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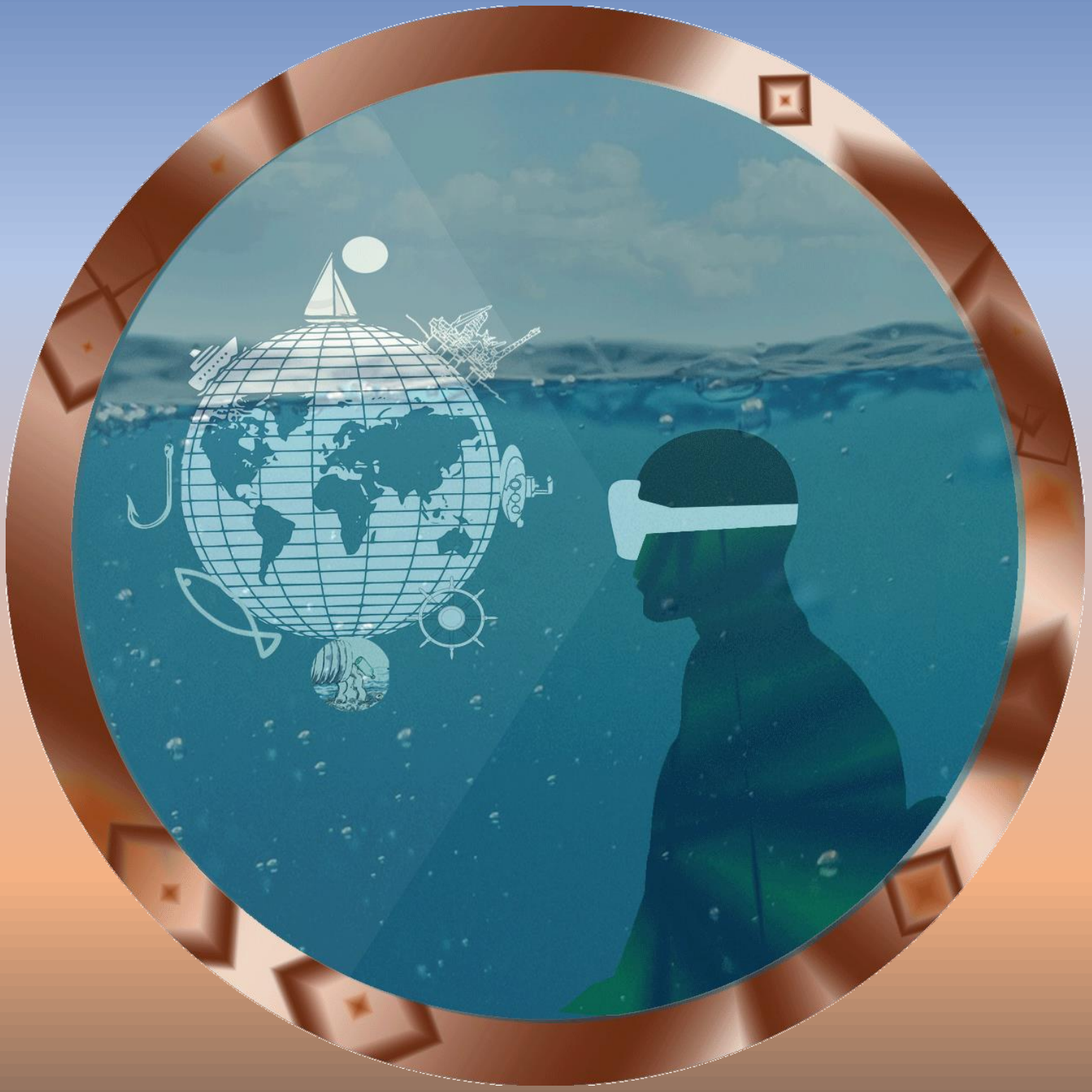
Marine and Life Sciences



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Hampton, S., Rabagliati, H., Sorace, A., & Fletcher-Watson, S. (2017). *Autism and bilingualism: A qualitative interview study of parents' perspectives and experiences*. PsyArXiv, *Preprint*. https://doi.org/10.31234/osf.io/76xfs

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Vassallo, A. I., & Mora, M. S. (2007). Interspecific scaling and ontogenetic growth patterns of the skull in living and fossil ctenomyid and octodontid rodents (Caviomorpha: Octodontoidea). In Kelt, D. A., Lessa, E., Salazar-Bravo, J. A., & Patton, J. L. (Eds.), *The Quintessential Naturalist: Honoring the Life and Legacy of Oliver P. Pearson* (pp. 945-968). 1st ed. University of California Press.

Thesis and Dissertation:

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Şimşek, E. (2018). Analysis of the factors affecting the discard fate for trawl fishery [Ph. D. Thesis, Iskenderun Technical University] (in Turkish).

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While the peer-reviewed journal literature should be accessible online without cost to readers, it is not costless to produce. However, experiments show that the overall costs of providing open access to this literature are far lower than the costs of traditional forms of dissemination. With such an opportunity to save money and expand the scope of dissemination at the same time, there is today a strong incentive for professional associations, universities, libraries, foundations, and others to embrace open access as a means of advancing their missions. Achieving open access will require new cost recovery models and financing mechanisms, but the significantly lower overall cost of dissemination is a reason to be confident that the goal is attainable and not merely preferable or utopian.

To achieve open access to scholarly journal literature, we recommend two complementary strategies.

I. Self-Archiving: First, scholars need the tools and assistance to deposit their refereed journal articles in open electronic archives, a practice commonly called, self-archiving. When these archives conform to standards created by the Open Archives Initiative, then search engines and other tools can treat the separate archives as one. Users then need not know which archives exist or where they are located in order to find and make use of their contents.

II. Open-access Journals: Second, scholars need the means to launch a new generation of journals committed to open access, and to help existing journals that elect to make the transition to open access. Because journal articles should be disseminated as widely as possible, these new journals will no longer invoke copyright to restrict access to and use of the material they publish. Instead, they will use copyright and other tools to ensure permanent open access to all the articles they publish. Because the price is a barrier to access, these new journals will not charge subscription or access fees and will turn to other methods for covering their expenses. There are many alternative sources of funds for this purpose, including the foundations and governments that fund research, the universities and laboratories that employ researchers,

endowments set up by discipline or institution, friends of the cause of open access, profits from the sale of add-ons to the basic texts, funds freed up by the demise or cancellation of journals charging traditional subscription or access fees, or even contributions from the researchers themselves. There is no need to favor one of these solutions over the others for all disciplines or nations, and no need to stop looking for other, creative alternatives.

Open access to peer-reviewed journal literature is the goal. Self-archiving (I.) and a new generation of open-access journals (II.) are the ways to attain this goal. They are not only direct and effective means to this end, but they are also within the reach of scholars themselves, immediately, and need not wait on changes brought about by markets or legislation. While we endorse the two strategies just outlined, we also encourage experimentation with further ways to make the transition from the present methods of dissemination to open access. Flexibility, experimentation, and adaptation to local circumstances are the best ways to assure that progress in diverse settings will be rapid, secure, and long-lived.

The Open Society Institute, the foundation network founded by philanthropist George Soros, is committed to providing initial help and funding to realize this goal. It will use its resources and influence to extend and promote institutional self-archiving, to launch new open-access journals, and to help an open-access journal system become economically self-sustaining. While the Open Society Institute's commitment and resources are substantial, this initiative is very much in need of other organizations to lend their effort and resources.

We invite governments, universities, libraries, journal editors, publishers, foundations, learned societies, professional associations, and individual scholars who share our vision to join us in the task of removing the barriers to open access and building a future in which research and education in every part of the world are that much more free to flourish.

For various reasons, this kind of free and unrestricted online availability, which we will call open access, has so far been limited to small portions of the journal literature. But even in these limited collections, many different initiatives have shown that open access is economically feasible, that it gives readers extraordinary power to find and make use of relevant literature, and that it gives authors and their works vast and measurable new visibility, readership, and impact. To secure these benefits for all, we call on all interested institutions and individuals to help open up access to the rest of this literature and remove the barriers, especially the price barriers, that stand in the way. The more who join the effort to advance this cause, the sooner we will all enjoy the benefits of open access.

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Measuring the performance of container terminals using data envelopment analysis; A case study from Iskenderun Bay

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A B S T R A C T

In developing and growing economies, the greatest need is for raw materials. Additionally, facilitating the delivery of the materials which are used for production and those produced for consumption to end users is of great importance. Sea transport and container shipping are the most widely used methods in the execution of these activities. In this study, the aim is to determine to what extent the increasing international logistics needs in the container shipping sector can be met through the container terminals in the İskenderun Bay, and which measures has need to analyse to enhance the performance of these terminals. Data Envelopment Analysis (DEA) method was used to determine the relative efficiency of container terminals, which is a non-parametric method. The input values and output values of the decision units (container terminals) identified within the scope of the study for the last five years were obtained, and their efficiency during this period was examined. In the analysis, the input variables considered were quay length, container storage area, number of berth cranes, the amount of ship berths, the amount of container handling equipment, while the output variable was the handled container quantity. Efficiency measurements were obtained using Data Envelopment Analysis, CCR, BCC input and output-oriented results were obtained. A comparison of efficiency among the evaluated container terminals was made within the scope of the study, and recommendations were provided for the enhancement of inefficient decision-making units.

INTRODUCTION

Following the significant changes in the world economy after the 1970s due to globalization, the amount of imports and exports in international trade has shown a significant increase. Transportation plays an important role in the rising foreign trade activities. Transportation involves the process of moving people or goods from one place to another. Alternatively, it can be defined as the movement of goods and services from their place of production to their place of consumption through various transportation methods. Among the transportation systems used today, maritime transportation has the largest share. Approximately 80% of global trade and 90% of Türkiye's imports and exports are carried out by sea (Topaloğlu, 2007). Moreover, the level of development in maritime trade has averaged 3.1% over the past 30 years (UNCTAD, 2009). The advantages of sea transportation include its relative safety compared to other methods, speed and practicality considering the level of goods transported, and economic efficiency due to the ability to transport large quantities at once. These advantages are the main reasons why sea transportation is preferred over other types. As a result, the maritime industry has experienced high growth rates along with the growth of world trade.

Technological advancements in the maritime field have played a critical role in the rise of global trade. These can be explained as increases in ship capacity, developments in handling methods, and advances in information and

communication technologies (Chlomodis and Pallis, 2002). These developments have facilitated transportation activities over long distances. To keep pace with the development in the global maritime sector and progress in proportion to these developments is a necessity for the continuation of the presence of countries and enterprises in maritime transportation.

Among the three main elements of maritime transportation-cargo, port, and ship-port efficiency can be considered the most influential on effectiveness/productivity. Initially defined as the place where the sea and land meet, ports were later seen as industrial and commercial centers, and today they serve as logistics bases. Ports have now become intermodal connection points in commercial competitions within the international supply chain (Esmer, 2010).

Ports can be defined as places where the mode of transportation changes. Despite being defined in many different ways in the literature, ports can be broadly described as open or closed areas and facilities providing physical spaces where ships can take refuge in adverse weather conditions, carry out loading-unloading operations, and embark and disembark passengers. They are established to provide infrastructure for these services, have the necessary units and organizations for inspection operations, are economically significant factors, serve as a transition mechanism between transportation methods, and enable the transfer between ship-to-ship, ship-to-land, and land-to-ship (Alkan and İncaz, 2003). In addition to being the fundamental element of maritime practices, ports contribute valuable benefits to the development of their location, the economy, and national defense. However, for ports' contributions to have a beneficial effect, efficient use and management of the port are necessary. The increase in port efficiency can be achieved not only by using technology but also by timely applying or developing new technologies.

In the maritime sector, point-to-point transportation has replaced port-to-port transportation, which was dominant until the 1960s. The system that enabled point-to-point transportation is container transportation. The increasing value of containerization has been an important factor in the development of ports (Beresford et al., 2004). Subsequently, technological changes in loading and unloading methods have strengthened the relationship between ports and their hinterlands. It can be said that the service area and infrastructure of ports have changed according to the requirements of international transportation (Teilet, 2006).

Terminals are specialized sections of ports for handling a specific type of cargo. Container terminals are places where cargo transfer is carried out between sea, land, and rail. In international container traffic, intermodal transportation, which is based on door-to-door transportation, is an essential mode. This mode of transportation involves a land or rail segment at both ends, in addition to the sea segment. Nowadays, ports tend to focus on a specific type of terminal. Therefore, ports generally operate through a single type of terminal. This enables ports to provide more reliable and faster services. The main goal of ports is to complete cargo handling in the healthiest and shortest way possible and to offer all other services to their customers without any issues. Thus, it is important to specialize in one or a few types of cargo (Bayar, 2005).

Container terminals are areas where container movements are carried out from land or rail to ship or vice versa, and container handling services are provided (Dowd and Leschine, 1990), Terminals play a crucial role in container transportation. They are connection points between sender and carrier systems. Terminals perform various functions to facilitate cargo movement. All transport modes use terminals. Terminals can be any point where mode changes, value-added activities, or both are performed, and where cargo is stopped or paused (UNCTAD, 2004). Containers arrive at the port by land or sea. They are handled by equipment on the port site and transferred to another ship, land, or rail. Container terminals are used to load and unload containers onto and from ships, temporarily store them, and deliver them from carrier to consignee or from sender to consignee (Ateş et al., 2010).

In today's container transportation by sea, there are three main routes. The most active and busiest of these routes, based on the preferences of regional operators and the development of container infrastructure in ports, is the Transpacific route (Kozanhan, 2008). Considering the Turkish maritime sector, the use of the Turkish Straits in maritime trade with countries bordering the Black Sea, Türkiye's geopolitical position in the Mediterranean, and its wide hinterland (Caucasus, Middle East, and Balkans) highlight Türkiye among many countries. The reasons for Türkiye lagging behind the world average in the maritime sector are attributed to the inability to effectively and efficiently use its geographical position and failure to adapt to developing technology.

Performance measurement in the port industry is done by evaluating changes in the port using multiple indicators (Ashar, 1997). Since ports are primary service providers for ships and cargo, it is evident that their performance cannot be evaluated with a single parameter. However, careful consideration should be given to which parameters to use in performance measurements using more indicators.

Data Envelopment Analysis (DEA) has been the most used method for port performance measurement in recent periods. DEA is a non-parametric method that allows comparison between enterprises using selected parameters and provides a way to compare the efficiencies of the enterprises being evaluated. Before conducting the analysis, it is necessary to know the details of the enterprises to be compared and ensure that the data to be evaluated is used for similar purposes. This method can be applied to many sectors such as insurance companies, agriculture, banks, schools, hospitals, fisheries, and ports. The efficiency analysis using DEA provides results based on the common input and output values used in the evaluation. Thus, it is relative. To accurately calculate efficiency in ports, it is essential to correctly determine the input and output units in the ports. Otherwise, the efficiency scores obtained from the port analysis may not be accurate (Ateş, 2010).

In the transportation sector, ports must evaluate their current status, identify underutilized resources, and take necessary measures to resolve inefficiencies to compete with other ports. Optimal use of resources is especially necessary in ports. In this context, the effectiveness of operations carried out at the port and the efficient use of resources are important. Developments in logistics have rapidly transformed both container transportation and port operations. These developments aim to ensure that the right product reaches the right place at the right time for the right price worldwide. As a result of this process, global logistics service providers have emerged over the past twenty years. The primary goal of these providers is to increase customer satisfaction. Reliable partnerships in the fields of distribution and transportation are crucial to achieving this goal (De Monie et al., 1998; Notteboom, 2004).

Iskenderun Bay has historically been an important trade center as a gateway for trade with Iran and India. Today, this region stands out with its ports in the Iskenderun Bay, which are the closest terminals to delivering expected increases in production in irrigation, agriculture, livestock, cold storage, packaging, food, and machinery industries to the Middle East and other countries. Factors such as the water issues in the Middle East, the Southeastern Anatolia Project, the Adana plains, the Adana-Yumurtalık free zone, the transfer of Azerbaijani and Caucasian oil to the Iskenderun Bay through pipelines, and the iron-steel industry increase the importance of the region today. It can be evaluated that the ports in the Iskenderun Bay and its surroundings have the widest hinterland both nationally and internationally in our country. Therefore, the facilities built and planned in the Iskenderun Bay, their economic positions, functions, external relations, and interactions with each other gain great importance (Alpar, 2001).

The aim of this study is to examine the efficiency level of container terminals in the Iskenderun Bay and to investigate the reasons affecting the efficiency of terminals that are not efficient.

MATERIALS AND METHODS

Study area

This study was conducted in the Iskenderun Bay, which, with an area of 2272 km², is located at the Northeastern Mediterranean Sea, the largest inland sea in the world (Figure 1). Iskenderun Bay is situated between 36° 19'–36° 55' N latitudes and 035° 33'–036° 12' E longitudes. Iskenderun Bay lies between the provinces of Adana and Hatay. The region is of high commercial importance in terms of sectors such as fishing, maritime logistics, tourism etc. (Can et al.,2020; Demirci et al., 2020; Demirhan et al., 2020; Akar et al., 2022; Yılmaz et al., 2022). Being developed in terms of both land and sea transportation, Iskenderun Bay is named after the Iskenderun district of Hatay. The Port of Iskenderun is the third largest port on the Mediterranean coast of Türkiye (Pachakis et al., 2013). Due to the attack on the Port of Beirut and the events in the Middle East, the Iskenderun Bay has gained more value and importance.

Figure 1. The location of the Iskenderun Bay within the Mediterranean

Within the boundaries of the Iskenderun Bay, there are two container ports: Limak Port located in the center of Iskenderun district and Assan Port located in the Sarıseki neighborhood of Iskenderun. Basic information about Limak and ASSAN container ports is provided below.

Assan Port

Assan Port is located at the easternmost tip of the Iskenderun Bay at 36°41'06"N, 36°11'40"E, in the Sarıseki neighborhood of Iskenderun district. Established in June 2010 by Assan Liman İşletmeleri A.Ş., a subsidiary of Kibar Group, in the Iskenderun Organized Industrial Zone, Assan Port has become one of the container terminals serving modern container ships within the Iskenderun Bay. Serving the same hinterland as Mersin, Assan Port Iskenderun operates as a second and very important alternative in the region. Assan Port continues its operations with the partnership of Terminal Investment Limited SA (TIL) since

2013. Assan Port's capacity is 250,000 TEU annually, and it provides services to "Container, General Cargo, Project Cargo, and Dry Bulk Cargo Ships" (Table 1). Geographically, Assan Port Iskenderun offers advantages to companies in the Eastern Mediterranean, Southeastern Anatolia, and the southern part of Central Anatolia; it is also the closest container terminal opening westward for Northern Syria and Iraq (Kibar, 2024).

Table 1. Assan Port Terminal Features (Kibar, 2024)

Port Characteristics	Specifications
Berthing Area	2 x 340 m
Depth	16 m - 19 m
Serviced Ship Types	Panamax, Post Panamax, Super Post Panamax, 350m LOA, 15.5 Draft
Capacity (Container)	250000 TEU/year
Capacity (General Cargo)	1700000 Tons/year
Duty-Free Zone - Total Area	47850 m²
Vehicle Parking Area	5000 m
Customs Zone - Pier Width	45 m
Customs Zone - Customs Area Outside Pier	80,434 m²
CFS Area	1600 m²
Closed Warehouse and Closed Area	1900 m²
Reefer Plug	288
IMCO Area	84 TEU

Limak Port

Limak Port is located at the southeastern tip of the Iskenderun Bay at 36°35′43″N, 36°11′22″E, in the Çay neighborhood of Iskenderun district. Historically significant, Limak Port (formerly known as Iskenderun TCDD Port) was transferred to Limak Port A.Ş. for 36 years on December 30, 2011, following the Privatization High Council's decision dated December 30, 2004, and numbered 2004/128. Following the transfer, Limak Port A. Ş. undertook extensive renovations to transform Iskenderun Port into a modern container port. Quay structures, storage areas, roads, port entrances and exits, warehouses, and all buildings were renovated or rebuilt, and the quay and terminal cranes were updated. Dredging operations enabled ships with a draft of up to 14.50 – 15.00 meters to berth. The port continues its operations under the name Limak Iskenderun International Port Management A.Ş. With a capacity of over 1 million TEU containers, LimakPort Iskenderun is one of the largest container ports in the Eastern Mediterranean region. Since its transfer to Limak Port A.Ş., container operations began in March 2013, and cargo volumes have significantly increased each year. LimakPort Iskenderun connects directly and via transshipment to many ports worldwide with mainline and feeder vessels (Limakport, 2024).

The port operates over an area of 1 million square meters, featuring long quay structures, a fully protective breakwater, and deep-water port characteristics. LimakPort, equipped with modern container handling equipment specifically designed for the port, including STS and RTG cranes, is container-focused. With comprehensive and multi-faceted investments, it has become the region's most important port for Ro-ro, Ro-pax, project cargo, bulk cargo, general cargo, and live animal cargo operations (Table 2).

Table 2. Limak Port Terminal Features (Limakport, 2024)

Port Characteristics	Specifications
Port Technical Features	1000000 m²
Port Area	8
Number of Quays	15.5 m
Container Quay Depth	732 m
General Cargo Quay Length	920 m
Container Quay Length	600
Reefer Plug	1000000 TEU / Year
Container Capacity	3247000 Tons / Year
Conventional Cargo Capacity (Bulk Cargo, General Cargo, Project Cargo)	120000 Vecihle / Year
Ro-Ro Capacity	30000 Truck / Year

Methodology

The purpose of this application is to calculate and compare the relative efficiency of container terminals operating in the Iskenderun Bay and to provide guidance for making inefficient terminals efficient by evaluating their performance. The goal is to optimize the use of existing resources at the terminals based on the findings obtained from the analysis. Additionally, efforts to improve container terminal efficiency and performance in the Iskenderun Bay will be examined.

In this study, the "Open Source DEA" software program was utilized to determine the efficiency levels of container terminals in the Iskenderun Bay. Data envelopment analysis was applied to container terminals in the Iskenderun Bay as part of the research. The method included a five-year period, and input-output changes were observed annually during this period.

Although the scope of this study involves analyzing the efficiency of container terminals operating in the Iskenderun Bay, due to the limitation of decision-making units [m+p+1=7 is required, but we only have 2 (Assan and Limak ports)], the efficiency evaluation will only cover Assan and Limak container terminals. Additionally, M.I.P. Port, Q Terminals Antalya Port, TCDD Izmir Alsancak Port, Nemport Port, Bandırma Çelebi Port, and Gemport Port container terminals, which are not located in the Iskenderun Bay but ensure homogeneous distribution in the analysis, closest container terminals to Iskenderun Bay operating in Türkiye were included. Statistical data for the years 2018, 2019, 2020, 2021, and 2022 were used, and the data envelopment analysis was conducted.

Statistical data for M.I.P. Port, Q Terminals Antalya Port, TCDD Izmir Alsancak Port, Nemport Port, Bandırma Çelebi

Port, and Gemport Port container terminals were obtained from the annual sector reports of the Turkish Port Operators Association (TÜRKLİM) and the websites of these ports. These statistical data were used solely to yield effective results from the analysis. Since the comments are based on the research results, the evaluations are only valid for the ports included in the study's sample.

Data Envelopment Analysis

In data envelopment analysis models, the objective is to maximize or minimize a function with certain constraints. In linear programming, where the efficient use of resources is desired, it is assumed that all coefficients related to the model are known, there is proportionality in the function and constraints, outputs and inputs are independent of each other, the results do not need to be integers, and the variables are positive (Ünsal et al., 2000). To measure the performance of container terminals operating in the Iskenderun Bay, both input-oriented and output-oriented CCR (CRS – Constant Returns to Scale) and BCC (VRS-Variable Returns to Scale) models were applied using the input and output variables with the Open Source DEA program.

CCR Model

The CCR model was developed by Charnes, Cooper, and Rhodes in 1978. In the CCR model, the ratio of output to input is determined by weights. The CCR model, which is based on the assumption of constant returns to scale, can be either input-oriented or output-oriented. Models can be established to minimize inputs while providing the same output quantity. These types of models are called input-oriented models. Models aiming to maximize output using the same level of input are called output-oriented models (Zerey, 2010).

Input-Oriented CCR Model

The Input-Oriented CCR Model investigates how much the input quantity should be reduced without changing the output level. In the input-oriented CCR model:

h_j is the efficiency score,

$h_j = 1$ and if the residuals are zero, this decision-making unit is efficient.

$h_j < 1$ means this decision-making unit is inefficient.

Objective Function:

$$Enb\ h_j = \sum_{r=1}^{n} u_r\ y_r \qquad (1)$$

Restrictions:

$$\sum_{i=1}^{m} v_i\ x_i = 1$$
$$\sum_{r=1}^{n} u_r\ y_r - \sum_{i=1}^{m} v_i\ x_i \leq 0$$
$$u_r, v_i \geq 0$$

In this formula, "hj" is the efficiency ratio of the j-th decision-making unit. The objective function in the model is to maximize the weighted average of the outputs. In the first equality, the weighted average of the inputs of the decision unit of interest is set equal to "1." Thus, the weighted average of the inputs is "1" for each decision unit. The constraint in the second equality ensures that the weighted average of the outputs is less than or equal to the weighted average of the inputs. Consequently, the OUTPUT / INPUT ratio can be at most "1" for each decision unit. For decision-making units that are inefficient, i.e., below the efficiency frontier, the weighted average of the outputs, or the efficiency ratio, will be less than "1" (Örkçü, 2004).

Output-Oriented CCR Model

The Output-Oriented CCR Model investigates how much the output quantity should be increased without changing the input quantity. The difference between the Output-Oriented CCR Model and the Input-Oriented CCR Model is that the ratio of weighted input to weighted output is minimized in the output-oriented model. In the output-oriented CCR model (Örkçü, 2004):

g_j is the efficiency score,

$g_j = 1$ and if the residuals are zero, this decision-making unit is efficient.

$g_j > 1$ means this decision-making unit is inefficient.

Objective Function:

$$Enb\ g_j = \sum_{i=1}^{m} v_i\ x_i \qquad (2)$$

Restrictions:

$$\sum_{r=1}^{n} u_r\ y_r = 1$$
$$-\sum_{r=1}^{n} u_r\ y_r + \sum_{i=1}^{m} v_i\ x_i \geq 0$$
$$u_r, v_i \geq 0$$

Here, g_j is the inefficiency ratio of the j-th decision-making unit.

BCC Model

The BCC model, is a technique developed by Banker, Charnes, and Cooper in 1984, and it is named after their initials. The fundamental difference between the BCC and CCR models is that the BCC model's Variable Returns to Scale (VRS) models are constrained by the intensity vector (λ), where the sum of the decision variables equals 1. This constraint removes the necessity for decision-making units in the CCR model to be scale-efficient. As a result, BCC models measure only technical efficiency for each decision-making unit under the VRS assumption. For a decision-making unit

to be CCR efficient, it must be both technically and scale-efficient, whereas for it to be BCC efficient, it only needs to be technically efficient. Therefore, while the CCR model measures total efficiency under constant returns to scale, the BCC model measures technical efficiency under variable returns to scale (Bowlin, 1998).

Input-Oriented BCC Model

The input-oriented BCC model is the BCC model that investigates the minimum amount of input needed to achieve the same amount of output. In the input-oriented BCC model, θ^* is the efficiency score;

θ^* =1 and if the residuals are zero, this decision-making unit is efficient.
θ^* <1 means this decision-making unit is inefficient.

Objective Function:

$$Enk\ \theta_k \tag{3}$$

Restrictions:

$$\sum_{j=1}^{t} \lambda_{jk} = 1$$

$$\theta_k x_{rk} - \sum_{j=1}^{t} \lambda_{jk}\, x_{rj} \geq 0$$

$$\sum_{j=1}^{t} \lambda_{jk}\, y_{ij} \geq y_{ik}$$

$$\lambda_{jk} \geq 0$$

Here, θ_k is the efficiency ratio of the k-th decision-making unit (Erpolat, 2011).

Output-Oriented BCC Model

The output-oriented BCC model is the BCC model that investigates the maximum output level achievable using the same amount of input. In the output-oriented BCC model, ω_k is the efficiency score;

ω_k = 1 and if the residuals are zero, this decision-making unit is efficient.
ω_k > 1 means this decision-making unit is inefficient.

Objective Function:

$$Enb\ \omega_k \tag{4}$$

Restrictions:

$$\sum_{j=1}^{t} \gamma_{jk} = 1$$

$$\omega_k y_{ik} - \sum_{j=1}^{t} \gamma_{jk}\, y_{ij} \leq 0$$

$$\sum_{j=1}^{t} \gamma_{jk}\, x_{rj} \leq x_{rk}$$

$$\gamma_{jk} \geq 0$$

Here, ωk is the inefficiency ratio of the k-th decision-making unit (Erpolat, 2011).

RESULTS AND DISCUSSION

Variables affecting terminal efficiency in container terminals have been largely identified as a result of studies in the literature. Although there are various perspectives, the general view is that the input variables such as quay length, terminal area (storage area), and the number or capacity of cranes (mobile cranes or large port cranes) used for container handling are the most important factors affecting the efficiency of container terminals. If a single output variable is to be used, the amount of containers handled (TEU) can be used as the output variable (Notteboom, 2004; Ateş, 2010)

In this study, the efficiency of container terminals was calculated. Five input variables and one output variable, which are necessary for the topic, were utilized. These variables are quay length (m), number of cranes at the terminal (units), container storage area (m²), number of berths (units), and number of container stacking vehicles (units) as input values. The amount of containers handled (TEU) was used as the output value.

Table 3. Quay lengths of container terminals

Port	2018	2019	2020	2021	2022
Assan Port	720	720	720	720	720
Limak Port	1170	1170	1170	1170	1170
MIP Port	3370	3370	3370	3370	3370
Q Terminals Antalya	1117	1117	1117	1117	1178
TCDD İzmir Alsancak	1414	1414	1414	1414	1414
Nemport	1080	1080	1080	1080	1689
Bandırma Çelebi	2973	2973	2973	2973	2973
Gemport	2040	2040	2040	2050	2050

It can be said that quay length is the most important input variable that can be used in measuring the efficiency of container terminals. A container quay is a structure that allows container ships to load and unload safely at ports using cargo handling systems, providing a connection between land and sea vehicles. Therefore, it is an important criterion when measuring efficiency. The data on the quay lengths of the container terminals included in the analysis are presented in Table 3.

Cranes

Cranes are the main equipment affecting the cargo handling capacity of container terminals. Therefore, they have been used as an input value in the study. The number of cranes examined includes the total of gantry cranes and mobile cranes used for container handling. The data on the number of container cranes at the container terminals included in the analysis are presented in Table 4.

Table 4. Number of container cranes

Port	2018	2019	2020	2021	2022
Assan Port	4	4	4	4	4
Limak Port	20	20	20	20	20
MIP Port	17	17	17	17	17
Q Terminals Antalya	6	6	6	6	8
TCDD İzmir Alsancak	12	12	12	8	8
Nemport	7	7	7	7	10
Bandırma Çelebi	9	9	9	9	9
Gemport	10	10	10	14	14

Container Storage Area

These are areas where containers for import and export products are temporarily stored until the ship arrives or the products are delivered to their owners by other means of transportation. The container storage area is one of the parameters that significantly affects port efficiency. The data on the container storage areas of the container terminals included in the analysis are presented in Table 5.

Table 5. Container storage areas

Port	2018	2019	2020	2021	2022
Assan Port	225.000	225.000	225.000	225.000	225.000
Limak Port	400.000	400.000	400.000	400.000	400.000
MIP Port	1253.355	1253.355	1253.355	1253.355	1253.355
Q Terminals Antalya	201.125	201.125	201.125	200.141	203.920
TCDD İzmir Alsancak	221.000	221.000	221.000	221.000	221.000
Nemport	100.000	100,000	100.000	100.000	240.000
Bandırma Çelebi	268.348	268.348	268.348	268.348	268.348
Gemport	868.000	868.000	868.000	1250.000	1250.000

Number of Berths

One of the primary goals of container ship operators, as with all ships, is to minimize the time a vessel spends in port. This idea is also a fundamental goal for port operators. Depending on the number of berths, multiple ships can operate simultaneously. Additionally, as the number of berths increases, the number of cranes and personnel will also increase. Therefore, the number of berths is an essential factor in the efficiency of a container terminal. The number of berths at the container terminals evaluated in the analysis is presented in Table 6.

Table 6. Number of berths at evaluated container terminals (units)

Port	2018	2019	2020	2021	2022
Assan Port	4	4	4	4	4
Limak Port	8	8	8	8	8
MIP Port	21	21	21	21	21
Q Terminals Antalya	8	8	8	8	9
TCDD Izmir Alsancak	9	9	9	9	9
Nemport	4	4	4	4	6
Bandırma Çelebi	12	12	12	12	12
Gemport	10	10	10	10	10

Number of Stacking Vehicles

The capacity and quantity of equipment used in both transporting and stacking containers on-site are considered crucial factors affecting the efficiency of a container terminal. Stacking equipment is essential in ports with a high number of incoming ships, large capacity and area, significant performance requirements, and the need for detailed planning. The number of stacking vehicles at the container terminals evaluated in the analysis is presented in Table 7.

