MARINE SCIENCE AND TECHNOLOGY BULLETIN

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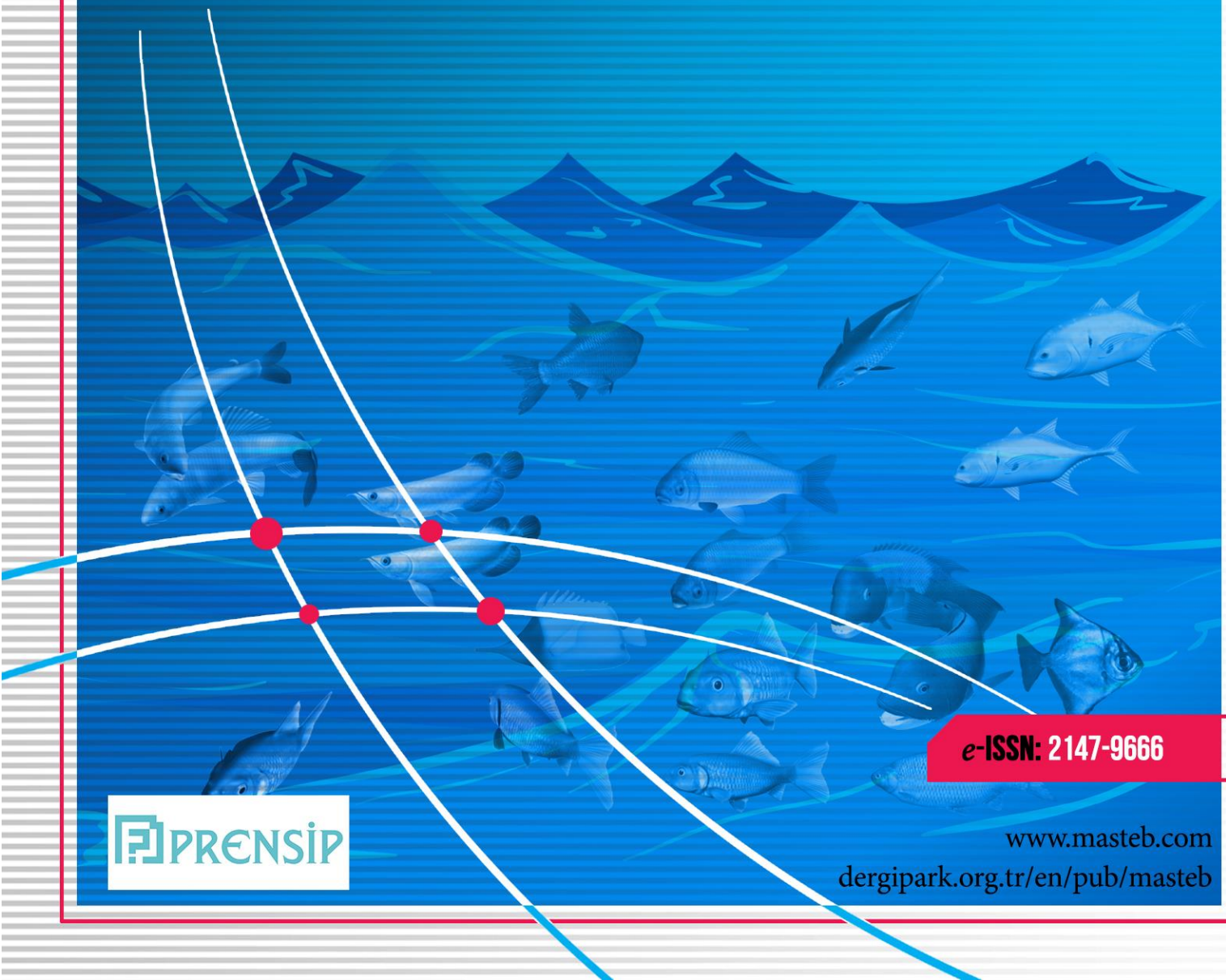

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Research areas include (but not limited):

Marine Sciences
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  - Results
  - Discussion
  - Conclusion
  - Acknowledgement (if required)
  - Compliance with Ethical Standards
    - Authors' Contributions
    - Conflict of Interest
    - Statement on the Welfare of Animals
    - Statement of Human Rights
    - Data availability
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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

Hetland, B., McAndrew, N., Perazzo, J., & Hickman, R. (2018). *A qualitative study of factors that influence active family involvement with patient care in the ICU: Survey of critical care nurses*. PubMed Central, *Preprint*. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5736422/?report=classic

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Brown, C., Laland, K., & Krause, J. (Eds.) (2011). Fish Cognition and Behavior. 2nd ed. Wiley-Blackwell.

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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.

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Conference Proceedings:

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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

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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 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, they are 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.

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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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2. Pre-Evaluation Process

In the pre-evaluation process, the field editors examine the studies, introduction and literature, methods, findings, results, evaluation

and discussion sections in detail in terms of journal publication policies, scope and authenticity of study. Study which is not suitable as a result of this examination is returned to the author with the field editor's evaluation report within four weeks at the latest. The studies which are suitable for the journal are passed to the referee process.

3. Referee Process

The studies are sent to the referees according to their content and the expertise of the referees. The field editor examining the study may propose at least two referees from the pool of Marine Science and Technology Bulletin Advisory Board or referee pool according to their field of expertise or may propose a new referee appropriate to the field of study.

The editors evaluate the referee's suggestions coming from the field editor and the studies are submitted to the referees. Referees are obliged to guarantee that they will not share any process or document about the study they are evaluating.

4. Referee Evaluation Process

The period given to the referee for the evaluation process is 15 days. Proposals for corrections from referees or editors must be completed by the authors within 1 month according to the "correction instruction".

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Referee evaluations are based in general on the originality of the studies, the method used, and the conformity with the ethical rules, the consistent presentation of the findings and results, and the examination of the literature.

This review is based on the following elements:

1. Introduction and Literature: The evaluation report contains the presentation and purpose of the problem addressed in the study, the importance of the topic, the scope of the relevant literature, the timeliness and the originality of the study.

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3. Findings: The evaluation report includes opinions on the presentation of the findings obtained in the frame of the method, the correctness of the analysis methods, the aims of the research and the consistency of the findings, the presentation of the required tables, figures and images and the conceptual evaluation of the tests used.

4. Evaluation and discussion: The evaluation report includes the opinion on the subject based on findings, relevance to research questions and hypotheses, generalizability and applicability.

5. Conclusion and suggestions: The evaluation report contains the opinion on the contributions to the literature, future studies and recommendations for the applications in the area.

6. Style and narration: The evaluation report includes compatibility of the headline with the content, appropriate use of English in the study, and references in accordance with the language of the study and APA rules.

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RESEARCH ARTICLE

Presence and phylogenetic confirmation of the non-indigenous *Penaeus pulchricaudatus* (Decapoda: Penaeidea) Stebbing, 1914 in the Mediterranean Sea

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ABSTRACT

One of the worst invasive species in terms of outspread and impact, kuruma shrimp *Penaeus japonicus* has spread subsequently in the Mediterranean basin after being misclassified for the first time as *P. canaliculatus* in Egypt. At the beginning of the 21st century, however, two morphologically or biometrically similar chromatic patterns of *P. japonicus* have been proven and clarified as two species. They do not differ morphologically, but genetically separate into form I *(P. japonicus*) and form II *(P. pulchricaudatus*). In the present study, we detect the presence and phylogenetic confirmation with mitochondrial cytochrome c oxidase subunit I (COI) gene sequences of the non-indigenous *P.pulchricaudatus* Stebbing, 1914 in the Mediterranean Sea, formerly accepted *P. japonicus*. This is the first finding in the Turkish Mediterranean waters and the first confirmation in the Mediterranean Sea.

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Introduction

Penaeus japonicus (Kuruma shrimp) Spence Bate, 1888 (Decapoda, Penaeidae) recognised as the worst invasive species in terms of expansion and impacts (Pancucci-Papadopoulou et al., 2005), and distributes widely throughout the Indo-West Pacific (Pérez Farfante & Kensley, 1997; Chan, 1998). The area covers South China, Japan, Indonesian Archipelago, Australia, Red Sea, eastern and southern Africa (Dall et al., 1990). The species also crossed the Mediterranean through the Suez Canal

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(Balss, 1927; Galil et al., 2002) and reached the English Channel (Galil et al., 2002).

In the Mediterranean, after being misclassified for the first time in Egypt as *P. canaliculatus* Olivier, 1811 (Balss, 1927), the species has spread subsequently along the Levantine coasts and has been successively recorded as *P. japonicus* in southern Turkey, Syria, Israel, Greece, Rhodes, Cyprus and Lebanon (Galil et al., 2002).Other records from France, Italy (the Adriatic coast), Greece (Amvrakikos & Vistonikos Gulfs), the Sea of Marmara, Black Sea and Spain (Mar Menor), are most likely owing to escapes from aquaculture facilities (Kampouris et al., 2018). Surprisingly, almost 90 years after the first misidentification by Balss (1927), a study by Tsoi et al. (2014), using molecular and phylogenetic analyses, showed that the Kuruma shrimp has been confused for a second time (Tsoi et al., 2005) and the invasive Mediterranean population is *Penaeus pulchricaudatus* Stebbing, 1914, previously considered as a lower synonym of P. japonicus. These two forms are genetically distinct according to sequence data and restriction profiles of mitochondrial genes (Tsoi et al., 2014), although no differences were observed between the two species in terms of morphological characters or biometric parameters (Tsoi et al., 2005).

In 1979, kuruma shrimp has originated from southern Japan to Italy (Lesina Lagoon) (Lumare et al., 2000), after that, it has become important commercially cultured shrimps in the Mediterranean countries such as Türkiye, Cyprus, Greece, Albania, Egypt, Israel (Kapiris, 1997) and Italy (Quigley et al., 2013). However, it is still unknown which *Penaeus* species dominates in shrimp farms (Tsoi et al., 2007). Despite the finding that "both species do not differ in other morphological characters or biometric parameters (Tsoi et al., 2005)", there are two records of *P. pulchricaudatus* in the eastern Mediterranean based solely on images (Kampouris et al., 2018) and in situ observations during a night dive (Kampouris et al., 2019). The existence of those cryptic species that are closely related requires the genetically identification of both wild and aquaculture stocks in the Mediterranean (Tsoi et al., 2005, 2007, 2014).

The aim of this study is to distinguish two similar species of Penaeus found in the eastern Mediterranean using the molecular analysis of the cytochrome c oxidase subunit I (COI) gene region and to show that the species is *P. pulchricaudatus*. Therefore, the correct description of this species would improve aquaculture development programmes and the knowledge-based fisheries management of this economically important resource in the Turkish Mediterranean coasts (Eastern Mediterranean).

Material and Method

Shrimp individuals were collected on board R/V "*Akdeniz Su*" using a standard otter-trawl net on the commercial trawling ground in the Antalya Bay, eastern Mediterranean (Figure 1). After hauling up, the specimens were stored in ethanol for DNA isolation.

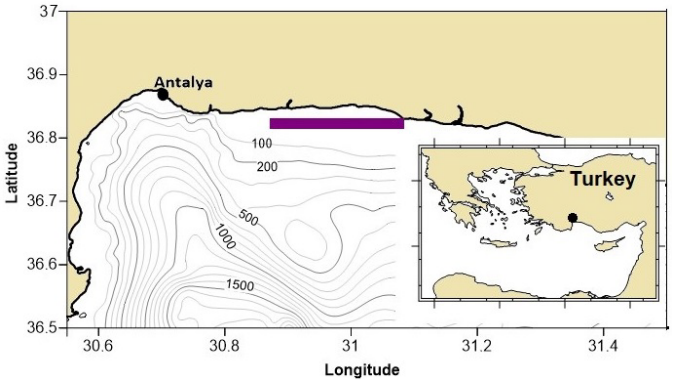

Figure 1. The study area and sampling stations in the Bay of Antalya, Türkiye (Deval, 2020)

DNA was purified from the soft muscle tissues (100 mg) using the Qiagen DNeasy Blood and Tissue Kit (Qiagen, USA) according to the manufacturer's instruction manual. Purity and quality of DNAs were checked by running the isolated DNAs on a 1% agarose gel. DNAs were stored at +4°C.

COI gene region was used as a DNA barcode for molecular identification and phylogenetic tree construction of Penaeidae family. COIf and TL2N were used as primers for PCR amplification of this gene from Palumbi & Benzie (1991) and Quan et al. (2001). Primers were synthesized by Macrogen (Netherlands). Polymerase chain reaction (PCR) amplification of the targeted genes was performed with modifications according to Quan et al. (2001) on a Biorad thermal cycle (Biorad, USA). Amplicons of gene were screened on 1.2% agarose (Applichem, USA) and they were sequenced using same COI primers. The DNA sequencing was performed by Macrogen (Netherlands) and Medsantek (Türkiye).

CodonCode Aligner 6.0.2 software (CodonCode Corporation) was used for assembling sequences. Then consensus sequences were determined by aligning the forward and reverse sequences and matched with nucleotide database in the GenBank using BLASTn (Altschul et al., 1997). COI sequence information of species of Penaeidae family found in Mediterranean Sea from GenBank database used for phylogenetic analyses. CLUSTAL W in MEGA-X was used

aligning COI sequences (Kumar et al., 2018). Pairwise distance matrices of COI gene were generated using the K2P (Kimura-2-Parameter) algorithm in MEGA-X software. The best nucleotide substitution model was defined for COI data set (GTR+G) in jModelTest v2.0 software for phylogenetic analysis (Darriba et al., 2012) under Bayesian information criteria (BIC). Bayesian inferences of gene phylogenies were carried out using Mr. Bayes (Ronquist et al., 2012). The Markov Chain Monte Carlo (MCMC) run was set to 4 chains and the analysis was carried out until the standard deviation of split frequencies fell under 0.01 (sampling every 1000 from 10,000,000 generations). The first 25% of trees were removed as burn-in and the consensus trees were visualized and coloured using Figtree v. 1.4.2 software (Rambaut, 2014).

Results

In the study, the COI gene were amplified as an 817 bp and used in the construction of the phylogenetic analyses. The COI sequences of the species in the Penaeidea family found in the Mediterranean Sea and reported in previous studies were taken from the GenBank database and included in the phylogenetic analyses. The COI dataset obtained as a result of the alignment consists of 876 characters belonging to 47 taxa. Although polytomy is seen in the phylogenetic tree constructed using the BI algorithm, the taxa are separated from each other. Our molecular analysis results and the high bootstrap values (62-100%) in phylogenetic trees (Figure 2), confirm that present sample were separated from *Metapenaeus affinis* H. Milne Edwards, 1837 and *Fenneropenaeus merguiensis* De Man, 1888 (100%) and clustered in *P. pulchricaudatus* (82%).

Discussion

Shrimp farming in Türkiye, especially along the southern Mediterranean coast, started in the early 1990s. *P. japonicus* (Japanese kuruma shrimp) was first farmed in 1995 in a semi-intensive system in Antalya (Eastern Mediterranean) (Türkmen, 2007). Two *P. japonicus* varieties I and II from the South China Sea was presented the first time by Tsoi et al. (2005) as they were morphologically very similar to each other but genetically different. According to this study, there are no definitive differences in morphometric characteristic between varieties I and II based on assessment of thirteen morphological

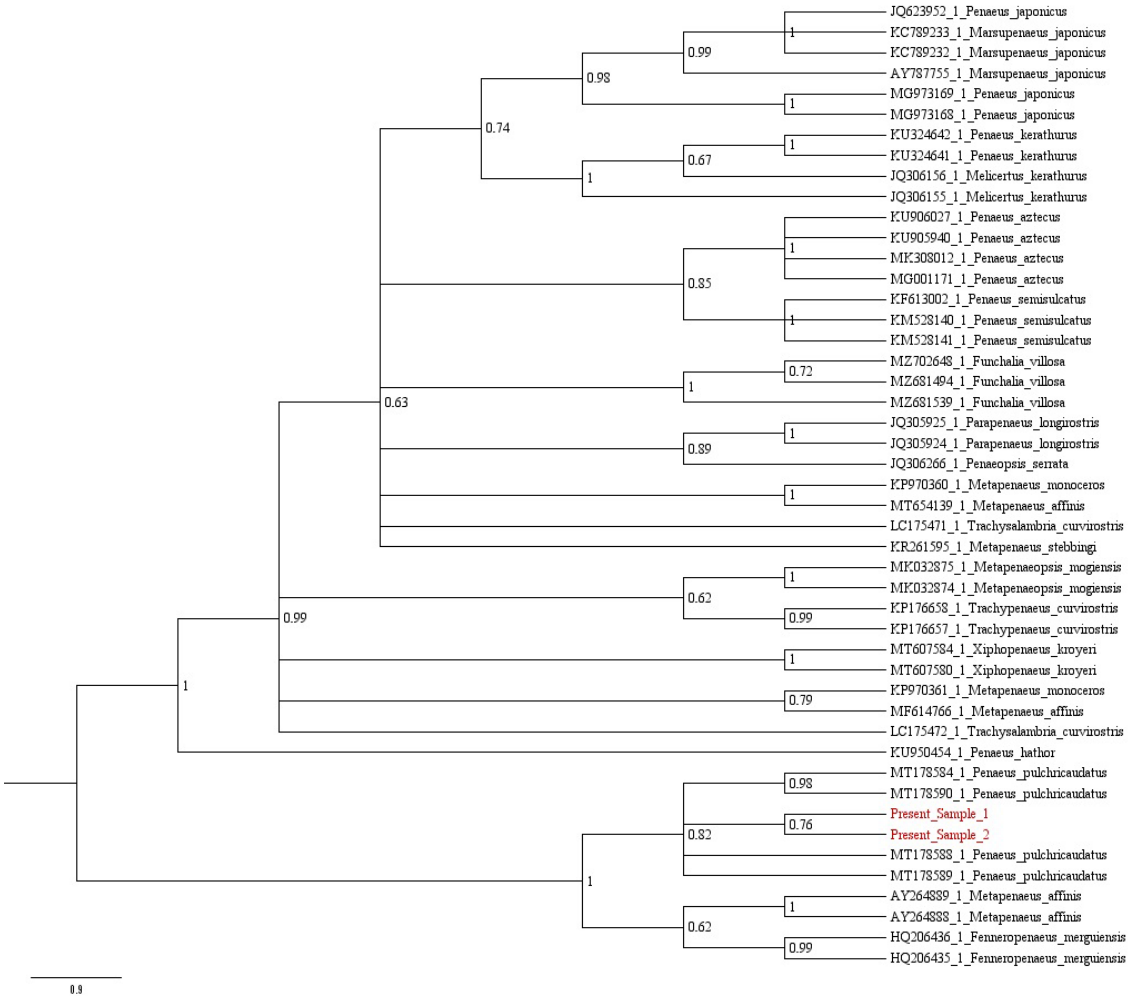

Figure 2. Molecular phylogenetic analysis using Bayesian inference for COI gene sequences

characters. Additionally, molecular analysis of the genes shows in Tsoi et al. (2005) that these two varieties separated different clades, with sequence divergences in 16S rRNA (1%), in cytochrome oxidase I (6-7%) and in the control region (16-19%).

In another study by Tsoi et al. (2007) by using the geographical distribution of these two varieties clarified ten localities based on the mitochondrial sequence analysis of the *P. japonicus*. According to his study result, variety I (*P. japonicus*) obtains populations from Taiwan, China and Japan while variety II (*P. pulchricaudatus*) consists of populations from Philippines Vietnam, Singapore, Australia, Israel (Tsoi et al., 2007).

After Israeli coasts, the result of our study confirmed that the species hitherto known as *P. japonicus* (variety I) is actually another species, *P. pulchricaudatus* (variety II) and presence also in the Antalya Bay, in the Mediterranean. *P. pulchricaudatus* is also seen that other species differ from each other in the phylogenetic tree constructed by Bayesian Inference method. Taxa within the scope of the study were separated from other species and clustered into *P. pulchricaudatus* (82%).

Since *P. japonicus* stock was presented to Italy in 1979 (Lumare, 1998), the kuruma shrimp has been continuously cultured in pond into the number of European countries such as Italy, France, Spain and Portugal (Quigley et al., 2013). However, most shrimp hatcheries still today depend upon the spawners (mature specimens) harvested from nearby wild stocks (Tsoi et al., 2014), therefore, it is unclear whether *P. pulchricaudatus* or/and *P. japonicus* is present in Mediterranean farms.

Conclusion

A wide study on the cultured shrimp in farms is essential to solve this emerging misclarification problem. Nevertheless, as in Türkiye in many other countries, it will be necessary to use *P. pulchricaudatus* instead of *P. japonicus* in fisheries statistics and many other official records.

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Compliance With Ethical Standards

Authors' Contributions

MCD: Sample collecting, wrote the first draft of manuscript.
HEY: Genetic analyses, Lab works and bioinformatics analyses.
İTÇ: Wrote paper, genetic analyses.
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 Statements

The authors confirm that the data supporting the findings of this study are available within the article.

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RESEARCH ARTICLE

Striking the balance: The priority ranking of flexible work arrangements in freight forwarding companies

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ABSTRACT

The Flexible Work Arrangements (FWA) is increasing its prominence in today's business world. Companies are increasingly adopting flexibility to improve employee happiness and overall operational efficiency as the landscape of work patterns evolves. There is a growing research need to address the relative importance of different FWA according to specific business fields of the companies. This study aims to contribute to the field of organizational management by systematically prioritizing and ranking various FWA in the context of Turkish freight forwarding companies using the Analytic Hierarchy Process (AHP) methodology. The literature mainly suggests available FWA and their individual contributions to employee satisfactions. However, there is a research gap to identify the most relevant methods that match the specific needs of the sea freight forwarding sector. This study tries to construct a complete hierarchy of flexible work arrangements by meticulously using the AHP framework and including the viewpoints of both academics and Human Resources (HR) officials. This study seeks to establish a comprehensive hierarchy of flexible work arrangements, taking into account practices such as remote work, flextime, flexplace, and leave control, among others, through a meticulous application of the AHP framework. The findings of this study are expected to provide practical insights, assisting freight forwarding firms in making educated decisions on the implementation and priority of flexible work practices and promoting a harmonious and productive work environment.

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Introduction

The topic of flexible work arrangements is gaining prominence in recent scholarly discussions. Contemporary studies in the literature have demonstrated that retaining talented and experienced personnel is a diligently pursued asset in the container shipping industry (Yildiz & Esmer, 2021; Yildiz et al., 2023a). Offering FWA can be an attractive job selection criterion for employees working in the container shipping companies. It can also help companies to attract and retain talented individuals who value work-life balance and flexibility in their work arrangements (Yusaini et al., 2023).

Flexible work arrangements have been associated with increased job satisfaction and improved employee well-being (Gajendran and Harrison, 2007). By providing employees with more control over their work schedules and locations, freight forwarding companies can contribute to higher job satisfaction and employee morale (Turkmen & Polat Dede, 2019). Flexible work arrangements, such as telecommuting or flexible scheduling, can help employees in the industry achieve a better work-life balance (Dilmaghani, 2020). This is particularly relevant in an industry that often involves irregular working hours and demanding schedules (Yusaini et al., 2023). Therefore, this area is not only attracting the academic research interests but also industrial interests specifically from human resource strategy perspective.

Flexible work arrangements are critical in catastrophe scenarios because they allow organizations and individuals to continue operations while adapting to changing business environment conditions (Yildiz & Akkas, 2023). Yildiz et al. (2023a), revealed that, during the pandemic, container shipping companies greatly benefited from flexible work arrangements. They allowed freight forwarding firms to swiftly adjust because they already had practices in place, such as working from home and rotating shifts.

Upon evaluating the given information, it becomes evident that flexible work arrangements play a crucial role in the container shipping industry, particularly for freight forwarders (Sulistiyani et al., 2023). Based on this point, the aim of this study is to identify which practices within flexible work arrangements, known for their significance to freight forwarders, are more important and feasible. As a result, it is intended to create a guide for companies that have not previously implemented these systems or are just starting to do so, helping them shape their priorities accordingly. In line with this, a comprehensive literature review was conducted to identify eight fundamentals of FWA practices. A questionnaire form was then created, consisting of pairwise comparisons, and administered to 20 experts including academics and industry representatives. The data obtained were processed using the Analytic Hierarchy Process (AHP) method, and ultimately, the prioritization of FWA practices specific to freight forwarder companies was determined.

Conceptual Background

FWA refer to practices that allow employees to have more control and flexibility over their work schedules, locations, and hours (Syihabudhin & Kinanti, 2022). These arrangements can include working from home, working outside regular office hours, reducing or extending contract hours, or banking overtime hours (Groen et al., 2018). The goal of flexible work arrangements is to support employees in achieving a better work-life balance, to enhance their well-being and job-related outcomes (Nijp et al., 2012; Wahab & Tatoglu, 2020; Butarbutar et al., 2022).

There is evidence to suggest that flexible work arrangements have positive effects on employees and organizations. Research has shown that flexible work arrangements can improve work-life balance, job satisfaction, organizational commitment, and employee engagement (Wahab & Tatoglu, 2020; Eshak & Egypt, 2021; Marumpe et al., 2023). They can also lead to increased productivity, performance, and well-being among workers (Subramaniam et al., 2015; Wahab & Tatoglu, 2020; Alzona & Villapando, 2021). Flexible work arrangements have been found to be particularly beneficial for certain groups, such as millennials and women (Subramaniam et al., 2015; Eshak & Egypt, 2021).

However, it is important to note that the impact of flexible work arrangements can vary depending on factors such as the extent of telecommuting, task interdependence, job discretion, and organizational support (Allen et al., 2015; Weale et al., 2017). Some studies have found mixed or inconclusive results regarding the relationship between flexible work arrangements and job satisfaction (Golden & Veiga, 2005). Additionally, the effectiveness of flexible work arrangements may depend on the specific context and industry (Weale et al., 2017; Groen et al., 2018). Flexible work arrangements can include various components that cater to the needs and preferences of both employees and employers. The components of flexible work arrangements can vary depending on the organization and the specific needs of the employees. However, some common components include:

Flextime

Flextime refers to a flexible work arrangement that allows employees to have control over their work schedules, particularly in terms of the start and end times of their workday (Crowley & Kolenikov, 2014; White et al., 2020). It provides employees with the flexibility to adjust their working hours to accommodate personal needs, such as family responsibilities, personal appointments, or other commitments (Chapman et al., 2016; Mohamed & Zaki, 2017).

The concept of flextime recognizes that individuals have different preferences and peak productivity periods throughout the day (Lyness et al., 2012). By allowing employees to choose their work hours within certain parameters set by the organization, flextime aims to enhance work-life balance and job satisfaction (Lee & Kim, 2010; Lee & DeVoe, 2012). It provides employees with the autonomy to structure their workday in a way that suits their individual needs and preferences, which can contribute to increased job satisfaction and reduced work-family conflict (Caillier, 2012).

Research has shown that flextime can have positive effects on various work-related outcomes. For example, studies have found that flextime is associated with improved work-family balance (Haque & Ahmed, 2016; Smith et al., 2019), increased job satisfaction (Caillier, 2012), higher productivity (Lee & DeVoe, 2012), decreased absenteeism (Wadsworth et al., 2010), and enhanced organizational commitment (Caillier, 2012). Flextime has also been found to be beneficial for attracting and retaining talent, particularly for individuals who value work-life balance and flexibility (Chapman et al., 2016).

Information technology (IT) workers often work flexible hours to meet project deadlines and complete tasks during their most productive periods. Furthermore, employees in marketing and sales may utilize flextime to accommodate client schedules and attend meetings or events at different times.

Remote work

Remote work, also known as telecommuting or working from home, refers to a flexible work arrangement where employees perform their job duties outside of the traditional office setting, typically using technology to connect with colleagues and complete tasks (Porto & Vega, 2023). Remote work has gained significant attention and popularity, especially with advancements in technology that enable mobile connections and the recent COVID-19 pandemic, which necessitated remote work for many organizations (Rañeses et al., 2022).

The impact of remote work on various aspects of work and life has been a subject of research and debate. Studies have examined the consequences of remote work on work-family conflict, job satisfaction, performance, turnover intent, role stress, and other work-related outcomes (Golden et al., 2006; Gajendran & Harrison, 2007; Allen et al., 2015). The findings have been mixed, with some studies suggesting that remote work enhances work-life balance and reduces conflict, while others indicate potential challenges and negative effects (Allen et al., 2015). It can also lead to higher productivity and performance (Gajendran & Harrison, 2007). The flexibility and autonomy provided by remote work can allow employees to better manage their work and personal responsibilities, leading to improved work-life balance and well-being (Felstead & Henseke, 2017).

Using collaboration and project management technologies, project managers may manage teams and monitor projects remotely. Some financial analysts and advisers give investment advice and financial planning services remotely.

Compressed workweek

A compressed workweek is a form of flexible work arrangement in which workers work their regular weekly hours over fewer days. A compressed workweek, as opposed to the usual five-day workweek, often consists of increased daily hours to satisfy the entire weekly work hours. Because of the compacted schedule, employees can take more consecutive days off, resulting in a three-day weekend or longer breaks. (Hyatt & Coslor, 2018). The compressed workweek concept seeks to give employees with greater flexibility, work-life balance, and the ability to cut travel time and expenses. Employers can also use it to fit special company demands or operational requirements without jeopardizing staff productivity or efficiency. The effectiveness of establishing a shortened workweek, however, is dependent on the nature of the job, employee preferences, and the company's capacity to efficiently manage the schedule (Arbon et al., 2012; Noback et al., 2016).

Nurses and healthcare workers often work 12-hour shifts three to four days a week, enabling them to take longer breaks. To enhance production efficiency, certain industrial firms use compressed workweeks, in which workers work longer hours but on fewer days per week. Police officers, firefighters, and paramedics usually work lengthy hours followed by many days off. To fulfill tight deadlines, workers in the mining and construction sectors may work shortened schedules throughout project stages. Truck drivers and long-haul transportation

workers sometimes work compressed schedules in order to finish lengthy journeys in a shorter amount of time.

Job sharing

The term "job sharing" refers to a flexible work arrangement in which two or more employees share the tasks and workload of a single full-time employment (Wadsworth et al., 2010). Employees share the hours and activities of the job amongst themselves in a job-sharing arrangement, allowing each individual to work part-time while collectively covering the full-time role (Thakur et al., 2018; Ouakouak et al., 2021).

Job sharing is often implemented to provide employees with greater work-life balance and flexibility, particularly for individuals who have personal commitments or prefer part-time work (Wadsworth et al., 2010). It allows employees to share the responsibilities of a full-time role while reducing their working hours, enabling them to fulfill other personal or family obligations (Thakur et al., 2018; Ouakouak et al., 2021). The benefits of job sharing can include increased job satisfaction, reduced work-related stress, improved work-life balance, and enhanced productivity (Wadsworth et al., 2010; Thakur et al., 2018). Job sharing can also help organizations retain valuable employees who may otherwise leave due to personal circumstances or the need for reduced working hours (Wadsworth et al., 2010; Thakur et al., 2018; Ouakouak et al., 2021).

Sales representatives or account managers may share a client portfolio, with each partner in charge of serving customers on particular days or at particular times. HR professionals may job share to handle recruiting, benefits administration, or employee relations activities, ensuring year-round coverage. Job sharing may be used by legal assistants, paralegals, and administrative employees in law firms to help lawyers and handle casework.

Reduced hours

Reduced hours are a sort of flexible work arrangement in which workers work fewer hours than the regular or full-time workweek. Part-time employees work less hours while still being considered employees of the firm, rather than the typical 40 hours per week (or the standard work hours in a given sector or nation) (Barnett & Gareis, 2002).

Reduced hours or part-time employment has several advantages for both individuals and companies. Employees benefit from enhanced work-life balance, increased scheduling flexibility, decreased travel time and expenditures, possible skill development, and less burnout. Cost savings, enhanced workforce management flexibility, access to a larger talent pool, higher employee retention, and the capacity to respond to seasonal or cyclical work needs can all benefit employers. Part-time employment arrangements can generate a win-win scenario by boosting employee well-being while also addressing the company's operational demands (Kallis et al., 2013; Barck-Holst et al., 2017).

Temporary or seasonal employees, such as those recruited for holiday retail roles or agricultural labor, usually have shorter work weeks. Interns and entry-level workers may begin with part-time hours to obtain experience before progressing to full-time roles. To accommodate several customers or personal obligations, consultants may provide their services on a part-time or reduced-hour basis. Due to the physically and intellectually demanding nature of their jobs, certain healthcare personnel, such as medical technicians and radiologists, may work fewer hours.

Flexplace

The concept of flexplace recognizes that not all work tasks require physical presence in the office and that employees can effectively perform their job duties from a remote location. It offers employees the flexibility to choose where they work, providing them with greater autonomy and control over their work environment. Flexplace arrangements are often facilitated by technology such as laptops, smartphones, video conferencing, and cloud-based collaboration tools, which enable employees to stay, connected and collaborate with their colleagues (Gajendran & Harrison, 2007; Allen et al., 2015).

Flexplace may provide several advantages to both people and enterprises. It gives additional flexibility in managing work and personal commitments for employees, decreases commute time and expenses, and improves work-life balance. It can also lead to increased job satisfaction, better well-being, and less work-family friction. Flexplace can benefit organizations by increasing employee productivity, increasing job satisfaction and engagement, reducing office space and overhead costs, and contributing to environmental sustainability by reducing commuting-related emissions (Hill et al., 2001; Gajendran & Harrison, 2007; Allen et al., 2015).

Software developers and engineers may collaborate with team members from faraway places by utilizing online tools and version control systems. Writers, content producers, and copywriters may work from any place with internet connectivity to create articles, blog posts, and marketing material. Translators and language experts often work from home to offer translation and interpretation services to

customers all around the globe. Telecommunications professionals may work remotely to assist network operations, conduct research, and manage projects.

Flexible scheduling

Flexible scheduling refers to a work arrangement that allows employees to have greater control and flexibility over their work hours and schedules. It involves giving employees the ability to adjust their start and end times, take breaks when needed, and potentially work non-traditional hours. The goal of flexible scheduling is to accommodate employees' personal needs and preferences while ensuring that work tasks and responsibilities are fulfilled (Baltes et al., 1999; Febriani & Sopiah, 2022).

Flexible scheduling has several advantages, including higher job satisfaction, better work-life balance, less work-family conflict, and improved employee well-being. It can also contribute to increased staff productivity, engagement, and retention. Flexible scheduling enables employees to better manage personal commitments such as childcare, schooling, or caregiving, and can contribute to a strong business culture and employee morale (Baltes et al., 1999; Febriani & Sopiah, 2022).

Workers in bars, restaurants, and cafés may use flexible scheduling to coincide with peak eating times and take staff availability into account. Hotel employees, such as front desk clerks, housekeepers, and concierge services, may have flexible hours to effectively handle guest check-ins and cleaning responsibilities. Police officers, firefighters, and paramedics use flexible scheduling, rotating shifts, and on-call arrangements to ensure round-the-clock coverage. Truck drivers, pilots, and logistics workers may have to work around delivery deadlines and customer requests. Healthcare personnel, such as nurses and physicians, employ flexible scheduling to offer round-the-clock patient care, with shifts stretching from day to night.

Leave control

Leave control, also known as leave management or time-off management, refers to the processes and procedures that a company uses to monitor, regulate, and track employee absences and leaves. It entails managing many sorts of leave, such as vacation, sick leave, personal days, maternity/paternity leave, and other forms of time off, while adhering to corporate rules, labor laws, and regulations (Wise, 2005).

Leave control, often known as leave management, has various advantages for both individuals and employers. For starters, it guarantees effective attendance management, assisting businesses in maintaining enough personnel numbers and ensuring productivity stays unaffected. Second, leave control allows workers to make educated judgments about their available leave alternatives by accurately managing their leave balances and accumulated time off. It encourages adherence to labor laws and corporate regulations, lowering the risk of legal challenges arising from leave entitlements and utilization. Furthermore, establishing fair and transparent leave rules via leave control generates a healthy work environment, increasing employee morale and satisfaction. Monitoring absence trends becomes easier, allowing employers to address potential attendance concerns as soon as possible. Overall, a good leave management system reduces administrative operations, increases productivity, and helps to a healthy work environment (Wong & Waldner, 2021).

Professionals in the transportation industry, including truck drivers and aircraft crews, utilize leave management software to request and manage time off while remaining on schedule. To seek time off while maintaining vital emergency services, police officers, firemen, and paramedics need leave control systems. Healthcare personnel, such as physicians, nurses, and medical staff, depend on leave management systems to seek time off for personal reasons or sickness while still guaranteeing enough patient care coverage.

Freight forwarding is a crucial aspect of the logistics industry, playing a major role in the movement of goods from one place to another (Min & Joo, 2009). Freight forwarders act as intermediaries between shippers and carriers, with the main objective of dispatching shipments via carriers (Gocer et al., 2023). They have the expertise and ability to arrange the movement of cargo from one destination to another within a short timeframe. Freight forwarders have established long-term relationships with carriers, allowing them to obtain favorable deals and ensure efficient transportation of goods (Vasantha & Meena, 2019).

The container shipping industry heavily relies on freight forwarders for the efficient consolidation and provision of cargo to container carriers for transport. Freight forwarders act as third-party logistics service providers, offering integrated services and serving as coordinators in supply chain management. They play a vital role in ensuring the smooth flow of goods and effective logistics operations in the container shipping industry (Ding et al., 2016). Freight forwarders also play a crucial role in facilitating global trade by providing efficient and reliable transportation services. They have extensive knowledge of international shipping regulations, customs procedures, and documentation requirements, which helps shippers navigate the complexities of cross-border trade.

Freight forwarders ensure compliance with legal and regulatory frameworks, minimizing the risk of delays or penalties in the shipping process (Notteboom & Merckx, 2006). Moreover, freight forwarders contribute to the competitiveness of container shipping by offering value-added services and enhancing supply chain efficiency. They act as intermediaries between multiple stakeholders, including shippers, carriers, and other logistics service providers, coordinating and optimizing the flow of goods. By streamlining logistics operations and improving coordination, freight forwarders help reduce costs, enhance service quality, and improve overall supply chain performance (Ozaydin & Gucluogullari, 2015).

In the container shipping industry, freight forwarders also play a significant role in carrier selection. Shippers rely on freight forwarders to assess and choose the most suitable ocean container carriers based on factors such as service quality, professionalism of carrier staff, and knowledge of services provided. Freight forwarders' expertise and experience in the industry enable them to make informed decisions that align with the specific needs and requirements of shippers (Fanam et al., 2016). Furthermore, freight forwarders contribute to risk management in the container shipping industry. They help shippers mitigate risks associated with fluctuating freight rates, market volatility, and uncertainties in the shipping market. By providing insights into market trends, offering hedging options such as forward freight agreements (FFAs), and leveraging their network of carriers, freight forwarders assist shippers in making informed decisions and managing risks effectively (Alexandridis et al., 2018).

The role of freight forwarders has evolved over time due to the increasing demand for transport services and changes in the industry landscape. Leading shipping operators, such as Maersk, have expanded their activities to include freight forwarding, posing a threat to traditional freight forwarders. To remain competitive, freight forwarders need to adapt to these dynamic changes and offer added value to their clients. This includes providing a wide range of services, ensuring service quality, and embracing sustainable practices (Skiba & Karas, 2022). Conversely, ocean freight forwarder companies, which sometimes act as carriers, suppliers, and agents, have recently started to function as shipping lines through long-term agreements (Yildiz et al., 2023a).

In today's changing economic environment, flexible work arrangements are critical for freight forwarding companies. These practices allow freight forwarders to respond quickly to the container shipping industry's ever-changing needs. Sea freight forwarding entails intricate logistics, customs regulations, and worldwide supply chain management, which often necessitates around-the-clock attention. Remote working, flexible hours, and job sharing enable employees to maintain a good work-life balance while ensuring the company's operations function smoothly. Furthermore, they can react quickly to crises or time-sensitive circumstances, improve employee retention, and attract a varied talent pool. In summary, implementing flexible work arrangements not only improves sea freight forwarding companies' resilience and agility but also helps their long-term success and competitiveness in the worldwide market (Sulistiyani et al., 2023; Yildiz et al., 2023a).

The FWA practices are more commonly seen in the developed countries and some developing countries interacting more with the developed world. In this research, FWA practices in the literature are evaluated in the perspective of their applicability to Turkish Sea Freight Forwarding companies. Although flexible working arrangements in freight forwarders recently have been investigated by Sulistiyani et al. (2023) from the perspectives of employee performance, this study further helps to explore the unknowns regarding the prioritization of different criteria and their practical implications. In light of this study, it will be possible to have a deeper understanding regarding the flexible working preferences of Freight Forwarder companies which is an essential gap in the literature.

Materials and Method

Research Approach

According to Vaidya & Kumar (2006), the Analytical Hierarchy Process (AHP) is a frequently used approach for multi-criteria decision-making. It enables the creation of ratio scales based on comparisons of various criteria, whether discrete or continuous. As described by Saaty (1987), these comparisons might be obtained from real data or a baseline scale expressing relative preferences and perceptions. According to Vaidya & Kumar (2006), AHP is a legitimate methodology for picking the best choices, whilst Saaty (2008) revealed that it is a systematic way for ranking distinct aspects in a hierarchy. Talib et al. (2011) and Salgado et al. (2015) have both said that AHP is a suitable approach for prioritizing criteria in the context of the HRM discipline.

The AHP method is also commonly applied to the problems of logistics management and freight forwarding. These problems include not only transport choice problems of freight forwarders but also choice criteria of costumers to select freight forwarders. For instance, Akman Durgut et al. (2022)

conducted research on the prioritization of digitalization barriers within the Turkish logistics industry. In another study, Yildiz et al. (2023b) examined the priority rankings of talent development practices within the container shipping industry, with participants including freight forwarders. Considering the findings from these studies, it is reasonable to assert that Analytic Hierarchy Process (AHP) is a valid method for conducting research in these domains.

AHP can be used in instances when the decision-maker can only offer judgment intervals based on perceptions rather than making firm decisions. The AHP method is commonly applied to the problems of logistics management and freight forwarding. These problems include not only transport choice problems of freight forwarders but also choice criteria of costumers to select freight forwarders. In this study, the researchers employed AHP to estimate the weightings of eight major Flexible Work Arrangements (FWA) practices widely discussed in the HRM literature in the current study. The data was gathered from the perspectives of Academics working in the field and HR officials working in freight forwarding companies, which are actively operating in Turkey.

In AHP method, a criteria comparison matrix (A) is generated based on the nearest possible integer generated from the mean responses of the participants (Equation 1).

$$A = \begin{bmatrix} 1 & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} = 1/a_{1n} & \cdots & 1 \end{bmatrix} \quad (1)$$

To perform AHP analysis the matrix needs to be normalized. The criteria comparison matrix is normalized with the Equation 2.

$$a'_{ij} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}}, i, j = 1,2, \dots, n \quad (2)$$

where a_{ij} is the comparison value of the two criteria. Then, priority weighing is calculated with the Equation (3) (Anonymous, 2023a).

$$w_i = \left(\frac{1}{n}\right) \sum_{i=1}^{n} a'_{ij},\ i, j = 1,2, \dots, n \quad (3)$$

The consistency ratio (CR) is used in AHP analysis to analyze the concurrency of expert perspectives. If the CR is 0.1 or below, the experts' judgments were consistent, and the study may proceed to derive the mean relative weights. If the CR is more than 0.1, it indicates a lack of consensus among the experts, and more data from other experts must be acquired before performing the study (Tzeng & Huang, 2011). When people have distinct value systems and behave autonomously, the emphasis changes to understand the values that each person discloses. These priorities can then be determined and summarized mathematically or geometrically (Forman & Peniwati, 1998). The formula of CR is given as below (Equation 4).

$$CR = ((\lambda_{max} - n))/((n-1) * RI) \quad (4)$$

where:

λ_{max} is the eigenvalue of the matrix.

n is the number of attributes.

RI is the random index dependent on n number.

The eigenvalue of the matrix is also calculated as follows (Equation 5).

$$\lambda_{max} = \left(\frac{1}{n}\right) \sum_{i=1}^{n} \left(\frac{\sum_{i=1}^{n} a_{ij} w_j}{w_i}\right) \quad (5)$$

where w_j is the priority weighting of criterion j.

Data Collection and Profile of the Respondents

A questionnaire survey was carried out to examine the significance of the eight primary FWA practices identified in the HRM literature. The poll included expert participants who compared the relative importance of certain FWA practices in pairs. The purpose was to identify the most viable procedures for freight forwarding firms. Each participant was asked to make separate and distinguishable judgments without the necessity of agreement on the relevance of criteria or alternate rankings. The goal of this method was to capture their impressions by having them pick between several possibilities. To reflect the perceived significance of one factor over another, participants utilized a pair-wise comparison scale (refer to Table 1).

Table 1. The research's linguistic scale

Explanation	Saaty AHP Scale (Crisp Values)
Equally preferred	1
Moderately preferred	3
Strongly preferred	5
Very strongly preferred	7
Extremely preferred	9
Equally to moderately preferred	2
Moderately to strongly preferred	4
Strongly to very strongly preferred	6
Very strongly to extremely preferred	8

Note: Source: Anagnostopoulos et al. (2007), Bakır & Atalık (2021), Yildiz et al. (2023b).

Purposive sampling was used to pick participants for this study, which means they were chosen based on specified criteria related to the research purpose. Purposive sampling's main goal is to choose experts to include in the sample who have mentalities shaped by experience, competence, and expertise in the subject of the research. In AHP studies conducted based on perceptions, the goal is to include the most suitable experts in the sample to ensure that the evaluations yield accurate and valid results. In this regard, purposive sampling is considered the most appropriate sampling method for the selection of the sample in this study. Potential participants had to have a high degree of expertise and experience with the topic matter, as well as indicate their availability and desire to participate in the study (Palinkas et al., 2015; Yildiz et al., 2023b).

The final sample included 20 people chosen for their participation in the industry and competence on the topic. In selection of industrial participants, Utikad Database was used, and it was targeted to reach min.10% of the companies considered in the scope of this study. The academic researchers involved in the study are actively affiliated with maritime faculties, specifically within the department of maritime business management. These academics have been included in the sample deliberately, as they possess expertise and engage in research related not only to freight forwarding but also in the fields of human resource management and management and organization in general. Table 2 contains detailed information about the respondents.

