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Investigation of the Genotoxic Effect of Acetamiprid in *Cyprinus carpio* Using the Micronucleus Analysis and the Comet Assay

Acetamiprid'in *Cyprinus carpio* da Genotoksik Etkisinin Mikronükleus Analizi ve Comet Testi ile Araştırılması

Türk Denizcilik ve Deniz Bilimleri Dergisi

Cilt: 8 Sayı: 2 (2022) 80-89

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ABSTRACT

Pesticides are considered to be one of the biggest economic and ecological problems in the aquatic ecosystem. Monitoring for toxic effects and screening for different insecticides is vital and crucial for reducing adverse effects on aquatic organisms and public health. Therefore, in this study, we aimed to determine genotoxic effect of acetamipridine in a model fish species, *Cyprinus carpio***,** using the micronucleus test and Comet assay. Common carp (average weight of 1.35 ±0.11g) were exposed to three different concentrations of acetamipridine (0.2, 0.4, and 0.8 g/L) based on previously detected aquatic environmental concentrations, constituting an acute test for a week. At the end of study, the Damage frequency (%), Arbitrary unit and Genetic damage index (%) were evaluated in gill and liver cells of carp by Comet assay. Also, micronucleus frequencies and erythrocyte abnormalities were determined in erythrocytes cells of carp by micronucleus test. Our results revealed significant increases in the frequencies of micronuclei and DNA strand breaks in *C. carpio*, following exposure to acetamipridine and thus demonstrated the genotoxic potential of this pesticide on fish. Our findings also indicated the suitability of the fish micronucleus test and comet assay in assessment of aquatic genotoxicity of insecticides.

Keywords: DNA damage, Acetamipridine, Micronucleus test, Comet assay, Pesticide, *Cyprinus carpio*

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ÖZET

Pestisitler, sucul ekosistemlerdeki en büyük ekonomik ve ekolojik sorunlardan biri olarak kabul edilmektedir. Suda yaşayan organizmalar üzerinde farklı insektisitlerin verdiği toksik etki izlenerek zararlı etkilerin azaltılması halk sağlığı açısından önemlidir. Bu çalışmada Asetamiprid'nin model organizma olan *Cyprinus carpio*'da genotoksik etkilerini Mikronükleus testi ve Comet testi ile belirlenmiştir. Sazan balıkları (ortalama ağırlık 1,35 ± 0,11 g) ortamdaki konsantrasyona bağlı olarak üç farklı asetamipridin konsantrasyonuna (0,2, 0,4 ve 0,8 g/L) maruz bırakılmıştır. Uygulama bir hafta uygulanarak akut test değerlendirmesi yapılmıştır. Çalışmanın sonunda, Sazanların solungaç ve karaciğer dokularına Comet testi uygulanarak Hasar sıklığı (%), Arbitrary unit ve Genetik hasar indeksi (%) değerlendirilmiştir. Ayrıca mikronükleus test tekniği ile sazan balıklarının kırmızı kan hücrelerinde mikronükleus frekansı hesaplanarak eritrosit anormallikleri saptanmıştır. Sonuç olarak; Asetamiprid maruz bırakılan *C. carpio*'da çekirdek anomaliliği ve DNA yapısında önemli farklılıklar gözlemlenmiştir. Elde edilen bulgular ayrıca; pestisitlerin sucul sistemdeki genotoksik etkilerinin değerlendirilmesinde comet testi ve mikronükleus test tekniğinin uygunluğunu da göstermiştir.

Anahtar sözcükler: DNA hasarı, Acetamiprid, Mikronükleus test, Comet test, Pestisit, *Cyprinus carpio*

1. INTRODUCTION

The extensive pesticide applications in agriculture and urban areas possesses the risk for aquatic environments, due to the contamination and persistency potencial of themselves or their metabolites (Turgut Meriç and Keskin, 2017). They can reach the food chain by seriously affecting non-target organisms and threatening biodiversity and ecological balance (Abd El Megid *et al*., 2020). Consumption of fish, which constitutes an important part of the aquatic ecosystem, poses a risk to human health (Ghayyur *et al*., 2021). Pesticides enter into aquatic ecosystems by agricultural run-off and may cause in physiological abnormalities, in aquatic organisms (Wanule and Siddique, 2010). Neonicotinoids are a relatively new class of pesticides, whose large scale application began around 1990 (Berheim *et al*., 2019). These compounds have been indicated as organophosphate substitutes, as they display reduced effects on ecosystems, due to their specific mechanism of action (of inhibiting nerve impulse transmissions in insects due to their structural similarity to nicotine (Yamamoto *et al*., 2012; Wang *et al*., 2015). Today, they are used against a wide range of insects due to their high efficacy and versatility of use. The acetamiprid (ACE) insecticide class contains at least seven major compounds with a market share of more than 25% of total global pesticide sales and replaces older worldwide groups such as organophosphate and carbamate insecticides. They are considered highly selective neurotoxins for insects and likely affect many more taxa, with far broader ecological effects than expected since the introduction of these third-generation insecticides (Vehovszky *et al*., 2018).

Acetamiprid is a fairly new member of the neonicotinoid group of insecticides to control insects and mites that damage plants. Intense and unconscious use of acetamiprid, which has the property of accumulating in water, adversely affects animals and environmental health. Acetamiprid has cytotoxic and genotoxic properties in mammals and aquatic organisms. It has been reported that it causes sister chromatid exchanges in cultures, micronuclei formation in blood lymphocytes and chromosomal anomalies (Hladik *et al*., 2018; Ma *et al*., 2019). Due to its physical and chemical properties, Acetamiprid is highly soluble in water and other organic solvents, stable to hydrolysis and photolysis (Guedegba *et al*., 2019). Considering the studies, it caused toxicity that led to behavioral changes in African catfish fry (Houndji *et al*., 2020). Acetamiprid was found to be risky on change in metabolites of zebrafish (Zhang and Zhao, 2017). It also severely affects health. Antioxidant biomarkers of aquatic invertebrates such as *Cirrhinus mrigala, Biomphalaria straminea (*Coss*i et al.,* 2020*)* and freshwater fish (Ghayyur *et al*., 2021). Furthermore, subchronic exposure of Acetamiprid induced oxidative stress in worms through reactive oxygen species (ROS) accumulation and altered catalase (CAT) and glutathione S transferase (GST) activities, in addition to elevation of lipid peroxidation (LPO) and DNA damage. (Li *et al*., 2018). Acetamiprid caused increased oxidative stress and neurotoxicity in mammals, rats (Dhouib *et al*., 2017; Doltade *et al*., 2019), and mice (Zhang *et al*., 2011).

Amongst various aquatic organisms, fish is a valuable bio monitor of aquatic ecosystem. Fish are the top consumers and play an important role in aquatic food chain by maintaining a balance in aquatic ecosystem pollution. Fish is an ideal indexical organism for assessment and documentation of water pollution, due to their potential to be directly exposed to different xenobiotics. Xenobiotics or carcinogenicity when come in contact with fish, different reactions are initiated among chemical and biological systems in body, that ultimately result into biochemical disturbances. Hence, it is necessary to determine the contaminant action mechanism and potential means to mitigate their impacts. For this reason, fish may be used as bio indicators of aquatic pollution for the quality assessment of the aquatic system (Bonomo *et al*., 2021). Fish is the best suitable to estimate potential risks due to their ability to metabolize and bio-accumulate contaminants in their bodies (Turan and Ergenler, 2019). Amongst various aquatic organisms, fish is a valuable bio monitor of water. Fish are the top consumers and play an important role in aquatic food chain by maintaining a balance in aquatic ecosystem pollution. Fish is an ideal indexical organism for assessment and documentation of water pollution, due to their potential to be directly exposed to different xenobiotics. Xenobiotics or carcinogenicity when come in contact with fish, different reactions are initiated among chemical and biological systems in body, that ultimately result into biochemical disturbances. Hence, it is necessary to determine the contaminant action mechanism and potential means to mitigate their impacts. For this reason, fish may be used as bio indicators of aquatic pollution for the quality assessment of the aquatic system (Bonomo *et al*., 2021). Common carp is also introduced as one of the most suitable fish models for toxicological studies (OECD, 1992). The dominance of common carp in the aquatic systems and having a better capacity for resistance against pollutants rather than other laboratory fish such as zebrafish and Japanese medaka are common reason for choosing this species for toxic test (Li *et al*., 2018).

Advances in technology and frequent use of pesticides have led to pollution of the environment and aquatic ecosystems (Gibbons *et al*., 2015). Pesticides are known to be the biggest problem for economically and ecologically important non-target aquatic species, including fish living in water bodies (Prusty and Patro, 2015; Rejczak and Tuzimski, 2015). Monitoring for toxic effects and screening for different insecticides is vital and crucial for reducing adverse effects on non-target organisms and public health. Therefore, in this study was aimed to determine genotoxic effect of acetamipridine in a model fish species, *Cyprinus carpio*, using the micronucleus analysis and Comet assay.

2. MATERIAL AND METHOD

2.1. Experimental Design

The experiment was carried out with 180 common carp (*C. carpio* L.) (with an average weight of 1.35 ± 0.11 g) at the Iskenderun Technical University, Faculty of Marine Sciences and Technology, Aquaculture Research and Development Center, Turkey. The carps were acclimated for 15 days in a well-aerated 30 L glass aquarium containing dechlorinated water, at room temperature (± 23 °C) with a constant photoperiod (12:12 light / dark cycle). The specimens were fed with commercial carp feed of 3% of their body weight and feeding was stopped 24 h prior to exposure of the insecticide**.** After acclimation the fishes were randomly divided into four groups (experimental and control groups with n = 15 fish per group). Three different concentrations of acetamipridine (0.2, 0.4, and 0.8 g/L) were selected based on previously detected aquatic environmental concentrations, constituting an acute test for a week. Each treatment group consisted of triplicates of 45 fish. At the end of the experiment, fish were anaesthetized with 5 mg /L quinaldine sulphate (Sigma Chemical Company, Germany) (Yanar and Genç, 2004). The specimens were manipulated only once they were unresponsive to physical stimuli (approximately 1 – 2 min), for the removal of tissue (gill and liver) for Comet assay and blood sampling for micronucleus assay.

2.2. Micronucleus (MN) Assay

Blood sampling was performed via cardiac puncture using a heparinized syringe and whole blood was used for subsequent analysis. Blood samples were taken from 15 individuals and the micronucleus test was applied to the erythrocytes and the formation frequencies were calculated. Three blood smears from each individual were prepared immediately after sampling as described in Mitkovska *et al*. (2020). After the prepared preparations are dried in air, they are mixed in 95% ethanol for 20 minutes. They are stained with 5% Giemsa solution for 20 minutes. Micronucleus evaluation was made by counting 1000 cells from each preparation. Morphological nucleus irregularities by peripheral smear Carrasco *et al*. (1990); They were evaluated under four main groups: notched nucleus, kidney nucleus, budded nucleus, lobed nucleus and binucleus.

2.3. Comet Assay

Comet assay was done according to cellular dissociation technique improved from Cavalcante *et al*. (2008). Firstly, gill and liver tissues of carps were homogenized and centrifuged at 3000 rpm at 4 °C for 5 min for the cell suspension, and then the cell pellet was retained. Singh *et al*. (1988) was followed for performing the single-cell gel electrophoresis. The slides were neutralized with ice-cold 0.4 M Tris buffer (pH 7.5), stained with 80 ml ethidium bromide (20 mg mL^{-1}). The slides were then examined at X40 magnification using a fluorescence microscope Image2M Zeiss). Images of 100 cells from each sample (gill and liver cell) were visually scored as proposed by classifying the nucleoids, which were assigned to one of five classes (0–4; with 0 signifying no visible tail and 4 almost all DNA in the tail) according to intensity of the comet tail. For comparison of the data from the comet assay, the damage percentage (%DF), the arbitrary units values (AU) and genetic damage ındex (GDI) were calculated as defined by Pitarque *et al*. (1999) and Collins (2004).

2.4. Statistical Analysis

Before statistical treatment, all data were tested for normality (Shapiro–Wilk test) and homogeneity (Levene analyze test). One-way ANOVA was performed in order to assess significant difference among treatment groups. Duncan's multiple range (DMR) test was used to compare means. Differences were regarded as statistically significant at $P < 0.05$ (Norusis, 1993).

3. RESULTS

Means and standard deviations of micronuclei and means of different classes of nuclear abnormalities counted in *C. carpio* from control and three different concentrations of acetamipridine are given in Table 1 and Figure 1.

Table 1. Means (%) and standard deviations of micronuclei and means of different classes of erythrocyte abnormalities counted in *C. carpio* obtained from control and three different concentrations of Acetamipridine (n=15).

Group	Micronucleus	Kidney	Binucleus	Notched	Lobed	Budded
Control	3.267±0.252^{a}	5.167±0.153^{a}	5.200±0.100^{a}	7.933±0.666^{a}	5.233±0.208^{a}	4.167±0.153^{a}
0.2 g/L	5.300±0.082^{b}	6.067±0.368^{b}	8.233±0.205^{b}	8.067±0.090^{a}	11.067±0.450^{b}	19.467±0.094^{b}
0.4 g/L	7.500±0.500^{c}	8.200±0.557^{c}	11.933±0.987^{c}	12.333±0.152^{b}	14.500±0.500^{c}	20.866±0.152^{c}
0.8 g/L	18.467±0.351^{d}	12.233±0.208^{d}	14.300±0.264^{d}	13.367±0.153^{c}	17.433±0.208^{d}	22.767 ±0.153^{d}
P	***	***	***	***	***	***

The data are shown as arithmetic mean ± standard deviation. *Values with different superscripts in each column indicate significant differences. Indicate significance level between micronucleus frequencies and erythrocyte abnormalities in peripheral erythrocytes of carps obtained from control and three different concentrations of acetamipridine (*, P<0.05; **, P<0.01; ***, P<0.001.

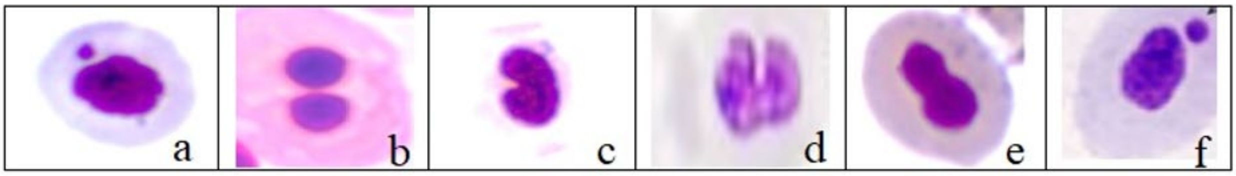

Figure 1. Nuclear anomalies in erythrocyte of *Cyprinus carpio* (a: Micronucleus, b: Binucleus, c: Kidney micronucleus, d: Notched micronucleus, e: Lobbed micronucleus, f: Budded micronucleus).

No fish mortality was observed at Acetamipridine treatment groups and the control during the experiment. In the erythrocytes of the carp, various nuclear abnormalities (micronucleus, binucleus, kidney nucleus, notched nucleus, lobbed nucleus and bud nucleus) were detected at treatment groups. As shown in the table 1, significant differences were observed (P< 0.001) in the frequency of micronucleus and other nuclear irregularities (kidney nucleus, binucleus, notched nucleus, lobed nucleus and budded nucleus) compared with the control group and Acetamipridine treatment groups during a week (Table 1). As result of the study, it is determined that the highest micronucleus frequency and erythrocyte abnormalities is significantly observed in 0.8 g L^{-1} group (p<0.001). Besides, it is observed that the other nuclear abnormalities (kidney nucleus, binucleus, notched nucleus, lobed nucleus and budded nucleus) in peripheral erythrocytes of carps at all treatment groups are significantly higher (p<0.001) compared to the control group (Table 1). As can be seen in our results, Acetamipridine treatment significantly increased the frequencies of nuclear abnormalities (P< 0.001).

Means and standard deviations of the damage frequency (DF %), arbitrary units values (AU) and genetic damage index (GDI %) in the gill and liver cells of *C. carpio* obtained from the control and three different concentrations of Acetamipridine are summarized in Table 2 and Figure 2.

Table 2. Means and standard deviations of DNA damage in the gill and liver cells of carp obtained from the control and three different concentrations of Acetamipridine (n=15).

Groups ($g L^{-1}$)	Damage Frequency (%)	Arbitrary Unit (AU)	Genetic Damage Index (DI) (%)
GILL			
Control	25.667±3.055^{a}	48.667±2.051^{a}	0.486±0.021^{a}
0.2	54.667±3.055^{b}	133.333±9.018^{b}	1.333±0.09^{b}
0.4	69.333±1.154^{c}	187.000±2.645^{c}	1.870±0.02^{c}
0.8	78.667±5.131^{d}	188.333±6.506^{c}	1.883±0.065^{c}
P	***	****	***
LIVER			
Control	36.333±2.309^{a}	36.333±2.309^{a}	0.363±0.023^{a}
0.2	38.666±4.509^{a}	73.333±6.658^{b}	0.733±0.066^{b}
0.4	58.000±0.001^{b}	108.666±5.507^{c}	1.086±0.055^{c}
0.8	68.000±1.732^{c}	184.666±7.371^{d}	1.846±0.073^{d}
P	***	****	***

The data are shown as arithmetic mean ± standard deviation. *Values with different superscripts in each column indicate significant differences. Indicate significance level between DNA damage in gill tissues of carps obtained from control and three different concentrations of acetamipridine (*, P<0.05; **, P<0.01; ***, P<0.001).

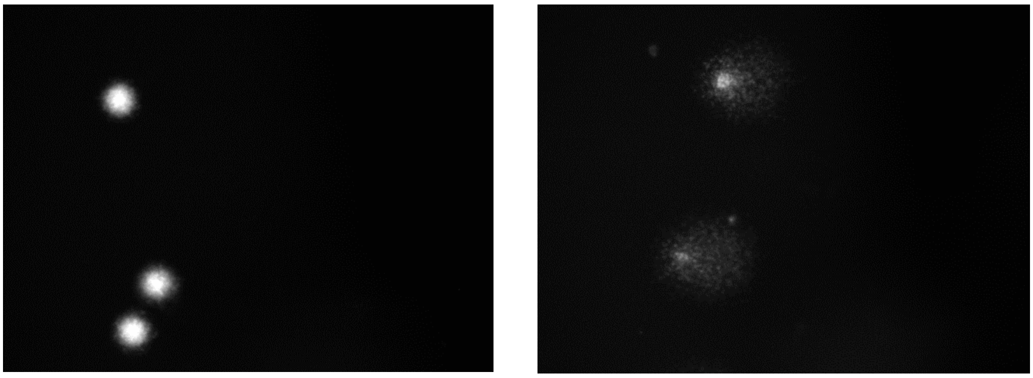

Figure 2. DNA damage in the tissues of *C. carpio* (undamaged (left picture) and damaged (right picture) cells)

As shown in the table 2, significant differences were observed (P<0.001) in the damage frequency and other parameters (AU and GDI) compared with the control and Acetamipridine treatment groups during the experiment. Acetamipridine treatment significantly increased the percentage of DNA damage in gill and liver cells of C. carpio (P<0.001). Similarly, Arbitrary Unit and Genetic Damage Index values are affected by Acetamipridine treatment (P<0.001). As a result of the study, it is determined that the highest damage frequencies (%) as 78.667±5.131 and 68.000±1.732 were significantly observed in 0.8 $g L^{-1}$ group at gill and liver cells respectively (P<0.001). The lowest damage frequencies (%) as 25.667±3.055 and 36.333±2.309 were obtained in the liver and gill cells of control group in this study. Besides, it is observed that other damage parameters (Arbitrary unit and genetic damage ındex) in the gill and liver samples of 0.2 and 0.4 $g L^{-1}$ group were significantly higher (P<0.001) compared to the control group (Table 2, Figure 2). The lowest AU and GD were significantly obtained in control group in this research. In this study, the DNA damage increased due to the increase in the concentrations of acetamipridine.

4. DISCUSSION

Acetamiprid is a relatively new member of the neonicotinoid group of pesticides used to control insects and mites that damage plants. Intensive and unknowing use of acetamiprid, which has the property of accumulating in water, adversely affects the health and environment of animals (Ma *et al*., 2019). Our findings revealed significant damage to the cells of the *C. carpio* following exposure to acetamipridine at different concentrations by the micronucleus test and comet assay. Our results also showed that blood, gill and liver cells of *C. carpio* can respond differently to DNA damage, reinforcing the importance of using different tissues as complementary tools for detecting genotoxicity in fish.

The acute toxicity of acetamipridine has been studied earlier in African catfish and the toxicity was found to be moderate to very high in terms of the 96-h LC50 value (Houndji *et al*., 2020). Houndji *et al*. (2020) suggested that ecological risk assessment of acetamipride (neonicotinoid) and lambda-cyhalothrin (pyrethroid), in aquatic environments should consider their contamination levels, and also recommended to pay special attention to behavioral changes related to their neurotoxicity for additional monitoring of the adverse effects of these insecticides. Yao *et al*. (2006) reported that the acetamipride increases the SOD and CAT enzyme levels in three bacteria species for a short time. The presence of SOD and CAT enzyme activities is important to indicate the presence of superoxide radicals (Turan *et al*., 2020). In physiological conditions, superoxide anions (O_2^-) are reduced by SOD to hydrogen peroxide (H_2O_2). CAT enzymes prevent the formation of hydroxyl radicals by converting hydrogen peroxide into H_2O and O_2. However, when the production of ROS and RNR is too high, an imbalance occurs between the antioxidant system and free radicals, which is called oxidative stress. This leads to the formation of hydroxyl free radicals which can cause DNA strand breakage by increasing superoxide and hydrogen peroxide anions (Paravani *et al*., 2019). ACE-induced cytotoxicity has been reported to be caused by superoxide anions (Gökalp Muranli *et al*., 2015).

Some investigations have reported the genotoxic effect of acetamipridine. Sandayuk and Kılıcle (2020) investigated genotoxic effect of acetamiprid in mouse bone marrow cells by CA (chromosomal aberration) and MN (micronucleus) test methods, reported that acetamiprid at 15 mg/kg dose was genotoxic-cytotoxic in mouse. Gokalp Muranlı *et al*. (2015) studied the genotoxic effects of single and combined uses of acetamiprid and propineb insecticides in human peripheral blood lymphocytes using micronucleus test technique. In their study, lymphocytes were exposed to acetamiprid (0.625, 1.25, 2.5 µg/mL), propineb (12.5, 25, 50 µg mL) and cetamiprid- propineb mixture (0.625 + 12.5, 1.25 + 25, 2.5 + 50 µg/mL) for 1 and 2 days). They found that exposure to a 48-hour acetamiprid- propineb mixture produced a significant increase in MN rates. Guedegba *et al*. (2019) reported that acetamipride (neonicotinoid) and lambda-cyhalothrin (pyrethroid) demonstrated an antagonistic effect for lethal concentrations of 5% to 15% lethal at 96 h (96 h-LC 5-15 in on Nile tilapia The results suggest that ecological risk assessment of these molecule (acetamipride (neonicotinoid) and lambda-cyhalothrin (pyrethroid) in aquatic environments should consider their contamination levels. Cavas (2011) reported that acetamipride has cytotoxic and genotoxic potential on small intestine cells using MN, comet and γH2AX test methods on CaCo-2 cells. Similarly, Hathout *et al*. (2021) investigated the protective potential of ascorbic acid (Asc) against oxidative stress and genotoxicity induced by sub-lethal concentrations (10, 20 and 50 mg kg^{-1}) of acetamiprid (Aceta) in *Oreochromis niloticus*. The results determined that acetamiprid (10 and 20 ppm) concentrations induced oxidative stress by changing antioxidant enzyme activities and transcripts. They observed that exposure to acetamiprid had genotoxic effects in DNA-damaged cells and ascorbic acid combined exposure could be an effective treatment against acetamiprid-induced oxidative stress in Tilapia. At this point our results are in agreement with those reported genotoxic potential of commercial formulations of acetamipride.

5.CONCLUSIONS

The current findings reveal that the acetamipride is a genotoxic insecticide inducing micronucleus frequency, erythrocyte abnormalities and DNA damage frequencies in *C. carpio*. Our findings also indicated the suitability of the fish micronucleus test and comet assay in assessment of aquatic genotoxicity of insecticides.

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CONFLICT OF INTERESTS

The authors decelerate that they have no conflict of interests.

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Research Article
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Investigation of the Effect of the Regenerative Organic Rankine Cycle System on Decarbonization for a Bulk Carrier

Dökme yük gemisi için Rejeneratif Organik Rankine Çevrimi Sisteminin Dekarbonizasyon Üzerindeki Etkisinin Araştırılması

Türk Denizcilik ve Deniz Bilimleri Dergisi

Cilt: 8 Sayı: 2 (2022) 90-103

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ABSTRACT

Shipping has a very important share in world trade. However, it has an inevitable effect on global greenhouse gas emissions. Therefore, there is a great motivation for the reduction of fuel consumption and exhaust emissions. Waste heat recovery systems based on Organic Rankine Cycle (ORC) technology have a significant potential to reduce fuel consumption and exhaust emissions. In this study, the optimization of the regenerative ORC was carried out for a bulk carrier. Multi-objective optimization was performed using a Grey Wolf Optimization algorithm that is a powerful and novel algorithm. Thermo-economic evaluations were carried out by considering the design and off-design working conditions of the ship. In addition, the impact of the optimized ORC system on decarbonization was investigated. The results showed that the annual average W_{net} was determined as 372.78 kW. The annual average fuel saving and the annual average CO_2 reduction were calculated as 522.83 tfuel/year and 1628.09 tCO_2/year, recpectively. The findings indicated that using the RORC system on ships is a promising solution for increasing emission restrictions and environmental concerns.

