.666 |
| **2-Sum** | 2 | 16 | 0.621 | 0.930 | **12-Aut** | 1 | 4 | 0.000 | 1.000 |
| **2-Aut** | 1 | 6 | 0.000 | 1.000 | **13-Spr** | 2 | 16 | 0.562 | 0.877 |
| **3-Spr** | 3 | 9 | 1.061 | 0.963 | **13-Sum** | 2 | 28 | 0.341 | 0.703 |
| **3-Sum** | 1 | 3 | 0.000 | 1.000 | **13-Aut** | 2 | 33 | 0.474 | 0.803 |
| **3-Aut** | 1 | 9 | 0.000 | 1.000 | **14-Spr** | 1 | 1 | 0.000 | 1.000 |
| **4-Spr** | 2 | 15 | 0.245 | 0.639 | **14-Sum** | 1 | 11 | 0.000 | 1.000 |
| **5-Spr** | 3 | 40 | 0.900 | 0.820 | **14-Aut** | 1 | 8 | 0.000 | 1.000 |
| **5-Sum** | 1 | 13 | 0.000 | 1.000 | **15-Spr** | 4 | 27 | 1.158 | 0.796 |
| **5-Aut** | 1 | 11 | 0.000 | 1.000 | **15-Sum** | 4 | 39 | 1.210 | 0.838 |
| **6-Spr** | 2 | 24 | 0.173 | 0.595 | **15-Aut** | 4 | 26 | 1.102 | 0.753 |
| **6-Sum** | 2 | 17 | 0.606 | 0.916 | **16-Spr** | 4 | 31 | 0.750 | 0.529 |
| **6-Aut** | 2 | 4 | 0.562 | 0.877 | **16-Sum** | 4 | 22 | 0.969 | 0.659 |
| **7-Spr** | 8 | 69 | 1.456 | 0.536 | **16-Aut** | 3 | 22 | 0.843 | 0.774 |
| **7-Sum** | 2 | 13 | 0.666 | 0.973 | **17-Spr** | 1 | 3 | 0.000 | 1.000 |
| **8-Spr** | 3 | 57 | 0.676 | 0.655 | **17-Sum** | 1 | 12 | 0.000 | 1.000 |
| **8-Sum** | 3 | 32 | 1.061 | 0.963 | **18-Spr** | 1 | 8 | 0.000 | 1.000 |
| **8-Aut** | 3 | 31 | 0.457 | 0.527 | **18-Sum** | 1 | 19 | 0.000 | 1.000 |
| **9-Spr** | 1 | 21 | 0.000 | 1.000 | **18-Aut** | 1 | 1 | 0.000 | 1.000 |
| **9-Sum** | 1 | 6 | 0.000 | 1.000 | **19-Spr** | 1 | 3 | 0.000 | 1.000 |
| **9-Aut** | 1 | 22 | 0.000 | 1.000 | **19-Sum** | 1 | 15 | 0.000 | 1.000 |
| **10-Spr** | 4 | 49 | 0.960 | 0.653 | **20-Spr** | 4 | 12 | 1.199 | 0.829 |
| **10-Sum** | 4 | 36 | 1.117 | 0.764 | **20-Sum** | 4 | 27 | 1.311 | 0.927 |
| **11-Spr** | 1 | 2 | 0.000 | 1.000 | **20-Aut** | 1 | 10 | 0.000 | 1.000 |

