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Original Budapest Open Access Initiative Declaration

An old tradition and a new technology have converged to make possible an unprecedented public good. The old tradition is the willingness of scientists and scholars to publish the fruits of their research in scholarly journals without payment, for the sake of inquiry and knowledge. The new technology is the internet. The public good they make possible is the worldwide electronic distribution of peer-reviewed journal literature and completely free and unrestricted access to it by all scientists, scholars, teachers, students, and other curious minds. Removing access barriers to this literature will accelerate research, enrich education, share the learning of the rich with the poor and the poor with the rich, make this literature as useful as it can be, and lay the foundation for uniting humanity in a common intellectual conversation and the quest for knowledge.

The literature that should be freely accessible online is that which scholars give to the world without expectation of payment. Primarily, this category encompasses their peer-reviewed journal articles, but it also includes any unreviewed preprints that they might wish to put online for comment or to alert colleagues to important research findings. There are many degrees and kinds of wider and easier access to this literature. By "open access" to this literature, we mean its free availability on the public internet, permitting any users to read, download, copy, distribute, print, search, or link to the full texts of these articles, crawl them for indexing, pass them as data to software, or use them for any other lawful purpose, without financial, legal, or technical barriers other than those inseparable from gaining access to the internet itself. The only constraint on reproduction and distribution, and the only role for copyright in this domain, should be to give authors control over the integrity of their work and the right to be properly acknowledged and cited.

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

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

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

II. Open-access Journals: Second, scholars need the means to launch a new generation of journals committed to open access, and to help existing journals that elect to make the transition to open access. Because journal articles should be disseminated as widely as possible, these new journals will no longer invoke copyright to restrict access to and use of the material they publish. Instead, they will use copyright and other tools to ensure permanent open access to all the articles they publish. Because 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.

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

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

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

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Double-Blind Review and Evaluation Process

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All the studies submitted to *Marine Science and Technology Bulletin* are evaluated by double-blind review method according to the following steps.

1. Initial Evaluation Process

The studies submitted to *Marine Science and Technology Bulletin* are first evaluated by the editor. At this stage, studies that are not in line with the aim and scope of the journal, are weak in terms of language and narrative rules in English contain scientifically critical mistakes, are not original worthy and cannot meet publication policies are rejected. Authors of rejected studies will be notified within one month at the latest from the date of submission. Eligible studies are sent to the field editor to which the study is relevant for pre-evaluation.

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".

Referees can decide on the suitability of the study by reviewing the corrections and may also request multiple corrections if necessary.

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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.

2. *Methodology:* The evaluation report includes information on the suitability of the method used, the choice and characteristics of the research group, validity and reliability, as well as on the data collection and analysis process.

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.

7. *Overall evaluation:* The evaluation report contains opinion on the authenticity of the study as a whole, its contribution to the educational literature and the applications in the area.

The journal considers that scientists should avoid research which kills or damages any species of fish which, using IUCN criteria, is regarded as threatened or is listed as such in a Red Data Book appropriate for the geographic area concerned. In accordance with this view, papers based on such research will not be accepted by the Journal, unless the work had clear conservation objectives.

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TABLE OF CONTENTS

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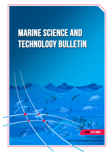

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RESEARCH ARTICLE

A novel frontier in the geographic distribution of the Japanese sea cucumber *Apostichopus japonicus* (Selenka, 1867) (Stichopodidae: Holothuroidea) in the world

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ABSTRACT

The natural distribution of the Japanese sea cucumber (*Apostichopus japonicus* Selenka, 1867), a sea cucumber species, is characterized by the Northwest Pacific. Long-term monitoring studies from 2020 to 2024 document a significant deviation from the known natural distribution of *A. japonicus* and its ability to extensively colonize the Gulf of Izmit, the easternmost part of the Sea of Marmara. This record is also the first documentation of the species from the Mediterranean Sea. Population data extracted from 67 samples allowed the determination of size and weight distribution, length-weight relationship, and condition factor. The study delves into the implications for fisheries management by evaluating the species' dispersion beyond its natural range and its adaptation, shedding light on potential threats from illegal hookah diving fisheries. While its presence offers potential economic benefits through fishing income, its emergence as an invasive species can pose critical ecological risks to the receiving ecosystem.