Keywords: Organic Rankine Cycle, waste heat recovery, multi-objective optimization, fuel saving, CO_2 emission

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ÖZET

Deniz taşımacılığı dünya ticaretinde çok önemli bir paya sahiptir. Ancak, küresel sera gazı emisyonları üzerinde kaçınılmaz bir etkiye sahiptir. Bu nedenle yakıt tüketiminin ve egzoz emisyonlarının azaltılması için büyük bir motivasyon bulunmaktadır. Organik Rankine Çevrimi (ORC) teknolojisine dayalı atık ısı geri kazanım sistemleri, yakıt tüketimini ve egzoz emisyonlarını azaltmak için önemli bir potansiyele sahiptir. Bu çalışmada, bir dökme yük gemisi için rejeneratif ORC atık ısı geri kazanım sisteminin optimizasyonu gerçekleştirilmiştir. Çok amaçlı optimizasyon, güçlü ve yeni bir algoritma olan Gri Kurt Optimizasyon algoritması kullanılarak gerçekleştirilmiştir. Geminin tasarım ve tasarım-dışı çalışma koşulları dikkate alınarak termoekonomik değerlendirmeler yapılmıştır. Ayrıca, optimize edilmiş ORC sisteminin dekarbonizasyon üzerindeki etkisi araştırılmıştır. Sonuçlar, yıllık ortalama W_{net}'in 372.78 kW olarak hesaplandığı göstermiştir. Yıllık ortalama yakıt tasarrufu ve yıllık ortalama CO_2 azaltımı ise sırasıyla 522.83 tyakıt/yıl ve 1628.09 tCO_2/yıl olarak hesaplanmıştır. Elde edilen bulgular, gemilerde RORC sisteminin kullanılmasının, artan emisyon kısıtlamaları ve çevresel kaygılar için umut verici bir çözüm olduğunu göstermiştir.

Anahtar sözcükler: Organik Rankine çevrimi, atık ısı geri kazanımı, çok amaçlı optimizasyon, yakıt tasarrufu, CO_2 emisyonu

1. INTRODUCTION

The maritime sector, which is responsible for approximately 90% of world trade, is of vital importance for the world economy (Töz et al. 2022). However, it has an impact of approximately 3% on global greenhouse gas (GHG) emissions. Maritime trade volume is expected to increase by 3.5% 2019-2024 compared to 2018. This indicates that emissions from ships will gradually increase. The international maritime organization (IMO) has introduced some strict rules such as EEDI (Energy Efficiency Design Index), SEEMP (Ship Energy Efficiency Management Plan), and EEOI (Energy Efficiency Operational Indicator) to solve this global problem.

Most of the ships (about 90%) use diesel engines as the main propulsion system. Diesel engines with an efficiency of around 50% release almost half of the fuel energy as waste heat. Therefore, the use of waste heat recovery systems is a very important solution for increasing efficiency. This will reduce fuel consumption and emissions, and will make a significant contribution to the target of decarbonization in maritime (Civgin and Deniz, 2021; Mallouppas and Yfantis, 2021). Different waste heat recovery technologies such as exhaust gas turbine system (EGT), Organic Rankine Cycle (ORC), Kalina Cycle (KC), thermoelectric generators (TG) can be used for marine diesel engine. In recent years, ORC has received increasing attention. The main difference between ORC and the basic Rankine Cycle is the use of organic refrigerants as the working fluid. ORC outperforms other methods, especially for waste heat recovery from low-temperature heat sources.

Ships are sailing with different main engine loads. This is one of the major challenges for a waste heat recovery system design. The design and off-design analysis should be carried out for more accurate analysis. Then, an operational profile-based simulation should be performed, taking into account the times spent at different main engine loads. Thus, annual net power output, fuel saving, and emission reduction amounts can be determined. On the other hand, there are limited studies that off-design analysis is performed in marine ORC studies (Yang and Yeh, 2015a; Yang and Yeh, 2015b; Yang and Yeh, 2014; Song *et al*., 2015).

There are very few studies that profile-based simulation is carried out by making design and off-design analyzes. Ahlgren *et al*. (2016) carried out an operational profile-based simulation for the passenger ship M/S Birka. Different working fluids were used for both simple and regenerative ORC in the study. The speed range of 12 to 14 kn, which corresponds to approximately 34% of the voyage time, was accepted as the design condition for ORC optimization. As a result of the study, it was seen that the largest mean net power output was given by the regenerative ORC cycle. In addition, the highest mean net power output for the regenerative cycle was obtained with benzene. The proposed ORC system provided fuel and cost savings by meeting approximately 22% of the ship's total electricity demand. Lümmen *et al*. (2018) compared ORC concepts for waste heat recovery in the hybrid powertrain of a fast passenger ferry. Different working fluid candidates were compared using a simple optimization based on the maximum amount of recoverable work. The regenerative ORC was determined as the most suitable solution to extract energy from the exhaust gases. In addition, R1234ze (Z) was found to be the most promising candidate. Shu *et al*. (2017) performed an ORC system simulation, taking into account the operational profile of M/S Birka. In the study, the working profile of the ship was examined under 6 different main engine load conditions. 45-55% engine load was chosen as the design condition, and off-design analyses were carried out for other operating conditions. As a result of the study, it was determined that R123 and R365mfc fluids provide more net power output than other fluids in all conditions. However, R123 produced more power at heavy engine loads, while the R365mfc was been shown to be more suitable for light engine loads. Mondejar *et al*. (2017) carried out an operational profile-based simulation by implementing a regenerative ORC for a cruise ship. The main purpose of the study was to evaluate the off-design performance of the optimized ORC. It was emphasized that the determined design conditions affect the total net power output for different operating conditions and the importance of the choice of design conditions is underlined. As a result of the study, it was determined that approximately 22% of the total electricity demand on board was met by using the maximum net energy production of the ORC system.

In recent years, optimization studies have attracted attention for the determination of the optimum ORC system parameters. These studies are divided into two as single-objective optimization and multi-objective optimization. Previous studies have generally been carried out with the single-objective of thermal efficiency, exergy efficiency, or net power output. In the next studies, multi-objective optimization studies have been carried out by adding parameters such as economy, environment, and safety to the thermodynamic indicators. De la Fuente *et al*. (2017a) carried out ORC optimization with particle swarm optimization algorithm for a container ship with a capacity of 4100 TEU. In the study, which was carried out considering the design and off-design operating conditions, the annual CO_2 reduction amount was used as the objective function. Four different working fluids, R1233zd(E), R236fa, R236ea, and R245fa, were used. The results showed that an ORC unit using sea water as the cooling water and R1233zd (E) as the working fluid was the best option. The annual CO_2 reduction amount was approximately 599 tons for the ORC unit using sea water as the cooling water. The annual CO_2 reduction amount was approximately 471 tons for the ORC unit using air as the cooling water. Akman and Ergin (2020) conducted an ORC study with genetic algorithm for a tanker with a capacity of 49990 DWT. The objective function was determined as exergy efficiency. The energy, exergy, and environmental parameters were analyzed at different main engine loads. The results showed that it was possible to increase the overall thermal efficiency of the ship power generation system by more than 2.5% under optimum conditions by using the onboard ORC system. Besides, the CO_2 reduction amount was achieved as 678.1 tons per year. It was also determined that the main engine should be operated between approximately 70% and 75% MCR in order to maximize exergy efficiency and minimize fuel consumption. Baldasso *et al*. (2019) investigated the effects of EGR and SCR on the performance of waste heat recovery units to be installed on new ships by using genetic algorithm for an LNG ship with a capacity of 2500 TEU. The annual electricity production, the volume of heat exchangers, and the net present value of the investment were taken as the objective function. De la Fuente *et al*. (2017b) performed ORC optimization with genetic algorithm for the Aframax tanker. In the study, simulations were carried out considering the design and five off-design conditions by using five different working fluids: benzene, heptane, hexamethyldisiloxane, toluene, and R245fa. Objective functions were selected as thermal efficiency, equipment dimensions (pipe and heat exchangers), and net power output. As a result of the study, it was determined that the use of ORC provided approximately 17% savings in both fuel consumption and CO_2 emissions compared to conventional steam RC.

The main purpose of this study is to investigate the annual fuel saving and CO_2 reduction amounts with the regenerative ORC (RORC) for the bulk carrier with a capacity of 109731 DWT. Main engine exhaust gas was used as waste heat. Design and off-design analyzes were carried out for different engine load conditions. Firstly, optimum RORC system parameters were obtained with Multi-Objective Grey Wolf Algorithm (MOGWA) for design working condition. Afterward, off-design analyzes were carried out using off-design models. Finally, the operational profile-based simulation was performed. Lastly, the annual fuel saving and CO_2 reduction amounts of the ship were determined.

2. MATERIAL AND METHOD

2.1. Bulk Carrier Waste Heat Analysis

In this study, the optimum waste heat recovery system for the bulk carrier Atlantic Dragon with a capacity of 109731 DWT was investigated. MAN 6G70ME-C9.5 is used as the main engine in the Atlantic Dragon. In order to apply a waste heat recovery system for a ship's main engine, waste heat information of the relevant main engine is required. The data of the MAN 6G70ME-C9.5 were obtained with the CEAS software provided by MAN (CEAS, 2021). The CEAS application provides power, speed, specific fuel consumption, exhaust gas mass flow rate, and exhaust gas temperature according to the main engine load in ISO standard (sea: 25°C, air: 25°C). Today, on most ships, the heat obtained from the exhaust gas is primarily used to meet the auxiliary heat demand on the ship. Therefore, firstly, the steam demand of the ship should be determined. In the doctoral thesis by De la Fuente (2016), an approximate correlation for the determination of steam demand was presented. In this study, De la Fuente's approximate correlation was used. The variation of the temperature and mass flow rate of the exhaust gas according to the main engine load after steam production was given in Figure 1.

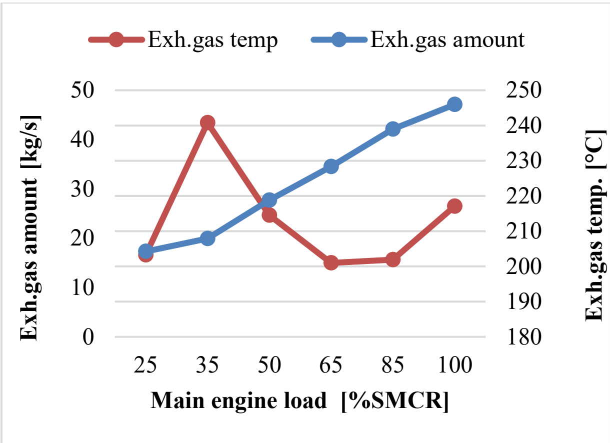

Figure 1. Exhaust gas properties after steam production for MAN 6G70ME-C9.5

2.2. RORC Thermodynamic Model

In this study, a waste heat recovery system for a bulk carrier was realized with the RORC system. The exhaust gas from the main engine enters firstly the boiler to meet the steam demand of the ship. The exhaust gas, which lost some of its heat, then entered the evaporator, and waste heat recovery was achieved. The schematic representation of the RORC system and the main engine was given in Figure 2.

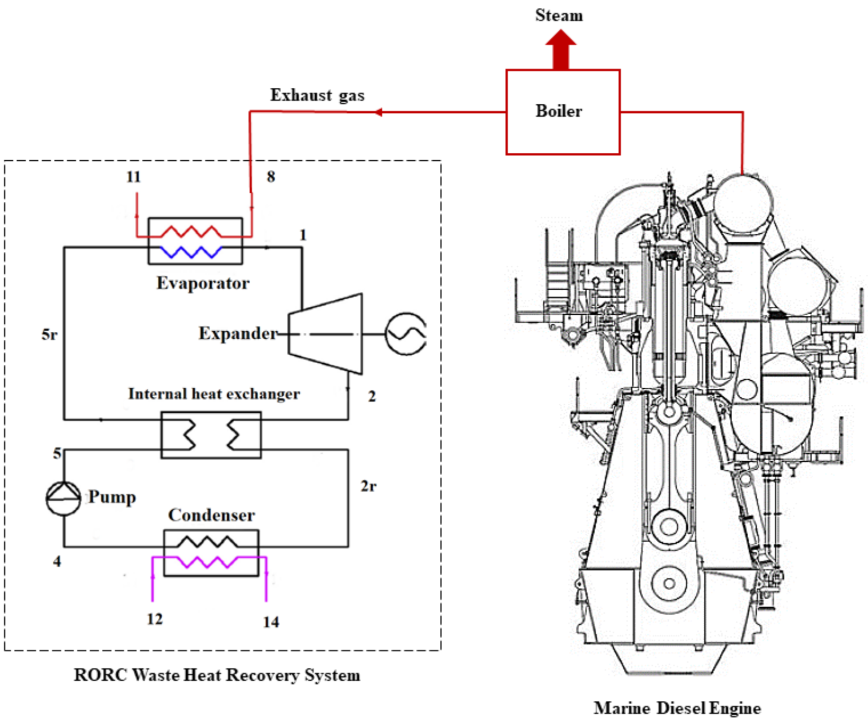

Figure 2. The layout of the RORC system and main engine for bulk carrier

The net power output of the RORC system ($\dot{W}_{net}$) is obtained as in Equation 1.

$$\dot{W}_{net} = \dot{W}_t \eta_g - \dot{W}_p - \dot{W}_{p,sw} \quad (1)$$

where η_g is generator efficiency. In addition, the effectiveness of recuperator (ε_{rec}) is calculated as follows:

$$\varepsilon_{rec} = \frac{T_2 - T_{2r}}{T_2 + T_5} \quad (2)$$

The thermal efficiency and exergy efficiency of the RORC system can be calculated as follows:

$$\eta_t = \frac{\dot{W}_{net}}{\dot{Q}_{eva}} \quad (3)$$

$$\eta_{ex} = \frac{W_{net}}{W_{net} + I_{tot}} \quad (4)$$

where I_{tot} is total exergy destruction in the system.
The exergy destruction of each component is calculated as follows:

$$I_p = m_f \cdot T_0 \cdot (s_5 - s_4) \quad (5)$$

$$I_{eva} = m_f \cdot T_0 \cdot \left[(s_1 - s_5) - \frac{h_1 - h_5}{T_H} \right] \quad (6)$$

$$I_t = m_f \cdot T_0 \cdot (s_2 - s_1) \quad (7)$$

$$I_{con} = m_f \cdot T_0 \cdot \left[(s_4 - s_2) - \frac{h_4 - h_2}{T_L} \right] \quad (8)$$

$$I_{rec} = m_f \cdot T_0 \cdot \left[(s_{2r} - s_2) + (s_{5r} - s_5) \right] \quad (9)$$

2.3. Heat Transfer Analysis

A shell-tube heat exchanger was used for the condenser, evaporator, and recuperator, which are the three main heat exchangers used in the RORC system. The evaporator is divided into three parts heating, evaporation, and superheating, and the condenser is divided into two parts as cooling and condensation to calculate the heat transfer coefficient and heat transfer area. Since the recuperator has a single-phase flow, it is analyzed in one part.
The working fluid in the heating and

superheating section in the evaporator unit and seawater in the condenser unit exhibit single-phase turbulent flow. Thus, the Nusselt number is calculated with the expression suggested by Gnielinski (1976). In addition, single-phase heat transfer occurring in the recuperator was also analyzed with this equation:

$$Nu = \frac{\left(\frac{f}{8}\right)(Re-1000)Pr}{1+12.7\left(\frac{f}{8}\right)^{0.5}\left(Pr^{\frac{2}{3}}-1\right)} \quad \begin{matrix} 0.5 \le \mathrm{Pr} \le 2000 \\ 3\times10^3 \le Re \le 5\times10^6 \end{matrix} \qquad (10)$$

where, Re and Pr represent the dimensionless Reynolds and Prandtl numbers, respectively. In addition, f is the friction factor and can be calculated with the Petukov equation (1970):

$$f = (0.79\ln(\mathrm{Re}) - 1.64)^{-2} \quad 3\times10^3 \le Re \le 5\times10^6 \qquad (11)$$

In the evaporation section, the working fluid is in two phases and the heat transfer takes place in the form of boiling heat transfer. In the study, boiling heat transfer calculations were performed with the approach presented by Güngor and Winterton (1986). The main boiling heat transfer expression is given in Equation 12.

$$h_t = E \cdot h_{lo} + S \cdot h_{pool} \qquad (12)$$

h_{lo} is the liquid phase convection heat transfer coefficient and is calculated using the Dittus-Boelter correlation as follows:

$$h_{lo} = 0.023 \cdot \mathrm{Re}_{t,l}^{0.8} \cdot \mathrm{Pr}_{t,l}^{0.4} \cdot \frac{k_{t,l}}{d_i} \qquad (13)$$

The two-phase convection factor E is calculated as in Equation 14.

$$E = 1 + 24000 \cdot Bo^{1.16} + 1.37 \cdot (1/X_{tt})^{0.86} \qquad (14)$$

Bo and X_{tt} are the boiling and Martinelli numbers, respectively.

The equation proposed by Cooper (1984) was used for pool boiling and shown as following equation.

$$h_{pool} = 55 \cdot P_{rdc}^{0.12} \cdot (-\log_{10} P_{rdc})^{-0.55} \cdot M^{-0.5} \cdot q^{0.67} \qquad (15)$$

P_{rdc} is obtained by dividing the operating pressure of the working fluid by the critical pressure (P_{ope}/P_{crt}). The compression factor S is obtained by the expression below:

$$S = (1 + 1.15\cdot10^{-6} \cdot E^2 \cdot \mathrm{Re}_{t,l}^{1.17})^{-1} \qquad (16)$$

The exhaust gas flowing by the shell side and the working fluid in the cooling section of the condenser unit exhibit a single-phase flow, and the heat transfer coefficient is calculated as follows (Bergman *et al.*, 2011):

$$Nu = 0.71 \cdot \mathrm{Re}^{0.5} \cdot \mathrm{Pr}^{0.36} \cdot \left(\frac{\mathrm{Pr}}{\mathrm{Pr}_w}\right)^n \qquad (17)$$

In the condensing section in the condenser unit, the working fluid is two-phase and the condensation process is analyzed as film condensation. The heat transfer coefficient for condensation can be calculated as in Equation 18.

$$h = 0.728 \cdot \left(\frac{g \cdot \rho_l \cdot (\rho_l - \rho_g) \cdot \mathrm{k}_l^3 \cdot h_{\mathrm{lg}}}{\mu_l (\mathrm{T}_{sat} - \mathrm{T}_w) \cdot \mathrm{d}_o}\right)^{1/4} \cdot N_r^{-1/6} \qquad (18)$$

where T_w is the wall temperature and T_{sat} is the saturation temperature. Nr is the average number of tubes in the vertical tube row, which can be considered as follows (Sinnott *et al.*, 2015):

$$N_r = \frac{d_b}{p_t} \cdot (2/3) \qquad (19)$$

2.4. Economic Analysis

The total cost of the RORC system was obtained with the Module Costing Technique. In this method, there are several steps. First, the purchase cost (Cp) for any equipment is obtained as follows:

$$\log C_{p,X} = K_{1,X} + K_{2,X} \cdot \log Y + K_{3,X} \cdot (\log Y)^2 \quad (20)$$

where K_1, K_2, and K_3 show the equipment cost coefficients and Y is the power in kW for the turbine and the pump, or the heat transfer area in m^2 for the heat exchangers. X index shows the related equipment. The bare module cost for the turbine is calculated with Equation 21 and for heat exchangers and the pump with Equation 22.

$$C_{BM,tur} = C_{p,tur} \cdot \left(F_{BM} \cdot F_{p,tur}\right) \quad (21)$$

$$C_{BM,X} = C_{p,X} \cdot \left(B_{1,X} + B_{2,X} \cdot F_{M,X} \cdot F_{P,X}\right) \quad (22)$$

where B_1, B_2, and F_{BM} are the coefficients of the relevant equipment, F_M is material factor and F_P is the pressure factor and is calculated for all elements as follows:

$$\log F_{p,X} = C_{1,X} + C_{2,X} \cdot \log P + C_{3,X} \cdot (\log P)^2 \quad (23)$$

P is the working pressure of its respective element. C_1, C_2, and C_3 are the pressure factor coefficients. All the above-mentioned coefficients were given in Table 1 for each element based on the year 2001

The generator cost ($C_{BM,g}$) was determined as follows (Wang *et al.*, 2015):

$$C_{BM,g} = 1850000 \cdot \left(\frac{W_{net}}{11800}\right)^{0.94} 1.5 \quad (24)$$

Finally, the total cost of the RORC plant (C_{tot}) is obtained as follows:

$$C_{tot} = \begin{pmatrix} C_{BM,eva} + C_{BM,\mathrm{con}} + \\ C_{BM,\mathrm{rec}} + C_{BM,\mathrm{p}} + \\ C_{BM,\mathrm{t}} + C_{BM,g} \end{pmatrix}_{2001} \cdot \frac{CEPCI_{2020}}{CEPCI_{2001}} \quad (25)$$

CEPCI is a chemical engineering plant cost index. $CEPCI_{2001}$ and $CEPCI_{2000}$ are taken as 397 and 599.5, respectively (Baldasso *et al.*, 2019; Lee *et al.*, 2020). In this study, electricity production cost (*EPC*) was used as an economic indicator and *EPC* is calculated as follows:

$$EPC = \frac{A_{inv} + COM}{W_{net} \cdot t_{op}} \quad (26)$$

where t_{op} is annual operating time of the RORC system and was taken as 7500 hours. *COM* is the operation and maintenance cost and was accepted as 1.5% of the total investment cost. Besides, A_{inv} is the annuity of the investment and determined as follows:

$$A_{inv} = C_{tot} \cdot CRF \quad (27)$$

where *CRF* is the capital recovery factor and is calculated as follows:

$$CRF = \frac{i \cdot (1+i)^t}{(1+i)^t - 1} \quad (28)$$

where, t and i show the RORC plant life and the interest rate, respectively. RORC plant life is taken as 20 years and the interest rate is 5% for this study.

2.5. Off-design Analysis

Ships work at different main engine loads during their voyage.

Table 1. Equipment cost coefficients (Turton *et al.*, 2008).

X	Y	$K_{1,X}$	$K_{2,X}$	$K_{3,X}$	$B_{1,X}$	$B_{2,X}$	$F_{M,X}$	F_{BM}	$C_{1,X}$	$C_{2,X}$	$C_{3,X}$
Evap.	A_{eva}	4.3247	-0.303	0.1634	1.63	1.66	1.4	-	0.0388	-0.11272	0.08183
Cond.	A_{con}	4.3247	-0.303	0.1634	1.63	1.66	1.4	-	0.0388	-0.11272	0.08183
Recup.	A_{rec}	4.3247	-0.303	0.1634	1.63	1.66	1.4	-	0.0388	-0.11272	0.08183
Pump	W_p	3.3892	0.0536	0.1538	1.89	1.35	1.6	-	-0.3935	0.3957	-0.00226
Turbine	W_t	2.7051	1.4398	-0.1776	-	-	-	3.4	0	0	0

This situation changes the mass flow rate and temperature of the exhaust gas. Therefore, the quality of waste heat also changes. While designing the RORC system on ships, both the design operating condition and off-design conditions should be considered. In this study, sliding pressure mode was adopted for off-design analysis. The off-design operating condition for the heat exchanger is analyzed by the equation given below.

$$UA_{od} = UA_d \cdot \left(\frac{\dot{m}_{od}}{\dot{m}_d} \right)^{\alpha} \tag{29}$$

where α exponent was taken as 0.6. This value was used in many studies and produced reasonable results for a shell and tube heat exchanger in marine ORC application (Shu *et al*., 2017; Mondejar *et al*., 2017; Baldasso *et al*., 2019; Baldi *et al*., 2015; Andreasen *et al*., 2017). The following expression is used for the off-design model of the pump.

$$\frac{\eta_{p,od}}{\eta_{p,d}} = c_1 \cdot \left(\frac{\dot{V}_{p,od}}{\dot{V}_{p,d}} \right)^3 + c_2 \cdot \left(\frac{\dot{V}_{p,od}}{\dot{V}_{p,d}} \right)^2 + c_3 \cdot \left(\frac{\dot{V}_{p,od}}{\dot{V}_{p,d}} \right)^1 + c_4 \tag{30}$$

The coefficients c_1, c_2, c_3 and c_4 are determined according to the performance curve of the pump. It was taken as $c_1 = -0.439$, $c_2=0.466$, $c_3=0.453$ and $c_4=0.519$ in the literature and was shown to produce sufficiently accurate results for ORC applications on ships (Baldi *et al*., 2015; Andreasen *et al*., 2017; Pierobon *et al*., 2014). The efficiency of the turbine for off-design operating conditions was obtained with the following equation:

$$\frac{\eta_{t,od}}{\eta_{t,d}} = \frac{N_{od}}{N_d} \cdot \sqrt{\frac{\Delta h_{is,d}}{\Delta h_{is,od}}} \cdot \left(2 - \frac{N_{od}}{N_d} \cdot \sqrt{\frac{\Delta h_{is,d}}{\Delta h_{is,od}}} \right) \tag{31}$$

For the off-design model of the turbine, the relationship between temperature, pressure and mass flow was determined as follows:

$$C = \frac{\dot{m} \cdot \sqrt{T_{in}}}{\sqrt{P_{in}^2 - P_{out}^2}} \tag{32}$$

2.6. Grey Wolf Optimization Algorithm

Grey wolf algorithm (GWA) was introduced by Mirjalili *et al*. (2014). The algorithm was developed with inspiration from the hunting technique and social hierarchy of grey wolves. Grey wolves have a 4-level hierarchical structure. At the first level, there is the alpha wolf called leader wolf. This is followed by beta, delta, and omega wolves, respectively. The duties and authorities of the wolf in each hierarchical group are different from each other. Grey wolves group hunting is another feature that makes them special. According to Muro *et al*. (2011), the main stages of grey wolf hunting are:

- Tracking, chasing and approaching the prey.
- Pursuing, encircling, and harassing the prey until it stops moving.
- Attack

Mirjalili *et al*. (2016) mathematically modeled the hunting mechanism of grey wolves and presented the literature for the solution of optimization problems. The encircling behavior of grey wolves was modeled as follows:

$$\vec{D} = \left| \vec{C} \cdot \vec{X_p}(t) - \vec{X}(t) \right| \tag{33}$$

$$\vec{X}(t+1) = \vec{X}_p(t) - \vec{A} \cdot \vec{D} \tag{34}$$

where t is the current iteration, $\vec{A}$ and $\vec{C}$ are the coefficient vectors, $\vec{X_p}$ is the position vector of the prey, and $\vec{X}$ is the position vector of the grey wolf. The vectors $\vec{A}$ and $\vec{C}$ are calculated as follows:

$$\vec{A} = 2\vec{a} \cdot \vec{r_1} - \vec{a} \tag{35}$$

$$\vec{C} = 2 \cdot \vec{r_2} \tag{36}$$

where $\vec{a}$ is a coefficient decreasing linearly from 2 to 0 over the iteration and $\vec{r_1}$, $\vec{r_2}$ are random vectors ranging from zero to one. It is assumed that alpha, beta, and delta have better knowledge of the potential location of the prey to mathematically model the hunting behavior of grey wolves. Therefore, the top three best solutions obtained so far are recorded and other search agents update their positions according to the positions of these three wolves. Thus, the following formulas are offered:

$$\overrightarrow{D_\alpha} = \left|\overrightarrow{C_1} \cdot \overrightarrow{X_\alpha} - \overrightarrow{X}\right| \quad (37)$$

$$\overrightarrow{D_\beta} = \left|\overrightarrow{C_2} \cdot \overrightarrow{X_\beta} - \overrightarrow{X}\right| \quad (38)$$

$$\overrightarrow{D_\delta} = \left|\overrightarrow{C_3} \cdot \overrightarrow{X_\delta} - \overrightarrow{X}\right| \quad (39)$$

$$\overrightarrow{X_1} = \overrightarrow{X_\alpha} - \overrightarrow{A_1} \cdot \overrightarrow{D_\alpha} \quad (40)$$

$$\overrightarrow{X_2} = \overrightarrow{X_\beta} - \overrightarrow{A_2} \cdot \overrightarrow{D_\beta} \quad (41)$$

$$\overrightarrow{X_3} = \overrightarrow{X_\delta} - \overrightarrow{A_3} \cdot \overrightarrow{D_\delta} \quad (42)$$

$$\overrightarrow{X}(\mathrm{t}+1) = \frac{\overrightarrow{X_1} + \overrightarrow{X_2} + \overrightarrow{X_3}}{3} \quad (43)$$

Mirjalili *et al*. (2016) was introduced the Multi-Objective Grey Wolf Algorithm (MOGWA) in 2016 for multi-objective problems. Mirjalili *et al*. (2016) added two new components to the basic GWA. The first component is an archive responsible for storing non-dominant Pareto optimal solutions. The second component is a leader selection strategy.