Numerical Analysis

Following the data collection process, the obtained data from the survey questionnaires are carefully elaborated, and three different criteria matrixes are established based on the perspectives of two different occupations and the total responses to survey questionnaires. This numerical analysis will help us not only determine the criteria weighing ranking for the total responses of the participants but also comprehend point-of-view differences between academic and industrial participants.

The numerical analysis will help us to prioritize the FWA criteria, calculate the eigenvalues, delta, and consistency ratios which are mentioned in the materials and method section. The numerical analysis of the study is performed by using Microsoft Excel and BPMSG AHP calculator software (Anonymous, 2023b). BPMSG is a web based free software which is applicable to criteria prioritization, and consistency ratio calculation. It also provides high quality visual illustration of the results. In the generation of the matrixes, the nearest integer numbers of the mean responses are used. In the final stage of the numerical analysis CR is calculated by using the following Warton Random Index (RI) scale. Since the problem has 8 criteria, the RI is considered as 1.41.

Table 2. Profile of the respondents

Participant No	Company/Institution	Occupation	Experience in the Field (Years)	Education
1	University	Academic Research	9	Doctorate
2	University	Academic Research	9	Doctorate
3	University	Academic Research	10	Doctorate
4	University	Academic Research	9	Doctorate
5	University	Academic Research	9	Doctorate
6	Freight Forwarder	Human Resources	21	Graduate
7	Freight Forwarder	Human Resources	6	Master's
8	Freight Forwarder	Human Resources	19	Master's
9	Freight Forwarder	Human Resources	13	Graduate
10	Freight Forwarder	Human Resources	13	Master's
11	Freight Forwarder	Human Resources	20	Master's
12	Freight Forwarder	Human Resources	1	Master's
13	Freight Forwarder	Human Resources	9	Master's
14	Freight Forwarder	Human Resources	15	Master's
15	Freight Forwarder	Human Resources	7	Master's
16	Freight Forwarder	Human Resources	6	Master's
17	Freight Forwarder	Human Resources	13	Graduate
18	Freight Forwarder	Human Resources	15	Master's
19	Freight Forwarder	Human Resources	7	Master's
20	Freight Forwarder	Human Resources	10	Graduate

Table 3. Warton RI scale up to 8×8 matrices

n	1	2	3	4	5	6	7	8
RI	0	0	0.58	0.90	1.12	1.24	1.32	**1.41**

Note: Source: (Franek & Kresta, 2014)

Results and Discussion

As an outcome of the numerical analysis, initially the criteria weighing, and criteria rank results are generated. The table 4 presents the criteria weighing and rank of the study. The table below illustrates weighing and rank results of the 5 academic participants, 15 Private Sector HR Professional participants and total 20 participants.

The results of the study shown the Remote work criterion as the most important criterion with 31.597 % among flexible job arrangements criteria. This importance is accepted as a bit higher by academic participants in comparison to industrial participants. The most notable difference between academics and industry professionals' perspective is the ranking of Flextime. Whilst it is ranked as 2nd by academics, it is ranked as 7th by the industry. Job sharing on the other hand is ranked as the least important criterion by all participant categories.

When we calculated the consistency ratio of academic participants' responses, we found it around 0.061 which is also smaller than 0.1 and therefore consistent.

Ultimately, we calculated the consistency ratio of Private Sector HR Professionals' responses, we found it smaller than 0.1 (approximately 0.059) and consistent.

The findings of the study indicate that the participants, followed by flexplace, leave control, flextime, flexible scheduling, a compressed workweek, reduced hours, and job sharing, perceive remote work as the most significant flexible work arrangement. This ranking suggests that remote work is highly valued and considered important in providing flexibility and work-life balance. The higher importance given to remote work by academic participants compared to industry professionals may reflect the growing acceptance and adoption of remote work in academic settings. Academics may have experienced the benefits of remote work, such as increased autonomy and flexibility, which could explain their higher ranking of remote work.

Flexplace's second-place rating underlines the importance of giving employees the flexibility to pick their work location, allowing them to maximize productivity while accommodating personal preferences. Leave control, ranked third, indicates that participants understand the necessity of giving employees the option to regulate their time off, presumably indicating the desire for harmonious work-life integration. The fourth-place position for flextime demonstrates its importance in giving employees more control over their working hours, potentially increasing job happiness and engagement. However, the significant disparity in its rating between academics and industry experts suggests divergent views on its application and advantages.

Flexible scheduling and compressed workweek, which rank fifth and sixth, demonstrate the complex nature of professional flexibility. While both techniques provide benefits in terms of adjusting to individual demands, the differences in their positions may be due to differences in operational requirements and personnel responsibilities within the freight forwarding business. Surprisingly, reduced hours came in seventh place, indicating that people may prefer alternative types of flexibility to reduced working hours. Job sharing's placement in the eighth and last position emphasizes its perceived limited application in the context of freight forwarding firms, possibly due to the nature of the industry's tasks and obligations.

Table 4. Criteria weighing results of the study

Criteria	Academic Weighing & Rank	Industrial Weighing & Rank	Total Weighing & Rank
Remote Work	0.328098 (Rank 1)	0.288937 (Rank 1)	0.31597 (Rank 1)
Flexplace	0.153195 (Rank 3)	0.20038 (Rank 2)	0.201063 (Rank 2)
Leave Control	0.125426 (Rank 4)	0.182159 (Rank 3)	0.155691 (Rank 3)
Flextime	0.22695 (Rank 2)	0.063138 (Rank 7)	0.096471 (Rank 4)
Flexible Scheduling	0.076898 (Rank 5)	0.094351 (Rank 4)	0.086054 (Rank 5)
Compressed Workweek	0.038454 (Rank 6)	0.080426 (Rank 5)	0.067377 (Rank 6)
Reduced Hours	0.03129 (Rank 7)	0.0663 (Rank 6)	0.05307 (Rank 7)
Job Sharing	0.01969 (Rank 8)	0.02431 (Rank 8)	0.024307 (Rank 8)

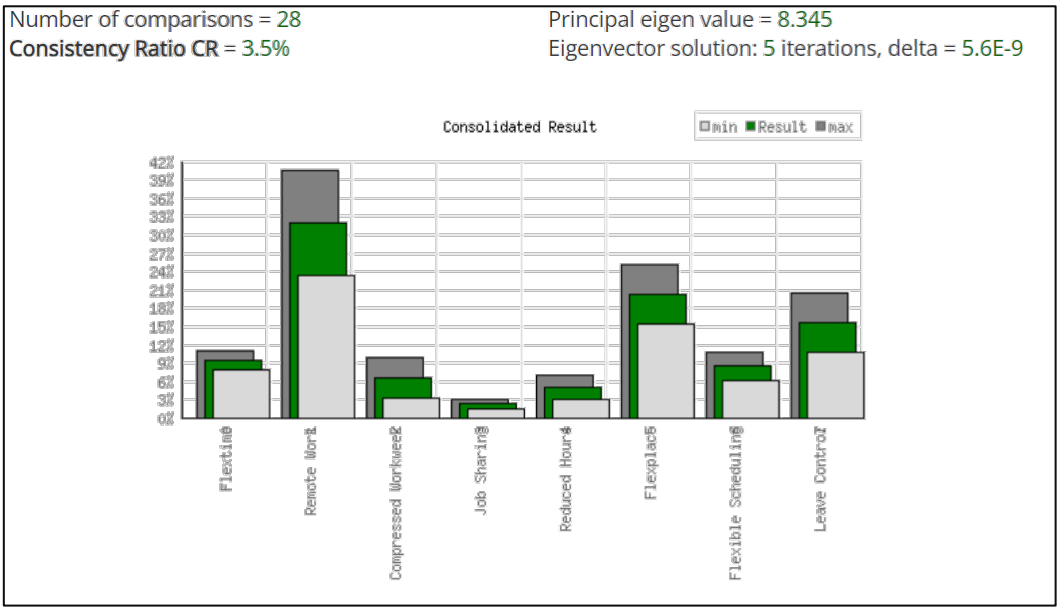

Figure 1. Consistency ratio of the total participant responses

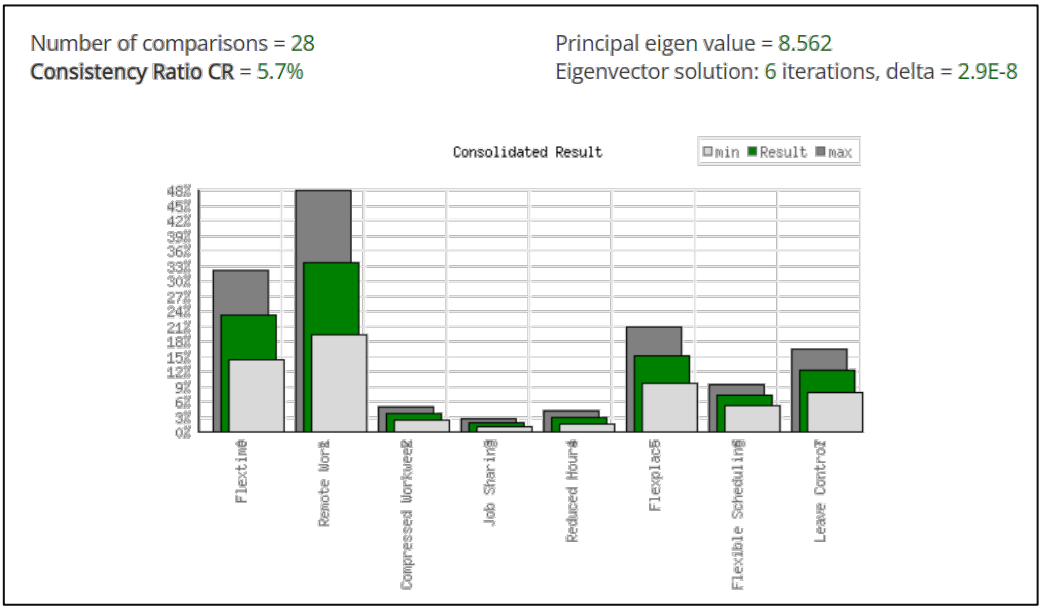

Figure 2. Consistency ratio of the academic participant responses

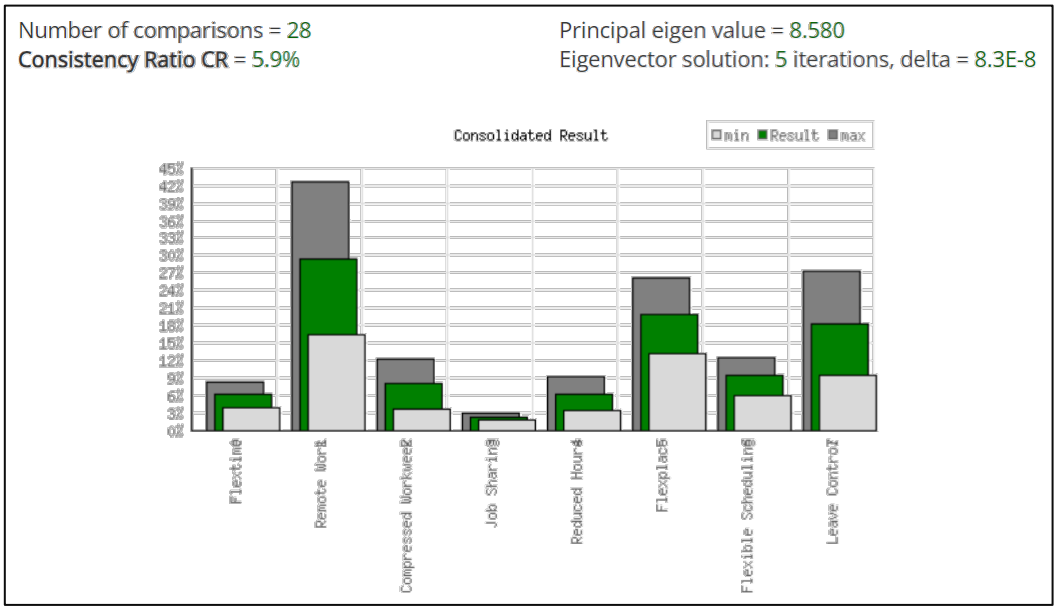

Figure 3. Consistency ratio of the private sector HR professionals' responses

The difference in the ranking of flextime between academics and industry professionals is notable. While academics ranked flextime as the second most important criterion, industry professionals ranked it lower, in seventh place. This difference may be attributed to the nature of work in the freight forwarding, which often involves shift work and irregular schedules that may not easily accommodate flextime arrangements. Job sharing was consistently ranked as the least important criterion by all participant categories. This suggests that job sharing may not be widely recognized or implemented in the freight forwarding. The challenges associated with coordination and communication in job-sharing arrangements may contribute to their lower perceived importance. The higher importance given to remote work by academic participants compared to industry professionals may reflect the growing acceptance and adoption of remote work in academic settings. Academics may have experienced the benefits of remote work, such as increased autonomy and flexibility, which could explain their higher ranking of remote work. This finding suggests that the context of the industry and the nature of work may influence the perception and importance of different flexible work arrangements.

The findings align with previous research that highlights the positive impact of flexible work arrangements on job satisfaction, work-life balance, and productivity (Giovanis, 2015; De Menezes & Kelliher, 2017; Sanders & Karmowska, 2020). The importance of flexible work arrangements for freight forwarding companies lies in their potential to enhance employee satisfaction, well-being, and retention. By offering flexible work options, these companies can attract and retain talented individuals who value work-life balance and flexibility (Yildiz et al., 2023a).

In their study examining talent management practices in container shipping companies, Yildiz et al. (2023a) emphasized the significance of flexible work arrangements. According to Yildiz et al. (2023a), participants highlighted the importance of flexible work arrangements, particularly remote work, during the pandemic, noting that it played a lifesaving role, and with the assistance of technological advancements, work could be efficiently managed with minimal disruptions. In this study, which includes freight forwarders in its sample, it is emphasized that in parallel with the findings of our study, the importance of remote work practice is underlined by industry representatives in their own words.

Employees working in the marketing and sales departments of freight forwarder companies often have high mobility. Due to their active customer visits, they are frequently out of the office and even out of town. Yildiz et al. (2018) identified job requirements for the marketing department, which is one of the departments where maritime business management graduates commonly work in freight forwarder companies. They emphasized that the ability to work from anywhere at any time is essential for this position. This supports why the flexplace practice holds high priority in our findings from a different perspective.

This study emerges as an original work that fills an important gap, as it is one of the first studies to detail and name flexible work arrangements, and there has not been a study before that individually addresses these practices within the service sector. Past studies have typically addressed flexible work arrangements as a whole and focused on their effects on different components and their benefits to companies and employees (Soltani et al., 2009; Subramaniam et al., 2015; Turkmen & Polat Dede, 2019; Sanders & Karmowska, 2020). In this regard, our assertion that flexible work practices are essential for the service sector, especially for freight forwarders, is indirectly supported. Our study takes this a step further by detailing the specific practices within flexible work arrangements and strives to create an understanding of which ones are more suitable and significant for freight forwarders. It is important to note that the study specifically focuses on freight forwarding companies, and the references provided cover a wide range of topics related to flexible work arrangements. Future research specifically targeting the freight forwarding would provide more insights into the importance and implications of flexible work arrangements in this context. When these findings are compared to the current research, it is clear that the desire for flexible work arrangements is context-dependent, impacted by industry-specific demands and individual preferences (Thompson et al., 2015). This study offers useful insights for both academics and business, as well as suggestions for freight forwarding firms looking to establish flexible work arrangements customized to their specific operating settings and workforce demands. FWA in maritime industry is not limited to implementations seen in freight forwarders. Shore Control Centre and remotely operated ships will be promising technologies enabling seafarers to work remotely in maritime industry (Dybvik et al., 2020; Wright, 2020; Kurt & Aymelek, 2022). Additionally, with increasing motivations towards smart ports via digitalization, it will be possible to see further digitalization and FWA in the freight forwarding operations.

Conclusion

This study set out to determine the criteria of flexible work arrangements and their relative importance in Turkish Sea Freight Forwarder companies. One of the objectives of the study was to evaluate the differences between academic and industrial perspectives regarding the flexible work arrangements. The study developed a survey questionnaire based on the existing literature. By using that questionnaire, quantitative primary data from 5 academic and 15 Private Sector HR Professionals working in Turkey were collected. The participants were selected based on their knowledge and experience in the field as appropriate to the sampling approach of the study. The collected data were elaborated and analyzed by applying the AHP criteria prioritization methodology. The numerical analyses of the methodology were performed via Microsoft Excel and BPMSG software.

The results of the study suggested that the remote work criterion would be seen as the most important criterion by both academic participants and private sector HR professionals. The study also determined a major difference in the prioritization of flextime criteria between academic and industrial participants. The findings of this study indicate the need for academic-industrial collaboration to work on this issue to evaluate the changing dynamics in the workplace of freight forwarding businesses.

This study is a novel and exploratory research helping to discover the criteria prioritization in FWA of Sea Freight Forwarding in Turkey. This study is significant for the industry due to its contribution to resource allocation of freight forwarding businesses to FWA. Additionally, it is equally important to academic literature due to its response to address the determined research gap. As a consequence of this study, it is also possible to obtain an in-depth insight to flexible working preferences of Freight Forwarder companies. The outcomes of this study will also increase the motivation to redefine workplace and FWA implementation in freight forwarding.

This study also has some limitations. One of the limitations of this research is the limited number of participations in the survey questionnaire from academia. This is due to a lack of direct expertise in academia regarding the HR focus on Freight Forwarding in Turkey. Another limitation of this study is not considering the gender and age of the participants in consideration of their evaluations. The study also does not consider the fuzziness of the responses and uses AHP as a research methodology. Despite the limitations, this study demonstrates a significant basis for freight forwarder companies in Turkey to prioritize their flexible work arrangements criteria.

This study is likely to trigger more publications in this research area. Future studies are expected to develop this model further including the fuzziness of the responses by employing a Fuzzy AHP methodology. Additionally, the criteria used in this research could be also calculated according to different departments of the Freight Forwarder business organizations. This would enable us to evaluate the importance of the criteria for each business department. Another possible research could be to perform a longitudinal study on Freight Forwarder companies to identify changes in criteria prioritization due to the endogenous and exogenous effects over time.

Compliance With Ethical Standards

Authors' Contributions

The authors handled all the tasks collaboratively. Both authors read and approved the final manuscript.

Conflict of Interest

The authors declare that there is no conflict of interest.

Ethical Approval

The ethical approval of this study was gathered from Ethic Committee of Iskenderun Technical University.

Data Availability Statement

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

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RESEARCH ARTICLE

The importance of CATZOC in passage planning and prioritization of strategies for safe navigation

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ABSTRACT

Maritime transport has a significant share in world trade. The unsafe operation of ships causes loss of life, loss of cargo, and marine environmental pollution. Commercial ships are equipped with advanced types of equipment. The nautical charts as aids to navigation are used on commercial ships to navigate safely between ports. The officer of the watch can see the risks in the navigation area by checking these charts. The risks indicated on the chart should be taken into account during the navigation of ships, and if the correct calculations are not made, serious accidents may occur. These calculations are based on both sufficient maritime experience and knowledge. This research studied the category zone of confidence (CATZOC) areas in ECDIS on ships, the limitations of the system, and their solutions. Recommendations received from experts for the solutions to the identified problems were determined and explained according to the priorities with the Fuzzy Analytical Hierarchy Process (FAHP) method.

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Introduction

In international trade, there are different forms of cargoes such as solids, liquids, live animals, ro-ro, containers and liquefied gas. Although the ship types are different, they all have a common purpose in navigation, which is navigational safety. Each device has a system designed to assist the master and officers of the watch during navigation. Ships are equipped with navigational equipment according to the rules regulated by the International Maritime Organization (IMO).

Ships can navigate in narrow channels and shallow waters and it is of great importance for the officers that the navigation

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charts used are reliable. Although the depths of the berths of the ports are shown on the navigation charts, in practice, shallow areas may occur due to natural sea movements and port operations. For this reason, ship manoeuvres in port areas should be applied carefully.

As the size of the ships increases, the draft of the ships also increases. When the ship is underway, speed increases the draft of the ship. This is called the dwarfing effect and has a greater effect in shallow water and fresh water, causing the draft of ships to increase further (Chénier et al., 2019). Besides unpredictable fluctuations, the rapid increase in ship sizes in recent years and the collaborations established by global line operators force container ports to increase their physical capacities (Efecan & Temiz, 2023). This is a risk because the greater the draft of the ship, the more likely it is to run aground at shallower depths. To mitigate these risks, nautical charts should be trusted and interpreted well. It is possible to check the depth controls with echo sounder in the areas where the ships are moving. The echo sounder device measures the depth instantaneously by means of sound echoes with the help of sensors located at the bow and stern of the ship. However, it does not help to get information before reaching a dangerous point; it only provides control (Talwani et al., 1966).

Due to their nature, the seas contain many risks, such as shallows, reefs, shipwrecks, corals, offshore platforms, fish farms, and navigational aid buoys. The master can see these risks on the bridge during look-out or on the charts. It is dangerous to approach or watch such risks. For safe navigation, the information on the charts constitutes an order of importance according to the type of voyage. For example, route planning and considering currents are more important in open sea navigation, while in narrow and shallow waters, effects such as dangerous areas, buoy locations, shoreline information, and tides are more critical (Başaraner et al., 2011). Master and watchkeeping officers need to be careful and prepared for these risks for the ship's safe navigation.

Today, electronic charts that replace nautical charts, along with navigation sensors and other navigation aid devices, have become an important area of use based on the creation of an integrated bridge system that will significantly increase navigational safety (Admiralty, 2021). These technological developments are supported by international standards (Er, 2007).

The reliability of the chart-based systems used on ships is vital for the safety of navigation. The Electronic Chart Display and Information System (ECDIS) is sophisticated navigational equipment developed to "assist the seafarer in route planning and tracking and, if necessary, display additional navigation-related information" as specified in the performance standards (IMO, 2006). The history of ECDIS dates back to the 1990s when several companies offered electronic chart systems for use on ships. Recognizing the need to prepare performance standards for ECDIS, IMO adopted the ECDIS Performance standards resolution (IMO, 1995).

This decision sets out the minimum requirements that must be met for the use of ECDIS as bridge equipment on conventional ships. With the adoption of the amendments to SOLAS in 2000, it was accepted that ECDIS complies with the provisions of the SOLAS Convention (IMO, 2000). Later in 2009, IMO established the implementation timeline as shown in Table 1. Today, the implementation of ECDIS on ships has expired, making it mandatory for ships to be equipped with ECDIS equipment.

ECDIS is an integrated information system that displays a wide variety of navigation information using spreadsheets. Designed with the ship operator in mind, ECDIS is a vital resource for efficient route planning and monitoring (Matek, 2019).

Table 1. ECDIS implementation timeline (Weintrit, 2015)

Ship Types	2011	2012	2013	2014	2015	2016	2017	2018
New construction passenger ships >500 GT	-	+	+	+	+	+	+	+
New construction tankers >3000 GT	-	+	+	+	+	+	+	+
New construction cargo ships >10000 GT	-		+	+	+	+	+	+
Except passenger ships>500 GT	-			+	+	+	+	+
Except tankers>3000 GT	-				+	+	+	+
Except cargo ships>50000 GT	-					+	+	+
Except cargo ships>20000 GT	-						+	+
Except cargo ships>10000 GT	-							+

The CATZOC used in ECDIS is an essential instrument for safe navigation. Over a long period, these depths have been calculated with different methods and charted. In the early days, measurements were made with wire cables and beam echo methods. Then, the wire drawing method was adopted, in which a wire is dragged by two or more ships with weights submerged to a constant depth (Helmsman, 2010). Depth was determined by stretching the wire with any obstacle in the covered area. Techniques applied today use sonar multiple beam waves to record depths. The collected information is processed with data that affects the measurement, such as tides, so the depths are as accurate as possible. This method will provide more accurate depth measurements (Saltaş, 2020). Category Zone of Confidence (CATZOC) values are applied to geographic areas to indicate whether the information meets a minimum set of criteria for location, depth accuracy, and seabed coverage. The Zone of Confidence (ZOC) value depends on the data's positional and depth measurement accuracy (Admiralty, 2021).

In the application of CATZOC, some deficiencies may occur. If the calculations are not performed accurately, this situation may lead to the grounding of the vessel.

Literature Review

Kusworo et al. (2019) used cross strips as independent data to test the quality of bathymetry data compared to overlay strips from Multibeam Echosounder (MBES) in the Bawean Island cases. The tests were carried out by 3 methods: 1. testing the crossing strip and the main strip overlapping the crossing strip, 2. testing the 25 crossing points between the main strip and the crossing strip, and 3. testing the overlap strip between the main strip along the crossing strip. The data obtained from the quality test were re-tested using statistical analysis methods to determine the extent to which the data can represent the data quality of the study area. As a result, it was found that testing the data of the cross lanes was more effective as the main lanes were not affected by the features.

Chénier et al. (2019) proposed a confidence level approach where a minimum number of SDB techniques is required, which must be agreed upon at a defined level to allow SDB estimates to be maintained due to the difficulty of validating Satellite Derived Bathymetry (SDB) data. The approach has been applied to a Canadian Arctic region combining four techniques. Based on International Hydrographic Organisation (IHO) guidelines, results are described, with each approach meeting the requirements of the Category of Confidence Zones (CATZOC) level C.

Acomi (2020) emphasised the effect of data accuracy on navigational safety. For this purpose, a model ship was considered in the Dover Strait bridge simulation scenario, assuming good weather conditions with no waves or currents. The Safety Contour was defined using a mathematical formula involving under keel clearance, heeling effect and tidal levels. The Safety Contour was then analysed taking into account the accuracy of the chart data. The results of this analysis contribute to a better understanding and increased awareness of CATZOC effects in determining safe waters for navigation.

Kastrisios et al. (2020) provided information on CATZOC, horizontal and vertical uncertainty of depth information, as well as seafloor coverage and feature detection. The current symbology creates visual clutter in high quality bathymetry fields. Furthermore, horizontal and vertical uncertainties cannot be adequately assessed by the user. This paper presents a research programme to develop a method to demonstrate bathymetric data quality and to integrate digitised uncertainties into ECDIS.

Chénier et al. (2020) attempted to collect the data needed by the Canadian Hydrographic Service (CHS) to produce wide-area navigational products for the Canadian coastline, the longest in the world. CHS products cover all Canadian waters, but there are gaps in the data. To prioritise these gaps, the CHS has developed a geographic information systems (GIS) tool called the CHS Priority Planning Tool (CPPT). The derived output of the CPPT helps prioritise areas that pose the highest risk to navigation.

Karström Hettman (2022) worked on extending CATZOC classifications in Swedish territorial waters by creating a model that can predict how fast the bathymetry will change at different locations from the SMA in Norrköping. Models and maps were prepared in ArcMap GIS to predict bathymetric changes of the seabed in the Baltic Sea. Factors in the models include seabed type, seabed slope and shipping corridors. The models and maps can be used to see which areas should be changed from A1 classification to a lower classification or the area should be re-measured. This study opens a new way to assess changes in the bathymetry of Swedish territorial waters without the need to re-measure surfaces and will help to know which areas to prioritise for re-measurement.

Radić et al. (2023) analysed the bathymetric data collection method. The collected depth data were compared with official data displayed on electronic navigational charts (ENC) in the United States. Four sea areas were selected where 104 depths were compared at the same positions and also categorized according to the criterion of navigational importance, namely

category confidence zones (CATZOC). Official depth data from hydrographic surveys and depth data collected from public sources for the same positions were compared and correlated, and it was concluded that CSB data, despite its limitations, is a very valuable addition to the existing official data.

Gülher & Alganci (2023) aimed to produce the first optical image-based SDB map of the shallow coast of Horseshoe Island and to perform a comprehensive and comparative evaluation with Landsat 8 and Sentinel 2 satellite imagery. The research considers the performance of empirical SDB models (classical, ML-based and DL-based) and the effects of atmospheric correction methods ACOLITE, iCOR and ATCOR. These models are followed by DL-based ANN and CNN models. However, the nonlinearity of the reflectance-depth relation is significantly reduced by the ML-based models. Furthermore, Landsat 8 performed better in the 10-20 m depth ranges and the entire (0-20 m) range, while Sentinel 2 performed slightly better up to 10 m depth ranges. Finally, ACOLITE, iCOR and ATCOR provided reliable and consistent results for SDB, with ACOLITE providing the highest automation.

Dias et al. (2023) aimed to minimize human effort by automating the detection of discrepancies between nautical charts and survey data. A GIS location model was developed based on specific rules derived from three analysis criteria: depth fields, minimum soundings and bathymetric models. The model produces six outputs, two for each criterion, to support the final human decision. The model has been tested in various hydrographic surveys, such as open waters and harbour surveys, and successfully validated by comparing the results with existing manual processes and other existing methods, such as the Sea Chart Adequacy Tools (CA Tools). Potential advantages over other methods are also evaluated and discussed, confirming the usefulness of this new approach for the adequacy and completeness assessment of nautical charts.

Horn (2023), used SDB for recursive mapping of Stono Inlet at large spatial and large temporal (2001-2022) scales. SDB methods summarized in the IHO-IOC GEBCO Cook Book: LANDSAT 8 Satellite Derived Bathymetry is used to derive bathymetric surfaces using the algorithm of Stumpf et al. (2003). Extinction depths are estimated to be between 5 and 10 feet in the Inlet. NOAA vDatum, ArcGIS Pro, Fledermaus, and ArcGIS Online (AGOL) were used for analysis and visualization. The results show that the high-resolution, high-quality WorldView 02/03 imagery data used for the 2016 to 2022 analysis years are necessary to obtain bathymetric surfaces in Stono Inlet that are useful only for visual bathymetric assessments.

Carreras Ruiz (2023) examined and analysed the principles of transition planning throughout onboard training. The voyage from Sakai (Japan) to Point Fortin (Trinidad and Tobago) is detailed and followed step by step to encourage deck officer candidates to acquire these competencies. The study also contributes to the assessment of the ship's performance in safety issues and its economic and environmental costs.

When the previous researches are examined, it is seen that the subject research has not been conducted before. The subject research both contributes to the literature and as new research, it will be an example for other researches in the future.

Material and Method

Material

Category Zone of Confidence

Table 2 shows the types of CATZOC symbols. By gaining a deeper understanding of the accuracy limitations of the data within the system, ships can manage risk levels while navigating a specific area. Based on errors in measurements in position and depth, accuracy data is divided into 6 ZOC.

The Zones of Confidence (ZOC) chart shows position accuracy, depth measurement sensitivity, and seabed for each of these values to help manage risk levels while navigating.

ECDIS displays these CATZOC values in Electronic Nautical Charts (ENC) using a triangle-shaped symbol pattern. The number of stars inside these symbols indicates the CATZOC value. For example, six stars indicate the highest data quality (A1) and two stars the lowest level (D). For CATZOC, unevaluated areas are shown as a symbol (U) (Teledynecaris, 2016). The maximum possible errors in each confidence zone depth and the positions marked in the charts are given. If for a graph or ENC, CATZOC is 4 stars (ZOC B), this means that the location of the depths and dangers marked in the ENC can have a margin of error of about 50 meters (Matek, 2019). Depths may have an error of up to 1 meter + 2%. If anywhere the graph shows depth of 20 meters, the error here could be 1.4 meters.

CATZOC is not a guide recently released with ECDIS. In fact, it was used in nautical charts before. Nautical charts contain source diagram. For example, the source diagram of the chart on the British Admiralty is shown in Figure 1.

As can be seen, the depths in the "c and d" areas are circled with a red line in Fig. 1. Depths in this area can have significant errors. The master and watchkeeping officers should be careful

of these errors. Depth and position categories on charts are shown in the information part of the chart, as in Figure 2.

It is necessary to consider the risk levels of this error percentage, which should be considered. Nautical charts do not include error rates for these depth measurements. The master and watch keeping officers should decide on the information in the diagram given in Figure 3.

The ECDIS user can visually transfer the CATZOC settings to the screen from the device's settings menu. The user has the opportunity to quickly analyse the system from the screen shot in Figure 4.

For the correct use of the CATZOC system, it is necessary to take precautions against possible errors everywhere. If entering a dangerous area while navigating, a safe distance must be maintained, taking into account the CATZOC category in that area. ZOC, passage planning, safety depth setting and UKC under ship depth need to be safely calculated. Maximum draft is the sum of the actual draft and the ship's squad at maximum speed.

Table 2. CATZOC table (Mavraeidopoulos et al., 2017)

CATZOC ECDIS Symbols	Position Accuracy (meter)	Depth Accuracy
A1 (6-star notation)	5 m	0.5 m + depth %1
A2 (5-star notation)	20 m	1.0 m + depth %2
B (4-star notation)	50 m	1.0 m + depth %2
C (3-star notation)	500 m	2.0 m + depth %5
D (2-star notation)	500 m over	2.0 m over + depth %5
U (U letter notation)	Not evaluated	Not evaluated

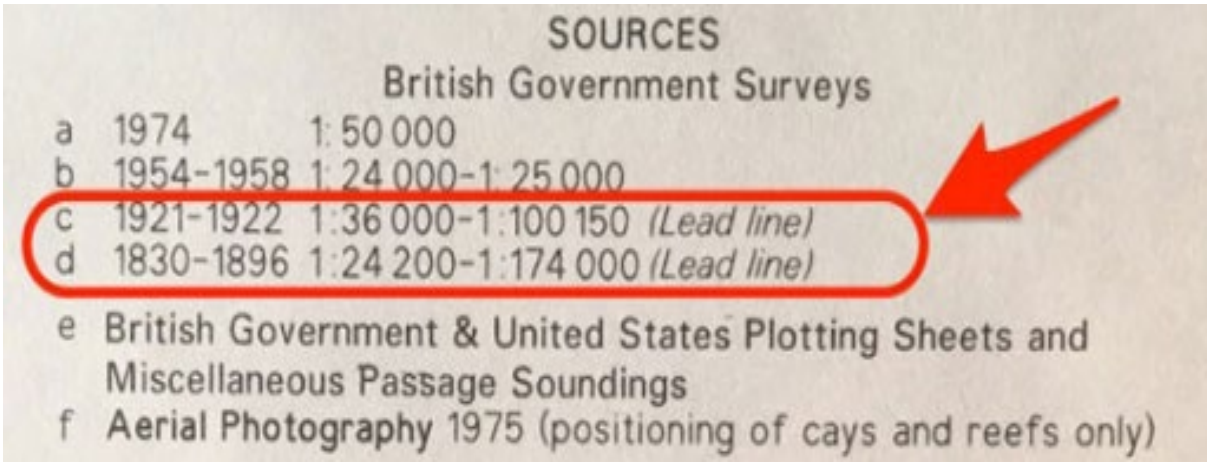

Figure 1. Depth and position categories indicated on the British admiralty nautical chart (Jassal, 2017)

Figure 2. Depth and position categories indicated on the chart (Azuike et al., 2012)

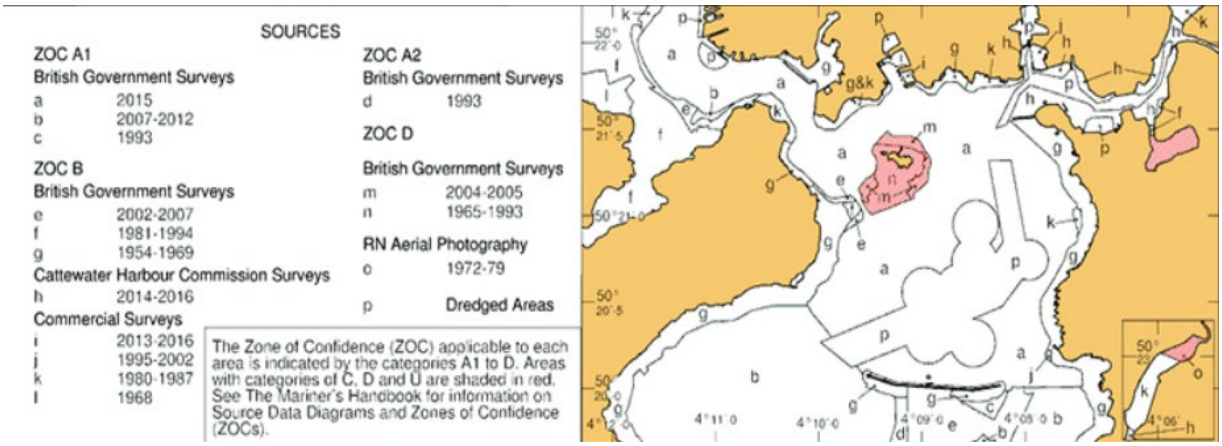

Figure 3. Nautical chart CATZOC information display (Azuike et al., 2012)

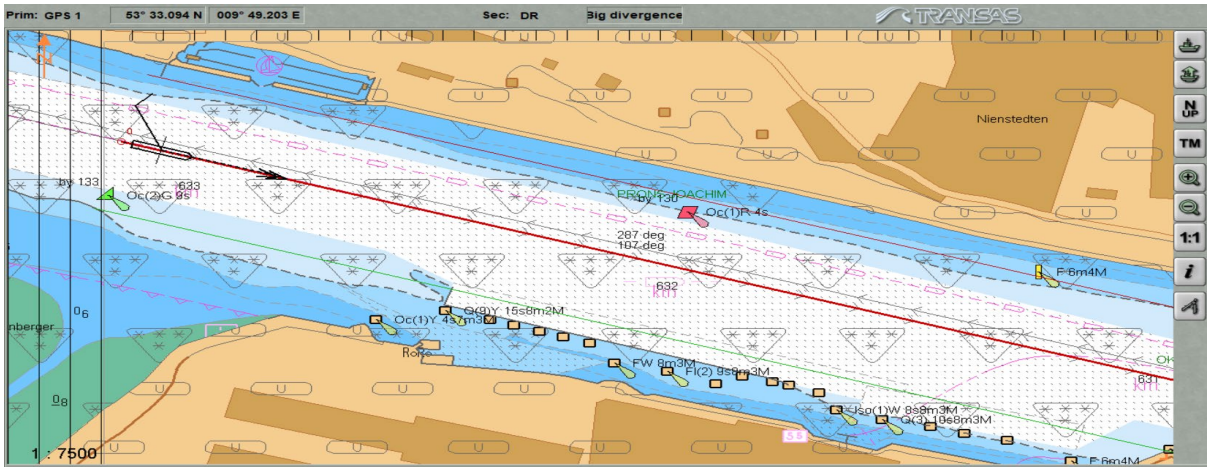

Figure 4. CATZOC display on ECDIS screen (Transas, 2020)

UKC means underwater opening and expresses the depth of water below the ship's keel line. Wind, tides, waves, seabed movement, and even continental movements can change the water depth, especially in coastal areas. On top of that, the squat effect of the ship also reduces the UKC. In this case, the water depth you read on the chart and the actual water depth will not be the same (Zadeh, 1965). UKC is calculated before entering narrow waterways, shores, and ports to eliminate the risk of stranding.

The importance of the UKC in the voyage plan can be explained as follows.

The Master shall ensure that there is an adequate under-keel allowance at all stages of the voyage and at all times while transiting in port or while at anchorage or at berth. The estimation of the smallest bottom clearances the vessel may encounter during the voyage and during port operations, which will permit the Master to identify possible manoeuvring constraints and decide on proper risk reduction measures, is therefore an essential part of passage planning that should never be neglected.

The under-keel allowance necessary for a safe bottom clearance varies with the specific local conditions and the size and handling characteristics of the ship and consists for practical purposes of two main elements:

1) A minimum Under-Keel Clearance (UKC) which should be maintained between the ship and the sea, river or canal bottom, and
2) An allowance for other variable factors that may be present as follows: The effects of squat, State of sea and swell, Past weather impact on water depths, Tidal and current conditions, particularly the range and stand of tide, Variation in water level due to barometric pressure or tidal surges, Changes in water density, Stability of the sea bed (sand wave phenomena), Accuracy of soundings, tidal information and predictions, Accuracy of ship's draught observations or calculations, including provision for hogging or sagging.

Vessel's size and handling characteristics, and increase of draught due to trim or heel, which is particularly important where vessels have a large beam, Reduced depths over pipelines or other known/charted obstructions.

The Equation (1) shows how to calculate the safety degree concept used in the calculations

$$Degree\ of\ Safety\ =\ Max\ Draft\ +\ Required\ UKC \quad (1)$$

First of all, the uncertainties in the depth errors given in the graphics should be eliminated. Calculations are made according to the information in Table 4 regarding depth accuracy. While navigating the ship's route passes through ZOC A1, and if the depth is assumed to be 15.7 meters, the minimum depth should be close to the passage route and necessary corrections should be made in these areas.

One of the components of the required UKC is the ZOC clearance. The CATZOC application for ZOC, A1 is expressed in Table 4 by the Equation (2):

$$ZOC\ (A1)\ =\ 0.5\ +\ 0.01\ \times\ DEPTH \quad (2)$$

$$ZOC\ permission\ (A1) =\ 0.5\ +\ 0.01\ x\ 15.7\ =\ 0.657\ \approx\ 0.7m$$

On the other hand, when calculations related to position accuracy are made according to the Deep Accuracy in Table 3, it is interpreted as follows.

If the depth position accuracy for ZOC A1, A2 and B is relatively high (position error less than 50 m for ZOC B), this value is 500 m and greater for ZOC C and D. In this case, not only the ZOC permission for the UKC needs to be accessed, but also the depth locations when plotting the fields in the table.

Transas type 5000 series bridge simulation program was used. Opinions about the problem that emerged as a result of the CATZOC implementation were received from the experts who worked on ships. The opinions received from the experts were prioritized by weighting them with the Fuzzy Analytical Hierarchy Process (FAHP). With the results obtained, alternative solutions were presented for the CATZOC implementation problem.

Method

Fuzzy Analytic Hierarchy Process (FAHP)

Fuzzy logic was emerged by the scientist Zadeh based on the concept of fuzzy set. Zadeh's (1965) fuzzy set theory is a mathematical theory created to eliminate uncertainty in human cognitive processes (Zadeh, 1965). Fuzzy logic, with people's most developed sense organs interprets the information obtained from the beginning of people's lives with the perspective and understanding style that they have developed under the influence of their environment (Yılmaz & Şahin, 2023). When the problems in daily life are evaluated, it can be said that there are many situations that do not show certainty and this situation arises from the fuzzy, uncertain and non-linearity of the real world (Sanca et al., 2022). According to this theory, the value obtained from the judgments of the people participating in the evaluation is a fuzzy number defined as the membership function (Başlıgil, 2005).

In fuzzy set logic, the degree of belonging to the cluster varies between 0 and 1, and 1 definitely belongs to the cluster, while 0 means that it does not belong to the cluster. Cluster belonging degrees can be defined with functions such as trapezoid, triangle, gaussian curve (Özdağoğlu, 2008).

It would be more appropriate for decision makers to give their opinions about the study in verbal expressions instead of a definite number. These verbal assessments are triangular fuzzy numbers that indicate the range of verdict (Soltani & Morandi, 2008) Triangular fuzzy numbers are represented by triple values such as (l, m, u). With l < m < u, the fuzzy number is in the interval [l, u] and the maximum value that can take is m.

In this study, Saaty's (1988) five-point scale is transformed into triangular fuzzy numbers scale, as the following 3 shows.

Table 3. Fuzzification of Saaty's scale (Soltani & Morandi, 2008)

Saaty Scale	Definition	Fuzzy Triangular Scale
1	Equally important	(1, 1, 1)
3	Weakly important	(2, 3, 4)
5	Fairly important	(4, 5, 6)
7	Strongly important	(6, 7, 8)
9	Absolutely important	(9, 9, 9)

Numerous the multi-criteria decision making (MCDM) approaches have been applied to tackle complex decision-making problems in many fields. AHP is sensitive to inputs and results can be unreliable if input data is biased (Singh et al., 2023). The FAHP method was used to determine the criterion weights. It was preferred to be implemented as it significantly reduces the subjectivity of the decision maker (Pavlov et al., 2023). In addition, there are many qualitative criteria supporting the application of this method. In this study, Chang's extended analysis method was used to determine the weights of the most ideal reactions related to CATZOC implementation.

Results

Category A 38,000 dead weight tonnage (DWT) liquid petroleum gas (LPG) tanker in loaded condition was chosen for ECDIS simulation practice. The maximum draught of the ship was 9.43 meters. Elbe Channel in Germany was selected as the navigation area, which is presented in Figure 8. The channel's lowest chart depth on the route was 12.6 meters. As can be seen in Figure 7, the ZOC category of the navigation area was category B.

Step 1: Based on Table 3, the depth accuracy for this scenario was calculated as approximately 1.3 meters by Equation (3).

This result means that the actual depth for ZOC (B) area can be between 11.3 meters and 13.9 meters within a 50 meters diameter area.

Step 2: Safety parameters were entered into ECDIS, as can be seen in Figure 8.

Step 3: The squat value was calculated by using Equation (4).

Step 4: The vessel information was entered into Ship Manager Stability 2020 software. When the tidal height was taken as 0.6 meters, the minimum available depth was calculated as 12.6 meters. The results indicated that the ship was expected to squat 1.66 meters at 15 knots. The planned route that the ship was expected to follow is given in Figure 9.

Step 5: It was tried to explain in this scenario implementation whether it is possible for the ship to pass through this route line safely.

Discussion

Two approaches can be followed in calculating the UKC used in the voyage plan. The first one is CATZOC calculation on ECDIS, and the second option is to use a simple UKC calculation formula according to shipping company requirements.

Option 1:

Some shipping companies require the water depth below the ship to be ten percent higher than the maximum draft of the ship (Equation 6). Detailed information is given in Table 4.

Table 4. Final draught calculation according to option 1

Item	Values
Draught	9.43 m
Squat (15 knt)	1.66 m
Company Requirement (%10 of ship draught)	0.09 m
Final Draught	12.09 m

Option 2:

ZOC category of the navigation area was category B. It means there may be an error of up to 1 meter + 2% in depth, according to Table 3.

First, Equation (7) is used to find the Maximum Sufficient Water Depth in ZOC B. The calculation results according to Equation (7) showed that the ship could pass through this area. However, it would be correct to check it according to the CATZOC calculation. The calculation details are explained in Table 5 and Table 6.

It can be thought that the value found as a result of the calculation in Table 7 may be inaccurate up to 1.3m, considering the Depth Accuracy for ZOC (B) found in the 1st step.