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Introduction

Sea cucumbers, scientifically known as holothuroids, constitute a diverse group of marine invertebrates, with approximately 1200 species distributed across the world's seas. They inhabit a variety of ecosystems, including coral reefs, shallow tropical coasts, and globally diverse marine environments (Aydın, 2016). Beyond their ecological importance, these organisms serve as integral components of aquatic ecosystems and stand as vital economic assets for fisheries in numerous coastal regions worldwide (Purcell et al., 2023). Sea cucumbers are deposit feeders, engaging in the consumption of diatoms and bacteria mixed with seafloor debris, thereby contributing significantly to the regulation of particulate organic matter covering benthic vegetation on hard reef surfaces (İşgören-Emiroğlu & Günay, 2007; Purcell et al., 2016). Notably rich in nutritional content (Çakli et al., 2004), sea cucumbers have been a preferred food source globally for centuries, particularly in Far East countries (Aydın et al., 2023). These creatures play a crucial role in aquatic ecosystems, serving as effective sources of income for fisheries worldwide (Dereli & Aydın, 2021).

Japanese sea cucumber (*Apostichopus japonicus* Selenka, 1867) is an echinoderm species belonging to the family Stichopodidae. Its distribution extends to the temperate waters of the Northwest Pacific, including Japan, China, the Korean Peninsula, and Far Eastern Russia, creating vital communities within shallow seawater habitats (Park et al., 2013; Purcell et al., 2023). Typically, this species inhabits from the intertidal zone to depths of 40 m. Substrate, salinity, water temperature, and habitat are factors that affect the distribution of the species (Lysenko et al., 2018; Purcell et al., 2023). The habitat of *A. japonicus* encompasses diverse coastal environments, where juveniles frequently inhabit areas characterized by the presence of algal and seagrass beds, along with oyster colonies (Minami et al., 2018). Within these habitats, *A. japonicus* plays a vital ecological role as a detritivore, consuming a wide array of organic matter, including diatoms, protozoa, bacteria, as well as animal and plant detritus. Furthermore, it efficiently re-utilizes residual food and fecal matter, contributing significantly to nutrient cycling processes within its ecosystem (Hamel & Mercier, 2013; Lysenko et al., 2015). The most economically important species, *A. japonicus*, is sold dried for $3000 per kilogram, at least twice as expensive as products from other holothurians (Purcell et al., 2018). This economic significance has led to substantial exploitation, resulting in declines in population abundance across its range. So, this species is listed as Endangered in the IUCN Red List of Threatened Species due to the decreasing population trend (Hamel & Mercier, 2013).

The sea cucumber assemblage comprises 37 species distributed among nine families in the Mediterranean Sea, nine of which are documented from Turkish seas (Aydın, 2016). This study presents the first documented occurrence of *A. japonicus* in the Sea of Marmara (SoM), in the easternmost part of the Mediterranean Sea, a significant deviation from its known natural geographical distribution. The research aims to understand the factors contributing to the species' presence and expansion in this distant region in the Mediterranean Sea by synthesizing existing literature. This study not only expands our understanding of the species' geographic range but also offers a crucial paradigm for comprehending marine ecosystem dynamics, influencing future research on species adaptability and conservation strategies in the broader context of the Mediterranean Sea.

Material and Method

The study area covers the coasts of the Gulf of Izmit located southeast of the SoM, which includes the Mediterranean General Fisheries Commission (GFCM) Geographical Sub-Area 28. The inception of the study transpired within the context of a biodiversity survey conducted on January 22, 2020, wherein researchers fortuitously encountered three *A. japonicus* samples in a specific geographical area. Extensive interviews were conducted with local fishing cooperatives and divers in the study area to confirm the recent presence of the species. This qualitative inquiry, coupled with insights from the fishing community, corroborated the existence of the sea cucumber species. As of this discovery in 2020, a longitudinal monitoring study was initiated to understand the dynamics of this newfound presence comprehensively. Several samples were also recorded during SCUBA surveys of another sea cucumber project carried out under the responsibility of the authors (TÜBİTAK project numbered 122Y004, covering the years 2022-2023). The monitoring studies incorporated a participatory approach involving citizen science. A total of 42 citizen reports covering the period 2021-2023 were diligently compiled through active engagement with individuals within the community. These reports served as vital inputs for expanding the understanding of the existence and distribution limits of the species. In conjunction with citizen participation, SCUBA diving was strategically carried out at regular intervals. These underwater surveys aimed to document and validate the extent of the *A. japonicus* systematically.

