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# TURKISH JOURNAL OF **MARITIME** AND **MARINE** SCIENCES

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*Research Article*
Turkish Journal of Maritime and Marine Sciences

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# Length-weight relationships, growth parameters, mortality and condition factor of Atlantic bonito (*Sarda sarda* Bloch, 1793) from the Southern Black Sea

# Güney Karadeniz'de yayılış gösteren Palamut Balığı (*Sarda sarda* Bloch, 1793)'nın boy-ağırlık ilişkileri, büyüme parametreleri, ölüm oranları ve kondisyon faktörü

Türk Denizcilik ve Deniz Bilimleri Dergisi

Cilt: 11 Sayı: 1 (2025) 1-13

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## ABSTRACT

The small tuna known as the Atlantic bonito (*Sarda sarda*) is one of the most important fishery species on the Black Sea coast of Türkiye. In this study, we sought to define some population parameters of Atlantic bonito based on indirect ageing using length frequency distributions. The aim of this study is to provide data that will serve the management of the bonito fishery. For analysis, the ELEFAN routine in the LFDA and FiSAT programs was utilized. During the migration period, we collected 2110 samples from purse seine (n=1009), gillnet (n=867) and hand lines (n=234) fishing in the Black Sea waters of Türkiye. The fork length varied between 13.1 and 60 cm, and the female-to-male ratio was 1:0.79. The length-weight relationships (LWRs) were calculated $W=0.0037FL^{3.3784}$ and Fulton's K:1.01±0.001. The growth was found to be positive allometric (Student's t-test, $p < 0.05$). von Bertalanffy Growth Parameters (VBGP) were computed as $L\infty$:71.59 cm, K:0.56 year-1, t0:-0.18 year. The seasonal oscillation in growth rate was calculated (C: 0.98) and winter point (WP): 0.54, growth performance index of Ø': 3.46, natural mortality (M: 0.74 $yr^{-1}$), fishing mortality (F: 2.81 $yr^{-1}$), total mortality (Z: 3.55 $yr^{-1}$) and exploitation coefficient (E: 0.79 $yr^{-1}$). As a result, the exploitation rate of *S. sarda* in the study area was found to be high.

**Keywords:** *Sarda sarda*, Black Sea, LFDA, ELEFAN, Condition factor, Growth parameters.

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## ÖZET

Atlantik palamudu olarak bilinen küçük orkinoslardan *Sarda sarda*, Türkiye'nin Karadeniz kıyılarının en önemli balıkçılık türlerinden biridir. Bu çalışmada, boy frekans dağılımları kullanılarak boya dayalı olarak palamut balığının bazı popülasyon parametrelerini tanımlamaya çalışıldı. Bu çalışmanın amacı palamut balıkçılığının yönetimine hizmet edecek sonuçlar sağlamaktır. Çalışmada verilerin analizi için LFDA ve FiSAT programlarındaki ELEFAN rutini kullanıldı. Palamut balığının Türkiye'nin Karadeniz sularında göçü boyunca gırgır (n=1009), uzatma ağları (n=867) ve olta (n=234) ile avlanan 2110 örnek toplanıldı. Örneklenen bireylerin çatal boyu 13,1 ile 60 cm arasında değişmekte olup, dişi/erkek oranı 1:0,79'dur. Boy-ağırlık ilişkileri (LWRs) $W=0{,}0037FL^{3{,}3784}$ ve Fulton's K:1,01±0,001 olarak hesaplanmıştır. Çalışma sonucunda büyümenin pozitif allometik olduğu bulunmuştur (Student's t-test, $p < 0{,}05$). von Bertalanffy Büyüme Parametreleri (VBGP) L∞:71,59 cm, K:0,56 $yıl^{-1}$, t0:-0,18 yıl olarak hesaplanmıştır. Büyüme oranındaki mevsimsel salınım (C: 0,98) ve kış noktası (WP): 0,54, Ø' büyüme performansı indeksi 3,46 olarak hesaplanmıştır. Doğal ölüm (M: 0.74 $yr^{-1}$), balıkçılık ölüm (F: 2,81 $yr^{-1}$), toplam ölüm (Z: 3,55 $yr^{-1}$) ve sömürü katsayısı (E: 0,79 $yr^{-1}$) olarak hesaplanmıştır. Çalışma sonucunda Karadeniz boyunca *S.sarda*'da işletme oranının yüksek olduğu tespit edilmiştir.


**Anahtar sözcükler**: *Sarda sarda,* Karadeniz, LFDA, ELEFAN, Kondisyon faktörü, Büyüme parametreleri.

## 1. INTRODUCTION

The small tuna known as the Atlantic bonito (*Sarda sarda,* Bloch, 1793) belongs to the Scombridae family (URL-1, 2023). It inhabits schools along the neritic area and can enter estuaries. Its distribution encompasses large temperate and tropical regions in the Atlantic, Gulf of Mexico, Black Sea, and Mediterranean on both hemispheres (URL-2, 2024). It grows rapidly and has a short lifespan. According to Cayré *et al*. (1993), *S. sarda* can grow up to a maximum fork length of 91.4 cm and a maximum weight of 11 kg. *S. sarda* has a high commercial value and has been an important top predator in the Black Sea basin (Prodanov *et al.* 1997; FAO 2013; Cengiz 2013). *S. sarda* has primarily been caught along the Turkish Black Sea coastlines since 1950 (Prodanov *et al.,* 1997). According to reports dating back over sixty years (STECF, 2014), almost all of the *S. sarda* caught in the Black Sea comes from Turkish waters. However, long-term data indicate significant fluctuations in Black Sea *S. sarda* landings in Türkiye (Figure 1).

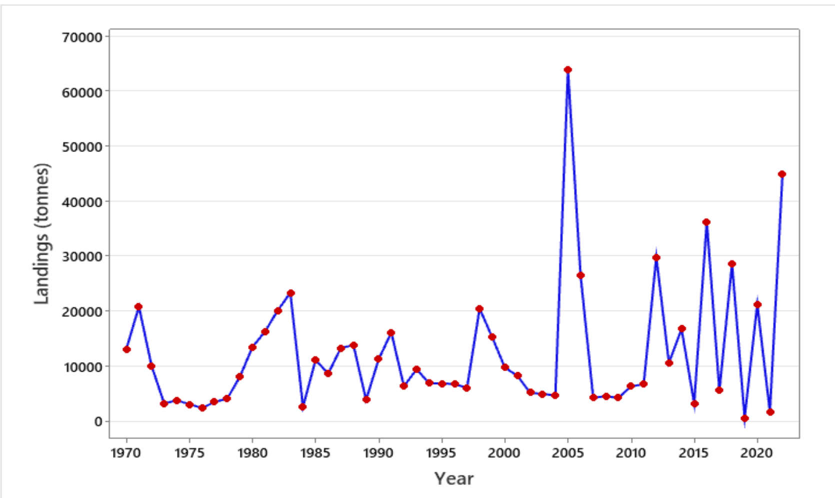


**Figure 1.** The landings of *S. sarda* on the Turkish coasts of the Black Sea (TURKSTAT, 2022)

It is seen that the world fisheries production of *S. sarda* caught in Türkiye was around 40% between the years 1950-2011. According to TURKSTAT (2022), approximately 75% of Türkiye's *S. sarda* comes from the Black Sea, even though this fish species is widely distributed and can be found in the Aegean, Mediterranean, Black, and Marmara seas. The fish migrate back to the Marmara and Aegean Seas to spend the winter after entering the Black Sea in the spring and feeding there until late autumn. During its migrations to the Black Sea, *S. sarda* primarily feeds on anchovies and horse mackerel, sprat, and other fish species to a lesser extent (Genç *et al.,* 2019). Age determination, growth, fecundity, feeding habits, reproductive biology, and genetics of *S. sarda* have been studied several researchers (Nümann, 1954; Demir and Demir, 1961; Tanakol *et al*., 1999; Zengin *et al*., 2005; Ateş *et al.,* 2008; Cengiz 2013; Kahraman *et al.,* 2014; Turan *et al*., 2015; Samsun *et al*., 2017; Genç *et al.,* 2019). The biology of *S. sarda* and other small tuna species is poorly understood in many regions. Research on these species is rare due to the difficulty of sampling small-scale fisheries, which constitute a large proportion of small tuna source fisheries (ICCAT 2000). Therefore, investigations should be conducted at the local or sub-area scale (Zaboukas *et al.,* 2006). This study aims to determine some population parameters of *S. sarda* in the Southern Black Sea during its migration period. The findings of this study are expected to help with the stock assessment of this species and the management of fisheries in the region.

## 2. MATERIALS AND METHODS

The study area was from Hopa (Artvin) to İğneada (Kırklareli), (latitude: 41.52414 E, 41.51670 N, longitude: 41.94051 N, 28.14820 E). Samples were taken at random from ports in the Black Sea during the *S. sarda* fishing season between July 2012 and February 2013 (Figure 2).

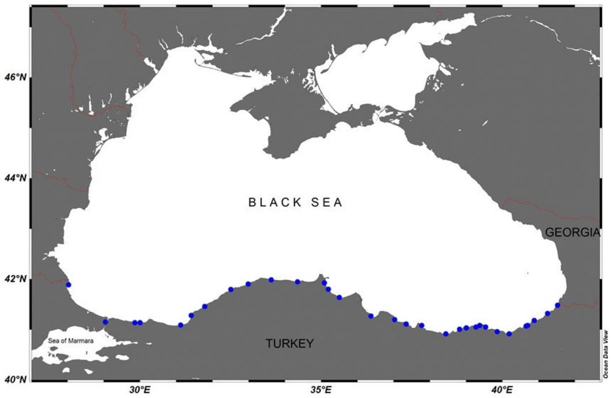


**Figure 2.** Sampling stations in the study area between Hopa and İğneada on the Turkish Black Sea coast

The fish sampled were caught using commercial purse seine boats (mesh size: 32 mm) and gillnet boats (mesh size: 64–88 mm). For every specimen, measurements of the fork length (FL, sensitivity 0.1 cm) and total body weight (TW, sensitivity 0.1 g) were taken. After the gonads were extracted, they were weighed (0.01 g), and a macroscopical determination of the sex was made (Macías et al., 2005). There were 2110 individuals in the *S. sarda* sample in total. The following equation was used to look at the length-weight relationships of *S. sarda* (Le Cren, 1951).

$$W = aFL^b \quad (1)$$

where FL refers to fork length (cm), W refers to total body weight (g), a: intercept, and b: slope are the regression coefficients. Regression analysis was used to find the values a and b and to figure out the growth pattern for the length and weight. Based on the estimated 'b' value, it was concluded that the growth was either allometric [($ts = (b-3) / Sb$) Sokal and Rohlf, 1987] or isometric ($H_0$, b = 3). In this formula, ts is the student t-test value, $b$ is the slope, and Sb is the standard error of the "b" value. The chi-square test was used to examine the overall sex ratio, and an independent-samples t-test was utilized to look for any potential significant differences in the mean length of males and females (Zar, 1996). Utilizing R for statistical analysis, a significance level of 0.05 was chosen (URL- 3, 2023). The Fulton's condition factor (K) was obtained from $K = 100 x W / L^3$ where W and FL stand for total weight and fork length. The von Bertalanffy growth (VBG) equation is used in various manners. The VBG equation, as given by Somers (1988), was used to define seasonal growth.

$$L_t = L_\infty \left[ 1 - e^{\left[ -K(t-t_0) + \left( C\frac{K}{2\pi} \right) sin2\pi(t-t_s) - \left( C\frac{K}{2\pi} \right) sin2\pi(t_0-t_s) \right]} \right] \quad (2)$$

where,
$L_\infty$ = the asymptotic fork length (cm),
K= the growth coefficient ($year^{-1}$),
$t_0$= the nominal age at which the fork length is zero,
$L_t$= the fork length at age t (cm),
C is the oscillations' amplitude. The equation has no seasonal variation when C=0 when, during the low growth season, C=1 growth becomes zero. ts is the beginning time of the sinusoidal growth oscillation. Here, WP (winter point), the time of year when growth is at its slowest, was substituted for ts, with WP = ts+0.5. Due to the ELEFAN only estimating two of the three growth parameters ($L_\infty$ and K), we used Froese and Binohlan's (2003) empirical equation for growth fitting to calculate the third parameter ($t_0$).

$$log(-t_0) = -0.3922 - 0.2752 \times logL_\infty - 1.038 \times logK \quad (3)$$

Seasonal VBG curves were fitted to the length distributions to provide the best goodness of fit values (Rn). The formula Rn= (10 ESP/ASP)/10 was used to calculate the quality of fit. ESP stands for the explained sum of peaks, the total of all the peaks and troughs that the VBG curve has hit. The best values of the available peaks are added to determine the available sum of peaks, or ASP. $T_{max}$ formula, as mentioned earlier, estimates the maximum age of fish based on growth parameters. The formula often referenced in this context is (Ricker,1975):

$$Tmax = t0 + 0.2996 / K \quad (4)$$

Where:
$T_{max}$: Maximum age of the fish
$t_0$: Theoretical age at which the fish's length is zero,
K: Growth coefficient from the von Bertalanffy growth model.

The length data analysis was fitted to length-frequency distributions grouped in 2 cm fork length size classes using the ELEFAN procedure in the based computer package, The Length Frequency Distribution Analysis (LFDA), version 5.0 (Kirkwood *et al*., 2001). It preferred this method instead of using L and K separately when comparing the phi prime index (Φ') of *S. sarda* (Pauly and Munro, 1984). This parameter made this equation.

$$\Phi' = log(K) + 2 log(L_\infty) \quad (5)$$

The instantaneous natural mortality coefficient (M) was determined using Pauly's (1980) empirical model as follows:

$$lnM = -0.0066 - 0.279 lnL_\infty + 0.6543 lnK + 0.463 lnT \quad (6)$$

in which T is the annual mean temperature of the environment in degrees Celsius (16 °C), (URL-4). The instantaneous total mortality coefficients were calculated by applying the length-converted catch curve developed by Pauly (1990) and Pauly *et al*. (1995) using the length-frequency data (Z). The fishing mortality ($F = Z - M$) is represented by the formula F * $Z^{-1}$, which equals the exploitation ratio (E).

## 3. RESULTS

A sample of 2110 *S. sarda* specimens—576 males, 730 females, and 804 undetermined formed the basis of the current investigation. In this study, the presence of individuals at the juvenile stage in some cases, along with the fact that certain specimens were not bought, resulted in the collection of only length and weight data at the point of landing. Consequently, this has led to a higher number of specimens for which sex could not be determined. Overall FL ranged from 13.2 to 60.8 cm (mean length: 29.78±0.13 cm), and total W ranged from 26.92 to 3950 g (mean weight: 419.28±7.1 g). Furthermore, 730 females measuring 13.2 to 40.0 cm (mean:

27.84±0.22 cm), 576 males measuring 13.6 to 37.9 cm (mean: 27.33±0.24 cm), and 804 unidentified specimens measuring 24.5 to 60.8 cm (mean: 33.28±0.17 cm) were examined (Table 1; Figure 3).

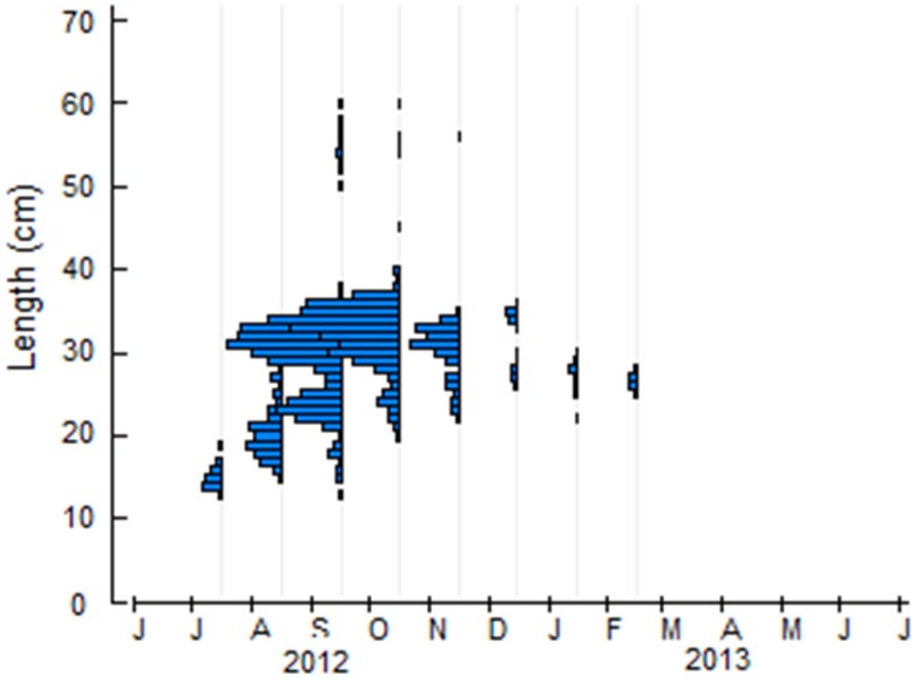


**Figure 3.** Length frequency distribution of the *S. sarda*, during migration periods in landings on the Turkish Black Sea Coast

**Table 1.** The number of individuals, mean fork length (cm), weight (g) and condition factor (K) by months in the 2012-2013 fishing season

| Months | N | FL [Mean±S.E, (min-max)] | W [Mean±S.E. (min-max)] | Condition factor (K) [Mean±S.E, (min-max)] |
|---|---|---|---|---|
| July-2012 | 47 | 15.53±0.19(*13.2-19.8)* | 41.77±1.91(27.22-89.53) | 1.04±0.01(0.86-1.23) |
| August-2012 | 187 | 20.74±0.21(15.4-28.9) | 116.76±4.28(37.4-313.33) | 1.05±0.01(0.91-1.34) |
| September-2012 | 808 | 29.62±0.21(13.6-60.8) | 415.62±13.88(26.92-3950) | 1.02±0.001(0.82-1.36) |
| October-2012 | 776 | 32.75±0.14(20.3-59.8) | 532.45±9.32(97.84-3750) | 1.02±0.001(0.81-1.3) |
| November-2012 | 211 | 30.78±0.24(22.5-56.6) | 401.5±14.38(133.75-2850) | 0.96±0.01(0.76-1.18) |
| December-2012 | 38 | 31.97±0.56(26.2-36) | 447.95±27.43(210.76-665) | 0.94±0.01(0.79-1.07) |
| January-2013 | 21 | 27.4±0.38(22.9-30.1) | 261.39±11.99(132-350) | 0.97±0.01(0.87-1.09) |
| February-2013 | 22 | 26.95±0.17(25.6-28.4) | 211.43±4.77(165.98-258.82) | 0.84±0.01(0.76-0.92) |
| Total | 2110 | 29.78±0.13(13.2-60.8) | 419.28±7.1(26.92-3950) | 1.01±0.01(0.76-1.36) |

The one-way ANOVA revealed that monthly mean lengths varied significantly. (F=213.43; df=7, $p$ <0.05). Table 1 and Figure 4 demonstrate the mean FL, mean W and Fulton's K values for all samples.

The sample contained more females than males (sex ratio 1:0.79). Females dominated almost all length classes when sex ratios varied with length class. Females had a mean weight of 332.87±7.47 g, and males had a weight of 314.34±8.22 g. The difference between the length distribution of males and females was insignificant. Female and male Fulton's condition factors ranged from 0.76 to 1.29 (with a mean of 1.01±0.08)–and 0.76 to 1.34 (with a mean of 1.01±0.08), respectively. In February 2013, the lowest average monthly Fulton's K values for the males and females were stated. Established in July 2012, the highest average monthly Fulton's K values were noted. Between the sexes, there were no statistically significant differences (H=1.48; df=1, $p$=0.22). All specimens were determined that the values of a and b were 0.0037 and 3.3784, respectively. The relationship between the two variables was significant ($p$ < 0.05). Furthermore, positive allometric growth was noted, and the t-test indicated no significant differences ($p$ >0.05) between the slopes ($b$) estimated for males and females (Table 2).

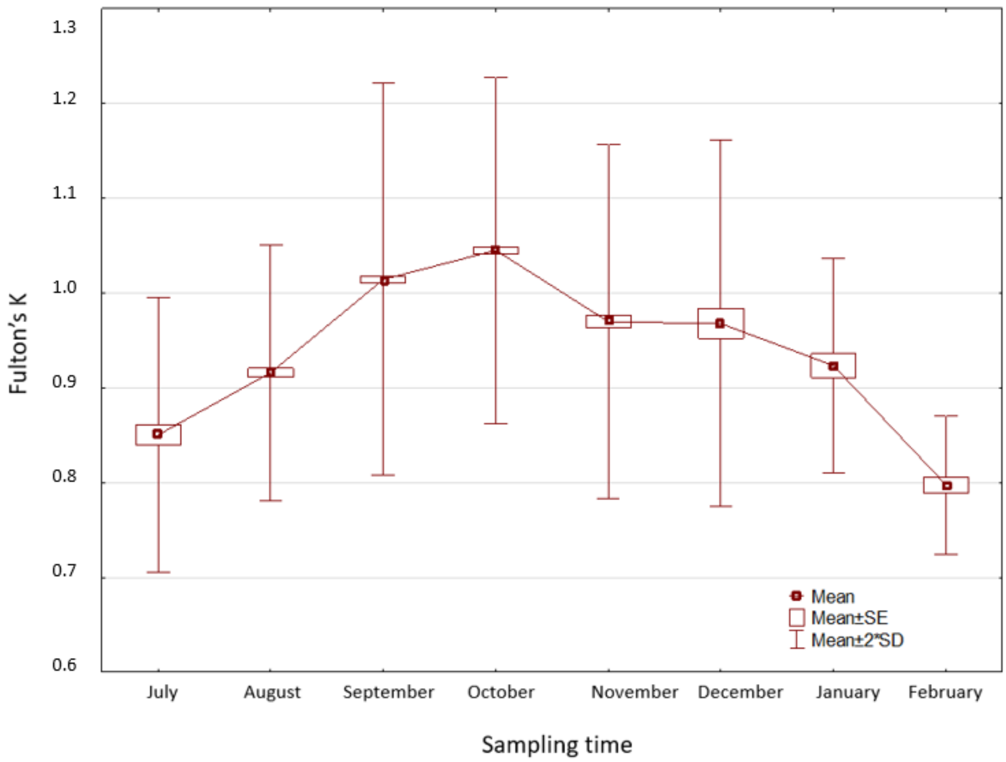


**Figure 4.** Monthly changes in the mean Fulton's condition factor estimated in *S. sarda*

**Table 2.** Parameters of the length-weight relationship of *Sarda sarda* in the 2012-2013 fishing season (N: sample size, FL: Fork Length (cm), SE: standard error, CI: confidence interval, *a*: intercept, *b*: slope, $r^2$: determination coefficient)

| Sex | N | $FL_{min}$–$FL_{max.}$ | $W_{min}$–$W_{max.}$ | Length-weight relationship | | | |
|---|---|---|---|---|---|---|---|
| | | | | LWR equation | S.E. of *b* (95% CI of *b*) | $r^2$ | Growth Type |
| F | 730 | 13.2-40.0 | 27.2-947.5 | $W=0.0039L^{3.3621}$ | 0.013(3.337-3.388) | 0.989 | Allometric (+) |
| M | 576 | 13.6-37.9 | 26.5-887.0 | $W=0.0040L^{3.3604}$ | 0.015(3.331-3.390) | 0.989 | Allometric (+) |
| Unidentified | 804 | 24.5-60.8 | 172.0-3950.0 | $W=0.0035L^{3.3962}$ | 0.021(3.354-3.438) | 0.970 | Allometric (+) |
| All | 2110 | 13.2-60.8 | 26.9-3950 | $W=0.0037L^{3.3784}$ | 0.008(3.363-3.394) | 0.989 | Allometric (+) |

The seasonalized VBG curve with the following parameters was obtained by the ELEFAN analysis: $L_\infty$: 71.59 cm, K: 0.56 year$^{-1}$, $t_0$: -0.18, C: 0.97, and WP: 0.54. Figures 5 demonstrate *S. sarda*'s growth patterns. The lifespan and phi prime index of *S. sarda* was calculated to be 3.46 and $t_{max}$: 5.17 years, respectively. Table 3 shows the FL and W data for both sexes according to fishing season. The sex ratio was 1:0.79, favouring females, and there was a significant difference between the sexes ($\chi2$= 18.159; df= 1; p < 0.001).

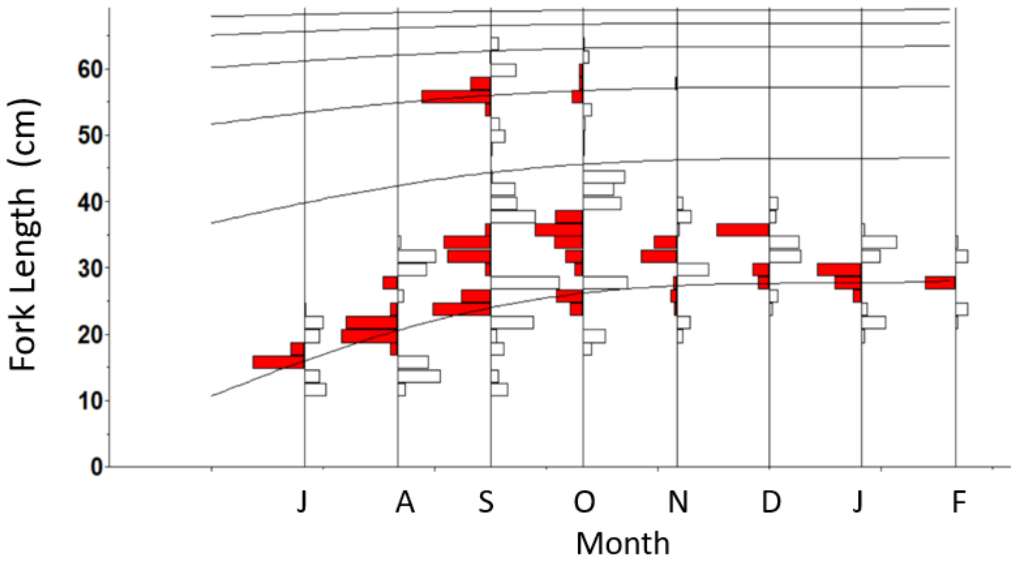


**Figure 5.** Seasonal growth curves superimposed on the restructured length-frequency histogram of *S sarda* (Bloch, 1793) (parameters: $L_\infty$ = 71.*59* cm Fork length, $K$ = 0.*56* year$^{-1}$ $t_0$= -0.18 year$^{-1}$, C = 0.97, winter point (WP) = 0.54)

**Table 3.** The monthly changes in male and female average length, weight, and female-male ratio in *S.sarda*

| Months | Female | | | Male | | | Number (F+M) | F:M | $\chi2_{est}$ | $\chi2$ test ($p$=0.05) |
|---|---|---|---|---|---|---|---|---|---|---|
| | N | $FL_{mean}$ | $W_{mean}$ | N | $FL_{mean}$ | $W_{mean}$ | | | | |
| July | 29 | 15.71 | 43.92 | 18 | 15.23 | 38.32 | 47 | 1:0.62 | 2.57 | 0.1086 |
| August | 91 | 20.19 | 103.51 | 84 | 20.38 | 107.84 | 175 | 1:0.92 | 0.28 | 0.5967 |
| September | 320 | 28.34 | 335.78 | 234 | 27.73 | 318.84 | 554 | 1:0.73 | 13.35 | 0.0003 |
| October | 222 | 31.8 | 480.39 | 186 | 31.23 | 450.38 | 408 | 1:0.84 | 3.18 | 0.0747 |
| November | 36 | 28.3 | 287.26 | 28 | 26.86 | 242.48 | 64 | 1:0.78 | 1.00 | 0.3173 |
| December | 7 | 28.67 | 271.41 | 8 | 27.56 | 245.76 | 15 | 1:1.14 | 0.07 | 0.7963 |
| January | 11 | 27.69 | 270.83 | 10 | 27.08 | 251.01 | 21 | 1:0.91 | 0.05 | 0.8273 |
| February | 14 | 27.00 | 213.16 | 8 | 26.88 | 208.39 | 22 | 1:0.57 | 1.64 | 0.2008 |
| **Total** | **730** | **27.84±0.216** | **332.87±7.468** | **576** | **27.33±0.24** | **314.34±8.22** | ***1306** | **1:0.79** | **18.159** | **0.00002** |

*The gender of all 2110 individuals sampled was not examined.