When the calculation results of Option 1 and Option 2 were compared, it can be seen that the difference is 0.19 m. Such a difference increases the grounding risk of the ship. It will cause an officer of the navigation to reach an erroneous result of up to 1.3 meters when applying the formula in option one. In this situation, the safe navigation of the ship cannot be mentioned. In the case of the implementation of the two options, a difference of 0.19 meters puts ships navigating in shallow waters at risk.

Since the ship is not safe to pass through this route line, solution methods will be presented with expert opinions.

$$Depth\ Accuracy\ for\ ZOC\ (B) = \pm[1.0 + (0.02 \times 12.6)] = 1.252 \approx 1.3\ m \quad (3)$$

$$Squatmax\ in\ meters = K\ x\ Block\ Coefficient\ x\ (Speed\ through\ water)2\ x\ 0.01 \quad (4)$$

$$\text{where; } K = \frac{Shallow\ water\ depth}{Stable\ draft\ of\ the\ ship} \quad (5)$$

$$Final\ Draft = Actual\ Draft + Squat + Company\ UKC\ Requirement \quad (6)$$

$$Maximum\ Sufficient\ Water\ Depth = Charted\ Depth - (1 + 2\%\ Charted\ depth) + Tide \quad (7)$$

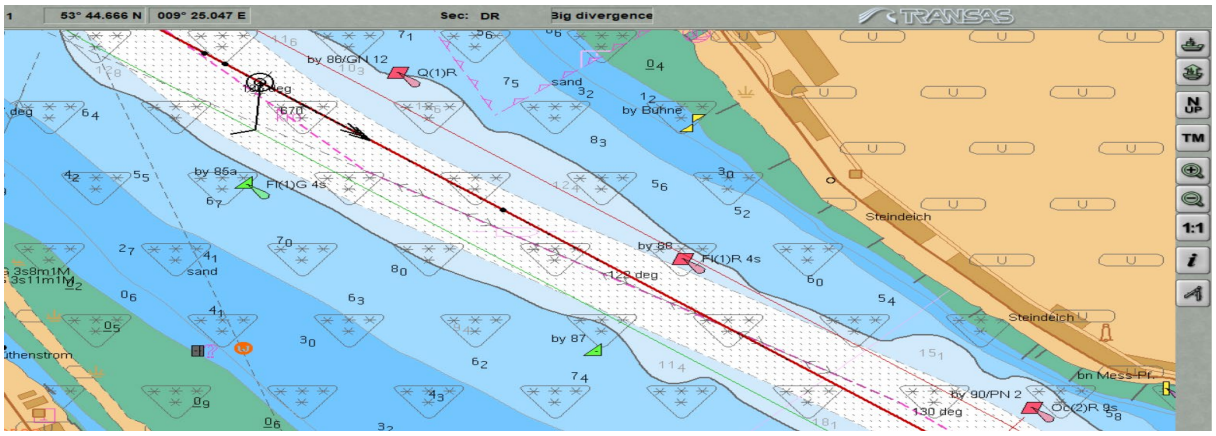

Figure 7. Navigation area of case analysis (Transas, 2020)

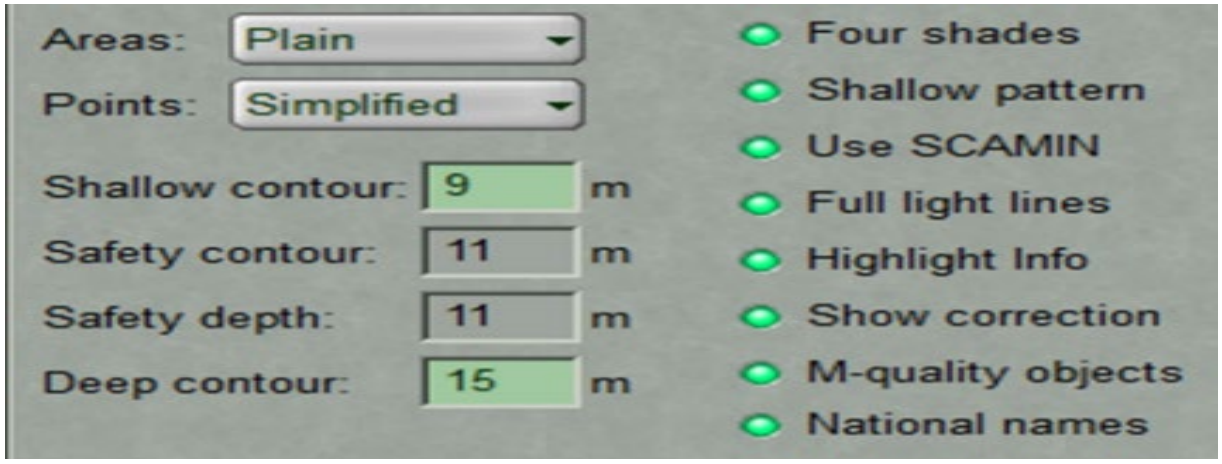

Figure 8. Safety parameters entered into ECDIS

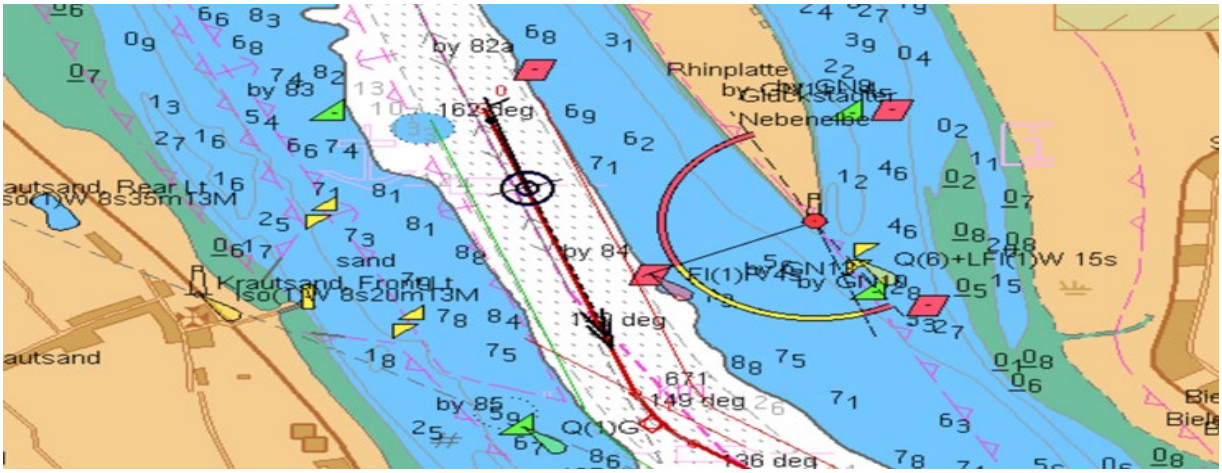

Figure 9. Scenario application area ECDIS screenshot (Transas, 2020)

Table 5. Calculation steps for depth

Depth on the Chart	A	Meter
Tidal Height at Ship's Crossing Time (Always Positive Effect)	B	meter
Sea Condition / Swell / Wind (Always Negative Effect)	C	meter
Chart Information Accuracy / CATZOC Value, If Any	D	meter
Maximum Sufficient Water Depth	E	meter

Table 6. Letters and distances

Letter	Values
A	12,6 m
B	0,6 m
C	N/A
D	-1,3 m
E	11,9 m

Determination of Alternative Decisions

Alternative options may need to be applied by ships related to the deficiency resulting from the implementation of CATZOC. Expert opinion was used to determine the alternatives. The number of experts consulted was ten. All the experts held Ocean Going Master certificates and served at sea for at least ten years. The ship type information that the experts worked on is given in Table 7.

The problem that occurred in the CATZOC implementation was shared with the experts in detail. Open-ended questions were asked to determine alternative options to follow to ensure navigational safety. The experts advised five options which are presented in Table 8.

Table 7. Expert specifications

Experts	Ship Type	Experience (Years)
Expert 1	Chemical Tanker	12
Expert 2	LPG Tanker	13
Expert 3	Chemical Tanker	14
Expert 4	Dry Cargo Ship	11
Expert 5	Container Ship	10
Expert 6	Chemical Tanker	12
Expert 7	Ro-Ro Ship	15
Expert 8	Bulk Carrier	12
Expert 9	Dry Cargo Ship	12
Expert 10	Oil Tankers	13

Pairwise comparison matrix established according to expert opinion. The data obtained from the experts were converted into fuzzy triangular numbers in Table 3. Then a single comparison matrix, which is given in Table 9, was created by taking the arithmetic means of the answers. The normalized weights of the criteria were calculated and presented in the same table.

Table 8. Definition of criteria

C_1: Reducing Speed	After detecting the risky part of the depth, it minimizes the squat by taking the speed on the ship to the lowest value when approaching that area.
C_2: Draft Adjustment	Adjusting the maximum draft of the ship at the port of departure before reaching the danger zone.
C_3: Information Exchange with Port Authority	It is to communicate with the relevant port authority before the ship enters the port limits, to obtain information about that region and to confirm that it is accessible.
C_4: Not Entering the Zone	If a risk analysis is made with the charterer and shipowner officials and a result that will pose a danger to the ship, it is decided not to enter the port of the ship. If this is done before the affreightment, it will not cause economic damage.
C_5: Tide Height Confirm	It includes receiving tide information from pilotage services located in this area and confirming whether there is sufficient depth underwater.

Table 9. Pairwise comparison matrix of criteria

C_1	C_2	C_3	C_4	C_5	Normalized W.
(1,1,1)	(2,3,4)	(3,4,5)	(4,5,6)	(2,3,4)	0.457
(1/4,1/3,1/2)	(1,1,1)	(2,3,4)	(4,5,6)	(1/4,1/5,1/6)	0.162
(1/5,1/4,1/3)	(1/4,1/3,1/2)	(1,1,1)	(1/4,1/3,1/2)	(2,3,4)	0.103
(1/6,1/5,1/4)	(1/6,1/5,1/4)	(2,3,4)	(1,1,1)	(1/6,1/5,1/4)	0.078
(1/4,1/3,1/2)	(6,5,4)	(1/4,1/3,1/)	(4,5,6)	(1,1,1)	0.201

Table 10. Sorting the criteria by weight

Criteria	Criterion Weights	Ranking
Reducing speed (C1)	0.45	1
Draft adjustment (C2)	0.16	3
Information exchange with port authority (C3)	0.10	4
Not entering the zone (C4)	0.07	5
Tide height confirmation (C5)	0.20	2

Conclusion

Navigation planning of merchant ships is very important and should be done carefully and in accordance with the rules for the safety and security of the ship and personnel. In the navigation planning of the ship, the safety issues of the ship should be followed regularly by the master and watch officers and should be at the top in terms of priority. After the completion of the ship's departure from the port, before the departure operation, the responsible officer of the watch on watch should make the necessary navigation plan and obtain the approval of the master. Maritime publications and navigational technical equipment and auxiliary equipment on board should support the correct use of the data used at each stage of the navigation plan.

According to today's maritime conditions, navigation plans, which were previously made on nautical charts, are now prepared on technologically advanced electronic nautical charts. With this development, route changes can be followed instantly and mistakes made can be seen more quickly. The drawing of the routes of the navigation plans, the navigation course points of the ship and all other necessary information are prepared on digital nautical charts. Depending on how the data in the nautical charts are measured and when they are measured, various errors may occur. The older the data in the nautical charts, the greater the existing error rate. The accuracy level is divided into six categories known as "CATZOC". For each CATZOC, the maximum error value is given for the depths and location shown in Table 2.

As seen above, the greatest risk occurs in shallow waters. The grounding of ships occurs not only on sandy bottoms but also on rocky bottoms and the structure of the ship is seriously damaged on rocky bottoms compared to sandy bottoms. In addition, depending on whether the ship is loaded or unloaded, the changes in the draft should be treated very carefully, especially where the A1, A2 and B symbols are located. Depths of shallow waters can change with tides depending on natural conditions. In addition, serious changes may have occurred in the existing depths with the recent natural events.

The application of CATZOC becomes mandatory when calculating UKC in shallow waters or when approaching a distress signal shown on ECDIS. For the navigational safety and security of the ship, the master and other officers of the watch are required to activate the CATZOC application. If the depths and position distances during the navigation of the ship are not calculated correctly, dangers such as grounding of the ship in the navigation area and damage to the ship's hull may occur. After determining the arrival route of the ship for navigation, the existing charts should be examined one by one, and if it is necessary to pass through risky areas according to the CATZOC category table, the affiliated marine management company should be informed. The marine management company may be requested to make a risk analysis of the ship related to the subject passage or information may be requested from the port state authorities about the reliability of the chart depths of the subject area. In this study, the opinions of the ship masters were taken on the measures related to the solution alternatives to be considered. The most important solution alternative obtained from the opinions of the masters was determined that the ship should continue its voyage at minimum speed.

The second critical solution option is determined that the conditions and times of the tide height in the sea in the area where navigation is carried out and the hazardous area is located should be confirmed from the units providing navigation pilotage services in that region. In this way, support should be received in a region that is unknown to the ship's crew and the safety and security of the ship should be ensured by acting according to the data and recommendations obtained. The solution options obtained in this study are presented as suggestions. Compliance or non-compliance with these suggestions is left to the preferences of other watchkeeping officers, especially the master of the ship. It is also important that the calculations carried out in the study are tried to be made accurately and completely and that the alternative

options specified in this study are taken into consideration. Another suggestion obtained as a result of the study is that it would be important to prepare a separate section under "Trust Zone" in the bridge manuals prepared by the maritime companies for the ships under their management and it would be a supportive and guiding situation in the decision-making phase of the ship personnel. It is thought that it will help and guide the master and officers of the watch in making navigation planning in risky areas.

It is hoped that the subject study will be an example and shed light on future studies. In addition, in the future studies, it is planned to carry out studies on navigation planning in the Marmara Sea, which is very busy and risky in terms of ship traffic, and what the ships should pay attention to in navigation planning.

Compliance With Ethical Standards

Authors' Contributions

OHA: Conceptualization, Methodology, Validation, Formal Analysis, Resources, Writing - Original Draft, Writing-Review and Editing, Data Curation, Software, Visualization, Supervision, Project administration, Funding acquisition.

OA: Conceptualization, Methodology, Validation, Formal Analysis, Resources, Writing - Original Draft, Writing-Review and Editing, Data Curation, Software, Visualization, Supervision, Project administration, Funding acquisition.

AUU: Writing - Original Draft, Writing-Review and Editing.

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 Statement

All data generated or analyzed during this study are included in this published article.

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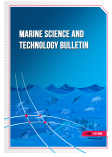

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RESEARCH ARTICLE

Green marketing strategies and climate change awareness in sustainable transportation: The case of airline companies

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ABSTRACT

The aviation industry contributes significantly to global greenhouse gas emissions, thereby contributing to the phenomenon of climate change. Green marketing strategies, which integrate environmental considerations into marketing practices, have emerged as a potential solution for reducing the environmental impact of airlines. This study's primary objective is to examine how airline companies address the challenges of climate change, sustainability, and green marketing in the transportation sector. The investigation utilized qualitative analysis, employing the MAXQDA-20 program to meticulously examine a variety of corporate documents, including sustainability reports, business reports, and investor presentations, to gain insight into how these companies address critical sustainability challenges and promote environmentally responsible practices. The findings emphasize the substantial overlap between climate change and sustainability-related topics, emphasizing their interdependence in academic discourse and business practices. The study illuminates the crucial role of green marketing in promoting eco-friendly travel options to consumers, suggesting that it can boost a company's reputation, appeal to environmentally conscious consumers, and contribute to a more sustainable future. This study offers valuable insights into the transportation sector's efforts to comply with sustainability-related regulations, particularly the carbon tax, while also offering insights into future strategies.

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Introduction

The global transportation sector, a pillar of modern society, serves a crucial role in connecting people, products, and economies (Green et al., 2015; Lopez-Arboleda et al., 2019). It plays a significant role in contributing to climate change, and the need for sustainable transportation solutions has become increasingly significant (Simionescu et al., 2017). The sector accounts for roughly 20 percent of global CO_2 emissions and is one of the main contributors to global warming and climate change (Stamos et al., 2015). The incorporation of sustainability principles within the transportation sector has become a pressing concern (Zhang et al., 2017). To address this challenge, the integration of green marketing strategies within the transport sector is essential. Green marketing focuses on promoting environmentally friendly practices and products, which can contribute to reducing carbon emissions and minimizing the environmental footprint of the sector (Khalili et al., 2019).

The aviation industry within the context of transportation is a significant contributor to global climate change, and airline companies are increasingly being called upon to develop climate-friendly ethics and strategies (Ruban & Yashalova, 2020). In response to this, many airline companies have started to implement green marketing strategies and initiatives to promote sustainability and reduce their environmental impact (Goetz & Graham, 2004). Green marketing involves incorporating environmental considerations into the marketing process and business practices, with the goal of providing consumers with better information about the environmental properties of products and services (Gordon et al., 2011; Delcea et al., 2018). One area where green marketing strategies can have a significant impact is in sustainable transportation. Airline companies are exploring various strategies to reduce their carbon footprint and promote climate change awareness in the context of sustainable transportation (Harvey et al., 2013). These strategies may include initiatives such as reducing emissions, investing in green technologies, and promoting sustainable travel options to consumers (Chang et al., 2015; Epstein & O'Flarity, 2019).

Recent developments in air transportation have increasingly focused on addressing climate change, promoting sustainability, and incorporating green marketing strategies (Noy & Givoni, 2018; Koščák et al., 2020; Ogryzek et al., 2020; Ovdiienko et al., 2021). The aviation sector is actively engaged in efforts to mitigate the carbon footprint, acknowledging the substantial influence that its activities have on climate change. Efforts have been made to improve air quality and reduce emissions through advancements in engineering, operational practices, and the use of alternative fuels. Sustainable practices in air transportation not only contribute to mitigating climate change but also have positive effects on air quality (Kerimray et al., 2020; Bartle et al., 2021). Green marketing strategies have also gained prominence, with airlines and airports promoting their environmental initiatives and sustainable practices to attract environmentally conscious consumers (Noy & Givoni, 2018; Bartle et al., 2021).

This study seeks to investigate comprehensively how airline corporations in the transportation industry respond to and navigate the intertwined challenges of climate change, sustainability, and green marketing. The primary objective is to obtain insight into the strategies employed by these companies in addressing critical sustainability concerns and promoting environmentally responsible practices. It is noteworthy that this study is centered on a comparative content analysis of the two major airline companies in Türkiye. Through a qualitative analysis of two airline company reports, we explore the implementation of 'Green Marketing Strategies' and 'Climate Change Awareness' within the context of sustainable transportation. We analyze business reports, sustainability reports, investor presentations, and other relevant documents using Maxqda qualitative analysis software. We do so to uncover these organizations' sustainability policies, determine their green marketing priorities, and assess their climate change awareness. This study is significant because it has the potential to guide transportation companies in aligning their practices with sustainability objectives and green marketing strategies, which, according to the literature, can have a positive effect on corporate image, business performance, and market share. In addition, by identifying recurring themes and patterns related to sustainability, green marketing, and climate change awareness, this research provides a comprehensive framework for understanding the interrelationships between these concepts within the transportation industry. This study aims to inspire and inform future strategies and initiatives in the transportation industry to support a more sustainable and environmentally conscious future.

This study is divided into several sections to investigate the confluence of climate change, sustainability, and green marketing in the transportation industry. In the "Conceptual Background" section, we provide context by discussing climate change, sustainability, and green marketing. The section titled "Methodology" describes our data collection and analysis procedures. The "Findings and Discussion" section presents

our research outcomes and discussions, and the "Conclusion" section concludes by synthesizing our findings and providing recommendations for the transportation industry.

Conceptual Background

Climate Change and Sustainability

Long-term changes in temperature, precipitation patterns, and other characteristics of the Earth's climate system are referred to as climate change. It is mostly driven by human actions such as the use of fossil fuels and deforestation, both of which emit greenhouse gases into the atmosphere and contribute to global warming. Climate change is a complex and multifaceted topic with profound implications for various industries, including the business sector (Linnenluecke et al., 2013). Extensive research has shown that climate change can have unpredictable, substantial, and strategic effects on firm value (Tyler & Chivaka, 2011). The strategic influence of climate change on enterprises primarily revolves around its potential consequences for competitiveness. For instance, changes in operational costs due to rising energy prices, shifts in consumer demand towards low-emission products, and the introduction of new technologies that may render existing competences obsolete are all examples of the potential consequences of climate change (Renukappa et al., 2013).

Sustainability and climate change are closely interconnected. Climate change poses significant threats to the sustainability of ecosystems, human health, and socio-economic systems. Sustainability practices and strategies play a crucial role in mitigating and adapting to climate change. Sustainable development goals, such as those outlined by the United Nations, aim to address the complex relationship between climate change, poverty, gender, and food security (Sopdie et al., 2021). By promoting sustainable practices in transportation and other sectors, it is possible to reduce greenhouse gas emissions, enhance resilience to climate change impacts, and promote the long-term sustainability of ecosystems and societies (Karakosta, 2016).

From a marketing standpoint, sustainability and climate change are becoming increasingly essential marketing considerations for the firms. Consumers are pursuing products and services that align with their values and contribute to sustainability initiatives (Fuller, 1999; Bruce & Daly, 2006). Climate change awareness and perceived effectiveness of actions can positively influence consumers' attitudes and intentions towards sustainable practices (Perera & Hewege, 2018; Alam et al., 2020). Green or sustainable marketing entails the promotion of products and services that have a reduced environmental impact, are ethically sourced, and satisfy the requirements of environmentally conscious consumers (Urhan et al., 2023). By incorporating sustainability into their marketing strategies, businesses can attract and retain consumers, improve their brand reputation (Park et al., 2022), and obtain a competitive edge in the marketplace (Taoketao et al., 2018). Sustainable practices may improve a company's reputation and brand image, resulting in improved consumer loyalty and trust (Kreiss et al., 2016).

Green Marketing

Green marketing is a marketing strategy that promotes environmentally friendly and sustainable products and services. It includes a variety of actions aimed at decreasing the negative social and environmental consequences of existing products and industrial systems while also promoting less harmful alternatives (Arseculeratne & Yazdanifard, 2013; Lu et al., 2013). Green marketing's major goal is to address environmental problems and encourage sustainable corporate practices. Companies use it to represent themselves as environmentally responsible and to fulfill the rising demand for environmentally friendly products and services. Green marketing methods seek to educate customers about the environmental advantages of products, influence consumer behavior toward more sustainable choices, and distinguish businesses from the competition (Yadav & Sharma, 2020). Consumers are increasingly conscious of the environmental impact of their purchasing decisions and actively seek out environmentally favorable alternatives (Priti, 2021). Green products and services may satisfy these consumers' desires and preferences, resulting in greater customer satisfaction and loyalty (Widyastuti et al., 2019). By adopting green marketing practices, companies can enhance their brand image, attract environmentally conscious consumers, and contribute to a more sustainable future (Lu et al., 2013). Green marketing, climate change, and sustainability have a complex and interwoven relationship within the framework of company management. Green marketing, or the promotion of environmentally responsible products and actions, is essential for combating climate change and achieving sustainability goals. (Islam et al., 2019).

Green marketing plays a crucial role in the air transportation industry, considering its environmental impact and the growing demand for sustainable practices (Kulanovic & Nordensvard, 2021). With concerns about climate change and the need to reduce carbon emissions, green marketing

initiatives help promote the industry's commitment to sustainability. By highlighting efforts to improve fuel efficiency, reduce emissions, and adopt sustainable practices, airlines and airports can attract environmentally conscious consumers (Karagiannis et al., 2019; Choi & Park, 2020). Moreover, green marketing strategies contribute to the overall image and reputation of the industry, demonstrating its dedication to environmental responsibility. These initiatives also align with the increasing importance of sustainability reporting and accountability in the airport industry. Additionally, the inclusion of air transportation in emissions trading schemes, such as the European Emissions Trading Scheme, further emphasizes the significance of green marketing in reducing greenhouse gas emissions (Anger, 2009; Karagiannis et al., 2019). Furthermore, green marketing efforts can drive innovation in the industry, encouraging the development and adoption of alternative fuels and technologies (Zhang et al., 2016).

Methodology

In this study, we conducted a comprehensive content analysis of documents using MAXQDA-20, a professional computer-assisted qualitative data analysis. This program is a widely utilized software application in research for the in-depth analysis of qualitative data (Lungu, 2022). It enables researchers to import and manage large volumes of data, conduct coding and categorization, and perform advanced data analysis techniques, such as thematic analysis and qualitative content analysis (Creswell & Clark, 2017; Jaafari et al., 2022).

In the methodology section, the concepts identified in the existing literature related to climate change, sustainability, and green marketing served as the foundation for our coding procedure. During the text coding, additional codes not initially identified in the literature were added to the list. This comprehensive strategy ensured that all relevant concepts were considered in the analysis. Utilizing thematic analysis, recurring themes, patterns, and trends related to sustainability, green marketing, and climate change awareness were identified. This robust methodology provides a comprehensive framework for gaining a deep understanding of how companies operating within the transportation industry navigate the complex landscape of sustainability, green marketing, and climate change awareness. To mitigate any potential biases, all relevant documents were carefully reviewed by two researchers. Both coders adhered to the same set of rules and instructions for coding to ensure consistency and data accuracy. In cases where disagreements emerged, thorough discussions were held to reach a consensus, thus establishing inter-coder dependability (Krippendorf, 2013). The inter-coder similarity between the two researchers' coding was 85 percent, which is an acceptable rate (Creswell, 2009).

Findings and Discussion

In this section, we summarize the findings and discussion of our study. The results of the content analysis on sustainability-related initiatives, green marketing techniques and climate change awareness mentioned in the reports of the two airlines in the study are compiled below. Themes in the study were initially identified through a review of the literature, and additional themes emerged during text analysis and classification. Notably, we observed a substantial overlap between climate change and sustainability-related topics. This overlap demonstrates their interdependence in both academic literature and business practices. Recognizing their inherent similarity and interdependence, we therefore present and discuss these themes collectively. This study provides a comprehensive review of how companies in the air transportation sector are approaching the intertwined challenges of climate change and sustainability, and reveals their common emphasis on green marketing concepts.

Based on our findings, Figure 1 visualizes an overview of the density of sub-themes under the main headings of climate change, sustainability and green marketing in the reports. Both group of reports prominently feature climate change-related expressions like "climate-related risk," "climate-related issues," "climate-related targets," and "climate-related legislations," indicating a significant focus on climate change in corporate communications. Additionally, as illustrated in Figure 1, the terms "emission" and "energy/fuel efficiency" as well as "renewable resources" are extensively discussed in both corporate documents as integral components of the topic of climate change and sustainability, respectively. Air transportation companies place a high value on energy efficiency. Because this industry is notorious for its high energy consumption, energy efficiency is a significant aspect of lowering costs and limiting environmental consequences. Terms like energy/fuel reduction" "fuel efficiency" "mitigation of fuel consumption" "energy policy" and "energy reduction" highlight corporations' efforts to save fuel and improve energy efficiency. Similarly, commonly used phrases such as "renewable energy/sources" "sustainable biofuels" and "clean energy" indicate companies' interest in renewable energy

sources. Renewable energy sources are less harmful to the environment than conventional fossil fuels and have the potential to decrease carbon footprints. Transportation firms may reduce their energy use by shifting to or employing renewable energy sources. This is an important step in implementing a more ecologically friendly company strategy and maintaining control over energy expenditures. These methods allow businesses to embrace sustainability for both environmental and commercial goals while also satisfying consumer expectations through green marketing techniques.

Sustainability is becoming more essential in business, particularly in transportation. Examining the relevant documents for the two firms reveals that they have comprehensive sustainability reports. Furthermore, these companies engaged in aviation transportation which has Carbon Disclosure Project (CDP) report. The CDP is an internationally recognized non-profit organization that oversees a comprehensive worldwide disclosure system aimed at effectively managing the environmental consequences of enterprises, communities, and governments. A CDP report refers to a formal document generated by this organization as a response to CDP's annual data request. Climate change, water security, and deforestation are the core concerns of CDP. Sustainability-focused practices offer a multifaceted approach that aims not only to reduce environmental impacts, but also to increase consumer satisfaction and brand value. In this context, the examined documents disclose that companies are actively attempting to stay abreast of developments in the field of sustainability. This effort correlates with the increasing expectations of their consumers, who place a greater emphasis on environmentally responsible transportation practices. The statement in P1 company's CDP climate change report that reads, "Sustainability is an increasingly critical aspect of our industry and – most importantly – the expectations of our customers" underscores the profound influence of sustainability, including green marketing, in shaping strategies and practices in the transportation industry. As transportation companies adapt to this changing environment, green marketing strategies have emerged as a key component of their approach, allowing them to not only meet sustainability goals but also satisfy customer preferences, fostering environmental responsibility and market competitiveness.

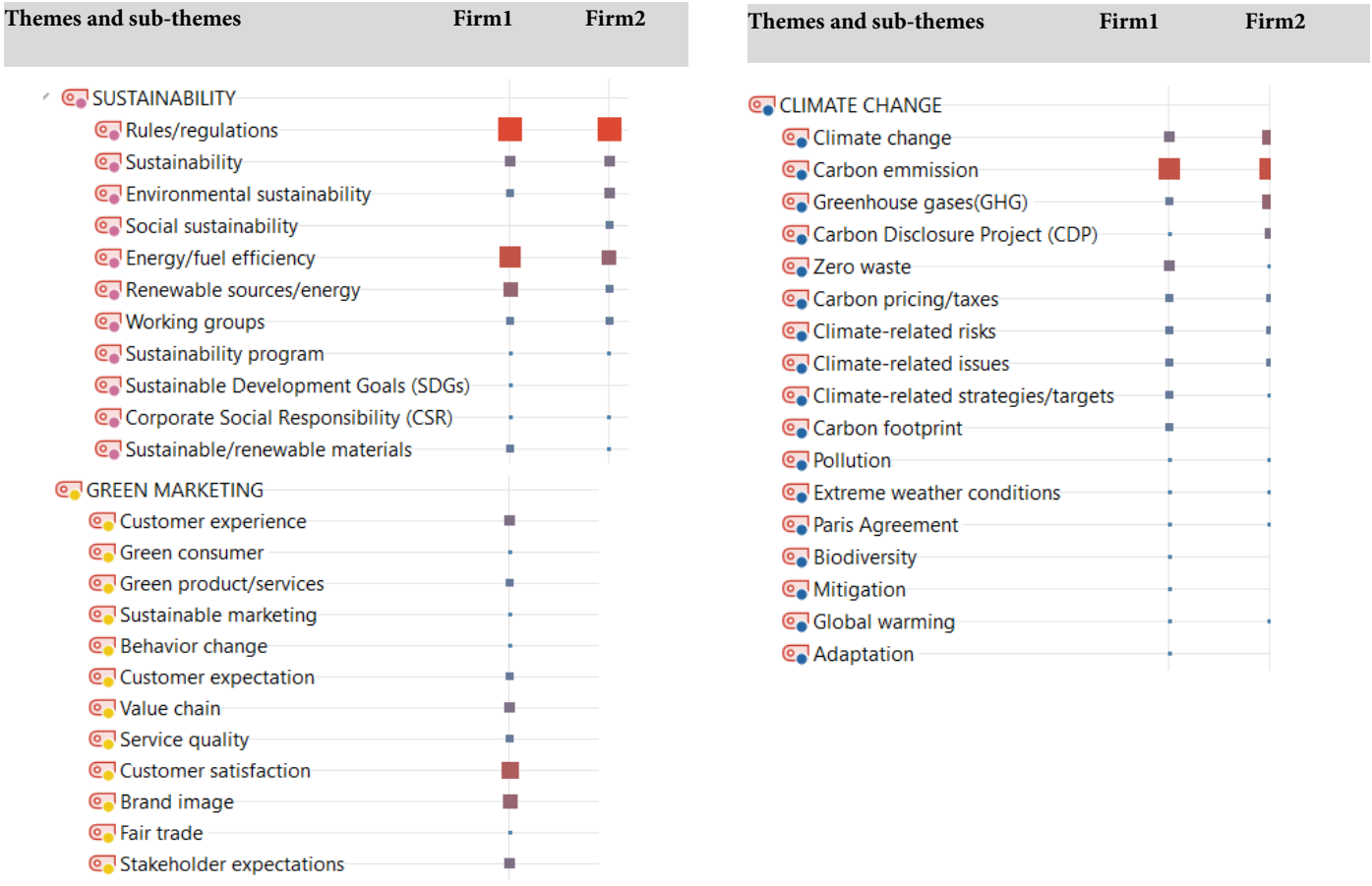

Figure 1. The intensity of the themes for each firm

Table 1. Frequency of the themes

	Themes	Related-Themes	Frequency
CLIMATE CHANGE	Emission/GHG	carbon emission, net zero carbon emission, emission intensity, emission efficiency, CO_2 emission, net-zero CO_2, zero emission, emission reduction, GHG emissions, lower emission, low emission rates, carbon reduction, reducing emission, emission reduction projects, emission reduction activities, emission performance calculations	183
	Climate-related words	climate change, climate-related issues, climate-related risks, climate-related risk assessments, climate-related opportunities, climate-related impacts, climate-related scenarios, climate-related responsibilities, climate-related disclosures, climate-related requirements, climate-related strategies/targets, climate-related regulations, climate-related legislations, climate-related reporting	124
	Carbon Disclosure Project (CDP)	Carbon Disclosure Project (CDP)	32
	Carbon Trade System	Emission Trading System (ETS), Cap and Trade system, emission trading schemes, carbon pricing	30
	Waste Management	waste management, zero waste, zero waste regulation, net-zero waste, recyclable waste, waste water management, waste sent for recycling, waste management education, zero waste project	29
	Carbon footprint	carbon footprint	22
	Adaptation	sustainability adaptation, sustainability principles adaptation, adaptation to environmental standards, adaptation to environmental regulations, adaptation to emissions monitoring, adaptation to international standards	19
	Paris Agreement	Paris Agreement	17
	Mitigation	mitigate environmental impacts, mitigate emissions, mitigate carbon footprint, mitigation of risks, mitigate the severity of the risks, mitigate a detected risk, risk mitigation activities, mitigation measures	14
	Climatic conditions	temperature extremes, climatic conditions, extreme temperatures, severity of extreme weather	12
	Global warming	global warming, greenhouse warming	9
	Pollution	air pollution, land pollution, water pollution, noise pollution, environmental pollution	8
	Biodiversity	biodiversity	5
	Deforestation	deforestation	3

Table 1. (continued)

	Themes	Related-Themes	Frequency
SUSTAINABILITY	Rules-Regulations	• BIST Sustainability Index • EN ISO 14001: 2015 Environmental Management System Standard • IATA Environmental Assessment Management System Program (IEnvA) • Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) • Carbon Disclosure Project (CDP) • IATA Net Zero Carbon Emissions by 2050 • IPCC Guidelines for National Greenhouse Gas Inventories, 2006 • Sustainalytics: Environmental, Social, Governance • European Union Emissions Trading System (EU ETS) • International sustainability indices (Dow Jones Sustainability Index, FTSE4Good, MSCI, ESG Indices, etc.)	140
	Energy/Fuel efficiency	Fuel saving, fuel-saving policy, fuel efficiency, mitigation of fuel consumption, energy policy, energy efficiency, energy reduction, lowering energy consumption, saving energy	94
	Sustainability/sustainable-	Sustainable transportation, sustainable development, sustainable aviation, sustainable sources, sustainability risks, sustainability offerings, sustainability efforts, sustainability performance, sustainability report, sustainability experience, sustainability awards, sustainability rating organizations	59
	Renewable energy/sources	Sustainable fuel alternatives, Sustainable Aviation Fuel (SAF), Microalgae-Based Sustainable Bio-Jet Fuel Project (MICRO-JET), biofuels/bio-based fuels, renewable fuels, renewable energy, renewable sources, sustainable sources, sustainable biofuels, clean energy	44
	Environmental sustainability	sustainable environment, environmental principles, environmental effects, environmental benefits, environmental strategies	38
	Sustainability-governance	sustainability strategy, sustainability related targets, sustainability policy, sustainability approach into its business strategy, sustainability program	33
	Sustainable materials	recyclable, renewable materials, sustainable packaging, environmentally friendly materials	23
	Social sustainability	social responsibility, Discrimination, inequality, human rights violations, forced labor and preventive and corrective practices	17
	Working groups	Sustainability Working Group (SWG), Sustainability Committee, Sustainability Environmental Advisory Council	18
	Corporate Social Responsibility (CSR)	Corporate Social Responsibility (CSR)	17
	Life cycle assessment	life cycle stage(s), life cycle analysis	9
	Sustainable Development Goals (SDGs)	Sustainable Development Goals (SDGs)	6

Table 1. (continued)

	Themes	Related-Themes	Frequency
GREEN MARKETING	Customer satisfaction	customer satisfaction, passenger satisfaction	55
	Value chain	value chain	42
	Brand	brand awareness, brand identity, brand value, brand positioning, brand recognition, brand vision, brand communication, brand value, brand loyalty	34
	Stakeholder expectations	stakeholder expectations, expectations of the stakeholders, stakeholder participation, stakeholder satisfaction	27
	Customer experience	customer experience, passenger experience	26
	Customer expectations	customer expectations, expectations of customers	16
	Service quality	service quality	17
	Behavior change	behavior change, changing customer behavior, behavioral change	11
	Green product/service	eco-friendly product, sustainable product/services, low-carbon products, sustainable products/services,	10
	Fair trade	fair trade	7
	Green consumer	environmentally friendly customers, environmentally conscious customers	4

As seen in Table 1, one of the frequently mentioned codes regarding sustainability and climate change is rules and regulations. In particular, the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) Regulations, the European Union Emissions Trading System (EU ETS), ISO 14001:2015 – Environmental Management Systems, the CDP results of two major airlines are mentioned extensively. CORSIA is a sector-specific compliance carbon pricing strategy that aims to ensure environmentally sustainable international aviation by addressing carbon emissions. To comply with CORSIA, the global aviation industry has a range of strategies at its disposal (ICAO, 2019). These include the utilization of eligible carbon credits, the adoption of sustainable aviation fuel (SAF), and the implementation of enhanced ground operations, air traffic management, infrastructure enhancements, and the incorporation of more fuel-efficient aircraft. ISO 14001:2015 is an Environmental Management System (EMS) standard that offers a framework for businesses to manage their environmental obligations and enhance their environmental performance. It aids in the integration of environmental management into overall company strategy and has been shown to boost top management commitment and communication (Fonseca & Domingues, 2018). The European Union Emissions Trading System (EU ETS) is a cap-and-trade system that the EU has developed to decrease greenhouse gas emissions. It is the world's first and biggest emissions trading program. It has acted as a model for various other worldwide carbon trading programs (Borghesi et al., 2019). It mandates energy-intensive facilities to minimize their CO_2 emissions and provides for the selling of CO_2 permits. The system is based on a cap-and-trade structure, which allows installation operators to freely exchange carbon emissions permits with one another. This allows for emissions reductions to be achieved in a cost-effective manner (Dechezleprêtre et al., 2023). These specific programs demonstrate firms' commitment to environmental sustainability and ethical corporate practices and boost their brand image as ecologically and socially responsible. These firms, who declare their environmental operations and efforts to the public and appropriate authorities, help create a greener future and boost their brand value with stakeholders and customers. In addition, frequently mentioned concepts such as "IATA Environmental Assessment Management System Program (IEnvA)", "IPCC Guidelines for National Greenhouse Gas Inventories", "Sustainalytics" and international sustainability indices (Dow Jones Sustainability Index, FTSE4Good, MSCI ESG Indices, etc.) reflect the standards, regulations and assessment tools used by companies to measure and report their sustainability efforts and environmental impacts. Furthermore, organizations directly related to sustainability, such as the Sustainability Working Group (SWG), Sustainability Committee, and Sustainability Environmental Advisory Council, are commonly cited in corporate reports. These teams inside the organization show increased knowledge of sustainability decision-making, strategy formulation, and execution. These teams' responsibilities go beyond sustainability to include topics like

climate change and green marketing. Businesses handle their sustainability goals and green marketing practices via these working groups, while also supervising the implementation of these initiatives.

Figure 2. Word cloud for firm1

Figure 3. Word cloud for firm2

When examining the outputs of the word cloud for Firm 1 as in Figure 2, terms "sustainability, environment, emissions, carbon, fuel, climate-related, CDP, CO_2e, fuel, risk, customer, corporate, social, metric" appear frequently. Similarly, in the word cloud for the second company in Figure 3, terms including "sustainability, management, emission, environment, carbon, fuel, IATA, CO_2e, CDP, value, customer, investor, social, and education" are prominent. Based on these results, it is evident that Firm 1 and Firm 2 share a similar emphasis on essential sustainability-related concepts. Both companies prioritize sustainability-related topics such as carbon emissions, energy efficiency, and environmental responsibility. Additionally, Firm 1 places a strong emphasis on customer satisfaction, customer-centricity, value, and value chain concepts, which are prominently featured in its word cloud.

Figure 4 compares the two sets of documents via two case model. The chart shows the distribution of codes from both sets of documents, including how often they occur. Both groups place a heavy focus on ideas related to climate change and sustainability, as seen by the use of phrases like "rules/regulations, carbon emissions, energy/fuel efficiency, renewable sources". General marketing phrases like "customer satisfaction", "customer expectation" and "brand image" however, are used far less often in the reports of Firm 2. In contrast, only Firm 1's reports include phrases that are characteristic of green advertising, such as "green customer," "fair trade," and variations thereof. Furthermore, it is worth highlighting that only "biodiversity, deforestation, mitigation, adaptation," and other terms largely connected to climate change appear in the reports of Firm 1. The findings highlight the importance of Firm 2 in the context of social sustainability.

In addition, the extensive use of climate-related terms, green marketing-related phrases like "green strategies" and "sustainable products," in the examined sustainability reports reveals a multifaceted approach by companies in addressing climate change and promoting sustainability. This signifies those businesses not only recognize climate change as a complex issue but also actively engage in sustainable practices and environmentally responsible marketing. This academic insight sheds light on how companies navigate the intricate landscape of sustainability, climate change, and green marketing, aligning their strategies with environmental consciousness and regulatory compliance to foster a sustainable future. Additionally, these reports underline the criteria for selecting collaborators within their supply chain. For example, CDP report of Firm 1 states that "Our company uses the 'Supplier Evaluation Procedure', which was implemented in 2021, and evaluates its suppliers based on its safety, quality, environmental, customer satisfaction, and occupational health and safety policies." The utilization of ISO 14001: Environmental Management Standards in this assessment elevates supplier quality and environmental awareness, allowing the organization to prioritize stringent environmental management requirements when selecting suppliers.

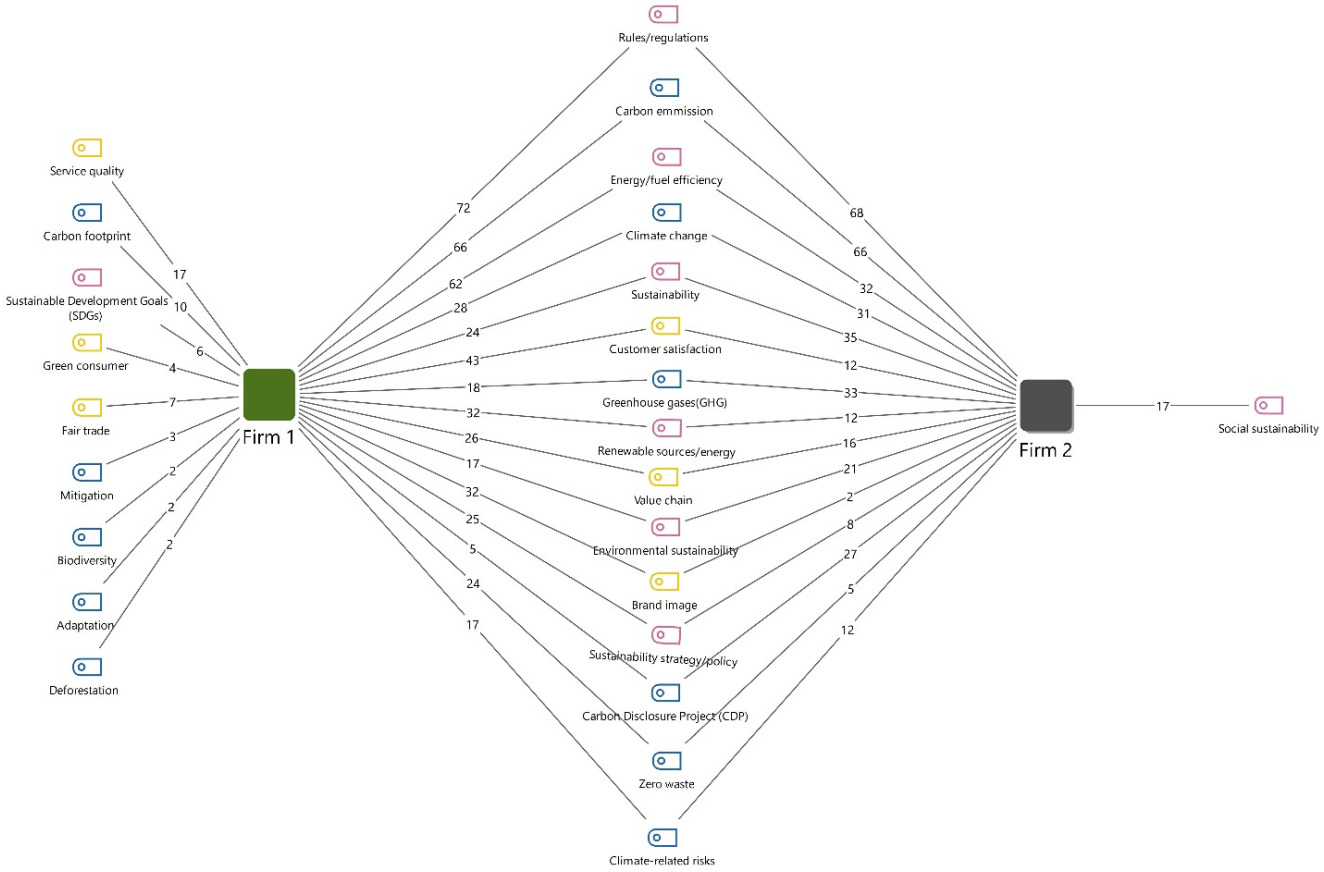

Figure 4. Two case model of the firms

Simultaneously, these reports emphasize the concept of the "value chain," recognizing its central role in the fields of sustainability and green marketing. They underline the need for an all-encompassing strategy that extends beyond their immediate operational boundaries and incorporates the entire value chain. By incorporating sustainability principles into the value chain, these companies aim to reduce their environmental impact, develop more sustainable products and services, and demonstrate their commitment to green marketing. These reports also examine the behavior and expectations of stakeholders, recognizing the importance of aligning with stakeholders who share similar sustainability objectives. This engagement with stakeholders highlights their commitment to transparency, responsibility, and responsiveness to evolving societal and environmental demands, as well as their dedication to sustainable business practices with an emphasis on green marketing principles.