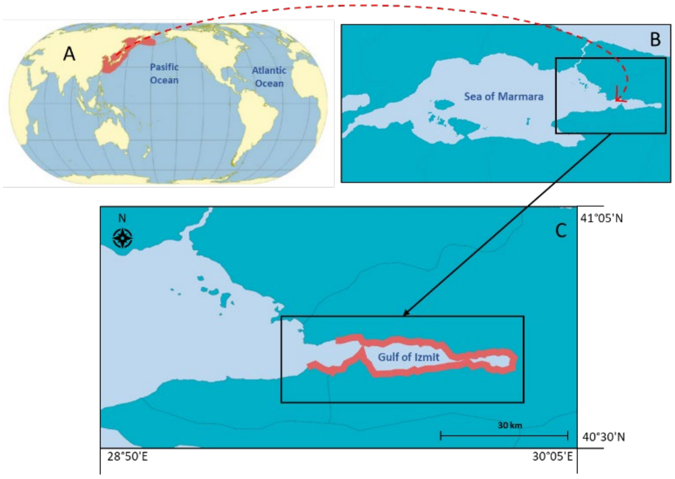

Figure 1. Map of the natural distribution area of *Apostichopus japonicus* (A - Drawn by Purcell et al., 2023) and its new distribution areas in the Gulf of Izmit (C) in the Sea of Marmara (B). The red solid line in C represents the distribution area for the first record in the Sea of Marmara.

Samples were identified according to the holothurian taxonomic identification key (Purcell et al., 2023), and their scientific name was checked from SeaLifeBase (Palomares & Pauly, 2023). The morphological characteristics of the identified specimens were systematically examined. The sea cucumber showcases three distinct ventral color variations: red, green, and black. These color types are accompanied by differing morphological characteristics (Choe, 1963). Dorsally, one may observe small dots ranging from brownish to greyish, while these dots tend to be more abundant on the ventral side. Its body shape is square in cross-section, tapering slightly towards both ends. Notably, large conical papillae are arranged in loose rows along the dorsal surface and in two rows at the lateral margins of the ventral surface. Ventral podia are arranged in three irregular longitudinal rows. The mouth is located ventrally and is surrounded by 20 tentacles. Lastly, the anus is situated terminally and lacks teeth (Purcell et al., 2023). This comprehensive morphological examination ensures accurate species identification and contributes to the broader understanding of the species' visual attributes (Figure 2).

For molecular and population studies, 67 samples were collected from depths of 3-20 m in long-term monitoring studies that lasted from the beginning of 2020 to the end of 2023. Collected samples were transported to the Ordu University Faculty of Marine Sciences Fisheries Laboratory in specialized tanks filled with seawater, providing optimal conditions for further examination. Given the dynamic nature of holothurians, where size and weight may vary due to morphometric measurements, particular attention was given to the potential impact of their ability to extract and expel internal organs or relax (González-Wangüemert et al., 2014). The samples were temporarily stored in plastic tanks filled with seawater during the transport. Subsequently, a meticulous procedure was employed for the extraction of internal organs. A longitudinal incision, approximately 3 cm in length, was made along the lateral surface of each specimen, allowing for the removal of the respiratory tree, gonads, and digestive tract (Aydın, 2019). A prompt measurement of the length from the mouth to the anal orifice of the sample was performed to mitigate potential size contraction post-gutting. Gutted length (GL in cm) measurement, crucial for accurate morphometric analysis, was executed using an ichthyometer with a precision of 0.1 cm. Simultaneously, the body weight (GW in g) was measured using a digital balance with a precision of 0.01 g.

The relationship between size and weight (LWR) was estimated employing Pauly's power equation: $W = aTL^b$, where W represents total gutted weight (GW in g), TL is the gutted length (GL in cm), and a and b denote regression parameters, representing the intercept (initial growth coefficient) and slope (growth coefficient), respectively. This equation was further utilized in its logarithmic form: $\ln(GW) = \ln(a) + b \cdot \ln(GL)$ (Ricker, 1975). Post-examination of curvilinear plots, outliers in GL and GW were excluded from the logarithmic analysis, as recommended by Froese (2006). Subsequently, 95% confidence limits (*CI*) for parameters a and b were calculated, and the coefficient of determination (r^2) was employed to assess the correlation between GW and GL. Pauly's *t*-test (Pauly, 1984) was employed to ascertain if the *b*-value coefficient significantly deviated from 3, determining whether species growth is isometric or allometric (Sokal & Rohlf, 1969). Additionally, Fulton's coefficient of condition factor (K) was calculated using the formula $K = 100[GW/(GL^3)]$, where GL is the gutted length, and GW is the gutted weight of the specimen (Froese, 2006). All statistical analyses were conducted using SPSS Ver. 26 software.