Spr: Spring, Sum: Summer, Aut: Autumn

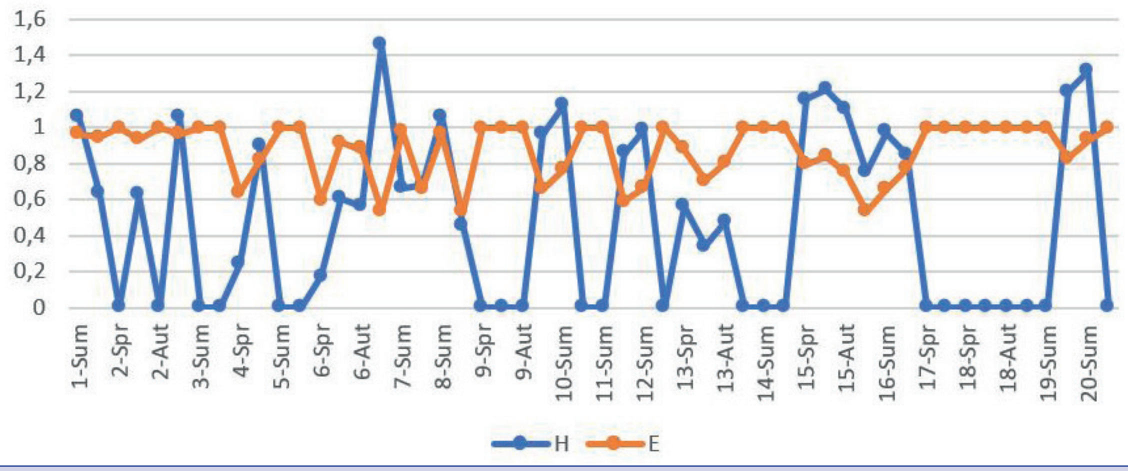


**Figure 2.** SHE diversity analysis graph of the stations (Spr: Spring, Sum: Summer, Aut: Autumn).

ined, it is seen that the stations have high quality water (Class I) or moderate polluted water (Class II) quality. As a matter of fact, as a result of the evaluation of the obtained physicochemical data and biological findings, it was seen that the physicochemical and biological water quality data showed parallelism.

Although the most important threat affecting the abundance and diversity of the members of the order Ephemeroptera, which is known as an indicator of clean water, is pollution, it is also known that the members of this order do not have tolerance to the decrease in the amount of dissolved oxygen and increasing