In the transportation industry, companies can enhance their reputation, appeal to environmentally conscious consumers, and contribute to fostering a more sustainable future by implementing green marketing strategies (Khalili et al., 2019). Another pivotal facet of green marketing within the domain of sustainable transportation is the active promotion of eco-friendly travel options to consumers. Airlines play a crucial role by providing information about the environmental impact of various travel choices, which includes advocating for the use of fuel-efficient direct flights and encouraging the utilization of public transportation at destinations (Chang et al., 2015). The findings of this study align with these practices, underscoring that both companies have invested efforts similar to these examples to motivate environmentally conscious behaviors among their customers.

When examining marketing-related concepts, the reports revealed that brand, customer satisfaction, quality of service, behavioral change, and customer expectations were prevalent terms. This demonstrates that companies are attempting not only to promote sustainability, but also to integrate brand identity, customer satisfaction, service quality, and green marketing strategies with sustainability objectives. Synergy between these factors highlights the significance of raising awareness of climate change and meeting consumer expectations to motivate behavioral change toward more sustainable decisions. This comprehension contributes to a comprehensive comprehension of transportation companies' strategies by illuminating how these elements, including green marketing, are seamlessly incorporated into their sustainability initiatives.

Conclusion

This research has thoroughly investigated the relationship between climate change, sustainability, and green marketing in the aviation industry. It has provided significant insights into the strategies and practices of two large airline companies. The study has revealed some significant results and consequences via a thorough content analysis.

The study highlights a significant correlation between sustainability-related topics and climate change, highlighting the interdependence of these critical notions in scholarly discussions and the operational approaches of the two airlines. This discovery underscores the degree to which the aviation industry is intrinsically connected to efforts to mitigate climate change and promote sustainability. The role of green marketing in the transport sector is particularly significant. It's clear that promoting environmentally friendly travel choices is essential to building a company's image and drawing in environmentally concerned customers. Examples of these travel options include pushing for direct flights that use less fuel and encouraging customers to use public transit while at their destination. The study has reaffirmed that these airlines actively use green marketing strategies to encourage their consumers to adopt eco-friendly practices. It is clear that these organizations prioritize the various dimensions of green marketing, and are aware of the important role that green marketing plays not only in meeting sustainability goals, but also in raising consumer awareness and improving market positions. Moreover, the importance of climate change awareness in shaping these strategies emerges through various indicators and institutional statements, reaffirming the increasing impact of sustainability and environmental issues on operational frameworks.

This study provides invaluable insight into the transportation industry's efforts to comply with sustainability-related regulations, specifically the carbon tax. In addition, it offers a compelling insight into the future strategies of this industry. This research facilitates a nuanced comprehension of transportation companies' multifaceted approaches by casting light on the intersection of sustainability, green marketing, and climate change consciousness. As these businesses respond to shifting market dynamics, they not only strengthen their commitment to sustainability, but also improve their corporate image and competitive advantage by incorporating green marketing.

This study has limitations due to its reliance on data from only two airline companies, rendering it unrepresentative of a larger and more diverse sample. This focused approach was deliberately selected to facilitate an in-depth comparison between these two specific enterprises. However, future research endeavors should utilize a larger sample size to allow for more extensive sectoral comparisons. In addition, the duration of the study could be extended to monitor industry developments over a lengthier period of time, and the research scope could be expanded to assess customer perceptions and measure the actual impact of sustainability strategies. If implemented, these recommendations have the potential to considerably enhance our comprehension in this domain and significantly contribute to the transportation industry's future sustainability and environmental consciousness.

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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.

Data Availability Statement

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

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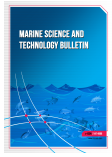

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RESEARCH ARTICLE

Modelling and analysis of pufferfish (*Torquigener albomaculosus*) circular nest on seafloor

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ABSTRACT

This study analyzed the structural features of the circular structures built by the male pufferfish (*Torquigener albomaculosus*) on the seafloor. This impressive circular structure which is built by male pufferfish exists in different depths and sizes on the seafloor. One of the objectives for the male pufferfish constructing these circular structures is to influence the opposite sex. The morphological features of these circular structures built on the sea floor were analyzed mathematically. This analytical study was performed using photographs received from the sea floor as well as the ratios of circular formations discovered in this context. During the image analysis, the histogram equalization method was used to improve the visuals and reveal the patterns of circular structures. The Hough transform method, which is commonly used in the determination of circular structures, was used in the process of precisely determining the dimensions of the obtained circular structures. The circle size ratios obtained from the images and the circular structure dimension ratios obtained from the observation were examined. When the ratio analysis results from 2 images and 6 observation data were examined, it was observed that significant traces of the golden ratio were seen in these nested circular structures. According to this study's analysis of the pufferfish nest, which demonstrated proper development, the percentage difference between the golden ratio and the radius of the circular structures was determined to be as low as 0.185%. Additionally, these circular constructions were recreated in 3D while preserving their proportions, and their hydrostatic pressure characteristics were analyzed depending on their actual depths on the seafloor.

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Introduction

Golden section or ratio (φ) is defined as the magical beauty of mathematics. This ratio is implemented in the area of art, architecture, music, design, etc. and it is frequently encountered as a result of examining the impressive works in these areas. Mankind has created many works by using this impressive ratio or number in nature. Even if this number inspires humans to produce more beautiful products, there is much more impressive work related to this impressive number in nature, which is the main source of this number and this value is also deeply linked with efficiency and environmental usefulness for nature (Meisner, 2018). The golden ratio can generally be defined as the relationship between the components that make up a total structure. This ratio is often defined as length, and sometimes as angular, but it is an impressive and fascinating concept in every aspect. The concept of the golden ratio is shown as the reason why some designs are more impressive than others. Although the concept has been known for a long time, there are many studies on this concept even today. The main reasons for this are because the golden ratio concept is intriguing, and our ability to observe and analyze the environment is increasing day by day as technology advances. There are many examples of traces of the golden ratio in the physical appearance of living organisms. Traces of the golden ratio can be observed in a wide variety of biological phenotypes. Furthermore, research shows that the golden ratio can be found in physiological signals that are central to our life, such as the electrocardiogram (ECG) (Ciucurel et al., 2018).

The trail of the golden ratio can also be found in weather patterns, sea waves and even planets on the solar system (Bartlett, 2019). The golden ratio is found in detailed analyzes of the body structures of living things. The trace of the golden ratio on the body of the monarch butterfly is shown in Figure 1 (Akhtaruzzaman & Shafie, 2011).

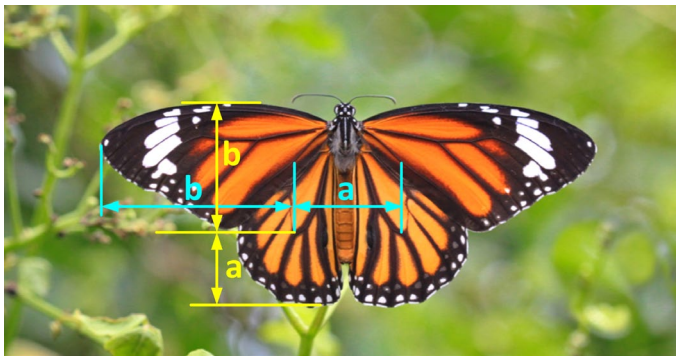

Figure 1. Golden ratio in *Danaus plexippus* wings

In addition, there are various traces of the golden angle, which is the part of the full angle according to the golden ratio in nature. The leaf distribution of *Bromelia humilis* is given in Figure 2 (Lüttge & Souza, 2019).

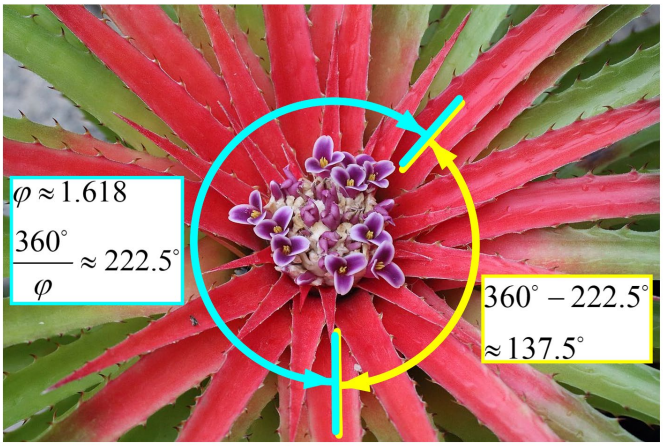

Figure 2. *Bromelia humilis* and golden angle

When the leaf distribution of such leafy plants is examined, there is a relationship between the golden ratio or angle value and the sunshine duration of the leaves in the lower part. With the leaves showing distribution depending on the golden angle, it is possible to capture maximum light in terms of the whole plant. In this way, it is ensured that the plants perform the maximum photosynthetic activity (Strauss et al., 2020). Thanks to the leaf distribution depending on the golden angle, the rate of blocking of the rays of each other is minimized.

In addition to the evidence of the golden ratio that can be seen with the bare eyes, some studies have found traces of the golden angle in internal organs. (Yalta et al., 2016). In a study examining the relationship between the golden ratio and organ morphology, the vertical and transverse dimensions of a healthy human heart structure converge to the golden aspect ratio regardless of ethnic origin. It has been observed that these values significantly deviated from the golden angle in heart-related diseases (Henein et al., 2011). The illustration of the human heart and the golden angle between inlet and outflow tract axes of the right ventricle is given in Figure 3. When the studies on the golden ratio and angle are examined, it has been revealed with impressive studies that these parameters are important not only in terms of efficiency, visuality, art, design, nature etc. but also in the field of health (Akhtaruzzaman & Shafie, 2011). In another study, it was shown that with the golden rhythm depending on the golden ratio, acute gait patterns can be improved in Parkinson's patients (Belluscio et al., 2021).

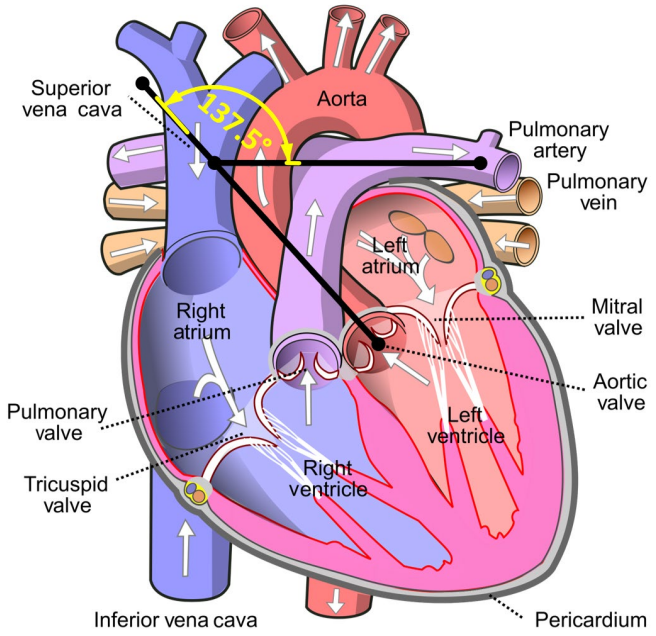

Figure 3. The golden angle between the ascending aorta and pulmonary artery

As can be seen in the examples given, there are very impressive traces of the golden ratio in the structures in nature. In this study, the relationship between the golden ratio and the structural statistical analysis of the circular structures formed by the puffer fish on the seabed was examined. In addition, the modeling outputs of the hydrostatic pressure distribution of this structure, which has traces of golden ratio, are given.

Historical Origins and Development of the Golden Ratio

The golden ratio is the most mysterious and impressive number according to scientists in history. It is believed that the golden ratio concept underlies most events in our daily lives, from why a design or person attracts our interest to the behavior of biological organisms in nature. As a result, the concepts of the golden ratio and its sub-concepts, such as the golden angle and golden rhythm, are extremely exciting and interesting to researchers (Nematollahi et al., 2020).

$$\varphi = \frac{\sqrt{5}+1}{2} = 1.61803\ldots \varphi^2 = \varphi + 1 \quad (1)$$

The illustration of the golden ratio with the line segment is given in Figure 4.

The golden ratio was first mentioned in Euclid's book called *Elements* in 300 BC. He presented a line by dividing the 0.6180399 points as the extreme and mean ratio and this value is called the golden ratio conjugate (Meisner, 2018). The relationship between the golden ratio and golden ratio conjugate (ϕ) is given in Equation 2.

$$\phi = \frac{1}{\varphi} = \frac{\sqrt{5}-1}{2} = 0.61803398\ldots \quad (2)$$

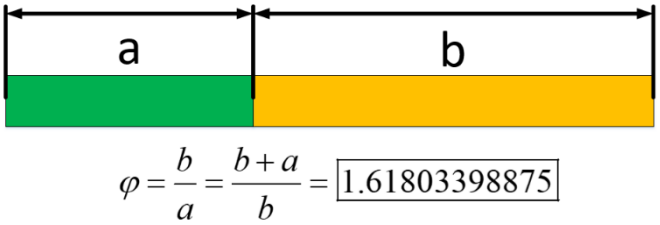

Figure 4. The golden ratio and line segment

Later, Euclid proved the connections of the golden ratio through the pentagram. The illustration of a golden ratio pentagram is given in Figure 5 and the relationship between distance is given in Equation 3 (Livio, 2008).

$$\frac{d}{c} = \frac{c}{b} = \frac{b}{a} = \varphi = 1.61803398875\ldots \quad (3)$$

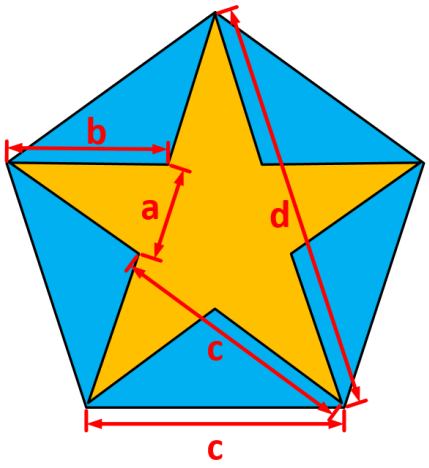

Figure 5. Golden ration and pentagram

The famous mathematician Muhammad ibn Musa al-Khwarizmi divided it into 2 parts of 10 units in length by the golden ratio in his book (The Compendious Book on Calculation by Completion and Balancing). Muhammad ibn Musa al-Khwarizmi's works in this area inspired Leonardo Fibonacci, who invented the Fibonacci series, the well-known mathematical series in history (Aksoy, 2016). The adventure of the golden ratio became even more impressive with the discovery of the Fibonacci series. After that the discovery, the charming relationship between the golden ratio and the Fibonacci series was found (Fletcher, 2006). The relationship between the Fibonacci series and the golden ratio is given in Equation 4. As shown in the equation below, the ratio between the last and previous elements of the Fibonacci series converges

to the golden ratio, and the convergence becomes more obvious as the number of elements increases. ($144/89 \approx \varphi$).

Table 1 shows the process of convergence of the Fibonacci series elements to the golden ratio.

$$FibonacciSequence \quad (4)$$
$$\underbrace{0,1,1,2,3,5,8,13,21,34,55,89,144,233,377,610,\ldots}$$

$3 \times 0.618 \approx 2$ $\quad 13 \times 0.618 \approx 8$ $\quad 55 \times 0.618 \approx 34$
$5 \times 0.618 \approx 3$ $\quad 21 \times 0.618 \approx 13$ $\quad 89 \times 0.618 \approx 55$
$8 \times 0.618 \approx 5$ $\quad 34 \times 0.618 \approx 21$ $\quad 144 \times 0.618 \approx 89$

Table 1. Golden ratio and Fibonacci series

F_{n+1}	F_n	$\frac{F_{n+1}}{F_n}$
2	1	2
3	2	1.5000
5	3	1.6666
8	5	1.6000
13	8	1.6250
21	13	1.6154
34	21	1.6190
55	34	1.6176
89	55	1.6182

According to studies of the early 1500s, Da Vinci is thought to be the first person to describe the concept of golden ratio with Vitruvian Man as a relationship between golden ratio and human body in literature (Iosa et al., 2018).

In the 17th century, Johannes Kepler discovered that the planets have an elliptical orbit in the solar system and that there are traces of the golden ratio in these orbits (Sugimato, 2021). In literature, the term gold in the golden ratio was first used in the 18th century by the mathematician Martin Ohm in his book named *the Pure Elementary Mathematics* (Meisner, 2018).

Greek letter phi (φ) is used by mathematician Mark Barr at the begging of the 20th century. This number, which has found a place in numerous studies since the day it was discovered and used to open the door to beauty and the spiritual world, is frequently used as the golden ratio due to its unique properties. Although it is not mentioned as much as the golden ratio in the literature, the golden angle which is derived from the golden ratio appears in many different fields such as the arrangement of the leaves of the plants (Strauss et al., 2020). The golden angle is obtained by dividing the 360 degrees of a circle with the golden ratio and as a result of this calculation, circle segments with values of approximately 222.5° and 137.5° degrees are obtained (Lüttge & Souza, 2019). The calculation of the golden angle is given in Equation 5.

$$\frac{b}{a} = \frac{b+a}{b} \approx 1.618 \Rightarrow \frac{360^0}{b} \approx 1.618 \Rightarrow \boxed{b \approx 222.5^0} \quad (5)$$
$$a + b = 360^0 \Rightarrow a + 222.5^0 \approx 360^0 \Rightarrow \boxed{a \approx 137.5^0}$$

The illustration of the golden angle which is derived from the golden ratio is given in Figure 6.

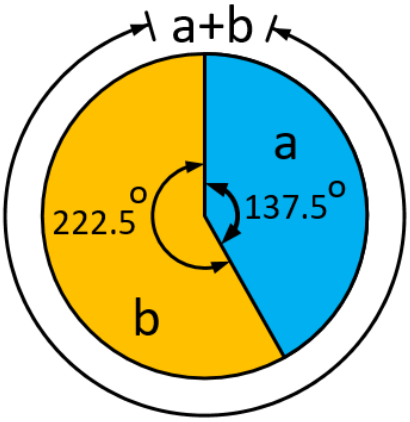

Figure 6. Golden angle

Another geometric shape that is associated with the golden ratio is the Fibonacci (golden) spiral. The golden ratio is the growth factor in the Fibonacci spiral, which is a logarithmic spiral. Every quarter-turn of the golden spiral increases its size by a factor of golden ratio (φ).In nature, the trails of the Fibonacci spiral can be found everywhere, even the universe is full of evidence of the Fibonacci spiral (Herrmann, 2018).

The curves of human ear shape or human bone structure or from the spirals of the nautilus seashell to galaxies contain evidence about the structure of Fibonacci spirals (Akhtaruzzaman & Shafie, 2011).

The illustrations of Fibonacci spiral are given in Figure 7 (Fletcher, 2006).

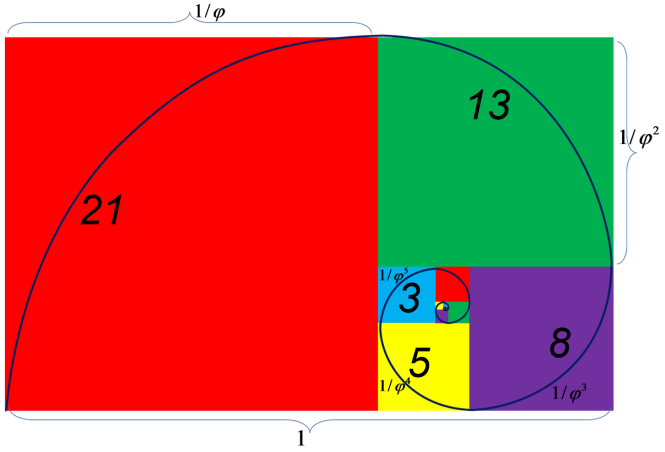

Figure 7. Fibonacci spiral

Samples of examples of the Fibonacci spiral in nature and the human body are given in Figure 8.

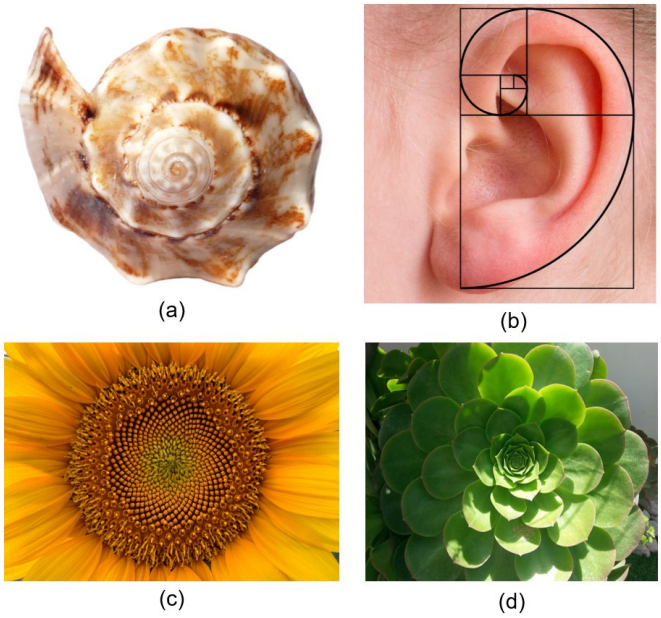

Figure 8. Samples of golden ratio in nature (a) *Turbo marmoratus* (b) Human ear *(Pinna)* (c) *Helianthus annuus* (d) *Aeonium glandulosum*

In addition to the many golden ratio traces found in nature, new structures containing the golden ratio are being discovered every day. Some of these discoveries are on our planet, some in the universe. The shape of a recently discovered fish nest was analyzed according to the golden ratio in this study. The name of this fish is the pufferfish and it has great ability to build a huge structure according to its own size on the seafloor and it is also called white-spotted pufferfish (*Torquigener albomaculosus*) in literature (Matsura, 2015).

Pufferfish (*Torquigener albomaculosus*)

The species of pufferfish named after its behavior, live in the Indian and Pacific oceans and general scientific name is known as "Torquigener" and the name of the fish whose behavior was examined and structured is defined as *Torquigener albomaculosus*. Figure 9 shows an image of male pufferfish. Male pufferfish can reach a maximum length of 12 cm, while females can reach a maximum length of 9.1 cm. (Matsura, 2015). This species is remarkable for its ability to construct huge circular structures on the seafloor and these impressive structures are vital in the decision-making process of female pufferfish during partner selection. (Schaedelin & Taborsky, 2009).

Figure 9. *Torquigener albomaculosus*, (a) lateral view, (b) dorsal view, (c) underwater photographs of *Torquigener albomaculosus* (d) construction stage, size (cm):8.8 SL, 10.9 TL, locality: Ryukyu Islands, Katetsu Cove, Amami-oshima Island, Male, NSMT-P 118118, holotype. Photo by Satoru N. Chiba.

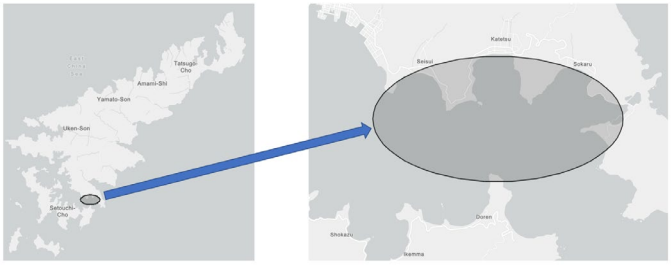

Figure 10. Map of *Torquigener albomaculosus* data collection locations (Ryukyu Islands, Katetsu Cove).

Circular Structures on the Seafloor

In 1995, constructions that are circular were discovered around the island of Amami-Oshima in southern Japan. The emergence of the associated structures is mysterious in the first stage, and it is assumed to be revealed by an organism or natural phenomenon, and these circular shapes are known as mystery circles. For a long time, these round constructions with a diameter of about 2 meters remained a mystery (Matsura, 2015). It was determined that these 2-meter circular structures were built around 2011 by puffer fish, a 12 cm pufferfish species, at depths of 10 to 27 meters. On both sides and with round grooves, related structures of varied shapes are constructed. The objective of these structures developed on the sea floor has been thought to be to impress opposite-sex fish (Kawase et al., 2013).

Underwater photographer Yoji Okata captured comprehensive images of this fish species' construction of circular formations in 2011. In 2012, Kawase and his colleagues recorded the creation of mysterious circular shapes belonging to this fish species and this detailed study formed the basis of our study by providing information about the emergence procedures of circular structures and the dimensions of the circular structure formed on the seafloor (Kawase et al., 2013).

Figure 11 illustrates the circular architecture made by male pufferfish on the seafloor. Inner and outer circles, sand peaks, and a pattern unique to each fish are all part of the circular structure that was built (Mizuuchi, 2018). The circular structure is formed after the separate construction stages of these different parts (Kawase et al., 2017). Females only visit these circular structures at the final stage, when the structure emerges. At the final stage, the male pufferfishes were seen decorating the radially aligned peaks with pieces of shell and coral at the final stage when the circular structure is fully revealed. It has been observed that the frequency of behavior at this stage has been significantly higher than during the other building processes. When a female pufferfish approaches a circular structure, the male mixes the sand particles in the middle of the structure. When the female enters the circular structure, the male advances away from the center zone and rush to her several times (Kawase et al., 2013).

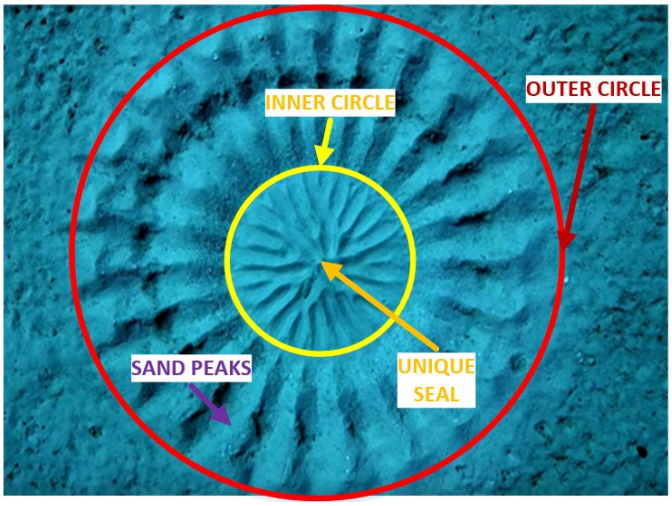

Figure 11. Circular structure of pufferfish and zones

Kawase et al. (2013) examined the developmental processes of 10 male pufferfish's circular structures. Each fish takes 7-9 days to develop the circle structure, and the circular structures formed by each fish vary. The water flow rate in the center was reduced by nearly 25% because of the circular structure's architecture. (Kawase et al., 2013). This is due to the unique seal structure at the center of the circular construction and made of fine sand, can be observed more permanently by the opposite sex. Figure 12 shows and describes circular structures (Catalbas & Gulten, 2022).

As a consequence, on the seafloor, a unique circular structure with a diameter of roughly 2 meters was created. With the influence of discharge following ovulation, this circular shape collapses and flattens (Kawase et al., 2014). The symbols of the puffer nests in the completed process are examined in this study. In Figure 13, the radius of the inner and outer circles is calculated using the pixel-based distance measurement method (Test 1).

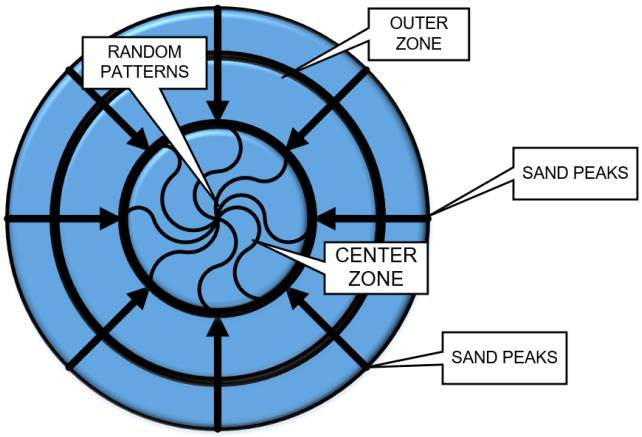

Figure 12. The illustration of the circular structure according to zones

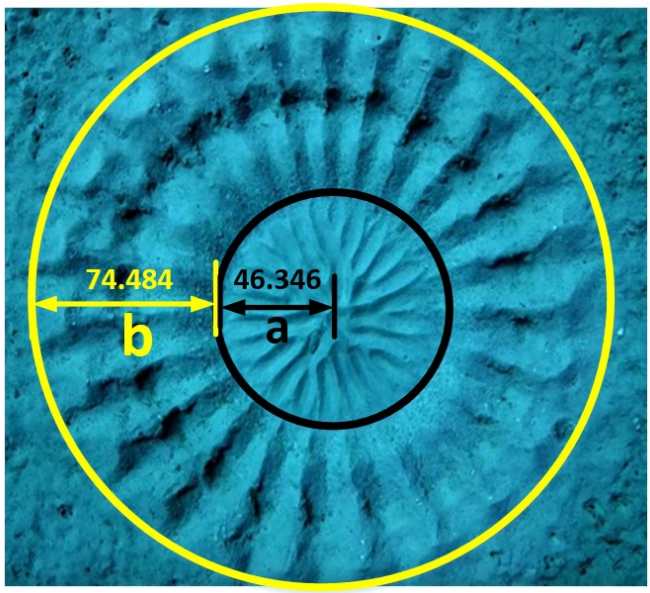

Figure 13. Golden ratio and pufferfish nest (*Test 1*)

When the radius of the circle of the pufferfish circular structure, which has reached the final stage, are examined, it is seen that the determined ratio converges to the golden ratio and it is given in Equation 6.

$$\varphi = 1.6180339 \ldots \quad (6)$$

$$Ratio(r) = \frac{b}{a} = \frac{74.484}{46.346} = \boxed{1.60712899}$$

In addition, the histogram equalization approach was applied to the images to make the details in the circular structure images more evident, as well as the traces of the inner and outer circle (Dhal et al., 2021). Figure 14 shows the input image of the circular structure and the histogram equalization result according to this input image (Test 2).

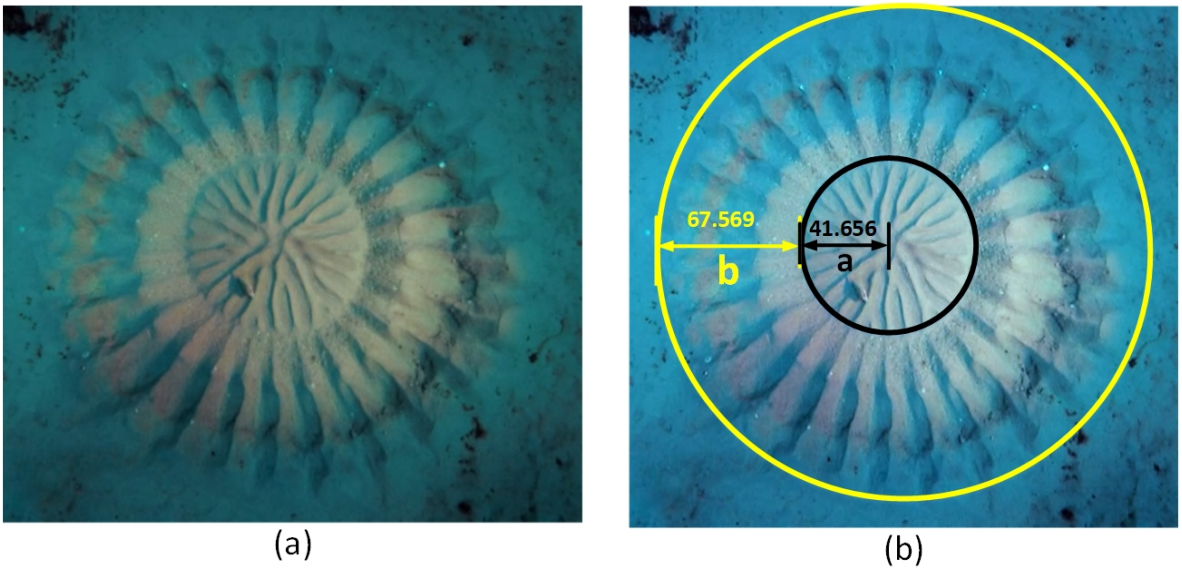

Figure 14. (a) Input image (b) Enhancement image and radius values (*Test 2*)

Table 2. Numerical parameters about pufferfish circular structure

Number of Pufferfish Nest	Number of Peak and Valley Pairs	Radius of Outer Circle (cm) (b+a)	Radius of Inner Circle (cm) (a)	Parameter (cm) (b)	Ratio ($r = \frac{b}{a}$)
S_1	24	82	32	50	**1.5625**
S_1	32	83	35	48	**1.7291**
S_3	24	80	31	49	**1.5806**
S_4	29	79	34	45	*1.3235*
K_1	30	100	50	50	*1*
K_2	27	105	40	65	**1.625**
Test 1	24	120.83	46.346	74.484	**1.6071**
Test2	26	109.225	41.656	67.569	**1.622**

Two circular structure images were analyzed in terms of radius ratio within the scope of this study and the results of these studies are indicated as Tests 1 and 2. Table 2 shows the results of another study in which these circular structures were investigated, as well as the results of the images analyzed in this study (Kawase et al., 2013). Table 2 shows the statistical analysis of the circular structures of the appropriately developed pufferfish nest used in this study. The inner and outer radii of the circular structures in the table are obtained from previous literature and image processing results. The distance of the outer circular structure to the inner circular structure and the distance of the inner circular structure to the center were analyzed. In these processes, distance in cm and pixel values were considered.

Figure 15. 3D model of pufferfish circular structure according to golden ratio

As a result of this analysis, 6 of the 8 radius ratios of circular structures were found to be similar to the golden ratio. It was determined that the average of the radius ratios of these 6 circular structures was 1.621. The average of radius ratios was determined as 1.614 in two test images that were especially improved with the histogram equalization method and whose radius ratios were determined on a pixel-basis measurement method. When these two results are viewed integrally, it is possible to find traces of the golden ratio in the radius ratios of these circular structures' inner and outer circles. Additionally, the special circular structure was realized as a 3D model by using real parameters in the construction processes of circular structures in this work. The 3D model of the circular structure obtained as a result of using parameters similar to the golden ratio is given in Figure 15. The aim of building this 3D model is to investigate the behavior of a circular structure with parameters on the seafloor.

With this 3D model created, the hydrostatic pressure on the seafloor and its effects on the structure have been analyzed in detail and it is given in Figure 16.

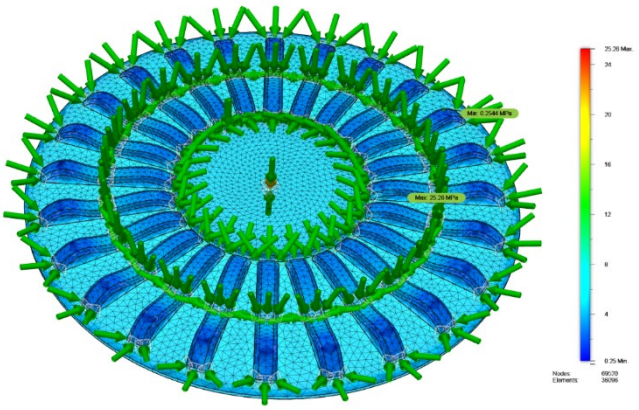

Figure 16. Simulation results of hydrostatic pressure on 3D model pufferfish circular structure

There are various processes involved in the construction of these impressive circular structures. These lengthy construction processes can only be realized if the integrity of the circular structures is preserved at all stages. It should also be noted that the female puffer only visits the circular structure after it has been fully revealed and decorated. As a result, this structure, which was produced on the seafloor and under variable conditions, must be highly resistant to external influences and preserve its integrity. Within the scope of this study, the images of these interesting circular structures were analyzed and reconstructed in a 3D model. When the circular structure was reconstructed as a 3D model depending on these ratios, it was observed that the hydrostatic pressure was uniformly distributed over the structure. As a result, a structure forms that can preserve its structural integrity until the construction processes are finished.

Conclusion

In this work, the morphological analysis of the impressive circular structures created by the male pufferfish to impress the opposite sex has been realized. The process of building these structures, which have a diameter of around 2 meters and are built on the seafloor, is divided into several stages. The process of constructing circular structures takes around 9 days, and the female pufferfish only visits these structures close to the end. The finishing and decoration work is completed by male pufferfish at the last stage. Throughout this process, the circular structures consistency and structural stability must be kept against altering seafloor conditions. When the development process of these structures was examined in detail, it was observed that the architectural ratios were not random. The histogram equalization approach was used in this work to bring out the features in images of two different circular structures, and the radius values of the inner and outer circles of these structures were determined using a pixel-based measuring method. The average value of the ratio between the distances of the circular structures of the pufferfish examined in this study and showing appropriate development is 1.621. The percentage error rate between the values in this calculation and the golden ratio is 0.185% and the absolute error value is 0.003. In the view of these error rates, it can be said that the circular structures of the pufferfish have strong traces of the golden ratio value. The fact that there are such strong traces of the golden ratio in the circular structures of the puffer fish, one of the most impressive structures on the seafloor and recently discovered, may lead to inferences that the traces of the golden ratio in nature may be more than expected. Additionally, the circular structures of pufferfish were reconstructed as a 3D model in this work using real-world characteristics. It has been observed that the 3D-modelled circular structures have an advantageous structure against the distribution of hydrostatic pressure on the seafloor.

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.

Data Availability Statement

All data generated or analyzed during this study are included in this published article.

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RESEARCH ARTICLE

Some population parameters of picked dogfish (*Squalus acanthias* L. 1758) incidentally captured in commercial fisheries in southern Black Sea shores and a first record of angular roughshark (*Oxynotus centrina*, L. 1758) for Black Sea

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ABSTRACT

The study, which aimed to determine some population parameters of picked dogfish (*Squalus acanthias* L. 1758) distributed in the Black Sea, was carried out in the five fishing seasons (between 2016 and 2023 years). The sharks draw attention as a bycatch for all fishing gear used in the Black Sea. In the study, total length (cm), weight (g) and sex (female/male) data were obtained from the sharks captured with all fishing gears (demersal trawl, midwater trawl, gillnets purse seine, turbot gillnets, trammel nets and bottom) used in commercial fishing activities in the Black Sea of Türkiye. A total of 576 specimens were collected all fishing gears during the sampling period. Length-weight relationship (LWR) was founded as $W=0.0097L^{2.8521}$ (R^2 =0.9854) for all the picked dogfish. Also, mean total length 48.9±0.707 cm respectively. In addition, the first record of the angular roughshark (*Oxynotus centrina*, L. 1758) species was given for the Black Sea coasts, which originated in the western Atlantic, was seen in the Mediterranean, Aegean Sea and the Marmara Sea of Türkiye. The shark, which was accidentally caught with a purse seine net, measured as 33.5 cm in total length and weighed 585 g.

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Introduction

Cartilaginous fish, class Chondrichthyes, are a very large and diverse group that includes subclasses of Elasmobranchii and Holocephali and contain approximately 1100 species in total (Compagno, 1990; Compagno et al., 2005). They are one of the major parts of marine ecosystem (Cortes, 2000) and have a cartilaginous skeleton unlike Osteichthyes or bony fishes with a bony skeleton (Bonfil, 1994). Cartilaginous fishes are main components of marine communities (Cortes, 2000) and they play an important role in the marine ecosystems contributing to the regulation of low trophic level organisms since the majority of them are predators (Myers & Worm, 2005; Coll et al., 2013).

Chondrichthyans face various threats that can be examined under three main groups: targeted fishery (direct exploitation), bycatch (indirect exploitation), habitat loss and degradation (Stevens et al., 2005). Sharks and rays appear to be particularly vulnerable to over-exploitation because of their K-selected life-cycles strategy. Cartilaginous fishes were characterized by slow growth, late attainment of sexual maturity, long life spans, low fertility, and natural mortality, and a nearby relationship between the number of young produced and the size of the breeding bio-mass (Stevens et al., 2000). As a result of these main threats, it is estimated that nearly one quarter of the cartilaginous species are classified as threatened (Dulvy et al., 2014).

The commercial value of cartilaginous fish is relatively low compared to other bony fishes caught in the Mediterranean basin. Currently the amount of cartilaginous fish harvested annually on a Mediterranean basin scale represent nearly 1.15 % of the reported total catch (Bradai et al., 2018; FAO, 2020). However, it is estimated that roughly 50% of the total catch of elasmobranch species remain unreported due to various issues (Bonfil, 1994). Türkiye with Italy and Tunisia contributed 76% of the total elasmobranch catches within the Mediterranean during the 1980–2008 period (Bradai et al., 2012). However, incidental catch of cartilaginous fish appears as a more important problem in the Mediterranean basin. It is suggested that almost all cartilaginous fish living in the Mediterranean are affected by the bycatch problem. In order of importance, trawls, purse seine, longlines, driftnets, gillnets, trammel nets and dredge are the main fishing gears which cause incidental catch of these fish in the Mediterranean basin (Cavanagh & Gibson, 2007).

Mediterranean Sea including Black Sea and Sea of Azov is home to probably 84 chondrichthyan species representing 8% of the total number of species of this group in the world although entire Mediterranean basin covers less than 1% of the total area of World seas (Serena, 2005). According to Bilecenoğlu et al. (2014), there are 65 chondrichthyan species belong to classes of Elasmobranchii (64 sp.) and Holocephali (1 sp.) in the Türkiye marine fish fauna and 10 of these elasmobranch species can be found in the Turkish coasts of the Black Sea. The most widely known cartilaginous fish in the Black Sea is the thornback ray (*Raja clavata*). Thornback rays are often caught as bycatch by various fishing gears (such as purse seine, demersal trawl, pelagic trawl, dredge, gillnets and trammel nets) along the Black Sea coasts (Kasapoğlu & Düzgüneş, 2013; Özdemir et al., 2021).

Besides, the picked dogfish (*Squalus acanthias*) is the most important shark species living in the Black Sea. The picked dogfish has slow growth and late maturity feature (Tserkova et al., 2022). The IUCN status of picked dogfish in the Black Sea countries were reported LC - least concerned for Georgia; NT-near threatened for Romania; EN- endangered for Türkiye (Radu & Maximov, 2012). However, IUCN Red List status of picked dogfish is vulnerable species (Fordham et al., 2016). A demersal, inshore and offshore sharks of the continental and insular shelf and upper slopes. Usually near the bottom, but also in midwater and at the surface occurs mainly between 10-200 m depth (Ebert et al., 2010).

There are few detailed scientific studies on the sharks of the Black Sea. In this study, some population parameters and length-weight relationships of picked dogfish captured as a by-catch in trawl nets (demersal and pelagic), set nets (turbot gillnets, trammel nets and bottom gillnets) and purse seine used in the southern Black Sea coasts of Türkiye were determined. Also, a new shark species (Angular roughshark, *Oxynotus centrina*) were given first record for Black Sea shores.

Material and Method

The study was conducted out in the Black Sea coasts of Türkiye at by using commercial fishing gears. Active fishing gears were otter demersal trawls, pelagic trawls (01 September 2018 – 15 April 2023) and purse seine (01 September 2022 – 15 April 2023). Passive fishing gears were turbot gillnets, trammel nets and bottom gillnets (01 September 2016 – 15 June 2023). The sampling areas were southern Black Sea shores of Türkiye (Survey areas: Samsun-SA1 Sinop-SA2, Kastamonu-SA3 and Zonguldak-SA4). These regions are an important migration point and direction of pelagic and demersal fish shoals in the Black Sea coasts of Turkey. The nautical chart of the survey area is shown in Figure 1.

Table 1. Mesh size of set nets (passive fishing gears) used on sea trials

Fishing gear	Material	Mesh Size
Turbot gillnets	Multifilament	320 mm, 340 mm, 360 mm, 400 mm
Trammel nets	Multifilament	32 mm, 36 mm, 40 mm, 44 mm, 48 mm, 52 mm
Bottom gillnets	Multifilament	32 mm, 36 mm, 40 mm, 44 mm

Figure 1. Survey areas in the study (SA1: Samsun coasts, SA2: Sinop coasts, SA3: Kastamonu coasts, SA4: Zonguldak coasts)

Samples were collected with trawl nets, purse seine and set nets (turbot gillnets, trammel nets and bottom gillnets) at depths ranging from 15 m to 120 m. Traditional demersal trawl nets used from three different fishing region (40 mm, 42 mm and 44 mm codend mesh size) in the survey. Tow duration of trawl nets was to 60-120 minutes.

A total of 120 hauls for demersal trawl, 60 hauls for pelagic trawl, 60 fishing operations for bottom gillnets and trammel nets, 60 fishing activities for turbot gillnets and 8 fishing operation for purse seine were conducted during the study period. Also, while the turbot nets used in the research were left in the sea for an average of 10 days, the bottom gillnets and trammel nets remained in the sea for 24 hours. Mesh size of passive fishing gears (set nets) used on the study were given Table 1.

Angular roughshark were captured incidentally on 24 December 2022 at a depth of 42 meters by the purse seine in Zonguldak-Ereğli (SA4) offshore of Southern Black Sea, (41°25'18" N – 31°33'09" E, coordinates). After determining the size measure and sex of the shark, it was released back to the sea alive (Figure 2). The sharks were defined by considering the morphological and biological characteristics of species. The sex of the sharks was established by the macroscopic investigate of the gonads, clasper or not clasper (Compagno, 1984; Froese & Pauly, 2023a, 2023b). Incidentally captured picked dogfishes were registered to the nearest 1 mm (total length) and weight to the nearest 5 g (Figure 2).