For genetic analysis, tissue samples were taken from the body wall of two specimens. DNA was extracted by using Genomic DNA Isolation Kit (AMBRD) according to the user's manual. Mitochondrial Cytochrome c oxidase subunit I (COI) sequences were partially amplified from the isolated DNA by PCR. PCR mixture included 10 ng of genomic DNA, 5 µl of 5X PCR Master Mix (AMBRD), 0.1 µM of each primer and final volume was 25 µl. PCR steps were as follows: initial denaturation at 95°C for 2 min; 30 cycles of denaturation at 95°C for 30 s; annealing at 50°C for 30 s; extension at 72°C for

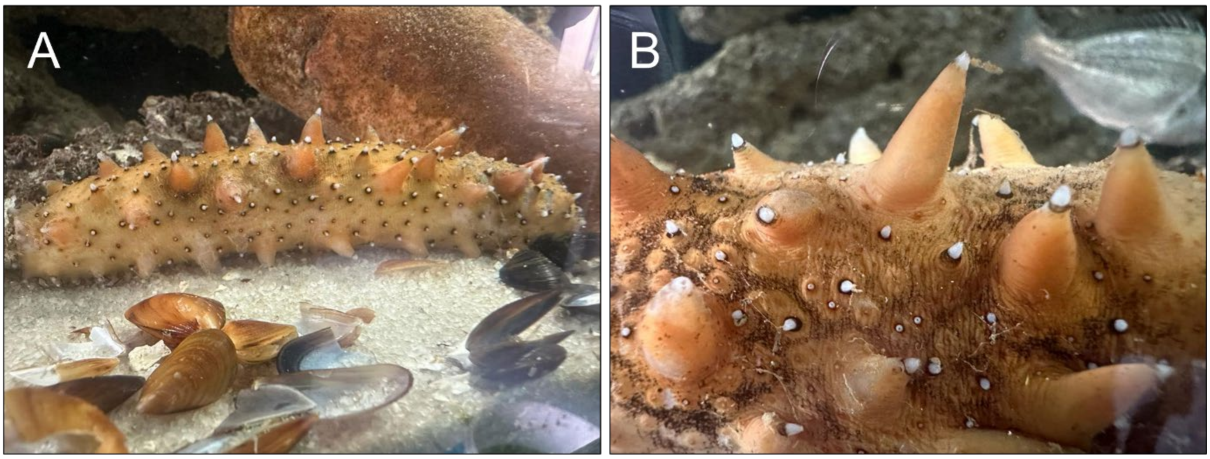

Figure 2. External appearance (A) and morphologically characterized papillae (B) of the *Apostichopus japonicus* (Photo: Dr. Aydın)

1 min. The PCR was completed with a final extension step at 72°C for 5 min. COIeF and COIeR primers were used to amplify 692 bp part of the COI gene (Arndt et al., 1996). Products were sequenced both ways (Macrogen Inc., Seoul, South Korea).

Chromatograms were manually checked and primer sequences were removed. The sequences were deposited in the NCBI GenBank (PP334764 and PP334765). Phylogenetic analysis was conducted on MEGA X platform (Kumar et al., 2018). With BLAST search highly similar sequences and related *Holothuroidea* spp. sequences obtained from NCBI GenBank were included for phylogenetic analysis. Sequences were aligned automatically and trimmed to minimize missing characters. The final data matrix consisted of 600 bases. The best-fit model of evolution was determined using the Akaike information criterion (Akaike, 1974) implemented in MEGA X. "GTR+G+I" was determined to be the best-fit model. Maximum Likelihood (ML) analysis was tested with 1000 bootstrap replicates. *Protelpidia murrayi* was used as outgroup.