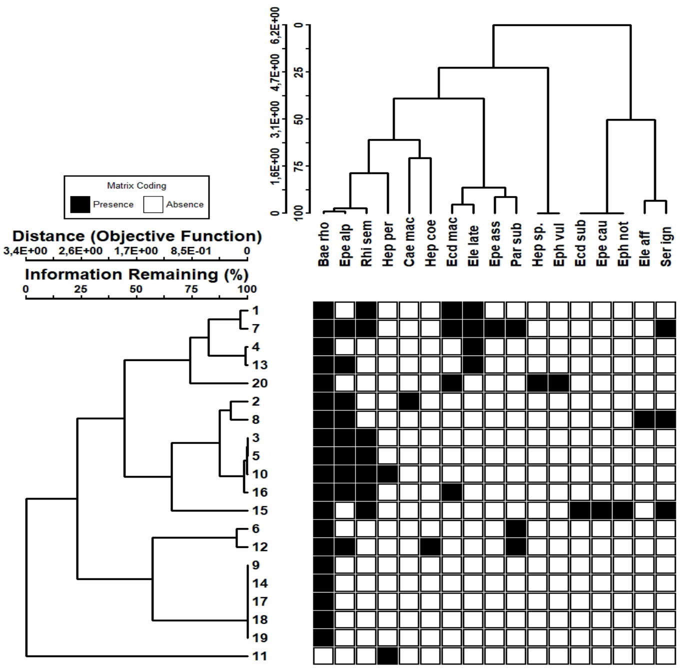


**Figure 3**. Two-way Cluster Dendogram (Bray-Curtis) of station similarities.

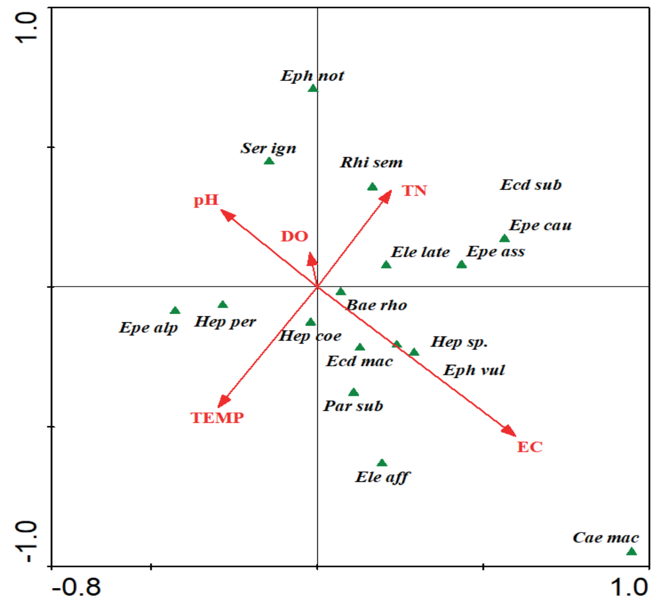


**Figure 4**. Canonical Correspondence Analysis between Ephemeroptera species and physicochemical parameters [▲: Species, TN: Total Nitrogen, EC: Electrical Conductivity, DO: Dissolved Oxygen, TEMP: Temperature, Bae rho: *Baetis rhodani*, Cae mac: *Caenis macrura*, Ecd mac: *Ecdyonurus macani*, Ecd sub: *Ecdyonurus submontanus*, Ele aff: *Electrogena affinis*, Ele lat: *Electrogena lateralis*, Epe alp: *Epeorus alpicola*, Epe ass: *Epeorus assimilis*, Epe cau: *Epeorus caucasicus*, Hep coe: *Heptagenia coerulans*, Hep fla: *Heptagenia perflava*, Hep sem: *Heptagenia* sp., Rhi sem: *Rhithrogena semicolorata*, Par sub: *Paraleptophlebia submarginata*, Eph vul: *Ephemera vulgata*, Ser ign: *Serratella ignita*, Eph not: *Ephemerella notata*].

pollution due to the increase in the organic matter input in the environment (Kazancı et al., 1997; Demir, 2005; Jandry et al., 2014). Ephemeroptera larvae of $O_2$ consumption is associated with the water temperature in the aquatic environment and increases depending on the increase in temperature. This situation creates serious threats in terms of species in the environment. In our study; seasonally, the temperature values between stations do not fall below 25 °C and vary between 8.2 and 22.6 °C. Likewise, pH, which is one of the most important variables reflecting the chemical composition and efficiency of water, is in the range of 7.36-8.91 at all stations, and it is seen that it contains reference values belonging to the high water quality class. Aquatic creatures adapt optimally to pH values between 5-9 in their environment; it is known that the productivity of acidic waters is low, while alkaline waters are high. In addition, there is a positive relationship between the mineral ratio and pH in aquatic environments (Ölmez & Saraç, 2009). The highly mineralized structure of all stations except the 8$^{th}$, 9$^{th}$, 11$^{th}$, 12$^{th}$, 13$^{th}$ and 14$^{th}$ stations supports this situation. The lowest pH in the studied stations belongs to the measurements in the autumn period. This can be explained by the decrease in the pH level due to the decrease in water in the autumn period. As a result, it can be said that the waters are of good quality in terms of temperature, dissolved oxygen, total nitrogen and pH parameters, the amount of organic matter and vegetation rate in the waters is low, and therefore eutrophication is low.

Values related to electrical conductivity, which express the capacity of water to conduct electric current, are in parallel with the temperature value and have been determined as one of the determining parameters affecting the distribution of taxa in the CCA diagram. According to the Pearson correlation analysis, although a positive relationship was observed between electrical conductivity and temperature, a high value was not reached. This is due to the fact that the temperature variable does not reach very high values in three seasons. At the same time, the ground structure is another factor that changes the electrical conductivity (EPA, 2006). In our study, the fact that the stations did not exhibit any sediment properties other than rocks, stones, gravel and coarse sand, the water temperature was below 25 °C and the dissolved oxygen values did not fall below 6, supports the low electrical conductivity and therefore the good water quality in terms of this parameter.

*Baetis rhodani*, a member of the Baetidae family, which has a cosmopolitan distribution in the worldwide and is known for its high population in aquatic systems, is also widely used as biological indicators of water quality (Williams et al., 2006). As a result of the study, this species was found in all stations except the 11$^{th}$ station and was observed in all seasons with a total of 602 individuals. Percentage frequency values of the stations for the spring, summer and autumn periods were calculated as 90, 85 and 65, respectively. It has been stated that this species is euriterm and also prefers regions with high and medium currents (Buffagni et al., 2009). There are records in many regions including western and eastern Turkiye (Küçüker, 2019). In some studies, it has been stated that this species is found in water quality steps I, II and III, it is observed in rivers every season and it is a common and pollution-tolerant species (Sladeck, 1973; Mısıroğlu, 1995; Tonguç, 2004). As a matter of fact, the fact that it is located very close to the center in the obtained CCA diagram and its high tolerance to variables supports the result of the prevalence of this species. It is also known that the optimum temperature for the reproduction and survival of this species varies between 3 °C and 22 °C (Elliot, 1972). Accordingly, the stream temperatures at all sampling stations show the appropriate temperature ranges for the *B. rhodani* species with the highest abundance.