Total mortality determined by using the length-converted catch curve (n=2110) produced a result of Z = 3.55 year$^{-1}$ ($a$=14.86, $b$=3.545; $R^2$=0.9883, n=4), confidence interval of Z = 2.37–4.72. The fishing mortality (F) was found to be 2.81 year$^{-1}$. Natural mortality (M) was estimated at 0.74 year$^{-1}$, according to the predicted exploitation rate of 0.79.

## 4. DISCUSSIONS

This study's findings indicated that the estimated length-weight relationship $W = 0.0037FL^{3.3784}$. The estimated slopes ($b$) for males and females did not differ significantly, according to the t-test, and positive allometric growth was also seen (Student's t-test $p < 0.05$). Similar findings were also reported by several other studies (Ret *et al.*, 1984; Oray *et al.,* 2004; Cengiz, 2013; Yankova, 2015; Kahraman *et al.*, 2014), while others reported contrasting results (Kara,1979; Rodriguez-Roda, 1966; Di Natale *et al.*, 2006) (Table 4). Several factors, which include the time of year, temperature, nutrition, surroundings, stomach fullness, age, maturity level, and sex, may affect the LWR parameters (Bagenal and Tesch, 1978).

**Table 4.** Comparison of the length-weight relationship estimated from previous studies for *Sarda sarda* (a: intercept, b: slope)

| Source | Area | N | $L_{min}$-$L_{max}$ | A | B |
|---|---|---|---|---|---|
| Dardignac,1962 | Atlantic (Morocco) | - | - | 0.0797 | 3.143 |
| Kara, 1979 | Turkish Black Sea and Sea of Marmara | 1608 | 14-90 | 0.0236 | 2.870 |
| Rodriguez-Roda, 1966 | West Mediterranean Sea, Spain | 165 | 40.0-55.0 | 0.0148 | 2.972 |
| Rey *et al.,* 1984 | West Mediterranean Sea, Spain | 878 | 19.0-72.0 | 0.0072 | 3.164 |
| Di Natale *et al.,* 2006 | Tyrrhenian coast, Italy | 240 | 35.0-82.0 | 0.0003 | 2.83 |
| | Sicilian coast, Italy | 109 | 35.0-67.0 | 0.0004 | 2.18 |
| Francevic et al., 2005 | Coast of the Adriatic Sea | 665 | 33.0-67.0 | 0.0085 | 3.123 |
| Oray *et al.,* 2004 | Turkish Black Sea and Sea of Marmara | 1168 | 23.0-66.0 | 0.0039 | 3.32 |
| Ateş *et al.,* 2008 | Turkish Black Sea and Sea of Marmara | 694 | 23.5-71.0 | 0.0054 | 3.215 |
| Cengiz, 2013 | Northern Aegean Sea | 238 | 23.8-72.0 | 0.0028 | 3.32 |
| Yankova 2015 | Black Sea, Bulgaria | 411 | 27.0-72.0 | 0.0028 | 3.22 |
| Kahraman *et al.,* 2014 | Turkish Black Sea and Sea of Marmara | 212 | 17.7-63.0 | 0.01 | 3.085 |
| Present study | The Black Sea coast of Türkiye | 2110 | 13.1-60 | 0.0797 | 3.3784 |

This VBG equation, K: 0.56, L∞: 71.59 cm, C: 0.97, and WP: 0.54, describes the growth curve of *S. sarda.* Using Pauly's (1980) formula, the maximum longevity ($t_{max}$) was determined to be 5.17 years. During its first year of life, *S. sarda* in the Black Sea grew quickly, reaching 38 cm FL in just four or five months. VBG parameters for *S. sarda* were estimated in different areas, shown in Table 5, and the results of the studies carried out in various seas are given.

**Table 5.** Comparison of von Bertalanffy growth parameters and growth performance indices estimated from previous studies for *S. sarda*

| **Reference** | **Growth parameter** | | | **Ø** | **Area** |
|---|---|---|---|---|---|
| | $L_\infty$ (cm) | k | $t_o$ | | |
| Zusser (1954) | 103.0* | 0.132 | –1.80 | 3.15 | Black Sea, Russia |
| Nümann (1955) | 67.8* | 0.79 | - | 3.56 | Turkish Black Sea |
| Majarova and Tkacheva (1959) | 81.5* | 0.525 | - | 3.54 | Turkish Black Sea |
| Nikolsky (1957) | 81.5* | 0.52 | - | 3.54 | Turkish Black Sea |
| Türgan (1958) | 64.0* | 0.86 | - | 3.55 | Turkish Black Sea |
| Nikolov (1960) | 95.6* | 0.24 | –1.24 | 3.34 | Black Sea, Bulgaria |
| Dardignac (1962) | 64.0* | 0.69 | –1.42 | 3.45 | Atlantic, Morocco |
| Kutaygil (1967) | 95.6* | 0.237 | -1.24 | 3.34 | Turkish Black Sea |
| Rey *et al.* (1984) | 80.8* | 0.35 | –1.70 | 3.36 | West Mediterranean Sea, Spain |
| Santamaria *at al. (*1998) | 80.6** | 0.36 | -1.37 | 3.37 | Ionian Sea |
| Zaboukas and Megalofonou (2007) | 82.9** | 0.24 | –0.77 | 3.22 | Greece |
| Valeiras *et al.* (2008) | 62.5* | 0.719 | -1.21 | 3.45 | Ionian Sea |
| Ateş *et al.* (2008) | 68.0* | 0.82 | –0.39 | 3.58 | Turkish Black Sea and Sea of Marmara |
| Cengiz (2013) | 69.8* | 0.76 | –0.44 | 3.57 | Northern Aegean Sea |
| Kahraman *et al* (2014) | 67.9* | 0.46 | –1.22 | 3.33 | Turkish Black Sea and Sea of Marmara |
| Yankova (2015) | 80.4** | 0.67 | -0.34 | 3.64 | The Black Sea coast of Bulgaria |
| Petukhova 2020 | 75.6* | 0.41 | | 3.37 | Black Sea (Russian Fed coast) |
| **Present study** | **71.59*** | **0.56** | **-0.18** | 3.46 | The Black Sea coast of Türkiye |

*Fork length, **Total length

In addition, the phi-prime value (Φ') from the current study did not differ significantly from that of previous studies (t-test -0.857, df:15, *p* >0.05). However, the sex distribution of *S. sarda* was determined and compared with other studies. (Table 6). As seen in Table 6, other studies, except for Ateş *et al.* (2008), found the frequency of females to be higher than males in the population.

Typically, the condition factor is used to compare the health, fatness, or condition of marine species. Its foundation is the theory that larger fish of a particular length have a higher physiological condition (Bagenal and Tesch. 1978). Fish condition factor (K) usually ranges from 0 to 2, with a normal fish's mean value being close to 1 (Heincke 1908). For both *S. sarda* sexes in this investigation, the K was quite near to 1.0. It is known that the condition factor of many fish species in the Black Sea is far below 1.0 (Dağtekin *et al*., 2022). Nonetheless, K that strongly correlates with a species's fat content, sex, size, season, and level of gonad development (Froese 2006). This is one way to express how this species is affected by generational migration. From mid-July onwards, the first juveniles of 10-15 cm in length and 30-50 g in weight enter the Black Sea and exhibit a rapid growth.

It is thought that optimum conditions for the species are of great importance here. This will result in a rapid increase in K due to the increase in weight and length. When K was used instead, since the change in condition factor is calculated from length-weight parameters, it is accepted as a more accurate estimate since the effect of fish size is eliminated in the change of condition factor. According to Fulton and K condition values, the condition decreased after October. November is the month in which a large amount of migration takes place of.  A second cohort of individuals come to the Black Sea at the end of the breeding season, and some individuals rarely remain in the Black Sea. They mainly begin to appear in November. When the two cohorts are taken into consideration, the growth curve slope begins to decrease with the entry of the second cohort fish. The study determined a total mortality rate (Z) of 3.55 year$^{-1}$. Notably, this figure indicates a significant contribution of fishing mortality to the overall mortality rate. The natural mortality rate, which accounts for deaths due to natural factors such as predation, disease, and environmental conditions, was found to be 0.74 year$^{-1}$. This disparity between total mortality and natural mortality underscores the substantial impact of fishing activities on the fish population. In this context, the exploitation rate was determined to be 0.79. According to Gulland (1971), this value indicates that the stock is over-exploited. According to Petukhova (2020), the natural mortality rate is 0.695 year$^{-1}$. Our results are typical for short-lived species, as Petukhova (2020) reported.

**Table 6.** Comparison of sex ratio of Atlantic bonito from various regions of the Black Sea and Mediterranean

| Reference | Area | Sex distribution | | | | F:M | $\chi 2_{est}$ | $\chi 2$ test (p=0.05) |
|---|---|---|---|---|---|---|---|---|
| | | Female | Male | Undetermined | Total | | | |
| | | N | N | N | N | | | |
| Ateş *et al*. (2008) | Turkish Black Sea and Sea of Marmara | 62 | 80 | 106 | 278 | 1:1.29 | 2.272 | 0.131 |
| Valeiras *et al. (*2008) | Western Mediterranean, Spain | 77 | 59 | 12 | 148 | 1:0.77 | 2.382 | 0.123 |
| Zaboukas and Megalofonou, (2007) | Eastern Mediterranean (Greece) | 122 | 118 | 157 | 397 | 1:0.97 | 0.067 | 0.796 |
| Kahraman *et al. (*2014) | Turkish Black Sea and Sea of Marmara | 100 | 89 | 23 | 212 | 1:0.89 | 0.640 | 0.424 |
| Nottesdat *et al. (*2013) | North Sea | 40 | 31 | - | 71 | 1:078 | 1.141 | 0.286 |
| Franicevic *et al. (*2005) | Adriatic Sea | 353 | 285 | 27 | 665 | 1:0.81 | 7.248 | 0.007 |
| Zorıca And Sınovčıć, (2008) | Adriatic Sea | 55 | 46 | - | 101 | 1:0.84 | 0.802 | 0.371 |
| Yankova, (2015) | The Black Sea coast of Bulgaria | 298 | 176 | - | 474 | 1:0.59 | 31.401 | 0.000 |
| Fletcher *et. al.,* (2013) | The Northeast Aegean Sea | 69 | 53 | - | 112 | 1:0.77 | 2.098 | 0.148 |
| Cengiz (2013) | The Northeast Aegean Sea | 100 | 82 | 56 | 238 | 1:0.82 | 1.780 | 0.182 |
| This study | The Black Sea coast of Türkiye | 730 | 576 | 804 | 2110 | 1:0.79 | 18.159 | 0.000 |

## 5. CONCLUSIONS

*Sarda sarda* exhibits significant fluctuations in population levels over the years. As noted historically by Demir (1961; 1963), these fluctuations have been documented and characterized, highlighting the dynamic nature of the atlantic bonito populations. Such variations may be influenced by a combination of ecological factors, fishing pressures, and environmental changes affecting their habitats. Understanding these fluctuations is crucial for effective management and conservation strategies for *Sarda sarda.*

According to Turkish Commercial Fishery Regulations 6/1, numbered 32629 (GDAR. 2024), S. *sarda* must measure at least 25.0 cm (TL). Nevertheless, no scientific data has supported this regulation. Therefore, additional studies must be done to precisely figure out *S. sarda*'s minimum landing size. When Exploitation rate (E) is less than 0.50, it suggests that the stock is under-exploited. Conversely, when E exceeds 0.50, the stock is considered over-exploited (Gulland, 1971). This situation can lead to overfishing, resulting in declines in fish populations, and can disrupt the ecosystem as well as economic stability for fisheries. Therefore, we recommend that management measures be taken to prevent the overexploitation of stocks. In addition, continuing to overfish bonito could eventually cause the spawning stock to fall below the levels needed to support the population. There is a need for a comprehensive study to be carried out simultaneously in the Aegean, Marmara, and Black Seas to solve some of the unanswered questions concerning *S.sarda*.

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## AUTHORSHIP CONTRIBUTION STATEMENT

**Yaşar GENÇ:** Conceptualization, methodology, writing-review and editing, data curation, software, project administration, funding acquisition. **Murat DAĞTEKİN:** Conceptualization, methodology, writing-original draft, writing-review and editing, data curation. **Nimet Selda BAŞÇINAR:** Editing and data curation, **Elvan TERCAN:** Data curation.

## CONFLICT OF INTERESTS

The authors confirm that they have no known financial or personal conflicts that would have appeared to impact the research presented in this study.

## ETHICS COMMITTEE PERMISSION

No ethics committee permissions is required for this study.

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# Relationship Between Maritime Transport and Economic Growth: Highest Maritime Transport European Countries

# Deniz Taşımacılığı ile İktidadi Büyüme Arasındaki İlişki: En Yüksek Deniz Taşımacılığına Sahip Avrupa Ülkeleri

Türk Denizcilik ve Deniz Bilimleri Dergisi

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## ABSTRACT

Maritime transport is one of the most widely used transport channels used by countries in foreign trade. The development of maritime transport affects the economic growth levels of countries. In addition, the increase in the level of economic growth of countries increases their share in international foreign trade and this situation increases the importance given by countries to maritime transport day by day. The identification of the effects of maritime transport in countries will provide important information on what countries should do against the shocks they will face in the future. In this context, the study aims to determine whether there is any causality relationship between maritime transport and economic growth variables in Belgium, France, Germany, Italy, Netherlands, Spain, Türkiye, and the United Kingdom, which have the highest maritime transport among European countries. The bootstrap panel causality test was employed to examine the causality relationships between the variables over the time frame of 2008:Q1-2020:Q2. According to the findings, there is a causality relationship from economic growth to maritime transport in all countries except Italy and the Netherlands. There is a causality relationship from maritime transport to economic growth in Türkiye and the United Kingdom. As a result, the relationship between maritime transport and economic growth varies from country to country. This situation reveals the necessity of developing national policies for maritime transport by considering the economic structures of the countries. These findings suggest that countries need more efficient and sustainable maritime transport policies.

**Keywords:** Maritime transport, Freight transportation, Economic growth, European countries

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## ÖZET

Dış ticarette ülkelerin en çok kullandığı nakliye kanallarının başında deniz taşımacılığı gelmektedir. Deniz taşımacılığının gelişimi ülkelerin iktisadi büyüme düzeylerine etki etmektedir. Ayrıca ülkelerin iktisadi büyüme düzeyindeki artışlar, uluslararası dış ticaretten aldıkları payını da artırmakta ve bu durum ülkelerin deniz taşımacılığına verdiği önemi her gecen gün daha da artırmaktadır. Deniz taşımacılığının ülkeler üzerindeki etkilerinin belirlenmesi, ülkelerin gelecekte karşılaşacakları şoklara karşı ne yapmaları gerektiği konusunda önemli bilgiler sağlayacaktır. Bu bağlamda çalışmada, Avrupa ülkeleri arasında en yüksek deniz taşımacılığına sahip olan Belçika, Fransa, Almanya, İtalya, Hollanda, İspanya, Türkiye ve Birleşik Krallık'ta deniz taşımacılığı ile iktisadi büyüme değişkenleri arasında herhangi bir nedensellik ilişkisinin olup olmadığının belirlemesi amaçlanmaktadır. Değişkenler arasındaki nedensellik ilişkileri 2008:Q1-2020:Q2 dönemi verileri ve bootstrap panel nedensellik testi yardımıyla incelenmektedir. Bulgulara göre, İtalya ve Hollanda hariç tüm ülkelerde ekonomik büyümeden deniz taşımacılığına doğru bir nedensellik ilişkisi bulunmaktadır. Türkiye ve Birleşik Krallık'ta ise deniz taşımacılığından ekonomik büyümeye doğru bir nedensellik ilişkisi bulunmaktadır. Sonuç olarak deniz taşımacılığı ile iktisadi büyüme arasındaki ilişkiler ülkeden ülkeye göre değişmektedir. Bu durum ülkelerin kendi ekonomik yapılarını dikkate alarak deniz taşımacılığına yönelik ulusal politikilar geliştirme gerekliliğini ortaya koymaktadır. Bu bulgular, ülkelerin daha verimli ve sürdürülebilir deniz taşımacılığı politikalarına ihtiyaç duyduğunu göstermektedir.


**Anahtar sözcükler**: Deniz taşımacılığı, Yük taşımacılığı, İktisadi büyüme, Avrupa ülkeleri

## 1. INTRODUCTION

International trade and competitiveness of national firms in international markets contribute to economic growth (Grossman and Helpman, 1991; Rivera-Batiz and Romer, 1991; Ayesu *et al*., 2023). Therefore, many countries increase their investments in transportation infrastructure in order to expand their share in international trade to achieve economic growth and development. Banister and Berechman (2001) claim that planned infrastructure investments that integrate alternative transportation channels will both increase domestic trade activity and increase competitive advantage in international trade. Investments in transportation infrastructure also provide external benefits to other sectors of the economy. This, in turn, results in increased economic activity, more employment opportunities, reduced unemployment, and an increase in income levels, contributing to overall economic growth (Barro, 1990). There are many studies in the literature that examine the relationship between the development of transportation infrastructure and economic growth. Most of these studies indicate the impact of investments in highways, maritime harbors, airports and railways on economic growth(Aschauer, 1989; Rephann and Isserman, 1994; Fernald, 1999; Cantos *et al*., 2005; Zhang *et al*., 2005; Yamaguchi, 2007; Anaman and Osei-Amponsah, 2007; Lall, 2007; Fan and Chan-Kang, 2008; Tervo, 2009; Crafts, 2009; Jiwattanakulpaisarn *et al*., 2010; Cohen, 2010; Akbarian and Ghaedi, 2011; Banister and Thurstain-Goodwill, 2011; Chia, 2011; Banister, 2012; Deng, 2013; Badalyan *et al*., 2014; Jaffee, 2015; Park and Seo, 2016; Song and Mi 2016; Jiang *et al*., 2017; Khan *et al*., 2018; Saidi *et al*., 2018; Park *et al*., 2019; Sharif *et al*., 2019; Mudronja *et al*., 2020). According to Brunel (2005), the development of a sophisticated civilization and steady growth have traditionally been regarded as dependent on the transportation industry. Thus, compared to less developed countries, industrialized countries have built and developed their transportation sectors more successfully (Özer *et al*., 2021).

Throughout history, societies separated by long distances have favored maritime transport to maintain social and economic relations with one another (Saeed *et al*., 2021). The liberalization of international commerce has caused a change in shipping routes, particularly since the early

1980s. This has resulted in the creation of new ports and the growth of connection networks for the international trade of commodities (Özer *et al*., 2021). During this period, the maritime sector witnessed the most significant developments (Li and DaCosta, 2013). For landlocked nations, effective and widespread maritime transport has been essential to the expansion of their international trade ties and their overall economic prosperity (Akbulaev and Bayramli, 2020). Due to these advancements, sea transportation has emerged as the main means of conducting international trade and is currently the biggest freight carrier in the world, playing a crucial role in the global economy (Mansouri *et al*., 2015; Özer *et al*., 2021; Saeed *et al*., 2021).

Recent advancements in maritime policies and technological innovations have significantly strengthened the link between maritime transport and economic growth. Research emphasizes the growing importance of digitalization and automation in ports, illustrated by the integration of smart port systems and autonomous shipping technologies, which improve operational efficiency and lower costs in international trade (Rodrigue and Notteboom, 2020; Wu *et al*., 2024). Additionally, the implementation of green shipping practices and policies aimed at reducing carbon emissions has become central to fostering sustainable growth in the maritime sector, with direct implications for economic development (Xylouris *et al*., 2024). These innovations in maritime transport are crucial for creating more competitive and sustainable international trade networks, reinforcing the connections between maritime policies, technological advancements, and economic growth. In light of these developments, maritime transport has emerged as the primary mode of international trade and is now the largest freight carrier, playing a critical role in the global economy. Considering the importance of maritime transport for international trade and economic growth, this study has decided to focus on maritime transport. Maritime transport accounts for over 70% of the value and over 80% of the physical volume of international trade (Li, 2022; United Nations Conference on Trade and Development [UNCTAD], 2023). Roads, highways, and railways play a crucial role in domestic transportation, providing alternative options for both local and international connections. However, they are not always the most practical choice for long distances and can be relatively costly. In contrast, air transport is faster, but when it comes to the long-distance transportation of physical goods, shipping is preferred due to its advantages in terms of both cost and capacity (Berrill, 1960; Saeed *et al*., 2021). Shipping is a popular option for delivering industrial raw materials, petroleum products, and containerized freight across medium and long distances since it offers superior economic efficiency in addition to its cost benefits (Huang *et al*., 2023). European Union, comprised mostly of developed countries, boasts a maritime fleet from 22 member countries, accounting for over 40% of the world fleet (Fratila *et al.*, 2021). The primary reason for developed countries to prioritize maritime transport to this extent is its role as a cornerstone of global trade (Bai *et al*., 2021). Moreover, marine transportation contributes significantly to economic growth and development in addition to its direct and indirect effects on a number of other sectors (Fratila *et al.*, 2021). Furthermore, engaging in international marine trade is essential for drawing in capital from throughout the world (Lane and Pretes, 2020). In this context, the aim of this study is to determine whether there is any causality relationship between maritime transport and economic growth in Belgium, France, Germany, Italy, the Netherlands, Spain, Türkiye, and the United Kingdom, which are among the European countries with the highest maritime transport activities.

Although there are studies examining the relationship between maritime transport and economic growth in the literature, the issue has not been examined comprehensively in the context of European countries. Moreover, some of the current studies include microeconomic analyses (Fratila *et al*., 2021). In this context, considering that a significant portion of global trade is carried out by developed countries through maritime transport (United Nations Conference on Trade and Development [UNCTAD], 2023), studies revealing the relationship between maritime transport and economic growth increase their importance.

Therefore, this study will examine the causality relationships between maritime transport and economic growth in the 8 European countries within the G-20 that have the highest maritime transport volume. The analysis covers the period from 2008: Q1 to 2020: Q2 using the bootstrap panel causality test developed by Kónya (2006). In particular, since the methodology used also takes into account cross-sectional dependence, the effects of economic and political shocks occurring in one of them on each other are not excluded. This study differs from previous research in its contemporary relevance, the selection of the group of countries studied, and the use of the analysis method, which has not been previously employed. These unique aspects of the study strengthen its potential contribution to literature.

In the following sections, literature review, data and methodology, findings and conclusions are presented respectively. The conclusion includes economic, political and theoretical implications.

## 2. LITERATURE REVIEW

The literature on maritime transport encompasses a wide range of research areas, including economic, environmental, logistical, and security dimensions. Among the most studied topics are the contributions of maritime transport to global trade volume and economic growth, with the critical role of sea routes in global supply chains also standing out (Notteboom *et al*., 2022). In addition, port management, logistical efficiency, and digitalization in shipping are prominent research themes in the literature (Notteboom *et al*., 2021). From an environmental perspective, issues such as air and water pollution caused by maritime transport, sustainability, and green port strategies are extensively debated (IMO, 2020). Furthermore, threats like maritime security, piracy, and smuggling are frequently discussed in the literature, focusing on security policies and preventive measures (Bueger, 2015). These studies shed light on the contributions of the maritime sector to economic growth and its role in promoting environmental sustainability.

In this part of the study, we first review the studies that examine the relationship between other transportation channels and economic growth. Then, the studies examining the relationship between maritime transport and economic growth are shown in Table 1.

Although a considerable number of studies in the literature examine the relationship between transportation and economic growth, this topic still maintains its relevance. One of the pioneering studies in investigating this relationship belongs to Fogel (1962). In Fogel's (1962) study, he attributed the rise of the United States at the end of the 19th century to railroad transportation. In subsequent periods, some researchers inspired by this study began to examine the relationships between rail transport and economic growth. Among these researchers, Badalyan *et al*. (2014), Sharipbekova and Raimbekov (2018), Khan *et al*. (2018), and Zou *et al*. (2021) have all found that rail transport leads to economic growth, while Hayaloğlu (2015) determined that economic growth positively influences rail transport. On the other hand, Apanisile and Akinlo (2013) and Otu and James (2015) obtained results that differ from previous studies, suggesting an inverse relationship between the variables. Additionally, Gherghina *et al*. (2018) identified a bidirectional causality relationship between the variables, whereas Sezer and Abasız (2017), Sun *et al*. (2018), and Özer *et al*. (2021) did not observe any causality relationship between the variables.

Several studies in the literature investigate the relationship between road transport and economic growth. Among these researchers, Uma *et al*. (2014), Badalyan *et al*. (2014), Otu and James (2015), Siyan *et al*. (2015), and Clinton *et al*. (2017) have all found that road transport contributes to economic growth. On the other hand, Beyzatlar *et al*. (2014) and Saidi and Hammami (2017) discovered evidence of a bidirectional causality relationship between the variables. However, Sun *et al*. (2018) did not find any significant relationship between road transport and economic growth. Based on the existing studies in the literature, it is apparent that there is a mutual interaction between rail/road transport and economic growth. Most study results support the idea that transport positively impacts economic growth. While a few studies suggest a slightly negative effect of road transport on economic growth, there is also a limited number of findings indicating no relationship between both forms of transport and economic growth.

Many studies have examined the correlation between economic growth and air transport, particularly in the last several years. Most of these studies suggest that air transport contributes to economic growth (Saheed *et al*., 2015; Arvin *et al*., 2015; Baltaci *et al*., 2015, Hu *et al*., 2015; Brida *et al*., 2016a; Sezer and Abasız, 2017; Sharipbekova and Raimbekov, 2018; Khan *et al*., 2018; Gherghina *et al*., 2018; Park *et al*., 2019; Zhang and Graham, 2020; İslamoğlu, 2022; Song *et al*., 2023). A group of researchers has found that economic growth has a positive effect on air transport (Fernandes and Pacheco, 2010; Yao and Yang, 2012; Chi and Baek, 2013; Hayaloğlu, 2015; Hakim and Merkert, 2016; Brida *et al*., 2018). Chang and Chang (2009), Baker *et al*. (2015). Brida *et al*. (2016b) identified a bidirectional causality relationship between economic growth and air transport. Almost all of the past studies consistently indicate a strong relationship between air transport and economic growth. The majority of findings conclude that air transport positively supports economic growth.

Since maritime transport has an important share in international trade, many researchers have investigated the economic effects of maritime transport. The available literature on the relationship between maritime transport and economic growth is presented in Table 1.