3. IMPLEMENTATION

One of the main challenges for ORC design is determining the working fluid. It is desired that the working fluid is environmentally friendly and non-hazardous. In this study, R245fa was selected as the working fluid. The global warming potential of R245fa is 950 and ozone depletion potential is 0, and it is frequently used in the literature. Hazard levels of working fluids are evaluated using the Hazardous Materials Identification System (HMIS) and the hazard level is scaled between 0 and 4. R245fa is defined as health hazard 2, reactivity hazard 1 and flammability hazard 0. Therefore, R245fa is environmentally friendly and safe.

After the working fluid was determined, the first stage of the implementation section was started. In the first stage, the multi-objective optimization of the RORC system parameters was performed with MOGWA for the design condition. W_{net} and EPC indicators were taken as objective function. The decision variables were evaporator pressure (P_{eva}), turbine inlet temperature ($T_{t,i}$), condensing temperature (T_{con}) and condenser pinch point temperature difference ($\Delta T_{PP,con}$) and recuperator effectiveness (ε_{rec}). The limit values of these decision variables were given in Table 2.

Table 2. Lower and upper boundary values of decision variables

Decision variables	Lower boundary	Upper boundary
P_{eva}	1500 kPa	$0.95P_{crt}$
$T_{t,i}$	$T_{sat,Peva}$	T_{exh}-20
T_{con}	30 °C	40 °C
$\Delta T_{PP,con}$	5 °C	15 °C
ε_{rec}	0.1	0.95

The limit value of the exhaust gas outlet temperature from the evaporator unit was selected as 140°C to prevent acid corrosion. All modeling and optimization processes were performed in Matlab environment. Also, the thermodynamic and transport properties of the working fluids were provided by integrating the CoolProp (Bell *et al*., 2014) database into the Matlab environment via Python.

As a result of multi-objective optimization, non-dominated solutions were obtained. The final solution from these candidate solutions was obtained by the Euclidean distance (D) approach. This approach was based on how close the solution candidates are to the ideal solution. The Euclidean distance of all candidate solutions was calculated and the smallest value was accepted as the final solution. The Euclidean distance expression was shown below:

$$D = \sqrt{\left(\dot{W}_{net} - \dot{W}_{net}^{ideal}\right)^2 + \left(LEC - LEC^{ideal}\right)^2} \quad (44)$$

In the second step of the implementation part, off-design analysis was performed. As it is known, it is essential to apply off-design models since ships often operate in off-design conditions depending on the changing main engine load and environmental conditions during their voyage. The operational profiles of ships generally vary according to the type of ship. Real-time measurements should be taken and statistical calculations should be carried out to determine the operational profiles of ships. However, it is also possible to create an approximate operational profile for each ship type. The approximate operational profile for the bulk carrier was given by MAN as in Figure 3.

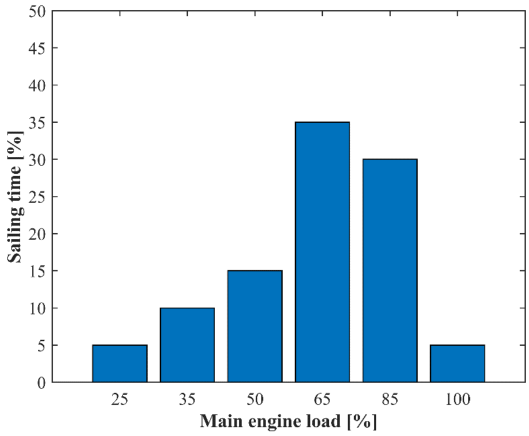

Figure 3. Main engine load profile for bulk carrier

The 65% main engine load was accepted as the design condition, the remaining engine loads were analyzed as off-design conditions. For the off-design conditions, maximizing W_{net} was taken as the only target, and optimization was carried out with an iterative process. An operational profile-based simulation was performed using the results obtained for all working conditions.

In this study, the energy obtained from the RORC facility is used to meet the ship's electricity demand. Therefore, the diesel generators on the ship will operate less, which will both provide fuel saving and make significant contributions to the prevention of environmental pollution. Therefore, considering that the specific fuel consumption of an average diesel generator is 0.187 kg/kWh and the annual operating time of the ORC plant is 7500 hours, the annual fuel saving of RORC systems is obtained as follows:

$$Fuel\ Saving = \dot{W}_{net} \times SFC \times t_{op} \left[\frac{t_{fuel}}{year}\right] \tag{45}$$

where SFC is specific fuel consumption and t_{op} is annual operating time. Using the annual fuel saving, the annual amount of CO_2 reduction can be calculated as follows:

$$CO_2\ reduction = Fuel\ Saving \times C_F \left[\frac{t_{CO_2}}{year}\right] \tag{46}$$

where C_F was carbon conversion factor and taken as 3.114 t_{CO_2}/t_{fuel} for heavy fuel (MEPC 245(66), 2014).

4. RESULT AND DISCUSSIONS

Pareto solutions were obtained as a result of the optimization process using MOGWA. In order to determine the final solution among the Pareto solutions, the Euclidean distance of each solution was calculated and the final solution was obtained as in Figure 4.

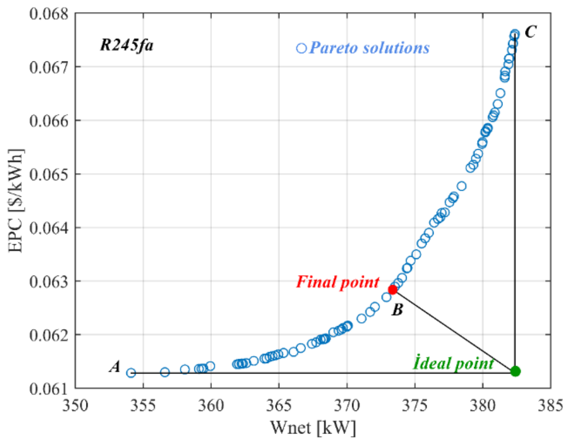

Figure 4. Pareto solutions for R245fa

In Figure 5, the blue circles represent the Pareto solutions, the green circle is the ideal point, and the red circle is the final point. The point at which EPC is minimum was marked A, the point at which W_{net} is maximum is C and the final solution was shown as point B. For the optimum RORC facility, EPC is required to be minimum and W_{net} to be maximum. W_{net}, exergy efficiency, and thermal efficiency were increasing from point A to point C. EPC and total cost were decreasing from point C to point A. As a result, point C was the most suitable in terms of thermodynamics, and point A was the most suitable solution economically. Since these two criteria cannot be met at the same time, point B is determined as the final solution by making a certain trade-off. Thus, the analyzes for the design operating condition of the RORC system with the R245fa working fluid were completed and the off-design analysis was performed for the performance under off-design operating conditions. There are two main constraints for off-design analyzes performed with the sliding pressure mode.; to prevent corrosion on turbine blades, the working fluid coming out of the evaporator is completely evaporated and the exit temperature of the exhaust gas from the evaporator is higher than 140°C to prevent acid corrosion in the ship's funnel. In the sliding pressure method, the condenser pressure was constant and the evaporator pressure was variable. Turbine inlet temperature (T_1), $\Delta T_{PP,con}$ and ε_{rec} parameters were calculated by the iterative solution method so that the heat exchanger areas calculated for the design condition at a given evaporator pressure would be the same as those in the off-design conditions. Table 3 shows the optimum value of the decision variables according to the overall main engine load.

Table 3. Optimum RORC system parameters of all operating conditions

Engine load [%]	**P_{eva} [Pa]**	**T_1 [K]**	**ε_{rec} [-]**	**$\Delta T_{PP,con}$ [K]**
25	1759000	475.335	0.844	2.9
35	3070000	495.08	0.792	4.9
50	3190000	470.71	0.792	5
65	3354558	454.12	0.866	5.06
85	3468450	459.03	0.786	5.4
100	3468450	480.2	0.783	5.4

As the main engine load increased, the optimum value of P_{eva} and $\Delta T_{PP,con}$ also increased. T_1 and ε_{rec} had different values according to RORC design constraint and heat load. Figures 5 and 6 show the variation of thermal efficiency and exergy efficiency according to main engine load, respectively.

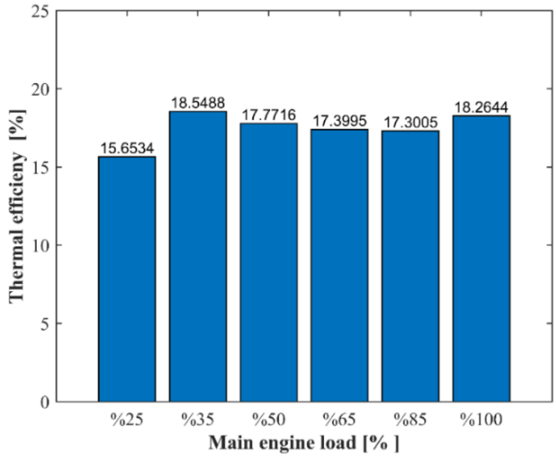

Figure 5. The variation of thermal efficiency for all main engine load

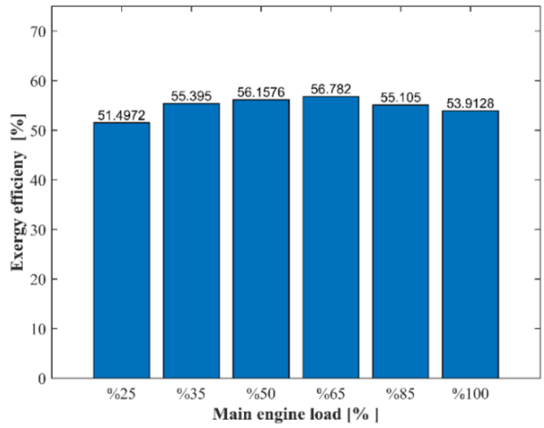

Figure 6. The variation of exergy efficiency for all main engine load

The highest value of thermal efficiency was determined as 18.55% at 35% engine load. The exergy efficiency was obtained as a maximum value of 56.78% at 65% engine load (i.e. design operating condition). After obtaining thermodynamic indicators for all main engine load, an operational profile-based simulation was performed. Table 4 shows the annual average W_{net} and EPC value, as well as fuel saving and CO_2 reduction.

Table 4. Operational profile based simulation for container ship

Parameter	Value
W_{net} [kW]	372.783
EPC [$/kWh]	0.0629
Fuel saving [t_{fuel}/year]	522.8292
CO_2 reduction [t_{CO2}/year]	1628.09

These results showed that the use of the RORC system for bulk carrier provides important contributions both in terms of economy and prevention of environmental pollution.

5. CONCLUSIONS

This study investigates the effect of installing a RORC system on a bulk carrier on fuel consumption and CO_2 reduction. Design and off-design analyzes were performed for the bulk carrier's main engine exhaust gas recycling. Firstly, optimum RORC system parameters were obtained with MOGWA for design working condition. Then, off-design analyzes were carried out using the iterative optimization method. Finally, the operational profile-based simulation was performed and the annual fuel saving and CO_2 reduction amounts of the ship were determined. The main conclusions of this study can be summarized as follows:

- W_{net} was determined as 373.37 kW for design condition.
- EPC was calculated as 0.06284 $/kWh for design condition.
- The total cost was determined as 1847598 $ for design condition.
- Exergy efficiency and thermal efficiency were calculated as 56.78% and 17.39%, respectively.
- The annual average W_{net} was determined as 372.78 kW.
- The annual average EPC was calculated as 0.0629 $/kWh.
- The annual average fuel saving was calculated as 522.83 t_{fuel}/year.
- The annual average CO_2 reduction was calculated as 1628.09 tCO_2/year.
- This study showed that using the RORC system on ships is a promising solution for increasing emission restrictions and environmental concerns.

In this study, the heat exchanger parameters were taken as constant. In future studies, heat exchanger optimization can be integrated into the main optimization process. In the present study, the gray wolf algorithm was used. However, new algorithms are added to the literature every year. Comprehensive performance studies can be conducted by using newly introduced algorithms in optimizing the ORC system. In the presented study, only ship exhaust gas was used as waste heat source. In future studies, different waste heat sources such as jacket cooling water and scavenging air cooling can be included in the ORC system and their effects can be investigated.

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AUTHORSHIP CONTRIBUTION STATEMENT

Samet GÜRGEN: Conceptualization, Methodology, Writing - Original Draft, Writing-Review and Editing, Software **İsmail ALTIN:** Writing-Review and Editing.

CONFLICT OF INTERESTS

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

ETHICS COMMITTEE PERMISSION

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Comprehensive Analysis of Port State Control on Turkish Flagged Ships Through the Association Rule Mining

Türk Bayraklı Gemiler Üzerine Uygulanan Liman Devleti Denetimlerinin Birliktelik Kuralı Madenciliği ile Kapsamlı Analizi

Türk Denizcilik ve Deniz Bilimleri Dergisi

Cilt: 8 Sayı: 2 (2022) 104-114

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ABSTRACT

Port state control (PSC) inspections are one of the best ways of improving safety at sea. Therefore, it is vital to determine the parameters that cause deficiencies in the prevention of ship accidents. The main purpose of this study is to analyze the PSC inspection results of Turkish flagged ships using the data mining model. Considering a total of 209 PSC inspection reports resulting in the detention of Turkish flagged ships between 2014 and 2019, the Apriori Algorithm was applied using SPSS Modeler 18.0 software to determine the association rules of deficiencies detected. The study found that the safety of navigation, living/working conditions, and emergency systems are the main factors creating association rules in deficiencies. However, when the deficiencies causing detention were analyzed, the most frequently associated variables were safety of navigation, certificate/documentation, and emergency systems. The results of the study are supposed to be useful for the flag state control mechanism to improve the port state control performance of Turkish flagged ships. We recommend that further research collect more data on the PSC inspection of ships flying other flags to update the proposed models and improve their analysis performance.

Keywords: Port State Control, Ship Inspections, Turkish Flagged Ships, Data Mining, Association Rule

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ÖZET

Gemi denetimleri, denizde emniyeti artırmanın en iyi yollarından biridir. Bu nedenle gemi kazalarının önlenmesinde eksikliklere neden olan parametrelerin belirlenmesi hayati önem taşımaktadır. Bu çalışmanın temel amacı, Türk bayraklı gemilerin denetim sonuçlarının veri madenciliği modeli kullanılarak analiz edilmesidir. 2014-2019 yılları arasında Türk bayraklı gemilerin tutulması ile sonuçlanan toplam 209 denetim raporu dikkate alınarak, tespit edilen eksikliklerin birliktelik kurallarını belirlemek için Apriori Algoritması uygulaması SPSS Modeler 18.0 yazılımı kullanılarak yapılmıştır. Çalışmada, seyir emniyeti, yaşam/çalışma koşulları ve acil durum sistemleri eksikliklerinin birliktelik kurallarını oluşturan ana faktörler olduğu bulunmuştur. Bunun yanı sıra, tutulmaya neden olan eksiklikler incelendiğinde, ilişki sıklığı en fazla olan değişkenler seyir güvenliği, sertifika/dokümantasyon ve acil durum sistemleri olmuştur. Çalışmanın sonuçlarının, Türk bayraklı gemilerin liman devleti denetimi performansının iyileştirilmesi için bayrak devleti kontrol mekanizmasına faydalı olacağı düşünülmektedir. Gelecek çalışmalar için önerilen modelleri güncellemek ve analiz performanslarını iyileştirmek adına daha geniş çaplı bir veri setinin kullanılması tavsiye edilmektedir.

Anahtar sözcükler: Liman Devleti Denetimi, Gemi Denetimleri, Türk Bayraklı Gemiler, Veri Madenciliği, Birliktelik Kuralı

1. INTRODUCTION

Port State Control (PSC) is an inspection mechanism applied to foreign-flagged ships, aims to protect navigational safety and the marine environment by detecting substandard ships. Although the control of the safety standards of the ships is in the flag state, the inadequacy of both the flag state and the recognized organizations in the detection of substandard ships has led to the emergence of PSC. Today, PSCs, which are applied in most of the world and considered as the last stage for the safety of ships, have been expanded with regional memorandums (MoU) and agreements. The control of the standards in the PSC inspections is carried out according to the requirements of the international conventions put into effect by the International Maritime Organization (IMO) and the International Labor Organization (ILO). If the ships cannot meet the standards in these conventions, some deficiencies can be revealed by port state control officers, moreover, ships are subject to a certain degree of detention according to the importance of the deficiencies detected (Tsou, 2019; Osman *et al*., 2020).

PSCs are usually stored in databases of memorandums of which the port state is a member. Although the format and content of the PSC inspection reports vary from memorandum to memorandum, generally, there is information such as ship profile information (ship name, IMO number, flag, age, tonnage, classification society, etc.), inspection information (date of inspection, port state performing inspection, type of inspection, etc.), inspection result (main and sub-deficiencies and deficiencies grounding detention). Over the years, the PSC inspection reports that have accumulated and continue to accumulate in the database of memorandums have created big data related to PSC. This big data can also enable us to reveal hidden information in PSC inspection reports by using data mining methods. In this context, this study analyzed the Turkish flagged ships detained by port state controls using the association rule mining method. This study aims to determine the information that is related to the variables in the PSC inspection reports of ships detained. It is thought that this information will be especially useful for the flag state authority, recognized organizations, and Turkish flagged ship owners to ensure safety standards. Additionally, the fact that there are very few studies on the analysis of PSC with association rule mining in the literature may make this study important in terms of filling the gap in the literature.

The other parts of the study are designed as follows; Literature review related subject and method is given in section 2. Material and method are explained in Section 3. The findings are shown in Section 4. A comparison of study findings with other studies is given in section 5, which is the results and discussion section. Finally, the study concludes with the conclusion section (Section 6).

2. LITERATURE REVIEW

Due to the importance of PSC in maritime safety, researchers have conducted extensive studies on this area. Data from PSC inspections have been used by researchers from different perspectives and methods in the studies. In the beginning, it is seen that the studies were generally on econometric analysis such as logistic regression and correlation analysis, but today, there is a tendency towards data mining and machine learning algorithms. There are a limited number of studies on association rule mining, which is one of the descriptive areas of data mining, and these studies have been conducted recently. Tsou (2019) investigated deficiencies of detention of Tokyo MOU using association rule mining method one of the data mining techniques. Big data analysis showed that the regularity relationship between the deficiencies and the factors related to these deficiencies is accurate and objective. In another study on the Tokyo MoU, the inspection results were examined with association rule mining using the Apriori Algorithm (Fu *et al*., 2020). Ship type, ship age, deadweight (DWT), and gross tonnage (GRT) of ship and deficiencies were included for analysis in their study. Osman *et al*. (2020) analyzed ships inspected in Malaysian ports using the same association rule algorithm. It has been stated that the knowledge discovery in the study can be used in the development of the ship target system and in determining the strategies in PSC inspections. Similarly, Chung *et al*. (2020) also analyzed Taiwan's major ports using the same algorithm. In this study, it was determined that deficiencies related to 'water/watertight conditions' and 'fire safety' were significantly related. Also, the authors determined that ship type has more effect on rule formation than other variables. In addition to the association rule, PSC inspections were also analyzed using various predictive data mining methods of such as Bayesian Networks, Support Vector Machines, Random Forest, Decision Tree (Wang *et al*., 2019; Xiao *et al*., 2020; Fu *et al*., 2020b; Yan *et al*., 2020; Yan *et al*., 2021). The common purpose of these studies was to develop a prediction model that could detect the PSC inspection results and to identify the variables that affect the inspection result.

When the studies on Turkish flagged ships are examined, it is seen that the studies are based on descriptive and relational (chi-square) analysis. Yılmaz and Ece (2017) investigated ship inspection results of Paris MOU (2011-2016). The detention rate of Turkish flagged ships has been found higher than the mean detention rate of Paris MOU. Also, it was determined that if a ship has had 5 or more deficiencies or has been older than 13 years, the risk of detention has been high. Akyar and Çelik (2018) analyzed 578 PSC inspection results of Turkish flagged ships inspected in Black Sea MOU. According to chi-square analyses, results showed that there is a significant relationship between the number of deficiency and inspection results and age. The main most frequently detected deficiencies have been life-saving appliances and safety of navigations. In another study, Tokyo MOU inspection results of the Turkish flagged (2016-2018) were evaluated using descriptive analysis. Life-saving appliances, safety of navigation, and fire safety deficiencies have been the most frequent main deficiencies in a total of 115 inspection results and 226 deficiencies (Bolat, 2019).

3. MATERIAL AND METHOD

In this study, the association rule method, which is one of the descriptive method of data mining, was applied. Data mining, which is also called knowledge discovery in a database, extracts implicit, previously unknown, and probable useful information from big databases (Chen *et al*., 1996).

Data mining is generally divided into two categories as descriptive and predictive. The association rule is included in descriptive data mining, which is used to summarize and generalize. This method, firstly developed by

Agrawal *et al*. (1993), is one of the most important and the most used techniques in data mining. The association rule aims to extract important correlations, frequent patterns, and associations among variables in databases (Zhao and Bhowmick, 2003; Maragatham and Lakshmi 2012). Association rule mining can describe as follows; *"Let $I=I_1, I_2,\cdots, I_m$ be a set of m distinct attributes, T be transaction that contains a set of items such that $T \subseteq I$, D be a database with different transaction records T_s. An association rule is an implication in the form of $X \Rightarrow Y$, where $X, Y \subset I$ are sets of items called itemsets, and $X \cap Y = \emptyset$. X is called antecedent while Y is called consequent, the rule means X implies Y".* Although there are various measurement units in the association rule, the most important ones are support (s) and confidence (c) values. Support (s) is the percentage of records containing $X \cup Y$ to the total number of records in the database, and the calculation of support is shown in Equation 1 (Zhao and Bhowmick, 2003).

$$Support(X \rightarrow Y) = \frac{Support\ count\ of\ XY}{Total\ number\ of\ transactions\ in\ D} \quad (1)$$

Confidence (c) is the ratio of the number of transactions containing $X \cup Y$ to the total number of records containing X, if the percentage passes the confidence threshold, an interesting association rule $X \Rightarrow Y$ can construct (Zhao and Bhowmick, 2003). Confidence is calculated as Equation 2;

$$Confidence(X \rightarrow Y) = \frac{Support(X \cup Y)}{Support(X)} \quad (2)$$

There are various association rule algorithms such as Apriori, Predictive Apriori, FP-Growth, and high performance is obtained in studies using these algorithms (Çakır *et al*., 2021). In this study, we used Apriori Algorithm that is the most commonly used association rule algorithm in the literature (Abaya, 2012).

3.1. Apriori Algorithm

Apriori Algorithm, which is developed by Agrawal and Srikan (1994), aims to generate association rules with high confidence values. This value shows the correctness of the rules and is used for sorting them. The fact that this algorithm provides high performance in studies where this algorithm is used has led to Apriori Algorithm being the most used algorithm in the association rule and the development of new algorithms based on this algorithm (Çakır *et al*., 2021). Some advantages of Apriori algorithm are easy to implement, use and learn by the researchers since the data structure is straightforward. For these reason, Apriori algorithm is called the most basic algorithm for association rules. However, Apriori algorithm requires repeated scanning of the database to generate candidates. In this case, which is the disadvantage of the algorithm, if the pattern is very large and long, this process requires a lot of time and memory (Kumar and Cheizan, 2012; Yuan, 2017; Wicaksono *et al*., 2020). Since the dataset in this study was relatively small, this disadvantage did not cause excessive time and memory requirements in the study.

The main process of Apriori Algorithm is as follows (Li *et al*., 2012);

Step 1. Set the minimum support and confidence by user instruction.

Step 2. Constitute the candidate 1-itemsets. Then, generate the frequent 1-itemsets by pruning some candidate 1-itemsets if their support values are lower than the minimum support.

Step 3. Join the frequent 1-itemsets with each other to construct the candidate 2-itemsets and prune some infrequent itemsets from the candidate 2-itemsets to create the frequent 2-itemsets.