Female/male ratio of picked dogfish was analyzed by Chi-square test (X^2). Fulton's condition factors (CF) were fixed by the Equation 1:

Figure 2. Measurement of the length of sharks

$$CF = \frac{W}{L^3} \times 100 \quad (1)$$

Length-weight relationships were predicted by fitting an exponential curve ($W=aL^b$) to the data (Pauly, 1984). Parameters "a" and "b" of the exponential curve were estimated by linear regression analysis over log-transformed data (Equation 2):

$$\log W = \log a + b \log L \quad (2)$$

where, W is the total weight (g) and L is the total length (cm), "a" is the intercept and "b" is the slope, using the least-squares method.

The association-degree between variables of W and L was calculated by the determination coefficient (R). Additionally, 95% confidence limits of the parameter b were estimated. The Student's "t test" was used for comparison of the slopes (Zar, 1996).

When the parameter 'b' is statistically equal to 3, the growth is called isometric, but the growth is positive allometric when the 'b' value is more than 3 and negative allometric when the 'b' value is less than 3 (Dutta et al., 2012).

Results

A total of 576 picked dogfish were collected all fishing gears during the sampling period (Figure 3). The more sharks were incidentally caught with active fishing gear than with passive fishing gear in the study. While the most sharks were caught by demersal trawls (338), the least were caught by purse seine (5). A total of 40 sharks were caught accidentally by midwater trawls. Totally 193 sharks were caught incidentally with passive fishing gear (turbot gillnets: 54, trammel nets: 87 and gillnets: 52).

It was determined that 54.9% of the samples were females (N=316), 45.1% males (N=260). The shortest individual, 27.2 cm (TL) was obtained in May 2022 and the longest 111.8 cm (TL) in November 2019. The values of picked dogfish examined, mean length and weight, standard error, minimum and maximum size and weight for sexes were given in Table 2. Sex ratio was 1 female: 0.67 male in the examined fishes. Statistical analysis using the Chi-square test (X^2) is significant for the species ($p<0.05$).

The length-weight relationships (LWRs) of picked dogfish were calculated as $W=0.0098L^{2.8561}$, $W=0.0103L^{2.8283}$ and $W=0.0112L^{2.8521}$ for females, males and all individuals, respectively (Figure 4). Length-weight relationships of sharks were highly significant ($p<0.005$) and presented in Table 3.

Fulton's condition factors were founded as 0.801±0.009 for all individuals. Mean condition factor of female was higher than male individuals (0.769±0.013 and 0.919±0.012).

In the study, angular roughshark was recorded the first time in the Black Sea. The total length and weight of the shark caught accidentally with a purse seine net was measured as 33.5 cm and 585 g. Also, sex of shark was determined as female (Figure 5).

Figure 3. Incidental shark catches for fishing gears used on southern Black Sea coasts

Table 2. Some meristic features of captured picked dogfish

Gender	Total Length (cm)			Total Weight (g)		
	Max	***Min***	***Mean***	***Max***	***Min***	***Mean***
Male	94.2	30.5	43.8±0.801	2988	199.5	315.0±13.111
Female	111.8	27.2	55.5±0.569	5235	255.5	326.5±14.369
All	111.8	27.2	48.9±0.707	5235	199.5	321.5±16.257

Table 3. LWR parameters of captured picked dogfish

Parameters	Female	Male	All
N	316	260	576
a	0.0098	0.0103	0.0097
b	2.8561	2.8283	2.8521
SE of b	0.05433	0.05117	0.04485
Coefficient of a 95%	0.0041-0.0169	0.0077-0.0188	0.0037-0.0157
Coefficient of b 95%	2.681-3.111	2.678-3.107	2.686-3.115
R^2	0.9871	0.9823	0.9854
Growth	Negative Allometric	Negative Allometric	Negative Allometric
p value	<0.005	<0.005	<0.005

Note: SE: Standard error

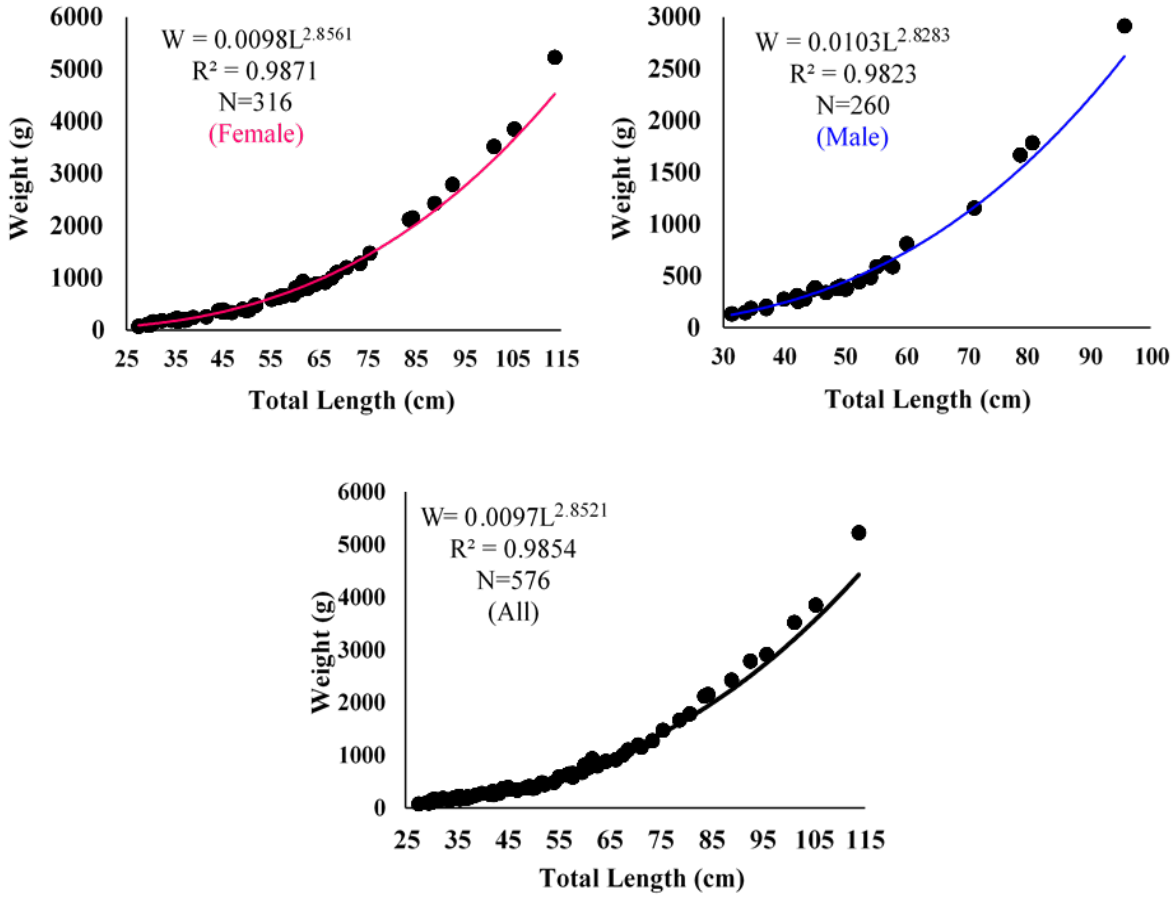

Figure 4. LWR graphics of picked dogfish (Female, male and all)

Discussion

Picked dogfish is assumed to be the most abundant living shark species (Dutta et al., 2012). While there are comprehensive studies on the species in the Aegean Sea, Mediterranean and Marmara Sea, research on the biology and population parameters of the species in the Black Sea is very limited.

In the Black Sea the largest catches of picked dogfish are along the coasts of Türkiye, although this fish is not a target species of fisheries, being yielded as by-catch in trawl nets and purse seine operations in the commercial fishing seasons. In the 1989 annual catches of Türkiye are 14558 tons. In subsequent years, they have decreased about 26.5 tons in 2011. It is stated that this decrease and rapidly collapse in picked dogfish stocks was caused by excessive and uncontrolled over-fishing pressure until the 2000s (Düzgüneş et al., 2005). Nowadays, commercial fishing of the species is prohibited in Turkey (Anonymous, 2020). Considering the slow growth and late maturity of the picked dogfish need to be protected and supported with

detailed study and precautions in order to maintain their existence in the marine ecosystem.

In this study, length-weight relationships of picked dogfish, the most important shark species of the Black Sea, were determined. Picked dogfish has been found to be negative allometric (b<3) growth (t test. p<0.005). The length-weight relationships parameter "b" typically varies between 2.0 and 3.5 (Froese et al., 2011).

There are a number of factors that may result in a high variability in the weight at length for any given fish species, including sex (e.g., one sex may have a wider length range, ovarian weight is usually larger than the weight of the testes), maturity stage and gonad size, weight of stomach contents, liver weight, parasite load, as well as the overall condition of the fish. Seasonal sampling and gear selectivity may result in different length and weight ranges observed for some species between the surveys (Silva et al., 2013).

Growth type of picked dogfish was established negative allometric in the studies except for Düzgüneş et al. (2005) in the southern Black Sea coasts of Türkiye. Likewise, it is stated that the majority of shark species for the Bulgarian coast of the Black Sea are female (Radu & Maximov, 2012). Also, the growth type was reported positive allometric in the Black Sea coasts of Bulgaria by the Yankova et al. (2011). Tserkova et al. (2022), found that the "b" value for male and female individuals of the species varies seasonally. Additionally, it was determined that growth was negative allometric for autumn and positive allometric for spring. Previous studies providing LWRs for picked dogfish Türkiye seas and other localities are shown in Table 4 to compare.

There are no studies on the condition factor of the picked dogfish have been found in the Black Sea. For this reason, a comparison could not be made for the Black Sea. In our study, similar results were obtained with values of condition factor of picked dogfish found from study in Marmara Sea. The average, minimum and maximum values of condition factor were reported for Marmara Sea 0.74, 0.63 and 1.00, respectively (Karadurmuş, 2022).

Studies conducted in the northwestern region of the Black Sea show that males are dominant (Maximov et al., 2008, 2010; Radu, 2016; Tserkova et al., 2022). While female (68%) appears to be dominant in the southeastern Black Sea coasts, the ratio of female to male is 2.1:1 (Düzgüneş et al., 2005). Demirhan & Seyhan (2007) reported that females dominated the samples, with 86.3% females (n=141) and 13.7% males (n=24). Likewise, it was stated that the majority of picked dogfish for the Bulgarian coasts of the Black Sea was female (Radu & Maximov, 2012). Similarly, it was determined that females were dominant in our study (1:0.67).

While previously there were new species entering the Black Sea through ship ballast water, in recent years, due to climate change and global warming, new species have been introduced to the Black Sea from other seas. Many species that have completed their adaptation period are rapidly spreading throughout the Black Sea (Bat et al., 2007, 2011; Üstün & Birinci-Özdemir, 2019; Radulescu, 2023). When it becomes an invasive species, it can cause the biological and ecological balance in the sea to be disrupted and biodiversity to change.

Figure 5. New shark for southern Black Sea coasts (Angular roughshark, *Oxynotus centrina*)

Table 4. LWR parameters from previously study of various authors for picked dogfish

Sex	N	$L_{Min-Max}$	a	b	Location	Author(s)
F+M	-	25.2-142.7	0.0153	2.757	Black Sea-RU	Anonymous (1988)
F	-	-	0.0059	2.889	Atlantic Coasts	Coull et al. (1989)
M	-	-	0.0057	2.889		
F+M	327	22.3-141	0.0022	3.141	Black Sea-TR	Samsun et al. (1995)
F	16	27-70.5	0.0112	2.775	Aegean Sea-TR	Filiz & Mater (2002)
M	16	38-56.5	0.0023	3.282		
F+M	32	27-70.5	0.0031	3.106		
F+M	32	27.0-70.5	0.0031	3.110	Aegean Sea-TR	Filiz & Bilge (2004)
F+M	535	49.4-101.5	0.0021	3.163	Pacific Coasts	O'Driscoll & Bagley (2004)
F+M	421	19.1-117.3	0.0020	3.150	Adriatic Sea-HR	Pallaora et al. (2005)
F+M	267	36.5-141.5	0.0090	3.342	Black Sea-TR	Düzgüneş et al. (2005)
F	312	17.1-115.0	0.0027	3.128	Aegean Sea-TR	İşmen et al. (2009)
M	253	20.8-87.5	0.0072	2.867		
F+M	565	17.1-115	0.0037	3.047		
F+M	22	112-144	0.0010	3.153	Black Sea-BG	Yankova et al. (2011)
F+M	8	41-52	0.00003	2.619	Marmara Sea-TR	Bök et al. (2011)
F	108	24.5-115.5	0.0015	3.249	North Sea	Wilhelms, (2013)
M	127	25.5-97.5	0.0041	2.984		
F	346	17.1-117.5	0.0075	2.860	Aegean Sea-TR	Yığın & İşmen (2013)
M	274	20.8-121.6	0.0030	3.110		
F+M	345	20-116	0.0017	3.208	British Islands	Silva et al. (2013)
F+M	2	36.5-75.5	0.0034	3.000	Mediterranean-ES	Barría et al. (2015)
F	176	-	0.00009	3.210	Adriatic Sea-IT	Bargione et al. (2019)
M	150	-	0.00009	3.200		
F	40	45-68	0.0070	2.990	Aegean Sea-TR	Cabbar & Yığın (2021)*
M	8	41-48.1	0.0053	3.050		
F+M	48	41-68	0.0048	3.080		
F	19	67-154	0.3939	2.113	Black Sea-RO (Autumn)	Tserkova et al. (2022)
M	143	29-131	0.0082	2.867		
F+M	162	29-154	0.0122	2.791		
F	7	105-143	0.0017	3.203	Black Sea-RO (Spring)	
M	9	37-120	0.0031	3.079		
F+M	16	37-143	0.0028	3.097		
F+M	22	17.6-71.2	0.0073	2.892	Marmara Sea-TR	Karadurmuş (2022)
F+M	108	30.2-80	0.0068	2.870	Black Sea-TR	Dağtekin et al. (2022)
F	**316**	**27.2-111.8**	**0.0098**	**2.856**	**Black Sea-TR**	**This study (2023)**
M	**260**	**37.5-94.2**	**0.0103**	**2.828**		
F+M	**576**	**27.2-111.8**	**0.0097**	**2.852**		

Note: **Fork length, TR: Türkiye, RO: Romania, BG: Bulgaria, HR: Croatia, ES: Spain, IT: Italy, RU: Russia.*

Many species such as rapa whelk, angler fish, puffer fish, sand steenbras, *Mnemiopsis leidyi, Beroe ovata,* Pacific oyster, starfish, Korean rockfish, which entered the Black Sea (Daskalov & Rätz, 2011; Sümer et al., 2016; Bilecenoğlu & Öztürk, 2018; Aydın & Gül, 2021; Birinci-Özdemir, 2022; Aydemir-Çil et al., 2023; Bilecenoğlu et al., 2023) are negatively affect ecological life and commercial fishing activities. For examples; reproduction, nutrition, prey-predator relationship, protection, shelter, habitat competition, decrease in target fish stocks, increase in bycatch species, work, time and income loss, damage and breakdown of fishing equipment.

Angular roughshark has most recently been assessed for The IUCN Red List of Threatened Species in 2020. The species is listed as endangered under criteria A2d (Finucci et al., 2021). There are many studies on the angular roughshark in the Mediterranean, Aegean Sea and Marmara Sea.

It is noteworthy that the number of individuals in these studies was low. It has been determined that female individuals are more dominant than male individuals. There are length, weight and gender data for the species, obtained from the Marmara Sea in 1960 but unpublished (Kabasakal & Özbek, 2022). The maximum length for the species was determined as 80 cm in Adriatic Sea, while the smallest size was reported as 29 cm in Aegean Sea (Dragičević et al., 2009; İşmen et al., 2009).

It is stated that the Atlantic-origin angular roughshark was last seen in the Türkiye seas during a diving observation in the Marmara Sea. In the study where the swimming behavior of the species was monitored, the total length of the species was recorded as 60 cm and female, recorded with an underwater camera (Kabasakal, 2009).

Angular roughshark, which was first recorded for the Black Sea in this study, is one of them. The serious increase in the water temperature of the Black Sea due to climate change accelerates the entry of many new species into the Black Sea and also allows them to adapt easily. It is not known what the effect of the angular roughshark will be when it enters the food chain in the Black Sea and its numbers increase.

Conclusion

Consequently, it is very important to conduct more detailed study on the picked dogfish, which is an important part of the Black Sea ecosystem and is considered in the vulnerable species category. In order to ensure biodiversity balance and sustainable fishing with maximum yield, new species entering the Black Sea should be quickly identified investigated and examined.

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Compliance With Ethical Standards

Authors' Contributions

SÖ: Designed the study, participated in marine field studies, collected the data, examined the samples, size and weight measurement of sharks, wrote the first draft of the manuscript, data curation, software, visualization, performed and managed statistical analyses, writing-review and editing, writing-review and editing, checked final of manuscript.

UÖ: Participated in sea experiments, collected the data, size and weight measurement of sharks, writing-review and editing, checked final of manuscript.

HAD: Participated in sea experiments, collected the data, checked final of manuscript.

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 Statement

All data generated or analyzed during this study are included in this published article.

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RESEARCH ARTICLE

Intraspecific shape analysis of Bali sardinella (*Sardinella lemuru*) using geometric morphometrics collected in the coast of Cabadbaran, Agusan Del Norte, Philippines

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ABSTRACT

Modern techniques are often applied to analyze the body shape differences among biological organisms. Also, taxonomy and systematics are two essential fields of Biology concerning shape discrimination. This study aims to identify the shape variations of *Sardinella lemuru* (Bali sardinella) using Symmetry Asymmetry Geometric Data (SAGE) Software Application. A total of 70 fish samples consisting of 35 males and 35 females were collected in Barangay Caasinan, Cabadbaran, Agusan Del Norte, Philippines. Standard laboratory procedures were done and fish samples were subjected to the analysis. Procrustes ANOVA revealed a highly significant difference ($P<0.0001$) among the components analyzed (individuals, sides, and individuals vs. sides). This implied that each of the fish samples exhibited different body shapes. Principal Component Analysis (PCA) obtained a high rate of Interaction/Fluctuating Asymmetry (76.79%) in males when compared to female samples (74.08%). The shape dissimilarities within the populations were associated with genetic components, ecological adaptations-swimming, predator escape, and resource competition. Thus, the present study identified shape disparity within the fish populations. The development of employing modern techniques enhances scientific methods to quantify shape dissimilarities among species individuals and assemblages.

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Introduction

Over the decades, using modern methods is a way of elaborating realistic shape analyses. It draws significant information to generate specific data useful to create knowledge. While determining shape discrimination with the use of modern techniques often utilized by many researchers. Form and shape transformation has been an ultimate requirement to evaluate biological phenotypes. Since then up to the present, detecting shapes and copying metric observations has been a challenge to recognize how various biological forms vary. A modern and systematic approach proved the connection between form and function. Thus, measuring the distinct factors could be used for detecting species characteristics (Richtsmeier et al., 2002). Body shape is an important aspect of identifying variations within the fish assemblages. It has been associated with numerous dynamic activities, such as food hunting, swimming, and escaping predators (Schoener, 1971; Webb, 1984; Martinez-Leiva et al., 2023). Additionally, fish body shape has also been influenced by mating (Martinez-Leiva et al., 2023). The shape of the fish was found to have phenotypic plasticity: this information showed the ability of single genotypes to create different phenotypes when open to ecological conditions (Pigliucci et al., 2006; Fusco & Minelli, 2010; Klingenberg, 2019).

Fish are commonly used as a biomarker of environmental status. They are the best sample for detecting conditions since they inhabit where most alteration occurs. Biological changes can affect its physiological activities and later may express its morphology. Ecological risks and anthropogenic activities may pose unfavorable conditions both in the environment and the organisms (Natividad et al., 2015). Over the years, aquatic habitat has become a place with a wide range of alterations (Dikshith et al., 1990). Aquatic modifications can be a factor in changing the genetic makeup of an organism and result in diversity and variation in the population (Trono et al., 2015). It causes intolerable effects, damaging the environmental state and leading to phenotypic differences (Duruibe et al., 2007). Adaptations are a key component that can alter the morphological traits of the aquatic organism (Jumawan et al., 2016). These are contributing factors that directly affect its state of well-being. The effect of adaptation may be described as morphological asymmetries through imperfect development (Cabuga et al., 2022). Individual and fish groups had a chance to adapt where necessary for survival. Ecological characteristics shown by juveniles and adults could be influenced by environmental factors through their embryonic development up to epigenetic modifications (Best et al., 2018; Jonnson & Jonnson, 2018). Moreover, morphological, sensorial, and behavioral changes occur during the fish's ontogenetic development dependent on exogenous influences such as temperature and food supply. Nonetheless, physiological traits (e.g., type of respiration and muscle reorganization) impact the metabolism activities of each sample (Burggren & Blank, 2009; Somarakis & Nikolioudakis, 2010; Biro & Stamps, 2010). The development of vital organs and sensory mechanisms is the result of metabolism changes that are associated with optimizing survival (Osse, 1997; Khemis et al., 2013).

To recognize the shape variation in fishes, Geometric Morphometric Analysis (GMA) was applied to demonstrate the unlike characteristic traits. Indeed, this was an effective tool to evaluate the developmental variability of an individual species as it represents the total population (Bergstrom & Reimchen, 2002). It serves as a significant mechanism to assess environmental pollutants that alter the species (Tomkins & Kotiaho, 2001). It is also identified as an efficient instrument for quantifying environmental conditions (Lecera et al., 2015). And a potential quantitative approach to assessing if the environment can provide ecological growth toward species (Angtuaco & Leyesa, 2004). In addition, GM was a simple and reliable means of identifying developmental instability (Ducos & Tabugo, 2015). It is widely known to describe indiscriminate nonconformities based on morphological traits (Swaddle, 2003). This application is widely recognized as it can deliberately identify the effects of several changes through species morphology (Jumawan et al., 2016). Furthermore, it is one of the most recognized scientific mechanisms because it can represent quantitative functions and analyze morphological shapes (Polly, 2012). This study utilized *Sardinella lemuru* a marine fish species called *Tamban* in the study area. A previous study was conducted by Luceño et al. (2014) employing the same species. The current study, however, would provide current information regarding the latter; as a result, this acts as the study's significance in examining the metric qualities of the fish samples. Therefore, this study used Geometric Morphometric to determine the differences in the body shape of both the male and female populations of *S. lemuru*.

Material and Method

Study Area

The study area was Barangay Caasinan, Cabadbaran City, Agusan Del Norte, Philippines (Figure 1). The fish collection

was done in May 2023 with the aid of local fishermen utilizing motorized boats or bancas and gillnets as their catching gears.

Fish Collection, Processing and Sex Determination

Totally 70 adult fish samples consisting of 35 males and 35 females of the same size were randomly collected. The freshly caught samples were placed in an ice box and brought to the laboratory for further processing. Individually, the fish were sorted according to their size and positioned on the top of the Styrofoam. Each fish's fin was spread and pinned to make it wider and visible and applied with 10% formaldehyde using a small paintbrush. After this, the ruler was placed in the bottom portion of each sample to obtain the total length (Natividad et al., 2015). Lastly, the image of each sample was then captured using a digital camera. The sex of the samples was determined through internal examination by checking the genitalia. Females exhibited yellow to orange granular textures in the presence of ovaries. While, the testes of males, are smooth to white and have a non-granular texture (Requiron et al., 2012).

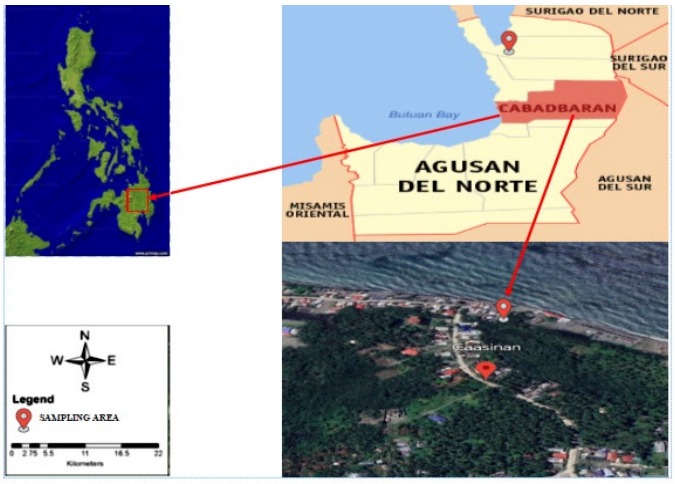

Figure 1. Map of the study area, Barangay Caasinan, Cabadbaran, Agusan Del Norte, Philippines

Landmark Selection and Digitation

The captured images were then categorized and sorted by sex. Then it was transferred and converted to a TPS file using the tpsUtil. The landmarking process of the samples was done through tpsDig2 (version 2, Rohlf, 2004). Sixteen (16) anatomical landmark points (Figure 2, Table 1) were utilized to digitize the samples of *S. lemuru*. To lessen the measurement error, the samples were tri-replicated. Its bilateral symmetry (left and right) was digitized using tpsDig2. The collected coordinates were then subjected to Symmetry and Asymmetry in Geometric Data (SAGE, version 1.04, Marquez, 2007) (Figure 3).

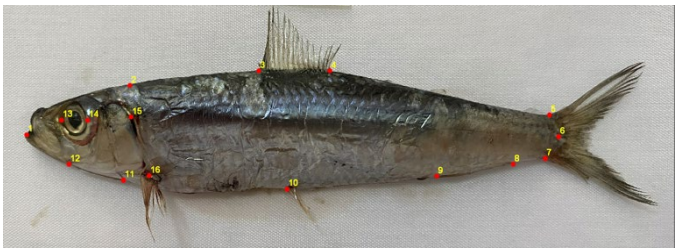

Figure 2. Digitized fish sample with sixteen anatomical landmarks

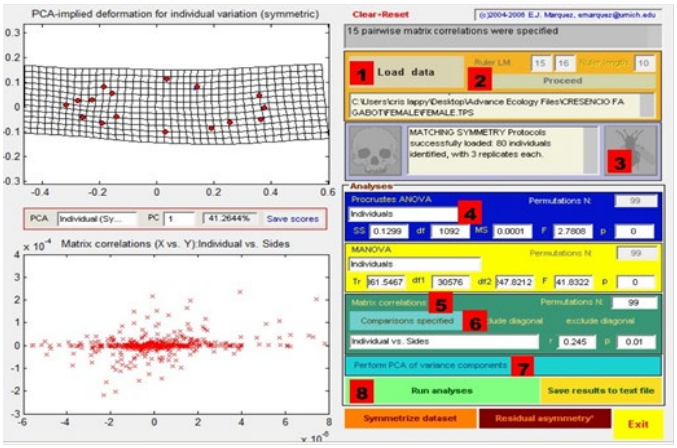

Figure 3. Symmetry and Asymmetry Geometric (SAGE) Data Software

Table 1. Description of the landmark points adapted from Paña et al. (2015)

Coordinates	Locations/Nomenclature
1	Snout tip
2	Posterior end of nuchal spine
3	Anterior insertion of dorsal fin
4	Posterior insertion of dorsal fin
5	Dorsal insertion of caudal fin
6	Midpoint or lateral line
7	Ventral insertion of caudal fin
8	Posterior insertion of anal fin
9	Anterior insertion of anal fin
10	Dorsal base of pelvic fin
11	Ventral end of lower jaw articulation
12	Posterior end of the premaxilla
13	Anterior margin through midline of orbit
14	Posterior margin through midline of orbit
15	Dorsal end of operculum
16	Dorsal base of pectoral fin

Shape Analysis and Data Generation

The Procrustes ANOVA test was applied to identify the significant difference in the symmetry of the three factors analyzed – individual, sides, and interaction of individuals and sides. The significant level was verified at $P<0.0001$. Along with this, the variances of its side and the estimation of directional asymmetry were also identified. The level of shape variations

was specified through percentages (%) which were analyzed and compared between male and female samples (Natividad et al., 2015).

Results and Discussion

Table 2 shows the Procrustes ANOVA on the body shape of *Sardinella lemuru* for both the female and male sexes. Three parameters (individuals, sides, and individuals by sides) were evaluated to identify shape defects in the fish population. The analysis was applied to both female and male samples. Individual samples' left and right sides were also compared and examined. It was observed that highly significant differences ($P<0.0001$) occur in the individual fish of both sexes, resulting in body shape differences when one of the fish samples is compared to another. Additionally, its sides displayed a quite a substantial variance, indicating varying asymmetries on the left and right samples. The detected dissimilarities could be an indication that the species samples were under environmental stress in the area while others were associated with endo-parasites. Under typical circumstances, symmetrical appearances in fish species were anticipated. However, the poor water quality of the disturbed environment affected the morphological characteristics of the fish species during their development (Lytle & Poff, 2004). Thus, deformities developed by absorbing the environmental perturbations that ultimately changed an organism's developmental hemostasis and gave rise to diverse phenotypic traits (Parsons, 1990). Further, considering the scenario it includes a wide array of factors such as changes in temperature and length of the growing season. However, the differences were also related to other environmental issues like resource availability, and water velocity (Craig & Foote, 2001; Kishida et al., 2010).

Table 2. Procrustes ANOVA test for samples of *S. lemuru* in terms of sexes

Factors	SS	DF	MS	F	P-value
Female					
Individuals	0.1485	952	0.0001	2.5945	0.0001**
Sides	0.0302	28	0.0011	18.7075	0.0001**
Individual x Sides	0.0549	952	0.0001	7.0073	0.0001**
Measurement Error	0.0161	1960	0	--	--
Male					
Individuals	0.1553	952	0.0002	2.5775	0.0001**
Sides	0.026	28	0.0009	14.6622	0.0001**
Individual x Sides	0.0603	952	0.0001	5.5827	0.0001**
Measurement Error	0.0222	1960	0	--	--

Note: *Side = directional asymmetry; individual x sides interaction = fluctuating asymmetry; * P<0.0001 significant, ns – statistically insignificant (P>0.05); significance was tested with 99 permutations.*

Table 3. Principal Component Analysis of *S. lemuru* in terms of sexes

PCA	Individual	Sides	Interaction (FA)	Affected Landmarks
			Female	
PC1	51.60%	100%	49.51%	1, 12, 14, 15, 16
PC2	11.54%		11.54%	1, 2, 3, 4, 5, 6, 7, 9, 10, 11, 13, 16
PC3	8.36%		7.58%	1, 2, 3, 4, 9, 10, 11, 12, 13, 14, 15, 16
PC4	6.50%		5.45%	8, 9, 10, 11, 13, 14
Total	78.00%		74.08%	
			Male	
PC1	53.06%	100%	45.72%	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 16
PC2	13.79%		14.38%	1, 3, 4, 5, 6, 8, 9, 10, 16
PC3	7.84%		10.85%	1, 4, 7, 8, 9, 10, 12, 15
PC4	5.06%		5.84%	1, 4, 9, 11
Total	79.75%		76.79%	

Note: Individual = individual samples, Sides= Left & Right, Interaction= Fluctuating Asymmetry.

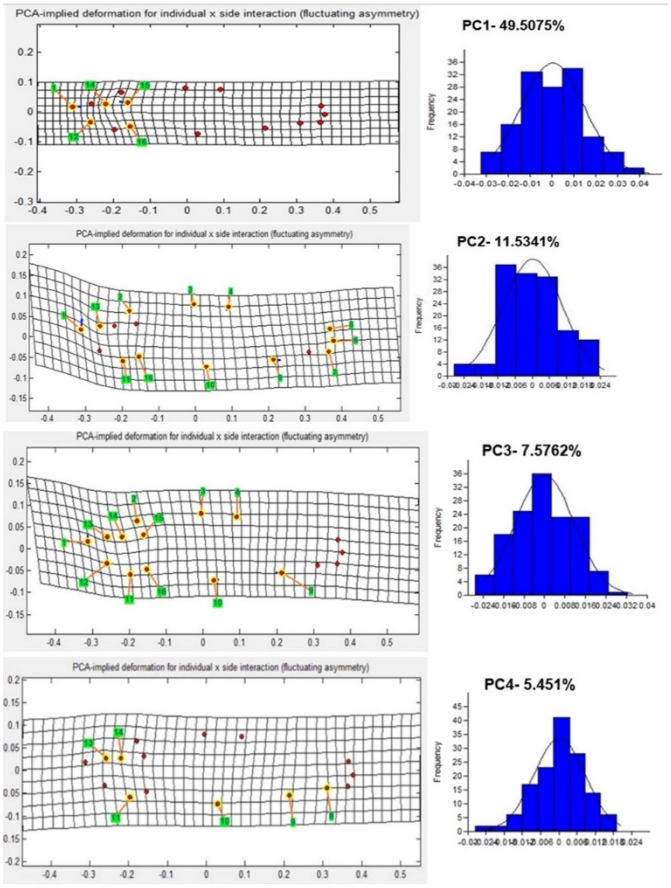

Figure 4. Principal Components (PC) implied deformation grid and a histogram of individual (symmetric) in *S. lemuru* female

Moreover, the observed differences in body shapes were associated with the influence of genetics and ecological factors i.e., feeding habits, prey and predator relationship, mobility, and the aging process (Cabuga et al., 2018). The study showed that female *S. lemuru* revealed a stout body outline compared to that of males which had a slender body shape. Evidently, female populations indicate larger abdomens which is linked to sexual maturation (Echem, 2016). Additionally, evidence in the body shape variations correlated with physiological traits such as growth, development, and reproductive stage (Parsons, 1987; Arendt & Wilson, 1999; Laugen et al., 2003; Salvanes et al., 2004; Conover et al., 2006; Kakioca, 2013). Previously, Thompson's work, which referred to the ideas of Galileo and Goethe on morphology and of Russell on functionalism, was the first to hypothesize that physical forces and transformations result in morphological space (Abzhanov, 2017). While the theory of morphology expresses that shape is a reflection of an organism to the ecology, evolution, and phylogenetic processes (Karr & James, 1975; Winemiller, 1991; Wainwright et al., 2002; Neige, 2003; Kerschbaumer & Sturmbauer, 2011; Price et al., 2011). Thus, measuring the distance and applying geometric morphological analysis (GMA) is the common technique for computing the degree of variation in shape, and the latter is the most forceful for depicting different visual patterns (Bookstein, 1991; James Rohlf & Marcus, 1993). Generally, numerous studies inferred that a fish with a more streamlined body shape exhibited maximum metabolic rates than a deep-bodied one within intra and interspecific levels (Petterson & Brönmark, 1999; Killen et al., 2016; Sánchez-González & Nicieza, 2022). These conditions were associated with lengthy swimming ability but the existing gap during these stages are shape and metabolism which may contribute to morphological differences (Latorre et al., 2020).

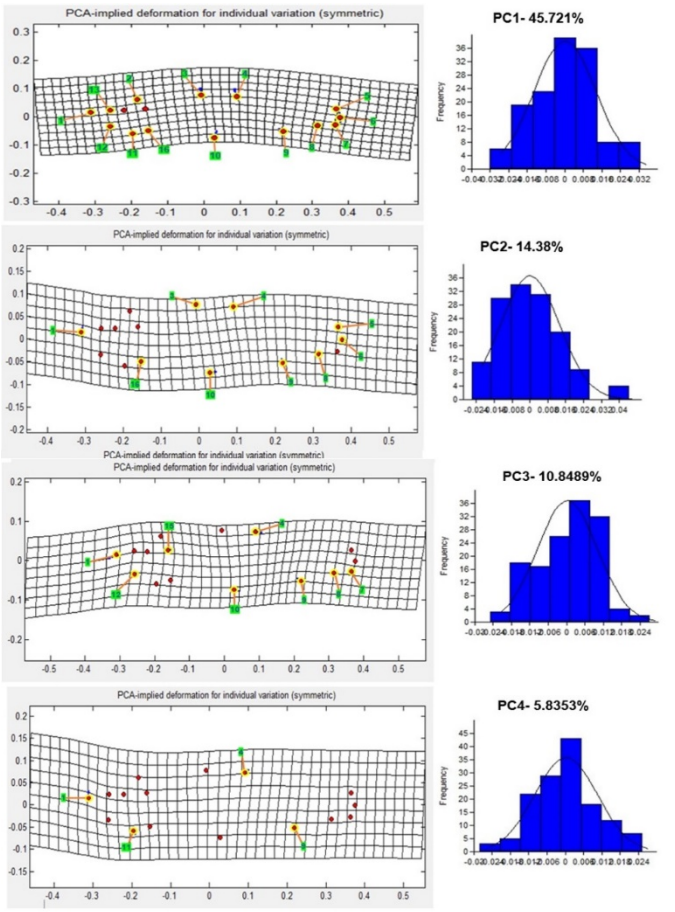

Figure 5. Principal components (PC) implied deformation grid and a histogram of individual (symmetric) in *S. lemuru* male

Using the symmetry and asymmetry scores, principal component analysis was applied to determine the Interaction (Fluctuating Asymmetry) and affected landmarks among the fish samples. Four principal components (PC) were considered in male and female samples (PC1-PC4). The four principal components (PC) accounted for 77.9544% of the total variation in female samples. PC1 accounted for 51.5961%, which has the highest variation. Unexpectedly, there were no commonly affected landmarks in female samples for the four principal component scores (Table 3). Subsequently, in male samples, the

four PCs also constituted 79.7482% of the cumulative variations. PC1 contributed the highest accounted variation with 53.055%. The commonly affected landmarks in male samples for the four PC scores were landmarks 1, 4, and 9 (Table 3). These were a portion of the snout tip, posterior insertion of the dorsal fin, and anterior insertion of the anal fin.

Male *S. lemuru* were observed to reveal higher affected landmarks with 79.7482% from the upper 5% of composite principal components from PC1 to PC4. PC1 reveals that all affected landmarks were found to have greater asymmetry. This means that male phenotypic variability tends to be high under conditions of environmental stress (Parsons, 1987; Holloway et al., 1990; Hoffmann & Parsons, 1991). On the other hand, female *Sardinella lemuru* reveals none affected landmark than to males from PC1 to PC4 with a total of 77.9544%. It was interesting to note that the affected landmarks were only observed in males than in female samples of *S. lemuru*. These affected landmarks were further shown in the deformation grid, and the histogram of the values revealed skewness, suggesting asymmetry in body form (Figures 4 & 5). This shows the anatomical landmark points affecting the male *S. lemuru*.

Moreover, it was also observed that male samples have the highest Interaction or Fluctuating Asymmetry (FA) at 76.79% compared to female samples at 74.08%. This suggests shape variances among the sexes. The higher the FA the more altered the body shape which was seen in the histogram provided in Figure 6. In general, those affected landmarks among the male and female fish samples could be attributed to their mobility and interaction within the environment. Further, energy utilization as a source for swimming could affect the physical traits of the species. While, reduced locomotion can be a reason for gaining higher speed (Dabrowski, 1986; Khemis et al., 2013; Nemova, 2016). Study shows that affected anatomical regions were significant for body movement during swimming and requires high protein content and oxygen supply. Nonetheless, this constituted the development of the axial musculature and was connected to the increased swimming activity due to avoiding predation. Nevertheless, given the limits of geometric morphometric analysis, all indication implies that distinct growth in body shape elongation may be more noteworthy than the ontogenetic period (Martinez-Leiva et al., 2023). During this transition, the body shape of fish modifies to develop deeper and laterally compressed, which is more suitable for speedy swimming (Koumoundouros et al., 2009; Kourkouta et al., 2021; Downie et al., 2021). Thus, the importance of identifying shape dissimilarities within the fish species could be visualized through patterns. Finally, with the aid of Geometric Morphometrics, it is now possible to get precise information on how two unique species within populations differ from one another in terms of physical features.

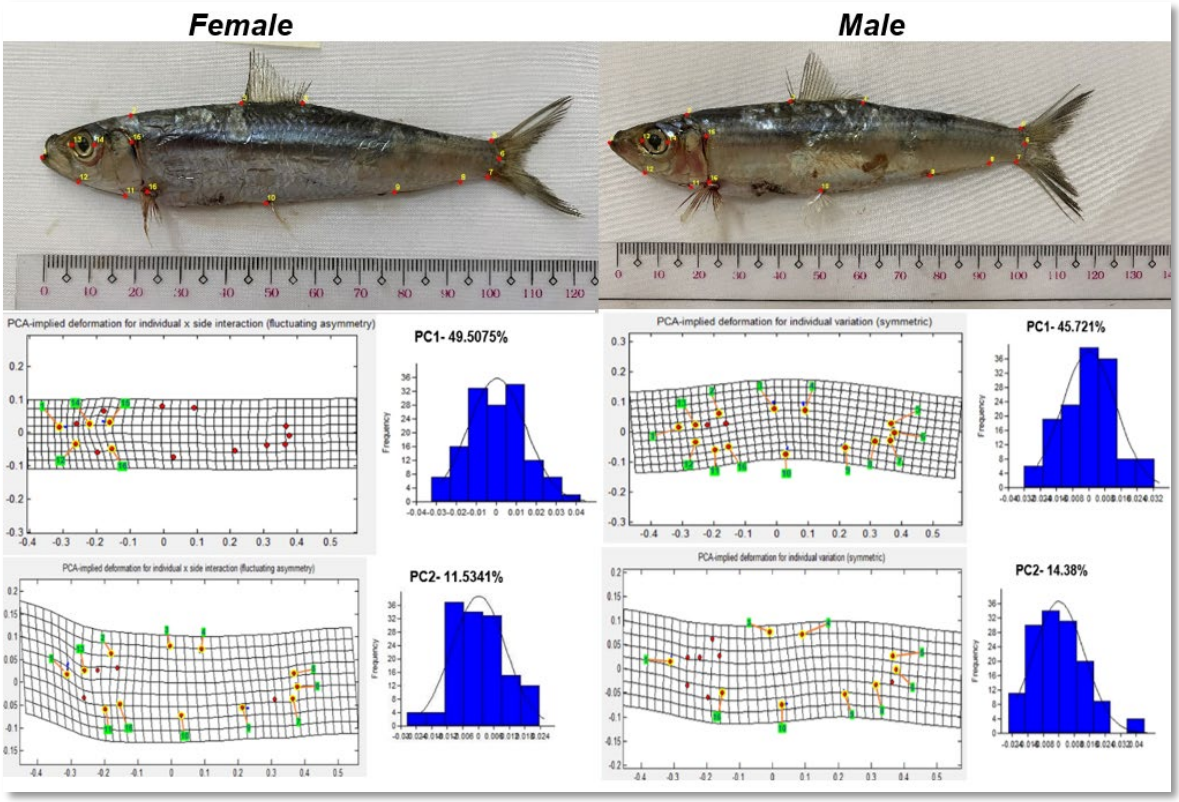

Figure 6. Actualized picture of digitized male and female fish with the affected landmarks shown in the PCA-deformation grid for PC1 and PC2

Conclusion

The present study has identified the intraspecific shape differentiation between the female and male *S. lemuru*. Procrustes ANOVA revealed a highly significant difference ($P<0.0001$), indicating morphological differences between sexes. While Principal Component Analysis shows that males exhibited a 76.69% rate of interaction (Fluctuating Asymmetry), which is higher compared to female with 74.07%. Further, several different anatomical landmarks points were affected among the fish samples. This suggests a disparity in the body shape that occurs among species of the same population. The implication suggests that phenotypic plasticity could play a significant role in the longevity of fishery resources. Evidently, using Symmetry and Asymmetry Geometric (SAGE) Data software applications enables one to draw vital information to understand shape variances within the same fish type and even more to numerous fish assemblages.

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Compliance With Ethical Standards

Authors' Contributions

CC: Designed the study and wrote the first draft of the manuscript.

JMP, RP, AJC, and PE: Performed the sampling and laboratory procedures.

MKA: Performed the Data Analysis

OLO: Wrote the Data Interpretation

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 Statement

All generated data and analysis are included in this published article. The generated data during the analysis are stipulated in the current study and available from the corresponding author on reasonable request.

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SHORT COMMUNICATION

Record of the largest *Symphodus tinca* (Linnaeus, 1758) in the Black Sea coasts

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ABSTRACT

This study records a remarkable finding in the Black Sea, where *Symphodus tinca*, a rare wrasse species. On June 9, 2023, during a biodiversity survey near Fener Island (Fatsa, Ordu, Türkiye), a male *S. tinca* was captured at a depth of 12 meters, measuring 316.0 mm in length and weighing 430.43 g. This specimen represents the largest ever recorded in the Black Sea. The factors behind this extraordinary finding, likely a result of species-specific and site-specific conditions such as low competition, favorable environmental factors, suitable habitats, and low fishing pressure, are complex and multifaceted. This finding not only contributes crucial data to the understanding of *S. tinca* growth patterns but also holds significance for its conservation, ecosystem management, and scientific research.

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Introduction

The Labridae family, is known for its extensive representation in the Atlanto-Mediterranean ichthyofauna, inhabits diverse marine environments across the globe, encompassing both tropical and temperate waters (Helfman et al., 2009). The Labridae family, represented by 21 species in Turkish territorial waters, and from them only eight ones spread on the Black Sea coasts (Bilecenoğlu et al., 2014; Karataş et al., 2021). *Symphodus tinca* (Linnaeus, 1758), commonly known as the East Atlantic peacock wrasse, exhibits a wide distribution in both the eastern and western Mediterranean regions, as well as the Black Sea. Its ecological preferences are extensive, encompassing rocky reef ecosystems covered with algal communities and colonized seagrass meadows. Individuals display adaptability to a depth range spanning from shallow waters to considerably 50 m depths (Pollard, 2010). It lives a solitary or in small groups disposition and feeds on a broad dietary spectrum comprising crabs, shrimps, bivalves, sea-urchins, and ophiuroids (Ouannes-Ghorbel & Bouain, 2006). Adults adopt a benthic lifestyle, concentrating their reproductive activities within well-defined inshore spawning

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grounds. This species displays pronounced sexual dimorphism during the reproductive phase (Golani et al., 2006).

There are various studies on the biological and morphological aspects of *S. tinca* along the Turkish coast (Karakulak et al., 2006; İlhan et al., 2008; Cengiz, 2021). In contrast to its relatively well-documented presence in the Mediterranean and Adriatic regions (Jardas, 1996), *S. tinca* is the least common wrasse species in the Black Sea. This paucity of presence has engendered substantial lacunae in scientific knowledge, with previous research efforts in the Black Sea being notably sparse (Kasapoğlu et al., 2016; Onay, 2021). This study presents the record of the largest individual case of *S. tinca*, a rare wrasse species within the Black Sea. This substantial finding not only augments our comprehension of *S. tinca* but also underscores the exigency of further research endeavors to unravel the intricacies of the distinct marine ecosystem in the Black Sea.