**Table 1.** Maritime Transport and Economic Growth

| Study | Periods | Country/Countries | Methodologies | Conclusions |
|---|---|---|---|---|
| **Zhang *et al.* (2005)** | 1995-2003 | The Pearl River Delta Region of China | Cobb-Douglass production function | Maritime → GRW + |
| **Korkmaz (2012)** | 2004-2010 | Türkiye | Regression | Maritime → GRW+ |
| **Igberi and Ogunniyi (2013)** | 1980-2010 | Nigeria | OLS and SUR | Maritime → GRW - |
| **Morrissey and O'Donoghue (2013)** | 2007 | Ireland | Input-output (IO) | Maritime → GRW + |
| **Shan *et al.* (2014)** | 2003-2010 | China | Regression | Maritime → GRW + |
| **Bottasso *et al.* (2014)** | 1998-2009 | 13 European countries | Spatial Autoregressive model (SAR) | Maritime → GRW + |
| **Hayaloğlu (2015)** | 1994-2011 | 32 OECD countries | Panel data method | GRW → Maritime + |
| **Park and Seo (2016)** | 2000-2013 | South Korea | Augmented Solow model | Maritime → GRW + |
| **Tunali and Akarçay (2018)** | 2010-2014 | Türkiye | Regression | GRW → Maritime + |
| **Gherghina *et al.* (2018)** | 1990-2016 | EU-28 countries | Panel data method | GRW ↔ Maritime |
| **Khan *et al.* (2018)** | 1990-2015 | 16 low & lower middle income and 24 upper middle & high income countries | Panel data method | Maritime → GRW + |
| **Mohamad Taghvaee *et al.* (2019)** | 1978-2012 | İran | Multaneous equations system | Maritime→ GRW + |
| **Park *et al.* (2019)** | 1996-2014 | 17 OECD members and 17 nonmember countries | Panel two-stage least squares method | Maritime → GRW + |

**Table 1.** Maritime Transport and Economic Growth (continued)

| | | | | |
|---|---|---|---|---|
| **Bagoulla and Guillotreau (2020)** | 2010-2014 | France | IO | Maritime → GRW + |
| **Freire-Seoane *et al.* (2020)** | 2008-2015 | Chile, Colombia, Costa Rica, Ecuador, El Salvador, Guatemala, Mexico, Nicaragua, Panama and Peru | Panel data method | Maritime → GRW + |
| **Akbulaev and Bayramli (2020)** | 2016-2018 | Russia, Azerbaijan, Turkmenistan, Kazakhstan and Iran | SWOT analysis | Maritime → GRW + |
| **Osadume and Uzoma (2020)** | 1980-2019 | Nigeria | ARDL and Granger Causality test | Maritime ↔ GRW |
| **Ochei and Mamudu (2020)** | 1981-2019 | Nigeria | Pairwise Granger Causality techniques and the error correction mechanism | Maritime → GRW - |
| **Emeç (2021)** | 2013-2020 | Türkiye | FMOLS method | Maritime → GRW + |
| **Usta and Sarı (2021)** | 2010-2019 | Türkiye | ARDL | GRW → Maritime + |
| **Fratila *et al.* (2021)** | 2007-2018 | 20 EU countries | Panel data method | Maritime → GRW + |
| **Özer *et al.* (2021)** | 1991-2016 | Türkiye | ARDL bounds testing | Maritime → GRW + |
| **Saeed *et al.* (2021)** | 2016 | China, Singapore, Korea, Hong Kong, Malaysia, Netherlands, Germany, USA, Great Britain, and Belgium | Path analysis | Maritime ↔ GRW |
| **Wang *et al.* (2021)** | 1990-2017 | South Korea | VAR and VECM | Maritime→ GRW + |
| **Yıldız (2022)** | 2013-2021 | Türkiye | Granger causality | Maritime + ↔ GRW + |
| **Tunali and Akarçay (2022)** | 1995-2019 | 11 OECD countries | Panel data method | Maritime → GRW + |
| **Yurdakul (2023)** | 2013-2021 | Türkiye | ARDL | Maritime Exp→ GRW +<br>Maritime Imp→ GRW - |
| **Song *et al.* (2023)** | 2010-2018 | South Korea | Panel VECM and Granger causality | Maritime ↔ GRW |
| **Ayesu *et a*l. (2023)** | 2010-2018 | 28 African countries | The system generalized method of moments approach | Maritime → GRW + |

| | |
|---|---|
| **Maritime** | Maritime Transport |
| **GRW** | Economic Growth |
| → | The direction of the one-way causality relationship |
| ↔ | Bidirectional causality relationship |
| + | Positive |
| - | Negative |

This literature review provides a thorough analysis of studies investigating the pivotal role of maritime transport and port infrastructure on economic growth across various countries and periods. Zhang *et al*. (2005) emphasized the significant influence of container ports in the Pearl River Delta region on regional economic growth from 1990 to 2002. Similarly, Korkmaz (2012) demonstrated, through time series analysis, the positive effects of maritime transport on GDP and trade volume in Türkiye between 1980 and 2010. Conversely, Igberi and Ogunniyi (2013) identified adverse impacts of maritime transport on Nigeria's industrial sector from 1980 to 2010 using the OLS method. In line with these findings, Morrissey and O'Donoghue (2013) highlighted the strong economic linkages of Ireland's maritime sector using input-output analysis, while Shan *et al*. (2014) illustrated that Chinese ports substantially promoted trade and investment through panel data analysis.

Bottasso *et al*. (2014) explored the direct and indirect effects of port activities on regional development by employing spatial econometric methods to analyze 13 European regions between 1998 and 2009. In a similar vein, Hayaloğlu (2015) found that advancements in the logistics sector contributed positively to economic growth in OECD countries between 2000 and 2012. Park and Seo (2016) demonstrated that South Korean seaports played a crucial role in supporting regional economies from 1995 to 2012. In Türkiye's case, Tunali and Akarçay (2018) revealed a positive correlation between maritime transport and industrial production from 2005 to 2017 via time series analysis. These results are supported by Gherghina *et al*. (2018), who examined the contributions of transport infrastructure to sustainable growth in the EU-28 countries between 1990 and 2016 using fixed-effects regression analysis. Khan *et al*. (2018) adopted a different approach, analyzing the effects of air, rail, and container transport on energy demand, customs tariffs, and economic growth from 1995 to 2014, and concluded that container transport stimulated economic growth. Mohamad Taghvaee *et al*. (2019) examined the elasticities of maritime and air transport on environmental pollution and economic growth in Iran from 1978 to 2012, finding a significant relationship between maritime transport and growth. Similarly, Park *et al*. (2019) explored the effects of maritime, land, and air transport on economic growth in both OECD and non-OECD countries from 2000 to 2015, concluding that maritime transport contributed positively to growth. Bagoulla and Guillotreau (2020) focused on the environmental impacts of maritime transport on France's economy, particularly regarding air pollution, and concluded that maritime transport boosted economic growth. Freire-Seoane *et al*. (2020) identified positive impacts of container transport on economic growth in Latin America during the late 1990s and 2010s.

Akbulaev and Bayramli (2020) demonstrated the positive relationship between maritime transport and economic growth in Caspian Sea countries. Additionally, Osadume and Uzoma (2020) found bidirectional positive effects of maritime trade on economic growth in Nigeria from 1980 to 2017 through Granger causality tests. In contrast, Ochei and Mamudu (2020) concluded that maritime transport had a negative impact on Nigeria's economic growth. Emeç (2021) analyzed the factors influencing Türkiye's maritime exports during the 2010s, while Usta and Sarı (2021) examined the strong relationship between maritime trade and economic growth in Türkiye between 2000 and 2020 using the ARDL method.

Finally, Fratila *et al*. (2021) emphasized the positive effects of maritime transport on economic growth in EU countries between 2007 and 2018. Özer *et al*. (2021) and Tunali and Akarçay (2022) confirmed the positive impact of container transport on economic growth in Türkiye and OECD countries through the ARDL method. Saeed *et al*. (2021) underscored the importance of maritime connectivity for international trade, while Wang *et al*. (2021) discovered a strong causal relationship between logistics infrastructure and economic growth in South Korea. Yıldız (2022) found bidirectional causality between maritime transport and economic growth in Türkiye. Yurdakul (2023) explored the connections between maritime trade, GDP growth, and the construction sector in Türkiye, concluding that maritime transport increased exports and reduced imports. Song *et al*. (2023) investigated the interrelationships between industrialization, urbanization, and CO2 emissions in South Korea, revealing the significant effects of maritime and air transport on economic growth. Ayesu *et al*. (2023) emphasized the contribution of port efficiency to economic growth in Africa.

This comprehensive overview clearly illustrates the critical role that maritime transport and infrastructure play in fostering economic development globally.

An examination of the investigations outlined in Table 1 discloses a substantial association between maritime transport and economic advancement across all studies. The majority of these inquiries underscore that maritime transport serves as a catalyst for economic growth. Conversely, the outcomes reported by Hayaloğlu (2015), Tunali and Akarçay (2018), and Usta and Sarı (2021) propose a reciprocal influence, indicating a positive contribution from economic growth to maritime transport. Notably, Ochei and Mamudu (2020) deviate from this trend by presenting an unconventional finding, asserting that maritime transport negatively impacts economic growth. The literature review confirms the impact of maritime transport on economic growth, as is the case with various transportation types.

This study sets itself apart from most prior research by virtue of its methodological approach, the specific cohort of countries under scrutiny, and the temporal variations considered. As a result, it is poised to make a substantial and distinctive contribution to the existing body of literature.

## 3. DATA AND METHODS

### 3.1. Data

For the study, the 2008: Q1 and 2020: Q2 periods of Belgium (BEL), France (FRA), Germany (GER), Italy (ITA), Netherlands (NLD), Spain (SPA), Türkiye (TUR), and United Kingdom (UK) is discussed in the model. In the model, economic growth (GRW-Percentage change, same period previous year) and maritime transport (MAR- gross weight of goods handled in main ports) variables are used. The time series of the MAR variable of specific nations in the sample, in particular, has been restricted, which is the reason for this period taken into account in the model. MAR (European Statistics, 2023) was accessed on the European Commission Eurostat database, while GRW was sourced from (Organization for Economic Co-operation and Development [OECD], 2023) database.

The quarterly trends of the variables for the countries in the model are presented in Figure 1 and Figure 2. The 2008 global financial crisis and the 2020 COVID-19 pandemic significantly impacted the GRW of countries such as BEL, FRA, GER, ITA, NLD, SPA, TUR, and UK. After the 2008 crisis, countries like Germany and the NLD demonstrated strong recovery, while ITA and SPA showed weaker performance. TUR recorded high growth rates in the early 2010s but was adversely affected by the 2018 economic crisis and the pandemic. In 2020, due to the pandemic, all countries experienced sharp declines in their growth rates. Particularly, growth recovery in ITA and SPA remained weak, whereas GER and the NLD exhibited more stable growth.

When examining the MAR data of the countries in the Figure 2, it is evident that the NLD leads significantly, with the highest trade volume in its ports. TUR has shown a steady increase since 2008, demonstrating consistent growth in port activities. GER maintains a stable and high MAR level, preserving its strength in maritime trade. FRA and SPA follow relatively flat trends, while ITA and the UK display more volatility, with the UK experiencing a sharp decline in recent years. BEL stands out as the country with the lowest MAR levels.

Table 2 provides descriptive statistics for the variables of the various countries. The data shown in Table 2 indicates that NLD has the highest per capita income (MAR), whereas BEL has the lowest. In terms of national income, the TUR has the greatest rate of GRW, while the ITA has the lowest rate. Additionally, it is seen that most of the variables do non-normal distribution. Therefore, it is important to use analyzes that take into account non-normal distribution.

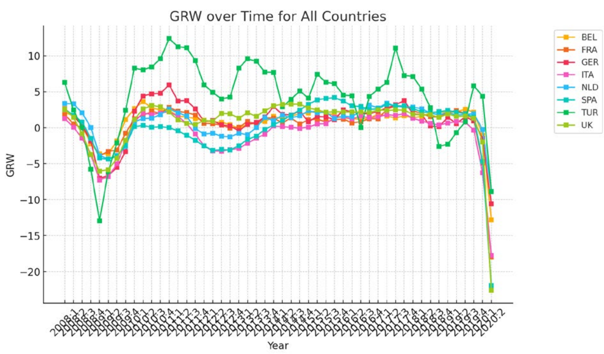


**Figure 1.** The trend of the GRW variable

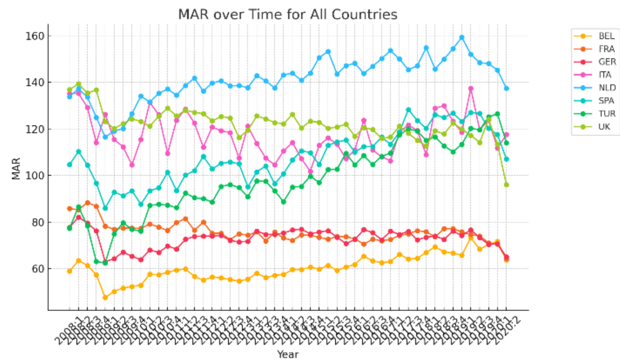


**Figure 2.** The trend of the MAR variable

**Table 2**. Descriptive Statistics

| Variables | Mean | Median | Max. | Min. | Std. Dev. | Jarque-Bera | J-B Prob. |
|---|---|---|---|---|---|---|---|
| **MAR_BEL** | 60.455 | 59.709 | 73.351 | 47.613 | 5.582 | 0.351 | 0.838 |
| **MAR_FRA** | 75.756 | 75.054 | 88.392 | 64.278 | 4.315 | 13.345 | 0.001 |
| **MAR_GER** | 72.893 | 73.876 | 82.140 | 63.002 | 4.124 | 3.567 | 0.168 |
| **MAR_ITA** | 17.504 | 116.790 | 137.414 | 101.780 | 8.791 | 2.019 | 0.364 |
| **MAR_NLD** | 141.214 | 142.242 | 159.216 | 116.473 | 9.302 | 4.066 | 0.130 |
| **MAR_SPA** | 108.105 | 106.834 | 128.246 | 85.952 | 11.344 | 1.636 | 0.441 |
| **MAR_TUR** | 98.110 | 96.494 | 126.452 | 62.472 | 15.675 | 0.986 | 0.610 |
| **MAR_UK** | 122.043 | 122.159 | 139.295 | 96.001 | 6.855 | 28.784 | 0.001 |
| **Variables** | **Mean** | **Median** | **Max.** | **Min.** | **Std. Dev.** | **Jarque-Bera** | **J-B Prob.** |
| **GRW_BEL** | 0.905 | 1.519 | 3.616 | -12.816 | 2.456 | 794.326 | 0.001 |
| **GRW_FRA** | 0.473 | 1.184 | 3.049 | -17.976 | 3.147 | 1161.664 | 0.001 |
| **GRW_GER** | 0.956 | 1.530 | 5.944 | -10.573 | 3.050 | 59.069 | 0.001 |
| **GRW_ITA** | -0.755 | 0.435 | 2.214 | -17.729 | 3.420 | 292.587 | 0.001 |
| **GRW_NLD** | 0.858 | 1.632 | 3.402 | -8.8534 | 2.348 | 75.663 | 0.001 |
| **GRW_SPA** | 0.080 | 0.877 | 4.168 | -21.937 | 4.051 | 587.583 | 0.001 |
| **GRW_TUR** | 4.302 | 5.236 | 12.378 | -12.933 | 5.235 | 16.674 | 0.001 |
| **GRW_UK** | 0.761 | 1.916 | 3.260 | -22.627 | 4.007 | 1128.161 | 0.001 |

### 3.2. Method

In this study, causality relationships between variables are investigated with the Panel Bootstrap Causality test developed by Kónya (2006). This causality test has advantages over many panel causality tests. Firstly, it does not matter whether there is a cointegration relationship between the variables or not. Secondly, the stationarity levels of the variables are not important and there is no need to investigate stationarity before the test. However, there are two fundamantal conditions to perform the test. The first of these is that there must be cross-sectional dependence in the models and the coefficients of the models must be heterogeneous.

The examination of cross-sectional dependence in this study relies on the application of several widely employed tests, including the Breusch-Pagan Lagrange Multiplier ($BP_{LM}$) test devised by Breusch and Pagan (1980), the Pesaran Cross-Sectional Dependence ($CD_{LM}$) test introduced by Pesaran (2004), the Lagrange Multiplier adjusted ($LM_{adj}$) test developed by Pesaran *et al*. (2008), and the Baltagi Cross-sectional Dependence ($LM_{BC}$) tests developed by Baltagi *et al*. (2012). Additionally, the determination of coefficient homogeneity/heterogeneity is facilitated through the utilization of the $\tilde{\Delta}$ and $\tilde{\Delta}_{adj}$ test statistics proposed by Pesaran and Yamagata (2008).

Kónya (2006) developed a causality test grounded in the Seemingly Unrelated Regression (SUR) estimator, as initially proposed by Zellner (1962). This test posits its superiority over the Ordinary Least Squares (OLS) estimate. Notably, the SUR system is constructed based on Sim's (1980) Vector Autoregressive (VAR) methodology. In the context of the study, the SUR system is applied to model the interrelationships among the variables (Kónya, 2006).

Model 1 is used to test the causality relationship from GRW to MAR, from MAR to GRW in Model 2.

N represents the number of countries (i=1, 2, 3, ......, 8) expressed in the equations, and t represents the time interval (t=2008: Q1,....., 2020:Q2). Also, *ml* represents the lag length and $\xi_{1,1,t}$ , $\xi_{1,2,t}$ ,..., $\xi_{1,N,t}$ , $\xi_{2,1,t}$ , $\xi_{2,2,t}$ ,..., $\xi_{2,N,t}$ , $\xi_{3,1,t}$ , $\xi_{3,2,t}$ ,..., $\xi_{3,N,t}$... are the error terms which are supposed to be white noises.

Kónya's (2006) panel bootstrap causality test, Wald test statistics are computed using the VAR equations established for each country within the Seemingly Unrelated Regression (SUR) system mentioned earlier. Critical values for the bootstrap approach are determined individually for each country. Thus, the problem of non-normal distribution will be prevented. The assessment of hypotheses involves comparing the generated Wald test statistics with the bootstrap critical values. The identification of causality relationships between the variables is achieved by imposing constraints on the coefficients, as outlined below. If not all $\beta_{1,N,l}s$ are zero, but all $\alpha_{2,N,l}s$ are zero; there is unidirectional Granger causality from GRW to MAR. If not all $\alpha_{2,N,l}s$ are zero, but all $\beta_{1,N,l}s$ are zero; there is unidirectional Granger causality from MAR to GRW (Kónya, 2006).

## 4. FINDINGS

Table 3 presents the outcomes of the cross-sectional dependence and homogeneity test, a prerequisite for the panel bootstrap causality test. Table 3 presents the outcomes of the cross-section dependency test, a crucial prerequisite for initiating the bootstrap panel causality analysis. The condition tested is denoted as "$H_0$: the model contains no cross-section dependence." Rejecting the null hypothesis ($H_0$) is warranted as the probability values associated with the test statistics, as shown in the table, fall below the predetermined levels of statistical significance. Consequently, it is established that cross-section dependence is present in both Model 1 and Model 2. The existence of cross-sectional dependence shows that a shock occurring in any of the countries may also have an impact on the other (Breusch and Pagan, 1980; Pesaran, 2004; Pesaran *et al*.,2008; Baltagi *et al*., 2012).

Homogeneity test results also show that there is heterogeneity in the models. This finding shows that the coefficients and causality relationships to be obtained will vary from country to country. Consequently, based on the findings presented in Table 3, there are no impediments to conducting the panel bootstrap causality test.

The causality results between MAR and GRW are presented in Table 4.

Our findings when we apply the Kónya (2006) causality test to our data differ by country and model. There is a causality relationship from economic growth to maritime transport in all countries except Italy and the Netherlands. Studies such as Gherghina *et al*. (2018), Saeed *et al*. (2021) and Yıldız (2022) also found causality relationships from economic growth to maritime transport. This finding is due to the fact that maritime transport is the most preferred mode of transportation used in international trade and is cheaper than other modes of transportation. Most developed countries attach great importance to maritime transport.

$$\left.\begin{aligned}
MAR_{1,t} &= \varphi_{1,1} + \sum_{l=1}^{ml_MAR_1} \alpha_{1,1,l} MAR_{1,t-1} + \sum_{l=1}^{ml_GRW_1} \beta_{1,1,l} GRW_{1,t-1} + \xi_{1,1,t} \\
MAR_{2,t} &= \varphi_{1,2} + \sum_{l=1}^{ml_MAR_1} \alpha_{1,2,l} MAR_{2,t-1} + \sum_{l=1}^{ml_GRW_1} \beta_{1,2,l} GRW_{2,t-1} + \xi_{1,2,t} \\
&\;\;\vdots \\
MAR_{N,t} &= \varphi_{1,N} + \sum_{l=1}^{ml_MAR_1} \alpha_{1,N,l} MAR_{N,t-1} + \sum_{l=1}^{ml_GRW_1} \beta_{1,N,l} GRW_{N,t-1} + \xi_{1,N,t}
\end{aligned}\right\} (1)$$

$$\left.\begin{aligned}
GRW_{1,t} &= \varphi_{2,1} + \sum_{l=1}^{ml_GRW_2} \beta_{2,1,l} GRW_{1,t-1} + \sum_{l=1}^{ml_MAR_2} \alpha_{2,1,l} MAR_{1,t-1} + \xi_{2,1,t} \\
GRW_{2,t} &= \varphi_{2,2} + \sum_{l=1}^{ml_GRW_2} \beta_{2,2,l} GRW_{2,t-1} + \sum_{l=1}^{ml_MAR_2} \alpha_{2,2,l} MAR_{2,t-1} + \xi_{2,2,t} \\
&\;\;\vdots \\
GRW_{N,t} &= \varphi_{2,N} + \sum_{l=1}^{ml_GRW_2} \beta_{2,N,l} GRW_{N,t-1} + \sum_{l=1}^{ml_MAR_2} \alpha_{2,N,l} MAR_{N,t-1} + \xi_{2,N,t}
\end{aligned}\right\} (2)$$

**Table 3.** Cross-Section Dependence Test and Slope Homogeneity Test Results

| Tests | Cross-section dependence | | | | Slope homogeneity | |
|---|---|---|---|---|---|---|
| **Models** | $BP_{LM}$ | $CD_{LM}$ | $LM_{BC}$ | $LM_{adj}$ | $\tilde{\Delta}$ | $\tilde{\Delta}_{adj}$ |
| **Model 1** | 389.74* (0.001) | 6.15* (0.001) | 48.25* (0.001) | -48.33 (0.001) | 2.52* (0.012) | 3.19* (0.001) |
| **Model 2** | 948.78* (0.001) | 30.35* (0.001) | 122.96* (0.001) | 123.04* (0.001) | 2.45* (0.014) | 3.10* (0.002) |

*, ** indicates cross-sectional dependence and heterogeneity at 1 and 5 percent statistical significance levels.

The absence of causality between GRW and MAR in ITA and NLD may be due to differences in economic structures and trade policies. In NLD, MAR levels are more influenced by global trade flows, making port activities independent of domestic economic growth. In ITA, economic growth relies more on internal factors such as industrial production and services, weakening the direct link to port activities. Additionally, differences in trade policies, infrastructure, and port capacity utilization may also contribute to this outcome.

There is a significant causality relationship from maritime transport to economic growth in Türkiye and the UK. As confirmed by most of the studies in Table 1, there are causality relationships from maritime transport to economic growth in most of the studies. However, it is an important finding of this study that these relationships were not detected in other countries. Moreover, it should be noted that there is a bidirectional causality relationship between maritime transport and economic growth for Türkiye and the UK. Again, Gherghina *et al.* (2018), Saeed *et al.* (2021) and Yıldız (2022) show that there will be significant bidirectional relationships between these variables.

**Table 4.** Kónya (2006) Causality Test Findings

| *$H_0$: GRW is not the Granger causality of MAR (Model 1)* | | | | |
|---|---|---|---|---|
| **Countries** | **Test Statistics** | **Critical Values** | | |
| | **Wald** | **10%** | **5%** | **1%** |
| BEL | 30.549* | 3.598 | 5.431 | 10.348 |
| FRA | 27.703* | 3.608 | 5.139 | 8.817 |
| GER | 4.542** | 3.813 | 5.654 | 10.711 |
| ITA | 0.183 | 3.469 | 4.900 | 8.504 |
| NLD | 1.034 | 3.789 | 5.430 | 9.915 |
| SPA | 4.102** | 3.521 | 5.013 | 9.507 |
| TUR | 6.258** | 3.786 | 5.596 | 10.403 |
| UK | 22.373* | 3.550 | 5.341 | 10.093 |
| *$H_0$: MAR is not the Granger causality of GRW (Model 2)* | | | | |
| **Countries** | | **Test Statistics** | **Critical Values** | |
| | **Wald** | **10%** | **5%** | **1%** |
| BEL | 2.025 | 3.712 | 5.306 | 10.037 |
| FRA | 3.127 | 3.828 | 5.525 | 9.628 |
| GER | 1.316 | 3.694 | 5.387 | 10.417 |
| ITA | 0.536 | 3.621 | 5.112 | 9.002 |
| NLD | 0.460 | 3.699 | 5.282 | 10.097 |
| SPA | 0.596 | 3.470 | 4.896 | 8.602 |
| TUR | 3.964** | 3.902 | 5.824 | 10.470 |
| UK | 5.229* | 3.723 | 5.314 | 9.431 |

*, **, and ***indicate rejection of the null hypothesis at the 1, 5, and 10 percent levels of significance.

## 5. DISCUSSION AND CONCLUSIONS

This study explores the causality relationships between maritime transport and economic growth variables among the European countries with the highest maritime transport activity, namely Belgium, France, Germany, Italy, the Netherlands, Spain, Türkiye, and the United Kingdom. The data utilized for this investigation spans from the first quarter of 2008 to the second quarter of 2020. The findings from the analysis can be summarized as follows:

- There is cross-sectional dependence in the models used. Shocks experienced in countries have the possibility of affecting other countries. This is an expected finding in a globalizing world and for countries with similar geography.
- The coefficients of the models are heterogeneous. This means that causality findings vary across countries. The specific characteristics of each country have led to this finding.
- Causality findings vary from country to country and are as follows:
  - There are causality relationships from economic growth to maritime transport in all countries except Italy and the Netherlands.
  - There are significant causality relationships from maritime transport to economic growth in Türkiye and the UK.
  - There are bidirectional causal relationships between variables in Türkiye and the UK.

These findings show that a shock that may occur in any of the countries in the relationship between maritime transport and economic growth may have an impact on other countries. Although a shock in one country may affect the others, the relationship between the variables differs from country to country. The countries included in our research subject have different economic characteristics and strengths. In addition, issues such as the importance these countries attach to maritime transport and the production of goods that will be subject to international trade affect the relations between these variables. The fact that developed countries attach importance to maritime transport shows that it is important in increasing the economic development levels of coastal countries.

The COVID-19 pandemic caused significant disruptions and logistical crises in maritime transport. During the pandemic, port closures, labor shortages, and supply chain interruptions led to major delays and increased costs across all maritime activities, especially container shipping. Container imbalances due to fluctuations in supply and demand throughout the pandemic adversely affected global trade flows. Disruptions in the transportation of essential goods were particularly pronounced, and in some regions, commercial activities nearly halted due to declines in trade and production (Notteboom *et al.*, 2021). Furthermore, this external shock affected all stages of the supply chain simultaneously, resulting in a significant economic contraction and breakdown in supply chains. However, it was observed that the impacts of the pandemic were relatively temporary, with the sector showing signs of recovery as demand returned (World Bank, 2020; UNCTAD, 2020).

The findings of this study indicate that the strong relationship between maritime transport and economic growth necessitates a focus on sustainability and green maritime technologies in future maritime policies. Global crises, particularly the 2008 financial crisis and the COVID-19 pandemic, have highlighted the critical role of maritime transport in driving economic growth. This underscores the need to make maritime transport infrastructure more resilient and environmentally friendly. Green ports, low-carbon maritime technologies, and innovations that enhance energy efficiency are crucial for supporting economic growth while reducing environmental impacts. Furthermore, the integration of technological developments such as digitalization and automation into maritime transport will enable the creation of a more sustainable and efficient supply chain. In conclusion, restructuring maritime transport within the framework of sustainability principles will contribute to the simultaneous achievement of future economic growth and environmental goals.

The study has some limitations. Due to the lack of data, data up to the 2nd quarter of 2020 were used at most. When the data are available, the analysis can be extended for a longer period. The relationships between these variables can also be investigated using different techniques.

## AUTHORSHIP CONTRIBUTION STATEMENT

**Şerif CANBAY:** Conceptualization, Methodology, Validation, Formal Analysis, Resources, Writing - Original Draft, Writing-Review and Editing, Data Curation, Software, Supervision. **Mustafa KIRCA:** Conceptualization, Methodology, Validation, Formal Analysis, Resources, Writing - Original Draft, Writing-Review and Editing, Data Curation, Software.

## CONFLICT OF INTERESTS

The authors declare that for this article they have no actual, potential or perceived conflict of interests.

## ETHICS COMMITTEE PERMISSION

No ethics committee permissions are required for this study.