Step 4. Repeat the steps likewise step 3 until no more candidate itemsets can be created. Additionally, Pseudo code of Apriori Algorithm created by Agrawal and Srikan (1994) is shown below;

L_1 ={large 1-itemsets};
for** (k =2; $L_{k-1} \neq \emptyset$; k++) **do begin
C_k =apriori-gen(L_{k-1}); //New candidate
forall** transactions $t \in D$ **do begin
C_t =subset(C_k, t); //Candidates contained in t,
***forall** candidates $c \in C_t$ **do**,*
c.count++;

end,
$L_k = \{c \in C_k \mid c.count \geq minsup\}$,
end,
Answer = $\cup_k L_k$;

3.2. Dataset Details

The dataset used for PSC inspection results, in which association rules are extracted using the Apriori Algorithm, consists of Turkish flagged ships detained between 2014 and 2019. A total of 209 PSC inspection results from 4 different memorandums, namely, Paris, Tokyo, Mediterranean, and Black Sea MoU, were extracted from the databases of the relevant memorandums. All the reports collected about the ships and the inspection results were combined in the MS-Office Excel file. The variables that are not included in the PSC inspection reports but included in the analysis have been added by writing the necessary codes on this file. Finally, in the dataset, there are 8 variables related to ship and inspection conducted and 19 variables related to main deficiencies. In an PSC inspection that results in detention, most of the deficiencies do not cause detention. In other words, a deficiency or some deficiencies may be effective in making the decision to be detained and these deficiencies are also indicated in the PSC inspection reports. Therefore, in this study, a separate data set was created in order to examine the relationship between the deficiencies that caused the detention. Before the analysis, necessary corrections were made by applying pre-processing steps such as data cleansing and data transformation to the dataset. The variables used in dataset and descriptive statistics of them are given in Table 1 and Table 2.

Table 1. Details of variables related to ship and PSC inspection

Variable	Category	Frequency (n)	Percentage (%)
Season	Spring	50	23.9
	Summer	42	20.1
	Autumn	60	28.7
	Winter	57	27.3
Memorandum Region	Paris	83 (4.3%)*	39.7
	Tokyo	10 (3.3%)*	4.8
	Black Sea	98 (4.4%)*	46.9
	Mediterranean	18 (1.7%)*	8.6
Type of Ship	Bulk Carrier	40	19.1
	General Cargo	127	60.8
	Container	6	2.9
	Ro Ro/Passenger	16	7.7
	Tanker	20	9.6
Age of Ship	Under average (<22.5)	104	49.8
	Above average (>22.5)	105	50.2
Size of Ship (GRT)	≤2500 GRT	67	32.1
	2500< . <5000 GRT	74	35.4
	≥5000 GRT	68	32.5
Classification Society of Ship	IACS member	107	51.2
	Not IACS member	102	48.8
Historical Detention Situation of Ship	No	148	70.8
	Yes	61	29.2
Number of Detention of Ship's Company	0	116	55.5
	1	46	22.0
	>=2	47	22.5

*Detention rate in related MoU (number of detentions/total number of PSC inspections)

According to analysis results, Turkish flagged ships were mostly detained in Paris and Black Sea MoU region. Also, the vast majority of ships arrested are general cargo ships (60.8%). Age of ship is divided into two categories according to the average age of Turkish flagged ships and it is seen that these two categories have almost equal ratios. In the same way, the classification societies of the ships are evaluated in two categories as IACS (The International Association of Classification Societies) members and non-members and they are almost at equal frequency. The size of the ship, which has a numerical value, has been made into 3 categories by using the equal frequency binning method using the SPSS Modeler 18.0 program. Safety of navigation (451), life saving appliances (339), and labor conditions (276) are the main deficiency areas with the highest frequency in the PSC inspections resulting in detention. When the deficiencies grounding to detention are examined, the deficiencies with the highest frequency are fire safety (124), safety of navigation (123), and emergency systems (107), respectively.

Table 2. Details of variables related to deficiencies

	Whole Deficiencies	**Deficiencies Grounding Detention**
Main Deficiency Area	**Frequency(n)**	**Frequency(n)**
Certificate/Documentation	237	46
Structural Conditions	67	25
Watertight Conditions	105	36
Emergency Systems	184	107
Communication	88	23
Ship Equipment	0	0
Fire Safety	270	124
Alarms	13	5
Safety of Navigation	451	123
Cargo Operations	9	1
Life Saving Appliances	339	93
Dangerous Goods	0	0
Main and Aux. Machines	171	45
Living/Working Conditions	143	15
Labor Conditions	276	36
Pollution Prevention	77	19
ISM	137	77
ISPS	7	0
Others	17	1
Total	**2591**	**776**

4. FINDINGS

Association rule analyses made in this section are given in sub-headings according to the variable types used in the analyses. SPSS Modeler 18.0 program was used in all analyses to extract association rules.

4.1. Association Rules of Variables Related to Ship and PSC Inspection

The purpose of this analysis was to determine how there is a correlation among variables related to ship and PSC inspection. In this direction, variables in Table 1 were included in the analysis. Before analysis, the support value was set to 10% and the confidence value to 80%. There is no determined or proven value for the threshold values in the literature. Since each data set has its own unique structure (number of data, number of variables, etc.), threshold values are mostly determined on the basis of the intuitiveness of the user such as trial-and-error approach (Osman et al., 2020). According to the result of the analysis, a total of 37 association rules that fit these threshold values were determined. It was found that the association rule with the highest percentage in the ranking made according to the support value is between ships that are classified IACS member classifications and ships that are under average age, with 51.196%. Additionally, general cargo ships, ships that are classified IACS member classifications and ships that are under average

age were the variables frequently seen in the rules where high support value occurs. Association rules with a support value of 30% and above are shown in Table 3. Of these 37 association rules, the 16 association rules with the highest confidence value (more than 95%) can be seen in Table 4.

Table 3. Association rules of variables related to ship and PSC inspection by support value

Antecedent	Consequent	Support (%)
AGE= underaverage	CLASS= IACS	51.196
TYPE= General Cargo	GRT= 2501< <5000	35.407
AGE= underaverage	GRT= >5001	32.536
CLASS= IACS	GRT= >5001	32.536
TYPE= General Cargo	GRT= <2500	32.057

Table 4. Association rules of variables related to ship and PSC inspection by confidence value

	Antecedent	Consequent	Support (%)	Confidence (%)
1	TYPE=Bulk carrier	GRT≥5001	19.139	100.000
2	TYPE=Bulk carrier and MOU=BlackSea	GRT≥5001	10.526	100.000
3	TYPE=Bulk carrier and AGE=underaverage	GRT≥5001	16.746	100.000
4	TYPE=Bulk carrier and CLASS=IACS	GRT≥5001	18.660	100.000
5	TYPE=Bulk carrier and MOU=BlackSea and CLASS=IACS	GRT≥5001	10.048	100.000
6	TYPE=Bulk carrier and AGE=underaverage and CLASS=IACS	GRT≥5001	16.268	100.000
7	TYPE=Bulk carrier	CLASS=IACS	19.139	97.500
8	TYPE=Bulk carrier and GRT≥5001	CLASS=IACS	19.139	97.500
9	TYPE = Bulk carrier and AGE=underaverage	CLASS=IACS	16.746	97.143
10	TYPE=Bulk carrier and GRT≥5001 and AGE=underaverage	CLASS=IACS	16.746	97.143
11	GRT≤2500 and MOU=BlackSea	TYPE=General cargo	13.397	96.429
12	GRT≥5001 and MOU=BlackSea and AGE=underaverage	CLASS=IACS	11.483	95.833
13	GRT≥5001 and COMPANY HISTORY=0 and AGE=underaverage	CLASS=IACS	11.483	95.833
14	TYPE=Bulk carrier and MOU=BlackSea	CLASS=IACS	10.526	95.455
15	TYPE=Bulk carrier and GRT≥5001 and MOU=BlackSea	CLASS=IACS	10.526	95.455

In the first 6 association rules with the highest confidence, the variable of ship size (≥5001) appears as consequent. The support values of these rules vary between 10% and 20%. Bulk carrier and Black Sea MoU seem to have a high correlation with ships over 5000 GRT. When the other rules with a high confidence value are examined, it is observed that they occur in the rules related to the classification society. In all of these rules, it is seen that ships are classified by IACS member classification societies. As with the size of ship, there is a correlation between the classification societies and especially the bulk carrier and Black Sea MoU. Likewise, when the rules are examined, there is a correlation between classification society (member of IACS) and the size of ship (≥5001). Such that the rule with the highest support value (32.536%) is between these two variables. In addition, the confidence value of this rule is 83.824%.

4.2. Association Rules of Deficiencies

In this analysis, it was attempted to reveal the association rules by analyzing all the deficiencies detected in the PSC inspection reports. The support value was set as 15% and the confidence value as 80% for analysis. The results of the analysis, which included a total of 2591 deficiencies identified in 19 main deficiency areas, can be seen in Table 2. A total of 72 association rules is determined, and the highest support value occurred between life saving appliances and safety of navigation deficiencies with 64.593%. It was highly probable that fire

safety and safety of navigation deficiencies can be observed together. Additionally, ISM and certificate/documentation deficiencies were also probably observed together with the deficiencies of safety of navigation. 12 association rules with a support value of 40% and above can be seen in Table 5.
According to the analysis results, 16 rules with the highest confidence values are shown in Table 6. The association rule with the highest confidence value is between safety of navigation and radio communication and emergency systems. This rule has 15.789% support value and 93.939% confidence value. In the analyses, it is seen that the safety of navigation is predominantly consequent. Safety of navigation has a high correlation, especially with emergency systems. In other words, these two deficiency areas are likely to be detected together. This is supported by a 50.718% support value and 84.90% confidence value between the two main deficiency areas. Radio communication and labor conditions are observed as other prominent deficiency areas in the rules.

Table 5. Association rules of deficiencies by support value

Antecedent	Consequent	Support (%)
Life Saving App.	Safety of Nav.	64.593
Fire Safety	Safety of Nav.	61.722
ISM	Safety of Nav.	55.502
Cert/Doc	Safety of Nav.	52.632
Labor Cond.	Life Saving App.	51.196
Labor Cond.	Safety of Nav.	51.196
Emergency	Fire Safety	50.718
Emergency	Life Saving App.	50.718
Emergency	Safety of Nav.	50.718
Emergency and Safety of Nav.	Life Saving App.	43.062
Fire Safety and Life Saving App.	Safety of Nav.	42.584
Labor Cond. and Safety of Nav.	Life Saving App.	40.191

Table 6. Association rules of deficiencies by confidence value

	Antecedent	Consequent	Support (%)	Confidence (%)
1	Radio Comm. and Emergency	Safety of Nav.	15.789	93.939
2	Living/Working Cond. and Emergency	Safety of Nav.	21.531	93.333
3	Propulsion/Auxiliary Mach. and Emergency	Safety of Nav.	19.617	92.683
4	Radio Comm. and Labor Cond.	Life Saving App.	19.139	92.500
5	Radio Comm. and Labor Cond.	Safety of Nav.	19.139	92.500
6	Radio Comm. and Fire Safety	Safety of Nav.	19.139	92.500
7	Living/Working Cond. and Cert/Doc	Safety of Nav.	18.660	92.308
8	Radio Comm. and Labor Cond. and Life Saving App.	Safety of Nav.	17.703	91.892
9	Radio Comm. and Labor Cond. and Safety of Nav.	Life Saving App.	17.703	91.892
10	Radio Comm. and Fire Safety and Life Saving App.	Safety of Nav.	17.225	91.667
11	Propulsion/Auxiliary Mach. and Fire Safety and Life Saving App.	Safety of Nav.	16.268	91.176
12	Labor Cond. and Emergency and Life Saving App.	Safety of Nav.	20.574	90.698
13	Living/Working Cond. and Emergency and Fire Safety	Safety of Nav.	15.311	90.625
14	Labor Cond. and Emergency	Safety of Nav.	24.402	90.196
15	Radio Comm.	Safety of Nav.	29.187	90.164
16	Radio Comm. and Fire Safety	Life Saving App.	19.139	90.000

4.3. Association Rules of Deficiencies Grounding Detention

The purpose of this analysis is to reveal the relationships between the deficiencies that cause the detention. A total of 776 deficiencies stated in the PSC inspection reports were included in the analysis. Since the number of deficiencies that caused the detention was relatively less than in other analyses. the support value was determined as 5% and the confidence value was determined as 70%. A total of 4 association rules were determined at these threshold values (Table 7). According to the results of the analyses, the support values of the association rules are between 5.263% and 6.220%, and the confidence values are between 72.727% and 81.188%. It is seen that the rule with the highest confidence value occurs among certificate/documentation, emergency systems, and safety of navigation. When the 4 rules are examined, it can be said that these deficiency areas are included in most of the rules and have a correlation. besides, there is a correlation between ISM and fire safety, especially (Rule 2 and 4).

Table 7. Association rules of deficiencies grounding detention

	Antecedent	Consequent	Support (%)	Confidence (%)
1	Cert/Doc and Emergency	Safety of Nav.	5.263	81.818
2	Emergency and Safety of Nav. and Fire Safety	ISM	6.220	76.923
3	Cert/Doc and Life Saving App.	Safety of Nav.	5.263	72.727
4	Cert/Doc and Fire Safety	ISM	5.263	72.727

5. RESULTS AND DISCUSSION

According to the results of the analyzes, quite broad results have been obtained about the Turkish flagged ships detained as a result of the PSC inspection. In terms of age, which is one of the important variables affecting the PSC inspection result, it has been determined that Turkish flagged ships have almost equal frequency below and above the average age. In addition, these detained ships are usually of small tannage and general cargo ships. The memorandum an classification soviety of ships have been important variables in association rule creation. Safety of navigation, emergency systems, fire safety, ISM, and life saving appliances have been found to be the predominant areas of deficiencies in association rules regarding deficiency areas. The results obtained in this study and the findings of the studies in the literature are evaluated in the following paragraph.

In this study, it has been determined that the age categories of the Turkish flagged ships detained have almost equal frequency and that the rules consist especially for ships under the average age (<22.5). This differs from the findings in the study by Tsou (2019) that indicates the detention of ships are generally older (over 25 years). Fu *et al.* (2020) also indicated that the detention risk of the older ships is higher. However, the fact that especially small tonnage ships encounter detention is the common output of both studies. Additionally, a correlation was determined between emergency systems and ISM among the deficiencies that cause detention in the study of Tsou (2019). This finding is also similar to this study as seen in Rule 2 in Table 5.

In the study by Osman *et al*. (2020), it was stated that the detention of ships was correlated with the port where the PSC inspection was made. Similarly, it has been determined that the memorandum is one of the prominent variables in the association rules in this study. The finding of Chung *et al*. (2020), which states that the type of ship is also an important factor causing detention, is also in line with this study. In particular, the frequency of detention of general cargo ships is high in Turkish flagged ships. In a study by Fu *et al*. (2020), it was determined that the frequency of detention of general cargo ships was high. Additionally, it can be said that bulk carriers are the dominant ship type in rule-making in association rules. It is the common finding of these two studies that the ship type has a greater effect on rule-making than the ship's classification society.

6. CONCLUSIONS

Port State Control is one of the most important mechanisms for the safety of ships. However, this ship inspection mechanism is a process that requires both cost and time. In addition to reducing these costs, it is critical to make PSC inspections more effective by providing inferences from past PSC inspection results to ensure ship and sea safety. In this direction, data mining can be considered as one of the most effective methods for solving this problem. In this study, the PSC inspection results of the Turkish flagged ships detained were analyzed using association rule mining, which is one of the descriptive methods of data mining. The main purpose of the study is to reveal meaningful relationships from the PSC inspection results.

It has been seen that bulk carriers and ships over 5000 GRT are the prominent variables in the formation of the association rule, as well as the PSC inspections in the Black Sea MoU region and the ships certified by IACS member classification societies are other important variables. Safety of navigation and emergency systems are highly correlated deficiency areas in detected deficiencies. However, there are correlations between safety of navigation, certificate/documentation, and emergency systems for deficiencies that caused the detention of Turkish flagged ships.

The results of the study are supposed to be useful for the flag state control mechanism in order to improve the port state control performance of Turkish flagged ships. Additionally, the study can help Turkish flagged ship owners and recognized organizations to evaluate their safety measures. The limitation of this study was to analyze only detained Turkish flagged ships. It is recommended to expand the data set and use different data mining methods by adding different flagged ships and memorandums for future studies.

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CONFLICT OF INTERESTS

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

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Investigation of the Effects of the Covid-19 Pandemic on Chartering and Brokering Activities

Covid-19 Pandemisinin Gemi Kiralama ve Brokerlik Faaliyetlerine Etkilerinin İncelenmesi

Türk Denizcilik ve Deniz Bilimleri Dergisi Cilt: 8 Sayı: 2 (2022) 115-130

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ABSTRACT

Maritime transport is an important part of the supply chain network and logistics services in international trade. As a result of the negative situation in the economy and trade due to the Covid-19 pandemic, the maritime freight transport market was also affected. In this context, the aim of the research is to evaluate the factors that affect the general operation of ship chartering and brokerage activities and company performance due to Covid-19. In the study, a survey was applied to 141 brokers by convenience sampling method. Data were gathered between 27 January and 30 July 2021. Correlation and regression analysis were conducted by using the IBM SPSS 22 program to evaluate the questionnaires. According to the results obtained, it is seen that the variable with the highest relationship on the general operation of chartering and brokerage activities is the freight market ($p=0.000$, $r= 0.477$), and the second variable is the psycho-social status of the brokers ($p=0.000$, $r= 0.445$). It is seen that the variable with the highest relationship on the profitability level of the charter and brokerage businesses is the freight market ($p=0.000$, $r= 0.366$), and the second variable is the ship and voyage planning ($p=0.000$, $r= 0.342$).

Keywords: International trade and logistics, Covid-19, maritime business, chartering and brokerage

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ÖZET

Denizyolu taşımacılığı uluslararası ticarette tedarik zinciri ağının ve lojistik hizmetlerin önemli bir parçasıdır. Covid-19 pandemisi nedeniyle ekonomi ve ticarette ortaya çıkan olumsuz durum sonucunda denizyolu yük taşımacılığı piyasası da etkilenmiştir. Bu kapsamda araştırmanın amacı Covid-19 nedeniyle gemi kiralama ve brokerlik faaliyetlerinin genel işleyişi ve firma performansı üzerinde etkili olan faktörlerin neler olduğunu değerlendirmektir. Çalışmada kolayda örnekleme yöntemiyle 141 brokere anket uygulanmıştır. Veriler 27 Ocak – 30 Temmuz 2021 tarihleri arasında toplanmıştır. Anketleri değerlendirmek için IBM SPSS 22 programı kullanılarak korelasyon ve regresyon analizleri uygulanmıştır. Elde edilen sonuçlara göre gemi kiralama ve brokerlik faaliyetlerinin genel işleyişi üzerinde en yüksek ilişkiye sahip değişkenin navlun pazarı (p=0,000, r= 0,477), ikinci değişkenin ise brokerlerin psiko-sosyal durumları (p=0,000, r= 0,445) olduğu görülmektedir. Gemi kiralama ve brokerlik işletmelerinin karlılık düzeyi üzerinde en yüksek ilişkiye sahip değişkenin navlun pazarı (p=0,000, r= 0,366), ikinci değişkenin ise gemi ve sefer planlamaları (p=0,000, r= 0,342) olduğu görülmektedir.

Anahtar sözcükler: Uluslararası ticaret ve lojistik, Covid-19, deniz işletmeciliği, gemi kiralama ve brokerlik

1. INTRODUCTION

World trade is increasingly based on long, large and complex supply chains, and maritime transport and associated logistics services form the backbone of these operations (Berle *et al.*, 2011; Balık *et al.*, 2015). Maritime transport is a set of interrelated activities involving different interrelated stakeholders, in which the transport, transshipment and distribution processes are integrated (Osobajo *et al.*, 2021). In maritime transport, the planning is made by considering international, regional and local economical, commercial, socio-cultural, political, legal, technological etc. applications and regulations. (Demirel, 2019). The diversification of port services, the development of integrated transport operations and the change in the traditional role of maritime transport through sectoral collaborations have made it one of the strategic elements focused on supply chain and logistics services (Yıldırım and Deveci, 2016; Yorulmaz and Birgün, 2017; Wendler-Bosco and Nicholson, 2020).

Due to the Covid-19 epidemic that emerged on 1 December 2019 in the Wuhan region of the People's Republic of China, countries were adversely affected in terms of health and economy. As a result of the rapid spread and lethal effect of the epidemic, transmitted from person to person all over the world, it was declared a pandemic by the World Health Organization (WHO) on March 11, 2021 (Budak and Korkmaz, 2020; Özlü and Öztaş, 2020). The change in the global supply-demand structure as a result of the pandemic has revealed visible changes in the structure of the international trade network (Vidya and Prabheesh, 2020).

The rate and severity of the spread of Covid-19 caused a contraction in production, employment, trade and consumption in the global economy, and this situation also affected the maritime sector. Taşkın (2020) addressed the measures for ships calling at ports in order to prevent the spread of the epidemic and to minimize its effects. In this context, measures have been taken such as disinfection of ships, obtaining a health permit indicating that there is no medical problem at the entrance to the port, preventing the entry of ships that have recently entered the ports that have been described as risky ports, quarantining them, if necessary, delivery of physical documents and notifications online, etc. Clasen and Olesen (2020) mentioned that the process of joining and disembarking the seafarers takes a lot of time due to the precautions and negatively affects the operation processes. In her study, Doumbia-Henry (2020) reported the serious difficulties faced by seafarers (quarantine requirements, border crossing restrictions, crew changes, disembarkation, certificate renewal, supply and ship surveys, etc.) during the

pandemic period. Zhu *et al*. (2020) tracked the movements of ships using the Automatic Identification System (AIS) and quantitatively investigated the effects of the Covid-19 pandemic on China's container ports. It was reported that the pandemic did not significantly affect the number of container ships arriving at Chinese ports but affected the average berthing times of container ships and significantly reduced the number of containers loaded and unloaded at ports. Ece (2020) examined the impact of the Covid-19 pandemic on container ports and transportation and stated that dry cargo and container ships were the ones most affected by the pandemic. Notteboom and Haralambides (2020), in their study on port operation and management after the Covid-19 pandemic, stated a decrease in the number of ships calling at the world ports, moderate-to-strong decreases in cargo volumes, and a complete decrease in activity in the industrial environments and logistics in the ports and surrounding areas because of the pandemic.
The aim of the present study is to reveal the factors that affect the general operation and profitability of ship chartering and brokerage activities during the Covid-19 pandemic, and to reveal the relationship in between. Since there is no similar study in the literature for chartering and brokerage activities, it is anticipated that the results of the research will contribute to ship brokers, ship brokerage companies and shipowners or chartered companies that have a chartering department in order to see the shaping of the market structure in unexpected crisis periods. In the research, first of all, the scope of ship chartering and brokerage services in maritime transport is explained in the theoretical framework. Afterwards, the sub-factors and relationship levels that are effective in the general operation of ship chartering and brokerage activities during the Covid-19 crisis were evaluated. Then, the sub-factors and relationship levels that affect the company performance (profitability) of chartering and brokerage businesses during the Covid-19 crisis were evaluated.

1.1. Chartering and Brokering Services at Maritime Transportation

Chartering a ship is the use of a ship in maritime transport by the active commercial enterprises involved in the maritime market through legal contracts and can be expressed as "charter", "vessel chartering", "ship chartering"(Özer, 2010). Chartering, which is an agreement for the commercial operation of a ship, is made between the ship owner and the charterer, and in return, the charterer undertakes to pay a fee called "freight" or "charting cost", depending on the type of charter (Bristow and Coutroubis, 2001). There are several types of chartering of ships. Factors such as the commercial area of the charterer, the conditions and connections of the cargoes, and the preferences of the ship owners play a decisive role in how the ship will be chartered (Öztürker, 2009). After determining the type of charter between the parties, the type of contract is also determined (Özer, 2010).
The person who operates his/her ship in maritime trade and responds to the transportation demand of her customer (charter) with her tonnage / carrying capacity is defined as the ship owner. According to Article 106 of the Turkish Commercial Code No. 6102, the ship owner is the owner of the ship who uses his/her ship in water for the purpose of gaining profit. In this context, it is seen that the requested carrying capacity in some cases does not belong to the registered owner of the ship and may be available to the lessee who chartered the ship according to the terms of the carriage contract. Accordingly, the charterer is considered to be the owner of the carriage contract (Göklergil, 1993). In this context, ship owners or operators assume the role of carriers due to the transportation of cargo by ship (Orhon, 2019).
Ship chartering is carried out through charter parties, which are mutually agreed upon by the parties. The charterer is the person who charters a part or whole place on the ship or ship for a fee, including the service of the personnel of that ship, based on time or voyage charter (Bayırhan and Nas, 2014). The charterer may also charter the ship to others, unless otherwise stated in the contract of carriage. The charterer can chart the agreed ship on a voyage or time basis, or he can carry his own cargo with the ship (Özdemir,

2009).

In practice, intermediaries called "brokers" are used in order to arrange the conditions that will be the basis of the contract between the ship owner/disponent owner and the charterer according to the consent of the parties and to bring the parties together (Öztürker, 2009). Ship brokers try to bring the parties they serve through mediation to a common point and to reach an agreement between the parties as a result of negotiations (Yorulmaz and Tonguç, 2021). Ship brokers are not a party to the freight contract, they are in the position of intermediary, and the commission and percentage they will receive in return for the service they provide are specified in c/p and are paid on the agreed freight. When the ship broker provides the agreement of the parties it represents, it will be entitled to receive the commission fee (Nomer, 2014).

It is important for the ship broker to have full knowledge of all leasing matters and processes and to protect all the rights of the party they represent by knowing a foreign language (Öztürkoğlu and Çalışkan, 2016). In the brokerage profession, besides the knowledge and experience, the person also needs to be able to make strategic, fast and correct decisions (Şendur, 2019). The most important reason for this is that brokers can make great contributions to the parties they represent with the right decisions they make, and they can cause serious losses in the slightest mistake they make (Öztürkoğlu and Çalışkan, 2016).

1.2. Effects of Covid-19 on the Maritime Transportation Market

Maritime trade is carried out in a high-risk market (Koray and Çetin, 2019). The maritime transport market fluctuates depending on the global economy, ship supply-demand changes and unexpected events or crises (Arslan, 2008). Maritime freight demand is a derived demand that is directly affected by economic cycles and international trade. Due to the imbalance in production and consumption as a result of Covid-19, the maritime sector is also adversely affected by the period (UNESCAP, 2020).

Production and supply chain activities have been adversely affected worldwide due to the Covid-19 pandemic in 2020. In this period, both global maritime trade and gross product growth decreased, and it is seen that the negative effects of the pandemic continue in 2021 (Oğuz, 2021). According to the International Money Fund (IMF), the Covid pandemic and associated quarantines resulted in the worst recession since the Second World War. Trade growth by sea fell from 1.7% in 2019 to -3.0% in 2020. Dry bulk trade growth fell from +0.5% in 2019 to -2.1% in 2020. The decline in tanker trade growth was -2.5% in 2019, compared to -9.6% in 2020. Finally, container shipping growth decreased from +2.0% in 2019 to -1.4% in 2020. The Baltic Dry Index (BDI) remained significantly stable with an average of 1,352 and 1,353 on an annual basis in 2018 and 2019, respectively, but fell more than 20% to 1,066 in 2020 (BRS, 2021).