Material and Method

The sample was collected during a biodiversity survey on June 9, 2023. The survey took place in the shallows of the southern part of Fener Island (41°03'32" N – 37°30'33" E), situated off the coast of Fatsa district in the Black Sea. Specimen was captured at a depth of 12 m using a commercial trammel net with a 44 mm mesh size. Species identification was carried out using (Quignard & Pras, 1986) taxonomic key specific to the Labridae. Additionally, the scientific name of the species was verified according to FishBase (Froese & Pauly, 2023). The total length (TL) of specimen was measured from the most forward point of the head, with the mouth closed to the farthest tip of the tail using a plexiglass ichthyometer with mm-level accuracy. Body weight (TW) was weighed individually using a digital scale with an accuracy of 0.01 g. To provide a detailed morphological description of the collected specimen, a set of 13 morphometrics were measured, detailed in Figure 1 according to Kasapoğlu et al. (2016). Morphological characters were taken with a Vernier caliper with a precision of 0.05 mm. Sex determination was made by considering the external morphology and coloration of the gonads (Sadovy de Mitcheson et al., 2010).

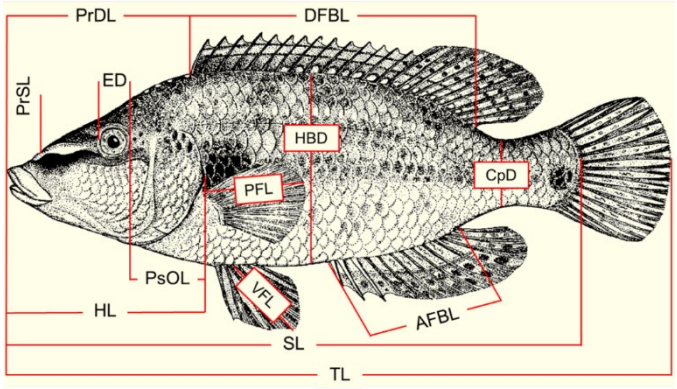

Figure 1. Morphological measurements: Total length (TL), standard length (SL), eye diameter (ED), head length (HL), caudal peduncle depth (CpD), highest body depth (HBD), dorsal fin base length (DFBL), ventral fin length (VFL), pectoral fin length (PFL), anal fin base length (AFBL), pre-snout length (PrSL), pre-dorsal length (PrDL), post-orbital length (PsOL). (The drawing was taken from Fischer et al. (1987) catalog book)

Results

A male *S. tinca* individual with a total length of 316.0 mm and a body weight of 430.43 g was obtained during the field studies (Figure 2). Detailed morphometric measurements specific to sample are presented in Table 1. These measurements provide a comprehensive overview of the physical characteristics of the collected specimen, facilitating a deeper understanding of their morphology and size. The external appearance of the specimen displayed distinct sex-related, the male sample exhibited a vibrant green-yellowish body coloration, complemented by sharp bluish spotting on the fins.

Figure 2. The male specimen of *Symphodus tinca* with 316.0 mm total length, captured from the Black Sea coast on June 9, 2023

Table 1. Morphometric measurements of male *Symphodus tinca*

Characters	Measures (mm)
TL	316.00
SL	253.00
ED	12.05
HL	88.15
Cpd	36.70
HBD	93.30
DFBL	128.00
VFL	151.90
PFL	50.15
AFBL	66.40
PrSL	36.00
PrDL	90.25
PsOL	33.75
Body weight (g)	430.43

Discussion

The largest individual of *S. tinca* ever known (TL=425.0 mm) was recorded in the Adriatic Sea (Pallaoro & Jardas, 2003). In Turkish territorial waters, the largest individuals, one female (TL=280.0 mm) and one male (TL=260.5 mm), were reported from the western coast of the Black Sea by Kasapoğlu et al. (2016). In this study, we report a male *S. tinca* individual, the largest known so far for the Black Sea. Considering the length-weight relationship based on preliminary parameter estimates by the previous scores given in Froese & Pauly (2023) (n=16, a=0.0148, b=2.97), the expected weights (421.05 g), a value close to our observed values (430.43 g), indicates that this specimen has grown almost following the previous estimated relationship.

The factors contributing to the discovery of such a large-sized individual in the study area, which are species- and site-specific, are multifaceted and complex. It's likely that suitable habitats and favorable environmental conditions play a significant role in the growth of individuals. Abundant nutrient concentration, suitable water temperature, oxygen levels, and other environmental factors can promote the availability of food resources and create an ideal environment for growth (Pauly, 1980; Gertseva et al., 2017; Volkoff & Rønnestad, 2020). The rarity of known predators of *S. tinca* in the region and reduced competition for resources in certain niches or habitats are plausible factors contributing to larger sizes. Lower predation and competition can allow individuals to allocate more energy and resources towards growth and survival (Hall & Kingsford, 2016). Wrasses are not targeted as target catches in commercial fisheries. By being caught as bycatch and then discarded, it might have a higher chance of survival compared to species subject to intense fishing pressure. Large individuals of *S. tinca* are an attractive target in spearfishing and should be considered a negligible threat. The presence of shelf area dominated by steep rocky cliffs (Tezcan et al., 2016) and extensive artificial structures (road construction, land acquisition, and airport construction) on the Turkish coast of the Black Sea (Aydın, 2018) could offer protection for individuals, allowing them to survive and grow larger. The stable population and the "Least Concern" status of *S. tinca* in the International Union for Conservation of Nature Red List (Pollard, 2010) suggest that the species is not currently facing major threats. This status and our predictions align with established ecological principles, and they collectively contribute to a better understanding of why this individual *S. tinca* reached such a large size in the study area. Further research and sampling efforts will be essential to confirm all these hypotheses and provide more detailed insights into the growth patterns and ecological requirements of species.

This study contributes valuable data that can be directly incorporated into these models by providing a maximum size record for *S. tinca* in the Turkish coast of the Black Sea. Maximum size records are critical parameters in stock assessment models used in fisheries science (Shephard et al., 2020). Such records serve far-reaching implications, not only for understanding the growth patterns of *S. tinca* but also for its conservation, ecosystem management, and scientific contributions. This record can be cited and referenced by other researchers in future studies, further advancing the understanding of this species. One last note: The Black Sea, once marred by environmental degradation and overfishing, has witnessed a notable increase in maximum size records of various marine species in recent years (Aydın, 2018, 2021; Özdemir et al., 2019; Aydın & Karadurmuş, 2021; Karadurmuş et al., 2021). Although this phenomenon is intriguing, it may be indicative of a broader positive trend in the Black Sea marine ecosystems. It is recommended to make further studies that reveal potential factors —such as environmental conditions, species-specific adaptations, ecosystem rehabilitation, governance and conservation initiatives, and scientific advancements—and their consequences, which have a possible impact on the increase of such records in the Turkish coasts of the Black Sea.

Compliance With Ethical Standards

Authors' Contributions

MA: Conceptualization, Methodology, Investigation, Formal analysis, Writing - Review & Editing.

UK: Conceptualization, Investigation, Writing - Original Draft, Writing - Review & Editing, Visualization.

All author contributions are equal for the preparation research in the manuscript.

Conflict of Interest

The authors declare that there is no conflict of interest.

Ethical Approval

All applicable international, national, and institutional guidelines for the care and use of animals were followed. For this type of study, formal consent is not required.

Data Availability Statement

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

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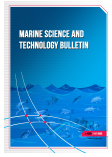

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RESEARCH ARTICLE

Investigation of the use of multi-criteria decision-making techniques in maritime studies with PRISMA method

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ABSTRACT

Multi-criteria decision-making (MCDM) techniques make it possible to reach the optimal solution among different criteria and priorities with their dynamic processes. The ability to analyse big data, use integrated techniques, respond to complex problems in terms of quantitative and qualitative criteria, and structure the result as a repeatable process for different decision makers makes these techniques an increasingly attractive source of reference. MCDM techniques are used in many different fields of science today. One of them is maritime studies. In the current maritime curriculum, the fact that decision-making is among the minimum requirements at both operational and management levels in deck and engine departments draws attention to the importance of the subject in maritime terms. At this point, investigating the use of multi-criteria decision-making techniques in the maritime field on a global scale will contribute to the literature. In this study, the use of MCDM techniques in maritime has been investigated with the PRISMA method. The findings contribute to the scientific literature by revealing the use of multi-criteria decision-making techniques in maritime, their change over time and their main fields of study. With the results obtained, it is aimed to reveal the profile of a methodological concept used globally in maritime studies and to serve as a reference for future studies. Given the evolving landscape of maritime publications utilizing the MCDM technique, the study results will be an incentive to explore potential avenues for future methodological advances.

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Introduction

Decision-making is first and foremost the result of a selection process. This process consists of awareness of the problem, defining the problem, developing solutions, and determining the best alternative. When the best alternative is put into practice, the decision-making process is theoretically completed and the decision is practically realized. In the scientific literature, new methods and approaches to the decision-making process are gaining importance day by day. MCDM techniques, which aim to reach the optimal solution among different criteria and priorities, find application in many different disciplines today.

MCDM addresses the research question in two stages. The first one is the selection of alternatives suitable for the decision makers' objectives and the second one is the ranking of these alternatives (Altın, 2020). At this point, the concepts of multi-objective decision-making and multi-attribute decision making come into play. While multi-objective decision-making searches for the best alternative among different conflicting objectives, multi-attribute decision-making approaches the ideal solution by assigning numerical values to the specific characteristics of the problem (Phua & Minowa, 2005; Dalbudak & Rençber, 2022). The research questions subject to MCDM are essentially based on choosing between certain alternatives by considering criteria appropriate to the dynamics of the problem. In other words, a syllogistic mechanism is inherent in decision-making. However, the alternatives that are subject to syllogism are not always sharply delineated and may be subject to some uncertainty. Decision-making science commonly uses fuzzy logic to deal with uncertainty. Fuzzy logic can be defined as a generalized version of classical two-valued logic based on [0-1] (Baykal & Beyan, 2004). According to another definition, it constitutes the intersection set of multi-valued logic system that assumes that propositions can take more than 2 values with reasoning in case of uncertainty (Özkan, 2003). The concepts of fuzzy logic, fuzzy set and fuzzy system were first introduced by L. A. Zadeh in 1965 (Zadeh, 1965; Yavuz & Deveci, 2014; Uludağ & Doğan, 2016). This theory, which was not accepted much at first, started to gain importance in the literature with the modelling of a steam engine control with a fuzzy logic system in 1975 in England (Şen, 2009; Yıldırım et al., 2016).

MCDM problems can use different methods simultaneously to reach the ideal outcome regardless of the uncertainty (Öztel, 2021). The critical distinction here is the decision maker's process of determining the most appropriate technique or techniques for the nature of the problem. Problems subject to MCDM are essentially categorized according to selection, classification and ranking. While selection problems are based on the selection of the ideal alternative among different options, classification techniques focus on the grouping of alternatives and ranking techniques focus on the priorities among alternatives (Dalbudak & Rençber, 2022). In the literature review, 26 multi-criteria decision-making techniques mainly used in the maritime literature were obtained. These are AHP (Analytic Hierarchy Process), AHP & QFD (Quality function deployment) & DEMATEL (Decision-making Trial and Evaluation Laboratory), AHP & TOPSIS (Technique for Order Preference by Similarity to Ideal Solutions), ANP (Analytic Network Process), BWM (Best Worst Method), CODAS (COmbinative Distance-based ASsessment), DECISION TREE, DELPHI, DEMATEL, FDM & PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluation), Fuzzy AHP, Fuzzy AHP & PRAT Proportional Risk Assessment Technique, Fuzzy AHP & TOPSIS, Fuzzy AHP & VIKOR, Fuzzy ANP, Fuzzy BWM, Fuzzy, DEMATEL, Fuzzy FMEA (Failure Mode and Effect Analysis), Fuzzy TOPSIS, PRAT, PROMETHEE, QFD, SMMA (Stochastic Multicriteria Acceptability Analysis) & TOPSIS, VIKOR (VIseKriterijumsa Optimizacija I Kompromisno Resenje), WASPAS (Weighted Aggregated Sum Product Assessment). Within the scope of the study, these techniques were examined according to their frequency of use and the most commonly used ones are examined below.

AHP divides the problem subject to MCDM into sub-problems by making pairwise comparisons and ranks them hierarchically. Thus, the ranking obtained makes it possible to solve the best alternative (Haliloğlu & Odabaş, 2018).

ANP can be defined as a generalized version of AHP. ANP refers to a more complex process for finding the weights of interacting components of problems that cannot be defined by a hierarchical structure (Üstün et al., 2005; Ömürbek et al., 2013). While AHP is based on a one-way hierarchy, ANP makes it possible to include more complex relationships in the decision-making process. Thus, it becomes possible to model complex problems that cannot be modelled with hierarchical structures due to decision levels and characteristics at the AHP level (Dağdeviren et al., 2006; Dalbudak & Rençber, 2022).

TOPSIS is a MCDM technique developed by Hwang and Yoon in 1981, which represents a multi-objective decision-making problem with "m" number of alternatives and "n" number of criteria with m points in n-dimensional space. TOPSIS, which is based on the concept of a compromise

solution, is based on the shortest distance to the positive-ideal solution and the farthest distance to the negative-ideal solution for the selection of the solution alternative. This idea was introduced by Hwang & Yoon (1981) and later developed by Zeleny (1982), Yoon (1987), Hall (1989) and Hwang et al. (1993) (Yoon & Hwang, 1995; Ömürbek et al., 2013). Fuzzy TOPSIS technique is the application of fuzzy logic integrated into TOPSIS technique.

VIKOR is a MCDM technique developed by Opricovic in 1998 for solving complex problems. VIKOR is based on the selection of the most appropriate alternative by including multiple criteria in the decision-making process and performing a ranking process that will provide maximum group benefit (majority rule) and minimum individual regret among different alternatives (Opricovic & Tzeng, 2004; Yıldırım et al., 2016, Dalbudak & Rençber, 2022). In other words, VIKOR is a useful technique when more than one criterion must be included in the selection process for the final decision. The VIKOR method operates on the assumption that the criteria weights are known. However, multi-criteria decision problems, by their very nature, do not always provide the researcher with a complete data set, which makes it difficult to quantify the criteria. Uncertain situations in reality and the existence of conflicting criteria emphasize the fuzzy VIKOR concept. Fuzzy VIKOR, which emerged by applying fuzzy logic to the VIKOR method, fuzzifiers both criteria and criteria weights in the decision-making process (Opricovic, 2011; Yıldırım et al., 2016).

WASPAS is a widely used technique in the decision-making process of multi-criteria problems. Developed in 2012 by Zavadskas et al. (2012), the WASPAS technique is essentially a synthesis of the Weighted Sum Model (WSM) and Weighted Product Model (WPM) methods (Adalı & Işık, 2017; Çakır et al., 2018; Dalbudak & Rençber, 2022).

PROMETHEE, developed by Brans in 1982, is essentially based on a ranking system and is a useful technique when it comes to ranking for solving multi-criteria decision-making problems. The technique is divided into partial ranking (PROMETHEE I) and full ranking (PROMETHEE II) (Brans et al., 1986; Ekin & Okutan, 2021). PROMETHEE enables the pairwise comparison of available alternatives according to 6 types of preference functions by means of specified criteria (Brans & Vincke, 1985; Ekin & Okutan, 2021).

DEMATEL, which stands for Decision-Making Trial and Evaluation Laboratory, focuses on the analysis of factors affecting the decision-making process and the relationship between these factors (Nilashi et al., 2015; Akın, 2017). Developed between 1972 and 1976 in Geneva, DEMATEL is based on graph theory to enable the analysis and hierarchical explanation of nested complex problem groups (Li & Tzeng, 2009; Aksakal & Dağdeviren, 2010). With the advantage of visualization, DEMATEL facilitates the solution of the problem by dividing the factors affecting the process into cause-and-effect groups (Li & Tzeng, 2009; Aksakal & Dağdeviren, 2010; Tzeng & Huang, 2011; Akın, 2017).

The concept of MCDM with its dynamic techniques and analysis methods is becoming increasingly important in many different fields of science. One of these is maritime studies. According to current maritime curriculum, learning and applying decision-making techniques are among the minimum requirements for both operational and management levels of deck and engine departments (Anonymous, 2018). At this point, it is a critical need for the literature to investigate the applications of MCDM techniques in the maritime studies on a global scale. In order to meet this need, this study seeks to answer the following research questions and aims to contribute to the literature with the results obtained.

- What are the main MCDM techniques used in maritime studies?
- What are the main areas of use of MCDM techniques in maritime studies?
- What is the time-dependent change of the studies carried out with MCDM techniques in maritime?
- What is the share of research articles using MCDM techniques in the maritime field in total studies?
- What is the distribution of research articles using MCDM in maritime studies according to journals and years?

This study aims to investigate the use of MCDM techniques in the maritime studies. For this purpose, a literature review covering the last 15 years was conducted through Scopus and Science Direct databases, focusing only on peer-reviewed research articles. Accordingly, both databases were first filtered with the keywords “multi-criteria decision making” and “maritime transportation” and review articles, book/book chapters, editorials, short communications and conference abstracts were extracted from the dataset. Within the scope of the study, only articles written in English were evaluated. The lower temporal limit was set as 2009, since this is the date of publication of the oldest article accessed with the relevant keywords. The literature review was conducted as of August 9, 2023 and the PRISMA method was used as the methodology. As a result of the first stage, 159 articles were found that used

MCDM techniques in maritime studies. The main distribution of the obtained studies according to their subjects was obtained as Engineering, Environmental Science, Social Sciences, Decision Sciences, Energy, Business, Management & Accounting, Mathematics, Computer Science, Earth and Planetary Sciences and Materials Science. Within these fields, maritime studies are focused on Maritime Economy, Maritime Education, Maritime Management, Maritime Policy, Maritime Safety, Maritime Transportation, Port Sustainability, Ship Energy Efficiency, Shipbuilding, Maritime Tourism. The results revealed the profile of the research articles that utilize the MCDM techniques of the maritime literature. Accordingly, using MCDM techniques have generally shown a steady upward trend, although they have shown small fluctuations in some years. Furthermore, the study profiles the most frequently used decision-making techniques using in maritime literature 15 years of literature and categorizes them according to topics. Obtained results showed that the main decision-making techniques used in the maritime studies are AHP, Fuzzy AHP, TOPSIS, Fuzzy TOPSIS, DEMATEL, ANP and VIKOR.

MCDM techniques are used in many different disciplines of science today. The main advantages of MCDM are that it makes big data analysis possible, techniques can be used in an integrated manner, complex problems can be answered in terms of quantitative and qualitative criteria, and the result is structured as a repeatable process for different decision makers. Accordingly, the use of MCDM in the academic literature is gaining more importance day by day and the number of studies conducted with MCDM is increasing in parallel. This study is the first to address the use of MCDM, which is gaining momentum on a global scale, in the maritime field from a holistic perspective. The obtained results aim contribute to the scientific literature by revealing the use of multi-criteria decision-making techniques in maritime, their time dependent change and their main fields of study.

Material and Method

In this study, the dataset obtained by filtering the studies using MCDM as a method in the maritime studies between 2009 and 2023 using Scopus and Science Direct databases. The mentioned databases were selected because they contain over 19 million peer-reviewed and accessible full-text articles in their portal and were considered to constitute a highly representative sample group on the subject. This data obtained through systematic literature search was then analysed using the PRISMA (Preferred Reporting Items for Systematic Review and Meta-Analysis Protocols) method.

PRISMA method, especially used in evidence-based medicine and health sciences, is one of the most common methods used to standardize meta-analysis reports. The PRISMA method, which proceeds with a dynamic checklist, provides an ideal roadmap for setting study boundaries, making it easier to focus on the research question. Because of these advantages, the method is used today in many different fields of science. In the Science Direct database, the mainly scientific disciplines using PRISMA systematic review are medicine and dentistry, neuroscience, psychology, nursing and health professions, biochemistry, genetics and molecular biology, agriculture and biological sciences, environmental sciences, social sciences, computer science, pharmacology, toxicology and pharmaceutical sciences.

In the PRISMA method, the data set that will form the basis for the screening emerges by selecting the inclusion criteria and removing duplicate publications that do not meet the criteria from the data set. The keywords, the year of the search and the date of the search constitute the most critical stages of the method. The fact that PRISMA can be replicated/tested by different researchers for further studies makes it attractive for use as a scientific method in different disciplines. Aşık & Özen (2019) defined the PRISMA process with the stages of detection, screening, eligibility and inclusion. The identification phase includes the characteristics of the databases, keywords and selected studies. By isolating duplicate studies, the number of studies subject to screening, i.e., the new "n" value, is obtained. These studies expressed with the new "n" value and the studies included/excluded in the research after screening are explained by stating their justifications. In this way, the studies included in the research are clearly revealed. In this study, the PRISMA method is adapted to maritime studies for the first time in the literature to the authors' knowledge, focusing on the use of MCDM techniques in maritime studies. Thus, it is aimed both to create an infrastructure for new studies in maritime studies and to make a methodological contribution to the maritime literature by using a new technique. The implementation of the PRISMA method to the study is given in Figure 1.

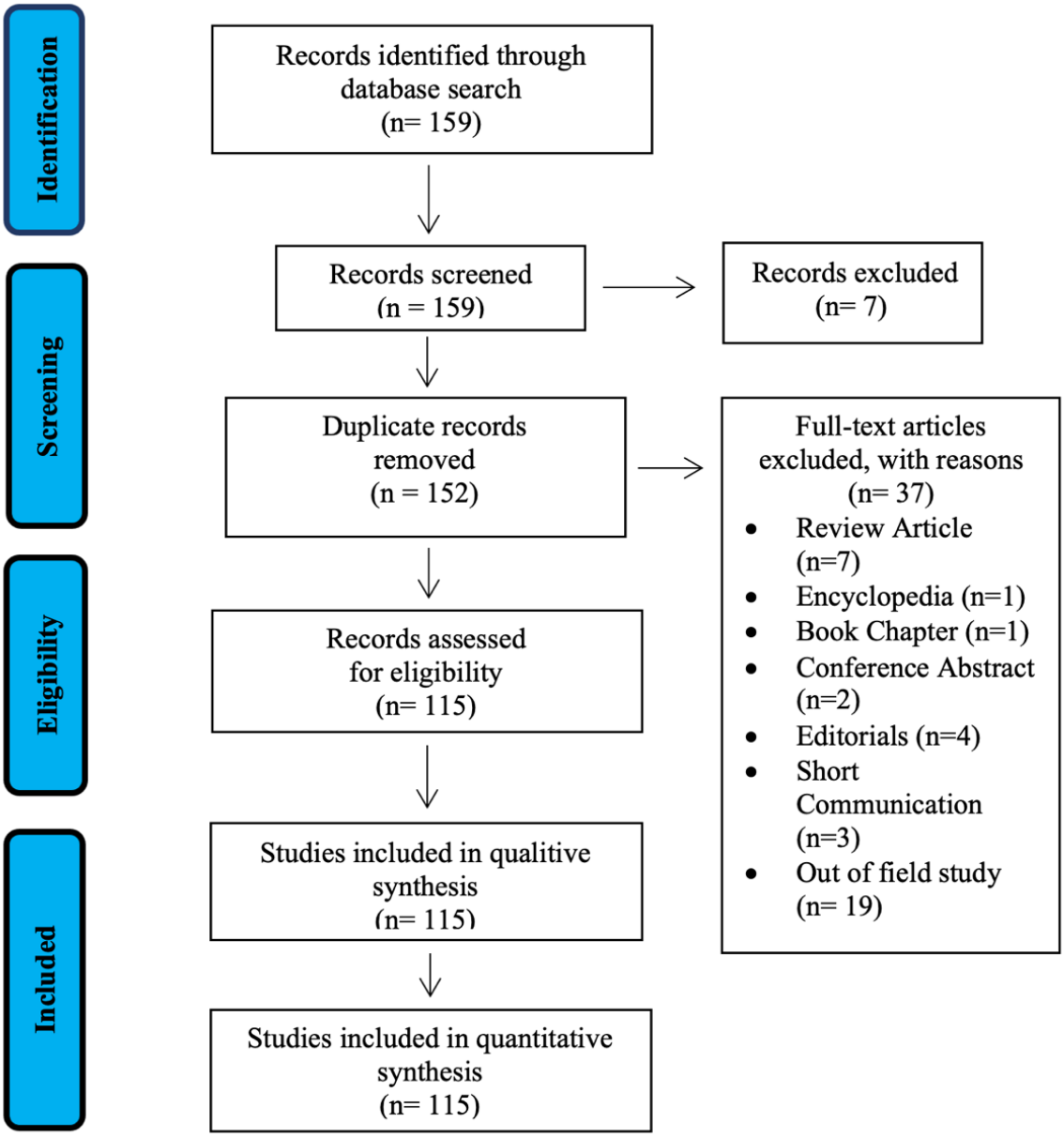

Figure 1. Implementation of the PRISMA method to the study

This investigation focuses only on English-language research articles that have been peer-reviewed and whose full text is available. The search was conducted on August 9, 2023 through Science Direct and Scopus databases with the keywords "multi criteria decision making" and "maritime transportation" and 159 articles were found. 7 of these articles were eliminated from the data set due to duplication. When the remaining 152 articles were scanned, a total of 37 studies, including 7 review articles, 1 encyclopaedia, 1 book chapter, 2 abstracts, 4 editorials, 3 short communications and 19 out-of-field articles, were excluded from the research because they did not meet the eligibility criteria. Thus, 115 articles that met the necessary criteria for the study were included in the qualitative and quantitative study.

Results and Discussion

The obtained results made it possible to reach more than one judgment. The results of the study firstly reveal the main using areas of MCDM techniques in maritime. Accordingly, the main areas where MCDM techniques have been used in the last 15 years of literature are maritime transportation, maritime safety, ship energy efficiency and sustainability. These areas are followed by maritime management, maritime economics, maritime education, maritime policy and shipbuilding. The results obtained are given in Figure 2.

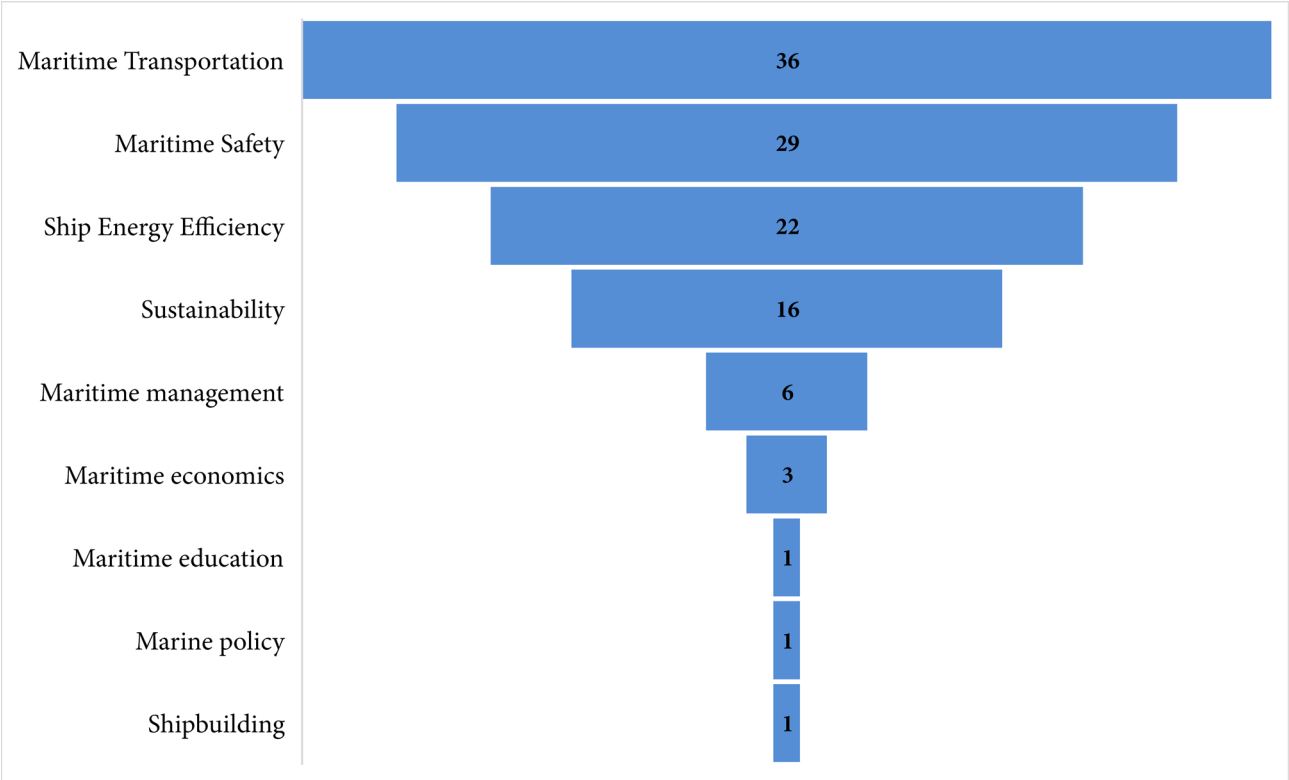

Figure 2. Application areas of MCDM techniques in maritime studies (2009-2023)

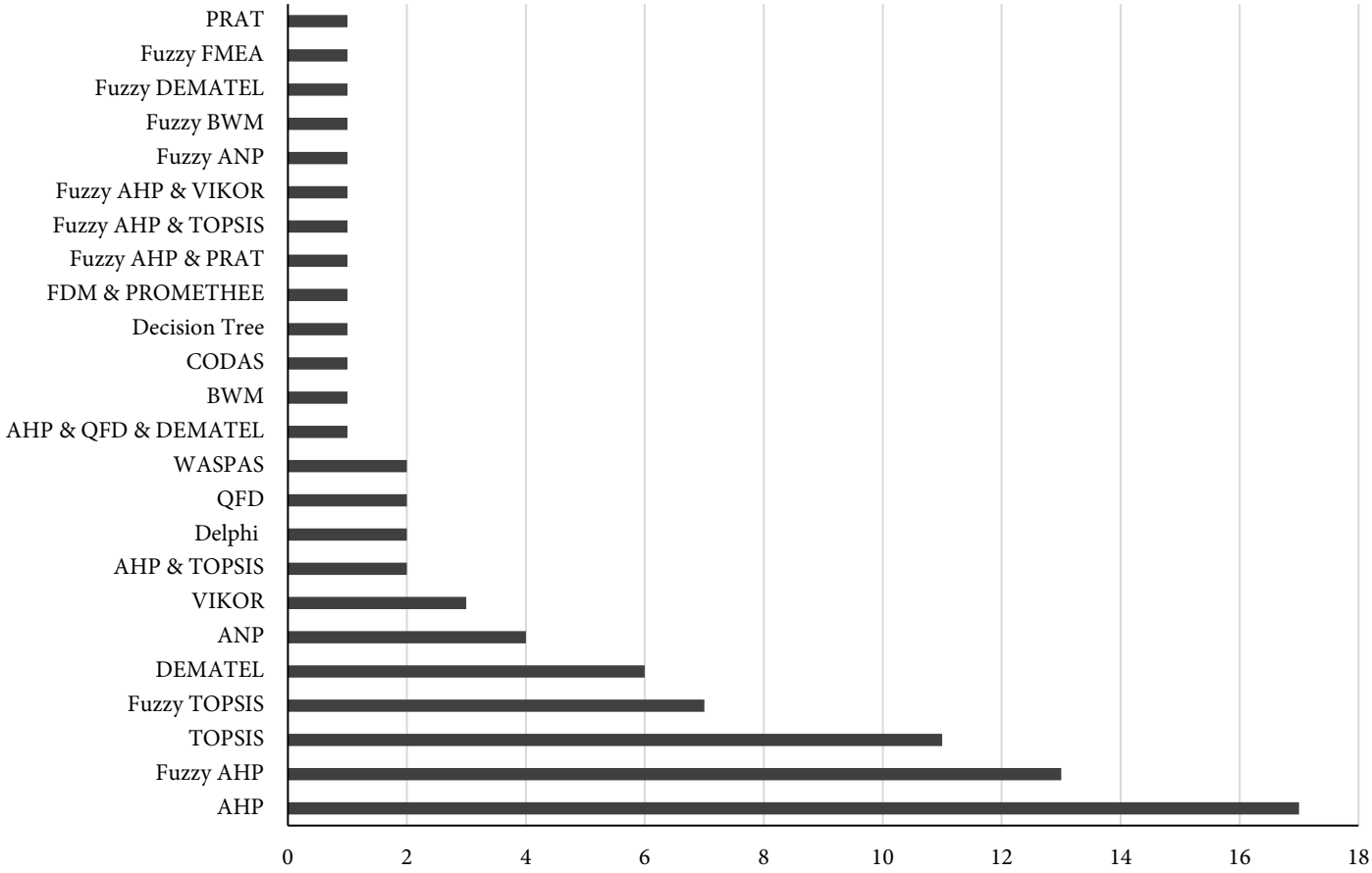

Figure 3. The frequency of use of MCDM techniques in maritime studies (2009-2023)

Table 1. Classification of studies with MCDM techniques according to keywords

Technique	Area
AHP	Maritime tourism, maritime transportation, sustainability, maritime safety, shipbuilding, shipyard, smart ports, ship energy efficiency
AHP & QFD & DEMATEL	Maritime Transportation
AHP & TOPSIS	Maritime Transportation
ANP	Maritime transportation, sustainability
BWM	Port sustainability
CODAS	Sustainability
DECISION TREE	Maritime safety
DELPHI	Sustainability
DEMATEL	Maritime safety, maritime transportation, sustainability, smart ports
FDM & PROMETHEE	-
Fuzzy AHP	Maritime education, maritime economics, maritime transportation, maritime management, ship energy efficiency, maritime safety
Fuzzy AHP & PRAT	Maritime Safety
Fuzzy AHP & TOPSIS	Ship energy efficiency
Fuzzy AHP & VIKOR	Maritime Transportation
Fuzzy ANP	-
Fuzzy BWM	Maritime Safety
Fuzzy DEMATEL	Maritime management
Fuzzy FMEA	Maritime safety
Fuzzy TOPSIS	Maritime transportation, maritime education, maritime safety
PRAT	-
PROMETHEE	Ship energy efficiency
QFD	Shipbuilding
SMMA & TOPSIS	Maritime transportation
TOPSIS	Maritime transportation, maritime safety, ship energy efficiency
VIKOR	Shipbuilding
WASPAS	Maritime economics, sustainability

The results also answered the question of which MCDM techniques are widely used in maritime. As a result of the literature review, 115 studies were analysed according to keywords and evaluated in terms of the technique used. Thus, the studies in the maritime with MCDM techniques were classified according to keywords. The findings are given in Table 1.

Table 1 shows that in the last 15 years, some techniques have been more widely used in maritime than others. These are AHP/Fuzzy AHP, ANP, BWM, CODAS, DECISION TREE, DELPHI, DEMATEL, Fuzzy FMEA, PRAT, PROMETHEE, QFD, SMMA, TOPSIS/Fuzzy TOPSIS, VIKOR and WASPAS. One of the main advantages of MCDM is that the techniques can be used integrated with each other according to the research question and data structure. The results obtained in this context show that the prominent techniques in terms of joint use are AHP & QFD & DEMATEL, AHP & TOPSIS, FDM & PROMETHEE, Fuzzy AHP & PRAT, Fuzzy AHP & TOPSIS, Fuzzy AHP & VIKOR and SMMA & TOPSIS.

Table 2. Share of maritime studies in total studies achieve

Years	All Studies	Research Articles	The share of research articles in total
2023	24	19	0.79
2022	31	26	0.84
2021	22	16	0.73
2020	16	13	0.81
2019	10	7	0.70
2018	12	7	0.58
2017	4	2	0.50
2016	10	7	0.70
2015	10	9	0.90
2014	2	2	1.00
2013	3	2	0.67
2012	4	2	0.50
2011	0	0	0.00
2010	1	0	0.00
2009	3	3	1.00

Obtaining the main MCDM techniques used in the maritime literature in the last 15 years has raised the question of their frequency of use. At this point, the number of times each technique was used independently of the keywords was investigated and the findings are presented in Figure 3.

Table 3. Distribution of studies examined by PRISMA method according to journals and years

Journal	Years														
	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Applied Mathematics and Computation												1			
Applied Ocean Research								1			1				
Applied Soft Computing											1				
Case Studies on Transport Policy														1	
Computers & Industrial Engineering														3	2
Computers & Operations Research							1								
Decision Analytics Journal															1
Electronic Commerce Research and Applications												1			
Energy											1				
Energy Conversion and Management: X													1		
Engineering Applications of Artificial Intelligence														1	1
European Journal of Operational Research								1							
Expert Systems with Applications	2			1			1				1	1	1		1
Fuel														1	
Information Sciences													1	2	
Innovation and Green Development															1
International Journal of Disaster Risk Reduction					1										
International Journal of e-Navigation and Maritime Economy							1								
International Journal of Hydrogen Energy				1										1	
International Journal of Industrial Ergonomics							1								
Journal of Air Transport Management										1		1		1	
Journal of Cleaner Production									1				2	1	1
Journal of Industrial Information Integration															1
Journal of Loss Prevention in the Process Industries								1							
Journal of Space Safety Engineering										1					
Marine Policy												1	1	1	
Marine Pollution Bulletin															1

Table 3 (continued)

Journal	Years														
	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Nuclear Engineering and Technology															1
Ocean & Coastal Management													1		1
Ocean Engineering	1							1		1	1	3	4	5	3
Procedia - Social and Behavioral Sciences							1								
Procedia Engineering							1								
Process Safety and Environmental Protection															1
Progress in Nuclear Energy														1	
Reliability Engineering & System Safety								1				1	2	1	1
Renewable Energy															1
Research in Transportation Business & Management												1		3	1
Safety Science							1	1	1	2				1	
Sustainable Energy Technologies and Assessments														1	
Sustainable Production and Consumption															1
The Asian Journal of Shipping and Logistics										1			1		
Tourism Management						1									
Transport Policy							1								
Transportation Research Part A: Policy and Practice					1			1				1			
Transportation Research Part B: Methodological												1			
Transportation Research Part D: Transport and Environment						1						1	1	2	
Transportation Research Part E: Logistics and Transportation Review							1			1	1		1		
Transportmetrica A: Transport Science											1				

Figure 3 shows that the most frequently used techniques in the maritime studies are AHP (17), Fuzzy AHP (13), TOPSIS (11), Fuzzy TOPSIS (7) and DEMATEL (6). This was followed by ANP and VIKOR techniques with a frequency of use of 4 and 3 respectively within 15 years. AHP & TOPSIS, DELPHI, QFD and WASPAS techniques have been repeated twice each in the 15-year period, while the other techniques have been used only once in the literature.

With the findings obtained, the temporal change in the use of MCDM techniques in the maritime studies has also been revealed. The decisive distinction here is to obtain profile of research articles. For this reason, review articles, conference abstracts, short communication, book chapters, encyclopaedias and editorials have isolated from the investigation. Thus, profile of research articles in total studies was observed. The results are presented in Table 2 and Figure 4.

The findings revealed that the studies in the data set followed a fluctuating course between 2009 and 2019. Between 2019 and 2022, it was observed that both the number of studies accessed and the number of research articles conducted in the maritime studies showed a steady upward trend. The relative downward trend in 2023 is explained by the fact that the study was conducted as of August 2023. The distribution of the studies examined by PRISMA method according to journals and years is given in Table 3.

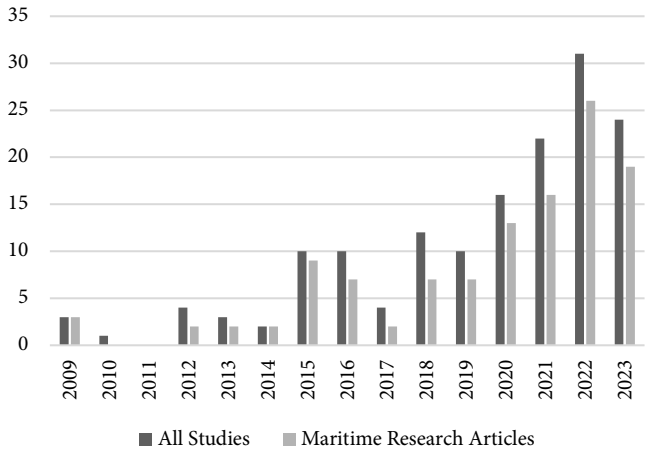

Figure 4. Time-dependent change in the use of MCDM techniques in the maritime studies

Conclusion

Today, MCDM techniques are gaining importance in every field of science. This study focuses on the implementations of these techniques in maritime studies in the literature and answers more than one research question with the results obtained. These results are presented below.

- Although the use of MCDM techniques in the maritime studies exhibited an unbalanced behaviour in the 15-year period, it generally showed an upward trend. Especially it has exhibited a steady upward trend between 2019 and 2022. By the end of 2023, this upward trend is expected to continue.
- In terms of MCDM, when the time-dependent change in the share of maritime research articles in the total number of studies accessed is examined, no steady upward or downward trend is observed.
- A review of 15 years of literature shows that the most commonly used MCDM techniques in maritime studies are AHP, Fuzzy AHP, TOPSIS, Fuzzy TOPSIS and DEMATEL.
- PRISMA, which is used as a study method, contributes to the maritime literature in terms of methodology and provides an alternative method for future studies.
- Obtained results show that the main areas of use of MCDM techniques in maritime transportation, maritime safety, ship energy efficiency, sustainability, maritime management and maritime economics in 15 years of maritime literature. When examined in terms of the technique used and the field of study, the results obtained are as follows.
  - The most used techniques in maritime transportation are AHP, AHP & QFD & DEMATEL, AHP & TOPSIS, ANP, DEMATEL, Fuzzy AHP, Fuzzy AHP & VIKOR, Fuzzy TOPSIS, SMMA & TOPSIS and TOPSIS.
  - The most used techniques in maritime safety are AHP, DECISION TREE, DEMATEL, FUZZY AHP & PRAT, FUZZY BWM, Fuzzy FMEA, Fuzzy TOPSIS & TOPSIS.
  - The most used techniques in ship energy efficiency are FUZZY AHP, FUZZY AHP & TOPSIS, PROMETHEE and TOPSIS.
  - The most used techniques in sustainability are AHP, ANP, BWM, CODAS, DELPHI, DEMATEL.
  - The most used techniques in maritime management are Fuzzy AHP, Fuzzy DEMATEL.
  - The most commonly used techniques in maritime economics are Fuzzy AHP and WASPAS.

Since full-text accessibility is the main criterion in this study, the databases scanned were limited to Scopus and

Science Direct and a basic framework was drawn with the results obtained. This research, which will form an infrastructure for future studies, suggests new researchers to reach micro-scale results by adding different databases to the dataset. In this way, the applications of the ever-renewing and developing analysis techniques of the scientific world in the maritime studies will constitute a reference source for future research.

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.

Data Availability Statement

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

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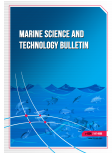

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RESEARCH ARTICLE

A study on fatty acid composition and quality indicators of anchovy (*Engraulis encrasicolus*) oils from different factories

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ABSTRACT

This study aims to investigate the impact of anchovy (*Engraulis encrasicolus*) oil produced in different factories on the fatty acid composition and quality indicators. The study utilizes anchovy oils obtained from three different factories. Fatty acid analysis was conducted using gas chromatography, and the results were expressed as percentages. Additionally, fatty acid quality indices such as atherogenic index (AI), thrombogenic index (TI), Polyene index (PI), and hypocholesterolemic/hypercholesterolemic ratio (h/H) were calculated. The findings of the study indicate that different processing technologies may influence the fatty acid composition of anchovy oil. Anchovy oils were observed to be rich in polyunsaturated fatty acids (PUFA) and notably contain omega-3 fatty acids such as DHA (docosahexaenoic acid) and EPA (eicosapentaenoic acid). This study provides valuable insights into anchovy oil production and quality, offering an in-depth understanding of sustainable nutrition. In conclusion, this study sheds light on a significant issue in the anchovy oil industry and may guide researchers and industry experts interested in improving the quality of fish oil products and supporting human health with potential opportunities.

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Introduction

Fish oil plays a pivotal role in both human health and various industrial applications (Bayrakli, 2021a; Yildiz et al., 2023). In recent times, the significance of omega-3 fatty acids, particularly DHA and EPA, in human nutrition has gained widespread recognition (Bayrakli et al., 2019; Bayrakli & Duyar, 2019a, 2019b, 2021a, 2021b; Bayrakli, 2021b; Duyar & Bayrakli, 2023). Polyunsaturated fatty acids (PUFAs) are well known to have specific pharmacological and physiological effects on humans (Singer & Calder, 2023).

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Fish oil is a highly valuable product produced in fish meal and oil factories, with approximately 18 million tons of fish being processed in these facilities worldwide annually (FAO, 2020). However, the sustainability of this sector is being questioned due to environmental factors and overfishing. Additionally, climate change is increasing drought conditions globally, impacting food resources. Therefore, to sustain civilizations, it is imperative to implement proper food policies (Bayrakli & Duyar, 2019b).

Fish oil is used as a crucial raw material in pharmaceuticals and dietary supplements, primarily owing to its preservative and healing properties. It is also a key component in the production of fish feeds, containing high levels of omega-3 fatty acids such as EPA and DHA. The fatty acid composition found in fish meat obtained through aquaculture has been linked to the composition of fatty acids in their feed (Truzzi et al., 2023). Consequently, it is desirable for fish raised in farms to have high levels of fatty acids, especially EPA and DHA (Santigosa et al., 2023). In the machines designed for fish meal and oil, firstly it is cooked and then pressed and the watery and solid parts are separated. the watery part is separated from the oil in the separator and refined and stored.

This study aims to investigate the impact of different processing technologies used in various factories on the quality and composition of products derived from anchovy (*Engraulis encrasicolus*). Furthermore, it seeks to evaluate the contributions of anchovy oils fatty acid values and calculated fatty acid quality indices to the literature. This research will deepen the understanding of fish oil production and quality, providing valuable insights for sustainable nutrition.