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# Cardiovascular Toxicity in *Daphnia magna*: Heart Rate Analysis Under Exposure to Crystal Violet, Ethanol, and Formaldehyde

# *Daphnia magna*'da Kardiyovasküler Toksisite: Kristal Menekşe, Etanol ve Formaldehit Maruziyette Kalp Atış Hızı Analizi

Türk Denizcilik ve Deniz Bilimleri Dergisi

Cilt: 11 Sayı: 1 (2025) 33-45

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## ABSTRACT

Water fleas have become valuable model organisms for ecotoxicity studies due to their ease of cultivation, transparent bodies, and high sensitivity to chemical pollutants. In this study, heart rates in Daphnia magna were examined to assess basic behavioral and physiological characteristics under exposure to known toxic chemicals. Crystal violet, ethanol, and formaldehyde selected for their distinct chemical properties and documented toxicity were utilized as toxic solutions. A slow-motion, video-based method was implemented to evaluate cardiovascular performance by monitoring heart rates in water fleas. Data for important parameters like heart rates, body reactions, and heart contraction were extracted from video recordings. It was found that crystal violet increased the heart rates of *Daphnia magna* (489±14.19) more than ethanol (450±40.67) and formaldehyde (445±48.21). Compared to the control group, formaldehyde caused a 28.51% increase in the heart rates of daphnids, while exposure to ethanol (30.54%) and crystal violet (35.89%) resulted in a lower increase. The response of water fleas to each of the three chemicals studied was determined as a statistically significant and noticeable increase in heart rate.

**Keywords:** Water flea, *Daphnia magna*, Heart rates, Crystal violet, Ethanol.

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## ÖZET

Su pireleri, kolay yetiştirilebilmeleri, şeffaf vücut yapıları ve kimyasal kirleticilere karşı yüksek duyarlılıkları sayesinde ekotoksisite çalışmalarında değerli model organizmalar haline gelmiştir. Bu çalışmada, *Daphnia magna*'nın bilinen toksik kimyasallara maruz kaldığında temel davranışsal ve fizyolojik özelliklerini değerlendirmek amacıyla kalp atış hızları incelenmiştir. Kristal menekşe, etanol ve formaldehit, kendilerine özgü kimyasal özellikleri ve belgelenmiş toksisiteleri nedeniyle toksik çözelti olarak seçilmiştir. Su pirelerinin kalp atış hızlarını izleyerek kardiyovasküler performanslarını değerlendirmek için yavaş çekim, video tabanlı bir yöntem kullanılmıştır. Kalp atışları, vücut tepkileri ve kalp kasılması gibi önemli parametreler için veriler video kayıtlarından çıkarılmıştır. Kristal menekşenin, *Daphnia magna*'nın kalp atışlarını (489±14,19), etanol (450±40,67) ve formaldehit (445±48,21) ile kıyaslandığında daha fazla artırdığı bulunmuştur. Kontrol grubuna kıyasla, formaldehit su pirelerinin kalp atışlarında %28,51'lik bir artışa neden olurken, etanol (30,54%) ve kristal menekşenin (35,89%) maruziyeti daha düşük bir artış sonucunu doğurmuştur. Su pirelerinin her üç kimyasala verdiği yanıt, kalp atış hızında istatistiksel olarak anlamlı ve belirgin bir artış olarak tespit edilmiştir.


**Anahtar sözcükler**: Su piresi, *Daphnia magna*, Kalp atışları, Kristal menekşe, Etanol.

## 1. INTRODUCTION

*Daphnia* or daphnids, are zooplanktonic organisms belonging to the class Crustacea and the phylum Arthropoda, typically found in freshwater, with sizes ranging from 0.2 to 5 mm. *Daphnia* are also called water fleas due to their jerky and jumping swimming movements (Chevalier, 2014). *Daphnia* usually has a completely transparent outer shell, which makes its internal organs completely observable from the outside (Johnsen, 2001; Ebert, 2022). In this manner, physiological responses like heart rates in *Daphnia* can be observed within the organism's body without any external interference (Rosenkranz, 2010).

*Daphnia* reproduces by a method called cyclic parthenogenesis, which allows them to alternate between sexual and asexual reproduction depending on the surrounding environmental conditions (Dukić, 2016; Gerber, 2018). Due to these features, it is possible to generate a significant number of individuals in a lab setting, improving the repeatability of experiments. The feeding habits of *Daphnia* form the basis of the mechanism that makes them sensitive to environmental changes. This sensitivity is particularly crucial in monitoring water quality and assessing the impact of environmental pollutants (Altshuler *et al*., 2011; Kim *et al*. 2015; Rodrigues *et al*., 2022). *Daphnia* filter water by straining algae and small organisms, which they then digest. This behavior makes them extremely sensitive to the quality and content of the water. Due to their sensitivity to various xenobiotics and environmental stress, *Daphnia* have been used as bioindicators in research on toxicity and the bioaccumulation of microplastics since the 1990s (Suman *et al*., 2021; Sönmez *et al*., 2022; Atamanalp, 2024).

Water fleas, particularly species from the *Daphnia* genus, are widely regarded as ideal models organisms for ecotoxicity research (Greene *et al*., 2017; Norambuena *et al*., 2019; Guilhermino *et al*., 2000). Their suitability is due to their ease of cultivation, transparent bodies, and heightened sensitivity to chemical contaminants (Ahmed, 2023). Cardiovascular function indicators are frequently utilized to assess toxicity (Villegas-Navarro *et al*., 1999). However, accurately measuring heart rate and blood flow, while minimizing bias, can be difficult given the unique heart structure, blood flow characteristics, and the rapid nature of the heartbeat. In water fleas, blood is not confined to vessels but is instead pumped into a cavity known as the hemocoel, where it mixes with interstitial fluid and is referred to as hemolymph (Santoso *et al*., 2020). As the heart contracts and the organism moves, hemolymph circulates through the organs and re-enters the heart via small openings called ostia (Offem *et al*., 2008;

Chung *et al*., 2016; Kundu and Singh, 2018). This circulatory process facilitates the exchange of gases and nutrients throughout the body of *Daphnia* species (Santoso *et al*., 2020).

The fact that *Daphnia magna*'s heart is myogenic, meaning it can generate its own cardiac contractions without neural input similar to the human heart, makes the studies on this subject particularly noteworthy. This is particularly intriguing because, as an arthropod, *D. magna* typically possesses a neurogenic heart, which requires neural stimuli for contraction, making it an exception among its class (Angus-Whiteoak, 2018; Matveeva *et al*., 2018). Previous research has examined the structure of the *D. magna* heart, revealing long striated myofibrils and a mostly single-cell-thick wall (Stein *et al*., 1965). The use of *D. magna* for studying the effects of various substances is further justified by the fact that human cardiac muscle is also striated. Additionally, the organism's relatively transparent body allows for easy measurement of heart rates, providing a model that is comparable to the human heart (Perez *et al*., 2019).

The study conducted by Villegas-Navarro *et al*. (2003) demonstrated that *Daphnia* is an effective model organism for toxicological and pharmacological research, particularly for examining the effects of substances on the cardiovascular system. The results suggest that analyzing *Daphnia*'s cardiac functions can reveal the toxicological effects of different substances. In the study by Kaas *et al*. (2009), *Daphnia magna* was used to investigate the cardiovascular effects of melatonin and ethanol. When both substances were combined, the decline in heart rates was even greater than expected. These findings confirm that *Daphnia* is a reliable model for cardiovascular pharmacology and toxicology studies.

Most studies in the field of ecotoxicology investigate broader endpoints such as mortality rates, reproduction, growth, and food consumption (Hellou, 2011). Molecular-level endpoints, such as enzyme activity or gene expression, are less frequently examined. However, the behavioral and physiological characteristics of an organism establish the connection between molecular-level endpoints and the organism itself (Connon *et al*., 2012). The inhibitory effect of a contaminant on the feeding rate of *Daphnia magna* can be analyzed by exploring a sequence of endpoints, ranging from behavioral aspects (such as thoracic limb and mandible activity) to physiological responses (like gut peristaltic activity), and ultimately to molecular levels (including digestive enzyme activity and gene expression) (Lari *et al*., 2017). This study aimed to investigate heart rates reflecting basic behavioral and physiological characteristics of *Daphnia magna* when exposed to known toxic chemicals.

## 2. MATERIALS AND METHODS

The research was designed as a three-phase experimental setup. For this purpose, data were obtained with 10 daphnids (n=10) without adding any factors and under control conditions. In the second stage, the reactions of daphnids to the selected chemicals and the changes in their heart rates over time were determined. At this stage, a special video program (Adobe Premiere Rush) and Image J Software were used.

### 2.1. Materials

Crystal violet ($C_{25}H_{30}N_3Cl$) is a cationic dye widely used in many industries such as textile, leather, paint, cosmetics and plastic. Studies have shown that crystal violet causes tumor formation in fish, reduces photosynthetic activation in aquatic plants and inhibits seed germination and growth in land plants (Mani and Bharagava, 2016). Crystal violet, which has high toxicity on mammals, has been reported in various studies to damage the skin, digestive and respiratory systems and to have carcinogenic effects in long-term exposure (Mani and Bharagava, 2016). Ethanol ($C_2H_5OH$) is a substance that is soluble in water and can easily dissolve oils. Thanks to these properties, it has a wide range of uses as a solvent, disinfectant and fuel. Studies have shown that ethanol has both acute and chronic toxicity (Li *et al*., 2015; Paprocki *et al*., 2022). Formaldehyde ($CH_2O$) is a colorless, flammable gas with a characteristic pungent odor. It is used for various purposes in many sectors such as textile, paint, food safety and plastic industry (Zhang, 2018). Formaldehyde, classified as "carcinogenic to humans" by the International Agency for Research on Cancer (IARC), possesses genotoxic properties and contributes to ozone layer depletion (McLaughlin, 1994; Protano *et al*., 2021).

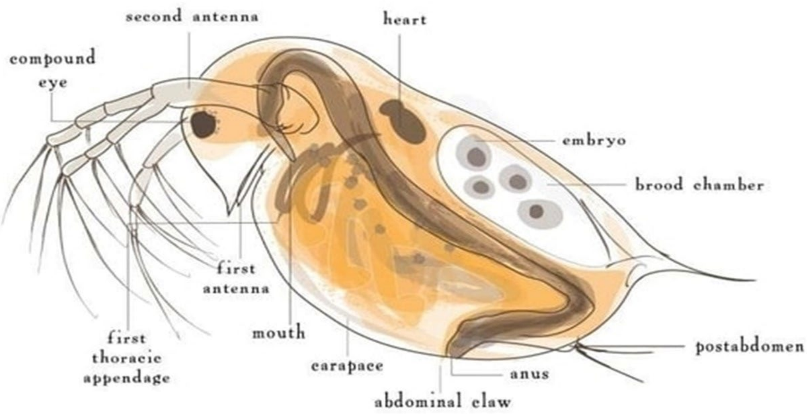
Crystal violet (CV) is a widely used chemical in microbiology studies because it causes bacterial wall destruction in the gram stain apparatus. Ethanol (E) is a toxic chemical commonly used in laboratory studies. It is preferred for environmental cleaning and analysis after microbiological experiments and is widely available for general use. First, behavioral responses and heart rates of water fleas were recorded at different concentrations of both solutions. Formadehyde (F) is frequently preferred in today's laboratories in studies aimed at preserving/preserving organism integrity (Sönmez and Sivri, 2016).

## 2.2. *Daphnia magna* culturing

A commercial strain of *D. magna* was cultured in freshwater at room temperature (22°C ± 1°C) with a photoperiod of 16 hours of light and 8 hours of darkness. The cultures were fed with $3.0x10^7$ cells/mL of green microalgae (*Spirulina* sp.) three times a week and with 0.1 mg/mL of dissolved baker's yeast once a week. To maintain dissolved oxygen (DO) concentrations above 4 mg/L, the cultures were aerated during the weekly experiments. The reconstituted water had the following physicochemical parameters: pH 7.5–8.5, hardness of 160–180 mg/L, conductivity of 250–600 µS/cm, and a temperature of 22°C. *Daphnid* density was maintained at approximately 40 neonates, 20 juveniles, and 12 to 16 reproducing adults per liter to avoid overcrowding. Under these conditions, daphnids reached maturity within 6 to 8 days after birth.

## 2.3. Heart rates of water fleas

The water flea *Daphnia*, a key branchiopod crustacean belonging to the order Cladocera, inhabits lotic ecosystems globally and is widely recognized as a model organism in the fields of ecology, evolution, and ecotoxicology (Ebert, 2022; Ngu *et al*., 2022). Additionally, *Daphnid* are commonly employed as environmental indicators in regulatory toxicology and are playing an increasingly significant role in “new approach methodologies” (NAM) for assessing chemical risks (Abdullahi *et al*., 2022). In *D. magna*, the single, small heart is easily visible when viewed under transmitted light using a low-power microscope (Figure 1). Heart rates can be monitored and quantified under various conditions, such as changes in water temperature or variations in the type and concentration of chemicals introduced to the water. Although changes in daphnid heart rates may not directly predict similar changes in the heart rates of humans or other vertebrates under the same conditions, this method provides a valuable approach for studying the impact of various chemicals on metabolic processes.




**(a)**

**(b)**

**Figure 1. (a)** The functional anatomy of an adult *Daphnia magna* (taken from Ebert, 2005; Tomar, 2024). **(b)** Image of *Daphnia* magna used in the experiments (Olympus stereo microscopes, 10x10 magnification) (please access the video taken during the counting from the link https://youtu.be/bj8xFXUydc0)

From the tank where the culture was maintained, random young daphnids were selected and placed on a slide. To prevent changes in the final concentration of the chemicals to which the daphnids would be exposed, the remaining culture medium on the slide, along with the daphnids, was removed using a Pasteur pipette. The daphnids were then exposed to a solution containing a drop of crystal violet (CV), ethanol (E), and formaldehyde (F) at a concentration of 1 ppm. A one-minute waiting period was allowed to ensure the chemicals were incorporated into the daphnid's circulation before counting the reactive heartbeats.

To count the heartbeats of the daphnids, videos were recorded using the camera of a Samsung Galaxy S22 smartphone in conjunction with an Olympus stereo microscope. The recorded videos were edited into 13 segments of 10 seconds each using Adobe Premiere Rush. Each 10-second segment was adjusted to slow motion, and the heart rates were counted. This procedure was repeated separately for each chemical and conducted three times. The heartbeats of the daphnids exposed to the prepared solutions were recorded on video for a total duration of 130 seconds. The video recordings focused on the heart chamber located towards the back of the *Daphnia* sp. (Saputra *et al*., 2023).

The data obtained were analyzed using SPSS 20 to perform a one-way ANOVA to determine if there was a statistically significant difference.

## 3. RESULTS AND DISCUSSIONS

In this study, the feasibility of using water fleas as indicator species was assessed based on their responses to the selected toxic chemical solutions, in order to facilitate the advancement of diagnostic methodologies and to evaluate various preventive and therapeutic strategies for Cardiovascular diseases. To determine heart rates without any chemical or stress factors, 10 daphnids were randomly selected from the water flea culture tank. The heart rates results of the ten daphnids are presented in Figure 2. It was found that the heartbeat is individual-level but not size-dependent in water fleas. After testing the ten water fleas, it was determined that *D. magna* has a robust heartbeat and blood flow rate, indicating that it is suitable for ecotoxicity testing. The heart rates of 10 daphnids, taken from the culture tank and measured over time without chemical exposure, averaged 313 beats per minute.

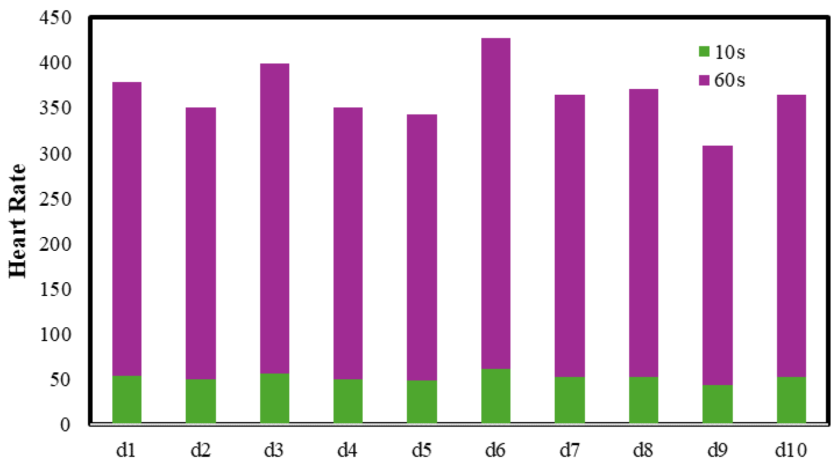



**Figure 2.** Heart rates results of ten *D. magna* (control group) (heart rates counting was done using Adobe Premiere Rush).

The study investigated the effects of CV, E, and F on the heart rates of water fleas. In Figure 3-a, the heart rates of three different *Daphnia magna* exposed to CV at a concentration of 1 ppm are shown in 10-second intervals. The highest average heart rate (84 beats per 10 seconds) was recorded for *Daphnia* sp. exposed to crystal violet, representing the highest heart rate count obtained in the study.

The average heart rate of *Daphnia* sp. exposed to formaldehyde in 10-second intervals was found to be 73.71 beats per 10 seconds. During exposure to formaldehyde, the lowest heart rates were observed in period t13 (61 beats per 10 seconds). It was noted that during the 3rd beat of interval t7, the heart of the daphnids contracted less. During ethanol exposure, the heart rates of daphnids ranged from a minimum of 66 beats per 10 seconds to a maximum of 81 beats per 10 seconds. In all ethanol exposure experiments, the heart rates of *D. magna* were found to be higher than that of the control group *D. magna* *($t$= 15.65; $p<0.05$)*. The heart rates of *Daphnia magna* exposed to crystal violet, ethanol, and formaldehyde were found to be 489±14.19, 450±40.67, and 445±48.21 per minute, respectively. As shown in Figure 4-a, 62% increase in heart rate was observed in *Daphnia magna* exposed to crystal violet. The change in heart rate following exposure to ethanol in the three different *Daphnia* sp. is presented in Figure 4-b. This change shows an increase in average heart rate to 76 beats per 10 seconds, indicating a 51% increase. Similarly, the effect of formaldehyde exposure on *Daphnia* heart rate is illustrated in Figure 4-c. Although formaldehyde, with a 28.51% increase in heart rate compared to the control, exhibited a lower increase than ethanol (30.54%) and crystal violet (35.89%). The one-way ANOVA test conducted between the groups F, CV, and E revealed a statistically significant difference among the groups (F(2.39) = 437.06, p < 0.001). The study demonstrates that crystal violet has a more pronounced effect on heart rate compared to ethanol and formaldehyde (p<0.001). The impact of crystal violet was found to be markedly higher than that of the other substances (p<0.001). The reliability of the results is enhanced, as the analyses were conducted using three different daphnids from the same genus.

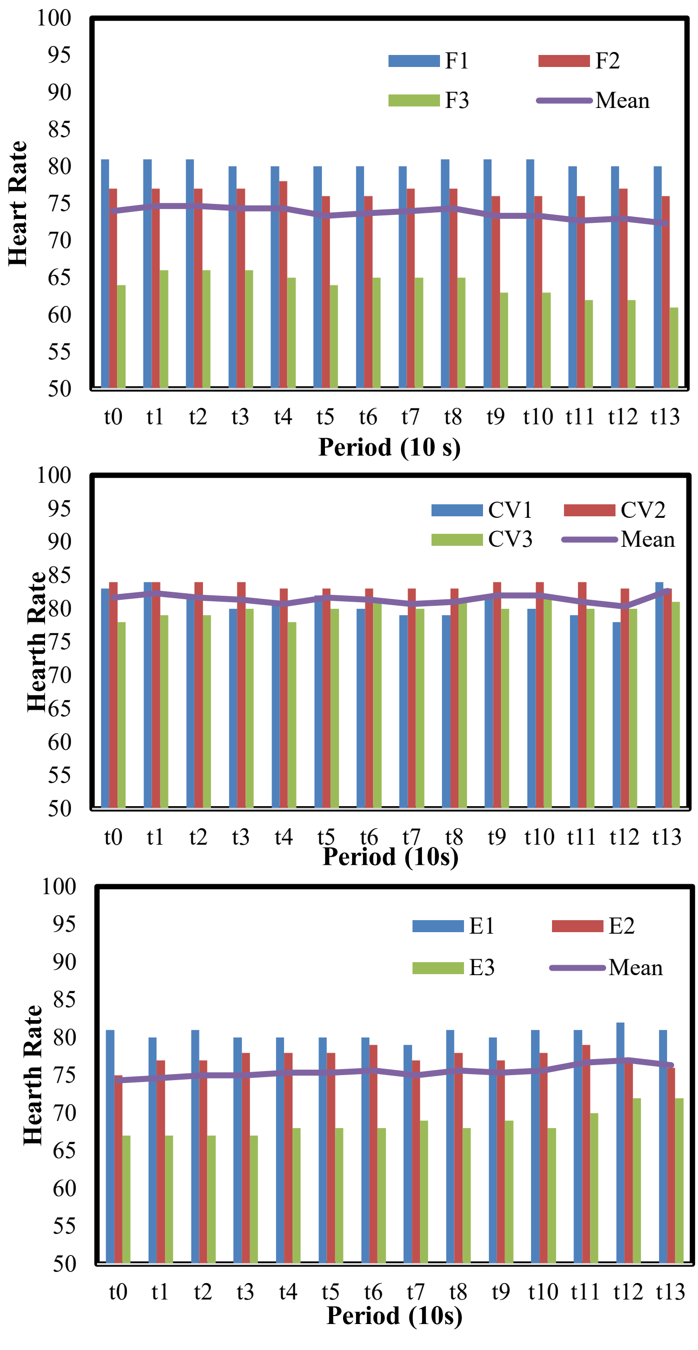



**Figure 3.** Heart rates of *D. magna* (n=3) exposed to different chemicals (CV, E, and F) depending on the periods (t=10 seconds)

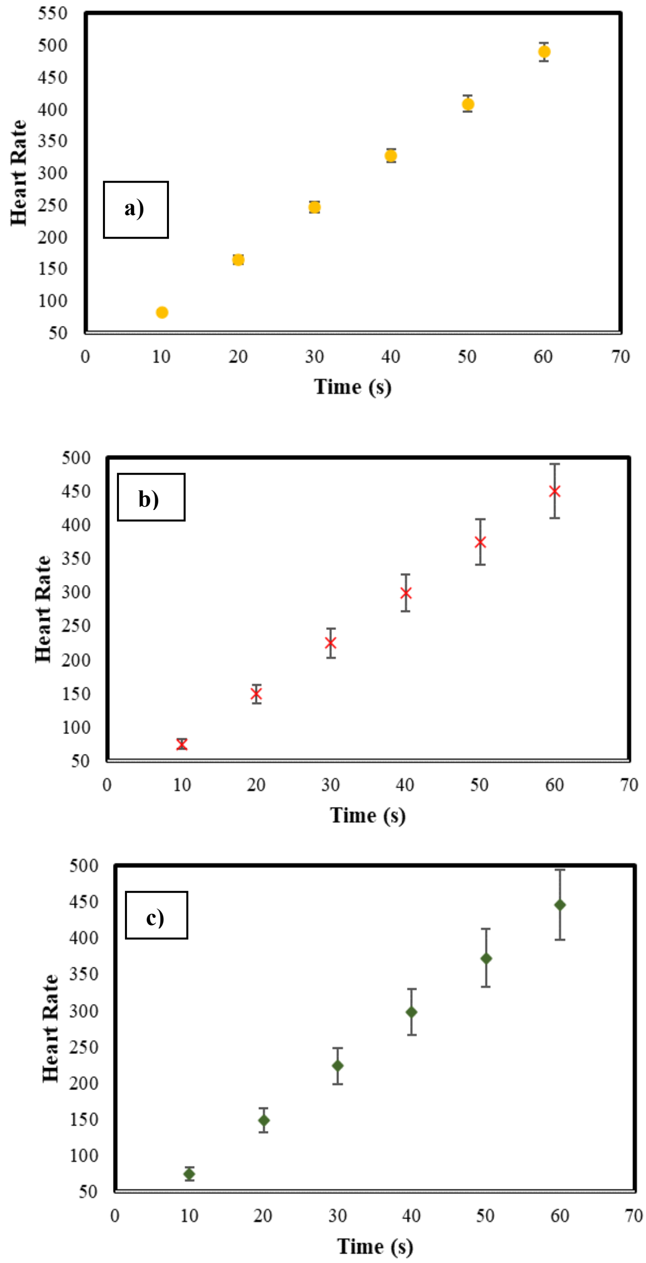



**Figure 4.** Heart rate of *Daphnia magna* exposed to different during the first 60 seconds chemicals (a-CV, b-E, and c-F)

Heart dimensions were compared during heart contraction in all chemical exposures (CV, E, and F) and significant differences were found in heart contraction ratios compared to the control group ($F(3,39)=1044.21$, $p<0.001$). The mean heart contraction ratio in the control group was found to be 4.28%. In contrast, a 23.19% increase in heart contraction ratio was observed in daphnids exposed to CV (Figure 5). Furthermore, differences of 38.59% and 12.77% were found in daphnids exposed to ethanol and formaldehyde, respectively. The highest difference compared to the control group was observed with ethanol exposure. Ethanol, isopropanol, and carbon dioxide can easily pass through cell membranes due to their lipophilic properties (Major *et al*., 2010). Therefore, the effects on the heart of daphnids are thought to be primarily caused by changes in cell membrane viscosity. Allen *et al*. (2019) tested the hypothesis that nicotine would raise the *Daphnia* sp. heart rate, while cannabidiol water would lower it, similar to how these drugs affect humans, because *Daphnia* sp. hearts have been shown to respond similarly in the presence of specific drugs. Their results neither supported nor contradicted the original hypothesis.

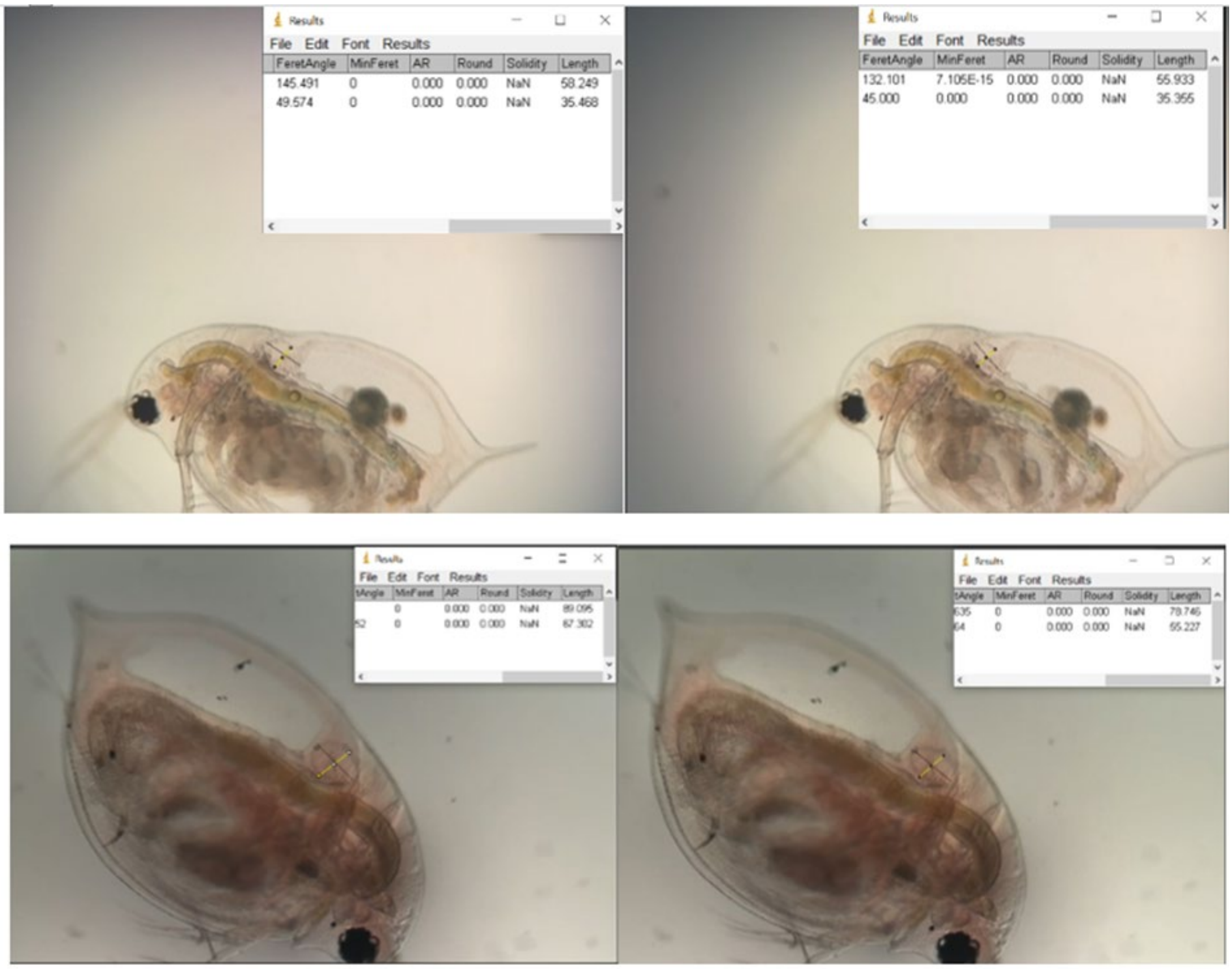



**Figure 5.** Detection of heart rates in daphnids using images obtained with the ImageJ software for a) control group and b) the group exposed to CV.