In terms of ports, when 2019 and 2020 are compared, it is seen that fewer port visits were made by most ship types in the first half of 2020 (Oğuz, 2021). The slowness experienced in the discharge of import loads due to the pandemic has also caused problems in obtaining empty equipment at the ports (Özkal, 2021). The most obvious change was observed in the port service processes of container ships at the beginning of the pandemic (Cengiz and Turan, 2021). As a result of the stoppage of production in China due to Covid-19, the decline in North American demand, and the decisions of countries to quarantine the containers at the destination port for 14 days, a shortage of empty containers has emerged in returns to Asia (Gray, 2020). In addition, when production operations halted in China at the beginning of the pandemic, the first strategy of the ship owners was blank sailing, that is, the cancellation of the voyages, and then they positioned empty equipment in the Far East, which they saw more profitable. The lack of sufficient capacity to be allocated to North Africa, especially to Europe, has led to backlogs. As a result of all these developments and high demand, freight rates have increased in the market (Özkal, 2021).

As demand for all ship sizes increased in the dry cargo market, freight rates also increased. Supramaxes were the biggest winners, with demand increasing by 10.6% in the first four months of this year compared to 2020. Capesize demand increased by 6.0%, while Panamax

increased by 1.5%. Demand for Handysize vessels has generated 7.3% growth from the beginning of 2020 (Sand, 2021).
Contracts of carriage (charter parties) were also affected in the Covid-19 pandemic. There have been some questions about demurrage during the Covid-19 period. In cases when the port is not suitable for loading/unloading due to quarantine or pandemic disease, questions have arisen as to whether the working periods will be counted as demurrage. Whether it is possible for the carrier to change route or berth at a different port due to Covid-19 varies according to the applicable law. It is seen that the Covid-19 outbreak is also closely followed by Protection and Indemnity (P&I) Clubs. In this context, the problem arises whether the ship's P&I club will cover what kind of expenses and at what stage it will be engaged (Tilegal, 2020).
In addition, in the Pandemic, restrictive measures like lockdown, social distancing, fear of catching illness etc. have psychologically and socially affected workers in all sectors (Osofsky *et al*., 2020; Pietrabissa and Simpson, 2020; Yılmaz *et al*., 2020). Reasons such as remote work, increased workload, and dismissals have negatively affected employee motivation, causing them to have emotional, physical, and social difficulties (Tuna and Türkmendağ, 2020).

1.3. Research Hypotheses

It is thought that Covid 19 has an impact on the general operation of ship chartering and brokerage activities and business profitability because of the decrease in vessel traffic in 2020 and the change of voyage plans (Millefiori *et al*., 2021), maritime companies' need for global financial support (Cengiz and Turan, 2021), and the return of the ships they rented in order to fill the empty capacities of their own ships, (ITF, 2021), the fluctuation of freight rates (UNCTAD, 2020), and the psycho-social negative effects of people (Osofsky *et al*. 2020). In this context, the hypotheses of the research are as follows:

H1: There is a statistically significant relationship between the effect of the pandemic on charter contracts and articles and the general operation of ship chartering and brokerage activities.
H2: There is a statistically significant relationship between the effect of the pandemic on the freight market and the general operation of chartering and brokerage activities.
H3: There is a statistically significant relationship between the psycho-social impact of the pandemic on brokers and the general operation of ship chartering and brokerage activities.
H4: There is a statistically significant relationship between the effect of the pandemic on ship and voyage planning and the general operation of ship chartering and brokerage activities.
H5: There is a statistically significant relationship between the effect of the pandemic on the marketing and financial management of enterprises and the general operation of chartering and brokerage activities.
H6: There is a statistically significant relationship between the effect of the pandemic on the charter party contracts and their articles and the profitability of the business.
H7: There is a statistically significant relationship between the effect of the pandemic on the freight market and the profitability of the business.
H8: There is a statistically significant relationship between the psycho-social impact of the pandemic on brokers and business profitability.
H9: There is a statistically significant relationship between the effect of the pandemic on ship and voyage planning and operating profitability.
H10: There is a statistically significant relationship between the effect of the pandemic on the marketing and financial management of businesses and business profitability.

2. MATERIAL AND METHOD

In the study, data were collected through convenience sampling. Convenience sampling is collecting data from the most easily, quickly and economically accessible participants of the population (Saruhan and Özdemirci, 2016; Coşkun *et al*. 2017). Data collection was carried out between 27/01/2021-30/07/2021 via Google Forms URL access link. In order to reach the brokers in Turkey, the Ship Brokers Association was contacted, and the survey access link was shared with the members of the association by sending a mass e-mail. In order to reach foreign brokers, the Federation of National Associations of Ship Brokers and Agents (FONASBA) was contacted. The survey access link was shared with its members via FONASBA official social media accounts.

In order to achieve the aims of the research, quantitative research method and questionnaire technique was used. Five-point Likert scale questionnaire was prepared by consulting the opinions of 4 academicians and 8 experts. The questionnaire consists of 39 questions under 7 headings.

The first part of the questionnaire includes questions about some demographic characteristics (gender, age, education level, occupation). Other sections include questions about the effects of the pandemic on chartering and brokerage activities, business performance, charter contracts and articles, freight market, psycho-social situation on ship brokers, ship and voyage planning, financial and marketing activities of businesses. In these sections, 1=strongly disagree, 2=disagree, 3=neither agree or disagree, 4=agree, 5=strongly agree.

The information of the scales used in the study is given in Table 1.

Table 1. Information about scales

Scale	Developed and Adapted to Turkish
Motivation	Developed by Dündar *et al*. (2007).
Burnout	Developed by Maslach and Jackson (1981) and adapted to Turkish by Ergin (1992).
Life Satisfaction	Developed by Kaba *et al*. (2017).
Job Satisfaction	Developed by Mueller and McCloskey (1990) and adapted to Turkish by Bayrakçı and Türkmen (2020).
Turnover Intantion	Developed by Cammann *et al*. (1979) and adapted to Turkish by Gül *et al*. (2008).

General names/concepts of main themes of the abovementioned scales were utilized in the questionnaire and, the impact of the pandemic on the brokers' internal factors regarding work-social life (psycho-social factors) was named as the main factor. These factors are concepts that are dealt with in social psychology as well as in industrial/organizational psychology and organizational behavior studies (Lawler and Porter, 1967; Cribbin, 1972; Lloyd and Hamner, 1979; Davis, 1982; Feldman and Arnold, 1985; Parnell and Crandall, 2003; Judge *et al*., 2009).

In order to test the reliability of the variables that are the subject of the research, Croanbach Alpha coefficient determination analysis was performed and the results are given in Table 2. Depending on the alpha coefficient, the reliability of the scale was graded as follows (Kalaycı, 2006).

- If $\alpha < 0.40$, the scale is unreliable,
- If $0.40 \leq \alpha < 0.60$, scale reliability is low,
- If $0.60 \leq \alpha < 0.80$, the scale is quite reliable,
- If $0.80 \leq \alpha < 1.0$, the scale is highly reliable.

Table 2. Reliability analysis

Cronbach's Alpha	N of Items
0.893	39

In addition, exploratory factor analysis was performed to test the validity of the variables that were the subject of the study, and the results in Table 3 were obtained.

Table 3. Validity analysis

Main Factors	Kaiser-Meyer-Olkin Measure of Sampling Adequacy	Approx. Chi-Square	Bartlett's Test of Sphericity df	Sig
The effect of the pandemic on charter contracts and articles	0.570	18.329	6	0.005
Impact of the pandemic on the freight market	0.646	114.014	15	0.000
Psycho-social impact of the pandemic on ship brokers	0.690	198.250	10	0.000
The effect of the pandemic on ship and voyage planning	0.864	479.994	55	0.000
The impact of the pandemic on the financial and marketing activities of businesses	0.704	170.827	55	0.000

The Skewness values of the main factors (independent variables) and dependent variables, which are the subject of the research, ranged between -0.753 and 0.104, and Kurtosis values between -1.163 and +1.386. The cause-effect relationship between the main factors and dependent factors and the direction and severity of the relationship between the two variables were examined. Data analysis was done using SPSS package program. The findings obtained after the statistical analysis were interpreted in tables.

3. RESULTS

3.1. Demographic features

Demographic characteristics of the participants are shown in Table 4. while calculating the percentages, each broker group was evaluated on its own number of participants.

A total of 61.43% of the participants were men. While the proportion of men is 85.9% for Turkish brokers, it is 23.2% for foreign brokers. While the participation rate of women was 75% for foreign brokers, it was 14.1% for Turkish brokers.

Although one person from each group did not answer the question regarding age information, it is seen that the participation in both groups is high in the 26-35 and 36-45 age ranges. In Turkish brokers, the age profile of the majority of the participants was in the 36-45 age range with 36.5%, while in foreign brokers, it was in the 36-45 age range with 30.4%.

When the education level of the participants is examined, it is observed that 72.9% of the Turkish brokers have a bachelor's degree, while 39.3% of the foreign brokers have a master's degree. While the lowest participant education level in Turkish brokers was high school with 3.5%, it was primary school with 1.8% in foreign brokers.

Looking at the brokerage fields of the participants, it was found that 45.9% of the Turkish brokers work as shipowners' brokers, while 44.6% of the participants in foreign brokers work as independent brokers. In general, 35.46% of the 141 participants were independent brokers, followed by 33.33% by ship-owner brokers and 31.21% by chartered brokers.

Table 4. Demographic characteristics of the participants

	Turkish Brokers		Foreign Brokers	
Gender	Frequency	%	Frequency	%
Male	73	85.9	13	23.2
Female	12	14.1	42	75.0
Prefer not to disclose			1	1.8
Total	85	100	56	100.0
	Turkish Brokers		**Foreign Brokers**	
Age	Frequency	%	Frequency	%
18-25	1	1.2	1	1.8
26-35	26	30.6	11	19.6
36-45	31	36.5	17	30.4
46-55	20	23.5	14	25
56 and above	7	8.2	12	21.4
Total	85	100.0	56	100.0
	Turkish Brokers		**Foreign Brokers**	
Education	Frequency	%	Frequency	%
Primary Education			1	1.8
High School	3	3.5	9	16.1
Associate degree	6	7.1	3	5.4
Undergraduate degree	62	72.9	17	30.3
Graduate	14	16.5	22	39.3
PhD			3	5.3
Total	85	100.0	56	100.0
	Turkish Brokers		**Foreign Brokers**	
Brokerage Ares	Frequency	%	Frequency	%
Shipowner Broker	39	45.9	8	14.3
Charterer Broker	21	24.7	23	41.1
Independent Broker	25	29.4	25	44.6
Total	85	100.0	56	100.0

3.2. Investigation of the Relationship Between the General Operation of Chartering and Brokering Activities and Sub-Factors in the Covid-19 Crisis

Correlation analysis was conducted to determine whether there is a significant relationship between the general operation of ship chartering and brokerage activities and sub-factors during the Covid-19 crisis, and the results in Table 5 were obtained.

When Table 5 is examined, it is seen that there is a statistically significant relationship at the 95% confidence interval between the variables that are the subject of the research and affected by the pandemic crisis and the general level of negative impact.

In this context, hypothesis H1 was accepted since $p < 0.005$. There is a significant relationship between the effect of the pandemic on charter contracts and articles and the general operation of ship chartering and brokerage activities.

Hypothesis H2 was accepted since $p < 0.005$. There is a significant relationship between the effect of the pandemic on the freight market and the general operation of chartering and brokerage activities.

Hypothesis H3 was accepted since $p < 0.005$. There is a significant relationship between the psycho-social impact of the pandemic on brokers and the general operation of chartering and brokerage activities.

Hypothesis H4 was accepted since $p < 0.005$. There is a significant relationship between the effect of the pandemic on ship and voyage planning and the general operation of ship chartering and brokerage activities.

Hypothesis H5 was accepted since $p < 0.005$. There is a significant relationship between the effect of the pandemic on the marketing and financial management of enterprises and the general operation of charter and brokerage activities.

It was found that the variable that has the most negative impact on the general operation of chartering and brokerage activities is the freight market. It is thought that the freight markets have been adversely affected due to the uncertainties experienced with the Covid-19, interruptions in supply chains, the decline in imports and exports, and reduction in the volume of maritime transport because of the increase in the waiting period at the ports.

It was found that the second variable, which has a negative effect on the general functioning of ship chartering and brokerage activities, is the psycho-social situation of the brokers. It is thought that the rate of transmission of Covid-19, the risk of death and the social restrictions of people affect the brokers psycho-socially.

Table 5. The relationship between the general operation of ship chartering and brokerage activities and sub-factors during the Covid-19 crisis

General Operation		The effect of the pandemic on charter contracts and articles	Impact of the pandemic on the freight market	Psycho-social impact of the pandemic on ship brokers	The effect of the pandemic on ship and voyage planning	The impact of the pandemic on the financial and marketing activities of businesses
	Pearson Correlation	0.277	0.477	0.445	0.335	0.364
	Sig. (2-tailed)	0.001	0.000	0.000	0.000	0.000
	N	139	139	139	139	139

3.3. Sub-Factors Affecting the General Operation of Chartering and Brokering Activities in the Covid-19 Crisis

Regression analysis was conducted to determine the sub-factors that affect the general operation of ship chartering and brokerage activities during the Covid-19 Crisis, and the results in Table 6 were obtained.

When Table 6 is examined, it has been determined that the freight market and psycho-social factors, which are thought to have an effect on the pandemic, have a statistically significant effect on the general functioning of ship chartering and brokerage activities. In addition, it is seen that the VIF and Tolerance values, which are the necessary conditions for the regression analysis, are within the desired limits. It is understood that the independent variables subject to regression explain the effect on the dependent variable (general functioning) at the level of 33%.

Table 6. Sub-factors that affect the general operation of ship chartering and brokerage activities during the Covid-19 crisis

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
	B	Std. Error	Beta			Tolerance	VIF
(Constant)	-0.060	0.493		-0.121	0.904		
The effect of the pandemic on charter contracts and articles	-0.038	0.143	-0.023	-0.265	0.791	0.649	1.542
Impact of the pandemic on the freight market	0.503	0.139	0.308	3.605	0.000	0.691	1.446
Psycho-social impact of the pandemic on ship brokers	0.351	0.098	0.285	3.570	0.000	0.793	1.261
The effect of the pandemic on ship and voyage planning	0.237	0.133	0.161	1.778	0.078	0.616	1.622
The impact of the pandemic on the financial and marketing activities of businesses	0.050	0.216	0.024	0.233	0.816	0.495	2.022

ANOVA F:13.010
R:0.573 R^2:0.328
Dependent Variable: General Operation
Predictors: (Constant), Effects on finance and marketing activities of businesses, Effect on charter contracts and articles, Psycho-social effect on ship brokers, Effect on freight market, Effect on ship and voyage planning.

There are values to be considered when performing multiple regression analyzes. The existence of multiple correlations between independent variables is a serious problem that can significantly affect regression models. A VIF value greater than 10 indicates a serious multicollinearity problem (Montgomery *et al*., 2013). The fact that the tolerance values are greater than 0.10 reveals that there is no problem of multicollinearity between the variables (Çokluk *et al*., 2012).

3.4. Investigation of the Relationship between Firm Performance (Profitability) and Sub-Factors of Chartering and Brokering Businesses in the Covid-19 Crisis

Correlation analysis was conducted to determine whether there is a significant relationship between the company performance of charter and brokerage companies and sub-factors during the Covid-19 crisis, and the results in Table 7 were obtained.

Table 7. The relationship between firm performance (profitability) and sub-factors of charter and brokerage firms in the Covid-19 crisis

		The effect of the pandemic on charter contracts and articles	Impact of the pandemic on the freight market	Psycho-social impact of the pandemic on ship brokers	The effect of the pandemic on ship and voyage planning	The impact of the pandemic on the financial and marketing activities of businesses
Decline in operating profitability	Pearson Correlation	0.203	0.366	0.228	0.342	0.301
	Sig. (2-tailed)	0.017	0.000	0.007	0.000	0.000
	N	138	138	138	138	138

When Table 7 is examined, it is seen that there is a statistically significant relationship between the variables affected by the pandemic crisis and the profitability level of the enterprises at the 95% confidence interval.

In this context, hypothesis H6 was accepted since $p < 0.005$. There is a significant relationship between the effect of the pandemic on the charter party contracts and their articles and the profitability of the business.

Hypothesis H7 was accepted since $p < 0.005$. There is a significant relationship between the effect of the pandemic on the freight market and the profitability of the business.

Hypothesis H8 was accepted since $p < 0.005$. There is a significant relationship between the psycho-social impact of the pandemic on brokers and business profitability.

Hypothesis H9 was accepted since $p < 0.005$. There is a significant relationship between the effect of the pandemic on ship and voyage planning and operating profitability.

Hypothesis H10 was accepted since $p < 0.005$. There is a significant relationship between the effect of the pandemic on the marketing and financial management of businesses and profitability.

It was found that the variable that has the most significant relationship with the profitability level of the charter and brokerage businesses is the freight market. This is thought to be due to the fluctuation in the freight market during the times when the supply and demand in the market was severely affected by Covid-19.

The second variable that has an effect on the profitability of charter and brokerage businesses is ship and voyage planning. The reason is thought to be due to personnel changes, long waiting period at anchor and port areas negatively affecting voyage planning.

3.5. Sub-Factors Effective on Firm Performance (Profitability) of Chartering and Brokering Businesses in the Covid-19 Crisis

Regression analysis was conducted to determine the sub-factors that affect the company performance of chartering and brokerage activities during the Covid-19 crisis, and the results in Table 8 were obtained.

When Table 8 is examined, it is seen that the unfavorable conditions regarding the freight market and ship and voyage planning, which are among the factors thought to be affected by the pandemic, have a statistically significant effect on the profitability of the business at the 95% confidence interval. According to this result, it can be said that as the level of negativity in the freight market and ship and voyage planning increases, the profitability of the business is negatively affected.

In addition, it is seen that the VIF and Tolerance values, which are the necessary conditions for the regression analysis, are within the desired limits. It is understood that the independent variables subject to the regression explain the effect on the dependent variable (business profitability) at the level of 19.5%.

Table 8. Sub-factors that affect the firm performance (profitability) of chartering and brokerage businesses during the Covid-19 crisis

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
	B	Std. Error	Beta			Tolerance	VIF
(Constant)	0.169	0.657		0.258	0.797		
The effect of the pandemic on charter contracts and articles	-0.146	0.198	-0.073	-0.735	0.464		
Impact of the pandemic on the freight market	0.516	0.178	0.269	2.906	0.004		
Psycho-social impact of the pandemic on ship brokers	0.100	0.127	0.068	0.791	0.430		
The effect of the pandemic on ship and voyage planning	0.483	0.201	0.259	2.398	0.018		
The impact of the pandemic on the financial and marketing activities of businesses	0.064	0.279	0.025	0.230	0.818		

ANOVA F: 6.411
R:0.442 R^2:0.195
Dependent Variable: Decreased operating profitability
Predictors: (Constant), Effects on finance and marketing activities of businesses, Effect on charter contracts and articles, Psycho-social effect on ship brokers, Effect on freight market, Effect on ship and voyage planning

4. CONCLUSIONS

The Covid-19 pandemic, which emerged on December 1, 2019 in the Wuhan region of the People's Republic of China, spread rapidly around the world and caused economic and sociological problems in countries. In addition, the fears of getting sick and dying that dominated people during this period also affected people psychologically. The Covid-19 pandemic has negatively affected the maritime sector as well as many sectors, and these effects have been felt on the freight, ship trading, new construction, and shipbreaking markets. Due to the lethal effect and rapid spread of the pandemic, the creation of a panic atmosphere and the declaration of a global pandemic forced the countries to take some preventive restrictions.

Many activities, such as curfews, partial or complete curfews, the shift of office workers to work from home, the cancellation of flights by road and air or subjecting them to special permits, have been restricted or temporarily suspended. Countries have taken various measures according to their own conditions for ships coming to their ports, shipyards and shipbreaking facilities. Agencies have started to request various documents related to Covid-19 in addition to the standard documents they request before the ships arrive at the ports. Due to quarantine measures, the entry and exit times of ships with suspected Covid-19 to ports, shipyards and shipbreaking facilities have been prolonged. Depending on these factors, there were also effects on ship chartering and brokerage activities. Questions arose as to who would be responsible for the costs incurred as a result of waiting due to Covid-19, and a sample clause was prepared by BIMCO and recommended to be added to the concluded contracts. The shock effect at the beginning of the pandemic and the restrictions applied afterwards had a negative impact on the supply and demand balances and affected the freight in the market. In this period, it was observed that large container line operators reduced their flights. In addition, the ports of the countries that keep the ships in anchor as a quarantine application were not preferred by the shipowners as they cause freight loss. Brokers have taken these issues into account in their chartering and brokerage activities.

Uncertainties experienced in the first place with Covid-19 caused negativities in supply chains, decrease in imports and exports, and consequently a decrease in ship connections, negatively affecting the freight markets. It has been observed that these negative effects have decreased after the vaccination studies against Covid-19 and the easing of restrictions. In addition, the risk of transmission and fatality of the disease affected people psycho-socially. In this context, the Covid-19 pandemic has affected many sectors as well as negatively affecting ship chartering and brokerage activities, which are one of the sub-branches of maritime management.

The aim of the research is to reveal the impact of the Covid-19 crisis on ship chartering and brokerage activities, and when we examine the results, it is noteworthy that there is a statistically significant relationship between the general operation of charter and brokerage activities in this period and the psycho-social factors affecting the freight market and ship brokers. In addition, it has been observed that there is a statistically significant relationship between the general operation of ship chartering and brokerage activities and the financial and marketing activities of enterprises, ship and voyage planning, and charter contracts and articles.

In addition, it has been determined that there is a significant and positive relationship between the profitability of the charter and brokerage companies and the freight market and ship-voyage planning. It has been revealed that a similar relationship is seen between the psycho-social effect on the ship brokers. In addition, the fact that a significant relationship was determined between the decrease in business profitability and the effect of the pandemic on leasing and contract clauses and the financial and marketing activities of businesses is among the other important findings of the study.

As a result, it has been observed that the freight market has a statistically significant effect on both the general operation of charter and brokerage services and the profitability of the companies in periods when the supply and demand in the market are severely affected, as seen during the Covid-19 pandemic. In this period, it is recommended to carefully monitor the current freight rates, the behavior of charterers and shipowners in chartering, which charter types are preferred more, and to watch online webinars and weekly reports about the freight market. In these periods, it is important to make the right ship and voyage planning. In addition, factors such as the problems experienced in personnel changes, the length of waiting times at the anchor and port areas, waiting in quarantine, difficulties in agreements for cargo/ship etc. are thought to have a negative effect on firm profitability. It is recommended for companies that carry out chartering and brokerage activities and for ship brokers to follow the freight market regularly, to make the right ship and voyage planning, and to analyze the psycho-social effects of the measures to be taken for the employees.

CONFLICT OF INTERESTS

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

ETHICS COMMITTEE PERMISSION

Author(s) declare that this study was conducted in accordance with ethics committee procedures of human or animal experiments. The study received ethics committee approval from Istanbul University with file number 2021/06.

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The Length-Weight Relationhsips (LWRs) of Some Fishes Along the Turkish Coasts of the Black Sea

Karadeniz'in Türkiye Kıyılarındaki Bazı Balık Türlerinin Boy-Ağırlık İlişkileri (LWRs)

Türk Denizcilik ve Deniz Bilimleri Dergisi

Cilt: 8 Sayı: 2 (2022) 131-160

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ABSTRACT

In this study 288 length-weight relationships of some fish species from the Turkish coasts of Black Sea were gathered from 138 studies, which were conducted by several researchers between 1989 and 2021. For all species, the "*b*" values ranged from 2.49 for *Trachurus trachurus* to 3.75 for *Alosa caspia*. The expected range of $2.5<b<3.5$ is confirmed for fish. It is thought that the high *b* value (3.75) given for *A. caspia* may be due to the size composition of the samples. Within species, *a* plot of log (*a*) vs *b* was used to detect outliers in weight–length relationships. In study, two outliers were determined for *Mullus barbatus* while, one outlier was determined for *Belone belone, Alosa immaculata, Merlangius merlangus* and *Neogobius melanostomus*.

Keywords: Regression parameters, fish, growth type, Black Sea, Turkish coasts

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ÖZET

Bu çalışmada, 1989-2021 yılları arasında, farklı araştırmacılar tarafından gerçekleştirilen 138 çalışmadan toplanmış, Karadeniz'in Türkiye kıyılarındaki bazı balık türlerine ait 288 boy-ağırlık ilişkisi yer almaktadır. Tüm türler için "*b*" değerleri 2.49, *Trachurus trachurus* ve 3.75, *Alosa caspia* arasında değişmektedir. Balıklar için *b* değerinin 2.5<*b*<3.5 aralığında olması beklenmektedir.
A. aspia için verilen yüksek *b* değerinin (3.75) örneklerin büyüklük kompozisyonundan kaynaklanabileceği düşünülmektedir. Türler içinde, boy-ağırlık ilişkilerindeki aykırı değerleri tespit etmek için log (*a*)'ya karşı *b* grafiği kullanıldı. Çalışmada, *Mullus barbatus* için iki aykırı değer belirlenirken, *Belone belone*, *Alosa immaculata*, *Merlangius merlangus* ve *Neogobius melanostomus* için bir aykırı değer belirlendi.

Anahtar sözcükler: Regresyon parametreleri, balık, büyüme tipi, Karadeniz, Türkiye kıyıları

1. INTRODUCTION

A great number of ecological and physiological factors in fish are related with size rather than age (Erzini, 1994). When considered from this point of view, growth analyses of fish populations are very important, especially in terms of fishery. Increases in the length and weight of a fish in unit of time is expressed in mathematical equations (Çetinkaya *et al*., 2010) and this way different species and populations can be compared and assessed within the context of different growth conditions.
In addition to its significance in many application areas such as fish biology, physiology, ecology and sampling method, length-weight relationships (LWR) enable the comparison of life and morphologies of fish populations or different fish species in different regions (Richter *et al*., 2000; Gonçalves *et al*., 1997).
Recently, there has been an increase in the number of studies investigating the LWRs of different fish species in different seas. In addition, there are also studies in Turkey which have compared LWRs (Gündoğdu *et al*., 2016), reviewed LWRs of fish species in Aegean Sea and freshwaters of Turkey (Akyol *et al*., 2017; Torcu Koç *et al*., 2006). The purpose of this study is to review LWRs of fish species in Black Sea coast of Turkey and to contribute to future studies.