Table 7. Number of stacking vehicles at evaluated container terminals (units)

Port	2018	2019	2020	2021	2022
Assan Port	19	19	19	19	19
Limak Port	42	42	43	56	56
MIP Port	70	70	70	76	76
Q Terminals Antalya	57	57	57	57	57
TCDD Izmir Alsancak	82	82	82	61	61
Nemport	65	65	65	65	74
Bandırma Çelebi	22	22	22	22	22
Gemport	68	68	68	79	79

Handled Container Volume

The only output value used in the study is the annual handled container volume (TEU). Container handling refers to the necessary loading and unloading services for containers. The primary goal of a port is to handle as much cargo as possible to generate maximum revenue and profit for the port. Therefore, this dimension is an essential criterion for measuring the efficiency of a container terminal. The volume of handled containers is the main indicator of port efficiency and how effectively input variables are used. The annual container handling volumes of the container terminals evaluated in the analysis are presented in Table 8.

Table 8. Annual container handling volume at evaluated container terminals (TEU)

Port	2018	2019	2020	2021	2022
Assan Port	225.496	248.594	244.643	214.484	177.661
Limak Port	311.261	379.809	466.184	464.571	481.883
MIP Port	1,722.711	1,939.029	2,009.724	2,097.349	2,020.967
Q Terminals Antalya	186.290	148.750	123.983	116.786	93.016
TCDD Izmir Alsancak	647.715	605.727	531.687	529.131	406.081
Nemport	390.071	430.014	484.371	544.568	558.648
Bandırma Çelebi	35.695	18.581	13.340	6.981	10.616
Gemport	524.652	547.190	570.427	682.064	676.782

The results of the Data Envelopment Analysis (DEA) were examined and interpreted for each model separately in

terms of efficiency values, reference groups, residual values, and input and output weights. The analysis results are detailed in the following sections.

Input-Oriented CCR Analysis Results

According to the model developed by Charnes, Cooper, and Rhodes, the results of the input-oriented analysis showing the efficiency status of the selected ports as decision-making units over the years are presented in the Figure 2.

The results of the input-oriented CCR analysis model, showing the efficiency scores, reference groups, and ratios of the ports examined over the years, are presented in the Table 9.

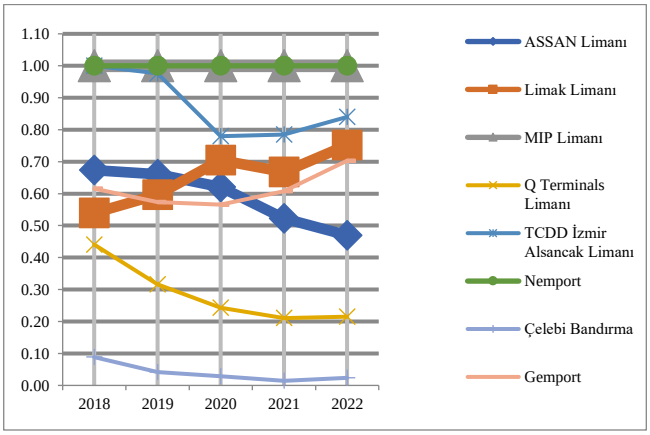

Figure 2. Efficiency status graph according to the input-oriented CCR analysis model

Table 9. Efficiency scores, reference groups, and ratios according to the input-oriented CCR analysis model

Decision-Making Units	Efficiency Score					Reference Group and Ratio				
	2018	2019	2020	2021	2022	2018	2019	2020	2021	2022
Assan Port	0.6735	0.6612	0.6210	0.5221	0.4697	MIP (0.11) Nemport (0.7)	MIP (0.11) Nemport (0.07)	MIP (0.10) Nemport (0.07)	MIP (0.09) Nemport (0.05)	MIP (0.08) Nemport (0.04)
Limak Port	0.5396	0.5966	0.7047	0.6682	0.7518	MIP (0.16) TCDD İzmir (0.06)	MIP (0.18) Nemport (0.07)	MIP (0.22) Nemport (0.08)	MIP (0.21) Nemport (0.08)	MIP (0,23) Nemport (0.07)
MIP Port	1.0000	1.0000	1.0000	1.0000	1.0000	-	-	-	-	-
Q Terminals Port	0.4406	0.3160	0.2429	0.2106	0.2151	MIP (0.05) Nemport (0.26)	MIP (0,04) Nemport (0.18)	MIP (0,03) Nemport (0.14)	MIP (0,02) Nemport (0.12)	MIP (0,01) Nemport (0.13)
TCDD Izmir Alsancak Port	1.0000	0.9767	0.7798	0.7845	0.8396	-	MIP (0,09) Nemport (0.98)	MIP (0,07) Nemport (0.79)	MIP (0,09) Nemport (0.63)	MIP (0,03) Nemport (0.62)
Nemport	1.0000	1.0000	1.0000	1.0000	1.0000	-	-	-	-	-
Çelebi Bandırma	0.0885	0.0415	0.0285	0.0144	0.0236	MIP (0,02) TCDD İzmir (0.01)	MIP (0,008) Nemport (0.005)	MIP (0,006) Nemport (0.003)	MIP (0,003) Nemport (0.001)	MIP (0,005) Nemport (0.002)
Gemport	0.6162	0.5735	0.5657	0.6081	0.7032	MIP (0,23) Nemport (0.31)	MIP (0,22) Nemport (0.29)	MIP (0,21) Nemport (0.29)	MIP (0,19) Nemport (0.52)	MIP (0.33)

The residual values of the variables for each year, berth length, number of cranes, container storage area, number of berths, number of stacking vehicles, and container handling volume according to the input-oriented CCR analysis model, are presented in the Table 10.

Based on the analysis results according to the model developed by Charnes, Cooper, and Rhodes, it is understood that M.I.P. Port and Nemport Port have been efficient throughout the entire analysis period from 2018 to 2022. When examining the efficiency scores and reference group values in Table 9 and the slack values in Table 10 for the container ports evaluated in the study according to the input-oriented CCR model:

Assan Port: The efficiency score decreased from 0.6735 in 2018 to 0.4697 in 2022. To increase efficiency, it should emulate M.I.P. Port by approximately 20% and Nemport Port by approximately 6%. The inefficiency is due to excessive berth length, crane number, and container storage area, which should be reduced as indicated in Table 10.

Limak Port: The efficiency score increased from 0.5396 in 2018 to 0.7518 in 2022, except for a drop to 0.6682 in 2021. To improve efficiency, it should emulate M.I.P. Port by approximately 20%, Nemport Port by 8%, and TCDD Izmir Alsancak Port by 6%. The inefficiency is due to excessive crane numbers, berth numbers, and stacking vehicles, which should be reduced as indicated in Table 10.

M.I.P. Port: It has been efficient throughout the period.

Q Terminals Antalya Port: The efficiency score decreased from 0.4406 in 2018 to 0.2106 in 2021 and slightly increased to 0.2151 in 2022. To increase efficiency, it should emulate Nemport Port by approximately 17% and M.I.P. Port by 3%. The inefficiency is due to excessive berth length, berth numbers, and stacking vehicles, which should be reduced as indicated in Table 10.

TCDD Izmir Alsancak Port: It was efficient in 2018, but the efficiency score dropped in 2019 and 2020, and then increased to 0.8396 in 2022. To improve efficiency, it should emulate Nemport Port by approximately 76% and M.I.P. Port by 7%. The inefficiency is due to excessive berth length, crane numbers, berth numbers, and stacking vehicles, which should be reduced as indicated in Table 10.

Nemport: It has been efficient throughout the period.

Çelebi Bandırma Port: It has the lowest efficiency score throughout the period, dropping from 0.0885 in 2018 to 0.0144 in 2021, with a slight increase to 0.0236 in 2022. To improve efficiency, it should emulate M.I.P. Port by approximately 0.8%, Nemport Port by 0.4%, and TCDD Izmir Alsancak Port by 1%. The inefficiency is due to excessive berth length, crane numbers, and berth numbers, which should be reduced as indicated in Table 10.

Gemport: The efficiency score decreased from 0.6162 in 2018 to 0.5657 in 2020 and then increased to 0.7032 in 2022. To improve efficiency, it should emulate Nemport Port by approximately 35% and M.I.P. Port by 24%. The inefficiency is due to excessive berth length, crane numbers, container storage area, and stacking vehicles, which should be reduced as indicated in Table 9.

Table 10. Residual values of variables according to the input-oriented CCR analysis model

Decision-Making Units	Year	Berth Length	Number of Cranes	Container Storage Area	Number of Berths	Number of Stacking Vehicles	Container Handling Volume
Assan Port	2018	20.24	0.24	997.90	0.00	0.00	0.00
	2019	19.87	0.23	979.67	0.00	0.00	0.00
	2020	18.66	0.22	920.17	0.00	0.00	0.00
	2021	21.56	0.23	0.00	0.01	0.00	0.00
	2022	9.85	0.16	0.00	0.02	0.00	0.00
Limak Port	2018	0.00	7.30	0.00	0.37	6.28	0.00
	2019	0.00	8.30	0.00	0.61	7.60	0.00
	2020	0.00	9.81	0.00	0.72	9.68	0.00
	2021	0.00	9.30	0.00	0.69	16.62	0.00
	2022	0.00	10.50	0.00	0.84	19.82	0.00
MIP Port	2018	0.00	0.00	0.00	0.00	0.00	0.00
	2019	0.00	0.00	0.00	0.00	0.00	0.00
	2020	0.00	0.00	0.00	0.00	0.00	0.00
	2021	0.00	0.00	0.00	0.00	0.00	0.00
	2022	0.00	0.00	0.00	0.00	0.00	0.00
Q Terminals Port	2018	46.68	0.00	0.00	1.45	4.99	0.00
	2019	33.48	0.00	0.00	1.04	3.58	0.00
	2020	25.74	0.00	0.00	0.80	2.75	0.00
	2021	22.47	0.00	0.00	0.69	2.22	0.00
	2022	0.00	0.25	0.00	0.94	1.89	0.00
TCDD Izmir Alsancak Port	2018	0.00	0.00	0.00	0.00	0.00	0.00
	2019	0.00	3.22	0.00	2.88	9.38	0.00
	2020	0.00	2.57	0.00	2.30	7.49	0.00
	2021	129.20	0.35	0.00	2.68	0.00	0.00
	2022	38.36	0.00	0.00	3.22	2.95	0.00
Nemport	2018	0.00	0.00	0.00	0.00	0.00	0.00
	2019	0.00	0.00	0.00	0.00	0.00	0.00
	2020	0.00	0.00	0.00	0.00	0.00	0.00
	2021	0.00	0.00	0.00	0.00	0.00	0.00
	2022	0.00	0.00	0.00	0.00	0.00	0.00
Çelebi Bandırma	2018	191.94	0.39	0.00	0.62	0.00	0.00
	2019	89.48	0.19	0.00	0.30	0.00	0.00
	2020	61.38	0.13	0.00	0.21	0.00	0.00
	2021	31.23	0.07	0.00	0.10	0.00	0.00
	2022	50.83	0.11	0.00	0.17	0.00	0.00
Gemport	2018	131.50	0.00	210,366.86	0.00	5.24	0.00
	2019	122.40	0.00	195,809.65	0.00	4.88	0.00
	2020	120.72	0.00	193,119.75	0.00	4.81	0.00
	2021	45.02	1.65	468,660.30	0.00	0.00	0.00
	2022	313.11	4.15	459,336.87	0.00	30.11	0.00

Output-Oriented CCR Analysis Results

According to the model developed by Charnes, Cooper, and Rhodes, the output-oriented analysis results showing the efficiency status of the selected ports over the years are presented in the Figure 3. When examining the efficiency scores and reference group values in Table 11 and the slack values in Table 12 for the container ports evaluated in the study according to the output-oriented CCR model:

Assan Port: The efficiency score decreased from 0.6735 in 2018 to 0.4697 in 2022. To improve efficiency, it should emulate M.I.P. Port by approximately 17% and Nemport Port by 10%. The inefficiency is due to excessive berth length, crane numbers, and container storage area, which should be reduced as indicated in Table 12.

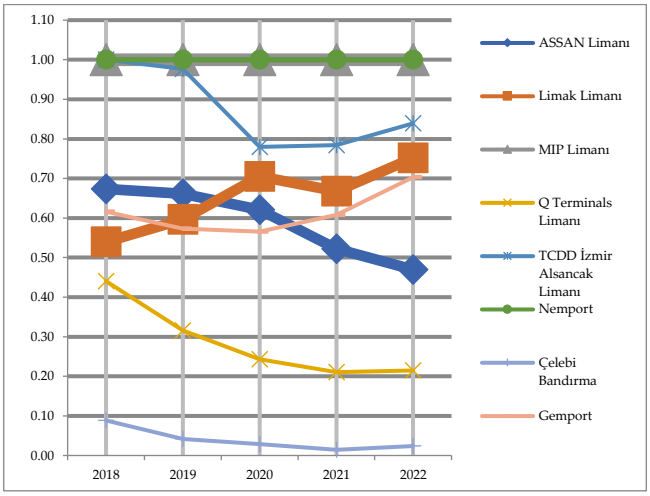

Figure 3. Efficiency status graph according to the output-oriented CCR analysis model

Table 11. Efficiency scores, reference groups, and ratios according to the output-oriented CCR analysis model

Decision-Making Units	Efficiency Score					Reference Group and Ratio				
	2018	**2019**	2020	**2018**	**2019**	2018	**2018**	**2019**	2021	**2018**
Assan Port	0.6735	0.6612	0.6210	0.5221	0.4697	MIP (0.17) Nemport (0.10)	MIP (0.17) Nemport (0.11)	MIP (0.17) Nemport (0.11)	MIP (0.17) Nemport (0.09)	MIP (0.16) Nemport (0.09)
Limak Port	0.5396	0.5966	0.7047	0.6682	0.7518	MIP (0.30) TCDD İzmir (0.12)	MIP (0.31) Nemport (0.12)	MIP (0.31) Nemport (0.12)	MIP (0.31) Nemport (0.12)	MIP (0.30) Nemport (0.09)
MIP Port	1.0000	1.0000	1.0000	1.0000	1.0000	-	-	-	-	-
Q Terminals Port	0.4406	0.3160	0.2429	0.2106	0.2151	MIP (0.11) Nemport (0.58)	MIP (0.11) Nemport (0.58)	MIP (0.11) Nemport (0.58)	MIP (0.11) Nemport (0.58)	MIP (0.05) Nemport (0.60)
TCDD Izmir Alsancak Port	1.0000	0.9767	0.7798	0.7845	0.8396	-	MIP (0.10) Nemport (1.01)	MIP (0.10) Nemport (1.01)	MIP (0.11) Nemport (0.80)	MIP (0.03) Nemport (0.74)
Nemport	1.0000	1.0000	1.0000	1.0000	1.0000	-	-	-	-	-
Çelebi Bandırma	0.0885	0.0415	0.0285	0.0144	0.0236	MIP (0.20) TCDD İzmir (0.10)	MIP (0.20) Nemport (0.12)	MIP (0.20) Nemport (0.12)	MIP (0.20) Nemport (0.10)	MIP (0.20) Nemport (0.10)
Gemport	0.6162	0.5735	0.5657	0.6081	0.7032	MIP (0.38) Nemport (0.51)	MIP (0.38) Nemport (0.51)	MIP (0.38) Nemport (0.51)	MIP (0.31) Nemport (0.85)	MIP (0.48)

Limak Port: The efficiency score increased from 0.5396 in 2018 to 0.7518 in 2022, except for a drop to 0.6682 in 2021. To improve efficiency, it should emulate M.I.P. Port by approximately 31%, Nemport Port by 11%, and TCDD Izmir Alsancak Port by 12%. The inefficiency is due to excessive crane numbers, berth numbers, and stacking vehicles, which should be reduced as indicated in Table 12.

M.I.P. Port: It has been efficient throughout the period.

Q Terminals Antalya Port: The efficiency score decreased from 0.4406 in 2018 to 0.2106 in 2021 and slightly increased to 0.2151 in 2022. To improve efficiency, it should emulate Nemport Port by approximately 58% and M.I.P. Port by 10%. The inefficiency is due to excessive berth length, crane numbers, and berth numbers, which should be reduced as indicated in Table 12.

TCDD Izmir Alsancak Port: It was efficient in 2018, but the efficiency score dropped in 2019 and 2020, and then increased to 0.8396 in 2022. To improve efficiency, it should emulate Nemport Port by approximately 89% and M.I.P. Port by 9%. The inefficiency is due to excessive berth length, crane numbers, berth numbers, and stacking vehicles, which should be reduced as indicated in Table 12.

Nemport: It has been efficient throughout the period.

Çelebi Bandırma Port: It has the lowest efficiency score throughout the period, dropping from 0.0885 in 2018 to 0.0144 in 2021, with a slight increase to 0.0236 in 2022. To improve efficiency, it should emulate M.I.P. Port by approximately 20%, Nemport Port by 11%, and TCDD Izmir Alsancak Port by 10%. The inefficiency is due to excessive berth length, crane numbers, and berth numbers, which should be reduced as indicated in Table 12.

Gemport: The efficiency score decreased from 0.6162 in 2018 to 0.5657 in 2020 and then increased to 0.7032 in 2022. To improve efficiency, it should emulate Nemport Port by approximately 59% and M.I.P. Port by 39%. The inefficiency is due to excessive berth length, crane numbers, container storage area, and stacking vehicles, which should be reduced as indicated in Table 12.

Input-Oriented BCC Analysis Results

According to the model developed by Banker, Charnes, and Cooper, the input-oriented analysis results showing the efficiency status of the selected ports over the years are presented in the Figure 4.

Table 12. Residual values of variables according to the output-oriented CCR analysis model

Decision-Making Units	Year	Berth Length	Number of Cranes	Container Storage Area	Number of Berths	Number of Stacking Vehicles	Container Handling Volume
Assan Port	2018	30.05	0.35	1481.73	0.00	0.00	0.00
	2019	30.05	0.35	1481.73	0.00	0.00	0.00
	2020	30.05	0.35	1481.73	0.00	0.00	0.00
	2021	41.30	0.44	0.00	0.02	0.00	0.00
	2022	20.98	0.34	0.00	0.05	0.00	0.00
Limak Port	2018	0.00	13.54	0.00	0.69	11.63	0.00
	2019	0.00	13.92	0.00	1.03	12.74	0.00
	2020	0.00	13.92	0.00	1.03	13.74	0.00
	2021	0.00	13.92	0.00	1.03	24.88	0.00
	2022	0.00	13.96	0.00	1.12	26.36	0.00
MIP Port	2018	0.00	0.00	0.00	0.00	0.00	0.00
	2019	0.00	0.00	0.00	0.00	0.00	0.00
	2020	0.00	0.00	0.00	0.00	0.00	0.00
	2021	0.00	0.00	0.00	0.00	0.00	0.00
	2022	0.00	0.00	0.00	0.00	0.00	0.00
Q Terminals Port	2018	105.95	0.00	0.00	3.28	11.32	0.00
	2019	105.95	0.00	0.00	3.28	11.32	0.00
	2020	105.95	0.00	0.00	3.28	11.32	0.00
	2021	106.68	0.00	0.00	3.29	10.56	0.00
	2022	0.00	1.16	0.00	4.39	8.77	0.00
TCDD Izmir Alsancak Port	2018	0.00	0.00	0.00	0.00	0.00	0.00
	2019	0.00	3.30	0.00	2.95	9.61	0.00
	2020	0.00	3.30	0.00	2.95	9.61	0.00
	2021	164.69	0.44	0.00	3.42	0.00	0.00
	2022	45.69	0.00	0.00	3.83	3.51	0.00
Nemport	2018	0.00	0.00	0.00	0.00	0.00	0.00
	2019	0.00	0.00	0.00	0.00	0.00	0.00
	2020	0.00	0.00	0.00	0.00	0.00	0.00
	2021	0.00	0.00	0.00	0.00	0.00	0.00
	2022	0.00	0.00	0.00	0.00	0.00	0.00
Çelebi Bandırma	2018	2168.94	4.45	0.00	6.97	0.00	0.00
	2019	2155.73	4.69	0.00	7.23	0.00	0.00
	2020	2155.73	4.69	0.00	7.23	0.00	0.00
	2021	2172.64	4.81	0.00	7.28	0.00	0.00
	2022	2150.90	4.71	0.00	7.31	0.00	0.00
Gemport	2018	213.42	0.00	341409.49	0.00	8.51	0.00
	2019	213.42	0.00	341409.49	0.00	8.51	0.00
	2020	213.42	0.00	341409.49	0.00	8.51	0.00
	2021	74.03	2.72	770715.77	0.00	0.00	0.00
	2022	445.24	5.90	653164.29	0.00	42.81	0.00

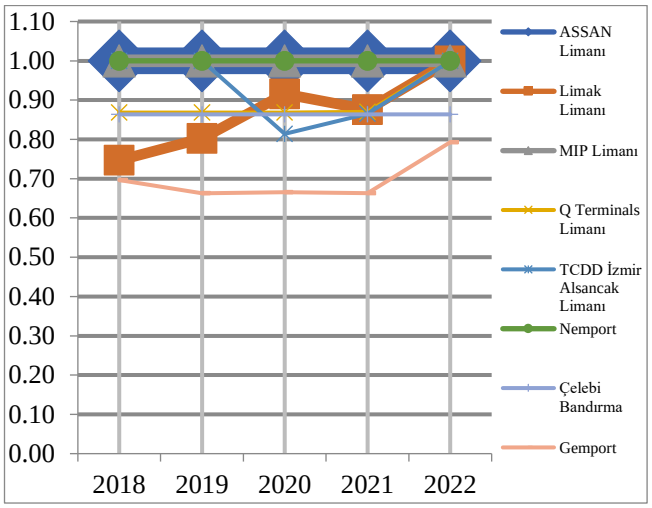

Figure 4. Efficiency status graph according to the input-oriented BCC analysis model

The results of the input-oriented BCC analysis model, showing the efficiency scores, reference groups, and ratios of the ports examined over the years, are presented in Table 13. The slack values for these ports are shown in Table 14. Upon examining the efficiency scores in Table 13, it is understood that Limak Port and Q Terminals Port were efficient in 2022, TCDD Izmir Alsancak Port in 2018, 2019, and 2022, and ASSAN Port, M.I.P. Port, and Nemport Port were efficient throughout the entire analysis period from 2018 to 2022. The findings are as follows:

Assan Port: It has been efficient throughout the period.

Limak Port: The efficiency score increased from 0.7466 in 2018 to 1.0000 in 2022, except for a drop to 0.8758 in 2021. To improve efficiency, it should emulate ASSAN Port by approximately 74%, M.I.P. Port by 6%, Nemport Port by 61% (2021), and TCDD Izmir Alsancak Port by 19%. The inefficiency is due to excessive crane numbers, container storage area, berth numbers, and stacking vehicles, which should be reduced as indicated in Table 13.

M.I.P. Port: It has been efficient throughout the period.

Q Terminals Antalya Port: The efficiency score remained constant at 0.8682 from 2018 to 2020 and then increased to 1.0000 in 2022. To improve efficiency, it should emulate ASSAN Port by approximately 60% and Nemport Port by 40%. The inefficiency is due to excessive berth length, crane numbers, berth numbers, and stacking vehicles, which should be reduced as indicated in Table 13.

TCDD Izmir Alsancak Port: It was efficient in 2018 and 2019, but the efficiency score dropped to 0.8140 in 2020 and then increased to 1.0000 in 2022. To improve efficiency, it should emulate Nemport Port by approximately 74%, ASSAN Port by 21%, and M.I.P. Port by 5%. The inefficiency is due to excessive berth length, crane numbers, berth numbers, and stacking vehicles, which should be reduced as indicated in Table 13.

Nemport: It has been efficient throughout the period.

Çelebi Bandırma Port: The efficiency score remained constant at 0.8636 throughout the period. To improve efficiency, it should emulate ASSAN Port by 100%. The inefficiency is due to excessive berth length, crane numbers, container storage area, and berth numbers, which should be reduced as indicated in Table 13.

Table 13. Efficiency scores, reference groups, and ratios according to the input-oriented BCC analysis model

Decision-Making Units	Efficiency Score					Reference Group and Ratio				
	2018	2019	2020	2018	2019	2018	2018	2019	2021	2018
Assan Port	1.0000	1.0000	1.0000	1.0000	1.0000	-	-	-	-	-
Limak Port	0.7466	0.8026	0.9156	0.8758	1.0000	ASSAN (0.80) MIP (0.01) TCDD İzmir (0.19)	ASSAN (0.92) MIP (0.08)	ASSAN (0.87) MIP (0.13)	ASSAN (0.35) MIP (0.03) Nemport (0.61)	-
MIP Port	1.0000	1.0000	1.0000	1.0000	1.0000	-	-	-	-	-
Q Terminals Port	0.8682	0.8682	0.8682	0.8701	1.0000	ASSAN (0.60) Nemport (0.40)	ASSAN (0.60) Nemport (0.40)	ASSAN (0.60) Nemport (0.40)	ASSAN (0.59) Nemport (0.41)	-
TCDD Izmir Alsancak Port	1.0000	1.0000	0.8140	0.8652	1.0000	-	-	ASSAN (0.14) MIP (0.05) Nemport (0.80)	ASSAN (0.28) MIP (0.05) Nemport (0.67)	-
Nemport	1.0000	1.0000	1.0000	1.0000	1.0000	-	-	-	-	-
Çelebi Bandırma	0.8636	0.8636	0.8636	0.8636	0.8636	ASSAN (1.00)	ASSAN (1.00)	ASSAN (1.00)	ASSAN (1.00)	ASSAN (1.00)
Gemport	0.6964	0.6627	0.6657	0.6630	0.7928	ASSAN (0.59) MIP (0.17) Nemport (0.23)	ASSAN (0.64) MIP (0.15) Nemport (0.21)	ASSAN (0.64) MIP (0.15) Nemport (0.21)	ASSAN (0.31) MIP (0.15) Nemport (0.54)	ASSAN (0.37) MIP (0.18) Nemport (0.45)

Gemport: The efficiency score decreased from 0.6964 in 2018 to 0.6627 in 2019 and then increased to 0.7928 in 2022. To improve efficiency, it should emulate ASSAN Port by 51%, Nemport Port by 33%, and M.I.P. Port by 16%. The inefficiency is due to excessive berth length, crane numbers, container storage area, and stacking vehicles, which should be reduced as indicated in Table 13.

Output-Oriented BCC Analysis Results

According to the model developed by Banker, Charnes, and Cooper, the output-oriented analysis results showing the efficiency status of the selected ports over the years are presented in the Figure 5.

Table 14. Residual values of variables according to the input-oriented BCC analysis model

Decision-Making Units	Year	Berth Length	Number of Cranes	Container Storage Area	Number of Berths	Number of Stacking Vehicles	Container Handling Volume
Assan Port	2018	0.00	0.00	0.00	0.00	0.00	0.00
	2019	0.00	0.00	0.00	0.00	0.00	0.00
	2020	0.00	0.00	0.00	0.00	0.00	0.00
	2021	0.00	0.00	0.00	0.00	0.00	0.00
	2022	20.98	0.34	0.00	0.05	0.00	0.00
Limak Port	2018	0.00	9.31	65832.60	0.88	0.00	0.00
	2019	0.00	10.98	11038.38	1.02	10.49	0.00
	2020	0.00	12.59	4932.77	1.07	13.61	0.00
	2021	0.00	11.26	169628.21	2.47	0.00	0.00
	2022	0.00	13.96	0.00	1.12	26.36	0.00
MIP Port	2018	0.00	0.00	0.00	0.00	0.00	0.00
	2019	0.00	0.00	0.00	0.00	0.00	0.00
	2020	0.00	0.00	0.00	0.00	0.00	0.00
	2021	0.00	0.00	0.00	0.00	0.00	0.00
	2022	0.00	0.00	0.00	0.00	0.00	0.00
Q Terminals Port	2018	104.68	0.00	0.00	2.95	11.95	105540.65
	2019	104.68	0.00	0.00	2.95	11.95	172968.31
	2020	104.68	0.00	0.00	2.95	11.95	217286.30
	2021	105.43	0.00	0.00	2.96	11.88	231996.68
	2022	0.00	1.16	0.00	4.39	8.77	0.00
TCDD Izmir Alsancak Port	2018	0.00	0.00	0.00	0.00	0.00	0.00
	2019	0.00	0.00	0.00	0.00	0.00	0.00
	2020	0.00	2.66	0.00	2.41	8.11	0.00
	2021	131.04	0.26	0.00	2.95	0.00	0.00
	2022	45.69	0.00	0.00	3.83	3.51	0.00
Nemport	2018	0.00	0.00	0.00	0.00	0.00	0.00
	2019	0.00	0.00	0.00	0.00	0.00	0.00
	2020	0.00	0.00	0.00	0.00	0.00	0.00
	2021	0.00	0.00	0.00	0.00	0.00	0.00
	2022	0.00	0.00	0.00	0.00	0.00	0.00
Çelebi Bandırma	2018	1847.59	3.77	6755.09	6.36	0.00	189801.00
	2019	1847.59	3.77	6755.09	6.36	0.00	230013.00
	2020	1847.59	3.77	6755.09	6.36	0.00	231303.00
	2021	1847.59	3.77	6755.09	6.36	0.00	207503.00
	2022	2150.90	4.71	0.00	7.31	0.00	0.00
Gemport	2018	154.92	0.00	229222.25	0.00	8.77	0.00
	2019	148.23	0.00	217065.64	0.00	8.70	0.00
	2020	148.82	0.00	218137.47	0.00	8.71	0.00
	2021	36.99	1.67	511426.67	0.00	0.00	0.00
	2022	445.24	5.90	653164.29	0.00	42.81	0.00

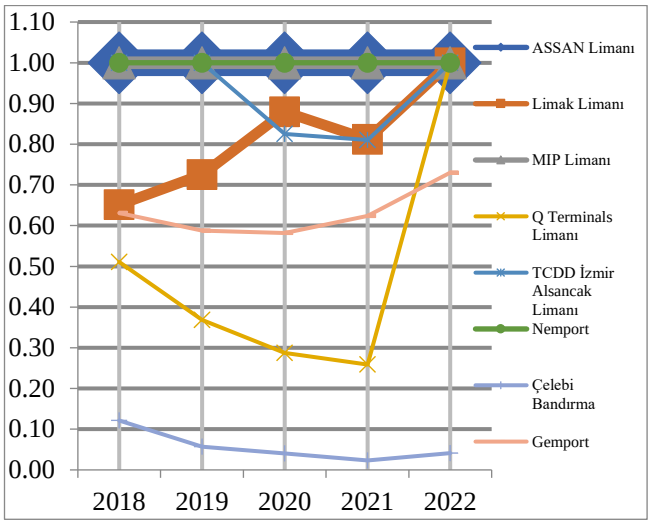

Figure 5. Efficiency Status Graph According to the Output-Oriented BCC Analysis Model

The results of the output-oriented BCC analysis model, showing the efficiency scores, reference groups, and ratios of the ports examined over the years, will provide further insights into their performance and areas for improvement. Based on the results of the output-oriented BCC analysis model, the efficiency scores, reference groups, and slack values for the container terminals evaluated over the years are presented in Table 15 and Table 16.

Upon examining the efficiency scores in Table 15, it is understood that Limak Port and Q Terminals Port were efficient in 2022, TCDD Izmir Alsancak Port in 2018, 2019, and 2022, and ASSAN Port, M.I.P. Port, and Nemport Port were efficient throughout the entire analysis period from 2018 to 2022. The findings are as follows:

ASSAN Port: It has been efficient throughout the period.

Limak Port: The efficiency score increased from 0.6510 in 2018 to 1.0000 in 2022, except for a drop to 0.8116 in 2021. To improve efficiency, it should emulate ASSAN Port by approximately 62%, M.I.P. Port by 13%, Nemport Port by 72% (2021), and TCDD Izmir Alsancak Port by 29%. The inefficiency is due to excessive crane numbers, container storage area, berth numbers, and stacking vehicles, which should be reduced as indicated in Table 15.

MIP Port: It has been efficient throughout the period.

Q Terminals Antalya Port: The efficiency score decreased from 0.5105 in 2018 to 0.2587 in 2021 and then increased to 1.0000 in 2022. To improve efficiency, it should emulate ASSAN Port by approximately 46%, Nemport Port by 50%, and M.I.P. Port by 4%. The inefficiency is due to excessive berth length, berth numbers, and stacking vehicles, which should be reduced as indicated in Table 15.