Material and Method

Material

This study was conducted in three different fish meal and oil factories located between the cities of Sinop and Samsun in the Black Sea region of Türkiye. Each of these factories has a daily average capacity of 2000 ton/day, forming the core material of the study. Fish oil samples were obtained from these factories in November 2022 during the processing of raw materials. The fish oil samples were filled into two 60-gauge lids for each group and stored in cold conditions to preserve their quality.

For laboratory analysis, the samples were sent to the Sinop University Scientific and Technological Research Application and Research Center. This center is equipped with a laboratory infrastructure that ensures reliable analysis procedures in compliance with standardized protocols.

Fatty Acid Composition

Fatty acid methyl esters were prepared according to the esterification and extraction principle (IUPAC, 1994). To esterify, 0.150 g of fish oil was weighed in a volumetric flask and 5 ml of methanolic 0.5 N NaOH was added on top of it. Then, accompanied by a cooler, it was saponified by boiling in a water bath for 15 m with boiling chip addition. After flowing 5 ml of BF3 reagent over the cooler, it was boiled for 5 more minutes and 2 ml of heptane was added. Then, after another 1 minute of boiling, the cooler was removed and the sample was gently taken into a 25 ml volumetric flask. The flask was rinsed with saturated NaCl, and the resultant solution was also added. 1-2 ml of liquid was taken via micropipette from the upper heptane phase and transferred to a glass bottle with a test tube. A few crystalline anhydrous Na_2SO_4 was thrown into the bottle, 1 µl of this solution was injected into Shimadzu gas chromatography (GC) and the fatty acid composition was determined (Erickson, 1993).

The GC system consists of an FID detector (Flame Ionization Detector), gas chromatography (Shimadzu, GC2014, Japan), and autoinjector (AOC-20i, Shimadzu, Japan). The instrument is controlled by GC solution software (Version 2.41.00 su_1). FAME WAX (polyethylene glycol, 30 meter × 0.25 mm I.D×0.2 µm, GC Columns Restek) was used as the chromatographic colon. GC operation conditions were as follows; injection mode: split ratio, split: 1/10, injection and detector temperature: 260 and 280°C, carrier gas and column flow: helium and 1.4 ml min-1, temperature program: initial temperature 5 m 100°C, 5°C increase per minute from 100°C to 150°C, 15 m at 150°C, 10°C increase per minute to 210°C, and 20 m at 210°C.

Peaks in gas chromatography by using the "Supelco 37 Component FAMEs Mix" standard. In obtaining data, methyl esters of fatty acids were calculated as the percentage of total fatty acids. The spectrum includes all commonly known fatty acid methyl esters.

According to this method, the fatty acid methyl esters were analysed by using a PUE UNICAM 204 Gas Chromatography equipped with a flame ionization detector using a Degs capillary column (2 MX 1-8 inc) coated with 0.25 µl of Supelco GP% OV-275 on 100/120 PAW-PMCS.

Lipid Quality Indices

Polyene index (PI) was used as a measure of PUFAs damage (Lubis & Buckle, 1990) and calculated according to the Equation 1:

$$PI = \frac{[EPA(C20{:}5n3)+DHA(22{:}6n3)]}{Palmitic\ acid(C16{:}0)} \quad (1)$$

AI, TI and h/H were calculated using the following equations (Ulbricht & Southgate, 1991; Abrami et al., 1992; Bayrakli & Duyar, 2019b; Bayrakli, 2021b; Duyar & Bayrakli, 2023) taking into account the different effects of different fatty acids on human health (Equations 2-4):

$$AI = \frac{(12{:}0+4(14{:}0)+16{:}0)}{\sum MUFA+\sum PUFA} \quad (2)$$

$$TI = \frac{[(14{:}0+16{:}0+18{:}0)]}{0.5(\sum MUFA)+0.5(n6PUFA)+3(n3PUFA)+\left(\frac{n3PUFA}{n6PUFA}\right)} \quad (3)$$

$$h/H = \frac{(C18{:}1+C18{:}2+C18{:}3+C20{:}3+C20{:}4+C20{:}5+C22{:}4+C22{:}5+C22{:}6)}{(C14{:}0+C16{:}0)} \quad (4)$$

Statistical Analysis

The data obtained from three different time periods were analyzed by Student's t-test analysis using the SPSS statistical package program (Version 10, SPSS Inc., Chicago, IL, USA), and differences among the means were compared by applying the Duncan's multiple range test. A significance level of 0.05 was used and the results were shown as mean values ± standard deviation (SD).

Results and Discussion

In this study, it was aimed to investigate the ΣSFA, ΣMUFA, ΣPUFA fatty acid content and AI, TI, PI, h/H quality indices of fish oils obtained from anchovy. The findings revealed the ΣSFA content of samples collected from three different factories. The average ΣSFA values were calculated as follows: Factory A, 34.25%±0.561; Factory B, 35.22%±0.188; and Factory C, 34.87%±0.374 (Table 1). There was no statistically significant difference among these values ($p>0.05$).

Atherogenic index (AI), thrombogenic index (TI), polyene index (PI), and hypocholesterolemic/hypercholesterolemic ratio (h/H) were calculated. The findings of the study indicate that different processing technologies may influence the fatty acid composition of anchovy oil. Anchovy oils were observed to be rich in polyunsaturated fatty acids (PUFA) and notably contain omega-3 fatty acids such as DHA (docosahexaenoic acid) and EPA (eicosapentaenoic acid)

However, a noteworthy outcome observed in the present study is that specific SFAs such as palmitic acid (C16:0), stearic acid (C18:0), and myristic acid (C14:0) were more dominant in certain factories. Palmitic acid was found to be the highest in Factory A at 15.54%±0.296, while stearic acid was most prominent in Factory C at 6.93%±0.157. Similarly, myristic acid significantly varied, with Factory B recording 5.78%±0.035. Statistically significant differences were observed among groups for these SFAs ($p<0.05$). The results of this study demonstrate that the SFA content of fish oils obtained from anchovies can vary depending on different factors such as the processing temperature and duration in the factories, as well as the freshness of the raw materials used in the process. These findings appear to be consistent with previous research. For instance, a study by Bayrakli & Duyar (2019b) examined the ΣSFA content of anchovy oils and similarly found that palmitic acid (19.80 %) was the most abundant in all groups, although this study (reported higher levels of palmitic acid. Furthermore, a study by Duyar & Bayrakli (2023) investigated the ΣSFA content of fish oils obtained from salmon internal organs and found similarities with the ΣSFA content of anchovy oils. Particularly, the conclusion that palmitic acid is the highest in ΣSFA aligns with this study (Öksuz et al., 2009; Oksuz & Ozyilmaz, 2010; Gencbay & Turhan, 2016; Durmuş, 2019; Yuneva et al., 2019).

In this study, we focused on the ΣMUFA (monounsaturated fatty acid) content, which was found to be 23.23%±0.949, 23.77%±0.066, and 23.50%±0.055 in the A, B and B factories, respectively. There was no statistically significant difference among these values ($p>0.05$). Oleic acid (C18:1 n9) was identified as the predominant ΣMUFA in all groups, with percentages of 14.30%, 14.75%, and 14.77%, respectively. These results indicate similarities in ΣMUFA content among the factories.

This finding is in accordance with previous research, such as the study of Bayrakli & Duyar (2019b) study, which examined the ΣMUFA content in anchovy oil and similarly identified oleic acid (C18:1 n9) as the predominant fatty acid in all groups. Previous studies have also reported similar ΣMUFA values and identified oleic acid as the dominant component (Durmuş, 2019; Gencbay & Turhan, 2016; Öksuz et al., 2009; Oksuz & Ozyilmaz, 2010; Yuneva et al., 2019). These consistent findings suggest that the ΣMUFA content of anchovy oil remains relatively stable across different factories and that oleic acid is a characteristic component of this oil. In line with these results, a study by Duyar and Bayraklı (2023) also reported a

Table 1. Fatty acid values (%) of fish oils obtained from 3 different factories

Fatty acid	A Factory	B Factory	C Factory
C10:0	0.04±0.000	0.04±0.006	0.05±0.012
C11:0	0.02±0.006	0.02±0.000	0.02±0.006
C12:0	0.15±0.006	0.18±0.000	0.17±0.006
C13:0	0.12±0.006	0.15±0.000	0.14±0.006
C14:0	5.35±0.084^{a}	5.78±0.035^{b}	5.65±0.046^{b}
C15:0	1.76±0.031	2.06±0.025	2.02±0.026
C16:0	15.54±0.296^{b}	14.85±0.115^{ab}	14.56±0.357^{a}
C17:0	2.03±0.036	2.17±0.021	2.10±0.006
C18:0	6.03±0.110^{c}	6.60±0.032^{b}	6.93±0.157^{a}
c20:0	1.97±0.026	2.10±0.021	1.90±0.032
C21:0	0.17±0.010	0.15±0.000	0.18±0.012
C22:0	0.06±0.000	0.07±0.01	0.09±0.015
C23:0	0.04±0.036	0.06±0.017	0.08±0.026
C24:0	0.97±0.015	0.99±0.020	0.97±0.057
C14:1	0.68±0.015	0.82±0.015	0.81±0.006
C15:1	0.39±0.010	0.48±0.021	0.47±0.015
C16:1	1.84±0.035	0.79±0.006	0.73±0.015
C17:1	1.40±0.012	1.54±0.017	1.49±0.015
C18:1n9c	14.30±0.183^{a}	14.75±0.070^{b}	14.77±0.044^{b}
C18:1n9t	1.26±1.218	2.58±0.021	2.32±0.061
C20:1	1.05±0.540	0.70±0.015	0.75±0.021
C22:1n9	0.52±0.168	0.38±0.006	0.39±0.006
C24:1	1.79±0.026	1.74±0.010	1.78±0.047
C18:2n6c	4.48±0.060^{a}	4.66±0.015^{b}	4.52±0.047^{a}
C18:2n6t	1.19±0.020	1.29±0.006	1.22±0.025
C18:3n3	3.68±0.061	3.86±0.006	3.82±0.023
C18:3n6	1.10±0.021	1.20±0.010	1.09±0.020
C20:2	1.14±0.017	1.17±0.020	1.16±0.020
C20:3n3	0.18±0.006	0.17±0.006	0.99±0.676
C20:3n6	2.80±0.081	2.62±0.102	3.13±0.256
C20:4n6	2.43±0.026	2.59±0.021	2.50±0.020
C20:5n3	9.29±0.095^{a}	9.61±0.140^{b}	9.36±0.040^{a}
C22:2	0.34±0.006	0.34±0.015	0.32±0.020
C22:6n3	15.89±0.106^{b}	13.47±0.042^{a}	13.49±0.388^{a}
ΣSFA	34.25±0.561^{a}	35.22±0.188^{a}	34.87±0.374^{a}
ΣMUFA	23.23±0.949^{a}	23.77±0.066^{a}	23.50±0.055^{a}
ΣPUFA	42.52±0.420^{b}	41.00±0.152^{a}	41.61±0.406^{a}
EFA	25.18±0.200^{b}	23.08±0.159^{a}	22.85±0.359^{a}
UNSFA/SFA	1.92±0.048^{a}	1.84±0.015^{a}	1.87±0.030^{a}
PUFA/SFA	1.24±0.011^{b}	1.16±0.010^{a}	1.19±0.024^{a}
DHA/EPA	1.71±0.007^{b}	1.40±0.020^{a}	1.44±0.046^{a}
omega-3	29.04±0.256^{b}	27.11±0.166^{a}	27.67±0.804^{a}
omega-6	12.00±0.150^{a}	12.37±0.067^{a}	12.46±0.359^{a}
omega-3 / omega-6	2.42±0.013^{b}	2.19±0.021^{a}	2.22±0.128^{a}
omega-6 / omega-3	0.41±0.002^{a}	0.46±0.004^{b}	0.45±0.026^{ab}
omega-9	16.08±1.269^{a}	17.70±0.072^{a}	17.47±0.025^{a}

Note: ΣSFA: Saturated fatty acid, ΣMUFA: Monounsaturated fatty acid, ΣPUFA: Polyunsaturated fatty acid, EFA: EPA+DHA. Different letters (a,b,c) in the same row shows significant differences ($p<0.05$) among the freshness groups.

high concentration of oleic acid with no statistically significant differences among groups. The stability and consistency of ΣMUFA content in anchovy oil, with oleic acid as the dominant fatty acid, underscore the potential for this oil to serve as a valuable and consistent source of monounsaturated fats for various industrial and nutritional applications.

In this study, the polyunsaturated fatty acid (PUFA) values exhibited variation among the different factories. The ΣPUFA content was calculated as follows: Factory A, 42.52%; Factory B, 41.00%; and Factory C, 41.61%. Statistical analysis did not reveal any significant differences between these values ($p>0.05$). Dominant PUFAs were identified as Docosahexaenoic acid (DHA, C22:6n3) and eicosapentaenoic acid (EPA, C20:5n3). DHA was found to be present at levels of 15.89%, 13.47%, and 13.49%, respectively, while EPA was determined at 9.29%, 9.61%, and 9.36%. Omega-3 fatty acids exhibited similarity among factories, while omega-6 fatty acids were recorded at 12.00%, 12.37%, and 12.46%, respectively. The omega-3/omega-6 ratio was calculated as 2.42, 2.19, and 2.22 for the three factories, respectively.

The importance of polyunsaturated fatty acids, particularly long-chain omega-3 fatty acids such as EPA and DHA, in human and animal nutrition has been increasing over time. Various studies have indicated their role in the treatment of coronary heart disease, COVID-19, and organ damage when taken through diets (Singer & Calder, 2023). Additionally, there is evidence suggesting that the consumption of these fatty acids can reduce the risk of cancer (Gheorghe et al., 2022).

The PUFA/SFA ratio in the fish oils obtained from factories ranged from 1.19 to 1.64 (Table 2). This value significantly exceeds the recommended minimum value of 0.45 for human health (HMSO, 1994). It demonstrates the nutritive quality of fish oil obtained from anchovies in terms of human health. These findings highlight the nutritional value of fish oils obtained from anchovies, particularly their high PUFA/SFA ratio. This is of great importance in the context of dietary recommendations and public health, as these fatty acids are associated with various health benefits, including cardiovascular health and the potential prevention of chronic diseases. Further research in this area can provide valuable insights into optimizing fish oil production for human consumption.

Previous studies have highlighted the variability in ΣPUFA content of Black Sea anchovy oil, ranging from 23.00% to 38.01%, with valuable proportions of EPA (4.9%–11.55%) and DHA (14.03%–20.05%) (Öksuz et al., 2009; Oksuz & Ozyilmaz, 2010; Gencbay & Turhan, 2016; Durmuş, 2019; Yuneva et al., 2019). The work of Bayrakli & Duyar (2019b) supports these findings.

EPA and DHA play a fundamental role in the prevention and treatment of numerous diseases, and since fish oil contains high levels of EPA and DHA, the sum of EPA + DHA is used to assess nutritional quality. In this study, EPA + DHA levels were determined to be 25.18%, 23.08%, and 22.85% in the respective factories. Considering the well-established potential health benefits of EPA and DHA in human metabolism, governmental and medical institutions worldwide recommend the regular consumption of approximately 500 mg/day of EPA + DHA to reduce the risk of cardiovascular diseases (Biandolino et al., 2023). Based on the results obtained from this study, fish oils obtained from the factories would meet the recommended amount for reducing the risk of cardiovascular diseases when added at 2 g to 100 g of food.

Atherogenic (AI) and thrombogenic (TI) indices, when exceeding 1.0, have been reported to be detrimental to human health (Ouraji et al., 2009). Lowering these values reduces the risk of coronary heart disease (Cutrignelli et al., 2008). According to the results of this study, AI values were similar among factories, calculated as 0.56 for Factory A, 0.59 for Factory B, and 0.57 for Factory C. These values were within the recommended limits for human health. Notably, in the study of Bayrakli & Duyar (2019b) study found an AI value of 0.86, and in the study of Duyar & Bayrakli (2023) study, this value decreased to 0.36. Similarly, TI values were also similar among factories, calculated as 0.25 for Factory A, 0.27 for Factory B, and 0.26 for Factory C. These values were acceptable for human health. in the study of Bayrakli & Duyar (2019b) study, the TI value was 0.28, and in the study of Duyar & Bayrakli (2023) study, it was also determined as 0.28. Additionally, in the study of Karsli (2021), AI values ranged from 0.11 to 0.70, and TI values ranged from 0.01 to 0.36, indicating no significant risk to human health.

Table 2. Calculated fatty acid quality indices

Index	A Factory	B Factory	C Factory
AI	0.56	0.59	0.57
TI	0.25	0.27	0.26
PI	1.62	1.55	1.57
h/H	2.50	2.53	2.61

Note: AI: atherogenic index, TI: thrombogenic index, PI: Polyene index, h/H: hypocholesterolemic/ hypercholesterolemic ratio

Polyene index (PI) can provide a meaningful tool to measure the oxidative stability of fish oils. A high PI value is

preferred. PI values varied among factories, measuring 1.62 for Factory A, 1.55 for Factory B, and 1.57 for Factory C in this study. In the study of Bayrakli & Duyar (2019b) study, the PI value was 0.95, and in the study of Duyar & Bayrakli (2023) study, it was calculated as 1.38.

The hypocholesterolemic/hypercholesterolemic ratio (h/H) of fatty acids is an indicator of whether the oil in the product is nutritious (Caglak & Karsli, 2017). A high h/H ratio signifies that the oil in the product is suitable for nutrition. The composition of fatty acids can vary depending on the fish species (Ozogul et al., 2013). h/H values also varied among factories, calculated as 2.50 for Factory A, 2.53 for Factory B, and 2.61 for Factory C. These values indicate that the products are suitable for nutrition. In the study of Bayrakli & Duyar (2019b) study, the h/H value was 1.73, and in the study of Duyar & Bayrakli (2023) study, it was recorded as 2.90.

Conclusion

This study has demonstrated some variations in the quality and composition of anchovy fish oils obtained from different factories. However, it is important to note that these differences are generally not statistically significant. This study focused on evaluating the quality of products obtained from factories that carry out anchovy fish oil production using different processing technologies.

While the saturated fatty acid content was similar between factories, specific SFAs (palmitic acid, stearic acid, and myristic acid) were observed to be more dominant in the factories. Monounsaturated fatty acid content also exhibited similarity among factories, with oleic acid being identified as the dominant MUFA. Polyunsaturated fatty acid content varied among factories, but essential PUFAs like EPA and DHA were found at similar levels. The EPA + DHA levels were indicative of these fish oils being a valuable source of nutrition for human health.

Atherogenic, thrombogenic indices and hypocholesterolemic/hypercholesterolemic ratio were within acceptable limits for human health, indicating the high quality of these fish oils. Polyene index (PI) values reflected good oxidative stability.

This study provides significant insights into anchovy fish oil production and quality. The results underscore the value of this product as a valuable resource for human nutrition and industrial applications. In the future, further research and development efforts will be needed to enhance the sustainability and quality of anchovy fish oil production.

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.

Data Availability Statement

The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

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RESEARCH ARTICLE

Fluctuations of physicochemical parameters in the waters of the Chattogram coastal area, Bangladesh

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ABSTRACT

Fluctuations in seasonal features of physicochemical factors in the coastal zone are expressively related to the development of aquaculture. The research examined some common physicochemical characteristics of water such as temperature, salinity, light penetration, pH, biological oxygen demand (BOD), dissolved oxygen (DO), total dissolved solids (TDS), total suspended solids (TSS), and nutrients like nitrite and phosphate for the Chattogram coast of the Bay of Bengal, Bangladesh, for a period about one year (December 2020 to November 2021) during the pre-monsoon, monsoon, and post-monsoon seasons. The analyzed physic-chemical parameters' spatio-temporal variability was discovered to be as follows: average temperature 28.20±2.28°C, light penetration 9.95±1.75 cm, p^H 7.38±0.17, salinity 20.11±1.44 ppt, DO 7.41±0.91 mg/l, BOD_5 8.28±1.15 mg/l, TSS 2.61±0.43 g/l, and TDS 21.99±2.06 g/l. The concentration of nutrients indicates significant variations, and their levels in the water increased during the monsoon period. Total nitrate-nitrogen ranged between 0.867 µg/l and 1.472 µg/l and total phosphate-phosphorus ranged between 0.221 µg/l and 0.844 µg/l. Shipbreaking activities near the study area possess adverse impacts on native geomorphology, freshwater inputs, rainfall, and the aquatic ecosystem as well. This research proposes the value of regular supervision to assess the status of water quality and the next prospect of aquaculture in the Chattogram coastal area. Seasonally, without DO, all values showed a significant difference, whereas $p<0.05$.

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Introduction

Bangladesh is a sloping, riverine nation (Pramanik, 1988) endowed with immense natural water bodies in a variety of forms (Ali et al., 2017; Mia et al., 2017), the largest of which is a 710 km long coastline. The littoral and estuarine regions consist of extensive muddy areas, brackish water, saline water, and confined bays. These locations are home to a large quantity of valuable life forms that are suited for ocean farming (Kamal & Khan, 2009). Estuaries serve as an intermediate region between the ocean and the land because they are fragile habitats with distinctive chemical and physical features. Numerous physical and chemical reactions occur as riverbanks and oceans interact, and those events might affect the state of the water. Surface water quality is a particularly delicate subject (Prasanna & Ranjan, 2010) that refers to the present state of the water body, which depends on various parameters and directly or partially controls the aquatic ecosystem (Srinivasan et al., 2013). The existence of organic and inorganic substances that are either deferred or melted in water determines the physicochemical characteristics relevant for water quality assessment. Water quality characteristics in aquatic habitats are the result of several biological, physical, and chemical exchanges (Ugwu & Wakawa, 2012). The physicochemical makeup and biological variety of an aquatic habitat determine its health (Venkatesharaju et al., 2010). Especially in tropical countries, which are characterized by mostly shallow water bodies, the coastal ecosystems are inherently rich in biodiversity and productive (Srinivasan et al., 2013). The coastal zone is one of the most significant commercial sectors in any state in the world. Additionally, this zone serves as a crucial filtration system and buffer zone for the coastal ecology (Srinivasan et al., 2013). Furthermore, each of these components exists in an intricate balance that is maintained by biological and physical procedures and is easily disrupted by environmental or human intrusion (Viles & Spencer, 2014).

Water quality analyses are a core component of an ecological tracking system for recreational spots and provide crucial data for the administration of the coastal zone (Ariza et al., 2007). Coastal effluent, agricultural runways, urban waste, and industrial discharge in the neighboring river can alter water quality (Inyang & Daniels, 2009). The purity of water is influenced by both organic and human procedures such as precipitation, sedimentation, and the degradation of crystalline materials (Chakrapani et al., 1993). Physical, chemical, and biological characteristics can be used to define the quality of aquatic body (Trivedi et al., 2009). However, there might be some link between these variables, and the major one could be used to determine the water's quality (Manjare et al., 2010). The biochemistry of the water body is significantly influenced by physical factors. The water quality of the study system can be significantly impacted by small changes in the environment, which could then have an impact on how nutrients are distributed both spatially and temporally and/or on biological communities (Sreenivasulu et al., 2015). As a result, while designing a water quality management program, seasonal changes in surface water quality must be considered (Ouyang et al., 2006). A vast area of polluted aquatic or coastal water bodies plays an important role in fish and wildlife resources. The establishment of water quality variations over time and space requires regular monitoring procedures (Prasanna & Ranjan, 2010). In this regard, a study was conducted to examine the status of physicochemical parameters of water and to know the seasonal fluctuations of these parameters in the Chattogram coastal area, Bangladesh.

Material and Method

This research was carried out at four locations (Banshkhali, Anwara, Patenga, and Dakshin Kattali) towards the littoral of Bangladesh, primarily in the Chattogram district. The position and details of the sampling sites are depicted in Figure 1, respectively. From December 2020 to November 2021, water samples were collected throughout three distinct periods: pre-monsoon, monsoon, and post-monsoon seasons. To conduct the physicochemical analysis, 500 ml of water samples were taken at each of the designated locations. Some physicochemical variables were measured on-site, while others were conveyed to the laboratory in opaque polyethylene plastic flasks, and ice cases; thus, the duration through sampling and analysis was less than 3 hours.

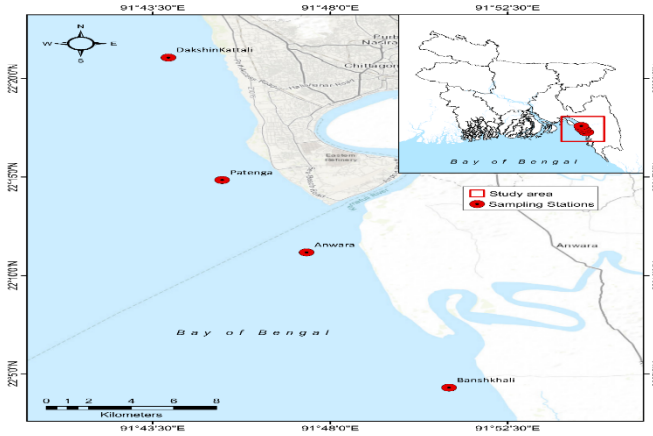

Figure 1. Study area map

Collection of Physicochemical Parameters

Within an extent of 3 meters, measurements of surface and subsurface water were taken at an offshore location that was 200 meters from the shoreline and in a low tide zone. A mercury thermometer was used to gauge the temperature of the water's outermost layer. Salinity was determined utilizing the Mohr-

Knudsen titration technique, and water pH was determined with a pen pH meter (Model: Phillips PW 8409) (Barnes, 1959; Eaton et al., 2005). Throughout the course of a 5-day time frame, the biological oxygen demand (BOD_5) of every water sample was determined through the OxiDirect BOD system (HACH). A handheld aquaculture kit (Model FF2, HACH, USA) was used to detect total hardness, dissolved oxygen (DO), and total alkalinity. A hydrophobic EC/TDS tester (Adwa AD31) was used to detect total dissolved solids (TDS) and electrical conductivity (EC). The Hach Kit (DR/2020, a direct-reading spectrophotometer) was used to quantify the amount of nitrate-nitrogen (NO_3-N) and phosphate-phosphorus (PO_4-P) using high-range chemicals (Nitra Ver. 5 nitrate reagent powder pillows for NO_3-N research and Phos. Ver. 3 phosphate reagent powder pillows for PO_4-P analysis).

Evaluation of Water Quality

The results were compared with the reference values (EQS, 1997; FAO, 2004; Santhosh et al., 2007; Hossain et al., 2009; Uddin et al., 2014; Talukder et. al., 2016; Saha et al., 2017; WHO, 2022) for water quality parameters, and followed by Uncumusaoğlu & Mutlu (2021).

Statistical Analysis

Before using Microsoft Excel to compute the numerical information derived from this study, the necessary adjustments and modifications were performed on the data. To assess whether or not there are any variations in the water quality measures that are statistically significant ($p<0.05$), a one-way analysis of variance (ANOVA) that was executed in Microsoft Excel was implemented. Using the IBM SPSS v27 program, the degree of significance of the findings was analyzed by Duncan's and Tukey's methodologies.

Results and Discussion

Spatial Variations of Physicochemical Parameters

Table 1 displays the physicochemical characteristics of study locations that were recorded throughout the time frame of this study. All the physicochemical characteristics, except pH, fluctuate significantly ($p<0.05$) depending on the time and season of year. The air temperature and water temperature both rise throughout the summer months, which is a typical occurrence. Among the stations, the measured water temperature revealed significant ($p>0.05$) seasonal change where the highest was in Pre-monsoon (30.69 ± 0.24^{a}) °C and the lowest was in post-monsoon (25.43 ± 0.23^{c}) °C (Table 1 and 2). Our study indicates clear seasonality. The present finding of water temperature was more or less similar to the findings of Haque et al. (2015) who found clear seasonality and the temperature range was 20-28.5°C and 21.2-29°C in Tidal Sangu River. Among the stations, the measured water temperature revealed no significant ($p>0.05$) spatial change, being lower (28.07 ± 1.76°C) and higher (28.45 ± 1.6°C). Boyle & Fraleigh (2003) and Ezzat et al. (2012) also eminent the expulsion of contaminants may raise the temperature of water, declining water levels, and rising concentrations of particulate pollutants throughout the summer cause the water to become hotter. St. 1 was shown to have been mostly contaminated throughout the research interval by the dumping of residential and urban rubbish. Industrial and municipal garbage has been shown by Bhouyan (1979) to have a considerable impact on the pH of the water at the disposal position. The pH ranged from 7.2-7.45, in sites and 7.25-7.53 among seasons without any significant difference ($p<0.05$) (Tables 1 and 2; Figure 3). pH was found to be oppositely related to both air and water temperatures and to have significantly risen over pre-monsoon to post-monsoon. The pH difference between the research and control sites fluctuates from the pre-monsoon to the post-monsoon seasons ($p>0.05$ seasonally) (Tables 1 and 2). This finding is consistent with the findings of Ferdousy et al. (2017). The ideal water pH range, according to WHO (2022), is between 6.5 and 8.5 (Uncumusaoğlu & Mutlu, 2021). Considering energy expenditure and environmental damage, our reported station's pH is in the standard range. The maritime salinity in Chattogram's coastal region was found to fluctuate between 19.37 ppt and 20.73 ppt at the surface, with Dakshin Kattali recording the lowest value throughout the monsoon and Banshkhali recording the highest average while on the post-monsoon (Tables 1 and 2; Figure 4). Temporally the value was highest (21.59 ± 0.36) in post-monsoon season and lowest in monsoon season. In every season, the salinity of surface waters is lower than that that exists in the deeper layers. Haque et al. (2015) recorded water salinity varied from 13 to 33 ppt in the tidal Sangu River and Ferdousy et al. (2017) discovered that water salinity ranged from 0.0 to 13.5 ppt year-round in Mongla River. Our results were lower than Haque et al. (2015) but higher than those of Ferdousy et al. (2017). The monsoon impact, rainfall, land drainage, and heavy rains, which were found to rise during the post-monsoon with the start of the dry season, may be to blame for the progressive drop in salinity after the month of June and its fall to zero ppt from September to December. Due to circulation in the Bay, river flow, dissolution, and runoff into the sea from rainfall, salinity varied during the research duration. The main characteristic of coastal water is salinity, and according to AHI (Saha et al., 2017), the ideal salinity level is about 25 ppt.

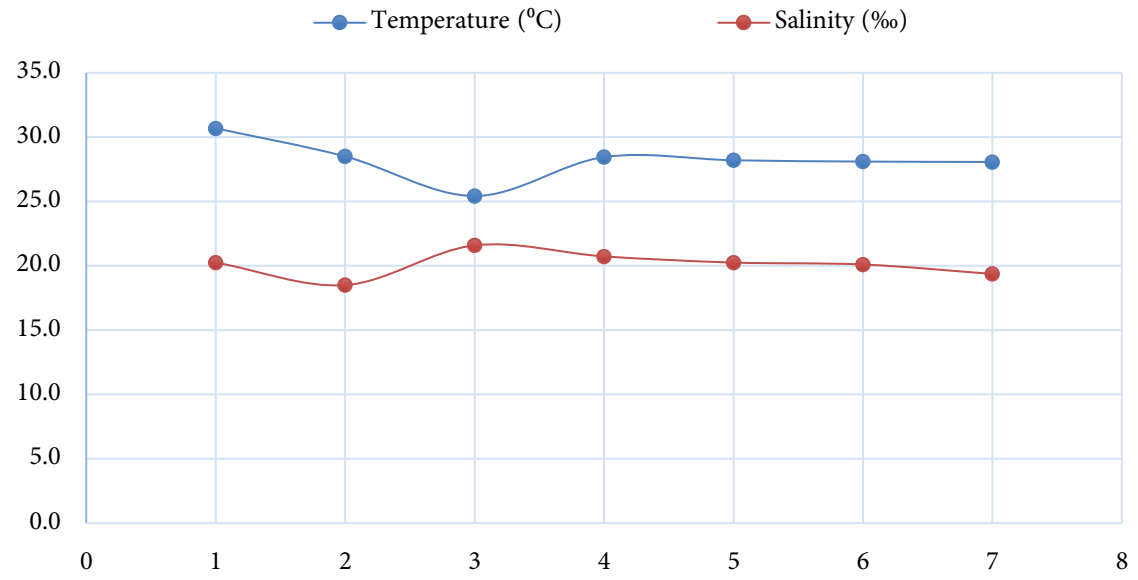

Figure 2. 1= Pre-monsoon, 2= Monsoon, 3= post-monsoon (seasonal variation); 4=st-1, 5=st-2, 6=st-3, 7=st-4 (spatial variation)

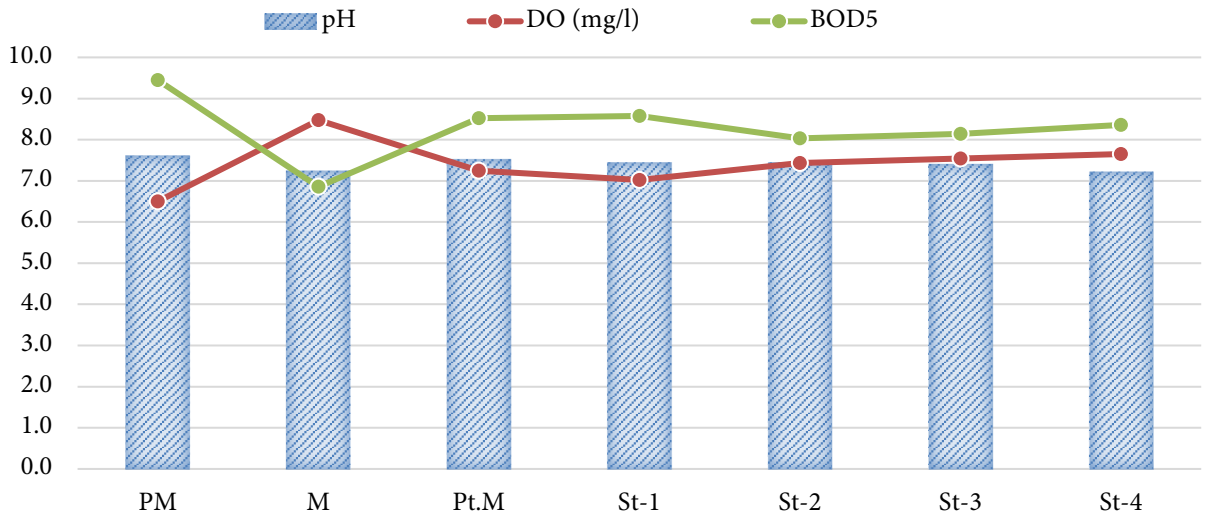

Figure 3. Effect of DO (mg/l) and BOD_5 (mg/l) basis on pH variation (seasonal & spatial variation)

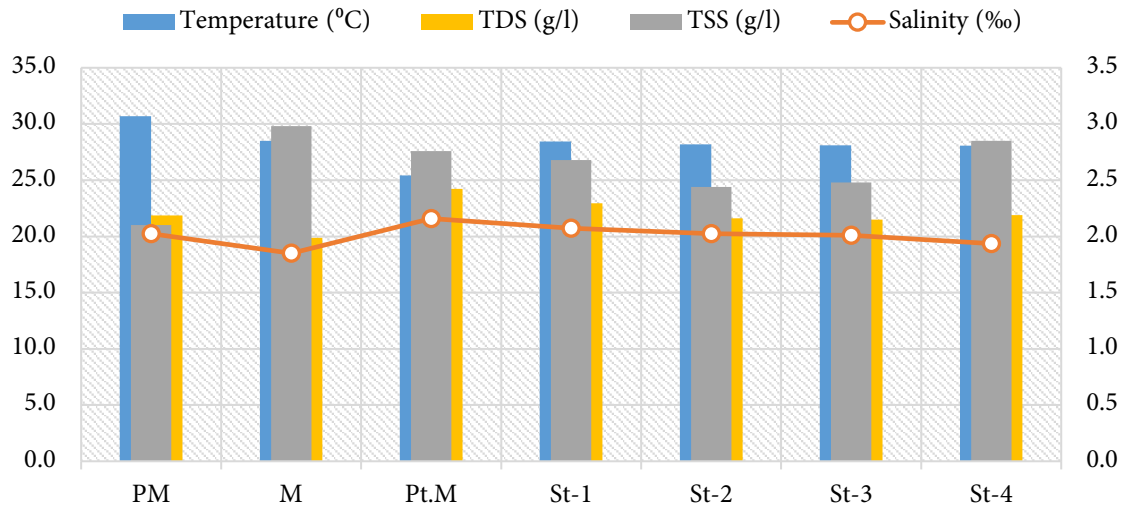

Figure 4. Salinity, variation with associated key features

Table 1. Physico-chemical parameters recorded from different study areas

Parameters	Banshkhali	Anwara	Patenga	Dakshin Kattali	Reference value
Temperature (°C)	28.45±1.6	28.2±1.34	28.1±1.31	28.07±1.76	20-30 (EQS,1997; Saha et al., 2017)
pH	7.45±0.13	7.45±0.13	7.41±0.06	7.22±0.04	6.5-8.5 (FAO, 2004; WHO, 2022)
Salinity (‰)	20.73±0.82	20.25±1.09	20.1±0.95	19.37±0.75	Saha et al. (2017)
DO (mg/l)	7.02±0.59	7.43±0.52	7.54 ±0.51	7.65 ±0.72	4-6 (Uddin et al., 2014)
Light Penetration (cm)	9.33±1.09	10.63±1.07	10.73±1.21	9.1±0.84	30-40 (Santhosh et al., 2007)
BOD_5	8.58±0.77	8.03±0.70	8.14±0.81	8.36±0.77	Saha et al. (2017)
TSS (mg/l)	2.68±0.28	2.44±0.25	2.48±0.26	2.85±0.33	Hossain et al. (2009)
TDS (mg/l)	22.95±1.38	21.61±1.17	21.49±1.25	21.9±1.49	<600 (WHO, 2022)
Nitrite-N_2 (µg/l)	1.17±0.149	1.32±0.13	1.28±0.11	1.08±0.04	Talukder et. al. (2016)
Phosphate-P (µg/l)	0.487±0.13	0.64±0.13	0.56±0.08	0.41±0.13	Hossain et al. (2009)

At St. 1, a substantial quantity of organic waste was subjected to elevated microbial breakdown, which resulted in a substantial decrease in DO. During the research time, noteworthy seasonal and geographic variations in DO content were also noticed. The monsoon season's greatest DO content in St. 4 (7.65±0.72 mg/l) suggests that while the lowest value (7.02±0.59 mg/l) was discovered in the highly polluted St. 1. One of the most important elements in any body of water is the amount of light that penetrates. In 2016, Talukder et al. (2016) also found that DO was high in the monsoon. DO varied from 7.02 to 6.65 mg/l in the experimental area, whereas the optimum value of DO is 5-8 mg/l. Using the effective influence of temperature on light penetration, pH, salinity, and other parameters seasonally, we found the average DO to be 7.41±0.91 mg/l ($p<0.05$) (Tables 1 and 2; Figure 2). The rate of photosynthesis is related to how much light gets into the plant. At different sites and times of year, the amount of light that got into the Chattogram coastal zone ranged from 9.1 to 10.73 cm during monsoon and post-monsoon, respectively, and the average amount of light that got in was 9.55±1.75 cm ($p<0.05$, annually) (Tables 1 and 2; Figure 4). The AHI of India (Saha et al., 2017) says that 30 cm is the best distance for light to get through.

At the experimental locations, the biochemical oxygen demand (BOD_5) of the coastal water ranged from 8.03±0.70 to 8.58±0.77 mg/l in research stations where the highest was in St. 1 and lowest in St. 2. BOD_5 levels were significantly higher during the pre-monsoon at onshore sites and lower throughout the monsoon at experimental offshore sites (Tables 1 and 2; Figure 3).

The TSS of Chattogram coastal water was measured there between 2.44±0.25 and 2.85±0.33 mg/l throughout the area while the highest was in Dasknin Kattali and the lowest was in Anwara, respectively. The TSS value was lowest during the pre-monsoon and highest during the monsoon at the study location. TSS has a positive correlation with TDS, salinity, transparency, and air temperature. The average value of TSS at Chattogram coastal water of various seasons was significantly different $p<0.05$ (Tables 1 and 2; Figure 4), which is higher than the optimum value of TSS of 2-3.2 g/l (Hossain et al., 2009). Our findings are more than the reference value in all stations. The maximum total dissolved solids (TDS) of 22.95±1.38 µg/l was recorded at St-1during post-monsoon, and the minimum value of TDS was 21.49±1.25 µg/l at St-3 during monsoon. All the seasons were significantly different ($p<0.05$). Hossain et al. (2009) showed that the optimum TDS value should be 12.8 to 29.1µg/l, whereas the average value of TDS was 21.99±2.06 µg/l (Figure 4). According to the reference, our recoded values are in the range.

At the experimental location's offshore site, the nitrite-nitrogen concentration level peaked during the monsoon (1.34±0.07 µg/l), but it thereafter declined to the lowest level (1.00±0.05 µg/l) seen onshore during post-monsoon. NO_2-N values fluctuate from pre-monsoon to monsoon at the experimental location. The peak level of nitrite-nitrogen concentration was observed in St. 1 (1.32±0.13) where the lowest was in Dakshin Kattali (1.08±0.04) (Tables 1 and 2; Figure 5) No significant difference was found between pre-monsoon and monsoon. Talukder et al. (2016) showed a 1.94-2.58 µg/l level of NO_2-N from the coastal waters of Salimpur and Chattogram along the Bay of Bengal. Haque et al. (2015) recorded Nitrate nitrogen concentrations varying from 0.9 µg/l to 2.2 µg/l in tidal Sangu River. Our result is more or less similar to other findings.

From coastal water, the maximum phosphate phosphorus content was determined in St. 2 (0.64±0.13) and minimum in the St. 4 (0.41±0.13) to be 0.32±0.05 µg/l during the pre-monsoon was the minimum value, and the maximum value was 0.66±0.00 µg/l in post-monsoon (Figure 5). Raju (2017) examined the range of PO_4-P levels from the southeast Indian

coast, from 0.29 to 2.15 µg/l. Haque et al. (2015) observed that PO_4-P concentration ranged from 1.5 to 2.9 mg/l with maxima and minima recorded in August and December, respectively, which is near the present study.

Seasonal Variation of Physicochemical Parameters

Temperature is one of the most important factors in increasing salinity. Despite the lower post-monsoon temperature, salinity rises due to low precipitation, a lack of fresh water, and other factors. According to Govindasamy et al. (2000), the amount of sunlight emitted, evaporation, insolation, freshwater intake, cooling, and rise and fall from nearby neritic seas all have a role in controlling surface water temperature. However, we have found a direct correlation between salinity, pH, light permeability, and water temperature. The association between water temperature and salinity was demonstrated by Özdemir et al. (2022). One of the most important chemical parameters in water quality fluctuations is dissolved oxygen, which influences both physical and biological processes in the water. The value of dissolved oxygen is a crucial issue in evaluating an aquatic ecosystem's water quality requirements. Seasonal observations of dissolved oxygen revealed an inverse relationship between temperature and salinity.

Among the key elements that improve chemical and biological properties is pH. Changes similar to these were also seen in Salimpur Coast, Chattogram, according to Talukder et al. (2016). He also demonstrated how pH, DO, and BOD_5 are related. Three locations in the research region are close to the estuary, where there is continual dissolution of saltwater by freshwater intrusion, and a single site is close to the Chattogram shipbreaking area. Numerous enterprises that demand oil disposal have an impact on coastal environments. pH remained slightly alkaline throughout the study period at all the stations. We noticed that the DO level gently increases from pre-monsoon to monsoon and decreases again from monsoon to post-monsoon. As high DO values showed in monsoons, BOD_5 was proportionally low. During monsoon season higher dissolved oxygen might be due to the effect of higher wind energy, air-sea interface combined heavy rainfall, and because of freshwater mixing. The water temperature during the post-monsoon was low because of strong land-sea breezes and precipitation, and the recorded high value during the pre-monsoon could be attributed to high solar radiation (Das et al., 1997). Seasonal variations in pH levels are caused by a variety of variables, including CO_2 removal by photosynthesis through bicarbonate depletion, mixing of saltwater by freshwater intrusion, poor primary production, decreases in salinity and temperature, and microbial disintegration (Karuppasamy & Perumal, 2000; Rajasegar, 2003).

Seasonal and spatial fluctuations among salinity and associated features:

The elevated salinity concentration is attributed to the rapid pace of vaporization, limited rainfall, the lack of river flow, tidal blending, and the predominance of neritic water from the open sea, as reported by Saravanakumar et al. (2008). The physicochemical parameters of the current research area's coastal water body demonstrated considerable seasonal fluctuations, which may be attributed to local climate circumstances. All the sites displayed the same trend with similar seasonal shifts. Salinity is a warning factor in the distribution of existing species, and its change owing to dilution from mixing and evaporation from temperature is most likely to stimulus the fauna in the intertidal region (Gibson, 1982). Salinity varies in response to changes in global temperature.

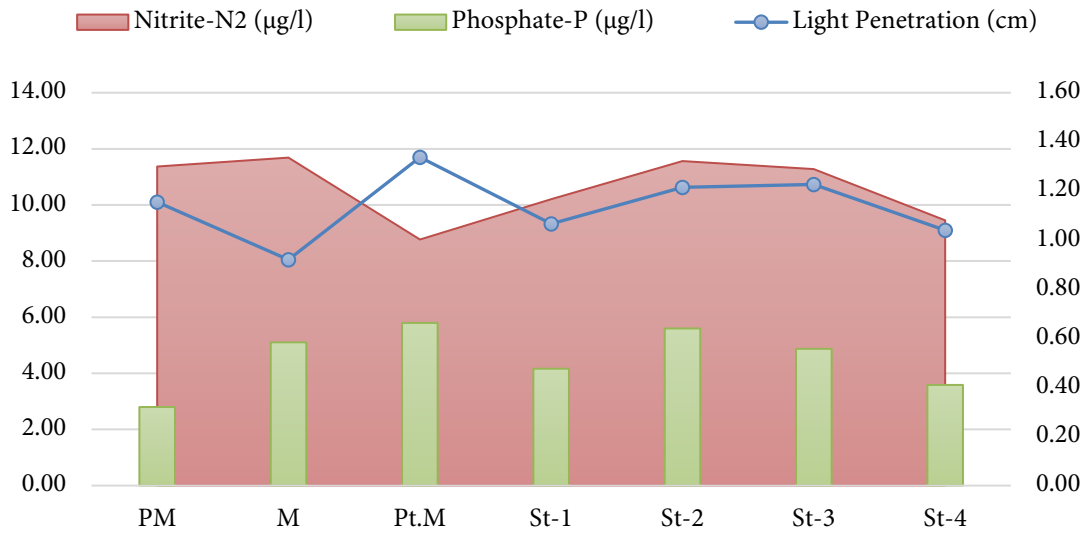

Figure 5. Nutrient variation and changes in LP

Table 2. Physico-chemical parameters recorded in different seasons.