2. MATERIAL AND METHOD

In the study, 288 of LWRs of 138 studies conducted in Turkish coast of the Black Sea between 1989 and 2021 were reviewed. Median values of the *a* and *b* parameters were estimated than all LWRs. A scatterplot between log(*a*) and *b* is applied to show the interdependence between parameters *a* and *b*. Parameter *a* is the coefficient of the arithmetic weight-length relationship and the intercept of the logarithmic form. Parameter *b* is the exponent of the arithmetic form of the weight-length relationship, and the slope of the regression line in the logarithmic form (Froese, 2006). A scatter plot between log(*a*) and b values was drawn for some reported species to determine the outlier values present in LWRs (Froese, 2000).
Fish species were named according to Fishbase (Froese and Pauly, 2022) and ITIS Report (Integrated Taxonomic Information System). Accordingly, the current names of some species are given in Table 1.

Table 1. Valid names of some fish species

Species Name	Valid Species Name
Alosa pontica	*Alosa immaculata*
Gadus euxinus/Gadus merlangus euxinus	*Merlangius merlangus*
Gobius batrachocephalus	*Mesogobius batrachocephalus*
Gobius melanostomus	*Neogobius melanostomus*
Liza aurata	*Chelon auratus*
Mugil so-iuy	*Planiliza haematocheilus*
Psetta maxima	*Scophthalmus maximus*
Psetta maxima maeotica	*Scophthalmus maeticus*
Solea nasuta	*Pegusa nasuta*
Spicara flexuosa	*Spicara flexuosum*

a, b and r^2 parameters were given in their original forms. Length (cm) was measured as total (TL) or fork length (FL), weight (g) was measured as whole body weight (W).

3. RESULTS

Table 2 shows LWRs of 138 studies reviewed in the study. The lowest b value was found in *Trachurus trachurus* with 2.4854 (Erkoyuncu *et al*., 1994), while the highest b value was found in *Alosa caspia* with 3.75 (Ergüden *et al*., 2011). Average b value of all studies was 3,077. The lowest a value was found in *Squalus acanthias* with 0.00000004 (Demirhan and Seyhan, 2007), while the highest a value was found in *Gadus euxinus* with 0.2721 (Düzgüneş and Karaçam, 1990). Average a value of all studies was 0.0110.

Table 2. Length-weight relationsips parameters of some fish species along the Turkish coasts of Black Sea (BT: Bottom Trawl, MT: Midwater Trawl, BMT: Beam Trawl, PS: Purse Seine, GN: Gill Net, TN: Trammel Net, L: Longline, HD: Hydraulic Dredge, EG: Encircling Gillnet, SN: Seine Net, D: Dalian (traps), DN: Drift Net, BS: Beach Seine, HL: Hand Line, SF: Spear Fishing, HN: Hand Net)

Species	n	TL_{range}	W_{range}	*a*	*b*	r^2	ampling Method	mpling Year	Sub-field	Reference
Alosa caspia	30	15.0-21.0	51.00-103.2	0.0013	3.750.954		GN, TN, L	2006-2007	Şile-Karasu	Erguden *et al*. (2011)
Alosa fallax	68	12.4-29.5	12.10-232.07	0.0110	2.8750.913		T, PS, GN, HD	2009-2011	Şile-Sakarya, Sinop-Hopa	Kasapoğlu and Düzgüneş (2014)
Alosa fallax pontica	42	16.1-23.5	26.57-104.72	0.0046	3.1630.958		GN, TN	2010-2011	Southern Black Sea	Yeşilçiçek *et al*. (2015)
Alosa immaculata	567	13.2-34.2	19.7-343.3	0.0078	3.040.952		GN, TN, L	2006-2007	Şile-Karasu	Erguden *et al*. (2011)
Alosa immaculata	730	10.2-38.8	7-535	0.0032	3.2850.992		GN, BT	2004-2005	Samsun	Yılmaz and Polat (2011)
Alosa immaculata	489	13.6-35.2	10.2-300.3	0.0035	3.21260.9780		MT	2010-2011	Sinop-Samsun	Özdemir and Duyar (2013)
Alosa immaculata	1312	11.5-34.9	9.5-381.2	0.028	3.320.98		G, BT	2016-2017	Sinop	Samsun *et al*. (2017)
Alosa maeotica	51	16.0-33.8	29.7-347.2	0.0062	3.090.981		GN, TN, L	2006-2007	Şile-Karasu	Erguden *et al*. (2011)
Alosa pontica	475	8.5-39.9	2.99-503.34	0.0027	3.33790.99		BT	1994-1995	Samsun	Özdamar (1993)
Alosa pontica	65	-	-	0.0081	3.10340.98		-	1988-1994	Sinop	Erkoyuncu *et al*. (1994)
Alosa pontica	1890	11.6-31.6	6.85-318.19	0.00212	3.38870.9835		BT	1992-1994	Sinop-Samsun	Samsun (1995a)
Alosa pontica	227	11.9-27.6	9.99-177	0.0046	3.12370.94		BT, MT	2004-2005	Sinop-Samsun	Kalaycı *et al*. (2007)
Alosa tanaica	431	23.30	-	0.0039	3.18320.99		MT	2008-2009	-	Özdemir *et al*. (2009c)
Alosa tanaica	38	15.5-30.0	29.8-275.1	0.0051	3.180.984		GN, TN, L	2006-2007	Şile-Karasu	Erguden *et al*. (2011)
Arnoglossus kessleri	60	4.3-9.8	1.2-8.94	0.021	2.9840.725		BT	2007	Trabzon	Ak *et al*. (2009a)
Arnoglossus kessleri	1548	2.0-8.1	-	0.0063	3.1820.940		BMT	2012-2013	Rize	Bilgin and Onay (2019)
Belone belone	278	23.7-60.3	12-277	0.0005	3.2450.97		EG	2003-2004	Samsun	Polat *et al*. (2009)
Belone belone	65	-	-	0.0005	3.20300.97		-	1988-1994	Sinop	Erkoyuncu *et al*. (1994)
Belone belone	647	28.8-51.6	26.9-177.2	0.008	3.090.87		GN, BT	2016-2017	Sinop	Samsun *et al*. (2017)
Belone belone	110	26.0-43.6	19.83-82.50	0.0031	2.70520.952		GN	2017-2018	Ordu	Samsun and Erdoğan Sağlam (2021)
Belone belone euxini	682	31.9-56.9	31.97-208.44	0.00047	3.22340.97		EG	1994-1995	Sinop	Samsun *et al*. (1995a)
Belone belone euxini	643	31.2-52.2	31.59-167.69	0.00055	3.17780.97		EG	1995-1996	Sinop	Samsun (1995b)

Table 2. continued

Belone belone euxini	585	28.5-48.8	62.25	0.0018	2.86350.933	EG	2001-2002	Sinop	Samsun *et al*. (2003)
Belone belone euxini	931	29.0-58.0	23.5-258.4	0.00076	3.1370.9363	PS, EG	2000-2001	Sinop	Samsun *et al*. (2006b)
Chelidonichthys lucerna	55	-	-	0.0070	3.08980.99	-	1988-1994	Sinop	Erkoyuncu *et al*. (1994)
Chelidonichthys lucernus	21	14.3-26.8	27.96-169.4	0.01	2.980.96	BT	2013	Zonguldak-Amasra	Türker and Bal (2018)
Chromis chromis	112	72.0-115.1*	5.96-26.56	0.0127	3.1170.834	TN	2018	Ordu	Aydın and Öztürk (2021)
Diplodus annularis	210	12.5-23.4	39.9-249.3	0.031	2.840.92	GN, BT	2016-2017	Sinop	Samsun *et al*. (2017)
Diplodus annularis	295	13.3-23	50.3-235.8	0.0554	2.660.895	TN	2015-2017	Ordu	Erat (2019)
Engraulis encrasicolus	1172	7.5-13.0	-	0.00643	2.9743 -	-	1988-1989	-	Ünsal (1989)
Engraulis encrasicolus	831	6.7-16.1	2.00-26.46	0.002314	3.4157 -	-	1985-1986	Central and Eastern Black Sea	Erkoyuncu and Özdamar (1989)
Engraulis encrasicolus	1420	4.85-16.85	1.46-21.08	0.00247	3.38320.9994	PS	1986-1987	-	Karaçam and Düzgüneş (1990)
Engraulis encrasicolus	1705	6.0-15.3	1.02-20.44	0.0047	3.1002 -	-	1987-1989	-	Özdamar (1991)
Engraulis encrasicolus	842	6.7-16.1	2.00-26.46	0.0023	3.41280.9944	PS	1985-19867	Sinop-Samsun	Özdamar *et al*. (1991)
Engraulis encrasicolus	840	7.24-14.40	1.99-16.49	0.00510	3.0480.970	PS	1993-1994	Eastern Black Sea	Mutlu *et al*. (1993)
Engraulis encrasicolus	43	-	-	0.0053	3.03870.97	-	1988-1994	Sinop	Erkoyuncu *et al*. (1994)
Engraulis encrasicolus	840	7.24-14.40	1.99-16.49	0.0051	3.0480.97	PS	1993-1994	Eastern Black Sea	Düzgüneş *et al*. (1995)
Engraulis encrasicolus	3891	6.1-15.3	1.04-24.25	0.0047	3.09750.98	PS	1994-1995	Sinop-Samsun	Özdamar *et al*. (1995a)
Engraulis encrasicolus	1664	7-13.8	1.9-15.8	0.0054	3.0400.944	-	1997-1998	Rize-Hopa	Gözler and Çiloğlu (1998)
Engraulis encrasicolus	543	6.2-13.5	1.462-18.193	0.00569	3.1170.89	PS	1996-1997	Trabzon-Rize-Hopa	Kayalı (1998)
Engraulis encrasicolus	1247	6.5-14.7	-	0.0086	2.65350.9404	PS	2002-2003	Trabzon-Hopa	Şahin *et al*. (2003)

Table 2. continued

Engraulis encrasicolus		6.0-15.0	-	0.0076	2.92	-	PS	1998-2000	Sinop	Samsun *et al*. (2004)
Engraulis encrasicolus	1245	6.5-15.2	0.98-20.80	0.0066	2.9669	0.96	PS, MT	2004-2005	Sinop-Samsun	Bilgin *et al*. (2006a)
Engraulis encrasicolus	1499	6.0-15.99		0.0101	2.7948	0.95	PS	2004-2005	Trabzon-Hopa	Şahin *et al*. (2006)
Engraulis encrasicolus	575	8.0-14.7	2.85-19.14	0.0174	2.6014	0.85	BT, MT	2004-2005	Sinop-Samsun	Kalaycı *et al*. (2007)
Engraulis encrasicolus	363	10.72	-	0.0093	2.8345	0.98	MT	2008-2009	-	Özdemir *et al*. (2009c)
Engraulis encrasicolus	3442	5.8-14.8	0.99-19.47	0.011	2.742	-	PS	2010-2011	Sinop-Trabzon	Erdoğan Sağlam and Sağlam (2013)
Engraulis encrasicolus	696	8.0-13.6	3.5-16.4	0.0180	2.6182	0.8784	MT	2010-2011	Sinop-Samsun	Özdemir and Duyar (2013)
Engraulis encrasicolus	1588	5.9-14.6	1.06-18.10	0.0124	2.711	0.944	BT, PS, GN, HD	2009-2011	Şile-Sakarya, Sinop-Hopa	Kasapoğlu and Düzgüneş (2014)
Engraulis encrasicolus	19	6.2-13.5	1.72-13.64	0.0182	2.549	0.974	GN, TN	2010-2011	Southern Black Sea	Yeşilçiçek *et al*. (2015)
Engraulis encrasicolus	10062	5.5-14.5	0.9-17.4	0.008	2.86	0.89	GN, BT	2016-2017	Sinop	Samsun *et al*. (2017)
Engraulis encrasicolus	312	7.4-14.1	1.84-22.11	0.002	3.38	0.97	BT	2013	Zonguldak-Amasra	Türker and Bal (2018)
Engraulis encrasicolus	1516	11.28±0.04	-	0.0096	2.8166	0.984	MT	2008-2009	Samsun	Özdemir *et al*. (2018)
Engraulis encrasicolus	579[1] 1988[2] 697[3] 621[4]	8.8-12.2 5.9-13.8 7.5-13.7 7.8-13.6	8.7-12.51 1.89-13.85 7.4-13.44 3.72-13.91	0.0082 0.0103 0.0092 0.007	2.8425 2.7863 2.8288 2.8854	0.9085 0.9668 0.9749 0.9242	PS, MT	2019-2020	Sinop	Özdemir *et al*. (2020)
Engraulis encrasicolus	3336 2149	10.8±0.02♀ 10.1±0.03♂	- -	0.0159 0.0078	2.5609 2.8757	0.8093 0.8783	PS	2013-2014	Rize-Trabzon	Bilgin and Solak (2020)
Gadus euxinus	890	13.2-24.9	20.1-119.6	0.2721	2.5734	0.9969	-	1998-1989	Trabzon	Düzgüneş and Karaçam (1990)
Gadus merlangus euxinus	4184	8.5-40.0	3.74-516.20	0.0043	3.1959	0.98	BT	1988-1989	Sinop-Samsun	Samsun *et al*. (1993)
Gadus merlangus euxinus	15875			0.0045	3.1872	0.99	BT	1991-1994	Sinop-Samsun	Samsun (1995b)

Table 2. continued

Gadus merlangus euxinus		14588.7-23.5	3.75-104.23	0.0050	3.1581	0.97	BT	1994-1995	Samsun	Özdamar and Samsun (1995)
Gadus merlangus euxinus		13029.0-24.0	5.70-118.65	0.0039	3.2384	0.9654	BT	1995-1996	Sinop	Samsun and Erkoyuncu (1998)
Gaidropsarus mediterraneus	21	10.8-27.1	5.62-181.19	0.0012	3.616	0.963	BT, PS, GN, HD	2009-2011	Şile-Sakarya, Sinop-Hopa	Kasapoğlu and Düzgüneş (2014)
Gobius batrachocephalus		1845.5-18.0	1.71-77.00	0.024	2.736	0.913	BT	2007	Trabzon	Ak *et al*. (2009a)
Gobius melanostomus		14258.0-20.5	6.25-98.74	0.0243	2.8505		BT	1994-1995	Samsun	Samsun (1995d)
Gobius melanostomus	73	9.1-35.0	8.58-381.42	0.010	3.033	0.886	BT	2007	Trabzon	Ak *et al*. (2009a)
Gobius niger		1197.6-13.2	5.3-28.6	0.0151	2.88	0.86	BT	2002	Trabzon-Rize	Demirhan *et al*. (2005a)
Gobius niger		1137.6-13.2	-	0.0113	3.00	0.91	BT	2002	Southeastern Black Sea	Demirhan and Can (2007)
Gobius niger		2278.0-25.3	5.37-168.7	0.0166	2.8690	0.96	BT, MT	2004-2005	Sinop-Samsun	Kalaycı *et al*. (2007)
Gobius niger		2085.6-15.7	1.69-45.00	0.009	3.041	0.889	BT	2007	Trabzon	Ak *et al*. (2009a)
Gobius niger		12719.1-30.3	55.0-283.3	0.0048	3.1781	0.9267	MT	2010-2011	Sinop-Samsun	Özdemir and Duyar (2013)
Gobius niger		1126.8-15.8	4.09-48.85	0.0180	2.856	0.953	BT, PS, GN, HD	2009-2011	Şile-Sakarya, Sinop-Hopa	Kasapoğlu and Düzgüneş (2014)
Gobius niger		1139.0-26.2	9-205	0.0135	2.9543	0.94	BT	2012-2013	Samsun-Ordu	Çalık and Erdoğan Sağlam (2017)
Hippocampus hippocampus		1632.7-13.7	1.11-4.68	0.004	2.949	0.563	BT	2007	Trabzon	Ak *et al*. (2009a)
Hippocampus guttulatus		2916.5-10.3	1.01-4.61	0.0044	2.898	0.819	BT, PS, GN, HD	2009-2011	Şile-Sakarya, Sinop-Hopa	Kasapoğlu and Düzgüneş (2014)
Lithognathus mormyrus	25	16.0-20.10	55.03-100.30	0.0711	2.3981	0.8171	TN	2017	Ordu	Aydın (2017a)
Lithognathus mormyrus		30615.7-31.0	49.23-393.8	0.0147	2.947	0.942	TN	2017-2018	Ordu	Aydın and Sözer (2019)
Liza aurata		50016.2-44.0	10-917	0.0038	3.21	0.87	-	2001-2002	Sinop-Samsun	Bilgin *et al*. (2006b)
Liza aurata		25520.2-40.8	81.2-618.4	0.044	2.52	0.89	GN, BT	2016-2017	Sinop	Samsun *et al*. (2017)
Merlangius merlangus	54	-	-	0.0034	3.2999	0.97	-	1988-1994	Sinop	Erkoyuncu *et al*. (1994)
Merlangius merlangus		164918.77	53.53	0.0039	3.217	-	GN	-	Eastern Black Sea	Aydın *et al*. (1997)

Table 2. continued

Merlangius merlangus		5.6-43.2	-	0.0052	3.142	-	BT	1991-1996	Trabzon	Genç *et al*. (1999)
Merlangius merlangus	904	7.7-22.7	2.99-79.79	0.0067	3.0248	0.96	BT, MT	2004-2005	Sinop-Samsun	Kalaycı *et al*. (2007)
Merlangius merlangus	2238	8.4-31.5	3.35-259.00	0.00427	3.2016	0.97	BT	2001-2003	Sinop	Samsun (2010)
Merlangius merlangus	2292	5.9-22.2	1.44-73.68	0.0054	3.146	0.919	BT, PS, GN HD	2009-2011	Şile-Sakarya, Sinop-Hopa	Kasapoğlu and Düzgüneş (2014)
Merlangius merlangus	2705	7.6-24.2	3.33-111.54	0.0046	3.195	0.947	GN, TN	2010-2011	Southern Black Sea	Yeşilçiçek *et al*. (2015)
Merlangius merlangus	140	10.0-27.0	9-118	0.0131	2.7723	0.91	BT	2012-2013	Samsun-Ordu	Çalık and Erdoğan Sağlam (2017)
Merlangius merlangus	1891	7.5—23.4	3.7-113.8	0.010	2.90	0.93	GN, BT	2016-2017	Sinop	Samsun *et al*. (2017)
Merlangius merlangus	318	7.8-22.7	2.67-76.28	0.006	3.01	0.96	BT	2013	Zonguldak-Amasra	Türker and Bal (2018)
Merlangius merlangus	1579	7.5-32.6	2.68-279.58	0.0046	3.173	0.9641	BT	2017-2018	Trabzon	Şahin *et al*. (2021)
Merlangius merlangus euxinus	4181	8.50-33.30	3.74-240.59	0.0043	3.1959	0.98	BT	1998-1989	Sinop-Samsun	Özdamar *et al*. (1996)
Merlangius merlangus euxinus	1349♀ 864♂	8.8-27.7	4.61-205.90	0.004856 0.005450	3.1510 3.1108	0.996 0.987	BT	1991	Trabzon	Şahin and Akbulut (1997)
Merlangius merlangus euxinus	24986	5.6-43.2	1.18-782.56	0.0052	3.141	0.989	BT	1991-1996	Trabzon	Genç *et al*. (1999)
Merlangius merlangus euxinus	1122♀ 608♂	- -	- -	0.0037 0.0042	3.2594 3.2065	0.9864 0.9807	BT	1996	Trabzon	Çiloğlu *et al*. (2001)
Merlangius merlangus euxinus	7357	5.0-32.5	-	0.0042	3.24	0.99	-	1990-1993	Black Sea Coastal Waters	İşmen (2002)
Merlangius merlangus euxinus	943	6.7-29.6	2.15-241.2	0.004	3.169	0.983	BT	2007	Trabzon	Ak *et al*. (2009a)
Merlangius merlangus euxinus	596♂ 1167♀	8-19 8.7-30	3.70-56.8 3.92-181.68	0.0036 0.0036	3.273 3.268	0.954 0.971	BT	2007-2008	Eastern Black Sea	Ak *et al*. (2009b)

Table 2. continued

Merlangius merlangus euxinus	793♂ 1091♀	10.3-21 10.1-23.1	6.42-67.16 6.33-96.73	0.0071 0.0060	3.0017 3.0651	0.8807 0.8671	GN	2010-2012	Sinop between Giresun	Erdoğan Sağlam and Sağlam (2012)
Merlangius merlangus euxinus	426	9.4-17.0	6.0-34.5	0.0104	2.8555	0.9333	MT	2010-2011	Sinop-Samsun	Özdemir and Duyar (2013)
Merlangius merlangus euxinus	2173	10.4-19.9	7.8-54.7	0.0068	3.0202	0.9866	BT, GN	2012-2013	Sinop-Samsun	Özdemir *et al*. (2018)
Merluccius merluccius	121	12.5-37.8	13.53-494.95	0.005	3.16	0.98	BT	2013	Zonguldak-Amasra	Türker and Bal (2018)
Mesogobius batrachocephal us	40	7.2-13.3	4.0-25.7	0.0289	2.60	0.88	BT	2002	Trabzon-Rize	Demirhan *et al*. (2005a)
Mesogobius batrachocephal us	37	7.2-13.3	-	0.0203	2.75	0.93	BT	2002	Southeastern Black Sea	Demirhan and Can (2007)
Mesogobius batrachocephal us	35	12.0-23.5	14-120	0.0149	2.7768	0.92	BT	2012-2013	Samsun-Ordu	Çalık and Erdoğan Sağlam (2017)
Mesogobius batrachocephal us	470	12.60-31.80	12.62-377.54	0.0062	3.13	0.9606	TN	201-2018	Ordu	Bengil and Aydın (2020)
Mesogobius batrachocephal us	641	5.3-34.0	1.34-372.90	0.0058	3.148	0.9621	TN	2019	Ordu	Aydın (2021a)
Mugil so-iuy	174	22.5-66.7	101-3260	0.010	2.98	0.968	TN	1995	Trabzon	Okumuş and Başçınar (1997)
Mugil so-iuy		32.0-76.0	300-4450	0.0139	2.9183		-	2004	Eastern Black Sea	Gözler *et al*. (2005)
Mullus barbatus	69	-	-	0.0070	3.1685	0.97	-	1988-1994	Sinop	Erkoyuncu *et al*. (1994)
Mullus barbatus	1561	6.3-19.3	4-103	0.0001	3.3946	0.9515	-	1990-1993	Eastern Black Sea	İşmen *et al*. (2000)
Mullus barbatus	421	6.8-6.9	1.4-63.8	0.0054	3.22	0.96	BT	2002	Trabzon-Rize	Demirhan *et al*. (2005a)
Mullus barbatus	176	6.6-18.4	2.94-60.16	0.0111	2.9633	0.98	BT, MT	2004-2005	Sinop-Samsun	Kalaycı *et al*. (2007)
Mullus barbatus	432	6.8-14.6	-	0.0051	3.24	0.97	BT	2002	Southeastern Black Sea	Demirhan and Can (2007)
Mullus barbatus	2693	5.3-19.0	1.2-73.4	0.0074	3.123	0.962	BT, PS, GN, HD	2009-2011	Şile-Sakarya, Sinop-Hopa	Kasapoğlu and Düzgüneş (2014)

Table 2. continued

Mullus barbatus	672	7.4-22.6	2.68-102.50	0.0066	3.119	0.925	GN, TN	2010-2011	Southern Black Sea	Yeşilçiçek *et al*. (2015)
Mullus barbatus	4928	6.3-18.9	3.62-62.42	0.0109	2.9886	0.9554	BT	2012-2014	İğneada-Rumelifeneri	Yıldız and Karakulak (2016)
Mullus barbatus	84	10.0-19.0	9-70	0.0089	3.0454	0.95	BT	2012-2013	Samsun-Ordu	Çalık and Erdoğan Sağlam (2017)
Mullus barbatus	663	9.0-18.4	7.97-71.29	0.004	3.36	0.92	BT	2013	Zonguldak-Amasra	Türker and Bal (2018)
Mullus barbatus ponticus	14553	4.4-23.5	0.72-143.7	0.0063	3.179	0.990	BT	1991-1996	Trabzon	Genç *et al*. (1999)
Mullus barbatus ponticus	14022	4.4-23.5	0.72-143.70	0.0063	3.182	0.991	BT	1990-1996	Trabzon	Genç (2000)
Mullus barbatus ponticus	714	6.1-21.9	2.08-161.14	0.007	3.139	0.990	BT	2007	Trabzon	Ak *et al*. (2009a)
Mullus barbatus ponticus	699	7.3-18.7	-	0.0107	2.9717	0.99	BT, TN	2004-2005	Sinop	Aksu *et al*. (2011)
Mullus barbatus ponticus	225	9.3-20.1	8.59-87.90	0.0108	2.9819	0.9703	MT	2010-2011	Sinop-Samsun	Özdemir and Duyar (2013)
Mullus barbatus ponticus	1435	6.4-21.5	2.09-105.40	0.0088	3.0338	0.97	GN, SN	2010-2011	Ordu	Aydın and Karadurmuş (2013)
Mullus barbatus ponticus	1602	8.2-19.8	5.6-86.5	0.007	3.15	0.97	GN, BT	2016-2017	Sinop	Samsun *et al*. (2017)
Mullus barbatus ponticus	229	8.7-14.4	6.4-29.4	0.0102	2.9909	0.979	BT, GN	2016-2017	Sinop	Erdem (2018)
Mullus barbatus ponticus	632	9.2-13.3	8.2-68.6	0.0137	2.902	0.92	BT, TN, GN	2015-2016	Sinop	Yılmaz *et al*. (2019)
Mullus surmuletus	80	7.1-14.0	3.21-33.83	0.0042	3.400	0.957	BT, PS, GN, HD	2009-2011	Şile-Sakarya, Sinop-Hopa	Kasapoğlu and Düzgüneş (2014)
Neogobius melanostomus	263	9.0-23.30	9.00-186.65	0.1145	3.0862	0.9281	TN	2001	Rize	Gözler *et al*. (2003)
Neogobius melanostomus	99	8.6-19.1	7.0-104.9	0.0063	3.29	0.93	BT	2002	Trabzon-Rize	Demirhan *et al*. (2005a)
Neogobius melanostomus	99	8.6-19.1	-	0.0047	3.39	0.95	BT	2002	Southeastern Black Sea	Demirhan and Can (2007)
Neogobius melanostomus	471♂ 397♀	7.4-25 7.5-19.7	- -	0.0110 0.0076	3.07 3.23	0.96 0.94	BT	2002-2005	Samsun	Gümüş and Kurt (2009)
Neogobius melanostomus	58	9.0-26.0	8-265	0.0059	3.3062	0.99	BT	2012-2013	Samsun-Ordu	Çalık and Erdoğan Sağlam (2017)