Table 15. Efficiency scores, reference groups, and ratios according to the output-oriented BCC analysis model

Decision-Making Units	Efficiency Score					Reference Group and Ratio				
	2018	2019	2020	2018	2019	2018	2018	2019	2021	2018
Assan Port	1.0000	1.0000	1.0000	1.0000	1.0000	-	-	-	-	-
Limak Port	0.6510	0.7250	0.8792	0.8116	1.0000	ASSAN (0.62) MIP (0.09) TCDD İzmir (0.29)	ASSAN (0.83) MIP (0.17)	ASSAN (0.83) MIP (0.17)	ASSAN (0.21) MIP (0.07) Nemport (0.72)	-
MIP Port	1.0000	1.0000	1.0000	1.0000	1.0000	-	-	-	-	-
Q Terminals Port	0.5105	0.3684	0.2870	0.2587	1.0000	ASSAN (0.46) MIP (0.04) Nemport (0.50)	ASSAN (0.46) MIP (0.04) Nemport (0.50)	ASSAN (0.46) MIP (0.04) Nemport (0.50)	ASSAN (0.46) MIP (0.04) Nemport (0.50)	-
TCDD Izmir Alsancak Port	1.0000	1.0000	0.8251	0.8103	1.0000	-	-	MIP (0.10) Nemport (0.90)	ASSAN (0.11) MIP (0.09) Nemport (0.80)	-
Nemport	1.0000	1.0000	1.0000	1.0000	1.0000	-	-	-	-	-
Çelebi Bandırma	0.1213	0.0570	0.0409	0.0233	0.0409	ASSAN (0.95) MIP (0.04) TCDD İzmir (0.01)	ASSAN (0.94) MIP (0.04) TCDD İzmir (0.02)	ASSAN (0.94) MIP (0.04) TCDD İzmir (0.02)	ASSAN (0.95) MIP (0.04) TCDD İzmir (0.01)	ASSAN (0.95) MIP (0.04) TCDD İzmir (0.01)
Gemport	0.6312	0.5880	0.5818	0.6243	0.7302	ASSAN (0.18) MIP (0.35) Nemport (0.47)	ASSAN (0.18) MIP (0.35) Nemport (0.47)	ASSAN (0.18) MIP (0.35) Nemport (0.47)	MIP (0.35) Nemport (0.65)	ASSAN (0.12) MIP (0.28) Nemport (0.60)

TCDD Izmir Alsancak Port: It was efficient in 2018 and 2019, but the efficiency score dropped to 0.8103 in 2020 and then increased to 1.0000 in 2022. To improve efficiency, it should emulate Nemport Port by approximately 85%, ASSAN Port by 5%, and M.I.P. Port by 10%. The inefficiency is due to excessive berth length, crane numbers, berth numbers, and stacking vehicles, which should be reduced as indicated in Table 15.

Nemport: It has been efficient throughout the period.

Çelebi Bandırma Port: The efficiency score decreased from 0.1213 in 2018 to 0.0233 in 2021 and then increased to 0.0409 in 2022. To improve efficiency, it should emulate ASSAN Port by 95%, M.I.P. Port by 4%, and TCDD Izmir Alsancak Port by 1%. The inefficiency is due to excessive berth length, crane numbers, and berth numbers, which should be reduced as indicated in Table 15.

Gemport: The efficiency score decreased from 0.6312 in 2018 to 0.5818 in 2020 and then increased to 0.7302 in 2022. To improve efficiency, it should emulate ASSAN Port by 13%, Nemport Port by 53%, and M.I.P. Port by 34%. The inefficiency is due to excessive berth length, crane numbers, container storage area, and stacking vehicles, which should be reduced as indicated in Table 15.

Table 16. Residual values of variables according to the output-oriented BCC analysis model

Decision-Making Units	Year	Berth Length	Number of Cranes	Container Storage Area	Number of Berths	Number of Stacking Vehicles	Container Handling Volume
Assan Port	2018	0.00	0.00	0.00	0.00	0.00	0.00
	2019	0.00	0.00	0.00	0.00	0.00	0.00
	2020	0.00	0.00	0.00	0.00	0.00	0.00
	2021	0.00	0.00	0.00	0.00	0.00	0.00
	2022	0.00	0.00	0.00	0.00	0.00	0.00
Limak Port	2018	0.00	12.47	79320.12	0.95	0.00	0.00
	2019	0.00	13.79	373.68	1.11	14.34	0.00
	2020	0.00	13.79	373.68	1.11	15.34	0.00
	2021	0.00	12.91	189408.56	2.76	0.00	0.00
	2022	0.00	0.00	0.00	0.00	0.00	0.00
MIP Port	2018	0.00	0.00	0.00	0.00	0.00	0.00
	2019	0.00	0.00	0.00	0.00	0.00	0.00
	2020	0.00	0.00	0.00	0.00	0.00	0.00
	2021	0.00	0.00	0.00	0.00	0.00	0.00
	2022	0.00	0.00	0.00	0.00	0.00	0.00
Q Terminals Port	2018	115.72	0.00	0.00	3.36	12.95	0.00
	2019	115.72	0.00	0.00	3.36	12.95	0.00
	2020	115.72	0.00	0.00	3.36	12.95	0.00
	2021	116.40	0.00	0.00	3.37	12.63	0.00
	2022	0.00	0.00	0.00	0.00	0.00	0.00
TCDD Izmir Alsancak Port	2018	0.00	0.00	0.00	0.00	0.00	0.00
	2019	0.00	0.00	0.00	0.00	0.00	0.00
	2020	93.75	3.95	0.00	3.22	16.48	0.00
	2021	160.18	0.40	0.00	3.42	0.00	0.00
	2022	0.00	0.00	0.00	0.00	0.00	0.00
Nemport	2018	0.00	0.00	0.00	0.00	0.00	0.00
	2019	0.00	0.00	0.00	0.00	0.00	0.00
	2020	0.00	0.00	0.00	0.00	0.00	0.00
	2021	0.00	0.00	0.00	0.00	0.00	0.00
	2022	0.00	0.00	0.00	0.00	0.00	0.00
Çelebi Bandırma	2018	2131.82	4.34	0.00	7.22	0.00	0.00
	2019	2130.19	4.38	0.00	7.25	0.00	0.00
	2020	2130.19	4.38	0.00	7.25	0.00	0.00
	2021	2133.60	4.40	0.00	7.26	0.00	0.00
	2022	2131.04	4.39	0.00	7.26	0.00	0.00
Gemport	2018	215.29	0.00	338874.71	0.00	9.35	0.00
	2019	215.29	0.00	338874.71	0.00	9.35	0.00
	2020	215.29	0.00	338874.71	0.00	9.35	0.00
	2021	161.76	3.47	742933.53	0.00	10.12	0.00
	2022	0.00	2.73	725699.75	0.00	10.88	0.00

Table 17. Average efficiency scores by year and analysis model

Decision-Making Unit	Year	CCR-I	CCR-O	BCC-I	BCC-O	Average Efficiency Score by Analysis Model
Assan Port	2018	0.6735	0.6735	1.0000	1.0000	0.8367
	2019	0.6612	0.6612	1.0000	1.0000	0.8306
	2020	0.6210	0.6210	1.0000	1.0000	0.8105
	2021	0.5221	0.5221	1.0000	1.0000	0.7611
	2022	0.4697	0.4697	1.0000	1.0000	0.7348
	Average Efficiency Score by Year	0.5895	0.5895	1.0000	1.0000	0.7947
Limak Port	2018	0.5396	0.5396	0.7466	0.6510	0.6192
	2019	0.5966	0.5966	0.8026	0.7250	0.6802
	2020	0.7047	0.7047	0.9156	0.8792	0.8011
	2021	0.6682	0.6682	0.8758	0.8116	0.7560
	2022	0.7518	0.7518	1.0000	1.0000	0.8759
	Average Efficiency Score by Year	0.6522	0.6522	0.8681	0.8134	0.7465
MIP Port	2018	1.0000	1.0000	1.0000	1.0000	1.0000
	2019	1.0000	1.0000	1.0000	1.0000	1.0000
	2020	1.0000	1.0000	1.0000	1.0000	1.0000
	2021	1.0000	1.0000	1.0000	1.0000	1.0000
	2022	1.0000	1.0000	1.0000	1.0000	1.0000
	Average Efficiency Score by Year	1.0000	1.0000	1.0000	1.0000	1.0000
Q Terminals Port	2018	0.4406	0.4406	0.8682	0.5105	0.5650
	2019	0.3160	0.3160	0.8682	0.3684	0.4671
	2020	0.2429	0.2429	0.8682	0.2870	0.4103
	2021	0.2106	0.2106	0.8701	0.2587	0.3875
	2022	0.2151	0.2151	1.0000	1.0000	0.6076
	Average Efficiency Score by Year	0.2850	0.2850	0.8949	0.4849	0.4875
TCDD İzmir Alsancak Port	2018	1.0000	1.0000	1.0000	1.0000	1.0000
	2019	0.9767	0.9767	1.0000	1.0000	0.9884
	2020	0.7798	0.7798	0.8140	0.8251	0.7997
	2021	0.7845	0.7845	0.8652	0.8103	0.8111
	2022	0.8396	0.8396	1.0000	1.0000	0.9198
	Average Efficiency Score by Year	0.8761	0.8761	0.9359	0.9271	0.9038
Nemport	2018	1.0000	1.0000	1.0000	1.0000	1.0000
	2019	1.0000	1.0000	1.0000	1.0000	1.0000
	2020	1.0000	1.0000	1.0000	1.0000	1.0000
	2021	1.0000	1.0000	1.0000	1.0000	1.0000
	2022	1.0000	1.0000	1.0000	1.0000	1.0000
	Average Efficiency Score by Year	1.0000	1.0000	1.0000	1.0000	1.0000
Çelebi Bandırma	2018	0.0885	0.0885	0.8636	0.1213	0.2905
	2019	0.0415	0.0415	0.8636	0.0570	0.2509
	2020	0.0285	0.0285	0.8636	0.0409	0.2404
	2021	0.0144	0.0144	0.8636	0.0233	0.2289
	2022	0.0236	0.0236	0.8636	0.0409	0.2380
	Average Efficiency Score by Year	0.0393	0.0393	0.8636	0.0567	0.2497
Gemport	2018	0.6162	0.6162	0.6964	0.6312	0.6400
	2019	0.5735	0.5735	0.6627	0.5880	0.5994
	2020	0.5657	0.5657	0.6657	0.5818	0.5947
	2021	0.6081	0.6081	0.6630	0.6243	0.6259
	2022	0.7032	0.7032	0.7928	0.7302	0.7324
	Average Efficiency Score by Year	0.6133	0.6133	0.6961	0.6311	0.6385

As a conclusion; this study evaluated the relative efficiency levels of ASSAN Port, Limak Port, M.I.P. Port, Q Terminals Antalya Port, TCDD Izmir Alsancak Port, Nemport, Bandırma Çelebi Port, and Gemport container terminals using input and output-oriented CCR and BCC models of Data Envelopment Analysis (DEA). The average efficiency scores by year and analysis model for the container terminals evaluated are presented in Table 17.

Analyzing the average efficiency scores of the container terminals examined within the scope of the study according to the years and according to the analysis model, it is seen that M.I.P. Port and Nemport Port are efficient. According to the average efficiency values of the other container terminals, TCDD Izmir (0.9038), Assan (0.7947), Limak (0.7465), Gemport (0.6385), Q Terminals (0.4875), and Çelebi Bandırma (0.2497) can be listed in descending order.

CONCLUSION

In today's world, where approximately three-quarters of global trade is conducted by sea, the importance of maritime logistics is increasing day by day. Considering that container transportation is the most preferred method in maritime logistics today, and ports are one of the most important factors in maritime transportation, this thesis study was conducted to analyze the current status of container terminals in the Iskenderun Bay, and identify measures that can be taken to ensure effective and efficient operations. The Data Envelopment Analysis (DEA) application was performed using the Open Source DEA package program. The findings of this study emphasize the importance of performance measurement for efficient and effective operation of container terminals, considering the significance of maritime trade for our country. Using DEA in port performance analysis is a correct initiative. Through these measurements, port operators can learn about their current status, strengths and weaknesses, overused inputs, and insufficient outputs, allowing them to develop strategies and plans to minimize wasted resources.

Performance analysis of the eight ports within the scope of the study was conducted using both input and output-oriented CCR and BCC models. According to the analysis results, the efficiency levels of the container terminals subject to the analysis, the reference terminals and their proportions, and the inputs that can be reduced to achieve efficiency were discussed.

The relative performance evaluation of ASSAN Port, Limak Port, M.I.P. Port, Q Terminals Antalya Port, TCDD Izmir Alsancak Port, Nemport, Bandırma Çelebi Port, and Gemport container terminals was conducted using DEA. The same ports were found to be efficient in both input and output-oriented CCR and BCC model applications.

This study covered a five-year period from 2018-2022, providing an advantage for calculating the average efficiency of the evaluated container terminals. Seasonal errors in input and output values or measurement errors caused by uncontrollable factors such as COVID-19 were minimized. Additionally, average efficiency scores by analysis model were calculated, and the general efficiency level rankings of the evaluated terminals were established.

After the analysis calculations, it was found that M.I.P. Port and Nemport Port were efficient among the evaluated container terminals. The current efficiency scores of the inefficient container terminals and the measures they need to take to improve were determined.

In similar studies conducted in past periods at container ports in Türkiye, it has been observed that results similar to those obtained in this research were achieved. With this application, it was concluded whether the evaluated container terminals were efficient or not. One significant finding of the study is that inefficient container terminals often need to reduce the number of cranes, berths, and stacking vehicles, as these inputs were found to be ineffectively used. A total of 160 efficiency values were calculated for eight different container terminals over a five-year period using four different methods, with only 62 of these values indicating efficiency.

For the container terminals in the Iskenderun Bay, it was found that ASSAN Port was efficient 10 times (in BCC-I and BCC-O models) with an average efficiency score of 0.7947, and Limak Port was efficient only twice (in 2022 in BCC-I and BCC-O models) with an average efficiency score of 0.7465. This indicates that both ports in the Iskenderun Bay are not efficient in average data but have high efficiency scores and can become efficient with necessary measures.

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Compliance with Ethical Standards

Authors' Contributions

This study is a part of M.Sc. thesis of the first author, which was carried out under the supervision of the second author. All authors contributed to the study conception and design. Data collection was performed by Engin Dal, analysis was conducted by Vahit Çalışır. The first draft of the manuscript was written by Vahit Çalışır. All authors read and approved the final manuscript.

Conflict of Interest

The authors declare that there is no conflict of interest.

Ethical Approval

For this type of study, formal consent is not required.

Data Availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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Seasonal analysis of Reyhanlı Dam Lake zooplankton fauna

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A B S T R A C T

This study was conducted seasonally in 2022 and 2023 in Reyhanlı Dam Lake (Hatay, Türkiye), which was established in 2020. Zooplankton fauna and main water quality characteristics were investigated. The average values of the water quality parameters (temperature, dissolved oxygen, conductivity and pH) measured in the dam lake were determined to be of first-class water quality. A total of 67 species were identified, of which fifty-four (54) species were Rotifera (80.60%), 7 species were Copepoda (10.45%) and 6 species were Cladocera (8.95%). Brachionidae was the most abundant with 14 species, Chydoridae represented by two species and Cyclopidae were represented by 3 species. According to the frequency index, 3 species ($F \geq 76\%$) were classified as constant and 11 species ($75\% > F \geq 51\%$) were classified as common. Of the 67 species recorded, only 29 species were very abundant (●) and abundant (○) in the different seasons. The highest species richness was recorded in the summer, with 54 species.

INTRODUCTION

Due to the lack of taxonomic studies, it is not possible to take the necessary measures for sustainable management and especially the protection of ecosystems. In Türkiye, which has a very rich fauna composition, unfortunately, there is still not enough taxonomic information on most living groups (Bozkurt and Genç, 2018). Türkiye, which has a very rich inland water potential, has many rivers, lakes and dams with an area of about one million hectares, which are negatively affected by increasing environmental degradation and colonisation.

Many reservoirs have been built for years for drinking water supply, irrigation, flood control and energy production (Yuksel, 2015), but as a result of population growth and industrialization, reservoirs are at risk of eutrophication, which can lead to a loss of biodiversity and disruption of the balance of the food chain (Brito et al., 2011). Therefore, limnological and biological factors in reservoirs should be studied and assessed, and the results should be used to improve water quality. Biotic and abiotic factors in the reservoirs can influence the diversity, density, biomass and spatio-temporal distribution of zooplankton species (Dorak et al., 2019).

Some aquatic organisms feed on zooplankton only at a certain stage of their life, particularly the larval stage, while many other species feed on zooplankton throughout their lives (Sales, 2011). This explains the close relationship between the diversity and abundance of zooplankton and the productivity of the aquatic environment (Brun et al., 2019). They play an important role in the aquatic environment as most zooplankton organisms such as copepods, cladocerans and rotifers feed on phytoplankton and rapidly convert plants into animal protein (Svanberg et al., 2022).

Although zooplankton is an important component of the food chain, some species are considered good indicators of eutrophication, pollution and water quality due to their

sensitivity to environmental changes (Ismail and Adnan, 2016). Zooplankton abundance and diversity, which are closely linked to water quality characteristics, increase and decrease with the trophic status of inland waters (İpek Alış and Saler, 2016), making studies of inland zooplankton increasingly important. Characterization of the zooplankton fauna of Türkiye, will contribute to a comprehensive understanding of Türkiye's biodiversity. In order to use these inland water resources efficiently, it is important to know the inland waters, aquatic organisms and their distribution in Türkiye.

This study was the first to investigate zooplankton biodiversity and main water quality characteristics in Reyhanlı Dam Lake (Hatay), a new reservoir. It also serves as an example for future studies.

MATERIALS AND METHODS

The study was conducted seasonally between May 2022 and December 2023 in the Reyhanlı Reservoir (36°20'27 "N 36°33'53 "E) in Hatay province (Figure 1). The Reyhanlı Reservoir (Hatay, Türkiye) has a total height of 29 m and a volume of 480 million m^3. It was built in 2020 on the Afrin and Karasu rivers for the purpose of agricultural irrigation. Although 5846.40 ha of agricultural land was created for irrigation purposes, it also creates new habitats for many aquatic animals and birds (Şimşek, 2022).

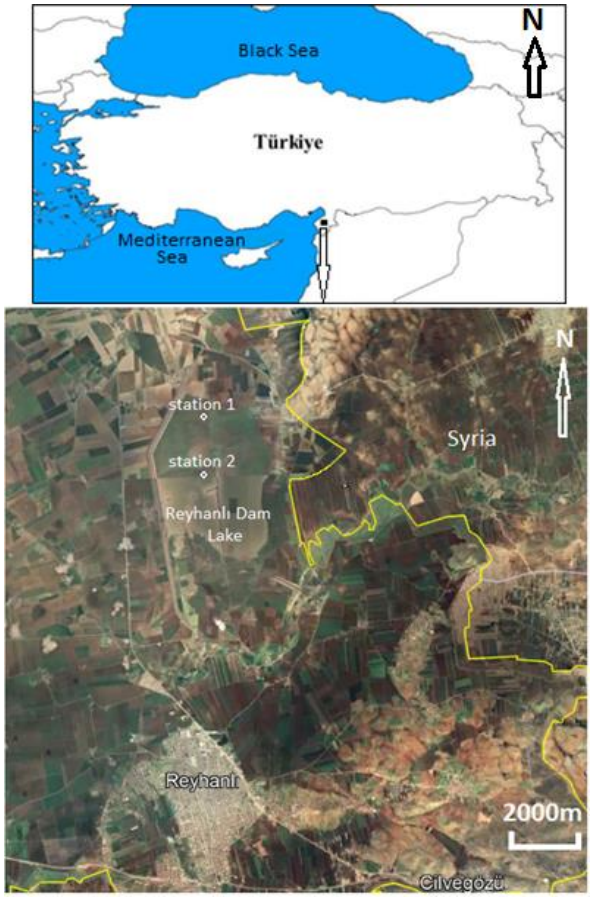

Figure 1. Reyhanlı Dam Lake and sampling stations

Zooplankton samples were collected seasonally at two different stations using a plankton net with a diameter of 0.30 m and a mesh size of 60 µm with horizontal and vertical hauls. Vertical hauls were performed ten times from the bottom to the surface, while horizontal hauls were performed from the water surface for 20 minutes at about 2 km/h with a motorboat. Macrophytes (*Elodea* sp. and *Ceratophyllum* sp.) collected from the northern and southern shores of the reservoir were brought to the laboratory in bags, washed in containers and filtered through the plankton net. All zooplankton samples were fixed in 4% formalin in the laboratory. Dissolved oxygen, water temperature, pH and conductivity were determined in situ using digital meters (oxygen and temperature: YSI Model 52 oxygen meter; pH: YSI 600 pH meter; conductivity: YSI Model 30 salinometer). The first sampling station is closer to the dam lake shore and at a depth of approximately 4-5 m, while the second station is closer to the dam midpoint and at a depth of 12-15 m, and its distance to the crest is around 500 m. Zooplankton species were examined and identified using an inverted microscope and a binocular microscope (Olympus CH40). Approximately 20 cc of each sample was sub-sampled to identify species and examined in a petri. This process was done at least 3 times in order to identify all species present. Soyer's (1970) frequency index (F %) was used to express the frequency of zooplankton species identified from plankton and plant samples in the study area. The results were determined as constant (F ≥ 76%), common (76% > F ≥ 51%), occasionally (51% > F ≥ 26%) and rare (F < 25%). Individuals belonging to the species were not counted, but their abundance was determined visually from their density in the petri dish. This was expressed as rare, few, abundant and most abundant, regardless of the Soyer index (Table 2). The specimens were identified according to Rylov (1963), Borutsky (1964), Scourfield and Harding (1966), Dussart (1967), Dussart (1969), Damian Georgescu (1970), Smirnov (1974), Negrea (1983), Apostolov and Marinov (1988), Reddy (1994), Segers (1995), Karaytug (1999) and Holynska et al. (2003).

RESULTS

Water temperature varied between 11.05±0.21°C (winter) and 25.00±0.28°C (summer), with a mean value of 19.89±5.80°C (Table 1). Dissolved oxygen ranged from 8.05±0.07 mg L^{-1} (summer) to 9.55±0.21 mg L^{-1} (winter), with a mean value of 8.75±0.59 mg L^{-1} (Table 1). The conductivity value ranged from 139±1.41 µS cm^{-1} (winter) to 235±7.07 µS cm^{-1} (fall), with a mean value of 187±43.23 µS cm^{-1} (Table 1). The minimum, maximum and mean pH values were 7.40±0.14 (summer), 8.65±0.07 (spring) and 8.18±0.51 (Table 1), respectively.

Table 1. Main water quality parameters (mean±SD)

Parameters	Spring	Summer	Fall	Winter	Annual Mean
Temperature (°C)	23.55±0.49	25.00±0.28	19.95±0.21	11.05±0.21	19.89±5.80
DO (mg L^{-1})	8.60±0.14	8.05±0.07	8.80±0.14	9.55±0.21	8.75±0.59
EC (μS cm^{-1})	156±5.66	218±3.54	235±7.07	139±1.41	187±43.23
pH	8.65±0.07	8.25±0.07	7.40±0.14	8.40±0.14	8.18±0.51

A total of 67 species were identified, of which fifty-four (54) species were Rotifera (80.60 %), 7 species were Copepoda (10.45 %) and 6 species were Cladocera (8.95 %) (Table 2). Among the rotifers, in which a total of 17 families were identified, the family Brachionidae was the most abundant with 14 species, followed by Lecanidae with 13 species. On the other hand, Trichocercidae, Mytilinidae, Asplanchnidae, Gastropodidae, Conochilidae, Dicranophoridae, Hexarthridae and Epiphanidae were represented with one species each. Of the Cladocera, five families were recorded, with the Chydoridae represented by two species, while the other families (Bosminidae, Moinidae, Macrothricidae and Ilyocryptidae) were represented by one species each (Table 2). Among the 5 families of Copepoda, the Cyclopidae were represented by 3 species and the other families (Ameiridae, Laophontidae, Ergasilidae and Lernaeidae) by one species each (Table 2).

The most common rotifers recorded in all seasons were, *Brachionus angularis*, *B. bidentatus*, *B. calyciflorus*, *B. caudatus*, *B. falcatus*, *B. quadridentatus*, *Keratella cochlearis*, *K. tecta*, *K. tropica*, *Platyias quadricornis*, *Lecane bulla*, *L. closterocerca*, *L. hamata*, *L. scutata*, *Polyarthra dolichoptera*, *P. vulgaris*, *Synchaeta stylata*, *Trichocerca pusilla*, *Asplanchna sieboldi*, *Collotheca pelagica*, *Pompholyx sulcata* and *Dichranophorus epicharis* followed by *Anuraeopsis coelata*, *B. budapestinensis*, *B. urceolaris*, *L. aculeate*, *L. flexilis*, *L. inermis*, *L. stenroosi*, *C. adriatica*, *C. colurus*, *L. patella*, *C. forficula*, *C. gibba*, *R. neptunia*, *D. hertzogi*, *C. mutabilis*, *A. ovalis* and *F. longiseta* (found in 3 seasons) (Table 2).

Among the Cladocera, *M. micrura*, which was recorded in 4 seasons, had the largest distribution habitat, followed by *B. longirostris*, *M. laticornis* and *I. sordidus* (recorded in 3 seasons). On the other hand, *A. robustus* and *O. mohammed* had the largest distribution area among copepods (found in 4 seasons) (Table 2). Some zooplankton species had a limited distribution and were only detected in one season: *L. furcata*, *L. hornemanni*, *L. luna*, *L. pyriformis*, *Lepadella rhomboids*, *T. ruttneri*, *Testudinella patina*, *C. unicornis* (Rotifera) and *M. rubellus* (Copepoda) (Table 2). The amount of zooplankton was generally not very abundant, with only some species occasionally reaching high densities. Of the 66 species recorded, only 29 species were very abundant (●) and abundant (○) in the different seasons, while the other species were fewer in number.

Most zooplankton species were recorded in summer with 54 species. This was followed by spring with 53 species, fall with 52 species and spring with 37 species. In terms of abundance, 7 species were very abundant (●) in spring, 7 species in summer and 3 species in fall. The seasonally very abundant (●) species were *B. angularis* (spring, summer and fall), *K. tecta*, *P. vulgaris* (spring, summer), *K. cochlearis*, *P. dolichoptera*, *P. sulcata*, *B. longirostris* (spring), *B. caudatus*, *K. tropica*, *S. stylata*, *N. hibernica* (summer), *C. pelagica* and *M. micrura* (fall) (Table 2). However, zooplankton was abundant (○) with 12 species in each season in spring, summer and fall and 5 species in winter (Table 2). The most abundant (○) species were *R. neptunia* (spring, summer, fall); *B. bidentatus*, *S. stylata*, *A. robustus* (spring, fall); *B. budapestinensis*, *P. dolichoptera* (summer, fall); *B. falcatus* (summer, winter); *B. quadridentatus*, *C. forficula*, *A. sieboldi*, *C. pelagica*, *C. vicinus* (spring, summer); *K. cochlearis*, *C. gibba*, *D. epicharis* (summer); *K. quadrata*, *N. hibernica*, *F. longiseta* (spring); *K. tropica*, *B. caudatus*, *B. longirostris*, *M. micrura* (winter); *P. vulgaris*, *D. hertzogi*, *M. ventralis*, *P. sulcata*, *A. costata*, *M. laticornis* (fall).

Species not found in aquatic plant samples but only in plankton samples; *A. coelata*, *B. angularis*, *B. budapestinensis*, *B. calyciflorus*, *B. falcatus*, *K. cochlearis*, *K. quadrata*, *K. tecta*, *P. vulgaris*, *S. stylata*, *A. sieboldin*, *P. sulcate*, *F. opoliensis*, *P. tentaculatus*, *M. micrura*, *C. vicinus*, *E. sieboldi*, *L. cyprinacea*. In contrast, some zooplankton species (*L. aculeate*, *L. flexilis*, *L. hamata*, *L. inermis*, *L. stenroosi*, *C. colurus*, *L. patella*, *C. forficula*, *E. najas*, *D. hertzogi*, *C. pelagica*, *C. mutabilis*, *D. epicharis*, *M. laticornis* and *I. sordidus*) were only found in aquatic plant samples. Some species (*L. furcate*, *L. hornemanni*, *L. pyriformis*, *T. ruttneri*, *T. patina*, *C. unicornis*, *M. rubellus*) were not assessed because they were found only once during the study, and others were found in both plants and plankton samples.

Table 2. List and abundance of zooplankton species in the dam lake (pl: plankton, op: on the plant. -: Absent, *: very few (rare 25-0.0%), +: few (occasionally 50-26%), ○: abundant (Common 75-51%), ●: very abundant (Constant 100-76%)

Species	Sampling Time								F%
	18.05.2022		10.06.2023		03.09.2023		17.12.2023		
	pl	*op*	*pl*	*op*	*pl*	*op*	*pl*	*op*	
Rotifera									
Brachionidae									
Anuraeopsis coelata de Beauchamp, 1932	*	–	–	–	*	–	*	–	38
Brachionus angularis Gosse, 1851	●	–	●	–	●	–	*	–	50
Brachionus bidentatus Anderson, 1889		○	–	+	*	○	*	+	75
Brachionus budapestinensis Daday, 1885	–	–	○	–	○	–	*	–	38
Brachionus calyciflorus Pallas, 1766	*	–	+	–	*	–	+	–	50
Brachionus caudatus Barrois & Daday, 1894	–	*	●	*	+	–	○	–	63
Brachionus falcatus Zacharias, 1898	*	–	○	–	+	–	○	–	50
Brachionus quadridentatus Hermann, 1783	+	○	○	○	*	+	+	*	100
Brachionus urceolaris Müller, 1773	–	–	+	–	+	–	–	+	38
Keratella cochlearis (Gosse, 1851)	●	–	○	–	+	–	+	–	50
Keratella quadrata (Müller, 1786)	○	–	+	–	–	–	–	–	25
Keratella tecta (Gosse, 1851)	●	–	●	–	+	–	*	–	50
Keratella tropica (Apstein, 1907)	+	+	●	*	*	*	○	+	100
Platyias quadricornis (Ehrenberg, 1832)	–	+	+	–	–	*	*	–	50
Lecanidae									
Lecane aculeata (Jabuski, 1912)	–	*	–	*	–	–	–	+	38
Lecane bulla (Gosse, 1886)	–	*	–	*	*	+	–	*	63
Lecane closterocerca (Schmarda, 1859)	–	+	–	+	*	–	*	*	63
Lecane flexilis (Gosse, 1886)	–	*	–	*	–	*	–	–	38
Lecane furcata (Murray, 1913)	–	–	–	*	–	–	–	–	13
Lecane hamata (Stokes, 1896)	–	+	–	+	–	+	–	+	50
Lecane hastata (Murray, 1913)	–	–	–	–	*	–	*	–	25
Lecane hornemanni (Ehrenberg, 1834)	–	–	–	*	–	–	–	–	13
Lecane inermis (Bryce, 1892)	–	+	–	+	–	–	–	+	38
Lecane luna (Müller, 1776)	–	–	–	–	*	*	–	–	25
Lecane pyriformis (Daday, 1905)	–	–	–	–	*	–	–	–	13
Lecane scutata (Harring & Myers, 1926)	*	*	*	*	–	*	*	–	75
Lecane stenroosi (Meissner, 1908)	–	*	–	*	–	–	–	*	38
Lepadellidae									
Colurella adriatica Ehrenberg, 1831	*	*	–	*	*	*	–	–	63
Colurella colurus (Ehrenberg, 1830)	–	*	–	*	–	*	–	–	38
Lepadella patella (Müller, 1773)	–	*	–	+	–	–	–	+	38
Lepadella rhomboides Gosse, 1886)	–	–	–	–	*	+	–	–	25
Synchaetidae									
Polyarthra dolichoptera Idelson,1925	●	*	○	+	○	+	*	–	88
Polyarthra vulgaris Carlin, 1943	●	–	●	–	○	–	*	–	50
Synchaeta stylata Wierzejski, 1893	○	–	●	–	○	–	*	–	50
Trichocercidae									
Trichocerca pusilla (Jennings, 1903)	+	*	+	*	*	–	*	–	75
Trichocerca ruttneri	–	–	+	–	–	–	–	–	13
Notommatidae									
Cephalodella forficula (Ehrenberg, 1830)	–	○	–	○	–	*	–	–	38
Cephalodella gibba (Ehrenberg, 1830)	–	+	–	○	*	–	–	–	38
Eosphora najas Ehrenberg, 1830	–	–	–	*	–	+	–	–	25
Philodinidae									
Rotaria neptunia (Ehrenberg, 1830)	+	○	○	○	*	○	–	–	75
Dissotrocha hertzogi Hauer, 1939	–	*	–	+	–	○	–	–	38
Mytilinidae									
Mytilina ventralis (Ehrenberg, 1830)	–	+	–	–	*	○	–	–	38

Table 2. (continued)

Species	Sampling Time								F%
	18.05.2022		10.06.2023		03.09.2023		17.12.2023		
	pl	*op*	*pl*	*op*	*pl*	*op*	*pl*	*op*	
Asplanchnidae									
Asplanchna sieboldi (Leydig, 1854)	○	–	○	–	+	–	+	–	50
Collothecidae									
Collotheca pelagica (Rousselet, 1893)	–	○	–	○	–	●	–	+	50
Collotheca mutabilis (Hudson, 1885)	–	*	–	+	–	+	–	–	38
Testudinellidae									
Testudinella patina (Hermann, 1783)	*	–	–	–	–	–	–	–	13
Pompholyx sulcata Hudson, 1885	●	–	+	–	○	–	+	–	50
Gastropodidae									
Ascomorpha ovalis (Bergendahl, 1892)	–	*	+	*	+	–	–	–	50
Trochosphaeridae									
Filinia longiseta (Ehrenberg, 1834)	○	*	+	*	+	–	–	–	63
Filinia opoliensis (Zacharias, 1898)	–	–	–	–	*	–	*	–	25
Conochilidae									
Conochilus unicornis Rousselet, 1892	+	–	–	–	–	–	–	–	13
Dicranophoridae									
Dichranophorus epicharis Harring & Myers, 1928	–	+	–	○	–	+	–	+	50
Hexarthridae									
Hexarthra intermedia (Wiszniewski, 1929)	*	–	+	*	–	–	–	–	38
Epiphanidae									
Proalides tentaculatus de Beauchamp, 1907	+	–	–	–	*	–	–	–	25
Cladocera									
Bosminidae									
Bosmina longirostris Müller, 1785	●	*	+	*	–	–	○	–	63
Moinidae									
Moina micrura Kurz, 1875	*	–	+	–	●	–	○	–	50
Chydoridae									
Alona costata Sars, 1862	–	+	–	–	*	○	–	–	38
Disparalona rostrata (Koch, 1841)	–	*	*	–	–	–	–	–	25
Macrothricidae									
Macrothrix laticornis (Jurine, 1820)	–	*	–	*	–	○	–	–	38
Ilyocryptidae									
Ilyocryptus sordidus (Liévin, 1848)	–	*	–	+	–	*	–	–	38
Copepoda									
Cyclopidae									
Cyclops vicinus Uljanin, 1875	○	–	○	–	+	–	–	–	38
Acanthocyclops robustus (Sars G.O., 1863)	○	–	*	–	○	*	+	–	63
Microcyclops rubellus (Lilljeborg 1901)	–	–	–	–	–	+	–	–	13
Ameiridae									
Nitokra hibernica (Brady, 1880)	–	○	–	●	–	–	*	–	38
Laophontidae									
Onychocamptus mohammed (Blanchard & Richard, 1891)	–	*	*	*	*	–	*	–	63
Ergasilidae									
Ergasilus sieboldi von Nordmann, 1832	–	–	*	–	*	–	–	–	25
Lernaeidae									
Lernaea cyprinacea Linnaeus, 1758	–	–	–	–	*	–	*	–	25
Seasonal species numbers	**53**		**54**		**52**		**37**		

When evaluated according to the frequency index, 3 species (F ≥ 76%) were classified as constant, 11 species (75% > F ≥ 51%) were classified as common, 35 species (50% > F ≥ 26%) were classified as occasionally and 17 species (F < 26%) were classified as rare. Among these dense species, *Brachionus quadridentatus* and *Keratella tropica* were determined with the highest frequency (100%) in all seasons. *Polyarthra dolichoptera* (88%), *Brachionus bidentatus, Trichocerca pusilla, Lecane scutata* and *Rotaria neptunia* (75%), *Brachionus caudatus*, *Lecane bulla*, *Lecane closterocerca*, *Colurella adriatica*, *Filinia longiseta*, *Bosmina longirostris*, *Acanthocyclops robustus*, *Onychocamptus mohammed* (63%), *Brachionus angularis*, *Brachionus calyciflorus*, *Brachionus falcatus*, *Keratella cochlearis*, *Keratella tecta*, *Platyias quadricornis*, *Lecane hamata*, *Polyarthra vulgaris*, *Synchaeta stylata*, *Asplanchna sieboldin*, *Collotheca pelagica*, *Pompholyx sulcate*, *Ascomorpha ovalis*, *Dichranophorus epicharis* and *Moina micrura* (50%) are other zooplanktonic organisms that are frequently seen (Table 2).