Parameters	**Pre-monsoon**	Monsoon	Post-monsoon
Temperature (°C)	30.69±0.24[a]	28.5±0.074[b]	25.43±0.23[c]
Light Penetration (cm)	10.1±0.47[a]	8.05±0.32[b]	11.7±0.51[a]
pH	7.37±0.08	7.25±0.029	7.53±0.09
Salinity (‰)	20.25±0.33[b]	18.5±0.26[c]	21.59±0.36[a]
DO (mg/l)	6.5±0.22[c]	8.48±0.19[a]	7.25±0.12[b]
BOD_5	9.45±0.19[a]	6.86±0.15[c]	8.53±0.07[b]
TSS (mg/l)	2.1±0.06[b]	2.98±0.15[a]	2.76±0.08[a]
TDS (mg/l)	21.87±0.81[b]	19.86±0.11[c]	24.22±0.21[a]
Nitrite-N_2 (µg/l)	1.30±0.077[a]	1.3358±0.07[a]	1.00±0.05[b]
Phosphate-P (µg/l)	0.32±0.05[b]	0.58±0.10[a]	0.66±0.00[a]

A crucial characteristic of coastal water components is salinity, which additionally improves TSS and TDS. Srilatha et al. (2012) also observed a wide range of salinity (15-35 ppt). The seasonal variation of TSS varied, and that also influenced water quality largely. TSS indicates the river runoff, industrial effluents, agricultural effluents, and municipal sewage that are contaminated in the estuary or coastal water body. Saha et al. (2017) described that the Water Quality Index (WQI) assessment is a maneuver to appreciate the fitness of the aquatic system by considering all the parameters relevant for determining the ecologically sensitive zone in the coastal stretch. Waters with high TDS are indigestible and potentially unwholesome (Patel & Parikh, 2013). In the present study, TDS values also varied from 19.86 to 24.22 g/l at the experimental seasons. In aquatic ecosystems, total dissolved solids are composed mainly of phosphates, carbonates, bicarbonates, chlorides, and nitrates of sodium, magnesium, manganese, potassium, organic matter, salt, and other particles (Mahananda et al., 2010).

Seasonal Variation in Nutrient Characteristics

Light penetration is a crucial nutritional component in all aquatic systems. The nutrient profile of coastal water always varies faster than that of fresh water. Light penetration of the Chattogram coastal zone varied from 8.05 to 11.70 cm throughout different seasons, and from 9.10 to 10.73 cm at four sampling locations. Photosynthesis requires light penetration. According to the graphical presentation, the light presentation in St. 4 should be greater than 10.63 cm. This coast site's dominant particle is mud rather than sand, silt, or others, which are composed of muddy shore and always mix up water and mud. That's why light penetration is low, similar to St. 4. Light penetration varies seasonally, depending on temperature, weather conditions, coast profile coastal composition, sediments, etc. Variations in phytoplankton, transparency, oxidation, and nitrate reduction may all contribute to variations in nitrite nitrogen ions (Talukder et al., 2016). Less freshwater intake, increased salinity, and a higher pH during the post-monsoon were the causes of the low nitrite content of 0.87µg/l. The amount of phosphorus in phosphate also varied significantly from the pre-monsoon to the post-monsoon, whereas $p<0.05$. High concentrations are visible during the monsoon as a result of increased salinity, regeneration, and phosphate release from the bottom into the aquatic pole due to turbulence and mixing processes (Kumar et al., 2015). In the Chattogram coastal area, the concentration of phosphate phosphorus varied between 0.221 µg/l and 0.844µg/l. The above graphical statistic shows that both the fluctuation of NO_2-N and PO_4 depend on light penetration.

Conclusion

Assets along the coast and in estuaries are essential to ecology and financial stability. Water quality governs the whole ecosystem, directly or indirectly. Presently, factories and several mills have been set up on the banks of the Chattogram coastal area. They discharge their effluent through the poor drainage system, which falls into the Karnafully River and adjacent coastal areas. Chattogram shipbreaking yard is in Foujdarhat, Bangladesh, along the 18-kilometer (11-mile) Sitakunda coastal strip. They also discharge the ship's trash into the sea, resulting in continuous crude oil spill, which is happening illegally. Physicochemical parameters fluctuate seasonally, which is remarkable for our coastal region. As a result, the health of the coastal waterways is gradually deteriorating. Since prehistoric times, Bangladesh's coastline region has played a vital role in the country's financial development by providing a variety of aquatic resources. Proper actions should be taken to protect this critical region from the deterioration of water quality for the sake of future generations.

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Compliance With Ethical Standards

Authors' Contributions

MR: Designed the study, Data acquisition, Data analysis, Drafting primary manuscript, Final approval, and Accountability
DP: Data analysis and drew table
NB: Data analysis and drew table
RM: Replying reviewer comments and drawing map
MS: Partial draft writing and reviewing
ZP: Data analysis and drew figure
TR: Data analysis and drew figure
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 Statement

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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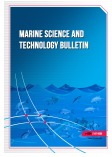

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RESEARCH ARTICLE

An application of the DEA-cross efficiency approach in Turkish dry-bulk and general cargo terminals

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ABSTRACT

Dry bulk and general cargo terminals are the facilities that should quickly adapt to global supply chain dynamics. Each loading/unloading, conveying, horizontal carriage and temporary storage process involves complex organizational structures and procedures. Planned physical investments may lead to inefficiency under dynamic environmental conditions and may also result in a waste of resources. This study aims to examine the technical efficiency of dry-bulk and general cargo terminals in Türkiye with DEA cross-efficiency and DEA Slacks-based models. The findings imply that the terminals handling iron and steel are more efficient than the others. Besides, on average, the dry bulk and general cargo terminals can achieve higher output levels with fewer infrastructures and handling equipment. Therefore, it may be appropriate for the terminals examined to revise their resource utilization rates and short-term investment strategies. Moreover, since it allows pair-wise comparisons of terminals handling similarly featured cargo, DEA cross-efficiency can play a crucial role in dry-bulk performance measurement. Input slacks of relatively inefficient terminals are also calculated.

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Introduction

Seaports are the critical actors in linking sea and land transportation (Antão et al., 2016). It is quite remarkable that the competition between the actors of the port industry is increasing day by day (Fancello et al., 2019). In addition, new trends in international trade, characterized by the globalization of consumption habits, greatly increase the importance of container transportation with its technical and economic advantages (Corbett & Winebrake, 2008). Ports, located at the interface of maritime and inland transportation, play an important role in the transportation (Notteboom et al., 2000).

Increasing marine traffic intensity, integration of logistics services also impacts the global supply of raw materials

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classified as dry bulk and general cargo handling demands (Tovar & Wall, 2015; Balci et al., 2018). Increasing ship sizes, triggered by economies of scale strategies, forced dry bulk and general cargo bulk terminals to review their infrastructure and equipment (Wu & Lin, 2015). On the other hand, quick handling with high-tech equipment, optimizing berth allocation to prevent delays, increased storage and providing multi-modal accessibility to the land and sea hinterland push dry-bulk and general cargo terminals to a competitive market. A market established with competitive elements can prevent monopolization and result in service improvement through innovative initiatives (de Langen & Pallis, 2005). However, fierce competition may cause the decrease of profitability of terminal operators and the quality of service (Figueiredo de Oliveira & Cariou, 2015).

The performance of dry-bulk and general cargo terminals is crucial for regional competition and national development strategies. The positive effects of the high performance go beyond the gradual increase in traffic volume. Due to their critical role in the supply chain, these terminals impact related activities such as marine insurance, finance and logistics. They create added value and employment, which affects regional and urban development prospects. In this sense, dry-bulk and general cargo terminal managers are interested in external benchmarks besides internal key performance indicators (Peckham, 2019). Minimizing costs and risks while doing so are the main goals for port managers. In this context, it is crucial to use performance indicators to achieve these goals (Antão et al., 2016). The scarcity of resources frequently makes infrastructure and equipment investments and efforts to improve operational performance riskier. Other factors can be highlighted as crucial when determining terminal performance related to the more organizational side of production, such as how effectively ports use inputs to produce current output and comply with technologies adopted by terminals. Therefore, efficiency measurement should be carried out upon any infrastructure or equipment investment, and medium or long-term investment decisions should be made with a balanced perspective between technical infrastructure and value-added service quality.

In this study, considering the heterogeneous structure of dry bulk and general cargo terminals, the DEA cross-efficiency model (Lim & Zhu, 2015) was applied under input-oriented (IO), variable returns to scale (VRS) production technology. Averaged appraisal by peers were calculated to rank the terminals in terms of efficiency levels. Moreover, similar terminals for handled cargo characteristics such as steel and iron were subjected to pair-wise comparisons in the cross-efficiency matrix, to reveal more accurate inferences.

Improving technical efficiency is crucial for managers to maximize the profitability of a seaport terminal. In this context, it is argued that this approach can pave the way for dry bulk and general cargo terminals to be examined more frequently, and it can be used as an effective benchmarking method in such heterogeneous environments. To our knowledge, this study is the first in the literature of dry-bulk and general cargo terminal efficiency. From this perspective, it will contribute significantly in both a theoretical and empirical manner.

The following section summarizes relevant literature on the container ports evaluated with DAE approaches. The material and methods section summarizes DEA and DEA cross-efficiency, the data and selected input/output variables. The results and discussion section represents the analysis results and comparison of relevant literature. Finally, the conclusions section summarizes the conclusions and limitations of this study and makes recommendations for further research.

Literature Review

Organizations should continually evaluate operations or processes related to products, services, marketing, and others to increase their performance. Performance evaluation techniques through benchmarking are searching for best practices to improve performance and increase productivity when no goals or engineering standards exist. Defining service standards is more complex than defining production standards. Therefore, benchmarking is mainly used to manage service operations. However, in comparisons to be made regarding a system, it is another challenge to evaluate the decision units in the system with more than one criterion and possible different performance metrics of these criteria. Moreover, this issue gets more problematic when the relationships between performance measures involve unknown interactions. Therefore, Data Envelopment Analysis (DEA) is widely used in many areas. DEA is a flexible approach to evaluating systems or operations that include multiple performance measures. Cooper et al. (2011) stated that the DEA is a data-driven approach evaluating the performance of similar decision units (DMUs) that transform multiple inputs into multiple outputs. The purpose of performance evaluation with the DEA is to examine the efficiency of a DMU and compare it with decision units to determine best practices. It is impossible to include every input and output of the production process and form the performance criteria in DEA into the model in all cases. Therefore, efficiency comparisons can be made with more

general inputs and outputs. In performance evaluation, by comparison, inputs and outputs can be physical inputs and outputs of a production process or general performance criteria. In the first case, an efficiency score is obtained, while in the latter, a composite performance index is obtained. DEA is a very convenient technique for evaluating operational processes. Because it is easy to adapt the data to the model and the fact that the mathematical model to be established does not require any distributional assumptions, unlike parametric models. This adaptability and flexibility of DEA have come to the fore in cases where other approaches cannot be used due to the complex structure between multiple inputs and outputs.

DEA is frequently used to evaluate the efficiency of seaports. Several studies in the literature are to examine the performance of seaports with DEA (Wiśnicki et al., 2017; Yüksekyıldız & Tunçel, 2020; Kim et al., 2022; da Costa, 2021; Jeh et al., 2022; Efecan & Temiz, 2023). Martinez-Budria et al. (1999) examined the efficiency of Spanish container ports via DEA-BCC and investigated the relationship between efficiency and managerial complexity. Further, Cullinane et al. (2004) analyzed the change in the efficiency of 25 container terminals using DEA window analysis. Cullinane & Wang (2006) evaluated the European container ports using CCR and BCC models to figure out the scale efficiency levels and existing production technology. Moreover, Schøyen & Odeck (2013) analyzed the efficiency of Northern Europe and the UK container ports with traditional DAE approach. Santiago et al. (2021) examined the financial and operational efficiency of Spanish container ports with a two-stage bootstrap DEA model. Wu et al. (2010) obtained the efficiency ranking of 77 container terminals worldwide using DEA cross-efficiency and presented benchmarks for inefficient terminals using cluster analysis. Similarly, Kim et al. (2022) evaluated Korean terminals with cross efficiency and cluster analysis. As known, two-stage models incorporated with DEA have been proposed commonly for the seaport efficiency measurement. Güner (2015) examined the Turkish seaports with a two-stage DEA model. The author argues two sequential steps that appear in the seaport operating process by assuming the outputs from the first stage are the inputs to the second stage. Port managers aim to maximize the freight handled and the number of served ships by using the existing resources in the first stage. Then, maximize the revenue from handling freights and served ships in the second stage. It is concluded that the two-stage DEA approach provides more proper results than those in single-stage DEA when there are sequential stages. In recent research, Baştuğ (2023) applied the DEA-SCOR model to Turkish container ports in the context of BRI (One Belt and One Road Initiative) and concluded that four large terminals are the most efficient gateways to handle inward and outward container traffic with their input variables. However, there are some challenges in port investment for BRI. BRI is related to some Turkish seaports close to the main Asia-Europe routes. Therefore, it can be inferred that the location of a seaport can be a significant heterogeneity factor. Therefore, benchmarked terminals should be as possible as homogenous. To draw inferences about technological changes of each terminal over the years. Baran & Górecka (2015) adopted Malmquist Total Factor Productivity in addition to the traditional DEA models. Yüksekyıldız & Tunçel (2020) evaluated the efficiency of container ports in Türkiye with Fuzzy Data Envelopment Analysis. The main idea behind working in a fuzzy environment was to get more flexible efficiency scores due to the imprecise data. Apart from technical efficiency, the researchers also assessed related handling issues. For instance, Arslan et al. (2021) evaluated the efficiency of maritime supervision services in dry-bulk terminals. Jeh et al. (2022) assessed the global terminal operators based on the operation characteristics and found that when the terminal infrastructure was expanded, the efficiency was improved. However, the returns to scale and technical change factors in the productivity change trend decreased. This result implies decreasing returns to scale production technology, and the infrastructure or equipment investments should be decided under these circumstances. On the other hand, despite the increasing focus on such new services provided in seaports and efforts to adapt to the supply chain and changing technologies, existing literature focuses predominantly on container terminals, overlooking the critical role of dry bulk and general cargo terminals. Possible reasons for the intense interest in container terminals can be the desire of researchers to reflect on the rapidly ongoing containerization on a global scale in their studies or the standard shape of containers. However, scientific studies on the efficiency of dry bulk and general cargo terminals are limited (Balci et al., 2018). Merk & Dang (2012) evaluated the efficiency of dry-bulk and general cargo terminals by dividing them into coal, iron and grain groups. This categorization related to the type of cargo may be linked to a desire to obtain homogenous benchmarking DMU sets. As conclusion, there was an efficiency potential of up to seventy per cent, especially in grain terminals. Suliman et al. (2019) similarly examined the technical efficiency of dry-bulk cargo terminals in Malaysia with DEA. They drew attention to the high performance of the terminals examined in the study in which they tried to create an appropriate empirical framework

for frontier-based relative efficiency measurement. Lee et al. (2014) and Balci et al. (2018) argued that the crucial role of dry bulk and general cargo terminals in the supply chain has been ignored in the literature. In addition, Schott & Lodewijks (2007) investigated what can be done for the handling, conveying and storing of bulk cargoes in the Le Havre-Hamburg region, while Bal & Esmer (2015) investigated the operational processes of liquid bulk cargo terminals in Turkey. Balci et al. (2018) examined the competition between dry cargo terminals. They concluded that even though dry cargo terminal selection criteria are similar to container terminals, their criteria importance weights are different. Denktaş Şakar & Uzun (2021) examined the role of dry bulk and general cargo terminals in the supply chain from the perspective of customer profiles in the Aliağa Region. They state that the characteristics of the service provided are at least as important as operational efficiency. Their findings revealed the service features of Aliağa terminals should be improved in a supply chain-oriented manner and the customers also attach importance to value-added service features.

As can be seen clearly from the relevant literature, relative efficiency measurement applications on dry bulk and general cargo terminals are quite limited. Due to the heterogeneity and the unique organizational structures of dry-bulk and general cargo terminals, there is lack of a proper measurement method. In this context, DEA cross efficiency method can be a proper alternative to the relevant literature as it is also applied to container ports and provide beneficial inferences in Wu et al. (2010) and Kim et al. (2022).

Material and Method

Charnes et al. (1978) (CCR hereafter) first introduced DEA-CCR, which gives a total efficiency estimate to draw inferences about what input and output ratio should be achieved in a production process. The CCR approach enabled efficiency evaluation with multiple inputs and outputs using linear programming instead of Farrell's (1957) linear fractional programming technique to measure productive efficiency, which caused controversy in the literature. Thus, the CCR model has gained substantial popularity in the relevant literature. Banker et al. (1984) (BCC hereafter) introduced the DEA-BCC, which makes up the piecewise linear convex frontier model. This technique can separate the scale efficiency from the total efficiency and determine the pure technical efficiency. Thus, it enables drawing inferences about production technology. The BCC model is the standard DEA model commonly used for technical efficiency estimation.

DEA analyses can be made based on the assumptions of production technologies that bring constant (CRS) or variable returns to scale (VRS), or they can be input or output-oriented. Input-oriented models are used to determine how much the inputs of inefficient DMUs should be reduced to achieve a certain output level, and output-oriented models are used to determine how much the outputs should be increased for inefficient DMUs to become effective. Within the scope of the study, it is assumed that the scales of DMUs change their efficiency values. Therefore, the input-oriented variable return to scale assumption is considered. The established efficiency model assumes that production output is exogenously given and inputs[1] should be minimized. Besides, it was assumed that the handling volume (TEU) must be high enough for the port management to cover fixed investment costs and make a profit. If high enough volumes are handled, the handling fee per container can represent almost the entire port activity. In this sense, DEA is a particularly suitable tool for evaluating the efficiency of service businesses, with this type of data condition (Sherman & Zhu 2006). For a dry-bulk and general cargo terminal, it is impossible to control demand. However, it may be possible to minimize inputs to achieve same output level. Therefore, it is assumed that output is given exogenously and the inputs should be minimized. In this context, an input-oriented (IO) VRS model in multiplier form can be written as following Eq. (1):

$$max \quad \sum_{r=1}^{s} u_r y_{r0} - \xi$$

$$s.t. \quad \sum_{i=1}^{m} v_i x_{ij} - \sum_{r=1}^{s} u_r y_{rj} + \xi \geq 0, \qquad j = 1, \dots, n$$

$$\sum_{i=1}^{m} v_i x_{i0} = 1$$

$$v_i, u_r \geq \varepsilon \; \forall i, r, \xi \text{ free in sign.} \qquad (1)$$

[1]Due to the difficulty in accessing confidential input prices, this study focused on technical efficiency.

It is assumed that there are n DMUs consuming m inputs to produce s outputs. DMU $k(k = 1, 2, \dots, n)$ uses a vector of inputs $x_k = (x_{1k}, \dots, x_{mk})^T \in R_+^m$ to produce a vector of outputs $y_k = (y_{1k}, \dots, y_{sk})^T \in R_+^s$ where ε is non-Archimedean infinitesimal.

For DEA, it is known as a commonly known rule to select a DMU set consisting of at least twice the total number of inputs and outputs (Golany & Roll, 1989). Banker et al. (1989) suggests at least three times the total number of inputs and outputs. In fact, these rules do not have a statistical basis and are not mandatory. However, they are frequently applied in the literature because they make it easier to distinguish DMUs from each other in terms of their efficiency scores. In addition, the number of samples should not be too small and should be sufficient to allow a partial border to be obtained.

Although DEA is an effective method for determining the best practice frontier, its flexibility in weighing multiple inputs and outputs and its self-assessment nature have been criticized. The cross-efficiency method was developed as an extension of DEA (Sexton et al., 1986). The idea behind this approach is to use DEA for peer assessment rather than pure self-assessment. The cross-efficiency approach has two crucial advantages over traditional DEA approaches (CCR and BCC). The first is to ensure ranking among DMUs, while the latter is to eliminate unrealistic weighting schemes without the need for weighting constraints obtained by using experts' opinions (Anderson et al., 2002).

Solving the model given in Eq. (1), the efficiency score of DMU_0 and the cross-efficiency scores of other DMUs evaluated by DMU_0 are obtained together. The cross-efficiency score is specific to DMU_j is written as following Eq. (2):

$$e_{0j} = \frac{\sum_{r=1}^{s} u_r^* y_{rj} - \xi^*}{\sum_{i=1}^{m} v_i^* x_{ij}} \quad (2)$$

The "⋆" in Equation (2) represents the optimal solution of the model. In cases where the free variable $\xi > 0$, the value calculated with Eq. (2) may be negative. This situation poses a problem in terms of determining efficiency scores. Averaging e_{ij} over i, a cross-efficiency score of DMU_j is obtained. To overcome this problem, Lim & Zhu (2015) suggest an alternative formulation given in Eq. (3) to calculate non-negative cross-efficiency scores under the VRS option.

$$e_{0j}^{o} = \frac{\sum_{r=1}^{m} v_r^* x_{rj}}{\sum_{r=1}^{s} u_r^* y_{rj} - \xi^*} \quad (3)$$

Cross-efficiency approach has been used in various fields, such as nursing homes (Sexton et al., 1986), preferential voting (Green et al., 1996), and selection of industrial R&D projects (Oral et al., 1991). However, as highlighted in Doyle & Green (1994), the non-uniqueness of DEA optimal weights/multipliers likely reduces the usefulness of the cross-efficiency scores. Specifically, the cross-efficiency scores obtained from the traditional DEA are generally non-unique and depend on alternative optimal solutions to DEA linear programs. Sexton et al. (1986) and Doyle & Green (1994) propose using a secondary objective to deal with non-unique DEA solutions. In this study arbitrary formulation is considered as formulated in Doyle & Green (1994). For more detail, see Doyle & Green (1994). Proposed cross-efficiency matrix is given in Table 1.

Table 1. Cross-efficiency matrix (Adapted from Doyle & Green, 1994)

Ranking DMU	**Ranked DMU**						**Averaged appraisal of peers**
	1	***2***	.	.	.	***22***	
1	$E_{1,1}$	$E_{1,2}$	.	.	.	$E_{1,22}$	A_1
2	$E_{2,1}$	$E_{2,2}$	.	.	.	$E_{2,22}$	A_2
.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.
22	$E_{22,1}$	$E_{22,2}$	.	.	.	$E_{22,22}$	A_{22}
	e_1	e_2	.	.	.	e_{22}	

Averaged appraisal by peers (peer appraisal)

Note: Simple efficiencies are in the leading diagonal. $E_{22,2}$ is the cross-efficiency accorded DMU-2 using DMU-22's weights. A and e are averaged without the leading diagonal, which is self-appraisal.

Table 2. Main characteristics of the terminals (TURKLIM, 2023)

DMU	Sub-region	Mainly Handled Cargo	Terminal Name	Throughput (mt)		
				2020	*2021*	*2022*
1	İskenderun	Iron and steel	İsdemir	12,641,715	13,817,579	12,679,955
2	Zonguldak	Coal	Eren	9,598,411	8,618,846	10,075,942
3	Karadeniz	Iron and steel	Erdemir	10,264,136	11,210,065	9,624,318
4	Mersin	General*	MIP	7,597,805	8,225,217	8,732,800
5	İskenderun	Steel and coal	Atakaş	6,065,210	8,513,717	8,182,862
6	İskenderun	Iron and steel	MMK	6,468,293	7,434,830	6,558,959
7	Marmara	Iron and steel	İçdaş	9,970,728	9,773,590	6,332,000
8	İzmir	Iron and steel	İDC	4,244,999	4,749,629	5,609,073
9	Karadeniz	Iron and steel	Yeşilyurt	5,421,909	5,580,908	5,575,650
10	Kocaeli	Cement	Nuh Çimento	5,245,845	5,297,874	5,529,368
11	Aliağa	General*	Batıliman	5,161,060	5,168,043	5,111,533
12	Çanakkale	General*	Çelebi Bandırma	3,876,200	4,377,533	4,386,561
13	İskenderun	Iron and steel	Ekinciler	2,879,628	3,602,393	4,172,882
14	Mersin	Cement	Yeşilovacık	3,989,976	3,771,348	4,061,556
15	Marmara	Iron and steel	Çolakoğlu	5,367,859	4,609,419	3,848,601
16	Gemlik	General*	Borusan	2,856,862	3,486,395	3,456,744
17	Ceyhan	General*	Torosport	3,719,727	2,465,759	3,400,201
18	Tekirdağ	General*	Ceyport	N/A	2,867,191	3,230,579
19	Samsun	General*	Ceynak Samsun	3,382,910	3,230,604	3,230,579
20	Tekirdağ	General*	Martaş	2,864,928	2,982,995	3,050,135

Note: * "General" labels mean various types of dry-bulk or general cargo instead of a specific one is handled. ** "mt" is defined as metric tons to represent the weight of cargo.

Since inconsistent results will be obtained if incorrectly determined input and output variables are included in the model, inputs and outputs should reflect the main objectives of the dry bulk and general cargo port as accurately as possible (Cullinane & Wang, 2006). Input data of 20 dry-bulk and general cargo terminals in Turkey covering the year of 2022; compiled from the annual reports of the Turkish Port Operators Association (TURKLIM, 2023). Output data of the terminals is also gathered from the same source covering the year of 2022 (TURKLIM, 2023). Data not included in the reports regarding input were accessed from the official websites of the examined terminals. The terminals examined are concentrated in the Eastern Mediterranean, Aegean – Aliağa and Marmara. Main characteristics of the terminals are given in Table 2.

When the literature is examined, it is seen that the annual cargo handled (mt) is the main output of a dry-bulk and general cargo terminal (Merk & Dang, 2012; Suliman et al., 2019). This value can represent almost all port activities, such as conveying, storage and discharge, as the handling service is directly or indirectly related to other services. Seaport terminal managers aim to maximize the annual handling amount. Therefore, in the relative efficiency analysis, the cargo handled in 2022 on a metric ton basis was taken as the only output variable.

The operation of dry-bulk and general cargo terminals at optimum capacity, in other words, the efficient use of existing resources, depends on the maximum use of the facilities for the shortest ship accommodate period (Bugaric & Petrovic, 2007). In this regard, infrastructure adequacy (berth dimensions, depth), efficient use of storage area and handling equipment come to the fore.

DEA has been used as a measurement method in many seaport efficiency models. The unique structures of bulk cargo ports make it difficult to measure performance and carry out evaluations. The lack of clarity on common standards on measures makes relative performance analysis even harder (Esmer, 2008). Therefore, it is assumed that technical equipment and infrastructure inputs that are as similar as possible constitute a proxy for other unobserved inputs. In these frontier-based models, direct inputs and outputs are quietly similar (Cullinane et al., 2006; Cullinane & Wang, 2006; Baran & Górecka, 2015; Serebrisky et al., 2016) and represent

technical equipment and infrastructure. Dry-bulk and general cargo handling services, which consist of loading, unloading, conveying, storage and discharge processes, are carried out with basic direct input combinations. These combinations of inputs represent direct investments in the infrastructure and superstructure of a dry-bulk and general cargo terminal. The decision-maker can significantly increase the handling amount by various strategic managerial decisions. Inputs frequently used in dry-bulk and general cargo terminals: total terminal area "area" (hectare), "total berth length" (m) where ships dock and the "length" (m) of the berth where handling operations are carried out, and the "equipment" (pieces) which is the total number of shore cranes used in handling operations. These variables constitute the direct inputs of the efficiency frontier model of the study. Merk & Dang (2012) also stated that these selected inputs are the physical inputs required to handle dry bulk and general cargo. The literature related to the bulk terminal efficiency is limited. However, container transportation is quite similar to determine measurable direct inputs. For instance, Cullinane & Wang (2006) examined the European container ports with a cross-sectional DEA framework using the same inputs such as terminal length (m) and area (m) and handling equipment (pcs). Cullinane et al. (2006) and Kim et al. (2022) considered the similar input combination on container ports and compared data envelopment analysis and stochastic frontier analysis. The different aspect of this study was the inclusion of yard handling equipment. These types of handling equipment are not unique and vary between terminals. Therefore, a problem can be occurred in the case of an input exists with a value of zero. Bulk cargoes generally take longer to be unloaded than loaded, as the operations cannot use the same combination of gravity and conveyor belts. Therefore, modeling efficiency based on the time the ship stays at the berth or the loading rate may lead to incorrect interpretations.

Results and Discussion

R computer software with deaR (Coll-Serrano et al., 2023) community contributed package was utilized to perform efficiency analyzes. The descriptive statistics of inputs and output variables are presented in Table 3. While the average berth length used for handling service is 1477.65 meters, the total number of shore cranes is 9.15, and the storage area is 18.101 hectares.

The storage area and the equipment utilized draw attention with its high standard deviation. The reason for this may be that the bulk cargo terminals examined differ in terms of the cargo handled. In this context, some types of cargo are temporarily stored in open storage areas due to their feature, while others are in silos. Similarly in some dry bulk terminals, the conveyors are in use to load the cargo, while others are using grabs to discharge cargo. This heterogeneous structure requires a pair wise comparison of terminals providing temporary storage services of the same features.

Table 4 represents the cross-efficiency matrix of the efficiency measures of the observed terminals. The column mean represents the efficiency, and the row mean represents the differentiated features of each terminal. Higher column averages of the terminal indicate higher efficiency and lower row averages indicate that the terminal is different from others (Kim et al., 2022). Dry bulk and general cargo terminals in Turkey have relatively large column mean, ranging from 0.502 to 0.972. On the other hand, a relatively small row range, from 0.504 to 0.831.

Table 3. Descriptive statistics of inputs and output variables

Variable	Obs	Mean	Std. Dev.	Min	Max
Output					
Average handling throughput (mt)	20	5842.515	2709.341	3050.135	12679.955
Inputs					
Berth length (m)	20	1477.650	772.386	500.000	3370.000
Storage area (Ha)	20	18.101	18.904	2.262	86.125
Handling equipment (pcs)	20	9.150	3.911	2.000	20.000
Depth (m)	20	19.165	5.898	11.000	32.000

Table 4. Cross efficiency matrix - Arbitrary formulation

DMU	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	A	Rank
1	**1**	0.943	0.615	0.793	1	0.608	0.842	0.588	0.678	0.666	0.575	1	0.573	0.491	1	1	0.692	0.855	0.731	0.687	***0.767***	**8**
2	0.918	**1**	0.493	1	0.740	0.14	0.635	0.665	0.352	0.270	0.441	0.819	0.407	0.516	1	1	0.672	0.697	0.558	0.364	***0.634***	**16**
3	0.977	0.927	**0.618**	0.626	1	0.555	0.979	0.544	0.528	0.541	0.613	1	0.451	0.297	0.922	1	0.595	1	0.643	0.503	***0.71***	**12**
4	0.745	1	0.522	**1**	0.884	0.108	1	0.708	0.339	0.233	0.491	0.988	0.464	0.404	1	0.849	0.604	0.655	0.549	0.377	***0.646***	**15**
5	1	1	0.575	1	**1**	0.344	0.708	0.607	0.641	0.529	0.502	0.898	0.565	0.657	1	0.993	0.714	0.733	0.685	0.676	***0.741***	**9**
6	0.746	0.728	0.544	0.914	0.768	**0.943**	0.743	0.575	0.918	0.934	0.515	0.987	0.744	1	1	0.778	0.765	0.623	0.831	1	***0.803***	**2**
7	0.195	0.397	0.286	0.930	0.325	0.087	**1**	0.635	0.251	0.206	0.335	1	0.713	1	0.779	0.297	0.455	0.255	0.510	0.424	***0.504***	**20**
8	0.571	0.821	0.349	1	0.461	0.035	0.883	**1**	0.141	0.084	0.348	0.896	0.240	0.312	1	0.727	0.529	0.503	0.371	0.127	***0.520***	**19**
9	0.989	0.878	0.576	1	1	0.889	0.683	0.566	**1**	0.900	0.502	0.908	0.678	0.938	0.983	0.916	0.757	0.679	0.776	1	***0.831***	**1**
10	0.737	0.728	0.550	0.898	0.782	0.942	0.760	0.575	0.917	**0.935**	0.522	1	0.746	0.951	1	0.773	0.758	0.629	0.832	1	***0.802***	**3**
11	0.958	0.916	0.616	0.611	1	0.546	1	0.537	0.519	0.533	**0.614**	1	0.445	0.287	0.910	0.983	0.584	1	0.635	0.494	***0.709***	**13**
12	0.737	0.728	0.550	0.898	0.782	0.942	0.760	0.575	0.917	0.935	0.522	**1**	0.746	0.951	1	0.773	0.758	0.629	0.838	1	***0.802***	**4**
13	0.563	0.696	0.522	0.973	0.823	0.442	0.800	0.576	0.822	0.702	0.498	1	**0.781**	1	0.960	0.643	0.698	0.530	0.779	1	***0.740***	**10**
14	0.563	0.696	0.522	0.973	0.823	0.442	0.800	0.576	0.822	0.702	0.498	1	0.780	**1**	0.960	0.643	0.698	0.530	0.779	1	***0.740***	**11**
15	0.910	0.970	0.471	1	0.674	0.138	0.595	0.670	0.331	0.259	0.424	0.795	0.395	0.557	**1**	1	0.679	0.680	0.551	0.343	***0.622***	**17**
16	0.898	1	0.558	0.76	0.836	0.169	0.974	0.651	0.355	0.292	0.550	1	0.399	0.299	1	**1**	0.616	0.852	0.579	0.354	***0.657***	**14**
17	1	0.844	0.543	0.97	0.799	0.839	0.652	0.578	0.827	0.826	0.487	0.898	0.651	1	1	0.947	**0.781**	0.679	0.776	0.862	***0.798***	**7**
18	0.860	0.836	0.496	0.536	0.595	0.207	1	0.585	0.273	0.275	0.556	1	0.313	0.209	0.925	1	0.554	**1**	0.540	0.260	***0.601***	**18**
19	0.737	0.728	0.550	0.898	0.782	0.942	0.760	0.575	0.917	0.935	0.522	1	0.746	0.951	1	0.773	0.758	0.629	**0.832**	1	***0.802***	**5**
20	0.737	0.728	0.550	0.898	0.782	0.942	0.760	0.575	0.917	0.935	0.522	1	0.746	0.951	1	0.773	0.758	0.629	0.832	**1**	***0.802***	**6**
e	***0.792***	***0.828***	***0.525***	***0.884***	***0.793***	***0.513***	***0.817***	***0.618***	***0.623***	***0.585***	***0.502***	***0.959***	***0.579***	***0.688***	***0.972***	***0.843***	***0.671***	***0.689***	***0.681***	***0.673***		

Table 5. Efficiency ranks and input slacks of the terminals

DMU	Efficiency Rank	Cross-efficiency score[1]	SBM Efficiency	Berth length (m)	Storage area (Ha)	Handling equipment (pcs)	Berth depth (m)
İsdemir	8	0.792	1	0	0	0	0
Eren	5	0.828	1	0	0	0	0
Erdemir	18	0.525	0.546	1386.748	11.652	1.294	11.294
MIP	3	0.884	1	0	0	0	0
Atakaş	7	0.793	1	0	0	0	0
MMK	19	0.513	0.657	241	78.025	2.4	0
İçdaş	6	0.817	1	0	0	0	0
İDC	15	0.618	1	0	0	0	0
Yeşilyurt	14	0.623	1	0	0	0	0
Nuh Çimento	16	0.585	0.703	368	24.75	2	0
Batıliman	20	0.502	0.539	713.643	8.790	1.777	14.476
Çelebi Bandırma	2	0.959	1	0	0	0	0
Ekinciler	17	0.579	0.566	1000	2	5	3
Yeşilovacık	10	0.688	1	0	0	0	0
Çolakoğlu	1	0.972	1	0	0	0	0
Borusan	4	0.843	1	0	0	0	0
Torosport	13	0.671	0.632	352.506	5.647	4.959	3.959
Ceyport	9	0.689	1	0	0	0	0
Ceynak Samsun	11	0.681	0.592	352.795	6.533	3.772	2.076
Martaş	12	0.673	1	0	0	0	0
Average		0.712	0.862				

According to the findings of the cross-efficiency analysis represented in Table 4, it is possible to make pair wise comparisons between terminals handling similar cargoes. For the cross-efficiency scores, based on the set of optimal weights, the performance and rank of terminals may vary. Therefore, the prices without further consideration cannot be used (Jahanshahloo et al., 2011). However, in light of the information given in Table 3, a pair wise comparison can be performed. For instance, İSDEMİR and MMK are two major iron and steel terminals serving in the same sub-region. In terms of cargo tonnage handled, it is seen that İsdemir handles approximately twice as much cargo.

The simple efficiency score of İSDEMİR is 1 and the score of the MMK is 0.94. When İsdemir was evaluated using the coefficients of the MMK terminal, the efficiency score was estimated to be 0.665. On the other hand, when MMK is evaluated using İSDEMİR's coefficients, the estimated efficiency score is 0.608. Similarly, the simple efficiency scores of İÇDAŞ and ÇOLAKOĞLU terminals located in the Marmara sub-region, which handle iron and steel intensively, are both 1. In this case, it can be said that İÇDAŞ and ÇOLAKOĞLU are fully efficient in terms of technical efficiency with their own weights. The efficiency level of ÇOLAKOĞLU is estimated to be 0.59 when evaluated with the input coefficients of the İÇDAŞ terminal. However, the efficiency level of the İÇDAŞ estimated, using the input weights of the ÇOLAKOĞLU is 0.78. Merk & Dunk (2012), in their efficiency evaluation of dry-bulk and general cargo terminals, found that iron-steel and grain terminals are more efficient than terminals that handle other types of cargo. They implied this finding was due to unique cargo features that can quickly adapt to the current developments in port technologies. In alignment with Merk & Dunk (2012), our finding simply that most efficient dry-bulk and general cargo terminals are iron and steel terminals handling heavier cargo in terms of tonnage output.

In addition to the IO-VRS cross efficiency (Lim & Zhu, 2015), the well-known IO-VRS Slacks-Based (SBM) DEA proposed by Tone (2003) is applied to figure out efficiency ranks and input slacks of the terminals and is shown in Table 5. The findings imply that Yeşilyurt, MMK and Nuh Çimento are

[1] Averaged appraisal by peers

the most efficient terminals. Contrarily, İçdaş, İDÇ and Ceyport are the least in terms of efficiency. These terminals can use the resources more efficiently, considering the technical infrastructure and equipment required to perform the handling processes. On average, the current output can be achieved with %16.8 less input. IO-VRS SBM model also provide beneficial information to draw inference regarding input slacks of relatively inefficient terminals. As shown in Table 5, Erdemir, MMK, Nuh Çimento, Batıliman, Ekinciler, Torosport and Ceynak Samsun can perform handling processes with less inputs. For instance, ERDEMİR can handle the same amount of output with 1386,8 meters less pier length, 11.65 Ha less storage area and 1.29 pcs less handling equipment.

Conclusion

Dry bulk and general cargo terminals are the facilities that should quickly adapt to global supply chain dynamics. Each loading/unloading, conveying, horizontal carriage and temporary storage process involves complex organizational structures and procedures. In addition, they are likely to face many risks in terms of safety depending on the physical and chemical structure of the cargo handled. Therefore, technical and operational efficiency should be given importance, and infrastructure and equipment should be evaluated together with the right strategies. For this, decision-makers need to determine dynamic strategies that take environmental conditions into account. Planned physical investments may lead to inefficiency under dynamic environmental conditions and may also result in a waste of resources. In this study, the efficiency of major dry-bulk and general cargo terminals in Türkiye was evaluated using DEA cross-efficiency. It is concluded that relatively most efficient terminals are iron and steel cargo handlers. It can be said that the intensity of the iron and steel can play a crucial role in this result. In pair wise comparisons, it can be argued that Yeşilyurt and MMK are the most efficient two iron and steel terminal. Nuh Çimento terminal draw attention as being other than a iron or steel terminal. According to the results, on average, it can be implied that higher output levels can be achieved in dry-bulk and general cargo terminals in Türkiye with less infrastructure and shore handling equipment. Therefore, it may be appropriate for the terminals examined to review their current resource utilization and investment strategies. Instead of increasing physical infrastructure and equipment investments, effectively implementing digitalization shaped by an environmentally friendly and sustainable perspective can make a significant contribution to the output level and increase the efficiency of other value-added services of the terminals. Although shore handling equipment seems unproblematic during the operation process, it may not be efficient due to environmental factors. By using artificial intelligence in berth planning, the berth occupancy rate, and thus, the crane utilization rate in handling operations can increase. In addition, reducing the horizontal transport distance by using less space will reduce the cargo on the transport equipment and carbon emissions, and will have a positive impact on the performance of the shore cranes. In this way, while the traffic flow within the terminal will be eased, it can be possible to develop an environmentally friendly strategy. As a result, technical efficiency can be increased by reaching higher handling levels with fewer inputs. In conclusion, improving technical efficiency can lead to higher productivity, lower costs, and improved competitiveness for the dry-bulk and general cargo terminals in the port sector. This application of the DEA-cross efficiency approach on dry-bulk and general cargo terminals is the first in the literature. It allows pair wise comparisons of terminals handling similar featured cargo. In this respect, the study will make significant contributions to the literature. The easy applicability of the method used shows that it is suitable for efficiency measurement in similar sectors and business lines.

The study is based on cross-sectional data that can be considered as a limitation. Because it could not be possible to draw inferences about technological changes of each terminal over years, which can be possible by a Malmquist Total Factor Productivity evaluation. By increasing the number of DMUs in future studies, it may be possible to integrate current clustering approaches into cross-efficiency analysis and make more accurate efficiency evaluations. Moreover, it paves the way to figure out technological improvements for each DMUs. To generalize the results, more comprehensive works must be carried out. As pointed out by Cullinane et al. (2004), to get a deeper insight about the inefficiency determinant, a two-stage analysis may be performed to consider observable heterogeneity factors such as location. Moreover, due to the difficulty in accessing confidential input prices, this study could not draw inferences about cost efficiency and lies around the technical efficiency. Lastly, for cross efficiency method, the weights used to calculate scores are not unique, and therefore much of the discussion in the literature is a about how appropriate weights can be selected (Balk et al., 2021).

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.

Data Availability Statement

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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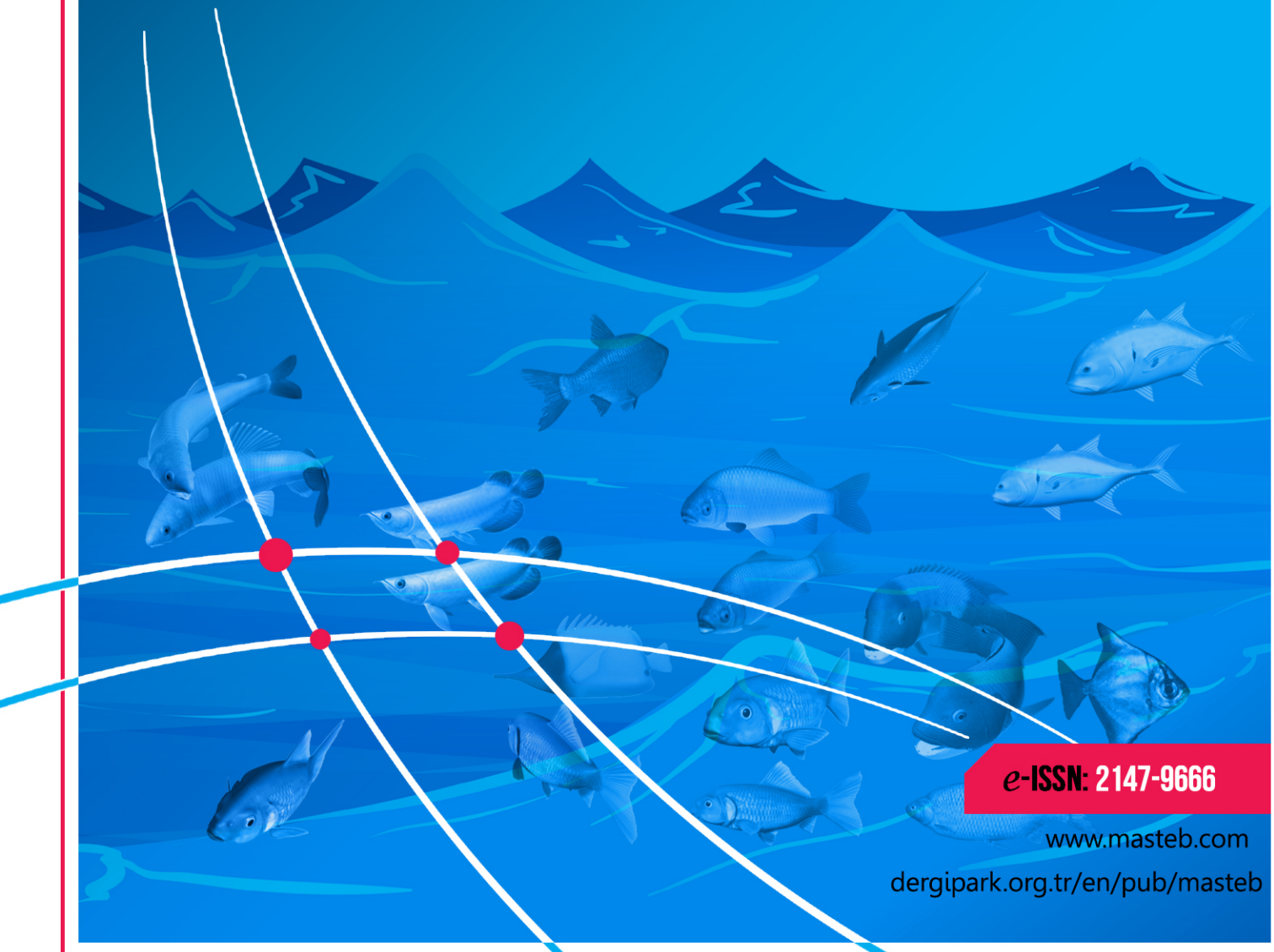

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