Table 2. continued

Neogobius melanostomus	2408	10.50-26.20	15.28-212.20	0.0069	3.1972	0.9549	TN	2017-2018	Ordu	Aydın (2021b)
Neogobius melanostomus	61	10.7-23.9	15.5-204.9	0.004	3.353	0.979	TN	2019	Ordu	Karadurmuş and Aydın (2021)
Ophidion barbatum	34	16.9-22.2	24.70-55.83	0.0096	2.777	0.918	GN, TN	2010-2011	Southern Black Sea	Yeşilçiçek *et al.* (2015)
Parablennius gattorugine	11	12.6-16.8	26.80-60.78	0.0125	3.021	0.953	GN, TN	2010-2011	Southern Black Sea	Yeşilçiçek *et al.* (2015)
Platichthys flesus	51	19.1-38.5	69.9-620.1	0.007	3.093	0.952	BT	2007	Trabzon	Ak *et al.* (2009a)
Platichthys flesus	16	15.7-32.7	35.59-390.02	0.0052	3.175	0.975	BT, PS, GN, HD	2009-2011	Şile-Sakarya, Sinop-Hopa	Kasapoğlu and Düzgüneş (2014)
Platichthys flesus luscus	48	-	-	0.0078	3.1090	0.98	-	1988-1994	Sinop	Erkoyuncu *et al.* (1994)
Platichthys flesus luscus	988	13.6-29.9	26.7-463.0	0.00341	3.3932	0.9643	BT	1992-1994	Sinop-Samsun	Samsun (1995c)
Platichthys flesus luscus	348	14.9-39.7	32.95-751.08	0.0062	3.1835	0.96	BT	1994-1995	Samsun	Özdamar *et al.* (1995b)
Platichthys flesus luscus	7610	5.5-38.0	1.62-684.40	0.0072	3.125	0.983	BT	1991-1996	Trabzon	Genç *et al.* (1999)
Platichthys flesus luscus	952	14.0-37.5	28.879-611.0	0.0103	3.028	0.9435	BT, TN, BS	1999-2001	Trabzon-Rize	Çiloğlu (2002)
Platichthys flesus luscus	836♂ 762♀	12-27.9 11.2-38.2	9.2-262.5 17.9-614.0	0.0202 0.0184	2.7898 2.8485	0.87 0.90	BT	1995-1996	Trabzon	Şahin and Güneş (2010)
Pomatomus saltatrix	19	-	-	0.0388	2.5582	0.92	-	1988-1994	Sinop	Erkoyuncu *et al.* (1994)
Pomatomus saltatrix	143	13.2-21.7	23.21-88.19	0.0130	2.8621	0.92	BT, MT	2004-2005	Sinop-Samsun	Kalaycı *et al.* (2007)
Pomatomus saltatrix	628	-	-	0.006	3.195	0.98	BT	2004-2005	Samsun	Özdemir *et al.* (2009a)
Pomatomus saltatrix	820	9.2-23.4	10.1-135.5	0.0037	3.3268	0.99	BT	2005-2006	Samsun	Özdemir *et al.* (2009b)
Pomatomus saltatrix	529	17.52		0.0030	3.3985	0.99	MT	2008-2009	-	Özdemir *et al.* (2009c)
Pomatomus saltatrix	14	11.6-22.2	12-131	0.003	3.336	0.978	BT	2007	Trabzon	Ak *et al.* (2009a)
Pomatomus saltatrix	207	12.2-24	15.4-127.2	0.0045	3.2501	0.9762	MT	2010-2011	Sinop-Samsun	Özdemir and Duyar (2013)

Table 2. continued

Pomatomus saltatrix	25	12.5-20.2	16.00-75.19	0.0092	3.005	0.865	PS, GN, HD	2009-2011	Şile-Sakarya, Sinop-Hopa	Kasapoğlu and Düzgüneş (2014)
Pomatomus saltatrix	125	13.5-23.6	22.01-161.19	0.008	3.12	0.962	-	2014	Samsun	Özpiçak *et al*. (2017)
Pomatomus saltatrix	820	16.1-27.5	32.5-227.9	0.005	3.25	0.95	GN, BT	2016-2017	Sinop	Samsun *et al*. (2017)
Pomatomus saltatrix	38	15.9-22.2	33.11-101.03	0.005	3.15	0.97	BT	2013	Zonguldak-Amasra	Türker and Bal (2018)
Pomatomus saltatrix	672	12.9-26.3	18.51-166.50	0.0104	2.978	0.977	-	2012-2013	-	Kalaycı *et al*. (2019)
Pomatomus saltatrix	101	14.0-26.0	25.87-189.31	0.0082	3.0913	0.973	GN	2017-2018	Ordu	Samsun and Erdoğan Sağlam (2021)
Psetta maxima	1445	-	-	0.0112	3.12	0.99	BT	1990-1996	Trabzon	Zengin *et al*. (2006)
Psetta maxima	760	16.2-79.2	63.5-9160.0	0.0106	3.1268	0.973	BT	2008	Trabzon	Şahin and Güneş (2011)
Psetta maxima	97	32.5-80.0	444.20-9456	0.0069	3.3757	0.9292	MT	2010-2011	Sinop-Samsun	Özdemir and Duyar (2013)
Psetta maxima	16	37.5-70.5	925-7865	0.0113	3.1171	0.93	BT	2012-2013	Samsun-Ordu	Çalık and Erdoğan Sağlam (2017)
Psetta maxima maeotica	1599	7.2-82.0	3-9620	0.0108	3.124	0.992	BT	1991-1996	Trabzon	Genç *et al*. (1999)
Raja clavata	40	-	-	0.0090	2.9208	0.96	-	1988-1994	Sinop	Erkoyuncu *et al*. (1994)
Raja clavata	193	18.0-90.0	15-4800	0.0023	3.2402	0.957	BT	2003-2004	Trabzon	Başçınar and Sağlam (2005)
Raja clavata	52	34.3-95	168-5450	0.001	3.42	0.91	L	2002-2003	Sotheastern Black Sea	Demirhan *et al*. (2005b)
Raja clavata	27	10.7-95.0	4.2-5025.0	0.0019	3.24	0.99	BT	2002	Trabzon-Rize	Demirhan *et al*. (2005a)
Raja clavata	102	27.8-88.2	97.20-3444.8	0.0027	3.1832	0.9783	MT	2010-2011	Sinop-Samsun	Özdemir and Duyar (2013)
Raja clavata	63	13.2-90.0	6.42-4364.00	0.0010	3.288	0.971	BT, PS, GN, HD	2009-2011	Şile-Sakarya, Sinop-Hopa	Kasapoğlu and Düzgüneş (2014)
Raja clavata	10	34.5-75.0	183-2980	0.001	3.4472	0.98	BT	2012-2013	Samsun-Ordu	Çalık and Erdoğan Sağlam (2017)
Sarda sarda	14	-	-	0.0297	2.6799	0.93	-	1988-1994	Sinop	Erkoyuncu *et al*. (1994)
Sarda sarda	1168	21.8-70.5**	110-5000	0.0039	3.3263	0.925	D, PS, TM, DN, BS, HL	2000-2001	-	Oray *et al*. (2004)
Sarda sarda	694	23.5-71.0	122.4-4724.0	0.0054	3.2146	0.983	PS	2003-2005	-	Ateş *et al*. (2008)
Sarda sarda	36	28.1-37.5	233.72-517.82	0.0502	2.562	0.891	BT, PS, GN, HD	2009-2011	Şile-Sakarya, Sinop-Hopa	Kasapoğlu and Düzgüneş (2014)
Sarda sarda	314	24.8-62.8	152.6-2478.5	0.002	3.45	0.97	GN, BT	2016-2017	Sinop	Samsun *et al*. (2017)
Sciaena umbra	329	-	-	0.0045	3.3024	0.96	SF, HN	2002-2003	Trabzon	Engin and Seyhan (2009)

Table 2. continued

Sciaena umbra	217	11.70-48.20	16.43-1934.48	0.0057	3.250.979	-	2019-2020	Samsun, Ordu, Giresun, Trabzon	Aydın and Bengil (2020)
Sciaena umbra	319	11.7-58	16.4-2485.17	0.0065	3.20250.9834	TN	2019-2020	Samsun-Ordu-Giresun-Trabzon	Aydın and Bodur (2021)
Sciaena umbra	54	117-580*	16.4-2485.1	0.000004	3.1900.9934	-	2019-2020	Samsun-Ordu-Giresun- Trabzon	Aydın and Bodur (2021)
Scophthalmus maeticus	506	29.81	494	0.0085176	3.2034 -	BT	1992-1994	Middle Black Sea	Samsun (1995a)
Scophthalmus maeticus	1989	7.2-82.0	-	0.0103	3.13900.9918	BT	1990-1996	Trabzon	Zengin (2000)
Scophthalmus maeticus	1011	23.9-69	212.1-5400	0.0074	3.220.96	GN	2001	Sinop	Samsun *et al*. (2007)
Scophthalmus maximus	168	23.0-72.0	-	0.128736	2.48700.9721	-	-	-	Doğan *et al*. (1990)
Scophthalmus maximus	149	181.0-630.0	-	0.0085	3.180.99	BT	1991	Eastern Black Sea	Avşar (1999)
Scophthalmus maximus	63	10.0-61.0	14.6-4494.4	0.007	3.2480.977	BT	2007	Trabzon	Ak *et al*. (2009a)
Scophthalmus maximus	264	14.0-70.0	34-5550	0.0085	3.15810.989	-	-	-	Eryılmaz and Dalyan (2015)
Scophthalmus rhombus	5	18.9-28.4	44.9-217.3	0.0013	3.570.97	BT	2002	Trabzon-Rize	Demirhan *et al.* (2005a)
Scorpaena porcus	31	-	-	0.0180	3.08000.99	-	1988-1994	Sinop	Erkoyuncu *et al*. (1994)
Scorpaena porcus	572	11.0-25.2	24.84-326.90	0.0219	2.9568	GN	1996	Sinop	Koca and Samsun (1997)
Scorpaena porcus	633	10.7-25.0	-	0.0540	2.590	BT	1996-1997	Sinop	Koca (2002)
Scorpaena porcus	262	6.3-23.5	5.6-257.2	0.0166	3.10150.980	BT	2003-2004	Trabzon	Başçınar and Sağlam (2005)
Scorpaena porcus	470	4.6-17.5	1.3-100.5	0.0124	3.190.94	BT	2002	Trabzon-Rize	Demirhan *et al.* (2005a)
Scorpaena porcus	525	4.6-22.9	1.34-220.0	0.015	3.100.99	BT, TN	2002-2003	Southeastern Black Sea	Demirhan and Can (2009)
Scorpaena porcus	136	8.5-29.2	13-508	0.0173	3.03370.98	BT, MT	2004-2005	Sinop-Samsun	Kalaycı *et al*. (2007)

Table 2. continued

Scorpaena porcus	351	5.0-34.2	2.1-406.1	0.009	3.272	0.880	BT	2007	Trabzon	Ak *et al*. (2009a)
Scorpaena porcus	379♂ 510♀	5.7-23.6 4.9-31.7	- -	0.0166 0.0163	3.0554 3.067	0.995 0.994	BMT	2002-2003	Sinop	Bilgin and Çelik (2009)
Scorpaena porcus	1061	6.7-25.5	-	0.0101	3.2546	0.96	GN	2012	Trabzon	Erbay (2013)
Scorpaena porcus	42	5.4-26.0	3.70-403.71	0.0210	2.982	0.973	BT, PS, GN, HD	2009-2011	Şile-Sakarya, Sinop-Hopa	Kasapoğlu and Düzgüneş (2014)
Scorpaena porcus	943	8.2-27.9	9.19-470.00	0.0091	3.301	0.962	GN, TN	2010-2011	Southern Black Sea	Yeşilçiçek *et al*. (2015)
Scorpaena porcus	50	8.5-21.0	13-165	0.0251	2.8992	0.97	BT	2012-2013	Samsun-Ordu	Çalık and Erdoğan Sağlam (2017)
Scorpaena porcus	411	6.2-24.0	4.10-235.12	0.0217	2.9548	0.9601	BT, GN	2016-2017	Samsun-Ordu-Giresun	Samsun and Erdoğan Sağlam (2018)
Scorpaena porcus	32	5.4-25.5	3.4-305.56	0.026	2.87	0.98	BT	2013	Zonguldak-Amasra	Türker and Bal (2018)
Scorpaena porcus	2442	2.8-33.2	0.31-775.6	0.0165	3.0559	0.9623	TN	2016-2017	Ordu	Aydın (2019)
Scorpaena porcus	344	7.0-27.0	4.08-406.07	0.0164	3.0785	0.977	GN	2017-2018	Ordu	Samsun and Erdoğan Sağlam (2021)
Scorpaena maderensis	78	6.0-10.0	4.32-20.44	0.032	2.84	0.96	BT	2013	Zonguldak-Amasra	Türker and Bal (2018)
Serranus scriba	15	11.3-25.0	16.4-220.0	0.0052	3.3478	0.9809	TN	2017	Ordu	Aydın (2017b)
Solea nasuta	19	-	-	0.0019	3.5805	0.97	-	1988-1994	Sinop	Erkoyuncu *et al*. (1994)
Solea nasuta	100	11.3-21.7	17.29-139.85	0.016	2.755	0.960	BT	2007	Trabzon	Ak *et al*. (2009a)
Solea nasuta	91	3.4-22.6	0.25-55.86	0.0042	3.265	0.987	BT, PS, GN, HD	2009-2011	Şile-Sakarya, Sinop-Hopa	Kasapoğlu and Düzgüneş (2014)
Solea solea	309	11.7-22.2	13.25-104.71	0.0062	3.111	0.901	GN, TN	2010-2011	Southern Black Sea	Yeşilçiçek *et al*. (2015)
Solea solea	528	11.0-27.60	10.70-263.20	0.0028	3.4226	0.96	TN	2015-2016	Sinop	Büyükdeveci *et al*. (2020)
Sparus aurata	109	15.7-21.2	62.2-136.8	0.035	2.70	0.86	GN, BT	2016-2017	Sinop	Samsun *et al*. (2017)
Spicara maena	12	12.1-19.4	4.34-77.52	0.0124	2.942	0.962	GN, TN	2010-2011	Southern Black Sea	Yeşilçiçek *et al*. (2015)
Spicara smaris	25	-	-	0.0061	3.2157	0.97	-	1988-1994	Sinop	Erkoyuncu *et al*. (1994)
Spicara smaris	517	-	-	0.005	3.26	0.975	BT	1991-1992	Samsun, Ordu, Trabzon, Rize	İşmen (1995)
Spicara smaris	6627	6.2-21.5	2.10-121.01	0.0069	3.135	0.986	BT	1991-1996	Trabzon	Genç *et al*. (1999)
Spicara smaris	83	11.2-20.0	14.24-87.67	0.0063	3.1504	0.96	BT, MT	2004-2005	Sinop-Samsun	Kalaycı *et al*. (2007)
Spicara smaris	528	8.3-24.2	3.51-29.4	0.009	3.008	0.856	BT	2007	Trabzon	Ak *et al*. (2009a)

Table 2. continued

Spicara smaris	103	8.0-20.4	8.11-92.23	0.0223	2.722	0.938	PS, GN, HD	2009-2011	Şile-Sakarya, Sinop-Hopa	Kasapoğlu and Düzgüneş (2014)
Spicara smaris	70	11.0-22.5	15-120	0.0075	3.1345	0.96	BT	2012-2013	Samsun-Ordu	Çalık and Erdoğan Sağlam (2017)
Spicara flexuosa	599	8.7-21.8	7.1-129.94	0.0118	2.9727	0.9487	GN	2015-2016	Rize-Hopa	Ergün (2018)
Spicara flexuosa	318	11.0-22.5	14.24-118.00	0.0079	3.0915	0.947	GN	2017-2018	Ordu	Samsun and Erdoğan Sağlam (2021)
Sprattus sprattus	5087	5.60-12.6	0.95-12.39	0.0079	2.8676	0.88	BT, MT	2004-2005	Sinop-Samsun	Kalaycı *et al*. (2007)
Sprattus sprattus	1927	5.007-12.265	0.619-11.520	0.0067	2.9446	0.912	MT	2004-2005	Samsun-Ordu	Polat *et al*. (2008)
Sprattus sprattus	1300	8.55	-	0.0092	2.8121	0.98	MT	2008-2009	-	Özdemir *et al*. (2009c)
Sprattus sprattus	599	5.9-10.9	1.4-8.1	0.0072	2.9278	0.9433	MT	2010-2011	Sinop-Samsun	Özdemir and Duyar (2013)
Sprattus sprattus	423	5.6-10.7	1.08-8.14	0.0064	2.921	0.916	BT, PS, GN, HD	2009-2011	Şile-Sakarya, Sinop-Hopa	Kasapoğlu and Düzgüneş (2014)
Sprattus sprattus	4214	8.5±0.01	-	0.0089	2.8259	0.981	MT	2008-2009	Samsun	Özdemir *et al*. (2018)
Sprattus sprattus	655	5.1-11.8	0.95-9.96	0.007	3.11	0.98	BT	2013	Zonguldak-Amasra	Türker and Bal (2018)
Sprattus sprattus phalericus	4186	3.3-13.0	-	0.0026	3.33	0.99	BT, MT	1990-1992	Black Sea of Turkey	Avşar (1995)
Sprattus sprattus phalericus	372	7.2-13.2	1.62-13.95	0.0021	3.46	0.9987	BT	1991	Trabzon	Şahin (1999)
Sprattus sprattus phalericus	4038	5.2-12.5	0.96-11.81	0.0062	3.0938	0.98	MT	2004-2005	-	Kalaycı *et al*. (2006)
Squalus acanthias	327	22.3-141.0	31-13150	0.0022	3.1413	0.9979	BT	1992-1994	Sinop-Samsun	Samsun *et al*. (1995b)
Squalus acanthias	168♂ 160♀	32-121 37-136	- -	0.0045 0.0035	2.92 2.99	0.987 0.993	BT	1991	Sinop- Samsun, Ordu, Trabzon, Rize	Avşar (1996)
Squalus acanthias	267	36.5-141.5	135-16140	0.009	3.3423	0.9607	PS, GN	1994-1995	Giresun, Trabzon, Rize	Düzgüneş *et al*. (2006)

Table 2. continued

Squalus acanthias	1780♂ 1840♀	30.0-120.0 30.0-140.0	117-6473 146-13157	0.0041 0.0053	3.0046 2.9294	0.996 0.9988	BT	1969-1973	Karaburun-Ereğli, Sinop-Samsun	Kutaygil and Bilecik (1998)
Squalus acanthias	176	34.1-144.8	109-15500	$0.4x10^{-8}$♀ $0.8x10^{-8}$♂	3.513 3.319	0.97 0.98	L, PS, GN	2000-2003	Southeastern Black Sea.	Demirhan and Seyhan (2007)
Syngnathus acus	280	15.6-39.2	1.0-16.66	0.0001	3.415	0.898	BT	2010-2011	Western Black Sea	Yıldız *et al*. (2015)
Trachinus draco	338	5.0-35.0	1.01-549.2	0.004	3.433	0.884	BT	2007	Trabzon	Ak *et al*. (2009a)
Trachinus draco	636	5.0-25.8	1.01-131.76	0.0069	3.0051	0.9632	BT	2009-2010	Trabzon	Ak and Genç (2013)
Trachinus draco	88	8.1-31.6	3.69-289.39	0.007	3.01	0.97	BT	2013	Zonguldak-Amasra	Türker and Bal (2018)
Trachurus trachurus	77	-	-	0.0290	2.4854	0.98	-	1988-1994	Sinop	Erkoyuncu *et al*. (1994)
Trachurus trachurus	-	6.5-19.0	-	0.0075	3.017	-	BT	1991-1996	Trabzon	Genç *et al*. (1999)
Trachurus trachurus	720	9.4-16.8	5.27-43.95	0.00759	3.05	-	MT	1995-1996	Samsun-İnebolu	Yücel and Erkoyuncu (2000)
Trachurus trachurus	6035	6.7-19.8	2.40-60.82	0.0062	3.0938	0.99	PS, MT, BT, GN	2003-2004	Sinop-Samsun	Kalaycı (2006)
Trachurus trachurus	1290	-	-	0.0063	3.0931	0.98	MT, PS	2004-2005	Samsun	Samsun *et al*. (2006a)
Trachurus trachurus	747	7.3-18.3	3.34-47.37	0.0086	2.9849	0.96	BT, MT	2004-2005	Sinop-Samsun	Kalaycı *et al*. (2007)
Trachurus trachurus	800	-	-	0.007	3.029	0.99	BT	2004-2005	Samsun	Özdemir *et al*. (2009a)
Trachurus trachurus	902	13.08	-	0.0074	3.0445	0.98	MT	2008-2009	-	Özdemir *et al*. (2009c)
Trachurus trachurus	267	6-15.7	1.75-44.32	0.004	3.249	0.946	BT	2007	Trabzon	Ak *et al*. (2009a)
Trachurus trachurus	1307	6.9-19.02	2.32-59.89	0.0049	3.17	0.96	GN, PS	2011-2012	Ordu	Aydın and Karadurmuş (2012)
Trachurus trachurus		11.0-11.9*	20.0-24.99	0.016	2.881	0.983	PS	2010-2011	Zonguldak	Erdoğan *et al*. (2016)
Trachurus trachurus	489	8.0-16.6	3.03-38.3	0.0056	3.12	0.98	BT	2013	Zonguldak-Amasra	Türker and Bal (2018)
Trachurus trachurus	479	7.8-18.0	2.67-54.47	0.0021	3.5118	0.973	GN	2017-2018	Ordu	Samsun and Erdoğan Sağlam (2021)

Table 2. continued

Trachurus mediterraneus	430	6.3-17.8	3-58	0.0108	2.98	0.97	PS	1996-1997	Trabzon-Rize-Hopa	Kayalı (1998)
Trachurus mediterraneus	1914	6.6-19.3	2.13-66.70	0.0075	3.017	0.989	BT	1991-1996	Trabzon	Genç *et al*. (1999)
Trachurus mediterraneus	1312	9.12-19	-	0.0089	2.955	0.9441	PS	2004-2005	Trabzon-Rize	Şahin *et al*. (2009)
Trachurus mediterraneus	696	-	-	0.0071	3.039	0.98	MT	2008-2009	Samsun	Erdem *et al*. (2010)
Trachurus mediterraneus	439	12.70	18.05	0.0093	2.9565	0.97	PS	2010	Trabzon	Atılgan *et al*. (2012)
Trachurus mediterraneus	526	9.4-15.1	4.6-25.2	0.0032	3.3018	0.8953	MT	2010-2011	Sinop-Samsun	Özdemir and Duyar (2013)
Trachurus mediterraneus	624	6.2-19.5	1.71-64.30	0.0050	3.138	0.972	BT, PS, GN, HD	2009-2011	Şile-Sakarya, Sinop-Hopa	Kasapoğlu and Düzgüneş (2014)
Trachurus mediterraneus	1870	7.1-20.3	3.2-67.7	0.010	2.93	0.89	GN, BT	2016-2017	Sinop	Samsun *et al*. (2017)
Trachurus mediterraneus	128	6.5-11.6	1.21-32.0	0.002	3.49	0.97	BT	2013	Zonguldak-Amasra	Türker and Bal (2018)
Trachurus mediterraneus	1467	7.1-20.3	3.2-67.7	0.0067	3.0848	0.94	PS	2016-2017	Sinop	Samsun *et al*. (2018)
Trachurus mediterraneus pon.	601	7.4-14.5	-	0.0048	3.22		-	-	-	Şahin *et al*. (1997)
Umbrina cirrosa	102	4.8-94	1.0-7051.1	0.009	3.0541	0.996	TN	2018-2019	Ordu	Aydın and Sözer (2020)
Uranoscopus scaber	116	6.1-26.4	3.8-298.7	0.0148	3.0392	0.971	BT	2003-2004	Trabzon	Başçınar and Sağlam (2005)
Uranoscopus scaber	69	5.3-21.8	2.1-201.9	0.0148	3.05	0.98	BT	2002	Trabzon-Rize	Demirhan *et al*. (2005a)
Uranoscopus scaber	346	5.2-21.9	2.0-182.5	0.0167	3.00	0.99	BT, TN	2002-2005	-	Demirhan *et al*. (2007)
Uranoscopus scaber	69	5.3-21.8	-	0.0150	3.05	0.98	BT	2002	Southeastern Black Sea	Demirhan and Can (2007)

Table 2. continued

Uranoscopus scaber	620	1.8-56.4	1.01-551.51	0.008	3.2260.815	BT	2007	Trabzon	Ak *et al*. (2009a)
Uranoscopus scaber	988	5.0-30.0	-	0.0128	3.09180.940	BT	2008	Eastern Black Sea	Ak *et al*. (2011)
Uranoscopus scaber	155	5.2-23.4	2.79-243.40	0.0252	2.8540.979	BT, PS, GN, HD	2009-2011	Şile-Sakarya, Sinop-Hopa	Kasapoğlu and Düzgüneş (2014)
Uranoscopus scaber	606	6.9-25.5	5.46-326.66	0.0103	3.1760.967	GN, TN	2010-2011	Southern Black Sea	Yeşilçiçek *et al*. (2015)
Uranoscopus scaber	82	10.5-23.0	18-207	0.0190	2.94870.96	BT	2012-2013	Samsun-Ordu	Çalık and Erdoğan Sağlam (2017)
Uranoscopus scaber	189	6.6-25.5	4.28-312.65	0.009	3.210.98	BT	2013	Zonguldak-Amasra	Türker and Bal (2018)
Uranoscopus scaber	88	10.5-23.0	21-207	0.0152	3.02340.980	GN	2017-2018	Ordu	Samsun and Erdoğan Sağlam (2021)

Log (a)-b scatter plot and corelation value (-0,571; $p<0.05$) were determined for all indivuduals (Figure 1). Different distributions relative to the regression line in Figure 1 show that the variation in log a is largely a function of the body shape of the species concerned.
Froese (2000) reported that a log a vs b plot must first be made to detect and exclude outliers, when discussing intra-species variation in LWRs. Some of species that have more than five LWR and that have outliers were considered. It was determined that *Mullus barbatus* had two outliers and the others (*Belone belone, Alosa immaculata, Merlangius merlangus* and *Neogobius melanostomus*) had one outlier each (Figure 2).