Lari *et al*. (2017) studied the effects of cadmium (Cd), suspended particles, and food on the beating rate of thoracic limbs and the frequency of mandible rolling in *Daphnia magna*. Their objective was to create an efficient method for simultaneously measuring all three endpoints on a single individual, which would enhance the reliability of the results. They presented an effective tool for assessing heart rate, thoracic limb movement, and mandible rolling with minimal stress for the test animals, enabling easy handling and adjustment of the test *Daphnia*'s position while reducing the time needed to perform the tests. Kwon *et al*. (2021) discovered that monitoring heart rate in real-time under aquatic conditions could enhance the accuracy of toxicity evaluations.

Bedrossiantz *et al*. (2023) exposed zebrafish, Japanese medaka, and *Daphnia magna* to sub-NOAEC concentrations of carbaryl and fenitrothion for 24 hours to evaluate their effects on heart rate (HR), basal locomotor activity (BLA), visual motor response (VMR), startle response (SR), and habituation. Both pesticides caused an increase in heart rates across all species, with the magnitude of the effect varying depending on the chemical, concentration, and organism.

In a study conducted by Kaas *et al*. (2009), ethanol was found to significantly reduce the heart rate of *Daphnia* sp. In the present study, a lower ethanol concentration was used compared to the previous study, and the exposure duration was extended. It has been noted that ethanol exhibits a stimulatory effect at low doses and an inhibitory effect at high doses, a phenomenon known as "biphasic" (Earleywine and Martin, 1993). The stimulatory effect of the low dose used in this study, which increased the heart rates of *Daphnia* sp., contrasts with the inhibitory effect of the high dose used in Kaas *et al*. (2009), which significantly reduced heart rates. This suggests that the findings of the previous studies are complementary and supportive of the results of this study.

A similar observation was made in a study by Bownik and Stępniewska (2015), where *Daphnia* species exposed to formaldehyde for longer durations (24-48 hours) exhibited a significant reduction in heart rates. As seen in Figure 3, this study, which reflects entirely acute (sudden) changes, demonstrated that formaldehyde at a concentration of 1 ppm significantly increased heart rate within the first 130 seconds. Considering this, it can be suggested that formaldehyde exhibits a stimulatory effect during short-term exposure. Additionally, as formaldehyde is known to exhibit a biphasic effect similar to ethanol, it may have acted as a stimulant during low-dose and short-term exposure. The inhibitory effects observed in previous studies involving long-term and high-dose exposure further support this conclusion.

## 4. CONCLUSIONS

In environmental toxicity tests, it is possible to employ endpoints related to reproduction, physiological, and behavioral changes in addition to other commonly used endpoints such as immobilization and lethality. Heart rate is a direct indicator of stress levels in water flea species. The results of this study demonstrate that the *D. magna* model offers promising and sensitive endpoints for assessing environmental toxicity, including non-lethal effects. The potential adverse outcomes observed after short-term exposure to low environmental concentrations of chemicals (i.e., below NOAEC values) underscore the importance of incorporating additional toxicological endpoints. These results highlight the necessity of integrating parameters such as behavioral responses or cardiac activity into predictive risk assessment methodologies. The wide range of endpoints presented concerning water flea applications further emphasizes its future potential.

## AUTHORSHIP CONTRIBUTION STATEMENT

**Arda Sarp KARADEMİR:** Conceptualization, Methodology, Microscopy, Formal Analysis, Visualization. **Melisa CAN:** Methodology, Formal Analysis. **Vildan Zülal SÖNMEZ:** Validation, Writing - Original Draft, Writing-Review and Editing**. Nüket SİVRİ:** Resources, Writing-Review and Editing, Supervision.

## CONFLICT OF INTERESTS

The author(s) declare that for this article they have no actual, potential or perceived conflict of interests.

## ETHICS COMMITTEE PERMISSION

No ethics committee permissions is required for this study.

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# The Effects of Digital Fatigue on Mental Health in Seafarers: Delphi and Multiple Regression Analysis

# Gemi Adamlarında Dijital Yorgunluğunun Mental Sağlık Üzerindeki Etkileri: Delphi ve Çoklu Regresyon Analizi

Türk Denizcilik ve Deniz Bilimleri Dergisi

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## ABSTRACT

The process of digitalisation has been found to exert a considerable influence on the mental wellbeing of those engaged in maritime activities, as well as on the prevalence of digital fatigue. The aim of this study is to analyse the effects of digital fatigue on seafarers' mental health. In the study, the data collected through questionnaires were subjected to analysis using regression analysis and the Delphi method. The findings indicate that prolonged screen use, an intensive digital workload, irregular sleep patterns and social isolation are the primary factors contributing to an increased prevalence of mental health issues among seafarers. In particular, digital communication and screen exposure have been identified as having a detrimental impact on mental health. Furthermore, it was determined that the implementation of stress management and psychological support mechanisms can effectively mitigate the adverse effects observed. The participants were predominantly young and had extensive experience with digital technology. Of the 150 seafarers who took part in the study, 70% were male and aged between 26 and 35 years. The findings indicate the necessity for strategic approaches to the management of the psycho-social risks associated with digitalisation. From the findings, only stress management indicates a negative correlation. These include the limitation of digital device usage, the implementation of social support programmes and the introduction of measures for stress management. These results are of significant value to ship-owning companies and maritime authorities, providing guidance on the protection of seafarers' mental health and the reduction of digital fatigue.

**Keywords:** Digital fatigue, Mental health, Seafarers, Maritime businesses, Regression analysis, Delphi

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**ÖZET**

Dijitalleşme, gemi adamlarının zihinsel sağlığı ve dijital yorgunluk düzeyleri üzerinde önemli etkiler yaratmaktadır. Bu çalışmanın amacı, dijital yorgunluğun gemi adamlarının zihinsel sağlığı üzerindeki etkilerini analiz etmektir. Araştırmada, anket yoluyla toplanan veriler regresyon analizi ve Delphi yöntemiyle değerlendirilmiştir. Bulgular, uzun süreli ekran kullanımı, yoğun dijital iş yükü, düzensiz uyku ve sosyal izolasyonun, gemi adamlarının zihinsel sağlık sorunlarını artıran başlıca faktörler olduğunu göstermektedir. Özellikle dijital iletişim ve ekran maruziyeti, zihinsel sağlık üzerinde olumsuz etkilere sahiptir. Ayrıca, stres yönetimi ve psikolojik destek mekanizmalarının bu etkileri hafifletmede olumlu katkı sağladığı tespit edilmiştir. Katılımcılar çoğunlukla genç ve dijital teknolojiye yoğun şekilde maruz kalan bir grup olup, araştırmaya katılan 150 gemi adamının %70'i erkek ve 26-35 yaş aralığındadır. Bulgulardan sadece stres yönetimi negatif korolasyona işaret etmektedir. Bulgular, dijitalleşmenin getirdiği psiko-sosyal risklerin yönetimi için dijital cihaz kullanımının sınırlandırılması, sosyal destek programlarının uygulanması ve stres yönetimine yönelik önlemler alınması gibi stratejik yaklaşımları önermektedir. Bu sonuçlar, gemi sahibi şirketler ve denizcilik otoriteleri için gemi adamlarının zihinsel sağlığını koruma ve dijital yorgunluğu azaltma konularında yol gösterici niteliktedir.

**Anahtar sözcükler**: Dijital yorgunluk, Mental sağlık, Gemi adamları, Denizcilik işletmeleri, Regresyon analizi, Delphi

## 1. INTRODUCTION

The maritime sector is one of the cornerstones of global trade, with more than 80% of world trade conducted by sea. This sector is undergoing a significant transformation process with constantly developing technologies and digital transformation processes (Arıcan *et al*., 2022). While digitalization aims to ensure that maritime operations are carried out faster, more efficiently and safely, it also affects the workload and mental health of seafarers (Hirata *et al.,* 2022). The term "digital technology" is used to describe a range of tools that enable the compression of large amounts of information into smaller storage devices that can be easily protected and transported (Mustafaoglu and Yasacı, 2018). Mental burden refers to the cognitive and emotional strain caused by excessive demands on an individual's mental resources, such as prolonged concentration or multitasking (Eaton *et al*, 2008). Over-reliance on technology, on the other hand, describes a dependency on digital tools and systems to the extent that it diminishes critical thinking, problem-solving abilities, or overall efficiency in the absence of these technologies. The pervasive use of digital technologies across a multitude of domains and the acceleration of communication processes in the contemporary era have collectively elevated the significance of these devices in people's lives (Pullen, 2009). Technological developments, including tablets, smart watches, smart televisions, computers, mobile phones and the internet, have become integral to the daily lives of individuals. This has had a significant impact on the way people communicate, learn and work. Maritime digitalization covers many technologies from ship management systems to bridge equipment, from electronic navigation systems to remote monitoring and management platforms (Arıcan *et al*., 2023). These technological developments have both transformed the way seafarers do business and increased their mental burden and brought the concept of digital fatigue to the agenda. Digital fatigue is defined in the literature as physical, mental and emotional exhaustion resulting from continuous and intense exposure to digital devices.

Digital fatigue can cause seafarers to lose focus, have difficulty concentrating and make mistakes in their daily operations. Constant use of digital devices disrupts sleep patterns, leading to loss of attention and fatigue, while social isolation and increased stress levels can cause seafarers to feel psychologically exhausted. Seafarers' failure to protect their mental health also risks their long-term work performance and the safety of maritime operations (Amanuel, 2023). For seafarers, especially long watchkeeping, continuous use of electronic devices and the information load brought by technology come to the fore as factors that increase digital fatigue. Technologies such as E-Navigation systems, advanced radar and automatic identification systems (AIS), Electronic Chart Display and Information System (ECDIS) have made the work of seafarers more complex. Table 1 shows the devices and systems related to maritime digitalization. Increasing digitalization keeps seafarers in front of the screen more and more, which may adversely affect mental health (Ichimura *et al.,* 2022). In recent years, an increase in ship accidents has been observed; 4.81% of these accidents are attributed to human factors such as cognitive overload and perception disorders caused by digital devices (Fan *et al.*, 2020). In recent years, an increase in ship accidents has been observed, with 4.81% attributed to human factors such as cognitive overload and perception disorders caused by digital devices (Fan et al., 2020). These challenges highlight the broader impact of digital fatigue, which not only increases the likelihood of distraction, wrong decisions, and timing errors during navigation but also contributes to mental health challenges such as stress and burnout among seafarers. Thus, digital fatigue emerges as a significant risk factor for both individual well-being and operational safety, underlining the need for targeted interventions.

While digitalization is expected to make maritime operations more efficient, over-reliance on these technologies can increase human errors. The continuous use of technological devices may disrupt the sleep patterns of seafarers and negatively affect their concentration. This situation has negative effects on mental health in the long term and may cause psychological problems such as depression and anxiety (Miseviciene *et al.,* 2020).

**Table 1.** Systems that can increase the effects of maritime digitalisation processes on seafarers

| Technology | Function | Effect on the seafarer |
|---|---|---|
| ECDIS | Provides ease of navigation | High attention span and long screen time |
| AIS | Continuously monitors vessel positions | Information overload, digital tracking obligation |
| | Monitors the ship's performance and operations | Constant supervisory pressure, performance anxiety |
| Radar and bridge technologies | Improves navigational safety | Information overload, mental fatigue |
| Remote ship management | Monitoring and management of ship operations from coast | Feeling of being under control, pressure in decision-making processes |
| Main machine control panels | Monitoring of critical parameters such as speed, power, operating status and temperature of the engine. | High attention span and long screen time |
| Integrated Automation System (IAS) | Monitoring and control from a central control panel. It provides control of engines, boilers, cooling systems and other auxiliary devices. | High attention span and long screen time |

New demands and increasing operational pressures in the maritime industry due to digitalization have introduced several risk factors that can harm not only the physical but also the mental health of seafarers. Accident analyses conducted over the past decade reveal a significant rise in ship accidents (Karabacak and Köseoğlu, 2021). It was determined that 4.81% of the factors contributing to marine accidents were due to cognitive overload (from computers, electronic navigational instruments, and digital documentation) (Fan *et al.,* 2020). Xue *et al.* (2021) further elaborates that fluctuating environmental factors, combined with human error, significantly contribute to ship accidents, corroborating the role of cognitive overload and absent-mindedness in seafarer-related incidents. Alongside the innovations that digitalization brings to seafarers' work processes, the pressures it places on their mental health are significant.

Wang *et al.* (2021) highlight that both environmental conditions and human errors significantly impact the severity of maritime accidents, aligning with the observed cognitive overload and perception issues in seafarers. These analyses show that absent-mindedness, sleep disorders, and perception issues are prominent in personnel-related accidents (Amanuel, 2023).

The concept of digital fatigue has been studied, particularly in the education system, in relation to the negative effects of online learning on mental health (Romero-Rodríguez *et al.,* 2023). In this context, it is possible to conclude that seafarers' continuous work with digital systems may lead to similar fatigue. The intensive use of digital devices not only negatively affects individuals' mental health but also reduces the performance of those in critical roles, such as healthcare professionals (Hilty *et al.,* 2022). At this point, digital mental health practices are considered an effective solution to combat digital fatigue and burnout (Borghouts *et al.,* 2021).

Digital addiction and digital fatigue have been shown to be manageable during extraordinary situations, such as the COVID-19 pandemic, by developing strategic approaches (Gregersen *et al.,* 2023). During the pandemic, burnout symptoms became widespread due to individuals' excessive use of digital devices, which has shaped much of the research in this field. Similarly, social media fatigue emerged as a common issue, where constant online presence caused stress and anxiety (Suni *et al.,* 2022). This demonstrates that digital fatigue is not only limited to work processes but also negatively impacts social life.

During the COVID-19 pandemic, digital fatigue became a major concern, particularly among academics and other professionals. Ghasemi *et al.* (2021) reported that the mental health of academics deteriorated, and their fatigue levels increased during the pandemic, with continuous use of digital devices being a primary cause.

With the rapid rise of digitalization, social media fatigue has also become a serious issue in the daily lives of individuals. Excessive digital device usage, particularly during the pandemic, led to disruptions in work-life balance and increased mental fatigue (Murtaza and Molnár, 2024). Social media fatigue highlights how the constant need to be online and engage in digital interactions can negatively impact psychological well-being. Bhati *et al.* (2022) found that social media fatigue is particularly prevalent among female students and that it negatively affects academic performance. These findings reveal that digitalization deeply influences not only professional environments but also educational and personal lives. In this context, the digital fatigue of seafarers needs to be objectively measured and assessed (Kunasegaran *et al.,* 2023). Such assessments play a critical role in monitoring and improving the mental health of seafarers. For individuals such as seafarers, who are continuously exposed to digital devices, such fatigue symptoms may lead to a severe decline in mental health and cognitive functions.

Although digitalization enhances operational efficiency in the maritime industry, it also introduces challenges that may negatively impact the mental health of seafarers. While digital technologies such as secure E-Navigation systems and sea surface communication make maritime operations more efficient, they also impose additional stress on workers (Usluer, 2024). Therefore, more research and strategies are needed to better understand and mitigate the effects of digitalization on seafarers. The Delphi and Multiple Regression Analysis methods used in this study are important in terms of deeply examining the effects of digital fatigue and determining the main factors affecting the mental health status of seafarers. While the Delphi method is used to ensure consensus among experts on the criteria affecting digital fatigue, Multiple Regression Analysis allows us to understand the relative effects of these criteria on digital fatigue. These methods enable a clearer analysis of the factors affecting the digital fatigue level of seafarers.

While digital fatigue has been extensively studied in other sectors, its specific impact on maritime professionals remains largely unexplored. Unlike land-based professions, seafarers face unique challenges such as prolonged isolation, irregular work hours, and high-stakes decision-making, all of which can exacerbate the effects of digital fatigue. This research aims to address this gap by investigating how digital fatigue influences the mental health and operational efficiency of seafarers, offering insights that are critical for improving their well-being and enhancing maritime safety.

The structure of this article is as follows: Section 2 will discuss digital fatigue and its effects on seafarers' mental health. Section 3 presents the impact of digitalization on seafarers' working conditions and a literature review of related studies. Section 4 provides a detailed summary of the methodologies employed, such as the Delphi method and multiple regression analysis. The findings are outlined in Section 5, analysing the effects of digital fatigue on seafarers' mental health. Section 6 discusses the operational and human resource implications of these results for the maritime industry. Finally, Section 7 offers recommendations for mitigating the potential risks of digitalization on seafarers' health and insights for future research.

## 2. FATIGUE AND ITS EFFECTS ON MENTAL HEALTH

### 2.1. Digital Fatigue

Digital fatigue is a state of mental, emotional and physical exhaustion caused by continuous and intense exposure to digital devices. This concept is associated with problems such as distraction, information overload and cognitive overload, especially caused by prolonged use of digital screens (Aulia and Asbari, 2023). With the rapid development of the digital age, dependence on technological devices and online interaction times have increased dramatically. Studies show that many people experience digital fatigue from being online all the time, especially as a result of the widespread use of working from home due to the COVID-19 pandemic (Twenge *et al.,* 2018). For example, distraction and difficulty focusing during online meetings can negatively affect employees' work performance and mental health. Bailenson (2021) from Stanford University addresses ‘Zoom fatigue’ caused by online meetings, emphasising that being constantly in front of the screen creates an intense mental burden on individuals. In addition, digital fatigue can also reduce the enjoyment of other activities in daily life. People feel compelled to stay connected to their smartphones even after work, which can put pressure on their personal time and cause physical and mental burnout (Ayyagari *et al.*, 2011). Thus, as the time spent with digital devices increases, individuals' social relationships, sleep patterns and overall happiness levels are also affected (Exelmans *et al.*, 2016). Digital fatigue, a growing issue, refers not only to the physical strain caused by long hours of screen use but also to the mental and emotional exhaustion arising from information overload and the constant need for digital vigilance (Ghasemi *et al.,* 2021). The rise of digital technologies in maritime operations, while improving efficiency, has also resulted in new stressors for seafarers. This phenomenon is particularly relevant in the maritime sector, where seafarers must operate advanced systems like IAS and continuously monitor ECDIS, radar systems, and AIS (Ichimura *et al.,* 2022).

In addition to the operational pressures, digital communication platforms—such as those used for remote ship management—add to the burden by requiring seafarers to stay connected and responsive at all times. This perpetuates feelings of being under constant supervision, which can heighten stress levels and lead to burnout (Usluer, 2024). Unlike traditional maritime operations where human judgment was paramount, modern systems demand continuous interaction with digital devices, leaving little room for mental respite. Moreover, the frequent alerts and alarms from these systems increase cognitive load and can detract from the seafarer’s focus on critical tasks, exacerbating mental fatigue (Fan *et al.,* 2020).

Research by Xu (2023) indicates that prolonged digital exposure directly correlates with mental health decline, noting heightened levels of anxiety, irritability, and sleep disorders among seafarers. These factors are further amplified during long voyages, where seafarers often lack social interaction, leading to isolation and an over-reliance on digital systems for both work and personal communication. Such isolation can intensify the effects of digital fatigue, making it a critical issue for the maritime industry to address.

Digital fatigue can lead to mental health problems in seafarers, such as increased stress, anxiety, and difficulty concentrating. Seafarers work under high cognitive load due to prolonged screen use and tasks that require constant monitoring. Research shows that digital fatigue reduces attention span and reduces work efficiency (Hilty *et al.,* 2022). For example, excessive use of digital devices can disrupt sleep patterns, which can lead to a decrease in work performance of up to 20% (Xu, 2023). In addition, the pressure to be constantly online increases stress levels in seafarers, deepening the feeling of mental burnout (Romero-Rodríguez *et al.,* 2023).

In this context, it is essential to develop robust strategies aimed at mitigating digital fatigue, including rotating watchkeeping patterns, limiting unnecessary digital exposure, and offering mental health support tailored to seafarers' unique working conditions (Hilty *et al.,* 2022). Table 2 below provides a summary of the key effects of digital fatigue on seafarers' mental well-being.

**Table 2.** The effects of digital fatigue on employees' mental health (Daniel *et al.,* 2022)

| Effect | Description |
|---|---|
| Stress level | Long screen times increase |
| Sleep pattern | Screen use impairs sleep |
| Work efficiency | Fatigue negatively affects |

### 2.2. Mental Health

Mental health is a state of emotional, psychological, and social well-being (Alonso *et al.,* 2016). This balance directly influences how a person thinks, feels, makes decisions, and interacts with the world around them. It also plays a critical role in abilities such as managing stress, overcoming challenges, and leading a productive life (Aulia and Asbari, 2023). For seafarers, mental health is particularly crucial due to stressors such as long voyages, limited social interaction, physical isolation, and changing weather conditions (Fu *et al.,* 2020). Individuals in this profession often work in confined, demanding environments, far from their families and social circles (Khodabakhsh *et al.,* 2021). Additionally, factors like watchkeeping work, disrupted sleep patterns, and tasks requiring constant attention can all negatively impact seafarers' mental health (Baygi *et al.,* 2022). Factors affecting the mental state of seafarers can be explained as age, marital status, loneliness, social isolation, being away from spouse and family, communication problems, boredom, burnout, stress, irregular and insufficient sleep, long and watchkeeping work, fatigue, spending time with ship personnel, intense workload, port inspections, insufficient shore leave, authoritarian hierarchy and mobbing on board, type of ship, piracy, traumatic events and work accidents (Baş and Doymuş, 2023). Within the maritime context, mental health is particularly significant due to the unique stressors seafarers face, including isolation, long working hours, exposure to digital technology, and the high-pressure environment of their work. These factors can lead to issues such as anxiety, depression, and burnout, which not only affect their personal well-being but also have operational implications for safety and efficiency at sea. Seafarers are particularly vulnerable to digital fatigue due to the constant reliance on digital systems for navigation, communication, and operational tasks, often coupled with the challenges of being in confined spaces and working irregular hours. This makes digital fatigue a critical issue that requires targeted strategies to mitigate its effects on mental health and safety at sea. Seafarers work under psychological pressure due to constantly changing environmental conditions, long watchkeeping and limited social interaction opportunities on board. This can lead to mental health problems such as loneliness, social isolation and depression. For example, fatigue resulting from long watchkeeping can lead to distraction and incorrect critical decision-making. These mental health problems can manifest themselves in daily work life as inattention, loss of focus and a tendency to make mistakes, increasing operational risks. The cumulative effect of these challenges makes it especially difficult for seafarers to maintain mental and psychological stability. Therefore, safeguarding the mental health of seafarers is vital not only for their well-being but also for ensuring the safety and efficiency of maritime operations. Stress management and psychological support strategies have been observed to play a critical role in alleviating digital fatigue and its effects on mental health in seafarers. Studies show that such strategies reduce individuals' stress levels and increase mental resilience (Borghouts *et al.,* 2021).

## 3. LITERATURE REVIEW

The first study examining the effects of digital fatigue on mental health was conducted by Fu *et al.* (2020). This research indicated that social media overload contributes to mental fatigue and burnout among individuals who excessively use information and system features. Stressor–strain–outcome method was used in their studies. Using this survey method, the study found that users overwhelmed by excessive information eventually reach a point where they abandon social media platforms. This finding underscores the importance of addressing mental health issues arising from intensive digital platform use.
Miseviciene *et al.* (2020) also explored the negative impacts of excessive digital technology use on health. Their research emphasized that "information fatigue" has severe consequences for mental well-being. The continuous influx of digital information was shown to exacerbate anxiety and burnout syndromes, increasing mental health problems. Like Fu *et al.,* this study used a survey to gather data, revealing that prolonged use of digital platforms is a significant contributor to digital fatigue, which seriously threatens mental health.
Tuncer and Levendeli (2022) focused on the mental and physical fatigue caused by excessive social network use in the digital communication age. Survey method and descriptive analysis were used in their studies. Their survey-based analysis revealed that the constant flow of interactions and notifications on social media platforms leads to mental overload, prompting individuals to reduce their usage. This finding highlights the role of social media platforms in creating mental fatigue through continuous interaction.
The relationship between digital addiction and sleep disorders was examined by Dresp-Langley and Hutt (2022). Clinical research and descriptive analysis were used in their studies. Their clinical research found that digital addiction disrupts sleep patterns, negatively impacting mental health. The study demonstrated that prolonged exposure to digital screens reduces sleep quality and triggers broader mental health issues.
Febreza and Junaidi (2022) investigated digital fatigue among university students, particularly in the context of online education. In their studies, 'selection and observation' and descriptive analysis were used as methods. Using selection and observation techniques, their study showed that prolonged screen exposure during online learning increased mental fatigue, reduced students' attention levels, and disrupted learning processes. This research highlighted the mental health challenges that arise from the watchkeeping to online education, particularly during the COVID-19 pandemic.
Aulia and Asbari (2023) conducted a qualitative descriptive study on the effects of digital fatigue on mental health. Qualitative descriptive study and descriptive analysis were used as methods in their studies. They found that digital fatigue leads to distraction, mental burnout, and anxiety, exacerbated by the growing use of digital media. The study stresses the importance of addressing digital fatigue's impact on mental health, particularly as media use increases.
Yasin *et al.* (2023) focused on the effects of smartphone overuse on mental fatigue and cognitive flexibility. Survey method and descriptive analysis were used in their studies. Their survey revealed that smartphone addiction contributes to mental fatigue and diminishes cognitive flexibility, underscoring the detrimental effects of digital fatigue on mental processes.
Finally, Singh and Pathak (2024) explored the increased screen time experienced by young people during the COVID-19 pandemic. Through qualitative and quantitative methods, their study found that this increased screen time led to mental health issues such as fatigue,

depression, and anxiety. The findings illustrate the long-term negative impacts of digital fatigue on the mental health of young individuals.

These studies collectively highlight the significant risks of digital fatigue on mental health, emphasizing the need to manage the overuse of digital technologies. Table 3 provides a summary of the key publications that form the basis of this study, outlining the gaps in the literature and underscoring the importance of further research in this area.