DISCUSSION

Temperature increases biological activity in water and accelerates biochemical reactions, which affects the reproduction, feeding and metabolic activities of aquatic organisms. Temperature is one of the most important environmental parameters affecting biodiversity and zooplankton density in aquatic ecosystems (Herzig, 1987; Sharma et al., 2007). Environmental conditions, particularly water temperature, have been reported to have a significant and positive effect on zooplankton diversity and abundance (Rossetti et al., 2009; Dorak, 2013). In this study, where similar results were found, the highest number of species (54 species) was found in the summer season when the average temperature is highest (25.00±0.28).

The amount of dissolved oxygen varies depending on the trophic state of the lakes and the water temperature (Viet et al., 2016). Studies have shown that low oxygen conditions can affect the growth, reproduction and distribution of zooplankton, and it has been reported that dissolved oxygen levels below 5 mg L^{-1} in freshwater can limit the growth of zooplankton (Karpowicz et al., 2020). In the study, the lowest dissolved oxygen was measured in summer and the highest in winter, as high temperature reduces dissolved oxygen in water and increases it at low temperature. The dissolved oxygen values found (8.05–9.55 mg L^{-1}) were above 5 mg L^{-1}. Looking at the dissolved oxygen content in the lake, it appears to be suitable for zooplankton life.

Conductivity, an important water quality parameter, is significantly related to zooplankton diversity, abundance and distribution, and an inverse relationship between conductivity and zooplankton species diversity has been found (Estlander et al., 2009; Tavsanoglu et al., 2015). In general, conductivity increases in places where there is insufficient water inflow due to evaporation when the water temperature rises. Pollution can increase the conductivity of lakes and rivers, as industrial and anthropogenic effluents often have high conductivity (Wetzel, 1983). While the electrical conductivity in the reservoir was found to be high in summer and fall and low in winter and spring, the conductivity values were found to be at a very low level between 139 and 215 μS cm^{-1} and suitable for zooplankton life (Estlander et al., 2009).

pH, which is important for the life cycle of zooplankton, can affect the abundance of zooplankton. Alkaline conditions strongly correlate with primary production and promote zooplankton growth and abundance (Bednarz et al., 2002; Mustapha, 2009), while low pH leads to a decrease in zooplankton abundance, species diversity and extinction of some species (Ivanova and Kazantseva, 2006). In the Surface Water Resources Quality Criteria Regulation (OSİB, 2015), published by the Ministry of Forestry and Water Affairs of the Republic of Türkiye, it is stated that the freshwater pH value, at which many aquatic creatures can sustain their normal life without harming their physiology, should be between 6.00 and 9.00. The pH of the reservoir is between 7.40 and 8.65 and is slightly alkaline and suitable for the survival of zooplankton species (Tessier and Horwitz, 2011).

This study is the first zooplankton study in the young Reyhanlı Reservoir, the construction of which was completed in 2020. 67 species were identified in this study, with the Rotifera being the dominant group with 80.30%.

Various studies have shown that rotifers dominate both qualitatively and quantitatively in stagnant waters, such as most lakes, ponds, reservoirs and wetlands (Jamila et al., 2014; Ismail and Adnan, 2016; Dorak et al., 2019; Saler et al., 2019). In addition, Segers (2007) reported that rotifers occur in almost all types of freshwater habitats, e.g., large permanent lakes, small temporary ponds, intermediate and capillary waters, acidic mineral lakes, fizzy drink lakes, hyperoligotrophic alpine lakes and sewage ponds.

Species reported by various researchers to be good indicators of eutrophic conditions and pollution are *A. coelata*, *B. angularis*, *B. calyciflorus*, *B. quadridentatus*, *B. urceolaris*, *K. cochlearis*, *K. tecta*, *K. tropica*, *L. patella*, *T. pusilla*, *C. forficula*, *R. neptunia*, *C. mutabilis*, *P. sulcata*, *A. ovalis*, *F. longiseta*, *B. longirostris* (Dussart, 1969; Voigt and Koste, 1978; Pesce and Maggi, 1981; Berzins and Bertilsson, 1990; Hansen and Jeppesen, 1992; De Manuel Barrabin, 2000; Petrusek, 2002; Shah and Pandit, 2013; Apaydın Yağcı, 2016; Heneash and Alprol, 2020) was also detected in this study. They also proposed that genus *Brachionus*, *Lecane*, *Trichocerca* and

Keratella can be considered a target taxon for more intensive monitoring of water quality and conservation planning on aquatic environment (Ceirans, 2007). Additionally, *M. micrura*, *C. vicinus* and *A. robustus* are species that are not indicators of eutrophication but are commonly found in eutrophic waters (Jana and Pal, 1985; Crosetti and Margaritora, 1987; Hart, 1990). Unlike these, four species (*P. stylata*, *Collatheca pelagica*, *C. mutabilis*, *F. opoliensis*) reported to be oligotrophy indicators by Sládeček (1983) were also found in this study.

The presence of a large number of eutrophication indicator species (17) and a smaller number of oligotrophication indicator species (4) in the dam lake suggests that the dam lake is under the threat of eutrophication, despite being newly established. However, the low abundance of eutrophication indicator species suggests that the dam lake is not currently under the risk of eutrophication. The majority of the species detected are widespread, cosmopolitan species (Keppeler 2003; Keppeler and Hardy 2004; Segers 2007; Melo Júnior et al. 2007; Santos et al., 2013) that have been detected in previous studies in this region (Eastern Mediterranean inland waters).

Some of the species in the study; *A. sieboldii*, *B. angularis*, *B. quadridentatus*, *C. gibba*, *C. pelagica*, *C. adriatica*, *C. colurus*, *F. longiseta*, *K. cochlearis*, *K. quadrata*, *K. tecta*, *L. bulla*, *L. closterocerca*, *L. flexilis*, *L. luna*, *L. pyriformis*, *L. patella*, *P. quadricornis*, *P. dolichoptera*, and *T. pusilla* have been reported to tolerate a wide range of conductivity (Arcifa et al., 1994; De Ridder and Segers, 1997; Baribwegure and Segers, 2001; Pattnaik, 2014). Some others; *B. calyciflorus*, *P. quadricornis*, *L. luna*, *C. adriatica*, *C. colurus*, *C. mutabilis*, *L. patella*, *T. patina*, *Nitokra hibernica* and acidic *K. cochlearis* and *C. gibba* have been reported to be euryhaline (De Smet 1996; De Ridder and Segers 1997; Fontaneto et al. 2006; Jersabek and Bolortsetseg, 2010; Defaye and Dussart 2011). The fewer species in the study are; *B. quadridentatus*, *B. urceolaris*. *L. bulla, L. flexilis*, *L. rhomboides* and *R. neptunia* have high tolerance to alkaline waters (De Smet, 1996; Ramdani et al., 2001; Rybak and Bledzki, 2010; De Smet, 1996; Rybak and Bledzki, 2010).

In this study, some species (*L. aculeate*, *L. flexilis*, *L. hamata*, benthic *L. inermis*, *L. stenroosi*, *C. colurus*, *L. patella*, *C. forficula*, *E. najas*, *D. hertzogi*, *C. pelagica*, *C. mutabilis*, *D. epicharis*, benthic *M. laticornis* and *I. sordidus*) was found only on plants. It has been reported by various researchers that the same species are commonly found on littoral plants and to a lesser extent on plankton (Koste, 1978; De Smet, 1993; Hingley, 1993; Segers, 1995; De Manuel Barrabin, 2000; Kuczynska-Kippen, 2000). Therefore, it is thought that the fact that it was found only on plants in the study is due to its general ecological characteristics.

Some species in the study (*A. coelata*, *B. angularis*, *B. budapestinensis*, *B. calyciflorus*, *B. falcatus*, *K. cochlearis*, *K. quadrata*, *K. tecta*, *P. vulgaris*, *S. stylata*, *A. sieboldi*, *P. sulcata*, *F. opoliensis*, *P. tentaculatus*, *M. micrura*, *C. vicinus*, *E. sieboldi*, *L. cyprinacea*) were never found on plants and were only found in plankton. Researchers have reported that these species are widely distributed, mostly found in pelagic, but less commonly on plants and benthic (Hutchinson, 1967; Ruttner-Kolisko, 1974; Margalef et al., 1976; Braioni and Gelmini, 1983; Koste and Shiel, 1986, 1987; Ramdani et al., 2001; Santos et al., 2013).

The crustacean parasitic copepods, *Lernaea cyprinacea* and *Ergasilus sieboldi*, have a life cycle in which males are free-living and adult females go through a free-living stage before becoming parasitic and feed on algae (Molnar and Szekely, 1997; Hossain et al., 2018). Therefore, due to the life cycle of these species, not all stages are parasitic and it is quite normal for them to be found in plankton.

CONCLUSION

The zooplankton species in the dam lake consist of cosmopolitan, widely distributed species that tolerate a wide range of conductivity, salinity and alkalinity. Rotifera was the dominant group, followed by Copepoda and Cladocera. The dominant families were Brachionidae and Lecanidae (Rotifera), Chydoridae (Cladocera) and Cyclopoidae (Copepoda). Although the dam lake is newly established, considering the high number of eutrophication indicator species (17 species).

COMPLIANCE WITH ETHICAL STANDARDS

Conflict of Interest

The author declares that there is no conflict of interest.

Ethical Approval

For this type of study, formal consent is not required. Permission to take water samples was obtained from the Ministry of Agriculture and Forestry with the official letter number E-67852565-140.03.03-5292356.

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Data Availability

The data supporting the findings of this study are available from the corresponding author upon request.

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Assessing the status and management of European eel, *Anguilla anguilla* (Linnaeus 1758) fisheries in Türkiye: Trends, challenges, and conservation strategies (2019-2023)

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A B S T R A C T

The European eel, *Anguilla anguilla* (Linnaeus 1758) is a species of critical ecological importance, facing significant population declines due to anthropogenic pressures such as habitat degradation, migration barriers, pollution, overfishing, and climate change. This study investigates the status of European eel fisheries in Türkiye from 2019 to 2023, focusing on the implications of local management practices and environmental changes on eel populations. Utilizing official catch data from the Turkish Statistical Institute, the study analyses trends across three Eel Management Areas (EMAs) in Türkiye. The results reveal a significant decline in eel catches in EMA-1, suggesting urgent conservation needs, while EMA-2 and EMA-3 exhibit relative stability, potentially reflecting effective local management practices and habitat suitability. The results underscore the necessity for region-specific management strategies that consider ecological, environmental, and socio-economic factors. This research contributes to the development of informed management strategies aimed at ensuring the sustainability of European eel fisheries in Türkiye, aligning with international conservation efforts.

INTRODUCTION

The European eel, *Anguilla anguilla* (Linnaeus 1758) is a critically important species in both freshwater and marine ecosystems, recognized for its complex life cycle and ecological significance. This species is in IUCN as a Critically Endangered fish species on the Red List (Pike et al., 2020). Historically, the European eel was abundant across Europe and North Africa; however, it has experienced a dramatic population decline over the past few decades. This decline is largely attributed to various anthropogenic pressures, including habitat degradation, migration barriers, pollution, overfishing, and the impacts of climate change (Bilotta et al., 2011; Denis et al., 2024; ICES, 2024). One notable aspect of the European eel's life history is its long migration from freshwater habitats to spawning grounds in the Sargasso Sea, which poses significant challenges for its survival (van Ginneken et al., 2005; Righton et al., 2016). This migratory behaviour, combined with environmental stressors, has rendered the species particularly vulnerable. Factors such as the construction of dams, alteration of river flows, and loss of wetlands significantly impact the availability of suitable habitats for eels (Cresci, 2020; Podda et al., 2022; Chen et al., 2023).

Türkiye's unique geographical position offers diverse ecological conditions suitable for eel habitats; however, the current status of European eel fisheries in the country has not been extensively studied, highlighting a crucial gap in

knowledge regarding the sustainability of this species. Recent conservation efforts, including fishing quotas and habitat protections, aim to address the decline in eel populations, but their effectiveness remains to be fully evaluated (Violi et al., 2015; Rohtla et al., 2020; Gurkan et al., 2024). Moreover, the International Council for the Exploration of the Sea (ICES) has emphasized the need for urgent management actions to mitigate the decline of the European eel, recommending further research into recruitment dynamics and habitat conditions (ICES, 2023). Given the increasing pressures on freshwater ecosystems and fish populations, it is critical to conduct comprehensive assessments of eel fisheries in Türkiye.

The Eel Management Area (EMA) is an area-based concept for the conservation and sustainable utilization of eels within defined geographical zones. An EMA sets out to achieve two objectives: the shrinking of the eel population base and the sustainable development of its ecosystems. EMAs are generally delimited by the natural features of a river basin. This makes it possible to administer more effectively, eel fisheries in as much as it looks at the relationship of ecosystems in which these species are found. By examining eel fishery in an area, advocated EMAs would assist in sustainable fish harvesting by providing pre-emptive recommendations. Which include the establishment of the annual limits for catches, suspension of fishing activities within specific timeframes, and ways of minimizing incidental catch (Dekker, 2016; Drouineau et al., 2018). This study aims to explore the status of European eel catches in Türkiye from 2019 to 2023, focusing on the implications of local management practices and environmental changes on the species' populations. Understanding these dynamics will contribute to the development of informed management strategies that support the sustainability of European eel fisheries in Türkiye. In this context, changes in fishing data in eel management plan areas in Türkiye were examined.

MATERIALS AND METHODS

This study examines the catches of European eel from various regions of Türkiye between 2019 and 2023. The research is based on official fishing data obtained from the Turkish Statistical Institute (TÜİK). The coverage of the study includes the eel catch data reported from provinces of Adana, Antalya, Aydın, Balıkesir, Denizli, Edirne, Hatay, Isparta, Kahramanmaraş, Manisa, Mersin, Muğla, Osmaniye, Çanakkale, and İzmir. The dataset includes annual catch amounts (tons) for each province.

Eel Management Area (EMA) Classification

Eel Management Area (EMA) is a geographical area created for the protection and sustainable management of a series of river basins (Özdilek and Özdilek, 2020). EMA regions facilitate the evaluation of province-based eel fisheries and give reliable suggestions for sustainable fishing.

Table 1 presents the distribution of eel catch data recorded in each province by EMA regions. The classification of provinces was evaluated by (Özdilek and Özdilek, 2020). According to this classification, the annual catch amounts and their importance for European eel conservation will be evaluated for the relevant regions. This regional classification is crucial for developing sustainable management strategies.

Table 1. EMA classification of Türkiye's European eel catching provinces

EMA Region	Provinces
EMA-1	Balıkesir, Çanakkale, Edirne, Manisa, İzmir
EMA-2	Aydın, Muğla, Antalya, Denizli, Isparta
EMA-3	Adana, Hatay, Mersin, Osmaniye, Kahramanmaraş

To assess the trends in European eel (*Anguilla anguilla*) catches across the different Eel Management Areas (EMAs) in Türkiye, we conducted a Mann-Kendall trend test on the annual catch data from 2019 to 2023.

RESULTS

The total European eel catch in Türkiye from 2019 to 2023 across all three Eel Management Areas (EMAs) amounted to 1549 tons. The distribution of catches by EMA is as follows: EMA-1 accounted for 184 tons (11.88%), EMA-2 contributed 821 tons (53%), and EMA-3 represented 544 tons (35.12%).

The European eel catch in EMA-1 exhibited a clear declining trend over the five-year period (Figure 1, Table 2). Starting with 46 tons in 2019, the catch declined progressively each year, reaching a low of 14 tons by 2023. This decline suggests either a decrease in eel population or changes in fishing effort and efficiency, a pattern that necessitates further investigation to establish underlying causes. The results obtained from the Mann-Kendall trend test showed a statistically significant declining trend of eel catch in EMA-1 region ($S= -10$, $P=0.0373$).

In contrast, EMA-2 demonstrated relative stability in catch amounts (Figure 2, Table 2). Beginning with 175 tons in 2019, there was a fluctuation in catch amounts over the years, with a dip to 157 tons in 2021 and 2022 followed by an increase to 166 tons in 2023. This variability showed a statistically insignificant trend over the study period ($S= -3$, $P=0.788$). The relatively stable catch figures suggest that local management practices, potentially including habitat protection efforts, might be maintaining stable eel populations in this region.

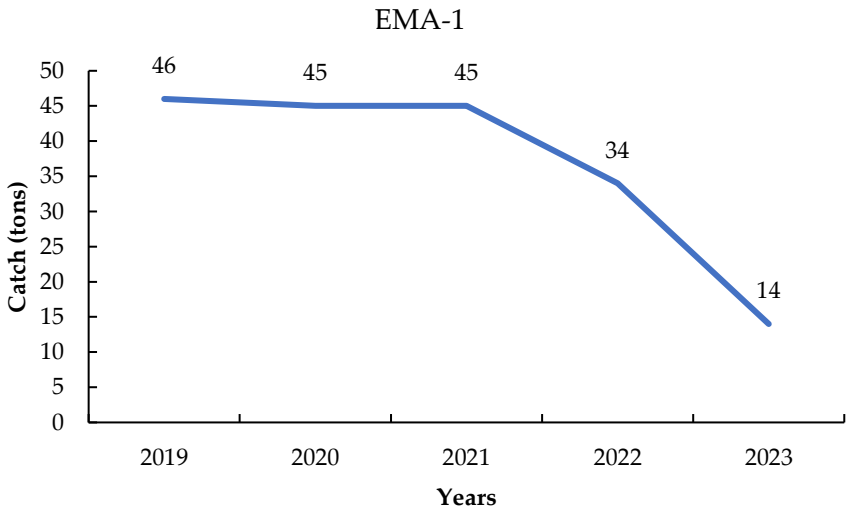

Figure 1. Annual catch amount of European eel in EMA-1 region of Türkiye (2019-2023)

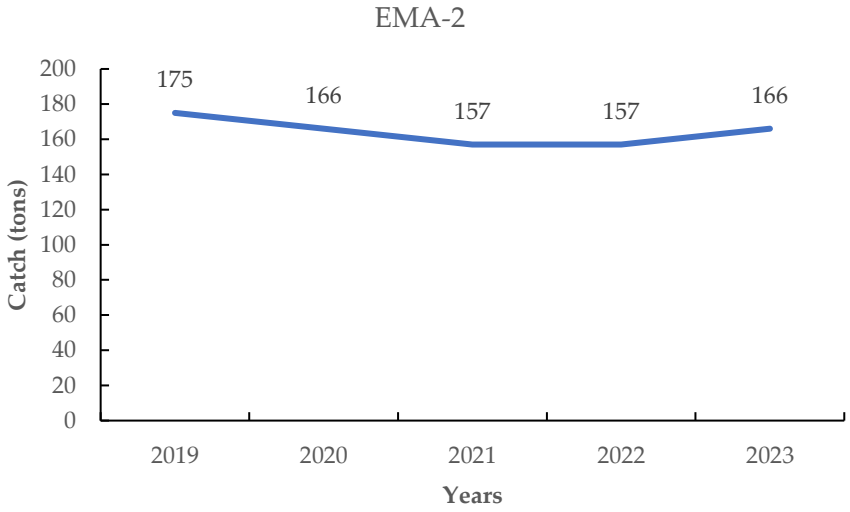

Figure 2. Annual catch amount of European eel in EMA-2 region of Türkiye (2019-2023)

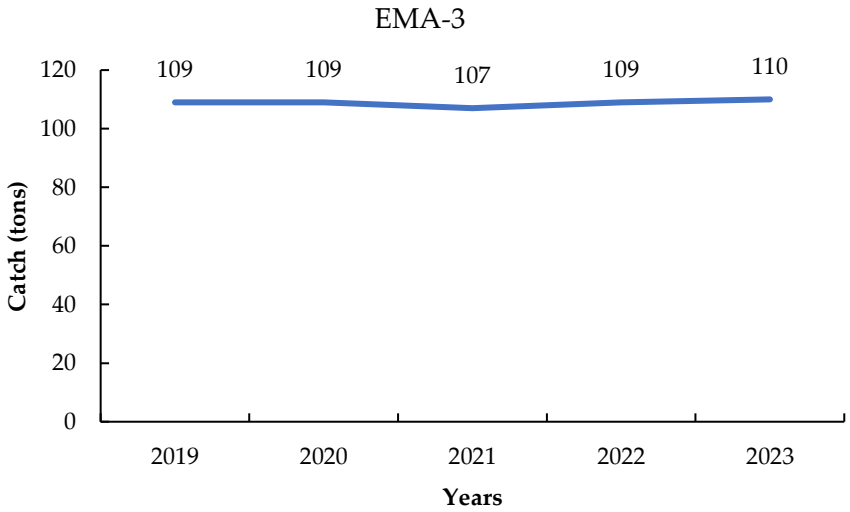

Figure 3. Annual catch amount of European eel in EMA-3 region of Türkiye (2019-2023)

Table 2. Annual European eel catch amount by EMA region and province in Türkiye (2019-2023)

Year	EMA Region	Provinces	Catch Amount (tons)
2019	EMA-1	Balıkesir, Balıkesir, Çanakkale, Edirne, Manisa, İzmir	46
	EMA-2	Aydın, Muğla, Antalya, Denizli, Isparta	175
	EMA-3	Adana, Hatay, Mersin, Osmaniye, Kahramanmaraş	109
2020	EMA-1	Balıkesir, Çanakkale, Edirne, Manisa, İzmir	45
	EMA-2	Aydın, Muğla, Antalya, Denizli, Isparta	166
	EMA-3	Adana, Hatay, Mersin, Osmaniye, Kahramanmaraş	109
2021	EMA-1	Balıkesir, Çanakkale, Edirne, Manisa, İzmir	45
	EMA-2	Aydın, Muğla, Antalya, Denizli, Isparta	157
	EMA-3	Adana, Hatay, Mersin, Osmaniye, Kahramanmaraş	107
2022	EMA-1	Balıkesir, Çanakkale, Edirne, Manisa, İzmir	34
	EMA-2	Aydın, Muğla, Antalya, Denizli, Isparta	157
	EMA-3	Adana, Hatay, Mersin, Osmaniye, Kahramanmaraş	109
2023	EMA-1	Balıkesir, Çanakkale, Edirne, Manisa, İzmir	14
	EMA-2	Aydın, Muğla, Antalya, Denizli, Isparta	166
	EMA-3	Adana, Hatay, Mersin, Osmaniye, Kahramanmaraş	110

The catch data from EMA-3 remained relatively consistent, with only minor fluctuations noted throughout the five years (Figure 3, Table 2). Starting with 109 tons in 2019, the catches slightly decreased to 107 tons in 2021, returning to 110 tons in 2023. The Mann-Kendall test showed an insignificant trend (S=1, P=0.85), indicating a stable capture that mirrors EMA-2's dynamics. This stability may reflect either robust local populations or consistent fishing practices.

The analysis of European eel catches in Türkiye from 2019 to 2023 revealed significant trends and regional variations across different Eel Management Areas (EMAs). Catch data were used to assess the population status of the European eel, complementing ongoing efforts to develop effective fishery management strategies.

DISCUSSION

The current investigation into the status of European eel, *A. anguilla* fisheries in Türkiye from 2019 to 2023 highlights critical trends that underscore the complexity of managing eel populations amidst varying regional pressures. The drastic reduction experienced in EMA-1 (Marmara and North Aegean Region) corresponds with some existing works which highlight the similar constraints facing the European eel populations where aquatic habitats are destroyed, migrations are disrupted and pollution abounds (Dekker, 2003; ICES, 2023; Órfão et al., 2024). These stressors have been widely acknowledged as primary factors contributing to the decline of eel populations across their range. Such stressors have been recognized widely as dominant reasons for the depletion of eel in all geographies. This emphasizes that there should be no further delay in taking all possible conservation measures, especially habitat restoration and stricter exploitation measures.

On the other hand, while the trends of eel landings in EMA-2 (Western Mediterranean Region) and EMA-3 (Eastern Mediterranean Region) were similar to other regions of the country, this could indicate inefficient regional variation monitoring exercises or adaptation to the environmental conditions and effects of 'the management measures in place. It has been reported that the Black Sea basin and the coast of the Mediterranean Sea are quite possibly enthusing more eel population due to the peculiar ecological condition or effective conservation strategies in place (Gurkan et al., 2024). Our results are consistent with the outcome obtained from previous studies emphasizing the need for localized strategies in the management of eels (Özdilek and Özdilek, 2020). For instance, current studies indicate that eels should be studied and potentially exploited as regional stock units with specific environments and economies. Such regional specificity is important in devising measures aimed at the management of eels that take into account the prevailing local conditions.

In the same vein, it has been reported that growth of European eels inhabiting some Turkish rivers varies with respect to environmental conditions (Yalcin Ozdilek et al.,

2006), showing their dependence more on local rather than migratory study and management approaches. This has been echoed in the many research programs working towards the international society for eel management that has decried ineffective generic approaches to eel management that do not reach the geographical local in which the eels are (ICES, 2023).

These results underscore the importance of region-specific management strategies, considering the varying trends observed in different EMAs. The notable decline in EMA-1 highlights an urgent need for targeted conservation efforts, including stricter fishing quotas or habitat restoration projects. Conversely, the stable conditions in EMA-2 and EMA-3 suggest that current strategies may be sufficient but also require ongoing monitoring to ensure effectiveness amidst potential environmental changes.

CONCLUSION

In conclusion, this study underscores the imperative of embracing a regionally nuanced management approach that considers ecological, environmental, and socio-economic factors to preserve European eel populations. Future policies should prioritize evidence-based adaptive management strategies, including continuous monitoring and data evaluation, to safeguard this critical species. Given the mounting pressures on freshwater ecosystems globally, a collaborative, informed approach to fisheries management will be crucial in sustaining eel populations and ensuring the long-term viability of Türkiye's eel fisheries.

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COMPLIANCE WITH ETHICAL STANDARDS

Authors' Contributions

AA: Data curation, Investigation, Visualization, Writing – original draft

HA: Conceptualization, Investigation, Methodology, Visualization, Writing – original draft, Writing – review & editing

All authors read and approved the final version of the article.

Conflict of Interest

The authors declare that there is no conflict of interest.

Ethical Approval

For this type of study, formal consent is not required.

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Not applicable.

Data Availability

The data supporting the findings of this study are available from the corresponding author upon request.

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Maritime transportation disaster management and humanitarian: Iskenderun region

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A B S T R A C T

Throughout history, natural and man-made disasters have caused severe humanitarian crises, both worldwide and in Türkiye. These disasters have necessitated extensive humanitarian aid as well as efficient and rapid logistics management. This article analyzes the role of maritime transportation in disaster management and humanitarian aid processes in Iskenderun Region, with a focus on the 6 February 2023 earthquakes in Türkiye. Utilizing literature through reviews, surveys, and data analyses, the study examines the effectiveness of maritime transportation in disaster response activities. The results of the survey conducted with 160 participants indicate that maritime transport plays a critical role in disaster management processes. While the majority of participants expressed that maritime transport provides a rapid and effective response to disasters, some participants highlighted the need for infrastructure improvements to enhance the efficiency of these processes. These findings suggest that the current maritime transport infrastructure requires strengthening to improve its effectiveness in disaster management. Most of the participants highlighted the rapid and effective responses enabled by maritime transportation and humanitarian aid processes, but some emphasized the need to strengthen its infrastructure.

INTRODUCTION

Disasters negatively impact the human lives and necessitate extensive humanitarian aid. A disaster is an unpredictable event that disrupts the course of life, often resulting in loss of life and property. Many disasters have occurred since the dawn of humanity. The term 'disaster' is derived from Arabic, meaning destruction, calamity, or catastrophe (Çeber, 2005). In brief, a disaster is a cumulative event caused by human-made or natural factors, resulting in long-term impacts on living beings and significant loss of life and property (Coppola, 2011).

Disasters can be categorized into natural and technological disasters. Natural disasters include earthquakes, landslides, volcanic eruptions, floods, tsunamis, droughts, environmental epidemics, desertification, deforestation, and pandemics. Technological disasters encompass nuclear, chemical, industrial, and maritime transportation accidents, as well as terrorist acts. These technological disasters can be triggered during the natural flow of life or as a result of natural disasters (Akyel, 2007).

Humanitarian aid is defined as all assistance including money, gifts, and services, provided to those in need. As opposed to development aid, humanitarian aid is intended to be temporary and is not aimed at long-term or permanent solutions. It includes daily essentials to sustain life temporarily. Long-term aid, also known as development aid, is typically implemented for a limited period before changes are made. The recipients of aid include the vulnerable groups such as elderly, disabled, displaced, refugees, and all victims of natural disasters, wars, and famines.

Research on the challenges of humanitarian logistics (HL) in disaster relief reveals significant obstacles to logistical organization, including poor communication. Kovács and Spens (2009) highlight that these challenges vary depending on the type, severity, location, and timing of the disaster. One of the main challenges is ensuring coordination of logistical activities at both intra-organizational and inter-organizational levels. Poor communication and teamwork can severely disrupt logistics operations, both within and between humanitarian organizations. Lack of standard procedures and training for logisticians reduces the efficiency of aid efforts (Kovács and Spens, 2009; Moshtari and Gonçalves, 2012).

Humanitarian organizations often struggle with disrupted supply chains caused by access restrictions, limited capacity, and security issues. Unpredictable road conditions, travel bans, and border closures make maritime transportation even more challenging. The distribution process becomes increasingly complicated as numerous local and international organizations, each with their own procedures and priorities, get involved (Balcik et al., 2008; Nikbakhsh and Farahani, 2017).