Results and Discussion

The discovery of *A. japonicus* in the SoM is the first record for the Mediterranean Sea and marks a significant geographical range expansion worldwide. Previous records confined the presence of this species to specific areas along the coastal areas of northeast Asia (Choe, 1963; Takahashi, 2003; Hamel & Mercier, 2013; Purcell et al., 2023), making the current finding a noteworthy extension of its known distribution (Figure 1). The identification of *A. japonicus* in the SoM not only contributes valuable data to the understanding of its ecological preferences but also raises intriguing questions about the factors influencing its dispersion. The hypothesis implicating ballast water of ships as a key factor for the transportation of *A. japonicus* is indeed compelling. The SoM is a crucial maritime transportation route with international circulation. According to official records (Kocaeli Governorship, Port Area in the Gulf of Izmit Report), Kocaeli Port ranked first with a share of 19% in the regional distribution of the number of ships calling at Turkish ports in 2021. The vast majority (6,669 ships with 69.8%) of the ships entering the Gulf of Izmit were foreign-flagged ships. The prevalence of foreign-flagged ships entering the Gulf of Izmit underscores the potential role of maritime transport in facilitating the translocation of *A. japonicus* to SoM. Human activities such as alternative fishing sources, aquaculture, or deliberate releases for biocontrol purposes may contribute to the spread of the species beyond its natural range. Additionally, the impact of climate change on the distribution patterns of marine species must be considered. Environmental changes, including global warming, can alter the distribution patterns of sea cucumbers (Uthicke et al., 2009; Scannella et al., 2022). If *A. japonicus* is adaptable and able to thrive in a broader range of conditions, it could naturally expand its distribution. The SoM may have environmental conditions such as temperature, salinity, and substrate type that are suitable for *A. japonicus*.

The first *A. japonicus* samples were recorded in the Gulf of Izmit on January 22, 2020. Throughout the monitoring studies, samples were found to be irregularly limited to a few individuals until the end of 2022. By 2023, significant densities have been recorded commonly distributed along approximately 40 km of coastline, indicating successful colonization. According to the monitoring studies covering the period 2020-2024, the species is distributed at depths of 3-20 meters in the region but is densely distributed at depths of 10-11 meters. The average abundance is approximately 80-100 individuals per 100 m^2. By the second half of 2023, it was recorded that an average of 300-400 individuals were recorded during a one-hour dive in different regions of the Gulf of Izmit. Such a high abundance indicates the successful settlement and reproduction of the *A. japonicus* in the Gulf of Izmit. The adaptability and phenotypic plasticity exhibited by certain species can be instrumental in their successful colonization of new environments (Yuan et al., 2018). *A. japonicus* may have evolved mechanisms to tolerate a diverse range of environmental conditions within the SoM. Considering the adaptation and colonization of *A. japonicus* in the SoM over time shows that various environmental parameters, including the temperature range suitable for gametogenesis, larval development, and settlement, are compatible with the reproductive requirements of the species. The plasticity in physiological and behavioral traits could be advantageous, allowing the species to acclimate to varying substrate types, water temperatures, and salinities (Morgan, 2008; Sun et al., 2018). The establishment of symbiotic relationships with native organisms or the exploitation of vacant ecological niches represents another avenue for successful colonization (Azevedo e Silva et al., 2023). *A. japonicus* may have formed ecological partnerships or adapted its feeding strategies to exploit available resources efficiently. The absence of natural predators in the SoM may emerge as a pivotal factor contributing to the successful colonization of *A. japonicus*. This absence may confer a significant ecological advantage, allowing the sea cucumber to proliferate without the constraints of predation pressure. Due to the colonization of the SoM, *A. japonicus* may compete with native holothurian species and consequently constitute a potential danger for them. Over time, populations of *A. japonicus* in the SoM may have undergone evolutionary changes, potentially enhancing their adaptability to the local environment.

A total of 67 specimens of *A. japonicus* were collected in the study area. GL and GW of the population exhibited a broad range, spanning from 7.5 to 21.0 cm and 12.51 to 122.74 g, respectively. The histogram distribution curve revealed a right-skewed trend (Figure 3), indicating a predominance of juvenile individuals within the population. Considering that the length of first sexual maturity begins at approximately 20 cm size (Palomares & Pauly, 2023) or 110 g body weight (Purcell et al., 2023), it is noteworthy that only a small part of the population (4.5% in both size and body weight, n=3) has reproductive potential. The existence of adult individuals capable of reproduction creates the potential for the sustainability of the population over time. Comparisons with previous studies from the natural distribution areas reveal recorded diverse sizes, with the largest reported size of 33 cm documented by Minami et al. (2018) in Maizuru Bay in the Sea of Japan. The observed size distribution in the SoM may be attributed to various regional factors, with significant impacts documented in the literature. Notably, the size distribution of *A. japonicus* appears to be predominantly influenced by its adaptive capacity to cope with physical environmental stressors, as opposed to being driven by the biotic and chemical properties of the water and substrate (Chen et al., 2022; Huo et al., 2024). Diverse factors significantly shape the size distribution of holothurians, and this pattern is particularly evident in populations facing challenges such as illegal fishing (Purcell et al., 2010). Interviews with fishermen's associations in the Gulf of Izmit revealed that *A. japonicus* was frequently collected illegally by hookah or SCUBA divers. *A. japonicus* juveniles remain in the leaves of rocky reefs and later migrate to deeper, muddy silt areas as adults (Arakawa, 1990), making them more vulnerable to illegal fishing. Illegal fishing activities that result in the loss of large individuals reflect the trend in size distribution and have been identified as a vital risk factor to the sustainability of populations.