**Table 3.** Summaries of similar publications in the literature

| Author(s) | Publication year | Journal name | Title | Subject | Method | Main findings |
|---|---|---|---|---|---|---|
| Mustafaoğlu, *et al.* | 2018 | Nobel | The negative effects of digital technology usage on children's development and health | Negative effects of digital technology on health | Literature review | It was emphasised that excessive use of digital technologies can lead to physical and mental health problems in individuals. |
| Fu *et al.* | 2020 | Information Processing & Management | Social media overload, exhaustion, and use discontinuance: examining the effects of information overload, system feature overload, and social overload | System feature overload, information overload and social overload lead to individuals' social media fatigue. | Stressor–strain–outcome | System feature overload, information overload and social overload have been found to lead to user fatigue. |
| Miseviciene, *et al.* | 2020 | Education scientific conference | Impact of digital technologies on people health and means to avoid information fatigue | The effects of digital technologies on human health and ways to avoid information fatigue the relationship between digital fatigue and mental health | Survey | Excessive use of digital technologies leads to information fatigue, and it is recommended to apply information management techniques to avoid this situation. |
| Tuncer and Levendeli | 2022 | Selçuk iletişim | From connected individual to tired individual: social network fatigue in the age of digital communication | Social media fatigue in the age of digital communication | Survey | Excessive use of social networks creates mental and physical fatigue in individuals, which leads users to interact less. |
| Daniel and Aleksander | 2022 | Fusion of multidiscipline research; an international journal | Future facts: unveiling mental health issues in the digital age | Mental health issues in the digital age | Literature review | It has been emphasised that digital stress and the increase in screen time that individuals are exposed to in the digital age negatively affect the mental health of individuals. |
| Dresp-Langley and Hutt | 2022 | IJERPH | Digital addiction and sleep | Digital addiction and sleep disorders | Clinical research | It has been observed that digital addiction leads to disturbances in sleep patterns, and this has negative effects on general health. |

**Table 3.** Summaries of similar publications in the literature (continued)

| | | | | | | |
|---|---|---|---|---|---|---|
| Romero-Rodríguez *et al.* | 2023 | Education XXI Conference | Digital fatigue in university students because of online learning during the Covid-19 pandemic | Digital fatigue caused by online learning during the pandemic | Self-administered survey | It has been found that digital fatigue is a common problem among university students studying online during the pandemic. This fatigue negatively affected academic performance. |
| Xu | 2023 | WMU | Research on prevention and management of seafarer fatigue | Significance of fatigue management. | Document analyses | Investigate the use of fatigue detection devices and sleep monitoring devices on board ships, assessing their accuracy and applicability in the maritime sector. |
| Tutar and Mutlu | 2024 | Journal of Communication Theory and Research | Digital fatigue scale: Validity and reliability study | Validity and reliability study of digital fatigue scale | Factor analysis | It was found that the Digital Fatigue Scale (DFS) is a valid and reliable scale and has a high capacity to measure fatigue experienced in digital environments. |

Based on the findings from the aforementioned studies, it can be indirectly concluded that digital fatigue significantly impacts the mental health of employees and students across various sectors. However, there remains a notable gap in the literature regarding the specific relationship between digital fatigue levels and mental health among seafarers. This study aims to address this gap by providing a comprehensive examination of how digital fatigue affects the mental well-being of seafarers. By exploring this relationship in depth, the research seeks to contribute valuable insights that can inform strategies for mitigating the negative effects of digital fatigue within the maritime sector.

## 4. MATERIAL AND METHOD

In this study, two primary methods will be used to analyse the relationship between the digital fatigue levels of seafarers and their mental health: the Delphi Method and Multiple Regression Analysis.

### 4.1. Delphi Method

The Delphi method will be employed to determine the criteria for analysing the relationship between digital fatigue levels and mental health. This method is a well-established technique used in survey studies. By utilizing sequential questionnaires, it evaluates opinions in a non-adversarial manner and provides repeated feedback on the current state of the group's consensus. This process informs group members about the status of their consensus, helps identify issues that participants may have overlooked or considered unimportant, and allows them to revise their opinions (Keeney *et al.,* 2011). Unlike brainstorming techniques used in nominal group approaches, the Delphi method enables the collection of opinions without the need for participants to be physically present. This is particularly beneficial for improving communication among larger, diverse, and geographically dispersed groups, which is a limitation of other existing methods. Consequently, it allows for a broad range of perspectives to be expressed, forming a solid basis for the analysis. Additionally, it minimizes psychological influences such as conformity to dominant views or social pressures, fostering independent thinking and the gradual development of reliable judgments (Linstone, 1979).

In Delphi applications, different consensus levels and scoring methods are employed based on sample size, research purpose, and available resources (Ndour *et al.,* 1992; Dalkey and Helmer, 1963; Hasson *et al.,* 2000). Similar to the study conducted by Hasson *et al.,* this research will use a 75% agreement rate and a scoring system ranging from 1 to 5. A total of 8 experts from maritime companies and organizations conducting psychological assessments of ship personnel will be selected for the questionnaire study. These experts were chosen because they have directly worked with ship personnel or have conducted assessments on their mental health and performance, which is considered crucial for the questionnaire's applicability. Their experience contributes to the realistic and relevant results of the survey questions. Experts were also used to identify the main factors used as independent variables. All selected experts work in marine psychology and ship management departments, possess at least ten years of industry experience, and are recognized as specialists in their fields. They included senior managers from maritime companies, psychologists specializing in occupational mental health, and maritime safety experts with a deep understanding of the challenges faced by seafarers. Their diverse backgrounds and roles in the industry ensured that the Delphi process was informed by a well-rounded perspective, allowing for more accurate and comprehensive insights into the mental health and digital fatigue issues affecting maritime professionals. The characteristics of these experts are detailed in Table 4. The 8 experts selected for the Delphi method were chosen based on their extensive experience in maritime operations, psychology, and mental health

**Table 4.** Profile of experts

| Expert | Area of expertise | Specialised area | Working time (Year) |
|---|---|---|---|
| Expert 1 | Psychologist | SMCPC * | 11 |
| Expert 2 | Ship management | SFM** | 12 |
| Expert 3 | Psychologist | SMCPC | 11 |
| Expert 4 | Ship management | SFM | 15 |
| Expert 5 | Ship management | SFM | 11 |
| Expert 6 | Psychologist | SMCPC | 14 |
| Expert 7 | Ship management | SFM | 15 |
| Expert 8 | Psychologist | SMCPC | 12 |

SMCPC*: Seafarers and maritime companies psychological counselling, SFM**: Ship and fleet management

The Delphi Method is a research technique that allows participants to anonymously share their views and work towards consensus through multiple rounds of feedback. This method is particularly effective for gathering expert opinions and supports decision-making processes on complex issues. In this study, the Delphi Method will be implemented according to the steps illustrated in Figure 1:

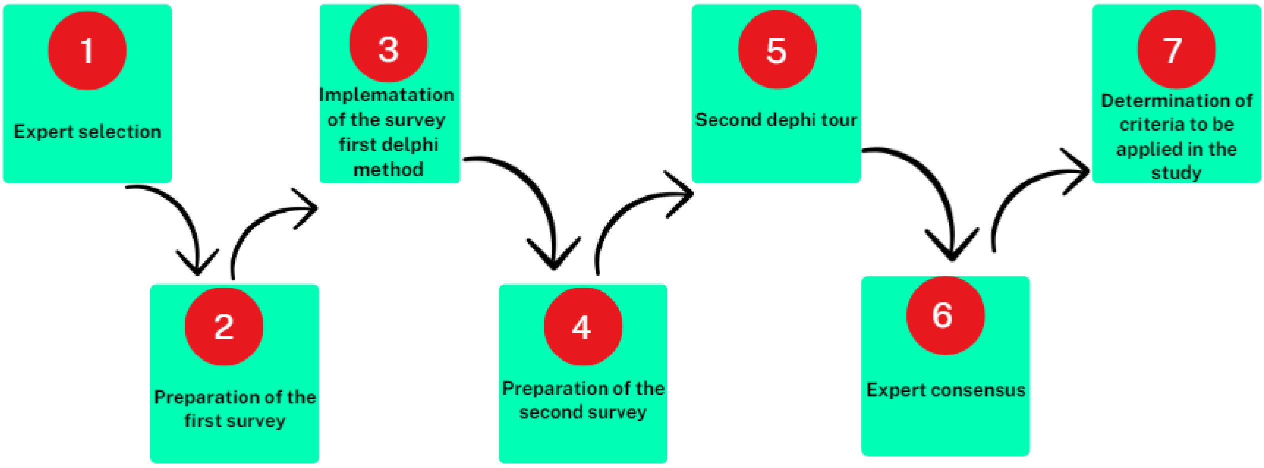


**Figure 1.** The flow of the Delphi method used in the study

### 4.2. Multiple Regression Analysis

Multiple regression analysis is a statistical method used to examine the relationship between a dependent variable and more than one independent variable (Montgomery *et al.,* 2021). Multiple regression analysis is a statistical method used to explore the relationship between a dependent variable (mental health) and multiple independent variables (such as digital fatigue, sleep patterns, screen time, and work hours). In this study, multiple regression analysis was employed to assess how various factors related to digital fatigue contribute to changes in mental health outcomes among seafarers. This method provides insight into the specific impact of digital technology usage on mental well-being, which is crucial for understanding and addressing mental health challenges in the maritime context. In this study, the dependent variable will be the mental health of seafarers, while the independent variables will be the factors affecting digital fatigue.

The mathematical expression of the Multiple Linear Regression model is expressed in equation (1).

$$Y = \beta_0 + \beta_1.X_1 + \beta_2.X_2 + \ldots\ldots\ldots + \beta_k.X_k + \varepsilon \qquad (1)$$

In this formula, $\beta_0$ and $\beta_1$ are unknown parameters of the model. ε is the error term and Y is the observable dependent variable, and X is the observable independent variable values (Seber and Lee, 2012). Karabulut and Şeker used the Multiple Linear Regression Analysis model as in equation (1) in their study in 2018 (Karabulut and Şeker, 2018). In this study, the Multiple Linear Regression Analysis model was used in a similar way. The reason for using this model is that it is accepted in the literature and is used as a powerful tool for understanding complex relationships in health and accident analyses, identifying risk factors and developing preventive strategies. In this study, the data collected through the questionnaire will be analysed with the stages in Figure 2:

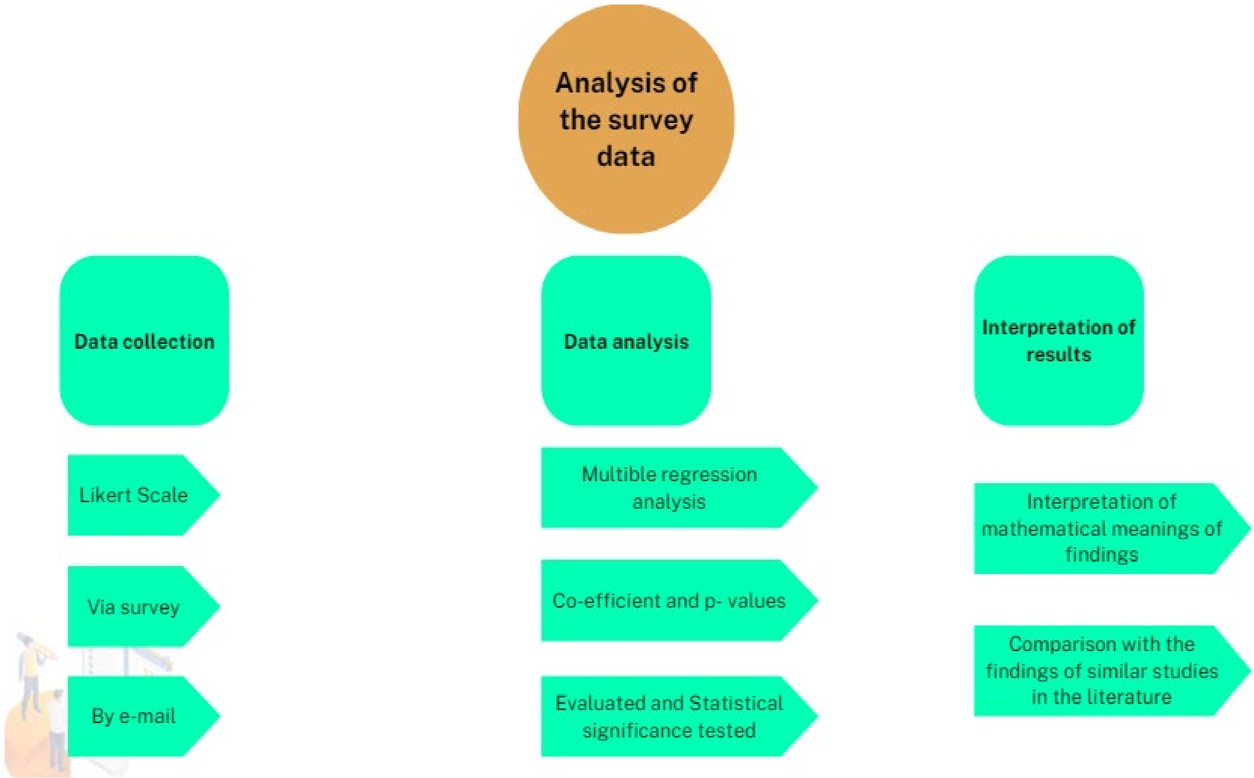


**Figure 2.** Diagram of the analysis of survey data

### 4.3. Questionnaire Form

The questionnaire utilized in this study was designed to assess the effects of digital fatigue and mental health among seafarers. It was based on the "Digital Burnout Scale," developed by Erten and Özdemir (2020) in their "Digital Burnout Scale Development Study." Cronbach's alpha (reliability analysis) coefficient was reported to have high internal consistency (0.957). Before administering the questionnaire to seafarers, it was tested for logical compatibility within the maritime context to ensure its relevance. For parametric tests to be applicable, conditions such as the normal distribution of data, random sampling, and similar subgroup variances must be met. However, beyond meeting statistical requirements, it is crucial that the data accurately reflects reality, as the primary purpose of scientific research is to generalize findings about a population by studying a sample representative of that population (Altunışık, 2008).

After the questionnaire was prepared, it underwent a pre-test on a sample of 30 individuals to evaluate its reliability and the consistency of the questions. Cronbach's alpha reliability coefficient was employed to measure this reliability. Cronbach's alpha reliability coefficient was 0.915 in the pre-test. Following this, the finalized questionnaire was distributed to seafarers for data collection.

The questionnaire consists of two main parts, totalling 29 questions. The first section consists of 5 questions aimed at collecting demographic information including age, gender, job position, income status and sea experience. The second part includes 24 questions using a 5-point Likert scale, focusing on factors affecting the digital fatigue and mental health levels of seafarers. Participants are asked to share their views on issues such as digital ageing, digital deprivation and emotional exhaustion. Confidentiality of participants will be maintained throughout the process, and the data collected will be analysed in the findings section of the study.

## 5. FINDINGS

### 5.1. Delphi Results

In the group discussions utilizing the Delphi method, participants were asked to evaluate 28 factors affecting digital fatigue and mental health. The experts provided their opinions on these criteria, and all criteria along with their average scores are presented in Table 5. Five criteria with an average score of 4 and above were identified as significant. Among these criteria, factors such as digital screen usage time, digital workload, the impact of sleep patterns, stress management, and the effects of social isolation were found to be crucial for protecting mental health. This process helped establish the main variables of the study.

As indicated in Table 5, digital screen usage time (4.50) and digital workload (4.33) emerged as key contributors to digital fatigue. In contrast, the effects of stress management (4.37) and sleep patterns (4.75) were highlighted as crucial for maintaining mental well-being. Additionally, the impact of social isolation (4.58) was noted as a significant concern, further emphasizing the relevance of digital-related work environments to seafarers' mental health. These five factors were identified as the most critical regarding digital fatigue and mental health, forming the core areas for further analysis in this research. Table 5 provides a detailed breakdown of these findings, including the means, standard deviations, and quartile distributions of the key variables. This statistical analysis offers a clearer understanding of the factors contributing to digital fatigue and their relationship to seafarers' mental health.

**Table 5.** Scoring of criteria as a result of delphi survey

| Criteria | Means | Standard deviation | $Q_3$%75 | Median | $Q_1$%25 | Quarter width |
|---|---|---|---|---|---|---|
| Sleep patterns | 4.75 | 0.62 | 5 | 5 | 5 | 0 |
| Digital display Duration of use | 4.50 | 0.67 | 5 | 5 | 4 | 1 |
| Type of digital devices | 3.08 | 0.67 | 3.75 | 3 | 3 | 0.75 |
| Digital workload | 3.25 | 1.29 | 4.75 | 3 | 2.25 | 2.5 |
| Use of artificial intelligence and automation | 3.59 | 0.77 | 4 | 4 | 3 | 1 |
| Personal information security concerns | 3.17 | 0.72 | 4 | 3 | 3 | 1 |
| Working hours and overtime | 3.92 | 0.90 | 4.75 | 4 | 3.25 | 1.5 |
| Accessibility of digital communication tools | 3.17 | 0.72 | 4 | 3 | 3 | 1 |
| Internet connection quality | 3.42 | 1.00 | 4 | 3 | 3 | 1 |
| Business processes and procedures | 2.75 | 0.87 | 3 | 3 | 2 | 1 |
| Outdoor activities | 3.07 | 0.66 | 3.76 | 3 | 3 | 0.75 |
| Outdoor or indoor work | 3.58 | 0.79 | 4 | 4 | 3 | 1 |
| Personal support systems | 3.25 | 1.29 | 4.75 | 3 | 2.25 | 2.5 |
| Stress management effect | 4.37 | 0.64 | 5 | 4 | 4 | 1 |
| Access to psychological support training and development | 3.21 | 0.71 | 4 | 3 | 3 | 1 |
| Opportunities | 3.92 | 0.90 | 4.75 | 4 | 3.25 | 1.5 |
| job satisfaction | 3.41 | 0.75 | 4 | 3 | 3 | 1 |
| Job security concerns | 3.28 | 0.72 | 4 | 3 | 3 | 1 |

**Table 5.** Scoring of criteria as a result of delphi survey (continued)

| | | | | | | |
|---|---|---|---|---|---|---|
| Mental health status | 2.83 | 0.72 | 3 | 3 | 2 | 1 |
| Working groups and team dynamics | 3.42 | 1.00 | 4 | 3 | 3 | 1 |
| Management and leadership style | 3.92 | 0.90 | 4.75 | 4 | 3.25 | 1.5 |
| Device usage time | 3.17 | 0.72 | 4 | 3 | 3 | 1 |
| Digital communication intensity | 3.21 | 0.73 | 4 | 3 | 3 | 1 |
| Digital technology proficiency level | 3.41 | 0.75 | 4 | 3 | 3 | 1 |
| Digital workload | 4.33 | 0.89 | 5 | 5 | 3.25 | 1.75 |
| social isolation | 4.58 | 0.67 | 5 | 5 | 4 | 1 |

## 5.2. Demographic Structure

The questionnaire used in this study was administered to 150 participants to assess the effects of digital fatigue and mental health among seafarers. According to Dolsen and Maclis (1991), a response rate exceeding 65% from questionnaires sent to participants is considered sufficient for meaningful contributions to survey studies. In this research, a target of at least 200 seafarers was set, and a response rate of 75% was achieved, resulting in 150 completed responses. This sample size is deemed adequate for interpreting the findings. Additionally, Tavşancıl and Keser (2002) state that the sample size for applying factor analysis should be at least five times the number of items on the scale. With 20 questions in the questionnaire, the sample size comfortably surpassed the minimum requirement of 100 participants.

Demographic information about the participants and findings related to digital device usage are presented in Table 6. The table 6 reveals that the majority of respondents (40%) fall within the 26–35 age group, with a significant male representation (70%). Participants' roles varied, with most being deck or engine officers (40%), followed by chief engineers (35%). Notably, 45% of participants had less than five years of experience, indicating a relatively young workforce among the sample.

**Table 6.** Demographic information

| Demographic criteria | Options | Percentage (%) |
|---|---|---|
| Age group | 18-25 | 30 |
| | 26-35 | 40 |
| | 36-45 | 30 |
| Gender | Female | 30 |
| | Male | 70 |
| Working position | Master | 25 |
| | Chief engineer | 35 |
| | Deck/Engine officers | 40 |
| Experience duration | 0-5 year | 45 |
| | 6-10 year | 30 |
| | 11 year and over | 25 |
| Income status | High | 30.5 |
| | Middle | 69.5 |

The analysis of the factors related to screen usage time, stress management, social communication, digital workload and sleep patterns, which are the titles of the main sections of the survey, according to the findings of the survey, is given in Table 7 with explanations.

**Table 7.** Explanation of the factors according to the survey results of the analysis.

| Factor | Description |
|---|---|
| Digital screen usage time | 35% of the participants use digital devices for an average of 4-6 hours a day, 30% for 1-3 hours, 20% for 7-9 hours, and 15% for more than 10 hours. The most frequently used digital devices are computers (80%), smartphones (65%), and tablets (40%). |
| Stress management | 60% of the participants stated that they have been frequently feeling stressed recently, while 25% mentioned that they experience this occasionally. Regarding the effect of digital device use on mental health, 55% of the participants indicated that this effect is at a moderate level, while 25% reported it as being very high. Attention deficit" was found by 65%. The rate of those who said they were stressed was 52.3%. |
| Social isolation | 35% of the participants stated that social isolation in digital technologies is at a moderate level. The other 65% of the participants stated that it is at a low level. Feel lonely when they do not have their digital devices is %31. The rate of those who feel restricted is 35%. |
| Digital workload | 40% of the participants evaluated the workload as intense. 35% of the participants who evaluated the effect of task variety found this very impressive. |
| Sleep patterns | 65% of the participants stated that sleep disorders are high. It was stated that 25% of them were normal and 10% of them had the highest level of sleep disturbance. |

The key factors examined in the questionnaire—digital screen usage time, stress management, social isolation, digital workload, and sleep patterns—are critical in understanding digital fatigue and its impact on mental health. These factors are explored in Table 7, which provides detailed explanations based on the survey results. About 35% of the participants reported using digital devices for an average of 4–6 hours per day, while 15% indicated usage of over 10 hours per day. The findings revealed that 60% of participants frequently felt stressed, with 55% attributing this to digital device usage. Social isolation was reported as a moderate issue by 35% of participants, though the majority (65%) rated it as a low-level concern. This discrepancy suggests that while digital technology can contribute to isolation, it may not be the most pressing issue for most respondents. As an important finding in table 7, 65% of the respondents agreed or strongly agreed with the question "I have attention deficit". Similarly, the rate of those who said that they felt stressed was 52.3%. The number of people who felt restricted was 35%. The number of respondents who said that they feel lonely when they do not have their digital devices (phone, tablet, computer, etc.) with them is 31%. Around 40% of participants rated their digital workload as heavy, with 35% indicating that the diversity of tasks was a significant factor in contributing to mental strain. This shows that while workload is a key stressor, task variety also plays a crucial role in overall digital fatigue. The survey found that 65% of participants experienced significant sleep patterns, underscoring the strong connection between digital device use and sleep disruption.

### 5.3. Regression Analysis Results

Regression analysis was conducted to examine the relationship between digital device use and mental health status. In order to utilize Formula (1), the values included as independent variables have the following meanings. Independent variables $\beta_0$: constant term (average mental health score), $\beta_1$: Effect of Digital Screen usage time, $\beta_2$: Effect of digital workload, $\beta_3$: Effect of sleep pattern, $\beta_4$: Effect of stress management, $\beta_5$: Effect of social isolation, $\in$: Error term. The effects of the values determined in the questionnaire and the independent variables calculated with the help of formula (1) on mental health are presented in Table 8 in single, double, triple, quadruple and quintuple combinations.

The analysis results show that there is a negative relationship between digital screen usage time and mental health status, but stress management has a positive effect. For example, each hour increase in screen time decreases the mental health score by an average of 0.15, while a unit increase in stress management increases the mental health score by an average of 0.30. The findings also highlight that digital workload, and social isolation had less of an impact individually, but when combined with screen usage time and other variables, they contributed to a more significant overall effect on mental health. For example, the combination of digital screen usage time, workload, and sleep patterns resulted in a larger decrease in mental health scores (-0.35), whereas the inclusion of stress management in the analysis mitigated this effect (-0.05).

**Table 8.** The effects of independent variables on mental health

| $\boldsymbol{\beta_n}$ | (betaβ) | $\boldsymbol{\beta_n}$ | (betaβ) | $\boldsymbol{\beta_n}$ | (betaβ) | $\boldsymbol{\beta_n}$ | (betaβ) | $\boldsymbol{\beta_n}$ | (betaβ) |
|---|---|---|---|---|---|---|---|---|---|
| Digital screen usage time | -0.15 | Digital screen usage time and digital workload | -0.25 | Digital screen usage time, digital workload and sleep patterns | -0.35 | Digital screen usage time, digital workload, sleep patterns and stress management | -0.05 | Digital screen usage time, digital workload, sleep patterns, stress management and social isolation | -0.10 |
| Digital workload | -0.05 | Sleep patterns and stress management | 0.20 | Stress management, social isolation and digital screen usage time | 0.10 | | | | |
| Sleep patterns | -0.10 | Social isolation and digital screen usage time | -0.20 | | | | | | |
| Stress management | 0.30 | | | | | | | | |
| Social isolation | -0.05 | | | | | | | | |

## 6. DISCUSSION

In this study, the results of the survey study, Delphi and regression analysis conducted to determine the effects of various factors on the digital fatigue and mental health of seafarers support the information in the literature. The survey results show that digital fatigue and mental health problems increase with the increase in the use of digital devices by seafarers. These findings confirm the relationship between digital fatigue and psychological health, which was previously revealed in the studies conducted by Febreza and Junaidi (2022). The findings obtained as a result of the Delphi analysis list the important criteria on the mental and physical health of seafarers. In the first place, sleep patterns play a critical role in seafarers' healthy lives, as long working hours and irregular watchkeeping can negatively affect sleep quality (acc. table 5). Social isolation comes second, emphasizing that isolated working conditions on the ship for long periods create psychological pressure and threaten individual well-being. The third criterion, the level of digital technology workload, shows the importance of employees being able to use these technologies effectively with the spread of digitalization in modern maritime activities. The stress management effect reveals how vital seafarers' ability to cope with stress is in managing the challenges and workload encountered on board (acc. table 5). While digital screen usage time stands out as a factor affecting employees' mental and physical energy, digital device screen usage reveals the effects of continuous screen work on digital fatigue and health (acc. table 5). These findings show that the maritime sector offers a wide range of improvement opportunities from digital skills to social support systems to increase the performance and well-being of employees. According to Table 7, the most used devices included computers (80%), smartphones (65%), and tablets (40%), suggesting that the high digital screen usage contributes significantly to the participants' daily activities and, potentially, to their fatigue levels. This highlights the moderate to high impact that digital environments have on mental health, particularly concerning stress levels. According to table 7, sleep patterns emerged as one of the most critical factors affecting both digital fatigue and overall mental health. In the row under the stress management heading in Table 7, 65 percent of respondents admitted to suffering from attention deficit disorder, highlighting the potential negative effects of digitalization on individuals. This finding suggests that digital fatigue or distraction from constant digital interaction is common. Similarly, stress management was mentioned under stress management and 52.3 percent of respondents reported feeling stressed, indicating that digital technologies can be a stressor in everyday life. The constant connectivity of the digital environment can cause pressure and stress on individuals. Another important finding under the row titled social isolation in Table 7 is that 35 percent reported feeling restricted by digital devices. This shows that digital devices can create a sense of obligation instead of freedom. Thirty-one percent of the participants stated that they felt lonely when their digital devices were not with them. This finding sends an important signal about developing digital addiction and excessive emotional attachment to devices. Feeling lonely without devices indicates the degree of emotional attachment to the digital world. These findings provide important data that draw attention to the possible effects of digitalization on individuals' mental health. Delphi analysis provided a critical method to identify the factors that digital fatigue most affects seafarers' mental health. In particular, criteria such as sleep patterns, social isolation and digital workload were found to be important in protecting seafarers' mental health. For example, the negative relationship between long screen time and sleep disturbances may increase the risk of distraction and work accidents. In maritime operations, practical applications such as regulating watchkeeping hours and limiting screen time can reduce these risks. These findings show that certain criteria directly contribute to operational safety and employee health in the maritime sector.