Among the order Ephemeroptera, the other family with the highest tolerance to organic pollution is Caenidae (Bargos et al., 1990; Timm, 1997; Grandjean et al., 2011). Although species belonging to the genus *Caenis* belonging to this family are found in all river types, they are generally distributed in areas with sandy, loam or gravelly ground structure and slow flowing and sometimes even stagnant waters (Malzacher, 1986). In this study, the *C. macrura* species was found only in the second station belonging to the autumn period. Looking at the CCA diagram, it is seen that this type is located at a separate point.

The Heptageniidae family, which includes the indicator species of unpolluted and undisturbed environments, is the family with the highest diversity in the sampled stations and is represented by five genera and 11 species (*E. macani, E. submontanus, E. affinis, E. lateralis, E. alpicola, E. assimilis, E caucasicus, H. coerulans, H. perflava, Heptagenia sp.* ve *R. semicolorata*). Species belonging to this family generally prefer very clean or lightly polluted xenosaprobic and oligosaprobic stream zones. Rarely, they can also be found in beta-mesosaprobic environments (Hellawell 1986, Hilsenhoff 1988, Kazancı 2001a, Bauernfeind & Humpesch 2001, Bauernfeind et al., 2002). Therefore, they constitute an important group used as clean water indicators in water quality studies (Kazancı et al., 2014). In the study, *E. alpicola*, which was seen at the 2nd, 3rd, 5th, 7th, 8th, 10th, 12th, 13th and 16th stations and was examined with a total of 151 individuals, was determined as the second most common taxon after *B. rhodani* with the frequency values of 40%, 30 and 10% in the spring, summer and autumn periods, respectively. It is known that this species, which is known to have a very low tolerance to organic pollution, prefers cold waters in terms of temperature and is known to spread in high flow waters rich in oxygen (Braasch & Jacob, 1976; Elliot et al., 1988). In the correlation of the obtained CCA diagram, it was seen that this species was in a negative relationship with the total nitrogen variable representing eutrophic conditions, and positively with dissolved oxygen representing clean conditions. Considering the other species of *Epeorus* genus, *E. assimilis* was observed only in the 7th station in the spring period, and *E. caucasicus* was observed only in the 15th station in the autumn period. It is known that both species are cold stenothermic creatures, they prefer stony and rocky ground structure with fast currents from the hypocrenon region to the metarhithron region, and their tolerance to pollution is very low (Kazancı, 2001a). *Rhithrogena semicolorata* species were examined with a total of 63 individuals at the 1st, 3rd, 5th, 7th, 10th, 15th and 16th stations and it was determined as the third most common taxon with the frequency values of 30%, 25% and 10% in the spring, summer and autumn periods, respectively. It has been stated that this species is euriterm and also prefers regions with high and medium currents (Buffagni et al., 2009). This species was generally found in most studies conducted in our country (Tonguç, 2004; Zeybek, 2007; Zeybek et al., 2012, 2014). In the obtained CCA diagram, it is positioned in relation to the total nitrogen variable. *Ecdyonurus* larvae are found in fast-flowing parts of streams and in areas with stony and rocky ground. They have a low tolerance for organic pollution (Bauernfeind & Soldan, 2012). *E. macani* belonging to this genus was observed in the 1st, 7th, 16th and 20th stations in the spring and summer seasons, while the *E. submontanus* was observed only in the 15th station in the autumn season. *Electrogena* is a genus that can be found in regions with oligosaprobic and beta-mesosaprobic features (Bauernfeind, 1995). *E. affinis* belonging to this genus was detected only in the 8th station in the autumn period, and for this reason, it is located further away from the other taxa in the CCA diagram. *E. lateralis* was observed in the 4th and 7th stations in the spring period and at the 1st and 13th stations in the autumn period. In the genus *Heptagenia*, three species were detected in the same stations in the spring and summer periods, of which *H. coerulans* was observed at the 12th station, *H. perflava* at the 10th and 11th stations, and *Heptagenia* sp. at the 20th station.