External factors, like the influence of social media, also affect humanitarian logistics. While social media can expedite information sharing, it can also spread misinformation and distract logistics teams. The presence of many new and emerging organizations, as seen after the 2010 Haiti earthquake, adds another layer of complexity to the process (Van Wassenhove and Besiou, 2013; Kunz and Reiner, 2016).

Throughout history, both globally and in Türkiye, natural and technological disasters have occurred frequently, requiring extensive humanitarian aid and effective logistics management. Maritime transportation lays a vital role in disaster management by enabling the rapid and cost-effective maritime transportation of large volumes of materials. According to UNCTAD, over 80% of the volume of international trade in goods is carried by sea, and the percentage is even higher for most developing countries (UNCTAD, 2021).

Modern disaster management involves Prevention of natural disasters and accidents, preparation activities for these situations, and post-disaster response and recovery activities. Initially, hazards are understood, and countermeasures are taken. Plans and training are prepared for potential disaster scenarios, and public awareness is raised. Rapid response during a disaster is crucial, such as search and rescue activities and delivery of essential materials such as food, water, medicine, and shelter. Post-disaster efforts, on the other hand, focus on repair of damaged areas and restoration of normalcy. Governments, aid organizations, and communities should work together, using technology effectively to minimize disaster impacts and build a safer and more resilient society (Kadıoğlu and Özdamar, 2008).

The relationship between modern disaster management and humanitarian logistics (HL) is critical for minimizing disaster impacts and ensuring effective aid. Modern disaster management comprises four main phases: mitigation, preparation, response, and reconstruction. These phases encompass the core processes of humanitarian logistics and determines how logistical activities can be optimized at each stage.

1. Mitigation: This phase involves taking steps to prevent or lessen the negative impacts of disasters. It starts with hazard analyses to identify risks, followed by implementing necessary structural and non-structural measures. From the perspective of humanitarian logistics, this means strategically positioning logistics facilities and pre-stocking essential supplies (Warfield, 2008).

2. Preparation: This phase focuses on activities to get ready before a disaster strikes. It includes organization of logistics networks, preparation of emergency plans, and rehearsals. It's also crucial to identify collaboration partners and align information and communication technologies during this phase (Kunz et al., 2014).

3. Response: This phase involves quick and effective action during a disaster. It includes distributing emergency supplies, evacuating the survivors, and providing essential services. From a logistics perspective, rapid mobilization and coordination of resources are crucial in this stage (Altay et al., 2013).

4. Reconstruction: This phase focuses on long-term solutions after a disaster. It involves reconstruction of damaged structure and Infrastructure and restoration of normalcy. Logistics processes play a key role in rehabilitation and solidarity efforts during this phase (Warfield, 2008).

Humanitarian logistics is vital in every phase of disaster management. For example, during the pre-disaster preparation phase, proper storage and supply chain management actions are essential. During the disaster response phase, quick interventions and the distribution of materials are critical. In the reconstruction phase, long-term logistics planning and sustainability are of utmost importance. Humanitarian logistics requires the coordination of various institutions and organizations, including governments, NGOs, and the private sector. Each entity contributes differently in their respective capacities and mandates. For instance, military units are capable of

rapid intervention, while NGOs play a crucial role in identifying and meeting needs by working closely with local communities (Kovács and Spens, 2007). Using maritime transportation during disasters allows for faster and more effective interventions. Historical examples, such as the use of Ottoman ships to deliver aid during the seven-year famine in Ireland in 1847, demonstrate the long-standing importance of maritime transportation in disaster response.

Identifying, preventing, and managing hazards and emergencies at seaports is also crucial. Skiba (2023) emphasizes the need for well-prepared laws and regulations to ensure maximum safety in maritime transportation. Because seaports play a critical role in security and crisis management and the port administrations must always be ready for a swift and effective response during crises (Skiba, 2023) and they cannot carry out these functions without suitable laws and regulations.

Dui et al. (2021) propose a new method to optimize resilience management in maritime transportation systems (MTS). The new method defined by Wan et al. (2018) is a strategic approach aimed at optimizing resilience management in maritime transportation systems (MTS). This method enables MTS to be prepared against risks, respond swiftly and effectively to operational disruptions, and strengthen its capacity to return to normal operations.

Incorporating components such as systematic risk assessment, flexible design, real-time monitoring, and stakeholder collaboration, this approach seeks to optimize the resilience capacity against potential disruptions while enhancing operational efficiency by considering the complex and dynamic nature of MTS. Their study shows that ports and maritime routes can easily be disrupted by political and natural events that cause significant socio-economic impacts. They developed a model based on post-disruption analyses to optimize the resilience of ports and routes, aiming to prioritize their restoration to enhance disaster management resilience. Dui et al stress the need for substantial measures to increase the resilience of maritime transportation systems, which would accelerate post-disaster recovery (Dui et al., 2021).

Effective communication during a disaster facilitates rapid intervention. Islam et al. (2020) utilize an Automatic Identification System (AIS) data for disaster management at ports which continuously transmits critical information such as the position, identity, speed, and route of ships. Their study aims to estimate the quantity of essential goods carried by ships using AIS data and artificial intelligence networks. This helps disaster managers more accurately assess post-disaster needs and make informed aid decisions. Islam et al highlight that AIS data improves post-disaster logistics processes and enables more effective aid distribution and can also enhance pre-disaster preparations (Islam et al., 2020). Proper maritime logistics planning during disasters is essential as chaos and lack of planning negatively impact disaster logistics.

Wang and Tanaka (2016) developed a planning model to optimize maritime logistics during emergencies or disasters. The model aims to optimize maritime logistics by assigning ships to relevant maritime transportation routes. Applied in a Tonankai earthquake scenario, the model estimates the required resources during a disaster. Their study demonstrates how to manage maritime logistics in emergencies by determining the necessary ships and materials under different scenarios. Wang and Tanaka emphasize that this model can be adapted to other disaster scenarios, ensuring efficient resource use in disaster management. Their study underscores the critical role of maritime logistics in disaster scenarios and the importance of proper planning for faster post-disaster recovery (Wang and Tanaka, 2016).

Ozkapici et al. (2016) was examined the intermodal aid distribution model involving maritime and road transportation in Istanbul. Given Istanbul's vulnerability to earthquakes, the model aims to utilize the flexibility and accessibility of maritime transportation for effective and reliable humanitarian logistics operations. The model focuses on transporting aid materials between the European and Anatolian sides of Istanbul using maritime routes, ensuring faster and more reliable delivery of aid materials to areas in need. Their study demonstrates how to optimize post-disaster aid operations using the flexibility and efficiency of maritime transportation (Ozkapici et al., 2016).

In conclusion, effective maritime logistics planning during disasters significantly contributes to humanitarian aid operations. The literature highlights that maritime transport plays a crucial role, particularly in providing logistical support, increasing capacity, and facilitating accessibility (Kovács and Spens, 2007; Rodrigue, 2014). In this context, the preparedness level of the Port of Iskenderun in disaster management and humanitarian aid processes is generally considered "moderate." However, studies on the resilience of ports and logistical challenges emphasize the need for further implementation of emergency plans, training programs, and awareness-raising initiatives (Lam and Su, 2015).

The assessments specific to the Iskenderun Port reveal that the effectiveness of emergency plans and training programs is "moderate" and that these processes need improvement. Over the years, investments and projects aimed at enhancing the resilience of ports against disasters

have proven insufficient. Therefore, it is evident that maritime transport strategies should be reviewed, and greater logistical support, capacity, and accessibility, particularly in disaster management processes, must be ensured (Van Wassenhove, 2006). Ultimately, reviewing current strategies and investing in projects that boost logistical capacity will enable ports to be used more effectively during humanitarian aid operations in times of disaster (Jahre and Heigh, 2008).

The purpose of this study is to highlight the critical role that maritime transport plays in humanitarian aid operations within disaster management. Disasters are unexpected events that deeply affect human life and threaten the fundamental structures of societies. In such situations, the swift and effective delivery of aid is one of the most vital components of saving lives and facilitating societal recovery. Maritime transport offers a strategic logistical solution in post-disaster recovery due to its capacity to deliver large quantities of aid materials quickly, economically, and across vast geographical areas. However, there is a significant gap in the literature regarding the integration of maritime transport into disaster logistics. This study aims to fill that gap by contributing to the more efficient delivery of humanitarian aid, thereby improving the living conditions of disaster victims more rapidly. From an academic perspective, this research not only emphasizes the strategic importance of maritime transport in disaster management processes but also lays the groundwork for the development of more effective, sustainable, and resilient logistical solutions. In doing so, it will help ensure that societies are more resilient and prepared for future disasters.

MATERIALS AND METHODS

This study evaluates the effectiveness of maritime transportation in disaster management and humanitarian aid processes in the Iskenderun Region through literature reviews, surveys, and data analyses. After preparing the questions and obtaining Ethics Committee approval, the survey was distributed to relevant individuals via Google Forms, and responses were recorded electronically with their consent. Initially, demographic information such as age, gender, education level, and occupation were collected. The survey responses were gathered and compiled into a table format.

The data was collected through the Google Forms platform, which automatically recorded and stored responses to the survey questions. The data was analyzed using Python. The survey conducted in the Iskenderun region on maritime transportation's role in disaster management and humanitarian aid processes was designed to include various demographic groups and types of institutions. The survey collected data from individuals working in different institutions, including humanitarian aid organizations, port operators, and students. Including participants from various genders and age groups ensured that the sample represented the stakeholders in the region. Data was collected through an online survey, allowing participants to respond over an extended period. This method provided scientifically and statistically valid results in evaluating the impact of maritime transportation on humanitarian aid processes during disasters. The collected data was analyzed using the Python programming language. First, the survey data was transformed into a table format using the Pandas library, and frequency and percentage analyses were conducted. This allowed for the calculation of the distribution and percentage of responses to each question. Next, a chi-square test was applied to examine the relationships between variables; this test was particularly used to evaluate the relationship between the impact of maritime transportation on disaster management and the institutions where participants work. If the p-value was less than 0.05, it was concluded that there is a significant relationship between the two variables. The analysis results were visualized using Matplotlib and Seaborn libraries, making the findings easier to interpret. In this way, the data was summarized using basic statistical methods, while also allowing for a deeper examination of more complex relationships.

In this study, we engaged 160 participants involved in maritime transportation and disaster management. We distributed surveys to 300 individuals and achieved a 53.33 % response rate, which is acceptable for representativeness in social sciences. The participants were professionals from sectors like maritime transport, humanitarian aid organizations, and port operations. Our selection criteria included maritime industry employees, staff from humanitarian aid groups, logistics experts, public sector workers, and representatives of non-governmental organizations (NGOs). By focusing on participants with experience in disaster management and maritime processes, we aimed to gather meaningful data. Consequently, reaching a broad group of professionals and drawing on their expertise provided us with reliable and comprehensive insights into the role of maritime transportation in disaster management.

Shipowners, port authority employees, freight forwarders, maritime logistics workers, academics in marine science, professionals working in the logistics sector of the private industry, and personnel from the General Directorate of Coastal Safety (KEGM) are among the other professions that participated in the survey. The students who participated in the survey are maritime faculty students, and

the survey was distributed to them.

RESULTS AND DISCUSSION

Demographic data and responses from the survey were recorded in numerical format with confidentiality maintained throughout the data collection process. During the evaluation of the research data, frequency and percentage analyses were applied to each question. Chi-square tests were conducted for categorical variables to assess the significance of the data ($p < 0.05$). Additionally, demographic analysis was applied to questions related to age, education, and occupation.

The average age of the participants is 34.9, with an age range between 18 and 57. In terms of gender distribution, it was observed that 80 participants were female, 75 were male, and 1 preferred not to disclose their gender. Regarding the distribution based on the type of institution the participants work for, the highest participation came from employees of port operations, with 44 participants. Additionally, 33 students and 24 employees of humanitarian organizations also participated in the survey.

When examining the participants views on the impact of maritime transportation in humanitarian aid processes during disasters, 52 individuals evaluated maritime transportation as having a 'very high impact,' while 47 considered it to have a 'moderate' impact. Fewer participants believed that maritime transportation was less effective. These findings reveal that the majority of participants perceive maritime transportation as playing a significant role in humanitarian aid processes.

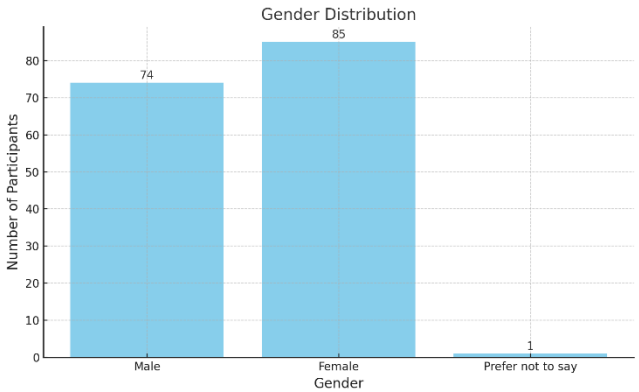

Figure 1. Gender distribution of survey participants

According to Figure 1, the number of male participants is approximately 74. The number of female participants is slightly higher, around 85. The number of participants who chose the "Prefer not to say" option is almost negligible. This distribution indicates a relatively balanced gender profile among participants, with a slight majority of female participants, presenting a positive picture regarding gender balance.

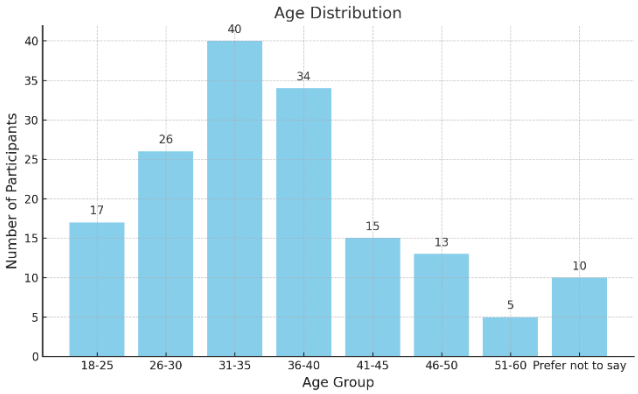

Figure 2. Age distribution of survey participants

Figure 2 shows the distribution of participants by age groups. The highest number of participants is in the 31-35 age group, with 40 participants. This is followed by the 36-40 age group with 34 participants, the 26-30 age group with 26 participants, and the 18-25 age group with 17 participants. The 41-45 age group has 15 participants, the 46-50 age group has 13 participants, and the 51-60 age group has 5 participants. Additionally, 10 participants preferred not to specify their age. This distribution indicates that the majority of participants are in their 30s, with a wide range of age groups represented.

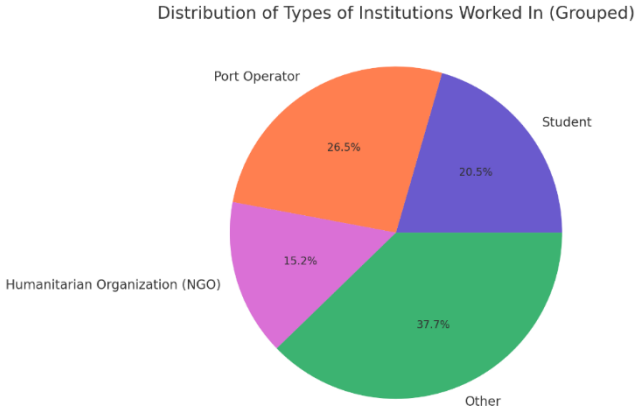

Figure 3. Distribution of the types of institutions worked

Most participants work in humanitarian aid organizations and port operations. The majority are employed by humanitarian aid organizations, with port operations being the second largest group. Students and the "Other" category are represented in lower proportions (Figure 3).

Percentage Analysis of Questions and Answers

1. How effective do you find maritime transportation in humanitarian aid processes during disasters? (Please select only one option)

Table 1. Frequency and percentage analysis of the survey question 1

Response	Frequency	Percentage (%)
Not Effective	3	5%
Slightly Effective	7	12%
Moderate	12	20%
Highly Effective	18	30%
Very Highly Effective	20	33%

The majority of participants (63%) find maritime transportation to be highly or very highly effective in humanitarian aid processes. maritime transportation is considered significant in disaster management and humanitarian aid processes by most participants (Table 1).

2. Which areas of maritime transportation do you think contribute to humanitarian aid during a disaster? (You can select more than one)

Table 2. Frequency and percentage analysis of the survey question 2

Area	Frequency	Percentage (%)
Speed	30	50%
Accessibility	20	33%
Capacity	25	42%
Logistical Support	35	58%
Other	5	8%

Most participants (50%) rate the preparedness of maritime transportation as good or very good. Logistics support and speed are the most significant contributing factors in maritime transportation during disasters. Improving these areas can enhance the effectiveness of maritime transportation (Table 2).

3. How prepared are the İskenderun Port for disaster management and humanitarian aid processes? (Please select only one option)

Table 3. Frequency and percentage analysis of the survey question 3

Response	Frequency	Percentage (%)
Very Poor	5	8%
Poor	10	17%
Moderate	15	25%
Good	20	33%
Very Good	10	17%

Most participants (50%) rate the preparedness of maritime transportation as good or very good. There is general satisfaction with the preparedness of maritime transportation for disaster management and humanitarian aid processes, but there are areas for improvement (Table 3).

4. What do you think about the emergency plans and training programs of ports? (Please select only one option)

Table 4. Frequency and percentage analysis of the survey question 4

Response	Frequency	Percentage (%)
Very Inadequate	8	13%
Inadequate	12	20%
Moderate	20	33%
Adequate	15	25%
Very Adequate	5	8%

33% of participants find these preparations to be moderate, while 25% find them sufficient. There are mixed opinions about the emergency plans and training programs of ports. There is a need to improve existing programs (Table 4).

5. Which institutions and organizations should collaborate to coordinate maritime transportation in humanitarian aid activities during a disaster? (You can select more than one)

Table 5. Frequency and percentage analysis of the survey question 5

Institution/Organization	Frequency	Percentage (%)
Local Governments	30	50%
NGOs	25	42%
Port Operations	35	58%
Emergency Management Agencies	40	67%
International Aid Organizations	20	33%
Other	5	8%

The most critical institutions for collaboration are emergency management agencies (67%) and port operations (58%). Participants also recognize the significant role of local governments (50%) and non-governmental organizations (42%). Emergency management agencies and port operations play key roles in coordinating maritime transportation. The participation of local governments and NGOs is also crucial (Table 5).

6. Which factor most influences the contribution of maritime transportation to humanitarian aid during a disaster? (Please select only one option)

Table 6. Frequency and percentage analysis of the survey question 6

Factor	Frequency	Percentage (%)
Speed	25	42%
Accessibility	15	25%
Logistical Support	20	33%

Speed (42%) is seen as the most influential factor. To enhance the effectiveness of maritime transportation, more emphasis should be placed on speed, logistics support, and accessibility (Table 6).

7. What improvements do you think should be made to increase the resilience of port infrastructure in İskenderun against disasters?

Table 7. Frequency and percentage analysis of the survey question 7

Improvement	Frequency	Percentage (%)
Infrastructure Strengthening	30	50%
Training and Drills	20	33%
Technological Investments	10	17%

Infrastructure strengthening is seen as the highest priority improvement. Strengthening infrastructure is considered the top priority for disaster resilience. Training and technological advancements are also important areas to focus on (Table 7).

8. What training should be provided to enhance the performance of maritime transportation in disaster management and humanitarian aid processes? (You can select more than one)

Table 8. Frequency and percentage analysis of the survey question 8

Training	Frequency	Percentage (%)
Emergency Response Training	25	42%
Logistic Planning Training	20	33%
Communication and Coordination Training	15	25%

Emergency response training (42%) is the most recommended. Emphasizing emergency response training is essential to improving the performance of maritime transportation in disaster management. Logistics and communication training also play supportive roles (Table 8).

9. Which communication tools should be preferred in humanitarian aid operations using maritime transportation? (You can select more than one)

Table 9. Frequency and percentage analysis of the survey question 9

Communication Tool	Frequency	Percentage (%)
Satellite Phone	20	33%
VHF Radio	25	42%
Internet-Based Systems	15	25%

VHF radio (42%) is identified as the most preferred communication tool. (Very High Frequency) is the name of radio waves between 30-300MHz. The system, which goes by different names such as Marine Radio (VHF Marine Radio), Radio Telephone, is a radio system that operates in the VHF frequency band and is used for marine vehicles to communicate with each other or with the land. This system uses frequencies between 156-174 MHz in the VHF frequency band. VHF radios are seen as the most effective communication tool in humanitarian aid operations. Satellite phones and internet-based systems are also critical communication tools (Table 9).

10. Which feature best expresses the importance of the sea bridge strategy in disaster relief operations? (You can select more than one)

Table 10. Frequency and percentage analysis of the survey question 10

Feature	Frequency	Percentage (%)
Rapid Access	30	50%
Wide Coverage	15	25%
Flexible Logistics	15	25%

Quick access (50%) is considered the most crucial feature. Quick access is highlighted as the most important feature of the sea bridge strategy in disaster relief operations. Wide coverage and flexible logistics are also valuable aspects (Table 10). Impact of maritime transportation During Disasters;

1. The impact of the institution type you work for on the effectiveness of maritime transportation during a disaster. There is a significant relationship ($p < 0.05$) (Table 11).
2. The preparedness of Iskenderun Port for disaster management and humanitarian aid processes, based on the institution type you work for. There is a significant relationship ($p < 0.05$) (Table 12).
3. The emergency plans and training programs of the ports, based on the institution type you work for. For each relationship: Chi-Square Statistic and p-Value. There is a significant relationship ($p < 0.05$) (Table 13).

Table 11. Chi-Square analysis of the impact of Institution Type on the effectiveness of maritime transportation during a disaster

Test Type	Value
Chi-Square Statistic	393.67
p-Value	0.0000894

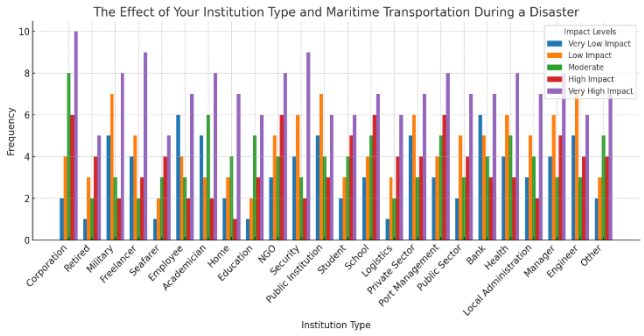

Figure 4. Type of Institution and the impact of maritime transportation during disasters

Figure 4 shows the levels of impact of maritime transportation during disasters by type of institution. The impact of maritime transportation varies by institution type, which may be due to the different levels of knowledge and roles these institutions have in disaster management processes. Many institutions and individuals may not be aware of the effectiveness of maritime transportation in disaster scenarios. In the logistics sector and port operations, institutions increasingly emphasize the efficiency of maritime transportation. However, it is observed that public and private sector employees not directly involved in these operations do not fully recognize the role of maritime transportation in disaster scenarios. This indicates the need to raise more awareness about the critical role of maritime transportation.

Improvement Suggestion: "Training and awareness campaigns should be organized for public and private sector employees to explain the critical role of maritime transportation in disaster scenarios, with an academic and humanitarian approach."

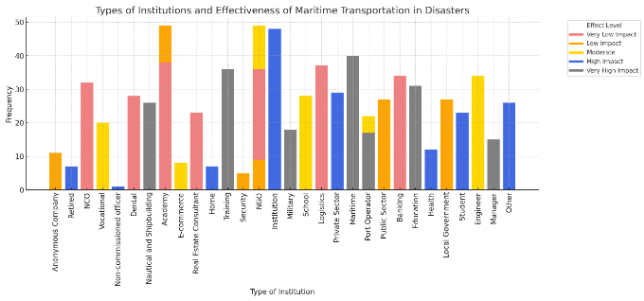

Figure 5. The impact of maritime transportation during a disaster by institution type worked

Figure 5 shows the preparedness levels of İskenderun Port for disaster management and humanitarian aid processes by type of institution. Different institutions have varying perceptions and experiences regarding port preparedness. Port operations and NGOs are the most informed and prepared in this regard.

Port employees and NGOs tend to assess the port's preparedness for disaster management more highly, while public and private sector employees appear to have a lower perception of preparedness. This suggests that institutions not directly involved in port operations may have less knowledge about disaster management processes.

Improvement Suggestion: "Comprehensive briefings and drills on the role of ports in disaster scenarios for public institutions and private sector representatives could enhance the overall level of preparedness."

Table 12. Chi-Square analysis of the preparedness of Iskenderun Port for disaster management and humanitarian aid processes by Institution Type worked

Test Type	Value
Chi-Square Statistic	357.64
p-Value	0.0065

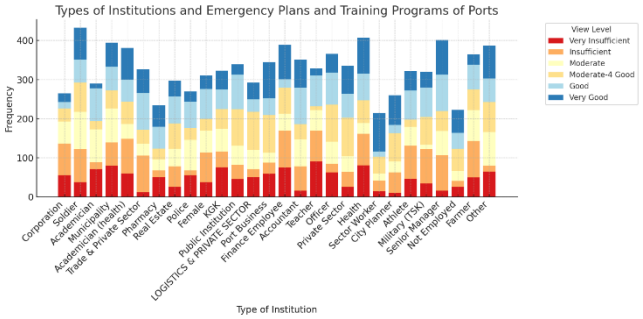

Figure 6. The preparedness of Iskenderun Port for disaster management and humanitarian aid processes by institution type worked

Figure 6 shows the opinions of different institutions on the emergency plans and training programs of ports. Various institutions have differing views on the effectiveness of these plans and programs, reflecting their unique experiences and emergency preparedness levels. Port employees and NGOs are more prepared in this area.

Port employees and those working in the logistics sector tend to find these plans and programs more effective, while employees from other institutions seem to rate the effectiveness of these programs lower. This may indicate that institutions outside the port are not sufficiently benefiting from such training.

Improvement Suggestion: "Emergency plans and training programs for ports should be expanded to reach a broader audience, and their effectiveness should be enhanced. In particular, training should be organized for employees who are not directly involved in logistics and port operations."

Table 13. Chi-Square analysis of the emergency plans and training programs of the ports by institution type worked result

Test Type	Value
Chi-Square Statistic	433.99
p-Value	0.00000019

Table 14. Frequency distribution of impact levels of maritime transportation during a disaster

Question	Chi-Square Statistic	p Value	Significance (p<0.05)
Effect of Maritime transportation During a Disaster Contribution	113.88	3.14×10^{-22}	Yes
Areas of Maritime transportation	717.73	9.81×10^{-148}	Yes
Preparedness of İskenderun Port	200.67	1.36×10^{-40}	Yes
Emergency Plans and Training Programs of Ports	69.78	4.55×10^{-13}	Yes

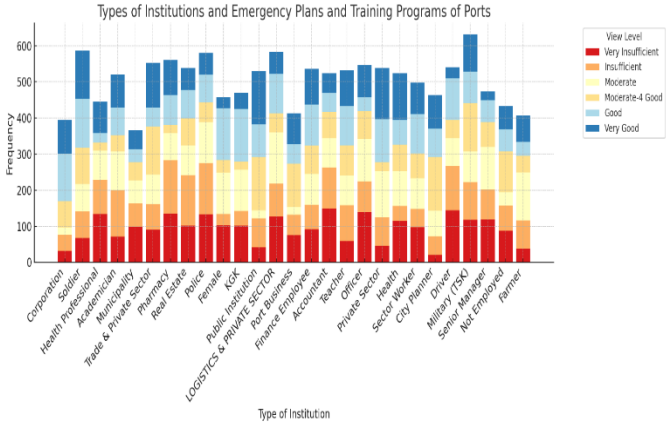

Figure 7. The emergency plans and training programs of the ports by institution type worked

Figure 7 shows the opinions about the emergency plans and training programs of the ports by institution type worked. Different institution types have various opinions about the effectiveness of emergency plans and training programs, with port employees and NGOs being more prepared.

When examining the impact of maritime transportation during a disaster: Question: "How effective do you find maritime transportation in humanitarian aid processes during a disaster?" The responses to this question do not show a random distribution. The chi-square test result indicates that the p-value is significantly less than 0.05, showing a consistent trend in participants' views on the effectiveness of maritime transportation during disasters. Most participants believe that maritime transportation significantly contributes to humanitarian aid during disasters, demonstrating broad acceptance of its critical role in disaster response.

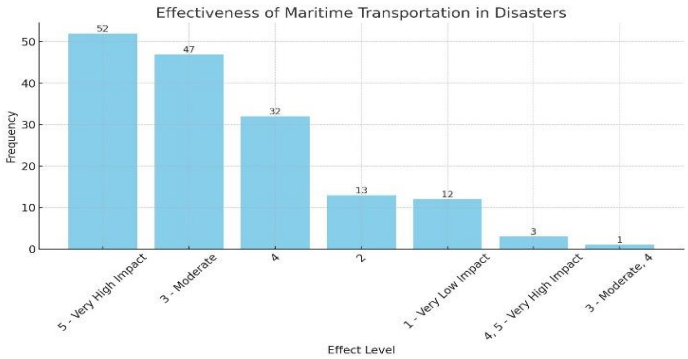

Figure 8. The impact of maritime transportation during a disaster

Highest Frequency: The "Moderate" opinion level, with 47 responses (27.5%), is the most common view. High Impact: The "5 - Very Good" and "4 - Good" levels have lower frequencies in total.

Comment: The emergency plans and training programs of the ports are generally considered moderately effective. This indicates the need to make these plans and programs more effective.

Overall Evaluation: The results for all questions indicate that participants have specific views on maritime transportation and port management issues, and these views are not randomly distributed.

Impact of maritime transportation: Participants consistently provided responses indicating the importance of maritime transportation during disasters.

In Figure 8, the majority of participants rated the impact of maritime transportation during disasters as 'Moderate.' This may suggest that the critical role of maritime transportation in disaster management processes is not fully recognized. The lower number of participants in the higher impact levels ('4 - Good' and '5 - Very Good') indicates that the role of maritime transportation in disaster scenarios is not sufficiently emphasized.

Improvement Suggestion: "To better highlight the role of maritime transportation in disasters and increase the potential benefits in this area, awareness campaigns and training programs should be organized, especially targeting institutions outside the maritime sector."

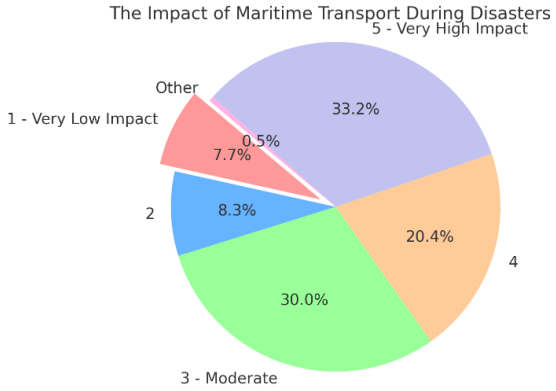

Figure 9. Chi-Square analysis of the impact of maritime transportation during a disaster

Very High Impact: Represents 33.2% of the responses. Moderate Impact: Represents 30% of the responses. Figure 9 visually indicates that a significant portion of participants believes in the high effectiveness of maritime transportation in disaster scenarios.

Improvement Suggestion: "To enhance the impact of maritime transportation in humanitarian aid processes, more comprehensive strategies should be developed. Sectoral collaboration and practical drills should be organized to explore how maritime services can be more efficiently utilized in disaster management."

Contribution Areas of Maritime Transportation in Disasters: Question: "Which areas of maritime transportation do you think contribute to humanitarian aid during a disaster?" The responses to this question also do not show a random distribution. The chi-square test result indicates a significant trend. Most participants identify "Logistics Support," "Capacity," and "Accessibility" as the critical areas where maritime transportation contributes significantly to humanitarian aid during disasters. This result suggests that these areas are generally recognized as important for effective maritime transportation in disaster situations.

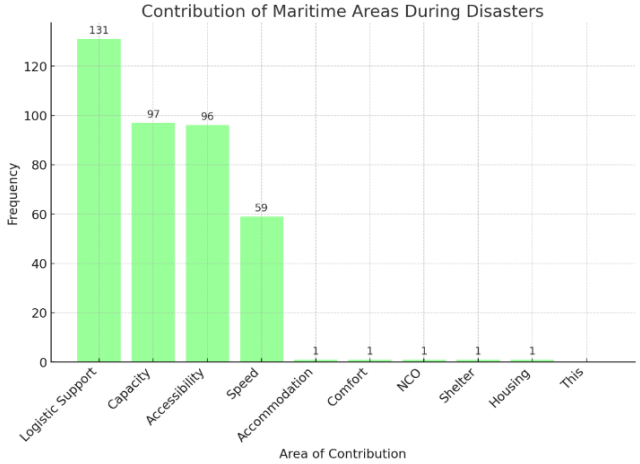

Figure 10. Chi-Square analysis of the contribution areas of maritime transportation

During a Highest Contribution Area: "Logistics Support," with 131 responses (81.88%), is the most commonly identified contributing area. Other Areas: "Capacity" (60.63%) and "Accessibility" (60.0%) follow, with "Speed" (36.88%) also being a significant factor. Participants consider logistics support the most critical contributing area in maritime transportation during disasters. Capacity and accessibility are also deemed important, indicating a need for improvement and development in these areas to enhance maritime transportation's effectiveness during disasters. Among the participants, logistical support is seen as the area where maritime transportation contributes the most to humanitarian aid processes. Capacity and accessibility are also noted as important factors, indicating that improvements in these areas are necessary to enhance the effectiveness of maritime transportation (Figure 10).