In the regression analysis, it was seen that digital screen usage time had the highest impact. In addition, it was determined that stress management has a positive and positive effect on mental health if it is done well (acc. table 8). Stress management factor has the highest positive effect with 0.30. This indicates that stress management plays a more significant ameliorative role on seafarers' mental health compared to other factors. As seen in Table 8, stress management has the potential to offset the negative effects of other factors such as digital screen time, digital workload and social isolation. If this factor is not managed effectively, the negative effects on seafarers' mental health can be exacerbated, leading to decreases in work productivity, burnout syndromes and long-term health problems. Therefore, prioritizing stress management and supporting seafarers in this regard plays a critical role in reducing digital fatigue and other psychosocial risks. Another prominent result in this study is that maritime companies should support seafarers, especially on stress. In addition, it was seen that the interactions between screen time and digital workload have a significant effect on mental health. Each additional unit of screen time and digital workload combined significantly declines mental health (acc. Table 8). This situation shows that the digital fatigue experienced by seafarers because of prolonged screen use negatively affects their psychological health. Previously, Ahsan *et al.* (2019) also showed a strong relationship between constant digital device use and stress and anxiety levels in their study on university students.

The findings of this study support and expand on previous research that has examined the link between digital fatigue and seafarers' mental health in depth. For example, Fan *et al.* (2020) reported that digital device use negatively affects mental health by increasing distraction and stress levels. This study makes a significant contribution to the existing knowledge by offering a perspective that also highlights the impact of digital fatigue on operational performance, especially in the maritime sector. These findings reveal that digitalization in maritime should be carefully considered not only in terms of productivity but also employee health.

Similarly, the effects of digital screen usage time, digital workload and sleep patterns on mental health are also clear. This four-variable effect increases the mental health score negatively by 0.35 (acc. Table 8). This result indicates that sleep disorders, screen time and digital work concepts worsen the psychological state of seafarers. In the literature, it has been stated in Alonso *et al.* (2016) that sleep quality has significant effects on work performance and general quality of life.

In this study, the relationship between social isolation and digital device use was also found to be significant. Reducing social isolation is effective in reducing the digital fatigue levels of seafarers. This study reveals that determined that social isolation has negative effects on the mental health of seafarers, which has not been revealed in studies outside of maritime. This criterion emerged as a different feature of the study from other studies. Unlike previous studies, this research identifies social isolation as a significant contributor to digital fatigue in maritime settings. Maritime companies can improve digital fatigue and mental health by effectively implementing stress management and psychological support systems. Companies can provide regular psychological counselling, especially for seafarers working on long-term assignments. They can also monitor the frequency of use of digital devices and offer digital detox days at certain intervals. For example, planning activities that increase social interaction of personnel on board can contribute to reducing social isolation. Such practices not only increase the mental resilience of seafarers, but also improve work performance. In this context, monitoring the long-term impact of stress management programs and support systems allows maritime companies to create a healthier work environment.

## 7. CONCLUSION

This study aimed to determine the effects on digital fatigue and mental health of seafarers. The findings obtained through the survey study and regression analysis show that the mental health of seafarers is negatively affected by the increase in digital device use.

Digital fatigue directly impacts seafarers' mental health, leading to reduced job performance. The regression analysis reveals that these relationships are statistically significant and that the 5 factors identified as a result of the Delphi method have significant effects on mental health. In particular, the relationship between digital device use time and mental health stands out as an important finding that should be noted.

In addition, this study concluded that factors such as social isolation, sleep patterns and stress management also affect the mental health of seafarers. This study determined that social communication plays an important role in reducing digital fatigue and improving mental health. In this context, it is emphasized that strategies should be developed to support the psychological health of individuals working in the ship industry. In maritime applications, flexible working hours that support sleep patterns can be created in watchkeeping planning to reduce digital fatigue. In order to reduce social isolation, it is important to develop technological infrastructures that will allow crew members to communicate regularly with their friends and families. In addition, psychological support programs can be organized at regular intervals to support the stress management skills of ship crew.

This study determined that factors such as digital screen time and digital communication intensity negatively affect mental health in seafarers. The data obtained show that prolonged screen use in particular causes distraction and concentration difficulties. For example, a crew member who is distracted by intense screen use may miss a critical detail while monitoring navigation systems. Similarly, prolonged digital exposure can increase the response time to alarm systems, which can lead to incorrect or delayed decisions in emergency situations. Social isolation and disruptions in sleep patterns also have a negative impact on mental health; this reduces both the daily work performance and the general quality of life of the crew.

The intensive use of digital devices, the necessity to be constantly online, the pressure of communication and the uninterrupted flow of information trigger digital fatigue, which causes psychological problems such as distraction, stress and burnout in seafarers. Especially in isolated working environments such as ships, the deepening of these problems can weaken decision-making processes and increase the risk of accidents. Inattention, incorrect interventions and wrong decisions due to mental fatigue and stress can lead to ship accidents. Therefore, it should not be ignored that digitalization is a factor that indirectly affects accidents in the maritime sector. This study makes significant contributions to the literature on digital fatigue and mental health of seafarers and reveals the need for further research in this area.

Based on the findings of this study, solution suggestions are given below.

-Limiting and regulating the digital device usage time of the personnel working on ships can reduce digital fatigue. Eye strain and mental fatigue can be prevented by taking breaks instead of prolonged exposure to digital devices during work.

-Social communication support programs can be developed to prevent social isolation of ship personnel. More frequent communication with friends and family can strengthen psychological well-being.

-Digital tools can be made more user-friendly for ship personnel to feel less digital fatigue. Software and devices with simple, fast and easy interfaces can reduce digital stress.

There are some limitations in this research. Among these limitations are the limited sample and the use of a single survey method. The time factor was ignored as the study collected data over a specific period. Long-term studies are needed to understand how changes in seafarers' digital fatigue and mental health evolve over time. External factors that have an impact on digital fatigue and mental health have been addressed in a limited way in this study. For example, seafarers' social life, sources of stress other than work intensity and factors in their personal lives could be examined more comprehensively. In addition, only Turkish seafarers were included in the sample.

Future studies can deepen these findings and provide more comprehensive data to determine strategies for protecting and improving the health of seafarers. It is important to monitor the effects of seafarers' use of digital devices on their mental health in the long term. In this context, longitudinal studies can be conducted to observe how the effects of digitalization change over time. More effective stress management and psychological support programs should be developed for seafarers who experience digital fatigue and mental health problems. Studies on this subject may provide recommendations for maritime companies. Future studies could examine the effects of digital devices and business processes on maritime operational efficiency in relation to mental health. While digitalization is hypothesized to improve business performance, how these processes also affect seafarers' psychological well-being could be explored. Besides this, future research could examine the long-term effects of digital fatigue on seafarers' work efficiency. In addition, the effects of demographic differences could be revealed in more detail by investigating the levels of digital fatigue experienced by seafarers of different age groups and experience levels.

The findings of this study underscore the critical need for industry-wide policies aimed at monitoring and managing digital fatigue among seafarers. Given the strong correlation between digital fatigue and mental health issues, it is imperative that maritime companies and regulatory bodies implement measures to protect seafarers' well-being. This includes establishing guidelines to limit screen time, promoting better sleep patterns, and providing psychological support services on board. Such policies could not only improve the mental health of seafarers but also enhance operational safety, reducing the risk of accidents linked to cognitive overload and distraction. Ultimately, these changes could lead to a healthier, more productive workforce, ensuring safer and more efficient maritime operations.

As a result, protecting the health of seafarers in the digital age is of critical importance for increasing efficiency in the sector and ensuring workforce sustainability.

## AUTHORSHIP CONTRIBUTION STATEMENT

**Ozan Hikmet ARICAN:** Conceptualization, Methodology, Validation, Formal Analysis, Resources, Writing - Original Draft, Writing-Review and Editing, Data Curation, Software, Visualization, Supervision, Project administration

## CONFLICT OF INTERESTS

I declare that this article has no real, potential or perceived conflict of interest.

## ETHICS COMMITTEE PERMISSION

I declare that this study was conducted in accordance with the procedures of the ethics committee for human or animal experiments. Ethics committee approval was obtained with the decision number 21 (E-94094268-200-655429) taken at the meeting of Kocaeli University Social and Human Sciences Ethics Committee dated 20/09/2024 and numbered 2024/09.

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# Determination of the Antibiotic Susceptibility of Pathogenic Bacteria Isolated from Cultivated Rainbow Trout (*Oncorhynchus mykiss*)

## Kültür Gökkuşağı Alabalıklarında (*Oncorhynchus mykiss*) Tanımlanan Patojen Bakterilerin Antibiyotik Dirençliliğinin Belirlenmesi

Türk Denizcilik ve Deniz Bilimleri Dergisi

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## ABSTRACT

The indiscriminate use of antibiotics in aquaculture is considered a major concern in terms of resistant pathogens that can lead to infectious diseases. In this study, antibiotic resistance profiles were determined in pathogenic bacteria isolated from fish during outbreak in six different rainbow trout farms located in the Adana region. Vitek 2 (automated systems) was used for advanced bacterial identifications following standard conventional method. After all, bacterial isolates were identified as *Aeromonas sobria*, *Pseudomonas fluorescens*, and *Lactococcus garvieae* with 90–95% similarity rates. In determining the antibiotic resistance profiles of the isolates, their susceptibility to 14 different antibiotics were evaluated with the Kirby Bauer disk diffusion method, and also, the presence of various antibiotic resistance genes of the isolates was investigated by the conventional PCR method using specific primer pairs. When the antibiogram test results were examined, it was determined that each isolate had different levels of antibiotic sensitivity, and all isolates were found to be sensitive only to tetracycline, gentamicin, and levofloxacin. According to the MAR (Multiple Antibiotic Resistance) index values, *A. sobria*, and *L. garvieae* (L2) isolates remained below the 0.2 critical value, while the index values of other isolates were calculated above this critical value. The presence of tetA and tetC resistance genes could not be detected among the isolates.

**Keywords:** Rainbow Trout, VITEK 2 (Automated System), Antibiotic Susceptibility, Multidrug Antibiotic Resistance

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**ÖZET**

Su ürünleri yetiştiriciliğinde gelişigüzel antibiyotik kullanımı, bulaşıcı hastalıklara yol açabilecek dirençli patojenler açısından büyük bir endişe kaynağı olarak değerlendirilmektedir. Bu çalışmada Adana bölgesinde yer alan gökkuşağı alabalığı üretimi yapan 6 farklı özel işletmede hastalık belirtisi gösteren balıklardan izole edilen patojen bakterilerde antibiyotik dirençlilik profilleri belirlenmiştir. Bakteri izolatlarının tanımlanmasında geleneksel kültür çalışmalarının ardından kit bazlı tam otomatize tanımlama sistemi (Vitek 2) kullanılmıştır. Bakteri izolatları *Aeromonas sobria, Pseudomonas fluorescens* ve *Lactococcus garvieae* %90-95 benzerlik oranlarıyla tanımlanmıştır. İzolatların on dört antibiyotiğe karşı antibiyotik duyarlığı, Kirby Bauer disk difüzyon yöntemi kullanılarak CLSI önerileri doğrultusunda gerçekleştirilmiş, genotipik olarak ise antibiyotik direnç genlerinin varlığı konvansiyonel PZR yöntemleriyle araştırılmıştır. Elde edilen sonuçlara göre antibiyotik duyarlığının her bir izolat için farklı düzeyde olduğu, sadece tetrasiklin, gentamisin ve levofloksasine karşı tüm izolatların duyarlı olduğu belirlenmiştir. ÇAD (Çoğul Antibiyotik Direnç) indeksi değerlerine göre *A.sobria,* ve *L.garvieae* (L2) izolatları 0.2 kritik indeks değerinin altında kalırken, diğer türlere ait indeks değerleri bu kritik değerin üzerinde hesaplanmıştır. İzolatlar arasında *tetA*, *tetC,* direnç genlerinin varlığı ise saptanmamıştır.

**Anahtar sözcükler**: Gökkuşağı Alabalık, VİTEK 2 otomatize sistemi, Antibiyotik Duyarlılık, Çoklu Antibiyotik Dirençliliği

## 1. GİRİŞ

Birçok bölgede sürdürülebilir su ürünleri yetiştiriciliğinin önündeki ana engellerden biri bulaşıcı hastalıkların kontrolü olmuştur. Yoğun kültür koşulları, balık refahını olumsuz etkilemesinin yanı sıra balıkların bağışıklık sistemini zayıflatarak çevredeki mevcut patojenlerin hastalığa yol açmasına neden olmaktadır (Sezgin *ve ark*., 2023). Su ürünleri yetiştiriciliği endüstrisinin gelişmesi ve bakteriyel hastalıkların yaygınlaşmasıyla birlikte, antibiyotiklerin yoğun bir şekilde kullanılması, bulaşıcı hastalıklara neden olabilen dirençli patojenler açısından ciddi bir endişe kaynağı olarak kabul görmüştür (Vignesh *ve ark*., 2011). Mikroorganizmaları öldürebilen veya büyümelerini engelleyebilen maddeler olarak nitelendirilen antibiyotikler, su ürünleri yetiştiriciliğinde terapötik, profilaktik veya metafilaktik ajanlar olarak yaygın bir şekilde kullanılmaktadır (Romero *ve ark*., 2012). Dünya genelinde bu alanda çoğunlukla Amoksisilin, Ampisilin, Kloramfenikol, Florfenikol, Eritromisin, Streptomisin, Neomisin, Furazolidon, Nitrofurantoin, Oksolinik Asit, Enrofloksasin, Flumekuin, Oksitetrasiklin, Tetrasiklin, Sulfonamid gibi geniş spektrumlu antibiyotikler kullanılmaktadır (Van Dongen *ve ark*., 2008; FAO, 2019). Su ürünlerinde antibiyotiklerin onaylanması, kullanım uygulamaları ve kalıntı limitleri konusunda her ülkenin kendi mevzuatı vardır. Türkiye su ürünleri yetiştiriciliğinde oksitetrasiklin, florfenikol, enrofloksasin ve oksolinik asit gibi etken maddeleri içeren 41 adet ruhsatlı antibakteriyel ürün bulunduğu belirtilmiştir (Güngör *ve ark*., 2021).

Antibiyotikler, direnç genlerinin gelişmesi ve dirençli hale gelen bakterilerin doğada yayılmaları sebebiyle etkilerini yitirmektedirler (Andersson ve Levin, 1999). Bakterilerde var olan direnç genleri plazmid yüzeyinde bulunurlar. Antibiyotiklere karşı oluşan direnç, bakteriler arasında gerçekleşen plazmid transferleri sebebiyle hızlı biçimde yayılır (Petersen *ve ark*., 2002). Ayrıca plazmid üzerinde yer alan bu direnç genlerinin insan için patojen olan diğer bakteri türlerine transferi insan sağlığı açısından da risk oluşturmaktadır (Dokumacı, 2024). Bakterilerin kendi aralarında yatay ve dikey olarak gerçekleştirdikleri gen transferi (Aoki, 1997) ile dirençli bakterilerin sayısı ve direnç kararlıkları artmakta, balık bakteriyel patojenlerine karşı kullanılan antibiyotiklerin etkileri azalmaktadır (Saitanu *ve ark*., 1994). Patojen bakterilere karşı antibiyotikler yeme ya da su ortamına karıştırılarak uygulanmaktadır. Belirtilen ana tedavi edici etkisinin yanı sıra antibiyotikler çevresel etki, aşılama gibi diğer stres etmenlerine karşı profilaktik ve büyüme teşvik edici ajanlar olarak da kullanılmaktadır. Bakteriler balık çiftliklerinde kullanılan birden fazla antibiyotiğe karşı aynı zamanda direnç geliştirebilmektedirler. Kullanılan bu antibiyotiklerin hedef canlı dışında sediment ve su katmanları için de kirletici olduğu ve birikim meydana getirdiği böylelikle hedef dışı bakterilerde dahi direnç oluşturduğu bilinmektedir (Gao *ve ark*., 2012). Bu durum antimikrobiyal direnç (AMR) olarak tanımlanmıştır (FAO, 2005). Bakterilerde direnç gelişimi, antibiyotiklerin bilinçsizce hedef dışı mikroorganizmaların sağaltımı için kullanılması, antibiyotiğin aşırı doz ya da düşük doz ve uzun süre uygulamaları sonucunda ortaya çıkmaktadır. Sonuçta ortaya çıkış yolundan bağımsız olarak dirençli bakteri varlığı tüm dünyada insan ve diğer canlıların sağlığı için tehdit oluşturmaktadır. Bu sebeple antibiyotiğe dirençli genlerin varlığını ve hareketliliğini tespit etmek oldukça önemlidir.

Türkiye'de balık çiftliklerinde balıklardan izole edilen patojen bakterilerde antibiyotiklerin direnç profillerinin belirlenmesi, farklı yıllarda yapılan çeşitli çalışmalarla ortaya konmuştur (Capkin *ve ark*., 2015; Türe ve Alp, 2016; Capkin *ve ark*., 2017; Hancı ve Onuk, 2018; Sezgin *ve ark*., 2023; Bhat ve Altinok, 2023; Yılmaz *ve ark*., 2024). Buna karşın, özellikle çalışma bölgesinde konuya ilişkin araştırma oldukça sınırlıdır. Adana ili ve civarı bölgede 25 adet lisanslı alabalık yetiştiricilik tesisinin faaliyet gösterdiği, bu tesislerde yaklaşık yıllık üretim kapasitelerinin ise 4085 ton sofralık ve 12.315.000 adet yavru üretimi olduğu bildirilmiştir (BSGM, 2023).

Bu nedenle çalışmada, Adana bölgesinde yetiştiriciliği yapılan Gökkuşağı Alabalık (*Oncorhynchus mykiss*)'larda hastalıklara neden olan önemli patojen bakterilerin tür tespiti yapılarak, bu türlerin çeşitli antibiyotiklere karşı gösterdikleri duyarlılık dereceleri ve direnç profilleri araştırılmıştır.

## 2. MATERYAL VE YÖNTEM

### 2.1. Balık Örneklerinin Temini, Patojen Bakteri İzolasyon ve Tanımlanması

Çalışma kapsamında Adana bölgesinde bulunan 6 farklı özel işletmeden 18 ay boyunca hastalık belirtisi gösteren gökkuşağı alabalığı temin edilmiştir. Hastalık belirtisi gösteren balıklarda nekropsi işlemleri aynı gün gerçekleştirilmiştir. Vücut yüzeyi %70'lik etil alkolle silinen balıkların karaciğer, dalak ve böbrek dokularından farklı agarlara (Tripticase soy agar, Brain Heart Infusion (BHI) agar, Thiosulfate Citrate Bile Sucrose agar, Mc Conkey agar (Oxoid, İngiltere) ve Shotts-Waltman agar) ekimler yapılmış ve besiyerleri inkübatörde 22 °C'de 24-72 saat süreyle inkubasyona bırakılmıştır. Bakterilerin tanımlanması konvansiyonel kültür çalışmalarını (gram boyama, koloni morfolojisi) takiben Vitek 2 (bio-Merieux, Fransa) tam otomatik tanımlama cihazı ile gerçekleştirilmiştir. Uygun besiyerinde üretilen izolatlar analiz edilene kadar %20 gliserol de -80°C'de muhafaza edilmiştir.

### 2.2. Antibiyotik Duyarlılık Testi

Stoktan alınan ve tür teşhisi yapılan tüm bakterilerin antibiyotik duyarlılık testleri Kirby Bauer Disk Diffüzyon metodu kullanılarak gerçekleştirilmiştir. Bakteri izolatları uygun koşullarda inkübe edilerek subkültüre edilmiş ve steril izotonik tuzlu su içeren tüplere aktarılmış, tüplerin içerisindeki yoğunluklar McFarland standart (bioMerieux sa, 69280, MarcyI'Etoile, Fransa) ile ölçülmüştür. 0.5 Mc Farland yoğunluğuna ulaştığında, hazırlanan bakteri süspansiyonları (0.1 ml) yayma plak yöntemiyle Müller Hinton Agar üzerine ekilmiştir. İzolatlara ait duyarlık tespitinde 14 antibiyotik kullanılmıştır (Tablo 1). Çeşitli konsantrasyonlarda antibiyotikli diskler steril pens yardımı agar yüzeyine yerleştirilmiş, 22°C'de 24-48 saat süreyle inkübasyona bırakılmıştır. İnkübasyon süresi sonunda kullanılan antibiyotik disklerin çevresinde meydana gelen inhibisyon zon çapları dijital kompas ile ölçülmüş, sonuçların değerlendirilmesinde CLSI kitapçığı kullanılmıştır (Tablo 2).

### 2.3. Çoğul Antibiyotik Direnç (ÇAD) İndeksi

Çalışılan izolatların çoğul antibiyotik direnç (ÇAD) indeksleri hesaplanmıştır. ÇAD indeksi hesaplanırken ÇAD=A/B formülünden yararlanılmış olup, formüldeki A: İzolatların direnç gösterdiği antibiyotik sayısını, B ise izolata karşı denenen toplam antibiyotik sayısını göstermektedir (Krumperman, 1983). Değerlendirmede ÇAD indeks değeri 0.2'den küçük ya da 0.2'ye eşit ise antibiyotik kullanımının düşük olduğu ya da kullanılmadığını, 0.2'den büyükse bakteri örneklerinin izole edildiği çevrenin antibiyotiklere yoğun miktarda maruz kaldığını ve yüksek risk içerdiğini göstermektedir (Krumperman, 1983).

**Tablo 1.** Araştırmada kullanılan antibiyotikler

| Antibiyotik | Antibiyotik kodu | Antibiyotik dozu | Antibiyotik markası |
|---|---|---|---|
| **Neomisin** | N30 | 30 µg | BD |
| **Ampisilin** | AM10 | 10 µg | BD |
| **Streptomisin** | S10 | 10 µg | BD |
| **Tetrasiklin** | TE30 | 30 µg | BD |
| **Amoksisilin/Klavulanik Asit** | AmC30 | 30 µg | BD |
| **Enrofloksasin** | ENR5 | 5 µg | BD |
| **Oksitetrasiklin** | T30 | 30 µg | BD |
| **İmipenem** | IPM10 | 10 µg | BD |
| **Gentamisin** | GM10 | 10 µg | BD |
| **Levofloksasin** | LVX5 | 5 µg | BD |
| **Sülfametoksazol/Trimetoprim** | SXT25 | 25 µg | BD |
| **Florfenikol** | FFC30 | 30 µg | BD |
| **Kloramfenikol** | C30 | 30 µg | BD |
| **Trimetoprim** | TMP5 | 5 µg | BD |

**Tablo 2.** CLSI standartlarına göre antibiyogram testi duyarlılık değerleri

| | Dirençli(R) | Duyarlı(S) | OrtaDuyarlı (I) | Referans |
|---|---|---|---|---|
| **Neomisin** | ≤12 | ≥17 | 13-16 | **CLSI,2018** |
| **Ampisilin** | ≤13 | ≥17 | 14-16 | **CLSIM100,2021** |
| **Streptomisin** | ≤11 | ≥15 | 12-14 | **CLSIM100,2021** |
| **Tetrasiklin** | ≤11 | ≥15 | 12-14 | **CLSIM100,2021** |
| **Amoksisilin/KlavulanikAsit** | ≤13 | ≥18 | 14-17 | **CLSI,2018** |
| **Enrofloksasin** | ≤16 | ≥23 | 17-22 | **CLSIVET01S,2020** |
| **Oksitetrasiklin** | ≤14 | ≥19 | 15-18 | **CLSI,2018** |
| **İmipenem** | ≤13 | ≥16 | 14-15 | **CLSIM100,2011** |
| **Gentamisin** | ≤12 | ≥15 | 13-14 | **CLSIM100,2021** |
| **Levofloksasin** | ≤13 | ≥17 | 14-16 | **CLSIM100,2011** |
| **Sülfametoksazol/Trimetoprim** | ≤10 | ≥16 | 11-15 | **CLSIM100,2021** |
| **Florfenikol** | ≤22 | ≥29 | 23-28 | **CLSIVET01S,2020** |
| **Kloramfenikol** | ≤12 | ≥18 | 13-17 | **CLSIM100,2021** |
| **Trimetoprim** | **≤10** | **≥16** | **11-15** | **CLSIM100,2011** |

### 2.4. DNA İzolasyonu ve Antibiyotik Direnç Genlerinin Tespiti

Uygun besi yerinde üretilen bakterilerden DNA İzolasyon işlemleri ticari kit (QIAamp DNA mini kit; Qiagen, Hilden, Almanya) yardımıyla protokolüne uygun olarak gerçekleştirilmiştir. Çalışmamızda kullanılan antibiyotik direnç genlerine ait (sulfonamid - sul2; tetrasiklin -tetA, tetC; beta laktam - ampC; aminoglikozit - aadA) spesifik primer dizileri Tablo 3' de sunulmuştur. PZR reaksiyonu her bir örnek için 12.5 µl 2X PZR master mix, 2 µl 100 ng genomik DNA, her primerden 1 µl (10 nmol/µl) ve 8.5 nükleaz içermeyen saf su olacak şekilde toplam 25 µl olarak hazırlanmış ve reaksiyonlar Veriti Thermal Cycler cihazında (Applied Biosystems) yürütülmüştür. Cihaz şartları 94ºC'de 45 saniye denaturasyon, 48-59ºC'de 45 saniye tutunma ve 72ºC'de 1 dakika uzama olarak toplam 30 döngüde tamamlanmıştır. Elde edilen PZR ürünleri 0.5 x TAE tampon çözeltisi ile %1'lik agaroz jelde 100 V' da 1 saat yürütülmüş, ardından jel görüntüleme sistemi kullanılarak bant büyüklükleri değerlendirilmiştir.

**Tablo 3**. Antibiyotik direnç genleri belirlenmesinde kullanılan primerler

| Primer Adı | Sekans (5'-3') | Hedef Gen-Bölge | PZR Ürünü Boyutu (bp) | Tutunma Sıcaklığı (°C) | Kaynaklar |
|---|---|---|---|---|---|
| **Tet A FW** | GCTACATCCTGCTTGCCTTC | *tet A* | 210 | 55 | Ng ve ark., 2001 |
| **Tet A RV** | CATAGATCGCCGTGAAGAGG | | | | |
| **Tet C FW** | CTTGAGAGCCTTCAACCCAG | *tet C* | 418 | 55 | Ng ve ark., 2001 |
| **Tet C RV** | ATGGTCGTCATCTACCTGCC | | | | |
| **Sul2 FW** | GCGCTCAAGGCAGATGGCATT | *Sul 2* | 293 | 59 | Kerrn ve ark., 2002 |
| **Sul2 RV** | GCGTTTGATACCGGCACCCGT | | | | |
| **AmpC FW** | TTCTATCAAMACTGGCARCC | ampC | 550 | 48 | Schwartz ve ark., 2003 |
| **AmpC RV** | CCYTTTTATGTACCCAYGA | | | | |
| **aadA FW** | TGATTTGCTGGTTACGGTGAC | aadA | 284 | 52 | Van ve ark., 2008 |
| **aadA RV** | CGCTATGTTCTCTTGCTTTTG | | | | |

## 3. BULGULAR

### 3.1. İzolatların tanımlanması

Çalışmamızda hastalık şüpheli olarak örneklenen alabalıklardan izole edilen bakteri izolatları, Vitek 2 Tam Otomatik Tanımlama Sistemi ile 5 izolat örneğinden 2 tanesi, *Lactococcus garvieae*, 2 tanesi *Pseudomonas fluorescens*, 1 tanesi de *Aeromonas sobria* olarak tanımlanmıştır.

Vitek® 2 sonuçlarına göre 1 numaralı izolat %99 oranında *A. sobria* olarak, 2 ve 3 numaralı izolatlar ise %90 oranında *P. fluorescens* olarak tanımlanmıştır. İzolatların koloni morfolojisi, basit boyama ve negatif Gram boyama sonucu bu tanımlamaları desteklemiştir. Vitek® 2 sonuçlarına göre 4 ve 5 numaralı izolatlar ise %95 oranında *L. garvieae* olarak tanımlanmıştır. İzolatların koloni morfolojisi ve pozitif boyama sonuçları bu tanımlamaları desteklemiştir. İzolatların GN ve GP ID kart üzerindeki diziliş sırasına göre biyokimyasal detayları verilmiştir (Tablo 4, Tablo 5, Tablo 6).