Taxa belonging to the Leptophlebiidae family are generally distributed in stony areas in the hypocrenon and rhithron regions of rivers (Buffagni et al., 2009). While the genus *Paraleptophlebia* is generally found in oligosaprobic regions, it can also be found in betamesosaprobic, xenosaprobic and alpha-mesosaprobic regions with a low probability (Kazancı, 2001a). In our study, *P. submarginata* species belonging to this family, which was found in all seasons, were observed at the 6th, 7th and 12th stations in the spring, at the 6th and 12th stations in the summer, and only at the 6th station in the autumn.

*Ephemera vulgata* species belonging to the Ephemeridae family, which is known to be tolerant of low oxygen concentration (Aydınlı, 2008), was found only in the 20th station in the spring and summer periods. It has been reported that this species is distributed in oligosaprobic, ethamesosaprobic and alphamesosaprobic regions and has a wide distribution from east to west in our country (Kazancı & Türkmen, 2008). This means that the species has a wide ecological tolerance to pollution. As a matter of fact, it is seen in the obtained CCA diagram that it is positioned in the opposite direction with the dissolved oxygen.

While individuals belonging to the Ephemerellidae family generally prefer stream regions with beta-mesosaprobic features, they can also be found in stream regions with oligosaprobic features. Although very rarely, it is possible to encounter individuals belonging to this family in alpha-mesosaprobic environments (Kazancı et al., 2014). The genus Ephemerella belonging to this family is also generally found in oligosaprobic, rarely betamezosaprobic and alpha-mesosaprobic regions (Kazancı, 2001a). In our study, *S. ignita* species belonging to this family were found in the 7th, 8th and 15th stations in the spring season and at the 8th and 15th stations in the summer season. It is known that individuals of this species have a wide ecological tolerance and spread in all types of rivers (Bauernfeind & Soldan, 2012). *E. notata* taxon was found only at the 15th station in the spring and summer periods. This species is generally known to be an alpha-beta mesosaprobic zone indicator (Kazancı, 2001a). In the obtained CCA diagram, it is seen that it is located at a distant point.

## CONCLUSION

When the stream types of the studied stations were examined, it was observed that all stream sediments were mostly rock, stone, gravel and coarse sand, and the stream velocity was high or moderate. In addition, the mineralization structure was found to be high throughout the stations. Although some agricultural and animal husbandry activities have been carried out around the stream, it can be said that this situation does not threaten the physicochemical properties of the stream. On the other hand, the absence of settlements around the stations supports that the streams are also clean in terms of domestic waste pollutants. Therefore, it has been determined that all physicochemical parameters are within reference ranges at a level that will not pose major threats, and that there is no intense pollution pressure from domestic, industrial and agricultural sources that will adversely affect the aquatic system.

Although there is no detailed study to determine the Ephemeroptera fauna in the Ceyhan Basin, from Kahramanmaraş, which is within the borders of the basin; the distribution of *Baetis* sp, *Ephemerella* sp., *Caenis* sp., *Isonychia* sp., *Siphlonurus* sp., and *Rhitrogena* sp. has been reported, and no individuals belonging to the *Isonychia* and *Siphlonurus* genera were found in our study (Kara & Çömlekçioğlu, 2004; Yıldırım, 2006; Ayas & Black, 2014). Apart from these taxa, other taxa identified are new records for the Ceyhan Basin. This study will provide important information about the Ephemeroptera fauna of our country and will be helpful for the aquatic ecosystem studies in the coming years.

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Short Communication

# A Note on *Thaparocleidus caecus* (Mizelle & Kritsky, 1969) (Monogenea: Dactylogyridae) Detected with Morphological and Molecular Tools in *Pangasianodon hypophthalmus* (Sauvage, 1878) Imported into Turkiye

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## ABSTRACT

*Thaparocleidus caecus* (Mizelle & Kritsky, 1969) Lim, 1996 (Dactylogyridae) was reported for the first time from iridescent shark-catfish (*Pangasianodon hypophthalmus*, Sauvage, 1878) imported into Turkiye via the aquarium fish trade. *T. caecus* were found on the gills of the examined fish with a prevalence of 28%. Identification, based on morphological characteristics for *T. caecus*, was confirmed by rRNA sequencing, evidencing the transfer of *T. caecus* to different countries. Our results emphasize that the ornamental fish trade poses a range expansion of un-documented parasite species.