Improvement Suggestion: "To enable maritime transportation to provide more efficient logistical support, infrastructure investments should be increased, and strategies should be developed to expand capacity."

Preparedness of İskenderun Port for Disaster Management and Humanitarian Aid Processes: Question: "How prepared are the İskenderun Port for disaster management and humanitarian aid processes?" The responses to this question do not show a random distribution. The chi-square test result indicates a consistent trend in participants' views on the preparedness of İskenderun Port for disaster management and humanitarian aid processes. Many participants believe the ports are moderately prepared, suggesting that while the current preparedness is not entirely inadequate, there is significant room for improvement.

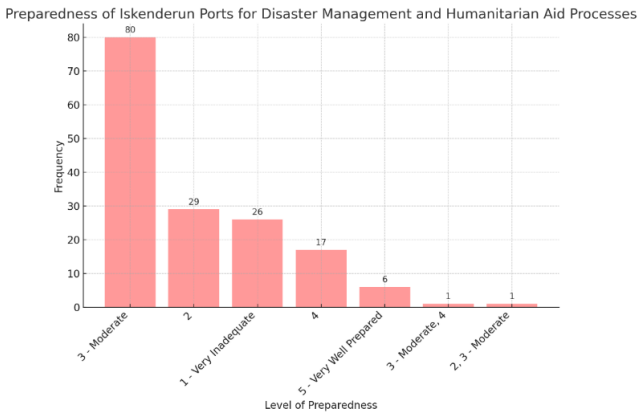

Figure 11. Chi-Square analysis of preparedness of Iskenderun Port for disaster management and humanitarian aid processes

Highest Frequency: "3 - Moderate" preparedness level, with 80 responses (50.0%), is the most common. Low

Preparedness: "1 - Very Inadequate" level, with 26 responses (16.25%), is less frequently selected.

Participants generally believe that the preparedness of İskenderun Port for disaster management and humanitarian aid processes is moderate, indicating the need for enhancements in their disaster readiness capacities.

Improvement Suggestion: "To improve the port's disaster preparedness level, more frequent and realistic scenario-based drills should be conducted, and existing emergency plans should be reviewed. Comprehensive training sessions should be organized for all relevant stakeholders (public, private sector, NGOs), and collaboration should be strengthened."(Figure 11).

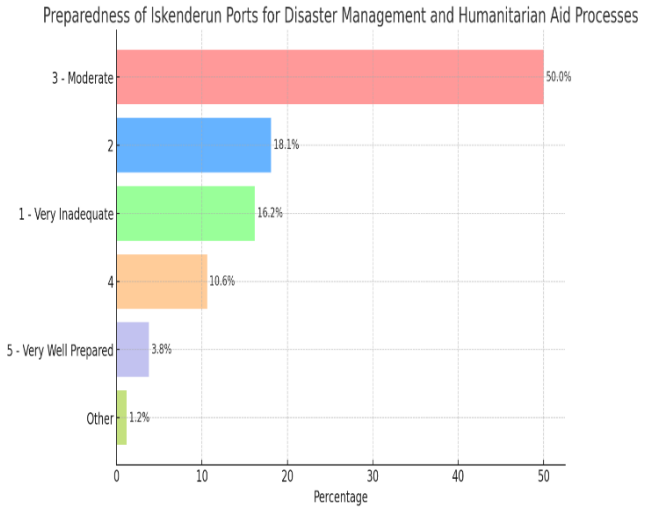

Figure 12. Percentage analysis of preparedness of Iskenderun Port for disaster management and humanitarian aid processes

Moderate Preparedness: Covers a 50% portion of the chart. High Preparedness: The "5 - Very Well Prepared" level covers only a 3.75% portion of the chart.

Figure 12 visually expresses the general consensus that the ports' preparedness is insufficient. The majority consider the preparedness level to be moderate, but very few participants consider it to be high. Emergency Plans and Training Programs of the Ports: Question: "What do you think about the emergency plans and training programs of the ports?" The responses to this question also do not show a random distribution and indicate a significant trend. The chi-square test result demonstrates that participants' views on the emergency plans and training programs of the ports are consistent. The majority believe that these plans and programs are "moderately" effective. This suggests that the emergency preparedness and training programs of the ports are seen as insufficient but not completely inadequate.

Figure 13. Percentage analysis of opinions on the emergency plans and training programs of the ports

Highest Frequency: The "Moderate" opinion level, with 44 responses (27.5%), is the most common view. High Impact: The "5 - Very Good" and "4 - Good" levels have lower frequencies in total. The emergency plans and training programs of the ports are generally considered moderately effective. This indicates the need to make these plans and programs more effective (Figure 13).

The majority of participants found the emergency plans and training programs of the ports to be 'moderately effective.' The small number of participants who found them highly effective indicates that the ports' preparedness and training capacities in this area may be insufficient."

Improvement Suggestion: "To enhance the practicality of emergency plans in ports, more drills should be conducted, and training programs should be offered to institutions that are not directly involved in port operations.

Overall Evaluation: The results for all questions indicate that participants have specific views on maritime transportation and port management issues, and these views are not randomly distributed. Impact of maritime transportation: Participants consistently provided responses indicating the importance of maritime transportation during disasters. Contribution Areas: Logistics support, capacity, and accessibility are identified as crucial areas in maritime transportation. Port Preparedness: The current preparedness level of İskenderun Port is generally viewed as insufficient and needs improvement.

This study examined the role of maritime transportation in disaster management and humanitarian aid processes in the İskenderun region. Specifically, in the context of the earthquakes that occurred in Türkiye on February 6, 2023, the capacity of maritime transportation to respond quickly to disasters and its contribution to humanitarian aid efforts

were analyzed. The majority of the 161 survey participants emphasized the critical role of maritime transportation in disaster management processes.

63% of participants stated that maritime transportation had a "high" or "very high" impact on humanitarian aid processes during disasters. This finding highlights the advantages of maritime transportation in terms of rapid, cost-effective, and large-scale material transport. However, 17% of participants stressed the need for infrastructure improvements. Strengthening ports and maritime transport routes after a disaster can help reduce disruptions in these processes.

The study highlighted three main areas where maritime transportation contributes to disaster management: logistical support, capacity, and accessibility. 58% of participants identified logistical support as the most critical area of contribution, while 50% emphasized the ability of maritime transportation to quickly provide materials and equipment. However, infrastructure strengthening was cited as a priority for making maritime transportation more effective in post-disaster situations.

The preparedness of İskenderun Port for disaster management and humanitarian aid processes was generally rated as "medium" by participants (50%). It was noted that improving existing emergency plans and increasing the frequency of drills would be necessary to enhance the port's preparedness level. The need to raise awareness of disaster management among public and private sector employees was also emphasized. These results suggest that current strategies need to be reviewed for İskenderun Port to play a more effective role in disaster management and humanitarian aid processes.33% of participants found port emergency plans to be "moderately" effective. Training programs were deemed inadequate by 20%, with suggestions that they should be developed to reach a broader audience. It is recommended that more frequent and realistic scenario-based drills be conducted to increase preparedness for disasters. In this regard, including sectors beyond port employees in disaster management training would enhance the overall level of preparedness.

Based on the study's findings, the following recommendations can be made to strengthen the role of maritime transportation in disaster management and humanitarian aid processes:

Infrastructure Strengthening: To increase the effectiveness of maritime transportation, it is necessary to strengthen the infrastructure of ports and transport routes. This will allow for the rapid supply and distribution of materials in the aftermath of disasters.

Training Programs and Drills: Comprehensive training programs should be organized for all stakeholders involved in disaster management, and more frequent drills should be conducted. Operational skills that enable the effective use of maritime transportation after disasters should be developed.

Institutional Cooperation: 67% of participants highlighted the critical importance of cooperation between local governments and emergency management agencies in maritime transportation and humanitarian aid processes. This cooperation should be strengthened to ensure more effective coordination after disasters.

Technological Investments: Advanced technologies should be utilized to improve the efficiency of logistical processes during and after disasters. Participants particularly mentioned that the use of AIS (Automatic Identification System) data and satellite-based communication tools could provide significant contributions to disaster management.

CONCLUSION

In conclusion, this study clearly demonstrates the critical role of maritime transportation in disaster management and humanitarian aid processes. However, it also underscores the need for improvements in current infrastructure and preparedness processes. To ensure the efficient operation of maritime transportation processes after disasters, investments in infrastructure should be increased, and logistical support capacities should be developed. In this way, the contribution of maritime transportation to humanitarian aid efforts can be maximized.

Compliance with Ethical Standards

Authors' Contributions

This article is based on the master's thesis of corresponding author titled "Maritime Transportation Disaster Management and Humanitarian Aid: Iskenderun Region". Sevim Oruç designed the study, collected the survey data and wrote the article together with Meltem Eken. All authors read and approved the final manuscript.

Conflict of Interest

The authors declare that there is no conflict of interest.

Ethical Approval

The study was approved by the Ethics Committee of Iskenderun Technical University, and informed consent was

obtained from the participants. (Approval Date/No: 27.02.2024/2)

Data Availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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Proximate composition and colour values of muscle tissue of male and female blunt-snouted mullet (*Mullus ponticus* Essipov, 1927) from Black Sea

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Research Article

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A B S T R A C T

In the Mediterranean and Black Sea, red mullet is a fish species of significant commercial value. It usually inhabits sandy and muddy bottoms in the Eastern Atlantic and Mediterranean basins, which include the Black Sea. Red mullet is subject to high fishing pressure from bottom trawling and small-scale fisheries, making it one of the most valuable bottom fish in the Mediterranean. It's also one of the primary species that bottom trawls catch for commercial purposes. Red mullet's distinct habitat requirements and sensitivity to environmental changes make it a commercially valuable species in the Mediterranean and Black Seas. Its high economic value and ecological importance make it an important focus of research and fisheries management efforts. The objective of this research was to ascertain the nutritional makeup and muscle tissue colour values of red mullet, both male and female, that were collected using bottom gillnets at Sinop, a Black Sea coastal city in the south. In this study, crude protein, crude fat, crude ash, moisture, carbohydrate, and energy values in female blunt-snouted mullet were found as 18.81%, 9.51%, 1.29%, 69.74%, 0.66%, and 199.14 Kcal/100 g. In male red mullet, crude protein, crude fat, crude ash, moisture, carbohydrate, and energy values were determined as 19.06%, 10.07%, 1.16%, 68.97%, 0.73%, and 206.20 Kcal/100 g. Colour analysis is an important finding in distinguishing females and males in various fish species and in understanding sexual dimorphism. It was found that female red mullets were more reddish and yellowish than male red mullets.

INTRODUCTION

Known by most as just "red mullet," this species of benthic fish inhabits the Northeast Atlantic and Mediterranean regions. It inhabits gravelly, sandy, and muddy bottoms up to 500 m deep on the continental shelf (Rodríguez-Romeu et al., 2020). Blunt-snouted mullet is one of the species that industrial bottom trawling targets, but it's also one of the species that's heavily caught using bottom gillnets, the most crucial fishing tool for small-scale fisheries (Özdemir and Erdem, 2011; Aksu et al., 2011; Özdemir et al., 2021). In Turkish seas; the Mullidae family is known to have two genera (*Mullus* and *Upenus*) and four species (*Mullus barbatus, Mullus surmuletus, Upeneus moluccensis*, and *Upeneus pori*) (Mater et al., 2003; Bat et al., 2008; Gündoğdu and Baylan, 2016). Blunt-snouted mullet (*Mullus ponticus*) is a subspecies specific to the Black Sea (Echreshavi et al., 2022; Fricke et al., 2024; Froese and Pauly, 2024).

The effects of climate change due to global warming, which is seen in all oceans and seas, are also felt in the Black Sea basin (Bat et al., 2007). Accordingly, the stock structures, population characteristics, reproduction time, reproduction areas and feeding behaviors of pelagic and demersal fish species in the Black Sea may also differ. Some changes in the

growth and first reproduction lengths of red mullet, one of the important demersal fish of the Black Sea, are remarkable. It is thought that all these factors and changes related to parameters may also affect the food composition of fish.

Red mullet feed on crustaceans, polychaete, and bivalves, and stable isotope analysis has revealed differences in diet and size-related trophic levels among sympatric fish species (Bautista-Vega et al., 2008).

The nutritional composition of red mullet, commonly known as red mullet, has been a subject of scientific research. Studies have emphasized seasonal changes in fat and fatty acids, and it has been discovered that this species is good for human diet and that its muscle lipids are rich in docosahexaenoic acid (DHA) and eicosapentaenoic acid (EPA) (Özoğul et al., 2011, Duyar and Bayraklı, 2023). It has also been found that the fatty acid composition of red mullet shows seasonal variation, which is affected by changes in water temperature and nutrient availability, affecting fish muscle quality (Polat et al., 2008). Furthermore, research comparing the effects of conventional and green extraction techniques on fish species' fatty acid profiles and lipid yield has demonstrated the high nutritional value of fish, which includes high levels of protein, vitamin, mineral, and lipid content (Özoğul et al., 2011). These findings underline the nutritional importance of red mullet in human nutrition, especially as a source of essential fatty acids and high-quality protein.

Blunt-snouted mullet has been a subject of interest in the Black Sea due to its nutritional composition, economic importance, and high consumption. Various studies have focused on the proximate composition, heavy metal concentrations, fatty acid profiles, and genetic differentiation of blunt-snouted mullet. Roncarati et al. (2012) and Duyar et al. (2023) investigated the proximate composition or heterogeneous profile of red mullet, emphasizing its importance as a widely consumed species in the European Union.

Based on the given references, the L*, a*, and b* values obtained from colour analysis in red mullet species can be attributed to various factors such as sex, nutrition, and regional and seasonal differences. Also, Corsi et al. (2002) monitored a marine coastal area using red mullet as a biological indicator, which can provide valuable information on colour changes due to regional and seasonal differences. Prazdnikov's (2016) study on karyology of red mullet provides genetic information that can be associated with colour differences and regional differences in the species. Kokokiris et al. (2014) study on oocyte development and spawning season of red mullet can provide valuable information on colour differences due to sex in the species.

Determination of L*, a*, and b* values in commercial fish species is very important for understanding sex-related colour differences and their potential implications for future studies. The study revealed statistically significant differences in a* and b* values between female and male individuals, suggesting that these values can be used as markers for sex discrimination (Bergero et al., 2019). In addition, the ability to distinguish between female and male colours in various teleost fish species highlights the importance of colour analysis in understanding sexual dimorphism (Kottler and Schartl, 2018). The use of colour analysis to highlight sex differences in fish species is supported by the literature on sexual dimorphism and colour discrimination in various fish species. The findings of the study contribute to the increasing knowledge on the role of colour in sex recognition and discrimination in fish, providing valuable information for future research in this area.

MATERIALS AND METHODS

The Black Sea coasts of Sinop were the study's location. The Sinop region is very important for small scale fisheries. Sinop region is three fisheries areas such as İnceburun region, outer harbour, and inner harbour region. Fishermen have been captured, especially whiting and blunt-snouted mullet, during all fishing seasons (Figure 1).

Red mullet samples were captured by set nets (gillnets and trammel nets) between 15 April 2022 and 31 August 2022. Nets have monofilament and multifilament material. The mesh sizes of gillnets and trammel nets were 32, 36, and 40 mm. Depth ranges used of set nets were between 15 m and 45 m.

Figure 1. The chart of the fish sampling area (İnceburun, outer harbour, and inner harbour)

Captured fish samples were placed in iced polystyrene boxes and brought to the laboratory, and proximate composition analyses were performed immediately. The total length and weight of all samples were measured as 1 mm and 0.001 g. Gender analyses of fish were performed macroscopically in the laboratory (Figure 2).

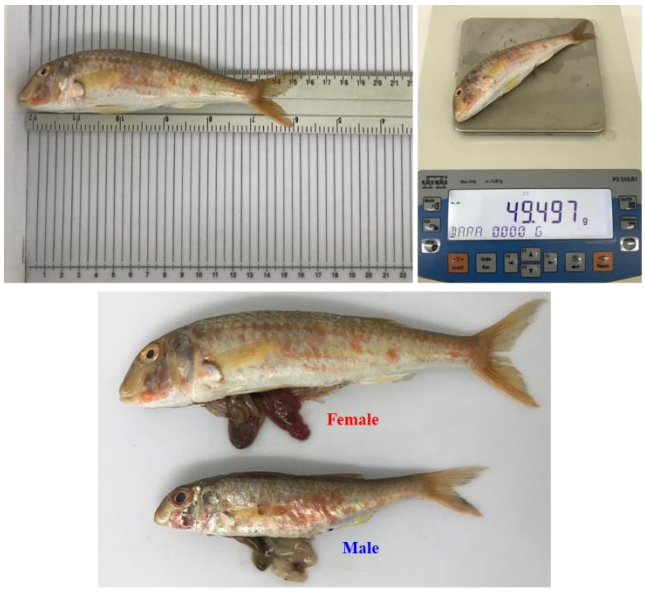

Figure 2. Male and female fish samples

The muscle tissue of the fish was taken and homogenized. Three parallels and two replications were used to analyze the nutritional of fresh red mullet. Nutritional composition analysis results are given in Table 2. From nutrient composition analysis, total crude protein was performed using Kjeldahl (AOAC, 1990), crude fat analysis (Bling and Dyer, 1959), crude ash analysis (AOAC, 1984), and moisture analysis (Ludorf and Meyer, 1973). Carbohydrate and energy amounts were calculated according to Merril and Watt (1973) using the following equations (Eqs. 1-2).

Colour measurements were determined using Konica Minolta/CR-A33a (Tokyo, JP) apparatus and CR-400 brand/model device with "Commission Internationale de l'Eclairage" (CIE) coordinate system parameters. The instrument was calibrated with black and white standard plates before the analysis. The Commission Internationale de l'Eclairage (CIE)-Lab L*, a*, and b* scores were obtained, which showed lightness, redness (+)/(-) greenness, and yellowness (+)/(-) blueness, respectively. Chroma and hue angle were also calculated using the following formulas (Eqs. 3-4) (CIE, 1976).

RESULTS

A total of 25 kg of blunt-snouted mullet was caught during this study. In this study, biometric data and the nutritional composition of female and male blunt-snouted mullet were investigated, and the results are given in Table 1.

$$Carbohydrate\ (g/100g) = 100 - (moisture + Fat + Protein + Ash \quad (1)$$

$$Energy\ (Kcal/100g) = (Fat * 9.50) + (Protein * 5.65) + (Carbohydrate * 3.90) \quad (2)$$

$$C* = \sqrt{a*^2 + b*^2} \quad (3)$$

$$h* = tan^{-1}\ (b*/a*) \quad (4)$$

Table 1. Biometric data and nutritional composition of red mullet

Parameters		Gender	Mean and Standard Errors
Biometric Data	Total Length (cm)	♂	14.51±0.090
		♀	16.69±0.080
	Weight (g)	♂	35.52±0.89
		♀	44.41±0.64
Proximate Composition	Moisture (%)	♂	68.974±0.106
		♀	69.741±0.375
	Crude Protein (%)	♂	19.060±0.030
		♀	18.809±0.146
	Crude Fat (%)	♂	10.070±0.348
		♀	9.507±0.050
	Crude Ash (%)	♂	1.169±0.071
		♀	1.288±0.048
	Carbohydrate (%)	♂	0.731±0.004
		♀	0.655±0.002
	Energy (Kcal/100g)	♂	206.201±0.110
		♀	199.142±0.090

Table 2. Colour findings of male and female blunt-snouted mullet.

Groups	Parameters						
	L*	**a***	**b***	**h***	**C***	**WI**	**YI**
♂	56.23±0.40[a]	2.39±0.23[b]	0.18±0.07[b]	4.18±1.27[b]	2.14±0.02[b]	55.52±0.41[a]	0.46±0.18[b]
♀	56.82±0.66[a]	6.69±0.30[a]	5.17±0.35[a]	37.61±0.92[a]	8.46±0.44[a]	55.99±0.64[a]	12.99±0.84[a]

Note: L* brightness/whiteness, a* redness/greenness, b* yellowness/blueness, h* hue angle (°), C* Chroma, WI whiteness index, YI yellowness index.

The colour parameters L*, a*, b*, h*, C*, whiteness index (WI), and yellowness index (YI) are essential in assessing the colouration of fish, which significantly influences consumer preferences and market value. The L* parameter indicates lightness, ranging from 0 (black) to 100 (white), while the a* and b* parameters represent colour dimensions where a* indicates the red-green axis and b* indicates the yellow-blue axis (Hajipour and Shams-Nateri, 2016; Ismail and Kocabay, 2018). The chroma (C*) is derived from the a* and b* values, reflecting the intensity of colour, and the hue angle (h*) describes the specific colour type (Conner and MacLean, 2013; Hajipour and Shams-Nateri, 2016). Furthermore, the whiteness index (WI) and yellowness index (YI) are critical for evaluating the visual appeal of fish products, as they quantify the degree of whiteness and yellowness, respectively, which can be influenced by factors such as lipid oxidation during storage (Li et al., 2022). These parameters are not only vital for quality control in fish processing but also serve as indicators of freshness and overall product quality, making them indispensable in the seafood industry (Liao et al., 2021). Table 2 displays the colour analysis results for the male and female blunt-snouted mullet used in this study.

The parameters such as chroma (C*), hue angle (h*), whitening index (WI), and yellowing index (YI) are determined by the L*, a*, and b*, which are the main components of the CIE colour coordinate system (Bekhit et al., 2018).

DISCUSSION

The moisture content of blunt-snouted mullet is an important aspect of its overall proximate composition, which influences its quality and shelf life. Studies have shown that the moisture content in blunt-snouted mullet can vary significantly depending on factors such as season, environmental conditions, and the fish's diet.

Male blunt-snouted mullet had a moisture content that was lower (68.97%) than female blunt-snouted mullet (69.74%), but there was no statistically significant difference between the two ($p>0.05$). Polat et al. (2008) found the moisture content of red mullet as 73.84% in their study. Tulgar and Berik found the moisture content of red mullet as 72.17% in spring in their study in 2012. Research indicates that the moisture content of red mullet typically ranges from approximately 70% to 80% of its total weight (Roncarati et al., 2012). For instance, moisture content in red mullet muscle significantly decreased during the spring season, which correlated with an increase in protein content. This inverse relationship between moisture and protein content suggests that as the fish accumulates protein reserves, particularly in preparation for spawning, the moisture content tends to decline (Polat et al., 2008).

Moreover, the proximate composition of red mullet has been documented to reflect its feeding habits. The fish primarily consumes benthic organisms, which may influence its moisture content due to variations in dietary intake (Roncarati et al., 2012). Additionally, environmental factors such as water temperature and salinity can also affect the moisture levels in red mullet, as these factors influence the fish's metabolic processes and overall health (Bouzgarrou et al., 2015).

The moisture content is crucial for determining the quality and shelf life of red mullet. Higher moisture levels can lead to a shorter shelf life due to increased susceptibility to microbial growth and spoilage (Bouzgarrou et al., 2015). Therefore, understanding the moisture content is essential for both consumers and fishery management to ensure the quality and safety of this commercially important species.

The average crude protein content of male blunt-snouted mullet in the Black Sea was determined as 19.06% (Çiloğlu and Akgümüş, 2019). In this study, the protein content of male and female blunt-snouted mullet was determined as 19.06% and 18.81%, respectively. Although the amount of protein in females is slightly less, there is no statistical difference between the sexes ($p>0.05$).

Because of the potential effects on nutrition and fisheries management, red mullet protein content is a topic of great interest. Research has indicated that a number of factors, such as seasonal variations and environmental circumstances, can have a substantial impact on the protein content of red

mullet. Specifically, Polat et al. (2008) found that protein levels in red mullet muscle significantly increased during spring, correlating with a decrease in moisture content, suggesting an inverse relationship between these two parameters. This seasonal variation is likely influenced by the abundance of food sources available to the fish, which affects their growth and nutritional composition (Polat et al., 2008).

Moreover, the proximate composition of red mullet has been documented to reflect its dietary habits. The fish primarily feed on crustaceans and polychaetes, which are rich in monounsaturated fatty acids but low in DHA (decosahexaenoic acid) (Roncarati et al., 2012). This dietary preference not only influences the fatty acid profile but also the overall nutritional value of the fish, including its protein content. For instance, the lipid content in red mullet has been reported to be higher than in some other fish species, which may also affect the protein-to-fat ratio (Tufan et al., 2018).

A comparative study of several fish species showed that red mullet's protein content is competitive with that of other economically significant fish, underscoring the fish's worth in the seafood industry. The protein content of red mullet is particularly significant for culinary applications, as it is a popular choice in Mediterranean cuisine, where it is valued for both its flavor and nutritional benefits (Biandolino et al., 2023).

In summary, the protein content of red mullet is influenced by seasonal variations, dietary habits, and environmental conditions, with reported values ranging from 14.54% to 20.26%. This makes red mullet a nutritionally valuable species in both ecological and culinary contexts.

More research needs to be done on this fish species to understand whether the meat of male and female blunt-snouted mullet living in the Black Sea differs in terms of crude protein content.

The fat content blunt-snouted mullet is a significant aspect of its nutritional profile, influencing both its culinary applications and its role in the diet of consumers. The lipid content of blunt-snouted mullet varies based on several factors, including seasonal changes, environmental conditions, and geographical location.

The crude fat contents in the meat of male and female blunt-snouted mullet in the current study were found to be 10.7% and 9.51%, respectively. Comparing results with other studies requires accounting for the differences in fat content across different species. Studies on the proximate composition of fish species have shown various levels of fat content. For example, a study on the fatty acid profile of various fish species reported a lipid content of 7.0% in red mullet (Roncarati et al. 2012). This suggests that the fat content of blunt-snouted mullet from the Black Sea is within the range observed in other fish species.

Research indicates that the crude fat content of blunt-snouted mullet can range significantly, with values reported between 3.68% and 5.76% depending on the specific conditions under which the fish were caught (Polat et al., 2008). For instance, Tufan et al. noted that blunt-snouted mullet caught from the Black Sea exhibited higher fat contents compared to other fish species, suggesting that environmental factors and feeding habits play a crucial role in determining lipid levels (Tufan et al., 2018). The lipid content is particularly influenced by the fish's diet, which primarily consists of benthic organisms such as crustaceans and polychaetes, known to be rich in essential fatty acids (Lloret et al., 2007).

Furthermore, the lipid reserves in red mullet are particularly important during pre-spawning periods, as they provide the necessary energy for reproductive activities. This seasonal accumulation of lipids may also explain the variations in fat content observed in different studies as fish prepare for spawning by increasing their fat reserves (Lloret et al., 2007).

In conclusion, the fat content of blunt-snouted mullet is variable, influenced by environmental factors, dietary habits, and seasonal changes. The lipid content ranges from approximately 1.26% to 18.12%, with significant implications for its nutritional profile and culinary uses. All things considered, more research taking into account processing techniques, gender effects, and species-specific variations is needed to provide a thorough comparison of fat content in different species, even though the fat content of male and female blunt-snouted mullet in the Black Sea is consistent with findings from other fish species.

The meat of blunt-snouted mullet inhabiting the Black Sea, both male and female, had crude ash contents of 1.17% and 1.29%, respectively. The gender differences were not statistically different ($p>0.05$). The crude ash content of blunt-snouted mullet let is an important parameter in assessing its nutritional and mineral composition. Ash content generally reflects the total mineral content of the fish, which can vary based on several factors, including diet, habitat, and environmental conditions.

Research indicates that the ash content in blunt-snouted mullet can be influenced by its feeding habits and the types of prey available in its habitat. For instance, polychaetes, which are known to be high in EPA and monounsaturated fatty acids but low in DHA, are the main food source for red mullets (Roncarati et al., 2012). This dietary preference can affect the overall mineral composition and, consequently, the ash content of the fish. In a study examining the mineral

composition of various fish species, including red mullet, it was found that the ash content is a significant indicator of the mineral levels present in the fish, which can range widely depending on environmental factors and dietary intake (Özden et al., 2009).

Moreover, the ash content can also be influenced by the fish's exposure to heavy metals and pollutants, as red mullets are benthic feeders that come into contact with sediments where such contaminants may accumulate (Ozuni et al., 2022). This exposure can lead to increased levels of certain trace metals in the fish, which would subsequently reflect in the ash content. For example, studies have shown that red mullet from contaminated areas exhibited higher concentrations of heavy metals, indicating a potential increase in ash content due to the accumulation of these minerals (Küçüksezgïn et al., 2001).

As for precise values, related studies on related species indicate that the ash content in red mullet usually varies from 1% to 3% of the total body weight, based on various factors including the fish's age, size, and environmental conditions. However, direct measurements of ash content in red mullet are not well documented in the literature (Abo-Taleb et al., 2021). Furthermore, the overall nutritional profile, including ash content, can vary seasonally, with some studies indicating that the nutritional composition, including protein and fat levels, can change significantly throughout the year, which may also affect ash content indirectly (Maravelias et al., 2006).

In conclusion, the ash content of blunt-snouted mullet is a multifaceted characteristic influenced by dietary habits, environmental conditions, and exposure to pollutants. While specific quantitative data may be limited, the general understanding of its mineral composition can be derived from related studies on fish nutrition and environmental impacts.

In this study, the carbohydrate content of male and female red mullets was found to be 0.73% and 0.66%, respectively. Fish's carbohydrate content varies greatly depending on a number of characteristics, such as species, sex, age, and environmental conditions.

The study by Lahnsteiner (2006) provides insights into the carbohydrate metabolism of red mullet, indicating that the carbohydrate levels in the fish are influenced by developmental stages, particularly during the vitellogenic phase of egg development. This suggests that the carbohydrate content may fluctuate based on reproductive status, which could explain some variability in your measurements. Furthermore, Koubaa et al. (2010) examined the chemical compositions of a number of fish species, such as red mullet, noting that moisture and nutrient content can differ significantly among species and even within the same species depending on their physiological state. These findings are consistent with our own study, and it's possible that the fish's sampling environment had an impact on the carbohydrate levels we saw.

Moreover, Soliman et al. (2017) highlighted those dietary habits, particularly the consumption of crustaceans and polychaetes, can influence the biochemical composition of red mullet. This dietary influence could account for the differences in carbohydrate content observed between sexes, as males and females may exhibit different feeding behaviors or preferences, potentially leading to variations in their nutritional profiles. The findings of Aguirre and Sánchez (2005) further support this notion, as they discuss resource partitioning between red mullet and other species, which could imply that dietary differences might also contribute to the observed carbohydrate levels.

Additionally, the research by Girolametti et al. (2022) on mercury content in red mullet suggest that environmental factors, including pollution levels, can affect the overall health and biochemical composition of fish. This environmental influence could also extend to carbohydrates metabolism, potentially explaining the differences in carbohydrate levels between male and female specimens.

In summary, the carbohydrate values you found as 0.73% in males and 0.66% in females are consistent with the existing literature emphasizing the influence of developmental stage, feeding habits and environmental conditions on the biochemical composition of red mullet. The variations in carbohydrate content between sexes may reflect underlying physiological differences or environmental adaptations, warranting further investigation into the factors influencing these nutritional metrics.

The energy content of fish muscle, typically expressed in kilos per 100 grams, varies significantly among species and is influenced by factors such as fat, protein, and carbohydrate composition. Fish muscle is predominantly composed of protein, which contributes to its nutritional value, but the total caloric density is mostly dependent on the fat content. For instance, fat provides approximately 9 kcal per gram, compared to 4 kcal per gram for protein (Raesen et al., 2017).

In this research, the energy amounts of male and female blunt-snouted mullet were found to be 206,20 (Kcal/100g) and 199,14 (Kcal/100g), respectively.

Numerous factors, such as the composition of fatty acids and metabolic processes, can have an impact on the energy content of fish muscle. For instance, Nordgarden et al. (2003) highlighted that the metabolism of Atlantic salmon involves significant β-oxidation of monounsaturated fatty acids

(MUFA), which are preferred energy substrates, indicating that energy utilization in fish muscles is closely tied to their lipid composition (Nordgarden et al., 2003). This suggests that energy values in red mullet may similarly be influenced by fatty acid profiles, and further research is warranted.

Moreover, the differences in energy storage between sexes have been explored in various species. O'Connor et al. (2012) noted that hepatic glycogen and muscle lipid content serve as measures of stored energy, which can vary based on sex and reproductive status. This aligns with the findings in red mullet, where the energy content may reflect the physiological demands placed on each sex, particularly during reproductive periods. In many fish species, females often prioritize somatic growth over reproductive investment until they reach maturity, which can affect their energy reserves (Buchtová et al., 2006).