### 3.2. Antibiyogram testi (Kirby-Bauer disk difüzyon yöntemi) Bulguları

Alabalık işletmelerinden izole edilen bakteri izolatlarının antibiyotiklere karşı göstermiş oldukları direnç ve hassasiyetler her bir bakteri izolatı için ayrı ayrı belirlenmiş ve gösterilmiştir (Tablo 7).

Antibiyogram test sonucuna göre 2 *Lactococcus garvieae*, 2 *Pseudomonas fluorescens*, 1 *Aeromonas sobria* suşunun farklı düzeyde antibiyotik duyarlılıklarının olduğu tespit edilmiştir. *A. sobria* suşunun 14 antibiyotiğin, 9'una duyarlı olduğu 2'sine karşı dirençli olduğu ve 3'üne orta derecede duyarlı olduğu saptanmıştır. *P. fluorescens* türüne ait ilk suşun (P1) 14 antibiyotiğin, 3'üne duyarlı olduğu 8'ine karşı dirençli olduğu ve 3'üne orta derecede duyarlı olduğu belirlenmiştir. *P. fluorescens* türüne ait ikinci suşun (P2) ise 14 antibiyotiğin, 5'ine duyarlı olduğu 6'sına karşı dirençli olduğu ve 3'üne orta derecede duyarlı olduğu saptanmıştır. *L. garvieae* türüne ait ilk suşun (L1) 14 antibiyotiğin, 10'una duyarlı olduğu 3'üne karşı dirençli olduğu ve 1'ine orta derecede duyarlı olduğu tespit edilmiştir. *L. garvieae* türüne ait ikinci suşun (L2) 14 antibiyotiğin, 13'üne duyarlı olduğu 1'ine karşı dirençli olduğu saptanmıştır.

**Tablo 4.** *Aeromonas sobria'* nın GN ID kart üzerindeki diziliş sırasına göre biyokimyasal detayları

| Nr | Test | Reaksiyon | Nr | Test | Reaksiyon | Nr | Test | Reaksiyon |
|---|---|---|---|---|---|---|---|---|
| 2 | **APPA** | - | 21 | **BXYL** | - | 42 | **SUCT** | - |
| 3 | **ADO** | - | 22 | **BAlap** | - | 43 | **NAGA** | - |
| 4 | **PyrA** | + | 23 | **ProA** | + | 44 | **AGAL** | - |
| 5 | **İARL** | - | 26 | **LIP** | - | 45 | **PHOS** | - |
| 7 | **dCEL** | - | 27 | **PLE** | - | 46 | **GlyA** | - |
| 9 | **BGAL** | - | 29 | **TyrA** | + | 47 | **ODC** | - |
| 10 | **H2S** | - | 31 | **URE** | - | 48 | **LDC** | - |
| 11 | **BNAG** | + | 32 | **dSOR** | - | 53 | **IHISa** | - |
| 12 | **AGLTp** | - | 33 | **SAC** | + | 56 | **CMT** | - |
| 13 | **dGLU** | + | 34 | **dTAG** | - | 57 | **BGUR** | - |
| 14 | **GGT** | - | 35 | **dTRE** | + | 58 | **0129R** | - |
| 15 | **OFF** | - | 36 | **CIT** | - | 59 | **GGAA** | - |
| 17 | **BGLU** | - | 37 | **MNT** | - | 61 | **IMLTa** | - |
| 18 | **dMAL** | + | 39 | **5KG** | - | 62 | **ELLM** | + |
| 19 | **dMAN** | - | 40 | **ILATk** | - | 64 | **ILATa** | - |
| 20 | **dMNE** | + | 41 | **AGLU** | - | | | |

*Nr: GN ID kart üzerindeki kuyucuk sıra numarası. Test: GN ID kart üzerindeki kuyucuklarda bulunan biyokimyasal test reaktifleri*

**Tablo 5.** *Pseudomonas fluorescens'* in GN ID kart üzerindeki diziliş sırasına göre biyokimyasal detayları

| Nr | Test | Reaksiyon | Nr | Test | Reaksiyon |
|---|---|---|---|---|---|
| 2 | **APPA** | - | 33 | **SAC** | - |
| 3 | **ADO** | - | 34 | **dTAG** | - |
| 4 | **PyrA** | + | 35 | **dTRE** | - |
| 5 | **İARL** | - | 36 | **CIT** | - |
| 7 | **dCEL** | + | 37 | **MNT** | - |
| 9 | **BGAL** | - | 39 | **5KG** | - |
| 10 | **H2S** | - | 40 | **ILATk** | + |
| 11 | **BNAG** | - | 41 | **AGLU** | - |
| 12 | **AGLTp** | - | 42 | **SUCT** | - |
| 13 | **dGLU** | + | 43 | **NAGA** | - |
| 14 | **GGT** | - | 44 | **AGAL** | - |
| 15 | **OFF** | - | 45 | **PHOS** | - |
| 17 | **BGLU** | - | 46 | **GlyA** | - |
| 18 | **dMAL** | + | 47 | **ODC** | - |
| 19 | **dMAN** | - | 48 | **LDC** | - |
| 20 | **dMNE** | + | 53 | **IHISa** | - |
| 21 | **BXYL** | - | 56 | **CMT** | + |
| 22 | **BAlap** | - | 57 | **BGUR** | - |
| 23 | **ProA** | + | 58 | **0129R** | + |
| 26 | **LIP** | - | 59 | **GGAA** | - |
| 27 | **PLE** | - | 61 | **IMLTa** | (-) |
| 29 | **TyrA** | + | 62 | **ELLM** | - |
| 31 | **URE** | - | 64 | **ILATa** | - |
| 32 | **dSOR** | - | | | |

*Nr: GN ID kart üzerindeki kuyucuk sıra numarası. Test: GN ID kart üzerindeki kuyucuklarda bulunan biyokimyasal test reaktifleri*

**Tablo 6**. *Lactococcus garvieae'*nin GP ID kart üzerindeki diziliş sırasına göre biyokimyasal detayları

| Nr | Test | Reaksiyon | Nr | Test | Reaksiyon |
|---|---|---|---|---|---|
| 2 | **AMY** | + | 32 | **POLYB** | + |
| 4 | **PIPLC** | - | 37 | **dGAL** | - |
| 5 | **dXYL** | - | 38 | **dRIB** | + |
| 8 | **ADH1** | - | 39 | **ILATk** | - |
| 9 | **BGAL** | - | 42 | **LAC** | - |
| 11 | **AGLU** | - | 44 | **NAG** | + |
| 13 | **APPA** | + | 45 | **dMAL** | + |
| 14 | **CDEX** | - | 46 | **BACI** | + |
| 15 | **AspA** | (-) | 47 | **NOVO** | + |
| 16 | **BGAR** | - | 50 | **NC6.5** | - |
| 17 | **AMAN** | - | 52 | **dMAN** | + |
| 19 | **PHOS** | - | 53 | **dMNE** | + |
| 20 | **LeuA** | + | 54 | **MBdG** | + |
| 23 | **ProA** | - | 56 | **PUL** | - |
| 24 | **BGURr** | - | 57 | **dRAF** | - |
| 25 | **AGAL** | - | 58 | **O129R** | + |
| 26 | **PyrA** | + | 59 | **SAL** | + |
| 27 | **BGUR** | - | 60 | **SAC** | + |
| 28 | **AlaA** | + | 62 | **dTRE** | + |
| 29 | **TyrA** | + | 63 | **ADH2s** | - |
| 30 | **dSOR** | - | 64 | **OPTO** | + |
| 31 | **URE** | - | | | |

*Nr: GP ID kart üzerindeki kuyucuk sıra numarası. Test: GP ID kart üzerindeki kuyucuklarda bulunan biyokimyasal test reaktifleri*

**Tablo 7.** Patojen izolatlara ait antibiyotik duyarlılık profilleri

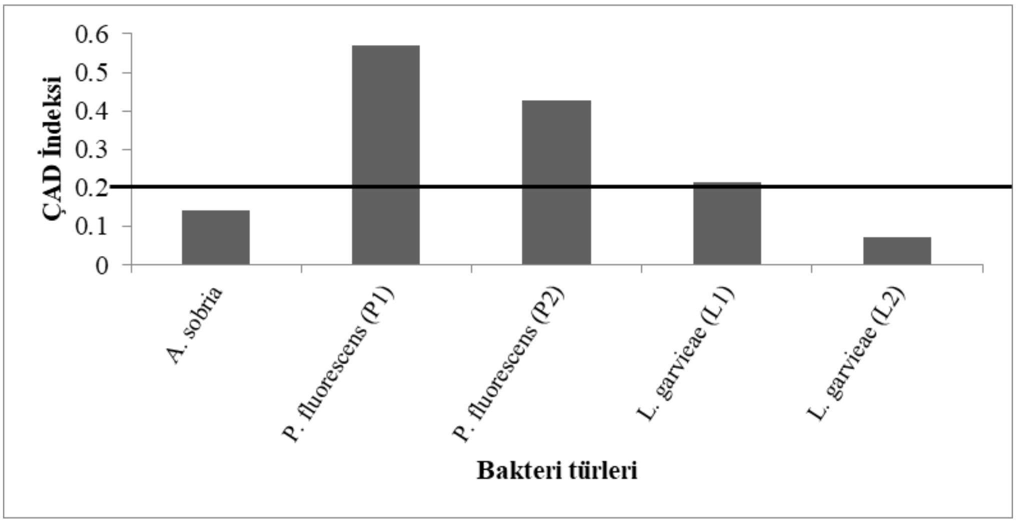
| **Bakteri izolatları** | **Antibiyotikler** | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | N | AM | S | TE | AmC | ENR | OT | IPM | GM | LVX | SXT | FFC | C | TMP |
| ***A. sobria*** | I (14) | S (40) | I (14) | S (36) | S (42) | S (27) | S (40) | S (45) | S (16) | S (29) | R (0) | R (11) | S (18) | I (11) |
| ***P. fluorescens* (P1)** | I (15) | R (0) | R (0) | S (23) | R (0) | I (18) | I (18) | R (13) | S (17) | S (25) | R (0) | R (0) | R (0) | R (0) |
| ***P. fluorescens* (P2)** | S (18) | R (0) | I (13) | S (21) | I (15) | R (16) | I (18) | S (28) | S (18) | S (20) | R (0) | R (0) | R (0) | R (0) |
| ***L. garvieae* (L1)** | S (17) | S (27) | R (8) | S (28) | S (26) | I (18) | S (26) | S (34) | S (17) | S (19) | R (0) | S (29) | S (38) | R (0) |
| ***L. garvieae* (L2)** | S (20) | S (33) | R (0) | S (34) | S (35) | S (32) | S (30) | S (42) | S (20) | S (30) | S (21) | S (36) | S (35) | S (25) |

*N: neomycin, AM: ampicilin, S: streptomycin, TE: tetracycline, AmC: amoxycilin+clavulanic acid, ENR: enroflaxacin, OT: oxytetracycline, IPM: imipenem, GM: gentamicin, LVX: levofloxacin, SXT: sulphamethoxazole+trimethoprim, FFC: florfenicol, C: chloramphenicol, TMP: trimethoprim,*
*R: Resistant: Dirençli, I: Intermediate: Orta Duyarlı, S: Susceptible: Duyarlı,*
*Zon çapı- mm*

### 3.3. Çoğul Antibiyotik Direnç (ÇAD) İndeks Değerleri

Alabalık işletmelerinden izole edilen bakteri izolatlarına ait ÇAD İndeks değerleri Şekil 1'de gösterilmiştir.

Balıklarda izole edilen bakterilerde en yüksek değer *P. fluorescens* (P1) izolatında 0.57 olarak hesaplanırken, en düşük değer ise *L. garvieae* (L2)'de 0.07 olarak hesaplanmıştır. ÇAD indeksi değerlerine göre *A.sobria* ve *L.garvieae* (L2) izolatları 0.2 kritik değerin altında kalırken, diğer izolatlara ait ÇAD indeksi değeri bu kritik değerin üzerinde hesaplanmıştır.




**Şekil 1.** Bakteri izolatlarına ait ÇAD İndeksleri. Yatay çizgi, 0.2 ÇAD kritik sınırını göstermektedir.

### 3.4. Antimikrobiyal Direnç Genlerinin Belirlenmesi

Çalışma kapsamında incelenen patojen izolatlar *A. sobria, P. fluorescens* (P1)*, P. fluorescens* (P2)*, L. garvieae* (L1)*, L. garvieae* (L2) arasında *tetA, tetC, Sul2, ampC* ve *aadA* direnç genlerinin varlığı Tablo 8' de verilmiştir. Patojen izolatlara ait antibiyotik direnç gen profilleri incelendiğinde, patojen izolatlar arasında *tetA* ve *tetC* direnç genlerinin varlığı saptanamamıştır. Dört izolatın (*A.sobria, P.fluorescens (P1), P.fluorescens* (P2) ,*L.garvieae* (L1)) *sul2* direnç genine, iki izolatın (*P.fluorescens (P1), P. fluorescens (P2)*) *AmpC* direnç genine ve iki izolatın da (*P.fluorescens* (P1), *L. garvieae* (L2)) *aadA* direnç genine sahip olduğu belirlenmiştir.

**Tablo 8.** Patojen izolatlara ait antibiyotik direnç gen profilleri

| Bakteri izolatları | Antibiyotik direnç genleri | | | | |
|---|---|---|---|---|---|
| | ***tetA*** | ***tetC*** | ***sul2*** | ***AmpC*** | ***aadA*** |
| ***A. sobria*** | - | - | + | - | - |
| ***P.fluorescens* (P1)** | - | - | + | + | + |
| ***P. fluorescens* (P2)** | - | - | + | + | - |
| ***L. garvieae* (L1)** | - | - | + | - | - |
| ***L. garvieae* (L2)** | - | - | - | - | + |

## 4. TARTIŞMA

Avrupa'da tatlı su balık türleri arasında gökkuşağı alabalığı (*Oncorhynchus mykiss*) en yaygın yetiştirilen ve ekonomik değeri oldukça yüksek bir türdür (FEAP, 2022). Dünya çapında pek çok ülkede gökkuşağı alabalığı yetiştiriciliği yapılmaktadır. Gökkuşağı alabalığının 2020 yılı itibariyle dünya çapındaki toplam üretiminin 959.600 tona ulaştığı bildirilmiştir (FAO, 2022). İran ve Türkiye, 2019 yılında dünya üretiminin sırasıyla %22 ve %13'ünü sağlayarak ana üretici konumuna gelmiştir (FAO, 2020). AB ile ilgili olarak Fransa ve İtalya, 2019 yılında AB üretiminin %19 ve %17'sini sağlayarak en büyük katkıyı sağlayan ülkeler olmuştur (FAO, 2020; FEAP, 2022). Gökkuşağı alabalığının yoğun yetiştiricilik koşulları, çeşitli patojenlere karşı duyarlılığını artırarak önemli kayıplara yol açmaktadır (Janssen *ve ark*., 2017). En yaygın görülen bakteriyel hastalık etkenleri ise *Vibrio anguillarum, Yersinia ruckeri, Lactococcus garvieae, Flavobacterium kolumnaris, Aeromonas hydrophila, Pseudomonas* *fluorescens* ve *Flavobacterium psychrophilum* patojenlerinden kaynaklanmaktadır (Toranzo 2004, Öztürk ve Altınok, 2014). Yapılan bu çalışmada Vitek2 otamatize sistem kullanılarak bakteri izolatları %90-95 benzerlik oranlarıyla *Aeromonas sobria, Pseudomonas fluorescens* ve *Lactococcus garvieae* olarak tanımlanmıştır. Sistemin bakteri izolatlarını konvansiyonel yöntemlere göre daha hızlı tanımlamasına karşın, tanımlamanın doğrulanması açısından ileri moleküler çalışmaların yapılmasına ihtiyaç vardır. Gökkuşağı alabalığından izole edilmiş *Lactococcus garvieae* Lg-per suşu fenotipik, biyokimyasal ve 16S rRNA dizisine dayanarak *L. garvieae* olarak doğrulanmış olsa da, Lg-per suşunun tüm genom dizilemesinin (WGS), Lg-per'in aslında *L. petauri* olduğunu ortaya koymuştur. Yapılan çalışmada, 16S rRNA'ya dayalı PCR tespit yönteminin, *Lactococcus* cinsinin tanımlanması için yeterli olmayabileceğini, bu durumun göz önüne alındığında, *L. garvieae* izolatlarının tüm genom dizilemesi (WGS) ile analiz edilmesi gerekliliği bildirilmiştir (Altınok *ve ark*., 2022).

*Lactococcus garvieae'nin* neden olduğu Laktokokkozis, dünya çapında gökkuşağı alabalığını (*Oncorhynchus mykiss*) etkileyen en önemli bakteriyel hastalıklardan biri olarak ortaya çıkmıştır ve gökkuşağı alabalığı popülasyonlarında %60-70'e varan önemli ölüm oranlarıyla sonuçlanmıştır (Meyburgh *ve ark*., 2017; Vendrell *ve ark*., 2006). Türkiye'nin batı kesiminde bulunan gökkuşağı alabalığı çiftliklerinde *L. garvieae*'nin ilk kaydının yapıldığı 2001 yılından bu yana (Diler *ve ark*. 2002), laktokok enfeksiyonlarını kontrol etmek için farklı antibiyotikler kullanılmıştır (Kubilay *ve ark*., 2005; Balta ve Balta 2019). Kubilay *ve ark*., (2005) ülkemizde gökkuşağı alabalık işletmelerinden izole edilmiş olan 9 farklı *L. garveiae* suşları için yaptıkları antibiyogram çalışmasında, suşların eritromisin, amoksisilin, kloramfenikol, ampisilin, enrofloksasin, sephalotin, vankomisin, spektinomisin, tetrasiklin, sefoperazon, sephalotin ve nitrofurantoin antibiyotiklerine duyarlı, gentamisin, linkomisin, penisilin, siprofloksasin, sulfametoksazol-trimetoprim, klindamisin, kanamisinsefuroksim, kolistin ve okzolinik asit antibiyotiklerine karşı ise dirençli olduğu bulunmuştur. Karadenizde yetiştiriciliği yapılan gökkuşağı alabalıklarından izole edilen *Lactococcus garvieae* etkeninin antibiyotik duyarlık profillerinin belirlendiği bir diğer çalışmada suşların amoksisilin, florfenikol, ampisilin, eritromisin ve oksitetrasikline duyarlı, trimetoprim, okzolinikasite ve sulfametoksazol/trimetoprime dirençli olduğu bildirilmiştir. Ayrıca neomisin, enrofloksasin, kanamisin, sefoperazon ve vegentamisine karşı değişen oranlarda duyarlık gösterdiği belirlenmiştir (Durmaz ve Kılıçoğlu, 2015). Konya İli çevresinde yer alan Gökkuşağı alabalığı çiftliklerinden izole ettikleri *L. garvieae* suşlarının antibiyotik duyarlılıklarının tespitine yönelik yapılan çalışmada ise tüm suşların, oksitetrasiklin, enrofloksasin, amoksisilin, eritromisin, florfenikol ve ampisiline duyarlı; neomisin ve sulfamethoksazol/trimetoprime ise dirençli olduğu tespit edilmiştir (Kav ve Erganiş, 2008). *L.garvieae* suşlarında yapılan bu çalışmada da benzer olarak çalışılan her iki suşunda ampisilin, enrofloksasin, tetrasiklin, kloramfenikol karşı duyarlı olduğu, *L.garvieae* L1 suşunun da sulfametoksazol+trimetoprim antibiyotiğine karşı dirençli olduğu tespit edilmiştir.

Pseudomonas septisemisinin etkeni olan *Pseudomonas fluorescens* fırsatçı bir patojendir. Türkiye'de patojen ilk olarak Ege Denizi'ndeki çipurada, daha sonra levrek, gökkuşağı alabalığı ve bazı süs balığı türlerinden izole edildiği rapor edilmiştir (Öztürk ve Altınok, 2014). Aksoy (2001) Ankara İli ve İlçelerinde bulunan Gökkuşağı alabalığı ve Aynalı sazan çiftliğinden izole edilen *P. fluorescens* suşlarının kanamisin, tetrasiklin ve oksitetrasikline duyarlı, sefalosiporin, trivetrin, ampisilin, gentamisin, neomisin, penisilin, kolistin, streptomisin ve eritromosine dirençli oldukları tespit edilmiştir. Gökkuşağı alabalığını tehdit eden önemli bakteriyel patojenlerin tespiti ve bu patojenlerin antibiyotik duyarlıklarının belirlenmesi üzerine yapılan farklı bir çalışmada ise aynı etkenin neomisin, enrofloksasin ve kanamisine duyarlı olduğu, eritromosin, oksitetrasiklin, trimethoprim, furazolidon, ampisillin, kloramfenikol, streptomisin, sulfamethoksazol/trimetoprim, sulfafurazol antibiyotiklerine karşı ise dirençli olduğu bulunmuştur (Özkök, 2005). Yapılan bu çalışmada ise benzer şekilde aynı etkene ait her iki suşunda ampisilin, sulfamethoksazol/trimetoprim, florfenikol, kloramfenikol ve trimethoprim antibiyotiklerine karşı dirençli olduğu tespit edilmiştir. Hareketli aeromonaslar *Aeromonas hydrophila, Aeromonas sobria* ve *Aeromonas caviae* balıklarda ölümcül bir hastalık olan Motile Aeromonas Septisemisine (MAS) neden olan önemli patojenlerdir (Cipriano, 2001). Ülkemizde MAS neden olan etkenlerin yaygın olarak izole edildiği bildirilmiştir (Özer *ve ark*., 2009; Filik *ve ark*., 2021). Durmaz ve Turk (2009) çiftliklerinden alınan alabalık ve su örneklerinden izole edilen motil Aeromonas bakterilerin oksitetrasiklin, karbenisilin ve streptomisin antibiyotiklerine yüksek direnç gösterdiklerini, bununla birlikte enrofloksasin ve siprofloksasine karsı %96, amikasine %92.3, oksolinik asit, piperasilin, mezlosilin, sefotaksim, imipenem ve flumekuine ise %76.9-84.6 oranlarında duyarlı olduklarını bildirmişlerdir. Özer *ve ark*., (2009) Mersin ilindeki yedi ticari gökkuşağı alabalığı çiftliğinden izole ettikleri 22 hareketli Aeromonas suşunun 2'sinin *Aeromonas sobria* olduğu belirlenmiştir. Balıktan izole edilen *Aeromonas sobria* şusunun antimikrobiyal duyarlığının belirlendiği bu çalışmada gentamisin, sulfamethoksazol/trimetoprim, enrofloksasine duyarlı, oksitetrasiklin, enrofloksasin ve novobiyosine dirençli, neomisin ve streptomisine orta derece duyarlı olduğu tespit edilmiştir. Yaptığımız çalışmada ise benzer şekilde aynı etkene ait şusun, neomisin ve streptomisine orta derece duyarlı olduğu ancak farklı olarak sulfamethoksazol/trimetoprim antibiyotiğine karşı dirençli, oksitetrasiklin, enrofloksasin antibiyotiklerine karşı ise duyarlı olduğu görülmüştür. İzole edilen bakterilerin farklı direnç profilleri göstermesi, coğrafi konumlardan ve örnekleme zamanlarından kaynaklanabileceği bildirilmiştir (Çapkın *ve ark*., 2015).

Ampisilin, neomisin, kanamisin, imipenem, eritromisin, oksolinik asit, oksitetrasiklin, trimetoprim+sülfametoksazol ve streptomisin, florfenikol birçok Avrupa ülkesinde ve Türkiye'de balık hastalıklarının tedavisinde yaygın olarak kullanılan antibiyotiklerdir (Çapkın *ve ark*., 2015; Kayış *ve ark*., 2009). Türkiye'deki balık çiftliklerinde en sık kullanılan antibiyotiğin sülfametoksazol olduğu bildirilmiştir (Çapkın *ve ark*., 2015). Bu çalışmada antimikrobiyal duyarlılık testi sonuçları bakterilerin %66.6'sının trimetoprim+sülfametoksazole %50'sinin streptomisin ve florfenikole dirençli olduğunu göstermiştir. Buna ek olarak, bazı izolatlarda SulII, AmpC ve aadA direnç genleri de tespit edilmiştir. Terzi (2013) Alabalık işletmelerindeki balıklardan izole edilen bakterilerde antibiyotik dirençliliğinin belirlenmesine yönelik yaptığı çalışmada, bakterilerin en çok *sul1* ve *sul2* genini taşıdığını belirlenmiş ve bu durumu bakterilerin sulfonomid grubu antibiyotiklere aşırı maruz kaldığını veya direnç sağlayan genleri diğer bakterilerden edinmiş olmasından kaynaklanabileceğini öne sürmüştür. Aynı çalışmada betalaktam direnci sağlayan genlerden ampC geninin, izole edilen bakterilerin %45.8'inde tespit edildiği bildirilmiş, genin yüksek oranda tespit edilmesinin sebebi kullanılan antibiyotiklerin bulaşmaları ile bakterilerin direnç geni geliştirdiklerinin veya kazandıklarının bir göstergesi olabileceği öne sürülmüştür. Direnç genlerinin diğer bakterilere geçme olasılığı göz önüne alındığında, kromozomal veya plazmit aracılı antibakteriyel direnç profilinin sık sık değerlendirilmesi gerekliliği ortaya çıkmaktadır. ÇAD indeksinin 0.2'den büyük olması su ürünleri yetiştiriciliğinde ağır dozda antibiyotik kullanıldığını göstermektedir (Osundiya *ve ark*. 2013). Bu çalışmada alabalıklardan elde edilen bazı izolatların ÇAD indeksinin 0.2'den büyük olduğu tespit edilmiştir. Bu durum, alabalıkların toplandığı çiftlikte antibiyotik kullanımının daha yoğun olduğunu ortaya çıkarmıştır.

## 5. SONUÇ

Etkili su ürünleri yetiştiriciliğinde, güvenli yönetim uygulamaları, uygun stoklama programları ve uygun hijyenik koşullar, bakteriyel patojenlerin girişini, bakteriyel enfeksiyonların görülme sıklığını ve dolayısıyla antimikrobiyallerin kullanımını sınırlandıracaktır. Antimikrobiyal direnç tehdidinin üstesinden gelebilmek için uygun yönergeleri takip eden sürekli izleme programları ve etkili politikaların uygulanması su ürünleri sektörünün daha sağlıklı gelişmesine katkı sağlayacaktır. Ancak sınırlı sayıda izolatla yapılan izleme çalışmalarının resmin tamamını yansıtmayabileceği, bir üretim alanındaki mevcut antimikrobiyal duyarlılığın daha doğru bir şekilde değerlendirilmesi için mümkün olduğunca çok sayıda bakteri izolatının değerlendirilmesi gerekliliği de bildirilmiştir (Sezgin *ve ark*., 2023). Balık ölümlerinin değerlendirilmesi, antibiyotik kalıntılarının değerlendirilmesi, sorumlu patojenlerin tanımlanması ve bunların antimikrobiyal duyarlılıklarının belirlenmesi, izleme programının bir parçası olarak periyodik olarak yapılmalıdır. Antibiyotik direncinin ortaya çıkması, balık çiftliklerinde uygun sürveyans ve sürekli izleme programlarının uygulanmasının yanı sıra diğer etkili alternatiflerin kullanımını da hatırlatmaktadır. Antibiyotik direncini azaltmak için probiyotikler, bitkisel tedaviler, fajlar, aşılar gibi alternatif çevre dostu tedavilerin de geliştirilmesi gerekmektedir. Bu durum, gıda kalitesini artıracak, insan sağlığı ve çevre üzerindeki olumsuz etkileri en aza indirecektir.

## TEŞEKKÜR

Yazarlar, Çukurova Üniversitesi Bilimsel Araştırma Projeleri Koordinasyon Birimi'ne finansal destekleri için teşekkür eder.

## ESER SAHİPLİĞİ KATKI BEYANI

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## ÇIKAR ÇATIŞMASI

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