**Keywords:** *Thaparocleidus caecus*, *Pangasianodon hypophthalmus*, shark-catfish, parasite transfer, aquarium fish trade

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## INTRODUCTION

Aquaculture and the ornamental aquatic animal trade provide access to the dispersal of non-native aquatic animal species (Peeler et al., 2011). The economic benefits of non-native introductions as in the tropical aquarium fish trade are clear. However, the movement of live animals is a serious risk for the spreading of diseases (Evans & Lester, 2001). It is known that the main locations of ornamental fish production are in Southeast Asian countries (Kim, Hayward, & Heo, 2002). Turkiye also imports various tropical aquarium fish from these countries; the imported fish species are wide in scale and number. The possibility of disease transmission via the main route of the live fish trade was reported in previous studies (Evans & Lester, 2001; Kim, Hayward, & Heo, 2002; Yildiz, 2005; Gjurčević et al., 2007; Kayis et al., 2009; Koyuncu, 2009; Tavares-Dias, Lemos, & Martins, 2010; Peeler et al., 2011; Trujillo-González et al., 2018; Trujillo-González et al., 2019). In these studies, different parasites recovered from the aquarium fish have commonly been identified: *Dactylogyrus* sp., *Gyrodactylus* sp., *Argulus* sp., *Ichthyobodo* sp., *Ichthyophthirius multifiliis* (Fouquet, 1876), *Trichodina reticulate* (Hirschmann & Partsch, 1955), *Capillaria* sp. and *Lernaea cyprinacea* (Linnaeus, 1758). There is no record of the occurence of *Thaparocleidus caecus* (Mizelle & Kritsky, 1969) Lim, 1996 in the imported *Pangasianodon hypophthalmus* (Sauvage, 1878) to Turkiye. However, the *Thaparocleidus* species; *T. siluri* (Zandt, 1924) Lim, 1996 and *T. vistulensis* (Siwak, 1932) Lim, 1996 were previously reported in *Silurus glanis* (Linnaeus, 1758) in Lake Gala (Edirne, Turkiye) by Soylu (2014) and *T. caecus* in *Pangasius pangasius* (Hamilton, 1822) by Tokşen, Zoral, & Şirin (2014). Herein we report the transfer of *T. caecus* isolated from *Pangasianodon hypophthalmus* (Pangasiidae) fish imported into Turkiye together with a brief morphological description and molecular identification.

## MATERIALS AND METHODS

Iridescent shark-catfish (*Pangasianodon hypophthalmus*) imported through Singapore were obtained from commercial suppliers within two working days of importation. The examined fish were clinically healthy with no signs of disease and selected randomly. The fish were examined with the permission of the Ankara University, Animal Ethical Committee (No:2015-12-136). The Fish were anaesthetically overdosed with clove oil, then humanely killed by severing the spinal cord with a sharp blade, and a complete ecto-parasitological examination was undertaken. A total of 54 shark-catfish (*P. hypophthalmus)* were examined under a microscope (Pritchard & Günther, 1982). The monogenean parasites found during examination were fixed in 70% alcohol and mounted in glycerin. The mounted parasites were photographed with a trinocular microscope (Leica CME) and the morphometric data of the parasite were obtained by Micro-cam version 5.5. The basic morphological keys used in the species identification were the sclerotized part of the attachment as well as the morphology and the length of the male reproductive organ in the parasite (Mizelle & Kritsky, 1969; Lim, 1990; Lim, 1996; Pariselle, Lim, & Lambert, 2006).