Moreover, the energy content of fish is not static; it can fluctuate based on seasonal changes and the fish's life stage, as well as its feeding habits and metabolic rates. For example, the caloric density of Pacific salmon has been closely linked to lipid content, with larger fish generally exhibiting higher energy values due to their greater mass and fat reserves (O'Neill et al., 2014). This variability underscores the complexity of assessing the energy content in fish muscle and the necessity of considering multiple factors that contribute to its nutritional profile.

The colouration of male and female red mullet is indeed differ, and this difference can be quantitatively assessed using colour parameters such as L*, a*, b*, hue, and chroma (Figure 3). These parameters are part of the CIELAB colour space, which provides a systematic way to describe colour in terms of lightness (L*), red-green chromaticity (a*), and yellow-blue chromaticity (b*) (Park, 2023; Ruan and Wang, 2023).

When it comes to colour analysis, pollution and habitat conditions are only two examples of the environmental elements that might have an impact on the pigmentation of red mullet. Studies have identified the red mullet as a bioindicator species for coastal pollution, where the colour of living fish can reflect the health of its habitat. Exposure to environmental heavy metals and polycyclic aromatic hydrocarbons (PAHs) in particular can change fish metabolic markers (Porte et al., 2002; Conti et al., 2012). Assessment of these pollutants has shown that red mullet accumulates these substances, which can alter its physiological and possibly chromatic characteristics (Lionetto et al., 2001).

Moreover, a great deal of research has been done on the reproductive biology of red mullet, and it has come to light that age, development, and maturity may all have an impact on pigmentation. For example, the size and maturity of the fish are associated with changes in pigmentation that may serve as a visual cue during mating seasons (Kokokiris et al., 2014; Carbonara et al., 2015). Histological analysis of gonadal maturation shows that the reproductive cycle of red mullet is closely linked to environmental conditions, which may also affect its colouration in different seasons (Balcı and Aktop, 2019).

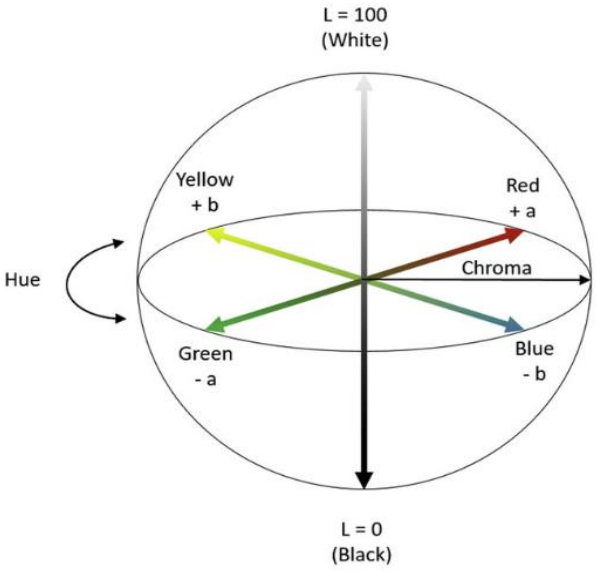

Figure 3. Colour diagram

In this study, the L* value, representing brightness-whiteness, was found to be 56.23 and 56.82 in male and female individuals, respectively. Between the sexes, there is no statistically significant difference ($p>0.05$). The a* value, which represents the red-green axis, was measured as 2.39 and 6.69 in male and female red mull blunt-snouted mullet, respectively. According to this result, female fish are reddish compared to male fish, while male red mullets were lower reddish, closer to green. The b* value, which shows colour distinction in the yellow-blue axis, was found to be 0.18 and 5.17 in male and female red mullet, respectively. Female blunt-snouted mullets were found to be more yellow, while male blunt-snouted mullets were found to be more bluish yellow than females.

Considered a qualitative property of colour, h* is the property by which colours such as redness or greenness are traditionally defined. It defines the variation of a particular colour compared to grey tones in the same range (O'Sullivan et al., 2003). This property is associated with absorbance differences at various wavelengths. The mathematical expression of the h* spectral range in colourimeters corresponds to 0/360, 90, 180, and 270° for redness, yellowness, greenness, and blueness, respectively (Škrlep and Čandek-Potokar, 2007). C*, which represents the quantitative property of chromaticity, is used to measure how much the h* parameter deviates from grey tones in the

same range. As the C* value increases, the colour intensity perceived by humans also increases, indicating more vividness and saturation in the appearance of the food (Pathare et al., 2013). WI combines brightness and yellow-blue colours into a single component, expressing the attractive whiteness that is an important determinant in consumers' decision to purchase the product (Škrlep and Čandek-Potokar, 2007). One of the most characteristic features of WI is that it perfectly reveals the whiteness/brightness change caused by the dehydration/drying of the food. YI indicates the degree of yellowing and is widely used to determine conditions such as contamination and oxidation with a single indicator (Pathare et al., 2013). High or low L*, a*, b*, C*, h*, WI, and YI values used in colour analysis have various meanings.

L* (lightness value); when high, it indicates that the sample is lighter, i.e., brighter or whiter, while when low, it indicates that the sample is darker.

a* (Redness/Greenness); It shows that it has more red tones when it is high and more green tones when it is low.

b* (Yellowness/Blueness); when high, it indicates that it has more yellow tones, while when low, it indicates that it has more blue tones.

C* (Chroma); when it is high, the colour is more saturated and vibrant. when it is low, the colour is duller.

h* (Hue Angle Value); either greenish or yellowish. When it is low, the colour is either blue or reddish.

WI (Whiteness Index); A high value suggests that the sample is closer to being white. A low value suggests that the sample is either more colourful or less white.

YI (Yellowness Index), A high value denotes greater yellowness in the sample, whereas a low value denotes less yellowness, or bluishness or whiteness.

These values are often important in terms of product quality, freshness, and consumer perception. For example, a brighter and whiter colour can be an indicator of freshness in foods such as fish. Chroma (C*), hue angle (h*), whiteness index (WI), and yellowing index (YI) parameters are determined by L*, a*, and b* parameters, which are the main components of the CIE colour coordinate system (Pathare et al., 2013). h*, which is considered a qualitative property of colour, is the property by which colours such as redness or greenness are traditionally defined. It defines the variation of a certain colour compared to grey tones in the same range (O'Sullivan et al., 2003). This property is associated with absorbance differences at various wavelengths. The mathematical expression of the h* spectral range in colourimeters corresponds to 0/360, 90, 180, and 270° for redness, yellowness, greenness, and blueness, respectively (Škrlep and Čandek-Potokar, 2007). C*, which represents the quantitative property of chromaticity, is used to measure how much the h* parameter deviates from grey tones in the same range. As the C* value increases, the colour intensity perceived by humans also increases, indicating more vividness and saturation in the appearance of the food (Pathare et al., 2013). WI combines brightness and yellow-blue colours into a single component, expressing the attractive whiteness that is an important determinant in consumers' decision to purchase the product (Škrlep and Čandek-Potokar, 2007). One of the most distinguishing qualities of WI is that it perfectly reveals the whiteness/brightness change caused by the dehydration/drying of the food. YI indicates the degree of yellowing and is widely used to determine conditions such as contamination and oxidation with a single indicator (Pathare et al., 2013). Gümüş (2021) determined the L*, a*, and b* parameters in red mullet (*M. barbatus*) as 68.29; 6.99, and 12.74, respectively. Male and female red mullets do exhibit differences in colouration, with females typically being more colourful and larger than males. Environmental variables also have an impact on these disparities in addition to genetic ones, which can affect the overall appearance and reproductive success of both sexes.

In studies examining sexual dimorphism in fish, it has been noted that female red mullets often exhibit brighter and more vibrant colours compared to males. In order to attract males, females may exhibit heightened colouring during the time of breeding, which makes this especially clear (Sieli et al., 2011). The a* value, representing the red-green axis, may also show higher positive values in females, indicating a greater presence of red hues, while males may have more subdued colours with lower a* values (Choubert, 2010; Ruan and Wang, 2023).

Chroma, which measures colour intensity, is another critical factor in distinguishing between the sexes. Females typically have higher chroma values, indicating a more intense colour saturation, while males may present with lower chroma values, reflecting a more muted appearance (Chajra et al., 2015; Calnan et al., 2017). The hue angle, which describes the type of colour, can also vary between sexes, with females often showing hues that are more appealing during mating displays (Choubert, 2010; Ruan and Wang, 2023).

Environmental factors can also influence these colour parameters. For instance, the availability of carotenoids in their diet can affect the pigmentation in red mullet, leading to variations in L*, a*, and b* values depending on the season and habitat conditions (Choubert, 2010; Pustina-Krasniqi et al., 2017). Such dietary influences can further accentuate the

differences in colouration between male and female red mullets, making it essential to consider both biological and environmental factors when studying their colour characteristics.

The CIELAB colour parameters L*, a*, b*, hue, and chroma can be used to objectively explain the notable colour differences between male and female red mullets. Particularly during breeding seasons, females usually exhibit brighter, more intense colours than males, and these differences are impacted by both hereditary and environmental influences.

CONCLUSION

In summary, although specific studies focusing only on L*, a*, and b* values of blunt-snouted mullet in the Black Sea are limited, the existing literature in the Mediterranean provides a basis for understanding how environmental factors and physiological conditions affect the colouration of this species. Future research could benefit from a targeted investigation of these colour metrics in both regions to improve our understanding of the ecological and health implications for red mullet.

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COMPLIANCE WITH ETHICAL STANDARDS

Authors' Contributions

HAD: Conceptualization, Data curation, Formal analysis, Writing – original draft, Writing – review & editing

SÖ: Investigation, Methodology, Data curation, Formal analysis, Writing – review & editing

All authors read and approved the final version of the article.

Conflict of Interest

The authors declare that there is no conflict of interest.

Ethical Approval

For this type of study, formal consent is not required.

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Data Availability

The data supporting the findings of this study are available from the corresponding author upon request.

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İskenderun Körfezi'nden avlanan *Nemipterus randalli* (Russell, 1986)'den elde edilen patojenlere karşı *Corchorus olitorius* bitki hidrosolünün antibakteriyel etkisi

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Anahtar Kelimeler:
Corchorus olitorius
Antibakteriyel etki
Hidrosol
Antibiyogram

Ö Z E T

Bu araştırmada, İskenderun Körfez'inden avlanılan *Nemipterus randalli* (n=15) bireylerinden izole edilen balık patojenlerinin identifikasyonunun yapılması ve izole edilen patojenlerin antibiyotik dirençliliğinin araştırılması, kullanılan *Corchorus olitorius* bitkisinden elde edilen hidrosolün tanımlanan bakteriyel patojenler üzerindeki in vitro antibakteriyel etkisinin belirlenmesi amaçlanmıştır. *C. olitorius* bitkisinden elde edilen hidrosolün GC-MS ile elde edilen kimyasal bileşenleri ve İskenderun Körfezi'nden avlanan *N. randalli* biraylerinden elde edilen patojenlere (*Klebsiella oxytoca*, *Pseudomonas aeruginosa* ve *Escherichia coli*) karşı antibakteriyel etkisi disk difüzyon yöntemi ile tespit edilmiştir. GC-MS analiz sonuçlarına göre, hidrosolün ana bileşeninin alpha.-Terpinyl acetate (%43,26) olduğu saptanmıştır. Disk difüzyon testi sonuçlarına göre, *C. olitorius* bitkisinden elde edilen hidrosolün *E. coli ve K. oxytoca* patojenlerine karşı kuvvetli antibakteriyel aktivite gösterdiği belirlenmiştir.

Antibacterial effect of *Corchorus olitorius* plant hydrosol against pathogens obtained from *Nemipterus randalli* (Russell, 1986) caught from Iskenderun Bay

Keywords:
Corchorus olitorius
Antibacterial effect
Hydrosol
Antibiogram

A B S T R A C T

The aim of this study is to identify the fish pathogens isolated from the *Nemipterus randalli* (n=15) caught in the İskenderun Bay, to investigate the antibiotic resistance of the isolated pathogens, and to determine the in vitro antibacterial effect of the hydrosol obtained from the *Corchorus olitorius* plant on the identified bacterial pathogens. Chemical components of the hydrosol obtained from the *C. olitorius* plant by GC-MS and its antibacterial effect against the pathogens (*Klebsiella oxytoca, Pseudomonas aeruginosa, and Escherichia coli*) obtained from *N. randalli* individuals caught in Iskenderun Bay have been determined by the disk diffusion method. According to the GC-MS analysis results, the main component of the hydrosol was determined to be alpha.-Terpinyl acetate (43.26%). The disk diffusion test results have determined that the hydrosol obtained from the *C. olitorius* plant showed strong antibacterial activity against pathogens *E. coli* and *K. oxytoca*.

GİRİŞ

İskenderun Körfezi sucul çeşitlilik bakımından zenginliğiyle ülkemizde önemli bir yere sahiptir. Çok çeşitli balık ve kabuklu sucul canlılara körfezde rastlamak mümkündür (Mavruk ve Avşar, 2023). İskenderun Körfezi evsel ve hastane atıklarının yanı sıra demir çelik fabrikaları, gübre fabrikaları, termik santral, gaz dolum tesisleri ve

çimento fabrikası gibi birçok atığa maruz kalmaktadır. Bu atıkların deniz kaynaklarına aktarılmasıyla sucul ortamdaki ekosistem doğrudan etkilenmekte ve bu kirletici maddeler canlılarda doğrudan veya dolaylı olarak çeşitli olumsuz birikimlere neden olmaktadır (Aykut ve Tezcan, 2022).

Patojenik bakterilerin farklı ortamlardaki dolaşımı, direncin yayılmasına ve çoklu ilaca dirençli suşların hızla ortaya çıkmasına neden olmaktadır (Manso ve ark., 2022). Antimikrobiyal direnç, insanları, hayvanları ve çevreyi etkileyen, giderek büyüyen küresel bir sorundur (Tacconelli ve ark., 2018).

Antibiyotik dirençliliği gösteren bakterilerin gıda yoluyla insana geçmesi insanda morbidite ve mortaliteye neden olmaktadır (Mataracı-Kara ve ark., 2021). Dünya genelinde balıklardan izole edilen bakteriler, bu bakterilerin sağaltım çalışmaları ve antibiyotik dirençlilikleri üzerine çalışmalar yapılmaktadır. Kimyasal antimikrobiyal maddelerin yan etkileri ve antibiyotik gibi ilaçlara direnç gösteren bakteriler araştırmacıları sürdürülebilirlik ilkesi ile bitkisel antimikrobiyal ajanları saptamaya yönlendirmiştir (Dolgun, 2022). Antibiyotikler bakteriyel enfeksiyonların neden olduğu hastalıkları tedavi edebilir ancak antibiyotiklerin yaygın kullanımlarının probiyotikleri azaltması gibi bazı yan etkileri olduğu bilinmektedir (Deng ve ark., 2023). Antibiyotiklerin neden olduğu hasarı hafifletmenin yanı sıra bağırsak mikrobiyotasının dengesini de koruyabilecek bu tür bitkisel ajanlara ihtiyaç duyulmaktadır. Dünya çapında var olan milyonlarca farklı kara ve deniz türü arasındaki sayısız olası etkileşimin sonucu oluşan doğal ürünler, bitkisel ilaç benzeri moleküller olarak büyük kimyasal çeşitlilikleri nedeniyle ilaç keşfinde giderek daha önemli bir rol oynamaktadır (Casertano ve ark., 2020). Bitkisel ürünler anti-inflamatuar, antikarsinojenik, anti-diyabetik, antibakteriyel, antifungal, antiviral, antimutajenik ve antialerjik özelliklere sahip olup genellikle antioksidan aktivite sergilerler (Ben-Shabat ve ark., 2020; Hazafa ve ark., 2020). Bitkisel metabolitlerin belirli bir grubu olan ikincil metabolitler, biyolojik aktivitelerinden dolayı eski çağlardan beri tüm dünyada birçok farklı geleneksel tedavi sisteminde kullanılan, uçucu yağlar olarak da bilinen uçucu bileşiklerdir (Sharifi-Rad ve ark., 2017). Bu metabolitler aynı zamanda farmakoloji, fitopatoloji, tıbbi ve klinik mikrobiyoloji alanında ve gıda ürünlerinin raf ömrünü uzatma konusunda antioksidan ve antimikrobiyal maddeler olarak uygulama alanı bulmuştur (Grijalva-Vallejos ve ark., 2024). Kimyasal olarak uçucu yağlar farklı kimyasal sınıflara ait aromatik bileşiklerin karmaşık bir karışımıdır; bitki materyalinin buharla damıtılması sırasında, polar, oksijenli, suda çözünebilen bileşenlerin küçük bir kısmı, yoğunlaşan su akışında tutulur (Sharfi-Rad ve ark., 2017). Hidrosoller (yani hidrolatlar) olarak adlandırılan uçucu yağlar preparatının bu yan ürünleri, birçok değerli bileşiğe ve bunların biyolojik özelliklerine rağmen sıklıkla kullanılmamaktadır (Rao, 2012). Sıvılaştırılmış su fazı, bitkinin suda kısmen veya tamamen çözünebilen uçucu bileşenlerinin belirli miktarları ile zenginleştirilmiştir. Bu nedenle hidrosoller parfümeride, kozmetikte, gıda tatlandırıcısında, aromaterapide ve geleneksel tedavilerde kullanılabilir (Sarkıç ve Stappen, 2018). Hidrosollerin uçucu yağlara göre çok daha seyreltilmiş solüsyonlar olduğundan irritabl etkileri bulunmadığı bilinmektedir ve böylece doğrudan cilde uygulanabilmektedir (Bezek ve ark., 2022).

Corchorus olitorius, Afrika ve Asya'nın yerli bir bitkisidir. Yapraklarından çorba yapımında ve halk hekimliğinde ateş, kronik sistit, soğuk algınlığı ve tümörlerin tedavisinde yararlanılmaktadır (Oboh ve ark., 2009). Bitkinin yapraklarından bazı kültürlerde beslenme alışkanlığı ve tekstil maddesi olarak yararlanılırken, tıbbi açıdan da geleneksel tıpta sınırlı olarak faydalanılmaktadır. *C. olitorius*, klinik kullanıma yönelik ilaç geliştirilmesinde değerli ve yeni bir kaynak olarak kabul edilmektedir. Yapısındaki flavonoidler, terpenler ve çeşitli yağ asitleri gibi bileşimler sayesinde bitkinin yara iyileştirici, antitümör, antikanser, antioksidan, antinosiseptif, antiinflamatuar, analjezik, antipiretik, antiviral, antibakteriyel, antikonvülsan, antidiyabetik ve antiobezite gibi birçok etkisinin olduğu bilinmektedir (Orieke ve ark., 2018; Abdel-Razek ve ark., 2022; Biswas ve ark., 2022)

Klinik ve bilimsel araştırmalarda küresel önem arz eden bu bitkinin su ürünleri üzerine kullanımına dair sınırlı literatüre denk gelinmiştir. Çalışmamızın amacı bu bitkiden elde edilen hidrosolün yaygın olarak var olan patojenler üzerindeki antimikrobiyal özelliğini test etmek ve ileride yapılacak olan analizlere ışık tutmaktır.

MATERYAL VE YÖNTEM

Çalışmada Kullanılan Bitki

C. olitorius bitkisinin (Tablo 1) yaprakları kurutulmuş olarak İskenderun/Hatay'da ticaret yapan Omran Kahve ve Baharatçılık firmasından temin edilmiştir.

Tablo 1. *C. olitorius* bitkisinin taksonomisi
Table 1. Taxonomy of *C. olitorius*

Sınıf	Bilimsel Ad
Alem	Plantae – Plants
Alt alem	Tracheobionta – Vascular plants
Üst Bölüm	Spermatophyta – Seed plants
Bölüm	Magnoliophyta – Flowering plants
Sınıf	Magnoliopsida – Dicotyledons
Alt sınıf	*Dilleniidae*
Takım	Malvales
Familya	*Tiliaceae* – Linden family
Cins	*Corchorus* L. – *corchorus*
Tür	*Corchorus olitorius* L. – nalta jute
İngilizce adı	Jute

Bitki Materyalinden Hidrosol Eldesi ve Kimyasal Bileşenlerinin Belirlenmesi

Temin edilen *C. olitorius* bitkisi bahçe bitkileri atlasından ve alanda çalışan akademisyenlerce teyit edilmiştir. Hatay Mustafa Kemal Üniversitesi Teknoloji ve Ar-Ge Uygulama Merkezinde *C. olitorius* bitkisinin hidrosolünün eldesi için bitki örnekleri ufaltıldıktan sonra 100 g bitki örneği 1 L distile su içerisinde Clevenger cihazı ile 3 saat bekleyerek hidrodistilasyon yöntemi ile hazırlanmıştır. Elde edilen hidrosol koyu renkli steril şişelere doldurulduktan sonra oda sıcaklığında soğumaları tamamlanmış ve +4°C buzdolabında kullanılana kadar saklanmıştır. *C. olitorius* hidrosolünün gaz kromatografisi-kütle spektrometresi analizi GC-MS ile Çukurova Üniversitesi Merkezi Araştırma Laboratuvarında (ÇÜMERLAB) analiz edilmiştir.

Bakteriyel Balık Patojenleri

İskenderun Körfezi'nden avlanılan *Nemipterus randalli*, ölü olarak balıkçıdan alınmıştır. Hemen sonra aseptik şartlar altında ve soğuk zincir ortamında İskenderun Teknik Üniversitesi Deniz Bilimleri ve Teknolojisi Fakültesi laboratuvarına getirilmiştir. Mikrobiyolojik çalışmalar steril kabin içinde gerçekleştirilmiştir. Balıklardan alınan bağırsak örnekleri steril falkon tüplerine 0,1 g alınarak seri dilüsyonlar hazırlanmıştır. Patojeni içeren son dilüsyon tüpünden 0.01 mL'lik öze kullanılarak %5'lik koyun kanlı ve eozin metilen blue (EMB) besiyerlerine kültür ekimi yapılmıştır. 35-37°C'de 24 saat inkübasyon sonucu üremeler değerlendirilmiştir. Üreyen balık patojenlerinin identifikasyonu Phoenix 100 ID / AST (Becton Dickinson Co., Sparks, MD., ABD) otomatik tanılama sistemi kullanılarak yapılmıştır.

Antibakteriyel Aktivitenin Tespiti

Disk difüzyon testi

C. olitorius bitkisinden elde edilen hidrosolün *Klebsiella oxytoca*, *Pseudomonas aeruginosa* ve Escherichia coli bakterilerine karşı antibakteriyel etkisi Kirby-Bauer disk difüzyon metodu ve Phoenix 100 ID / AST (Becton Dickinson Co., Sparks, MD., ABD) otomatize sistemi kullanılarak tespit edilmiştir. Hazırlanan hidrosol maddesi 6 mm çapında steril boş disklere emdirilip, steril kabinde kurutulmuştur. Testler her bakteri örneği için üç tekerrürlü olarak yapılmıştır. *C. olitorius* hidrosolü içeren diskler ile antibakteriyel duyarlılık testi çalışılmıştır. İnkübasyon sürecinden sonra disklerin etrafında oluşan inhibisyon zon çapları ölçülerek bu değerlerin ortalaması alınmıştır. Antibiyotik duyarlılıkları, EUCAST standartlarına göre, Kirby-Bauer disk difüzyon yöntemi ve Phoenix 100 ID/AST otomatik sistemi ile çalışılmıştır. Kirby Bauer disk difüzyon yöntemi için bakteri izolatları muller hinton agara 0.5 Mc Farland (1.5x108 kob/mL) yoğunluğunda yayılmıştır. Antibiyotik duyarlılıkları EUCAST (European Commıttee On Antimicrobial Susceptıbility Testing, www.eucast.org) standartlarına göre değerlendirilmiştir. Zon çapları her antibiyotik diski için EUCAST kurallarına göre duyarlı, artmış dozda duyarlı veya dirençli olarak değerlendirilmiştir.

BULGULAR

Bitkiden Elde Edilen Hidrosolün Kimyasal Bileşenleri

Araştırmada kullanılan *C. olitorius* bitkisinden elde edilen hidrosolün kimyasal bileşeni GC-MS ile analiz edilmiştir. Bitkinin hidrosolünde en yüksek oranda bulunan bileşen alpha-terpinyl acetate %43,26 olarak tespit edilmiştir. *C. olitorius* bitkisinin hidrosolünün CS-MS ile tespit edilen bileşenleri aşağıdaki tabloda verilmiştir (Tablo 2).

Tablo 2. *C. olitorius* bitkisinden elde edilen hidrosolün GS-MS ile ölçümlenen kimyasal bileşenleri
Table 2. Chemical components of the hydrosol obtained from the *C. olitorius* measured by GS-MS

BİLEŞEN	Retention Time (RT)	%
D-Limonene	19,57375	6,64
2-Hexenal, (E)-	19,93905	1,31
Eucalyptol	20,09253	4,45
2-Carene	23,64428	0,76
Nonanal	28,35027	1,82
Copaene	33,29565	0,47
Linalool	34,44988	3,86
Linalyl acetate	35,15592	0,99
Terpinen-4-ol	37,23873	1,42
Caryophyllene	37,86342	2,86
.alpha.-Terpineol	40,8103	5,59
.alpha.-Terpinyl acetate	41,0528	43,26
(-)-Carvone	42,22232	4,62
Benzaldehyde, 4-(1-methylethyl)-	43,65888	5,88
Anethole	44,98497	4,25
5,9-Undecadien-2-one, 6,10-dimethyl-, (E)-	46,00713	0,81
trans-.beta.-Ionone	48,51805	3,47
9-Eicosyne	48,61013	2,21
3,4,4-Trimethyl-3-(3-oxo-but-1-enyl)-bicyclo[4.1.0]heptan-2-one	48,73598	0,51
Cyclohexene, 1,5,5-trimethyl-6-acetylmethyl-	49,39288	0,46
cis-Z-.alpha.-Bisabolene epoxide	50,1192	1,13
2-Pentadecanone, 6,10,14-trimethyl-	53,25747	0,54
5,5,8a-Trimethyl-3,5,6,7,8,8a-hexahydro-2H-chromene	53,59512	0,45
Phenol, 2-methyl-5-(1-methylethyl)-	54,36865	0,61
Phytol	64,02545	1,64

Antibakteriyel duyarlılık

Araştırmada İskenderun Körfezi'nden avlanan *Nemipterus randalli*'nin bağırsaklarından elde edilen bakteriyel patojenlere karşı *C. olitorius* bitki hidrosolünün antibakteriyel etkisi disk difüzyon testi ile belirlenmiştir. İnkübasyon sonucunda üç farklı bakteri kolonisi tespit

edilmiştir. *E. coli*, *K. oxytoca* ve *P. aeruginosa* bakterilerinin identifikasyonu yapılmıştır. Disk difüzyon testi sonuçlarına göre, kullanılan *C. olitorius* bitkisinden elde edilen hidrosolün *E. coli*, *K. oxytoca* ve *P. aeruginosa* bakteri türleri üzerinde antibakteriyel etkileri araştırılmıştır. Hidrosolün *E. coli* bakterilerinde en yüksek inhibisyon zon çapı (20 mm), *K. oxytoca* en yüksek inhibisyon zon çapı (18mm) ve *P. aeruginosa* (0) inhibisyon zon çapı saptanmıştır İnhibisyon zonu 15 mm'den büyük olursa kuvvetli, 8-15 mm arası orta ve 1-8 mm arası zayıf aktivite olarak değerlendirilmiştir (Bansemir ve ark., 2006). Buna göre; *C. olitorius* hidrosolü *E. coli* suşlarından dört tanesine kuvvetli (B1, B2, B7, B9), üçüne orta (B3, B4, B8) derecede etki etmiş ve diğer iki suşa (B5, B6) karşı herhangi bir etkisi saptanmamıştır. Araştırmada kullanılan *K. oxytoca* suşlarından A1 ve A5 numaralı suşa karşı kuvvetli, A2, A3 ve A8 numaralı suşa orta derecede etki gösterirken, A4, A6 ve A7 numaralı suşa karşı etki etmemiştir. *P. aeruginosa* suşuna karşı ise herhangi bir etkin zon çapı saptanmamıştır. (Tablo 3).

Tablo 3. *C. olitorius* hidrosolünün *E. coli*, *K. oxytoca* ve *P. aeruginosa* bakteriyel suşları üzerinde oluşturduğu inhibisyon zon çapları (mm)

Table 3. Inhibition zone diameters (mm) formed by *C. olitorius* hydrosol on *E. coli*, *K. oxytoca,* and *P. aeruginosa* bacterial strains

Bakteriyel Suşlar	*C. olitorius* Hidrosolü
Escherichia coli (B1)	20 mm
Escherichia coli (B2)	16 mm
Escherichia coli (B3)	12 mm
Escherichia coli (B4)	10 mm
Escherichia coli (B5)	-
Escherichia coli (B6)	-
Escherichia coli (B7)	18 mm
Escherichia coli (B8)	12 mm
Escherichia coli (B9)	16 mm
Klebsiella oxytoca (A1)	18 mm
Klebsiella oxytoca (A2)	13 mm
Klebsiella oxytoca (A3)	12 mm
Klebsiella oxytoca (A4)	-
Klebsiella oxytoca (A5)	17 mm
Klebsiella oxytoca (A6)	-
Klebsiella oxytoca (A7)	-
Klebsiella oxytoca (A8)	11 mm
Pseudomonas aeruginosa (A1)	-
Pseudomonas aeruginosa (A2)	-
Pseudomonas aeruginosa (A3)	-
Pseudomonas aeruginosa (A4)	-

(-): İnhibisyon zon çapı oluşmadı.

Balık bağırsak örneklerinden elde edilen 21 mikrobiyal izolatın 9 tanesi (%42,85) *E. coli*; 8 tanesi (%38,09) *K. oxytoca*, ve 4 tanesi (%19,04) *P. aeruginosa* türü olarak belirlenmiştir.

İzolatlardan *E. coli* suşlarının otomatize sistemle saptanan duyarlılık profili ampicillin antibiyotiğine karşı dirençli (MIC > 16), amikacin (MIC ≤ 8), amoxicillin clavulanate (MIC 8/2), ceftriaxone (MIC ≤ 1), ciprofloxacin (MIC ≤ 0.25), levofloxacin (MIC ≤ 0.5), ertapenem (MIC ≤ 0.25), gentamicin (MIC ≤ 2), imipenem (MIC ≤ 0.25), meropenem (MIC ≤ 0.125), piperacillin-tazobactam antibiyotiklerine karşı duyarlı (MIC ≤ 4/4) olarak bulunmuştur.

İzolatlardan *K. oxytoca* suşlarının otomatize sistem ile saptanan duyarlılık profili amikacin (MIC ≤ 8), amoxicillin clavulanate (f) (MIC ≤ 2/2), ampicillin sulbactam (f) (MIC4/8), cefepime (MIC ≤ 1), ceftazidime (MIC ≤ 1), ceftolozane-tazobactam (MIC ≤ 1/4), ceftriaxone (MIC ≤ 1), ciprofloxacin (MIC ≤ 0.125), ertapenem (MIC ≤ 0.25), gentamicin (MIC ≤ 2), imipenem (MIC ≤ 0.25), levofloxacin (MIC ≤ 0.5), meropenem (MIC ≤ 0.125), piperacillin-tazobactam antibiyotiklerine karşı duyarlı (MIC ≤ 4/4) olarak saptanmıştır.

İzolatlardan *P. aeruginosa* suşlarının otomatize sistem yöntemi ile saptanan duyarlılık profili amikacin (MIC ≤ 8), meropenem (MIC ≤ 0.5) ve ceftolozane-tazobactam antibiyotiklerine karşı duyarlı (MIC ≤ 1/4), cefepime, ceftazidime, ciprofloxacin, imipenem, levofloxacin ve piperacillin-tazobactam antibiyotiklerine karşı artmış dozda duyarlı olarak bulunmuştur.

TARTIŞMA

Son yıllarda hidrosoller, patojenik ve bozulmaya neden olan mikroorganizmaları kontrol etmek için potansiyel antimikrobiyal adaylar olarak ortaya çıkmıştır. Hidrosollerin gıda ürünlerinde ve kozmetik sanayinde uygulanmasının yanı sıra antimikrobiyal çalışmalarda kullanımının da umut verici olduğu gözlenmektedir. Literatürde şifalı bitkilerin, baharatların ve bunların uçucu yağlar ve diğer ekstraktları gibi türevlerinin antimikrobiyal özelliklerini araştıran artan sayıda çalışma bulunmaktadır. Her ne kadar çalışmalar esas olarak prosesin birincil ürünlerine, örneğin uçucu yağlara odaklansa da genellikle kullanılmadan kalan damıtma atığı, bitki materyali ve su kalıntılarında birçok değerli bileşik içermektedir (Dikmetaş ve ark., 2019).

Bu çalışmada kullanılan bakteriyel suşlar, yaygın olarak ortaya çıkan gıda kaynaklı patojenlerin temsilcileridir. *E. coli*, *K. oxytoca* ve *P. aeruginosa* dünya çapında hastane kaynaklı enfeksiyonların önde gelen ve sıklıkla klinik açıdan önemli antibiyotiklere karşı direnç gösterdikleri bilinen patojenlerdir (Monegro ve ark., 2022).