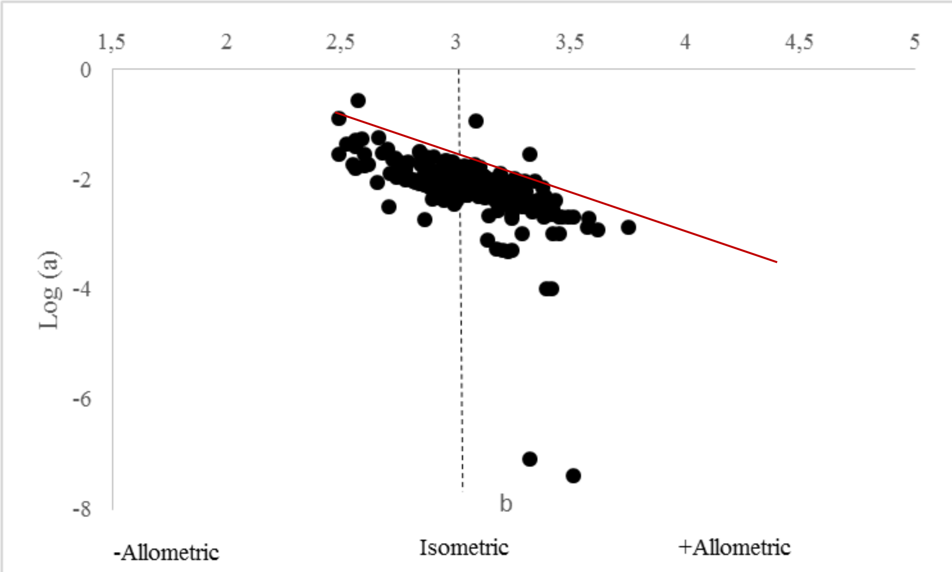

Figure 1. Scatter plot of mean log a over mean b for fish species with body shape information. Areas of negative allometric, isometric and positive allometric change in body weight relative to body length are indicated

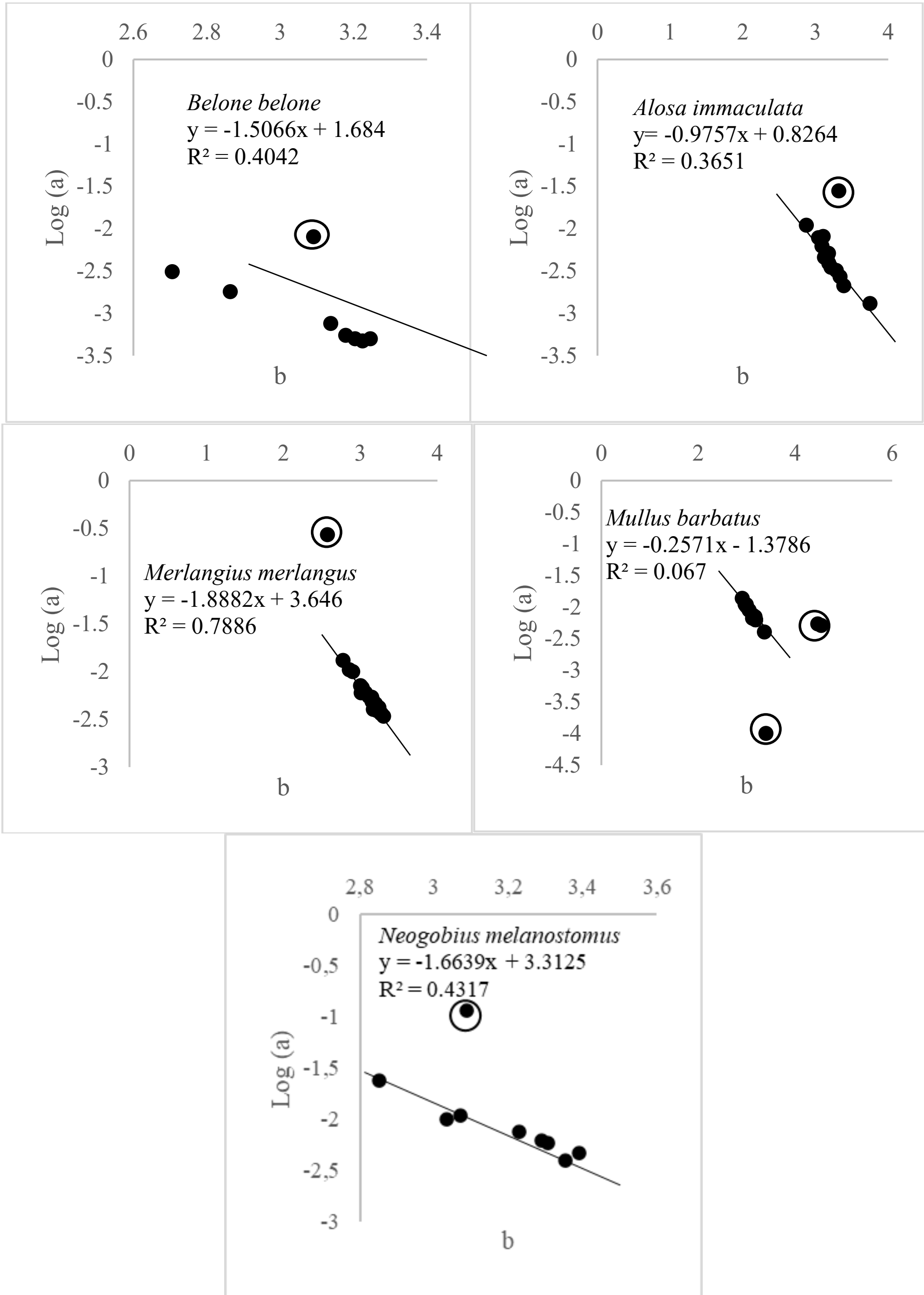

Figure 2. The log a vs b graph of 5 species. The circled points are the outliers.

4. DISCUSSION AND CONCLUSIONS

In the study, LWRs of 138 studies which included 51 species of 29 families studied in Turkish coast of Black Sea were reviewed. Bilecenoğlu *et al*. (2014) reported 154 fish species of 52 families for Black Sea region. In terms of family, 50% of the existing families were studied in Turkish coastline. Most studies fish species belonged to Gadidae, Clupeidae, Engraulidae, Carangidae, Gobiidae, Mullidae and Scopthalmidae families. However, in terms of the number of species, it can be seen that length-weight association of 27% were determined. Akyol *et al*. (2017) reported that of the 448 fish species in Aegean Sea, length-weight association parameters of 46.4% were studied. Gündoğdu *et al*. (2016) reported thatmost of the samples in studies conducted in Turkey came from trawling and thus studies of the same species were in the majority. In the same study, they reported that although *b* value differed depending on a great number of factors, regional differences were more effective.

Froese *et al*. (2011) reported that 100 specimens were sufficient as the number of samples for height-weight association studies; however, they also added that fewer individuals could be accepted for rare species. Akyol *et al*. (2017) that while this number was reasonable for species less than 20 in number which were difficult to find, the number had to be discussed again and for species which were plenty in number but calculated with less number of species, location differences could be important. On the other hand, even though sample size for fish are low (n<20) the r^2 value may be significantly strong (e.g. *E. encrasicolus* (0.974), *S. maena* (0.962) and *P. gattorugine* (0.953) from Yeşilçiçek *etal*. (2015), *P. flesus* (0.975) from Kasapoğlu and Düzgüneş (2014), *P. saltatrix* (0.978) from Ak *et al*. (2009a), *R. clavata* (0.98) from Çalık and Erdoğan Sağlam (2017), *S. rhombus* (0.97) from Demirhan *et al*. (2005a), *S. scriba* (0.9809) from Aydın (2017b)).

In the study, two outliers in *M. barbatus* and one each in *B. belone*, *A. immaculata*, *M. merlangus* and *N. melanostomus* were determined according to the log a vs b plot made to detect and exclude outliers. Gündoğdu *et al*. (2016) determined that *Merluccius merluccius* has two outliers and *Arnoglossus latema*, *Citharus linguatula* and *Raja clavata* have one outlier each. A robust regression analysis of log a over b identifies one outlier and after its removal linear regression explains 99% of the remaining variance. The strong interrelationship between parameters a and b is linearized in a plot of log aover band helps in detecting WLRs that are questionable (Froese, 2006).

The b value of LWR is generally expected to be in the range of 2.5-3.5 for fish (Carlander, 1969), and *b* values can be affected by environmental conditions, sampling season, sampling location, sampling techniques and size composition of samples. High the *b* value (3.75) gave for *A. caspia* by Ergüden *et al*. (2011). It is thought that this may be due to the size composition of the samples (15.0-21.0 cm, 51.00-103.2 g).

Coverage of the full-size range, ideally with the number of specimens being equally distributed among size classes (e.g., 10 small, 10 medium-size, and 10 large specimens), in order to avoid over- or underestimation of *b* (Froese *et al*. 2011).

Within-species variance in weight–length relationships can be substantial, depending on the season, the population, or annual differences in environmental conditions. When discussing within-species variation in weight-length relationships, the focus should be on the variation in the condition that is likely to trigger variation in parameters *a* and *b*, once outliers have been identified. Furthermore, when investigating isometric and allometric growth, it should be discussed whether current length-to-weight studies cover a sufficiently wide seasonal and geographic range to be representative for the species (Froese, 2006).

As a result, this study includes length-weight association parameters of most species prevalent in Turkish coastline of Black Sea between 1989 and 2021 and presents a list of resources for future studies.

CONFLICT OF INTERESTS

The authors decelerate that they have no conflict of interests.

ETHICS COMMITTEE PERMISSION

All applicable international, national, and/or institutional guidelines for the care and use of animals were followed by the authors.

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Investigating the moisture content of flax fibre reinforced composite materials

Keten elyaf takviyeli kompozit malzemelerin nem muhtevalarının incelenmesi

Türk Denizcilik ve Deniz Bilimleri Dergisi Cilt: 8 Sayı: 2 (2022) 161-166

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ABSTRACT

Increasing environmental consciousness, triggered by global climate change awareness, has found a response in the composite material industry and has pushed the industry representatives to search for environmentally friendly alternatives to conventional materials. To reduce the carbon footprint and minimize the damage to nature, the preference for natural fibres instead of synthetic fibres can be considered a step taken in this context. Today, it is possible to see natural fibre applications in many industrial products, including automobile interior parts.
The purpose of using flax fibre in composite materials is not different from conventional fibres, however, their hydrophilic characteristics make flax fibre composites sensitive to temperature and the humidity of the surroundings. This study aims to investigate the moisture content of flax fibre composites as well as their hybrids with E-glass fibres at room temperature by using thermogravimetric analysis (TGA). It is observed that flax fibre samples have a moisture content of 4.9%, while E-glass samples have only a moisture content of 0.5%. The hybrid samples lay between these two values having a moisture content of 2.5%.

Keywords: Flax fibres, Moisture content, Hybrid composites, TGA

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ÖZET

Küresel iklim değişikliği fakındalığının tetiklemesiyle artan çevre duyarlılığı, her sektörde olduğu gibi kompozit malzeme sektöründe de karşılık bulmuş ve sektör temsilcilerini çevreci çözümler araştırmaya itmiştir. Karbon ayak izini düşürmek ve doğaya verilen zararı minimuma indirmek için konvansiyonel malzemeler olan sentetik elyafların yerine doğal elyaflar tercih edilmeye başlanması bu bağlamda atılmış bir adım olarak değerlendirilebilir. Otomobil iç parçalarının da dahil olduğu birçok endüstriyel üründe doğal elyaf uygulamaları görmek mümkündür.
Kompozit malzemelerde keten elyafın kullanılma amacı geleneksel elyaflarda olduğundan farklı değildir; ancak keten elyafların hidrofilik karakteristiği, bu elyafın kompozitlerini sıcaklığa ve çevrenin nemine duyarlı hale getirir. Bu çalışma, termogravimetrik analiz (TGA) kullanarak keten elyaf takviyeli kompozitlerin ve bu elyafların cam elyafla yaptığı hibrit kompozitlerin oda sıcaklığında sahip oldukları nem miktarını araştırmayı amaçlamaktadır. Keten elyaf numunelerin nem muhteviyatları %4.9 olarak bulunurken, bu değer cam elyaf numuneler için %0.5 olarak bulunmuştur. Hibrit numunelerin nem muhteviyatları bu iki değerin arasında %2.5 olarak bulunmuştur.

Anahtar sözcükler: Keten elyaf, Nem oranı, Hibrit kompozitler, TGA

1. INTRODUCTION

Fibre-reinforced composite materials, which allow the production of complex structures thanks to their easy workability, have also become the preferred materials in the maritime field thanks to their high corrosion resistance (Bulut and Erdoğan, 2011). However, the energy consumed to produce synthetic fibres used today, and therefore the amount of CO_2 released to nature has begun to be questioned due to increasing global warming awareness. The energy consumed for the production of one kilogram of the most commonly used fibres today, such as carbon fibre and E-glass fibre, is approximately 500 MJ (Zhang *et al*., 2020) and 54.7 MJ (Joshi *et al*., 2004). In terms of the global warming indicators, the corresponding carbon emissions are 36 and 2.7 CO_2 kg/kg, respectively (Boegler *et al*., 2014).
The fact that natural fibres have been used instead of synthetic fibres in this period of increasing environmental and global warming effects shows that environmental awareness has also found a response in the field of composites. The stems of plants such as flax, jute, ramie, and sisal are processed into fibres and used as reinforcement material in composite materials (Ashori, 2008). Especially in the interior panels of automobiles, where lightweight is required to reduce fuel consumption (Khalfallah *et al*., 2014), the applications of flax and jute fibres are increasing day by day. If the values given for carbon fibre and E-glass fibre are compared with flax fibres, the environmental impact of the situation is illustrated more clearly: The energy required to produce one kilogram of flax fibre is 9.55 MJ (Joshi *et al*., 2004) while the corresponding global warming indicator is -1.4 MJ (Boegler *et al*., 2014). This means that while the flax plant is developing photosynthesis, aside from releasing carbon during respiration, it releases O_2 to nature and captures carbon from the atmosphere.
Switching from synthetic composite materials used in many fields to natural composite materials that are completely environmentally friendly is too optimistic for today (Shah *et al*., 2013; Deka *et al*., 2013). To produce "green" composite materials both the resin and fibre must have such green properties to achieve this goal (Benega *et al*., 2017). However, as of today, natural resins are not able to compete with conventional resins, in terms of mechanical and thermal properties, as well as physical properties, such as viscosity, etc. (Dallons, 2005). Materials based on cashew nut shell liquid hardeners, linseed and soybean oils resin, and UV-cured systems are being developed (Dallons, 2005). However, the best results are found when hybrid systems, comprising synthetic and biobased materials, are used in tandem (Benega *et al*., 2017).
The mechanical properties of flax fibre, which is

one of the most promising natural and sustainable fibres, are lower than the mechanical properties of E-glass fibre, but thanks to their low densities, they can compete with E-glass fibre in terms of specific mechanical properties (Yan *et al*., 2014). However, due to climatic conditions, production processes and environmental factors in which flax fibres are produced, great differences are observed in the mechanical properties of these fibres (Andersons *et al*., 2005). Baley *et al*. (2020) and Blanchard *et al*. (2016) stated that these differences are high at the elementary flax fibre level, but these decrease in the fibre bundle formed by the elementary fibres. Not only the variations that make working with natural fibres hard but also their hydrophilic characteristics, tendency to absorb water. Moudood *et al*. (2019) studied the effect of moisture in flax fibres and its effect on the mechanical properties of their composites. It is reported that humid fabrics lead to poor microstructural quality and deformations on the finished products, such as warpage.

Cheour *et al*. (2016) investigated the effects of moisture absorption on the behaviour of flax/epoxy composites with different fibre orientations. It was stated that the fibre orientation has a significant effect on moisture ingress and the moisture in flax fibres leads to an increase in damping properties.

Lu *et al*. (2022) studied the effect of moisture absorption of both technical and elementary fibres on their flexural properties. It was reported that fibre-matrix debonding occurs when flax fibres swell due to moisture.

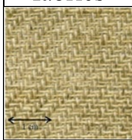
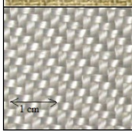
Assaedi *et al*. (2015) studied the thermal behaviour of flax reinforced composite materials by TGA. The degradation of flax fibres was observed in three stages: evaporating of the water absorbed by the fibre, between the temperature of 25 ^{0}C and 250 ^{0}C, decomposition of cellulose between 240 ^{0}C to 365 ^{0}C, and flax fibres decomposition above the temperature of 365 ^{0}C. However, the moisture content of the samples has not been the scope of the study.

The effect of moisture content on mechanical and damping properties of flax fibre composites has been studied by several researchers but the moisture content of flax fibre composites and their hybrids with E-glass fibres have not been studied. This study aims to investigate the moisture content of flax fibre composites and their hybrids with E-glass fibres by employing TGA. To compare the moisture contents, the moisture content of E-glass fibre composites was also studied.

2. MATERIALS AND METHOD

E-glass and flax fibres with different areal weights were used to ensure that the samples were of approximately the same thickness. The physical properties of the fibres used are given in Table 1 (Cihan *et al*., 2019). Gurit Prime 20V epoxy resin and Gurit FAST hardener were used for the composite manufacturing.

Table 1. Physical properties of the fabrics utilized.

Woven fabrics	Fibre type and weave	Areal weight (g/m^2)	Fibre diameter (μm)	Thickness (mm)
	Flax, 2x2	283	23	0.32
	E-glass, 2x2	590	19	0.56

2.1. Sample production

Six-layer symmetrical composite laminates with three different configurations namely, $[G_2F]_s$, $[FGF]_s$ and $[F_3]_s$ were produced by vacuum-assisted resin infusion technique (E denotes E-glass fibres and F denotes flax fibres). This method minimizes the amount of air that can enter the composite material, allowing materials with higher mechanical properties to be obtained than materials produced by the hand lay-up method (Yuhazri and Sihombing, 2010).

The produced laminates were left to cure at laboratory temperature (20 ^{0}C) for 24 hours. After this process, the laminates were post-cured for 7 hours in an oven at 65 ^{0}C to increase the mechanical properties and environmental resistance of the laminates. Then, samples were prepared by grating the laminates into small particles in a ceramic vessel. Each vessel contains about 10 mg of grated laminate particles.

2.2. Thermogravimetric analysis

The TGA is performed over a temperature range of 25-800 ^{0}C with a heating rate of 10 ^{0}C /min under a nitrogen atmosphere. The relationship between the residual weight and temperature is plotted for the $[G_3]_s$ and $[F_3]_s$ samples, and the $[G_2F]_s$ layup is tested to find out whether there is a distinct behaviour for the three components. Upon increasing the temperature, moisture in the samples is first evaporated producing information on how much moisture is present in the sample.

3. FINDINGS AND DISCUSSION

Thermo Gravimetric Analysis (TGA) approach provides information on the changes in physical and chemical properties of materials that are measured as a function of constantly elevating temperature. As well as information on the decomposition temperature of components of the composites, which in turn, indicates the fibre volume content of the composite materials, given each constituent has a distinct decomposition temperature and there is enough equipment resolution. Along with information on decomposition temperatures, the TGA also provides information on the moisture content of the composite materials. It can also show the evaporation of other solvents when involved.

The $[G_3]_s$ samples have a moisture content of 0.5% as shown in Figure 1. The epoxy in the samples starts to decompose near 300 ºC and it continues until all the epoxy resin burns out, leaving the unburned fibres and epoxy ash to be weighted. These values are used to determine the component content of the constituents. This approach applies to the $[G_3]_s$ layup laminates as epoxy resin and E-glass fibres have different decomposition temperatures.

Moisture is the first constituent that is subtracted from the composite samples with the increasing temperature as the moisture in the composite is in a weak bond or free state (Assaedi *et al.*, 2015).

The decomposition of epoxy resin occurred between the range of 300 - 400 ^{0}C whereas no decomposition of E-glass fibres is observed between the range of 0 - 800 ^{0}C, as shown in Figure 1. E-glass fibre volume fraction for $[G_3]_s$ layup can then be calculated after removing the remaining ash residue of the epoxy.

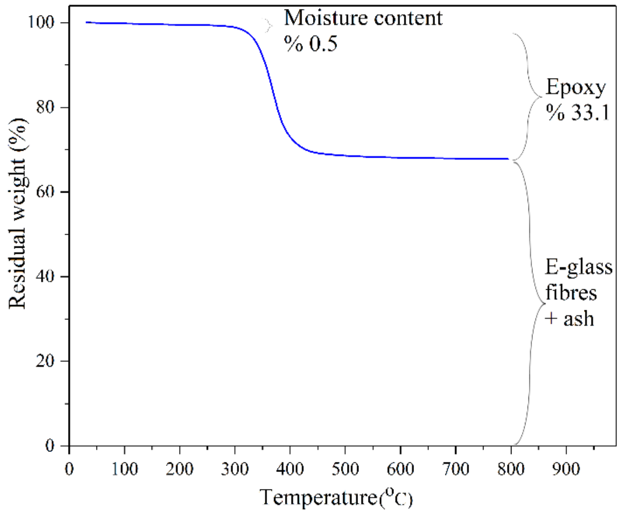


Figure 1. Residual weight vs. Temperature plot of $[G_3]_s$ samples generated by the TGA.

The moisture content of $[G_2F]_s$ was 2.5%, as shown in Figure 2. It was impossible to determine the decomposition temperature of epoxy resin and flax fibres with the parameters used. There is no distinct decomposition behaviour observed in the curve that renders the determination of the flax fibre content.

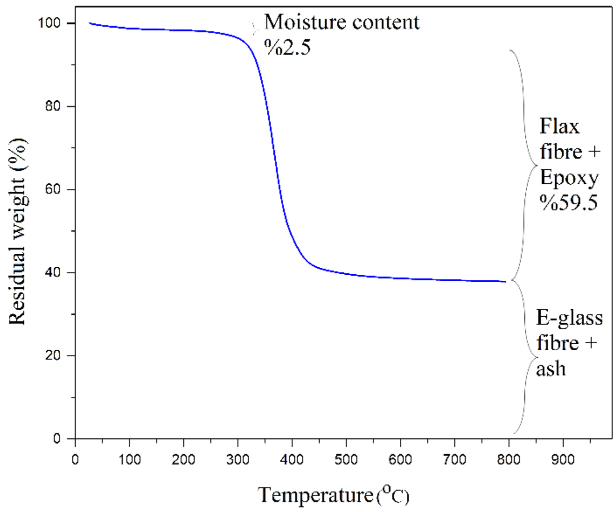


Figure 2. Residual weight vs. Temperature plot of $[G_2F]_s$ samples generated by the TGA.

In Figure 3, the first significant reduction in the weight is observed between 80-120 ^{0}C, where water in the sample evaporates. This stage is followed by the degradation of the epoxy resin and flax fibres between the temperature of 300-400 ^{0}C. After about 500 ^{0}C, the curve flattens out, no constituent left to be burnt out. The remaining is the ash of the epoxy resin and the flax fibres.

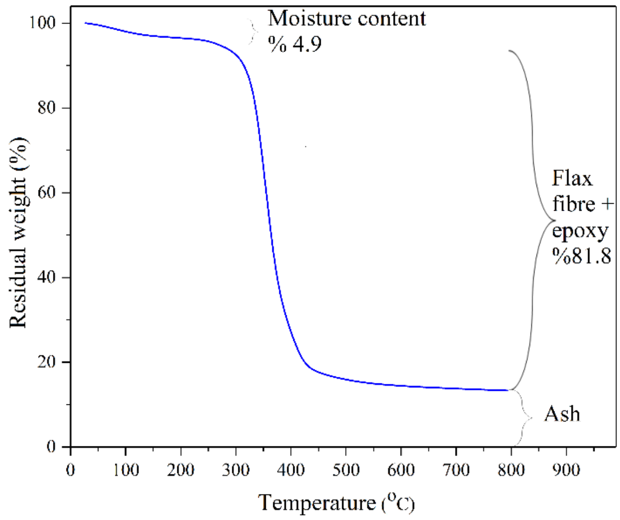


Figure 3. Residual weight vs. Temperature plot of $[F_3]_s$ samples generated by the TGA.

The moisture content grows as the flax fibre content increases as shown in Table 2.

Table 2. Mean moisture content of the samples.

	$[G_3]_s$	$[G_2F]_s$	$[F_3]_s$
Moisture Content (%)	0.5	2.5	4.9

This behaviour can be attributed to hydrophilic characteristics of flax fibres that cause degradation in the mechanical properties, causing stress at the fibre/matrix interface region resulting in weak matrix/fibre interfaces (Azwa *et al*., 2013).

4. CONCLUSION

TGA results show that the moisture content increases as the flax fibre volume fraction of the laminates increases. Since the moisture content has a significant effect not only on the mechanical properties but also on the damping properties, the moisture content of the samples needs to be determined and taken into account for a reliable reading. By this means, the interpretation of the experimental results will be more reliable. For further work, slower heating ramps may be employed to increase the graph resolution and to indicate distinct decomposition temperatures.

AUTHORSHIP CONTRIBUTION STATEMENT

Mehmet CİHAN: Conceptualization, Methodology, Validation, Formal Analysis, Resources, Writing - Original Draft, Writing-Review and Editing, Data Curation, Visualization. **Marcos Antonio Gimenes BENEGA:** Review and Editing, Data Curation, Visualization, Methodology, Validation, Formal Analysis. **Hélio RIBEIRO:** Review and Editing, Data Formal Analysis.

CONFLICT OF INTEREST

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

ETHICS COMMITTEE PERMISSION

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