For molecular analysis, monogeneans were preserved in absolute alcohol. The prevalence (%) and the mean intensity of the parasite were assessed as reported by Bush et al. (1997). For molecular discrimination, a Qiagen D Neasy Blood & Tissue Kit was used for DNA extractions. The quantity and quality of the extracted DNA was assessed with a Colibri nano-spectrophotometer. The template DNA was adjusted to a final concentration of 50 ng/µL. The amplification of 649-bp-long fragment from the 5′ region of the partial 18S and ITS-1 region was done using a primer pair S1 (5′ ATTCCGATAACGAACGAGACT 3′) that binds with the terminal region of the 18S gene and H7 (5′ GCTGCGTTCTTCATCGATACTCG-3′) (Sinnappah et al., 2001). PCR amplifications were performed as previously described by Keskin, Unal, & Atar (2016). Briefly, 8 µl of 5x FIREPol Master Mix Ready to Load (Solis BioDyne, Estonia), 1 µl of each primer (F, R), template DNA (2 µl) and distilled water (28 µl) in a total reaction volume of 40 µl were used for the amplifications. The thermal cycler was run according to Keskin, Unal, & Atar (2016). An optimal fragment size of PCR products was checked using agarose gel (2%) electrophoresis. QIAGEN QIAquick Gel Extraction kit was used for Purification of PCR products. Sequencing was performed on an ABI Prism 310 genetic analyzer, using both primers for bidirectional sequencing. The ClustalW was used for the alignment of nucleotide sequences (Thompson et al., 1994) and edited using MEGA 6 (Tamura et al., 2013). Taxon DNA/Species Identifier v1.7.7 was applied to quantify the proportion of correctly identified queries according to Best Close Match (BCM), with a 3.0% threshold (Meier et al., 2006). The barcode sequence was trimmed by 649 base pairs with a reference sequence FJ493153.

## RESULTS AND DISCUSSION

The ectoparasite found on the gills of *P. hypophthalmus* was identified as *Thaparocleidus caecus* (Figure 1).

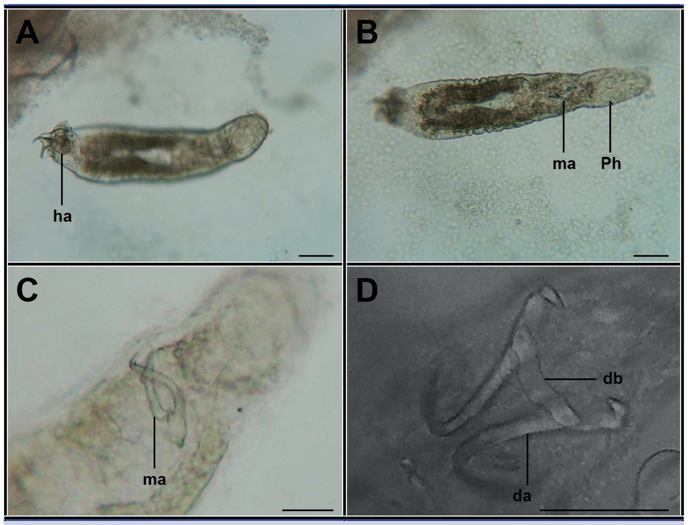


**Figure 1**. *Thaparocleidus caecus* recovered from the gills of *Pangasianodon hypophthalmus* A) ha: haptoral armature B) ma: male apparatus, ph: pharynx C) ma: male apparatus D) da: dorsal anchor, db: dorsal bar (scale bar = A,B:100 µm; C,D: 50 µm).

Of the quantitative parasite descriptors of *T. caecus* in *P. hypophthalmus*, the prevalence was found to be 28% and mean intensity 37.73± 10.15 (Table 1).

**Table 1.** The prevalence and mean intensity of *T. caecus* recovered from the gills of *P. hypophthalmus.*

| Host fish species | Parasite species | Examined Fish Number | Prevalence (%) | Mean Intensity (MI±SE) |
|---|---|---|---|---|
| *P. hypophthalmus* | *T. caecus* | 54 | 28 | 37.73±10.15 |

(MI: mean intensity, SE: standart error)

*T. caecus* (Dactylogyridae) described in the gill filaments of freshwater iridescent shark-catfish, *P. hypophthalmus* has been imported into Turkiye from Asia. The literature exists for the parasite species described here and its host. Monogeneans from Pangasiidae with their morphological and molecular characteristics were previously reported by Lim, Timofeeva, & Gibson (2001), Pariselle, Lim, & Lambert (2006), Thuy & Buchmann (2008), Šimková, et al. (2013), Chaudhary et al. (2014), Tripathi, Rajvanshi, & Agrawal (2014). The *Thaparocleidus* species are gill monogeneans showing host specific character for the Siluriform group of fish (Lim, 1996).

The *Thaparocleidus* species found in different Pangasiidae (Siluriformes) were described in detail by Pariselle, Lim, & Lambert (2005) and Pariselle, Lim, & Lambert (2006). The prevalence of *T. caecus* found in *P. hypophthalmus* showed similarity with the record of prevalence for *T. caecus* exists in the same fish in India (Tripathi, Rajvanshi, & Agrawal, 2014).