İlhan ve ark. (2007), *C. olitorius* bitki özütünden üç ayrı ekstrakt (petrol eteri, metanol ve etil asetat-su) hazırlayarak yaptıkları çalışmalarında petrol eteri özütü ile test ettiklerini ve *E. coli* bakteri suşunda 20 mm inhibisyon zonu elde ettiklerini bildirmişlerdir. Ojeleye ve ark. (2023), *C. olitorius* etanolik yaprak ekstraktı ile çoklu ilaç dirençli bakteriler üzerinde yaptıkları bir çalışmada ise *E. coli* bakteri suşunda 33 mm, *P. aeruginosa* bakteri suşunda ise 35 mm inhibisyon zon çapı saptadıkları gözlemlenmiştir. Özdenefe ve ark. (2018) *C. olitorius* yaprak ekstraktının çeşitli kimyasallar

(metanol, etanol, kloroform ve hekzan) ile yapmış oldukları in vitro antimikrobiyal aktivite çalışmalarında *E. coli* ve *Klebsiella* spp. bakteri suşları üzerinde herhangi bir inhibisyon zon çapı saptamadıklarını bildirmişlerdir. Khan ve ark. (2022), *C. olitorius* yaprağının etanol ve sulu ekstraktları ile yapmış oldukları farmakognotik ve antibakteriyel aktivite çalışmalarında *E. coli* bakteri suşu üzerinde sulu ekstraktın etanol ekstraktından daha iyi bir aktivite gösterdiğini bildirmişlerdir (6,23 ± 0,02 mm). Ibrahim ve ark. (2011), *C. olitorius* tohumlarından hidro distilasyon ile elde ettikleri yağın fizikokimyasal özellikleri ve invitro antibakteriyel etkisi çalışmalarında ise en etkili inhibisyon zon çapını *P. aeruginosa* bakteri suşunda 8,2 ± 2,1 mm olarak bulduklarını bildirmişlerdir. Abir ve ark. (2019) yapmış oldukları bir çalışmada ise *C. olitorius* yaprak özütünün 6 fraksiyonunu (At, Bt, Ct, Dt, Et ve Ft) denemiş oldukları bakteriyel suşlardan *E. coli* suşunda 9,5 ± 0,60 mm ile 15 ± 2,58 mm arasında değişen inhibisyon zon çapları tespit ettiklerini bildirmişlerdir. Bu çalışmada antibakteriyel aktivitede gözlemlenen farklılıklar test edilen hidrosolün biyolojik özelliklerinin değişken kimyasal bileşimine bağlanabilir.

SONUÇ

Bu çalışmada, İskenderun Körfezi'nden avlanan *Nemipterus randalli* bireylerinden elde edilen patojenlere karşı *C. olitorius* bitki hidrosolünün antibakteriyel etkisi araştırılmıştır. Bu bitki ile ilgili su ürünleri sektöründe çok fazla çalışma yapılmamıştır. Yapılan çalışmalarda ise *C. olitorius* bitkisinin yem katkısı olarak su ürünlerinde kullanımının olumlu etkiler gösterdiği gözlemlenmiştir. *C. olitorius* bitkisinin su ürünleri sektöründe yem katkı maddesi olarak çalışıldığına literatür araştırmalarında rastlanılmıştır (Singh ve ark., 2016; Oke ve ark., 2021; Afe ve ark., 2022). Su ürünleri yetiştiriciliğinde kullanılan yeme bu bitkinin ilavesi ile balıkların büyüme parametrelerine ve hematolojik parametrelerine olumlu etkiler yaptığı bildirilmiştir.

Sonuç olarak, bu çalışmanın *C. olitorius* bitkisinden elde edilen hidrosolün sucul canlılar üzerindeki antimikrobiyal etkisi, balık hastalıklarının sağaltımında yararlanılabilirliği, sucul canlılardaki immün sisteme olan katkıları gibi pek çok konuya ışık tutacağı düşünülmektedir. Ayrıca antibakteriyel etkinlikle ilgili ümit verici bulgular göz önüne alındığında, bitkinin değişik coğrafyalardan edinilen *C. olitorius* bitkisinin bileşenlerinin yeni nesil antibakteriyel ilaçların başlıca aktif bileşenlerinin ortaya konulması için daha fazla analize ihtiyaç olduğu düşünülmektedir.

Etik Standartlar ile Uyum

Yazarların Katkısı

Yazarlar eşit oranda katkı sağlamışlardır.

Çıkar Çatışması

Yazarlar herhangi bir çıkar çatışması olmadığını deklare etmektedir.

Etik Onay

Yazarlar balık örneklerini ölü bir şekilde balıkçıdan temin ettiklerini ve bu tür bir çalışma için resmi etik kurul onayının gerekli olmadığını bildirmektedir.

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Some morphometric characteristics of *Alburnus caeruleus* (Heckel, 1843) in Adıyaman region, Türkiye

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A B S T R A C T

In this study, the distribution and some diagnostic features of *Alburnus caeruleus* in Adıyaman region were determined. The research was carried out in 18 stations which contains two natural lakes (Azaplı and Gölbaşı Lakes), two reservoirs (Atatürk and Çat Reservoir) and 10 stream systems. *Alburnus caeruleus* individuals were detected from Kahta Stream, Sofraz Stream, Ziyaret Stream, and Çakal Stream. The average length of *A. caeruleus* individuals caught in the research area is 73.70-81.91 mm, and their average weight is 3.70-5.56 g. It was determined that the colours and patterns of *A. caeruleus* individuals differed according to stream habitats, the number of line lateral scales was 51-55, and the number of pharynx teeth was 2.5-5.2. *A. caeruleus* has a limited distribution in the streams in the Adıyaman region, from minimal populations and needs to be protected. Additionally, *A. caeruleus* has the potential to be an ornamental fish in aquariums.

INTRODUCTION

Species belonging to the genus *Alburnus* are mostly primarily distributed in Türkiye, Syria, the Caucasus, Europe and Iran (Kottelat and Freyhof, 2007; Seçer et al., 2020). Recent studies have recorded 29 species of the *Alburnus* genus in Türkiye, 18 of which are endemic (Çiçek et al., 2018; Freyhof and Turan, 2019; Bayçelebi, 2020; Seçer et al., 2020). Additionally, Türkiye is the speciation center for this genus (Özuluğ and Freyhof, 2007). The *Alburnus* genus has a bright-looking and light-coloured body, greenish-brown back, silver-white sides and abdomen. They live in flocks in lakes and fast-flowing areas of rivers close to the pelagic zone (Geldiay and Balık, 2009). *Albburnus caeruleus* is endemic in the Tigris-Euphrates River Basin and distributed in Türkiye, Syria, Iran and Iraq (Coad, 2010, 2020; Zareian et al., 2015; Kaya et al., 2016; Birecikligil et al., 2017; Esmaeili et al., 2018; Saç, 2020).

In the Merzimen Stream, a branch of the Euphrates River close to Adıyaman region, Turan et al. (2014) described a new species *Alburnoides recepi*. However, Birecikligil et al. (2017) examined the morphometric and molecular characteristics of fish samples from the same locality and found that they were synonymous with *A. caeruleus*. Dorafshan et al. (2014) state a high polymorphism level between *Alburnus mossulensis* and *A. caeruleus*. Saç (2020) states that *A. caeruleus* is highly sensitive to many important threats, such as invasive species and pollution. It is essential to update information on the geographical distribution of freshwater fish. This study aimed to reveal the distribution of *A. caeruleus* in the rivers in Adıyaman region and some of its diagnostic features, thus forming a step towards future studies.

MATERIALS AND METHODS

Adıyaman is located in the middle Euphrates Basin. The most important river of the basin is the Euphrates River and the others are; Göksu Stream, Sofraz Stream, Aksu Stream, Karasu, Çakal Creek, Ziyaret Stream, Eğri Stream, Kalburcu Stream and Kahta Streams. There are Gölbaşı and Azaplı lakes and Atatürk Reservoir in Adıyaman region. Kahta Stream, which takes its source from the southeastern Taurus Mountains, constitutes one of the most important tributaries of the Euphrates River.

Table 1. Sampling localities and their coordinates

Location	Longitude (E)	Latitude (N)
Gölbaşı Lake	37°47′38″E	37°38′55″N
Göksu, Tut area	37°56′55″E	37°45′54″N
Çat Reservoir	38°14′05″E	38°02′44″N
Kömür Stream	38°27′39″E	37°50′41″N
Kahta Stream, Bulam village	38°15′27″E	37°55′12″N
Ziyaret Stream, Zey village	38°16′29″E	37°48′13″N
Eğri Stream	38°11′36″E	37°46′40″N
Azaplı Lake	37°33′18″E	37°44′39″N
Atatürk Reservoir, Çamgazi region	37°41′08″E	38°17′39″N
Atatürk Reservoir Samsat region	37°33′51″E	38°29′14″N
Aksu Stream	37°50′23″E	37°44′54″N
Çakal Stream	38°09′51″E	37°43′21″N
Ziyaret Stream	38°20′10″E	37°46′02″N
Sofraz Stream, Üçgöz region	37°57′09″E	37°37′20″N
Kalburcu Stream	38°30′15″E	37°45′44″N
Göksu Stream	37°46′26″E	37°51′54″N
Kahta Stream, Cendere region	38°36′36″E	37°56′06″N
Kahta Stream, Teğmenli village	38°36′36″E	37°56′06″N
● Kahta Stream	38°15′27″E	37°55′12″N
● Ziyaret Stream	38°16′29″E	37°48′13″N
●Çakal Creek	38°09′51″E	37°43′21″N
● Sofraz Stream	37°57′09″E	37°37′20″N

Note: (●Locality where *A. caeruleus* is found)

This study was carried out in the in the streams, lakes and reservoirs in Adıyaman region between April 2012 and December 2013. A total of 18 localities were sampled and the presence of *A. caeruleus* individuals was detected in 4 localities. The geographical locations of the research area are given in Table 1.

Fish samples were caught in streams by using electroshock devices. The GPS coordinates of the sampling stations were determined. The caught fish samples were brought to the Hydrobiology Research Laboratory in 5-L plastic containers in a 4% formaldehyde solution. Then, the fish's length measurements (mm) were made with a digital calliper with a precision of 0.01 mm, and the weight measurements were made with a digital scale with a precision of 0.01 g. The localities where *A. caeruleus* individuals were caught are shown in (Figure 1).

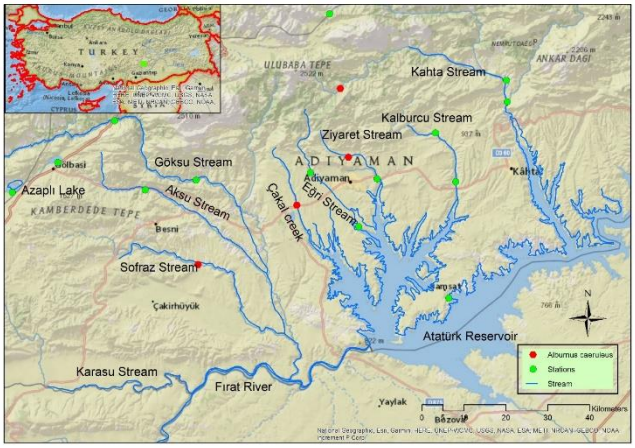

Figure 1. Sampling localities in Adıyaman region

RESULTS AND DISCUSSION

According to the results obtained from field studies, *A. caeruleus* individuals have a very limited distribution in Adıyaman region, with their presence identified in Kahta Stream, Ziyaret Stream, Çakal Stream, and Sofraz Stream (Table 1).

The body of *A. caeruleus* is slightly flattened from the sides and is covered with scales. The dorsal fin begins slightly behind the base of the ventral fins. The mouth is small and terminal. The lips are underdeveloped, and whiskers are absent. The lower jaw is longer than the upper jaw and is directed upwards. The caudal fin is forked, and the free ends of the lobes are pointed. *A. caeruleus* can be easily distinguished from other *Alburnus* species by its laterally flattened body structure and black spots on its body (Figure 2a). However, these black spots are not always present and vary according to habitats and seasons (Figures 3a, 4a, 5a). *A. caeruleus* individuals in Adıyaman region generally live in the flowing, clean streams with rocky and gravel bottoms (Figures 2b, 3b, 4b, 5b).

Table 2. Length, weight and some meristic character counts of *A. caeruleus* individuals detected in Adıyaman region

Characteristics		**Kahta Stream**			**Sofraz Stream**			**Ziyaret Stream**			**Çakal Stream**		
		n	*x*	*sd*	*n*	*x*	*sd*	*n*	*x*	*sd*	*n*	*x*	*sd*
Total weight (g)		3	4.90	0.42	4	4.50	0.56	5	5.56	0.73	2	3.70	0.42
Total length (mm)		3	73.70	4.14	4	75.45	5.06	5	81.91	1.64	2	75.57	1.55
Fork length (mm)		3	66.50	3.80	4	61.95	2.65	5	73.73	4.23	2	65.79	0.87
Standard length (mm)		3	58.86	4.34	4	54.78	1.59	5	65.70	1.08	2	59.93	0.42
Meristic characters		**Kahta Stream**			**Sofraz Stream**			**Ziyaret Stream**			**Çakal Stream**		
Dorsal	Spine	3			3			3			3		
	Soft ray	8			8			8			8		
Anal	Spine	3			3			3			3		
	Soft ray	16			17			16			17		
Ventral	Spine	1			1			1			1		
	Soft ray	8			8			8			8		
Pectoral	Spine	1			1			1			1		
	Soft ray	14			14			12			12		
Pharynx teeth		2.5-5.2			2.5-5.2			2.5-5.2			2.5-5.2		

Note: *n*: Number of fish, *x*: mean, *sd*: standard deviation.

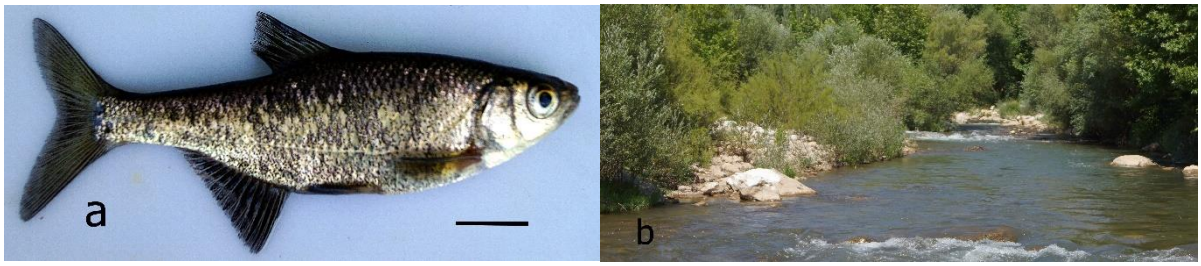

Figure 2. a) The specimen of *A. caeruleus* (total length: 76.63 mm, total weight: 5.29 g, scale: 10 mm). from b) Kahta stream

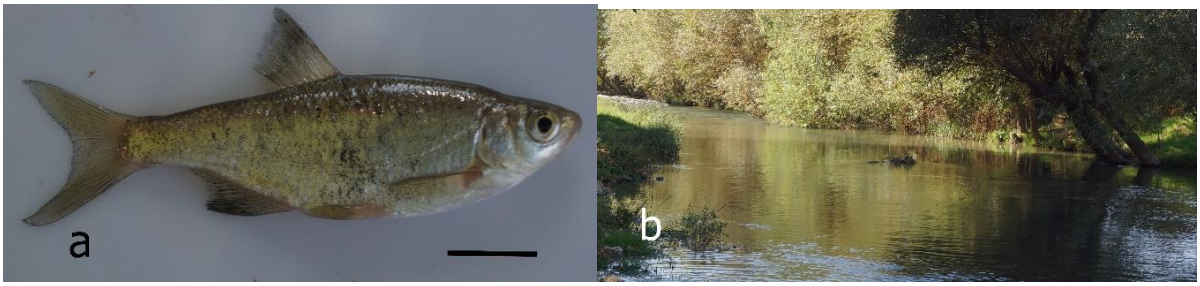

Figure 3. a) The specimen of *A. caeruleus* (total length: 65.13 mm, total weight: 3.5 g, scale: 10 mm) from b) Sofraz stream

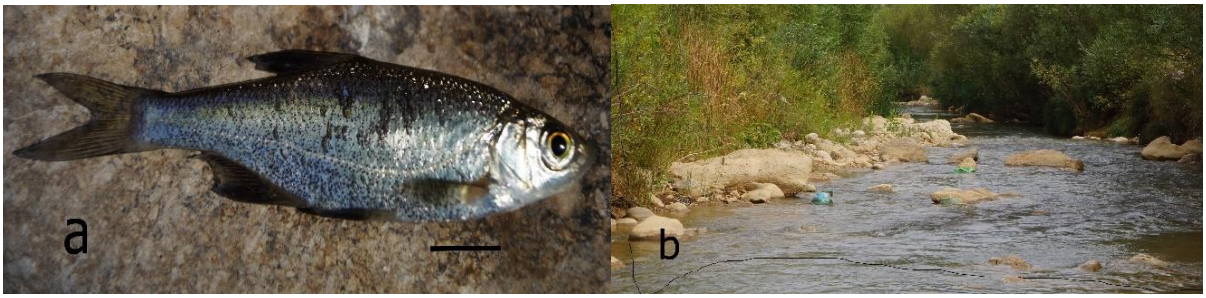

Figure 4. a) The specimen of *A. caeruleus* (total length: 83.26 mm, total weight: 6.4 g, scale: 10 mm) from b) Ziyaret stream

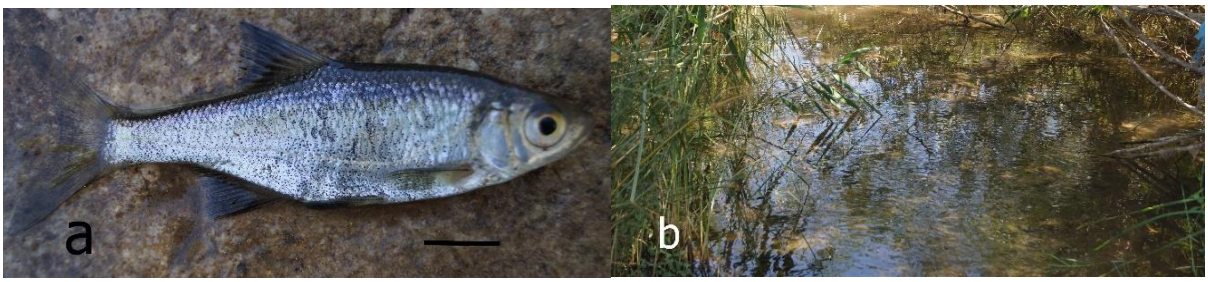

Figure 5. a) The specimen of *A. caeruleus* (total length :74.47 mm, total weight: 4.0 g, scale: 10 mm) from b) Çakal stream

The free edge of the dorsal fin of *A. caeruleus* is straight, and the number of rays is D: II-III 8-9. The number of lateral line scales varies between 51- 55. The base of the anal fin is long, and its free edge is slightly convex. Pharynx teeth are in two rows and are 2.5-5.2 in diameter (Table 2). Length (mm) and weight (g) of *A. caeruleus* individuals identified from the research area in Table 2. Accordingly, the average size of the individuals (n:14) caught from Kahta, Sofraz, Ziyaret and Çakal streams is between 73.70-81.91 mm, and their weight is between 3.70-5.56 g (Table 2).

Sungur (2009) describes some diagnostic features of *A. caeruleus*: lateral line scales number 58-69 (59) states that the number of pharyngeal teeth is 2.5-5.2 and their average length is 5.8 cm. Kaya et al. (2016) state that *A. caeruleus* is distributed in the tributaries of the Tigris River; its standard length is between 62-83 mm, and the number of lateral line scales is 53-55, similar to our research findings. Negative factors affecting *A. caeruleus* populations in streams in Adıyaman region are ponds for irrigation purposes, sand-gravel pits, etc. factors such as. Additionally, *A. caeruleus* is in the LC category according to IUCN status (Çiçek et al., 2023). Although the *A. caeruleus* in question has no economic value in terms of fisheries, it can be used as an ornamental fish in the aquarium (Sungur, 2009).

CONCLUSION

A. caeruleus exhibited a limited distribution within the streams of Adıyaman region. The individuals displayed varied colours and patterns across different stream habitats. Several negative factors impact *A. caeruleus* in these streams, including irrigation ponds, sand-gravel pits, and other similar disturbances. Additionally, *A. caeruleus* has the potential to be an ornamental fish in aquariums.

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COMPLIANCE WITH ETHICAL STANDARDS

Conflict of Interest

The author declares that there is no conflict of interest.

Ethical Approval

For this type of study, formal consent is not required.

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Data Availability

The data supporting the findings of this study are available from the corresponding author upon request.

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Observations on body surface area and aspect ratio in various species of the order Syngnathiformes

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A B S T R A C T

Swimming ability in fish is directly related to body shape, manifesting in various values for swimming speed and body surface area. The constant value used in calculating body surface area derived from length or weight measurements differs between pelagic and benthic species. Furthermore, the aspect ratio is closely related to the feeding pattern, as well as being connected to the swimming speed which is effective in executing escape movements from existing predators in their natural environments. This study presents body surface area and aspect ratio values for nine Syngnathiformes species caught off Turkish coasts. It aims to provide a comparative scientific contribution for members of this order.

INTRODUCTION

Displacement is a fundamental aspect of fish behaviour, occurring either actively or passively within a three-dimensional aquatic environment. The scientific community's understanding of fish swimming physics and physiology has evolved significantly, with seminal works by Blake (1983) and Webb (1984) laying the groundwork. Videler's (1993) comprehensive study further advanced this field of research. To elucidate the correlation between swimming performance and body morphology in fish, a thorough examination of their functional anatomy is essential.

Swimming essentially relies on three fundamental movements: rising, forward acceleration, and stabilization. Fish can coordinate backward thrust movements while maintaining a stationary position against the current, primarily through tail movements (Bainbridge, 1963). Sambilay Jr. (1990) noted that lift and drag forces work together to propel a fish's body forward. The ratio or relation between these forces determines the performance needed for movement.

Swimming performance is understood within the paradigm of general morphology, performance, and harmony (fitness); however, the importance of a fish's body shape in swimming ability is particularly significant (Langerhans and Reznick, 2010). Videler (1993) explained that swimming performance depends on drag force and propulsive force-both closely related to body morphology. This relationship enables fish to effectively forage, escape or hide from predators, and migrate (Fisher and Bellwood, 2002). Furthermore, understanding a fish's body surface area provides insight into the relationship between body weight and surface area. Kayser (1951) claimed the "surface law," which explains the direct, linear relationship between energy metabolism and body surface. Determining body surface

area may allow several important comparisons: such as gill areas of marine fish (Gray, 1953), attachment surfaces of external parasites relative to fish size (Jaworski and Holm, 1992; O'Shea et al., 2006), and aspects of body energy metabolism (Sébert et al., 2004).

Sébert et al. (2004) simplified the methods for calculating body surface area in fish, focusing on eels. The basic formula for surface area is $S = K w^{2/3,}$ where 'S' is the surface area, 'w' is the body weight, and 'K' is a species-specific "constant." While K values typically range from 5 to 18, they hover around 10 for species other than fish with rounded or elongated bodies (Gray, 1953).

Generally, K values of laterally compressed (depressiform) and dorsoventrally flattened (compressiform) species are higher than those of streamlined or fusiform fish (Gray, 1953). Body surface area can vary even among individuals of the same species. Recent studies have shown that three-dimensional fish structures provide more accurate calculations of body surface area (O'Shea et al. 2006). Expressing metabolism in terms of surface area rather than body weight is considered a more accurate approach for marine fish. This method could be particularly advantageous for fish populations in aquaculture. For instance, it may help establish standards for determining the sizes of potential pathogens (Sébert et al., 2004).

The aspect ratio of a fish's caudal fin is closely linked to its swimming speed, which in turn affects how it consumes food and escapes predators in its natural habitat. Pauly (1989) noted that this ratio correlates with a fish species' average level of movement. This key feature influences not only a fish's swimming speed but also its metabolism, food consumption, and ultimately, its survival in the wild.

Westneat and Wainwright (2001) stated that a fish's body profile and surface area contribute to drag calculations in the water column, while the caudal fin's shape primarily determines thrust force. Consequently, the relationship between a fish's pelagic or demersal lifestyle and its aspect ratio warrants careful consideration (Ayana and Ganga, 2019). Aspect ratio values vary among families and species due to differences in fin shapes (Ayana and Ganga, 2019). For instance, Scombrid species exhibit aspect ratio values between 4 and 9, which influences how wing-like their caudal fin's morphometric structure appears (Westneat and Wainwright, 2001). This study focuses on determining the body surface area and aspect ratio values of select Syngnathiformes species found along Türkiye's coastline.

MATERIALS AND METHODS

This study examined the relationship between body surface area and weight for 233 fish specimens among nine species of the order Syngnathiformes collected from Turkish seas between 2018 and 2022. *F. petimba* (Lacepède, 1803) individuals were collected from the nets of commercial fishermen by seasonal sampling as bycatch, while individuals of *S. abaster* (Risso, 1827), *S. acus* (Linnaeus, 1758), *S. tphyle* (Linnaeus, 1758), *S. tenurostris* (Rathke, 1837), *S. variegatus* (Pallas, 1814), *N. ophidion* (Linnaeus, 1758), *H. hippocampus* (Linnaeus, 1758) and *H. guttulatus* (Cuvier, 1829) were obtained by monthly sampling using beach seine. The total length (TL, cm) of all samples was measured with a 0.1 mm precision ruler, while their weights (W, g) were measured with a 0.1 g precision scale. Body height, body width, and the dimensions of the caudal fin (length, height, and width) were measured using digital calipers.

The length-weight relationship was evaluated using Ricker's (1975) equation $W= a \times L^b$, where a and b are regression constants, L represents total length (cm), and W represents body weight (g). Gray's (1953) formula $S=Kw^{2/3}$ was used to determine the body surface area, where K represents the constant value and w represents body weight. Additionally, Pauly's (1989) formula $A=h^2/L$ was used to calculate the Aspect Ratio, where h represents the height of the caudal fin and L represents its length. The obtained data was evaluated using the Microsoft Excel program.

RESULTS AND DISCUSSION

Although the body surface area and K (constant) values for each species in Table 1 were calculated using both weight and total length, all evaluations were based on body weight. Species belonging to the order Syngnathiformes exhibit different K values. Table 1 shows that the minimum body surface area constant (K) value, determined as a function of weight, was lowest in *Syngnathus variegatus* at 0.17 and highest in *Fistularia petimba* at 33.59. Based on body weight calculations, the surface area value of *S. abaster*, which has the lowest body weight, is 12.88, while *F. petimba*, with the highest body weight, has a value of 33.59.

The table reveals that K values are low for slender or stocky species, while high K values are found in relatively flattened and laterally compressed ones. Gray (1953) suggests that fish with the lowest K values represent semi-stocky and short-bodied species, while the highest K value indicates flattened fish species. In this context, *S. variegatus* is classified among the semi-stocky and short-bodied species within the order, whereas *F. petimba* appears to be among the fish species that have undergone relative flattening in the dorsoventral direction. The K value relates to taxonomic position, body shape, and body weight (Gray, 1953). The b values express the total length-weight relationship of the species. Species showing positive allometric growth (b > 3)

include *H. hippocampus*, *F. petimba*, *S. variegatus*, and *S. abaster*. In contrast, species exhibiting negative allometric growth (b < 3) are *N. ophidion*, *H. guttulatus*, *S. tenuirostris*, and *S. typhle* (Table 1).

Table 1. Estimated body surface area and length-weight relationships of species determined according to length and weight function (S: Body surface area, TL: total length (cm), W: weight (g))

Species	N	TL	W	Surface Area Formulas		LWR
				TL	W	
Syngnathus abaster	21	3.4-10.0	0.03-0.4	$S=0.0006L^{2.86}$	$S=12.88W^{0.33}$	$W=0.0003L^{3.04}$
Syngnathus acus	21	4.5-10.2	0.04-0.5	$S=0.0004L^{3.11}$	$S=12.45W^{0.30}$	$W=0.0004L^{3.11}$
Syngnathus tphyle	19	11.2-19.8	0.4-3.3	$S=0.0009L^{2.63}$	$S=2.20W^{0.18}$	$W=0.0009L^{2.62}$
Syngnathus tenurostris	21	6.7-12.2	0.1-0.6	$S=0.0012L^{2.46}$	$S=6.80W^{0.92}$	$W=0.0012l^{2.46}$
Syngnathus variegatus	11	7.3-11.2	0.2-0.5	$S=0.0003L^{3.04}$	$S=0.17W^{0.18}$	$W=0.0003L^{3.04}$
Nerophis ophidion	40	8.4-21.4	0.1-0.6	$S=0.0511L^{0.63}$	$S=15.29W^{0.05}$	$W=0.051L^{0.62}$
Hippocampus hippocampus	12	8.0-13.9	0.95-6.5	$S=0.001L^{3.39}$	$S=8.19W^{0,29}$	$W=0.001L^{3.39}$
Hippocampus guttulatus	35	11.3-16.5	4.3-11.8	$S=0.0178L^{2.31}$	$S=7.48W^{0.29}$	$W=0.017L^{2.31}$
Fistularia petimba	22	37.8-50.0	20.7-80.5	$S=0.0002L^{3.24}$	$S=33.59W^{0.01}$	$W=0.0002L^{3.23}$

Table 2. Allometric growth models of species' body surface area (according to length and weight)

Species	Length			Weight		
	a	*b*	r^2	*a*	*b*	r^2
Syngnathus abaster	-3.52	3.29	0.55	0.97	0.17	0.55
Syngnathus acus	-0.36	2.56	0.95	1.09	0.31	0.96
Syngnathus tphyle	-0.44	3.06	0.64	1.17	0.25	0.65
Syngnathus tenurostris	-0.46	2.28	0.67	1.11	0.28	0.69
Syngnathus variegatus	-0.44	2.88	0.85	1.11	0.28	0.85
Nerophis ophidion	-0.67	0.72	0.05	1.18	0.08	0.05
Hippocampus hippocampus	0.39	3.51	0.85	0.91	0.25	0.83
Hippocampus guttulatus	0.55	2.58	0.67	1.16	0.24	0.67
Fistularia petimba	-1.07	5.36	0.95	1.43	0.47	0.94

Table 2 presents the regression results of body surface area dependent on fish total length and body weight for each species in the order. These results offer preliminary insights for calculating the average surface area of the fish species studied. The allometric results of body surface area, based on length and weight in Table 2, show that the b value differs from 1. The highest correlation values-indicating that body surface area relates to both total length and weight are 0.95-0.96 for *S. acus*, and 0.95-0.94 for *F. petimba*, respectively. Table 3 displays the aspect ratio (A) values for some species in the order Syngnathiformes.

Table 3. Aspect ratio (A) values of the species.

Species	Min-Max	Mean ± SE
Syngnathus abaster	0.26-2.80	0.99±0.22
Syngnathus acus	0.01-2.00	0.92±0.20
Syngnathus tphyle	2.11-2.46	2.65±0.60
Syngnathus tenurostris	0.30-0.40	0.28± 0.05
Syngnathus variegatus	0.40-2.55	0.47±0.14
Nerophis ophidion	N/A	N/A
Hippocampus hippocampus	N/A	N/A
Hippocampus guttulatus	N/A	N/A
Fistularia petimba	0.11-1.18	0.27±0.06

N/A: Not Avaliable

In Table 3, among the species of the order, the lowest aspect ratio value was observed in *S. acus* (0.01), while the highest value was detected in *S. abaster* (2.80). However, these values cannot be calculated for seahorse species as they morphologically lack a caudal fin. Few studies have determined the aspect ratio (A) values of marine fish species. Among these, the AR value in Scombrid species ranges between 4–9 (Westneat et al., 2001). The high AR values in Scombrid species' swimming performance are attributed to the functional structure of the myomeres in the caudal region. Ayana and Ganga (2001) found that aspect ratio (AR) values of some pelagic and demersal species along the Indian coast range from 1.1 to 8.76. They observed that fast-swimming fish (e.g., tuna) have high AR values, while slow-swimming fish (e.g., groupers) have low values. Notably, groupers, as ambush predators, benefit more from the thrust provided by AR for sudden acceleration during prey capture. In our study, many members of the Syngnathiformes order, which exhibit ambush feeding behaviour, have AR values ranging approximately between 1 and 2.65. So, in this study, our findings are pioneering as there are no studies on Body Surface Area and Aspect Ratio for the Syngnathiformes.

CONCLUSION

These results suggest that pipefish species, like slow-swimming groupers, show AR results closely tied to body acceleration movement and feeding behaviour. In

conclusion, we expect that the fin performances supporting the swimming ability of Syngnathiformes species in Turkish seas will provide valuable data for future studies.

Compliance with Ethical Standards

Authors' Contributions

ŞG: statistical calculations, writing of the article, ET: preparing the text for publication, SB: preparation of the article. All authors read and approved the final manuscript.

Conflict of Interest

The authors declare that there is no conflict of interest.

Ethical Approval

For this type of study, formal consent is not required. All relevant international, national, and/or institutional guidelines for the care and use of animals were adhered to.

Data Availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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