The morphological characteristics of *T. caecus* were four granulated eyespots, an elongated body, a circular pharynx, a male capulatory organ, a dorsal anchor larger than the ventral anchor, 14 marginal hooklets and a v-shape ventral bar (Figure 1). The total body length and width of *T. caecus* were measured to be 772.55±31.13 µm and 153.88±9.87 µm, respectively. The morphometric data on the parasite are presented in Table 2.

**Table 2.** Morphometric data of *Thaparocleidus caecus* in *Pangasianodon hypophthalmus*.

| Characters measured (µm) | (Mean±SE) (Min-Max) |
|---|---|
| **Body** | |
| Total body length | 772.55±31.13 (614,11-992,28) |
| Total body width | 153.88±9.87 (60,82-197,71) |
| Pharynx diameter | 74.17±2.65 (71-79) |
| **Male apparatus** | |
| Male capulatory organ lenght | 64.19±3.13 (58-71.25) |
| Male accessory piece | 46.39±3.46 (40-56) |
| **Dorsal anchor** | |
| Dorsal anchor length | 54.53±4.87 (47-64) |
| Dorsal anchor width | 11.35±0.38 (11-12) |
| Dorsal bar length | 46.30±1.56 (44.74-47.86) |
| **Ventral anchor** | |
| Ventral anchor length | 28.88±0.42 (28-29) |
| Ventral bar length of one side | 29.07±1.42 (28-30) |

Morphometric characters measured are given in mean (µm) ±SE (standard error) followed by minimum-maximum (Min-Max) values in parentheses.

The morphological structure and morphometric data of the male copulatory organ and attachment organ are considered important criteria in the species identification of *Thaparocleidus* (Šimková, et al., 2013). In our study, the measured data of attachment parts including anchors (ventral and dorsal) and the male copulatory organ size were within the ranges of previous reports on *T. caecus* by Mizelle & Kritsky (1969), Lim (1990), Tripathi, Rajvanshi, & Agrawal (2014) and Chaudhary et al. (2014). The morphology of *T. caecus* assessed in this study also complies with these previous studies.

In the genetic analysis, the Basic Local Alignment Search Tool (BLAST) showed a 99% sequence similarity for species identification of *T. caecus*. A nucleotide composition analysis indicated 46.7% QC. The nucleotide sequence of *T. caecus* identified in this study was recorded in GenBank under the accession number MK464252. All of the confirmed positive *T. caecus* amplicons were 99% homologous to *T. caecus ITS1* GenBank sequences (FJ493153). Thus, the genetic analysis of *T. caecus* was previously documented by Šimková, et al. (2013), Chaudhary et al. (2014) and Tripathi, Rajvanshi, & Agrawal (2014).

Our results concluded that the parasites are continuously being transferred between various locations in the World with the route of the aquarium fish trade. The pathogens spreading to new areas with the host's movement is undoubtedly recognised. Ultimately, it is not a new problem but it does seek new solutions. Evidentially, *T. caecus* in *P. hypophthalmus* is being reported to be transferred to Turkiye for the first time with this study. Więcaszek et al. (2009) stated that monogenoid parasites found on Pangasiids imported from South-Asia to Europe have no potential threat due to their narrow host specificity. However, Tripathi (2014) highlighted the invasive potential of parasitic monogenoids including the *Thaparocleidus* species via the aquarium fish trade.

## CONCLUSION

The detection of *T. caecus* in *Pangasianodon hypophthalmus* imported into Turkiye demonstrated that the parasite transfer within the ornamental fish trade is a challenging issue in relation to parasite dispersal between countries. Diversification of *Thaparocleidus,* associated with a host changeover, is a potential risk for the native fish of Turkiye. Considering the possible dangers of parasite transfer to native host populations and aquaculture, much more emphasis should be given on studies to assess the actual impact of the parasites on different fish species. The ornamental fish trade is a serious threat for parasite movement thus, a new strategy for "pre-border controls" to prevent parasites spreading via the aquarium fish trade should be developed.

**Conflict of interests:** Authors declare that there is no conflict of interest regarding the publication of this paper.

**Ethics committee approval:** The study protocol for fish was approved by Ankara University, Animal Ethical Committee (No:2015-12-136). Animals (fish) were handled according to the international animal ethical rules.

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