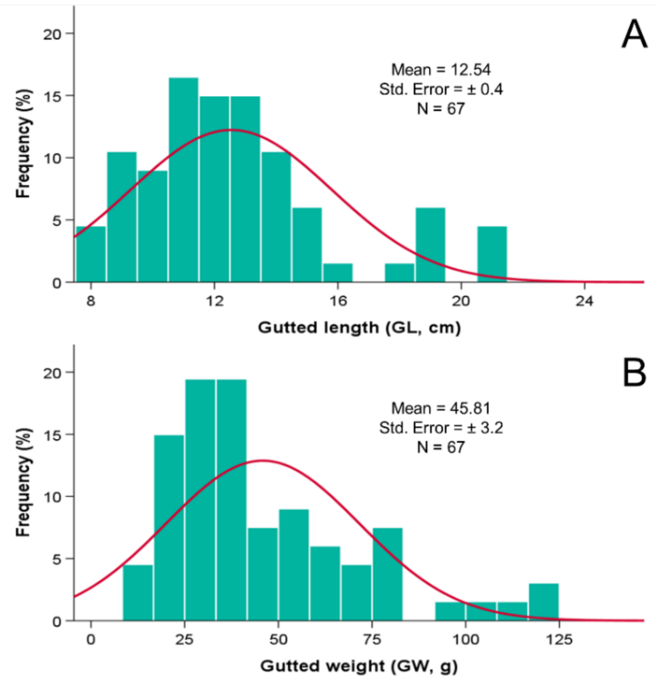

Figure 3. Histogram chart of gutted length (A) and gutted weight (B) of the *Apostichopus japonicus* in the Sea of Marmara. Red lines represent the normal curve of the population

Table 1 provides detailed information on the population structure and statistical data relevant to evaluating the LWR of *A. japonicus*. The calculated LWR equation was determined as $GW = 0.2669GL^{2.0033}$. The estimated *b* value was significantly lower than 3 (*t*–test, $t_{67} = 10.531$, $p < 0.05$), indicating a negative allometric growth pattern within the population. This finding aligns with limited previous studies (Dong & Zhou, 1984; Zhan et al., 2019) and suggests that as the specimens grow, their weight does not increase proportionally, reflecting potential ecological and environmental influences on growth. Various factors contribute to the observed negative allometric growth, including changes in environmental parameters, nutritional conditions, sex, reproductive status, seasonal variations, and the physiological state of the holothurians. Food competition, overfishing, and the trophic potential of marine ecosystems may be identified as potential drivers for this growth pattern (Jennings et al., 2001; Ahmed et al., 2018; Aydın, 2020). Additionally, recent algal blooms in the SoM (Karadurmuş & Sarı, 2022) and intense domestic and industrial pollution in the Gulf of Izmit (Ediger et al., 2016) may indicate poor water conditions, which could directly or indirectly impact the growth of the specimens. The strong correlation between GL and GW ($r^2 \geq 0.85$) suggested a consistent relationship between body size and weight, indicating that size may be a reliable indicator of the weight of *A. japonicus* (Froese, 2006).

Table 1. Estimated length-weight relationship parameters of *Apostichopus japonicus* from the Sea of Marmara (95% *Cl*: confidence intervals)

Population structure	
Sample size (*n*)	67
Length range (GL, cm)	7.5 – 21.0
Weight range (GW, g)	12.51 – 122.74
Regression parameters	
Intercept (*a*-value)	45.979
95% *Cl* of *a*	55.643 – 36.314
Slope (*b*-value)	7.318
95% *Cl* of *b*	6.572 – 8.064
***b* test**	
Coefficient (r^2)	0.85
Pauly's *t*-test	10.531
Growth	Negative allometry

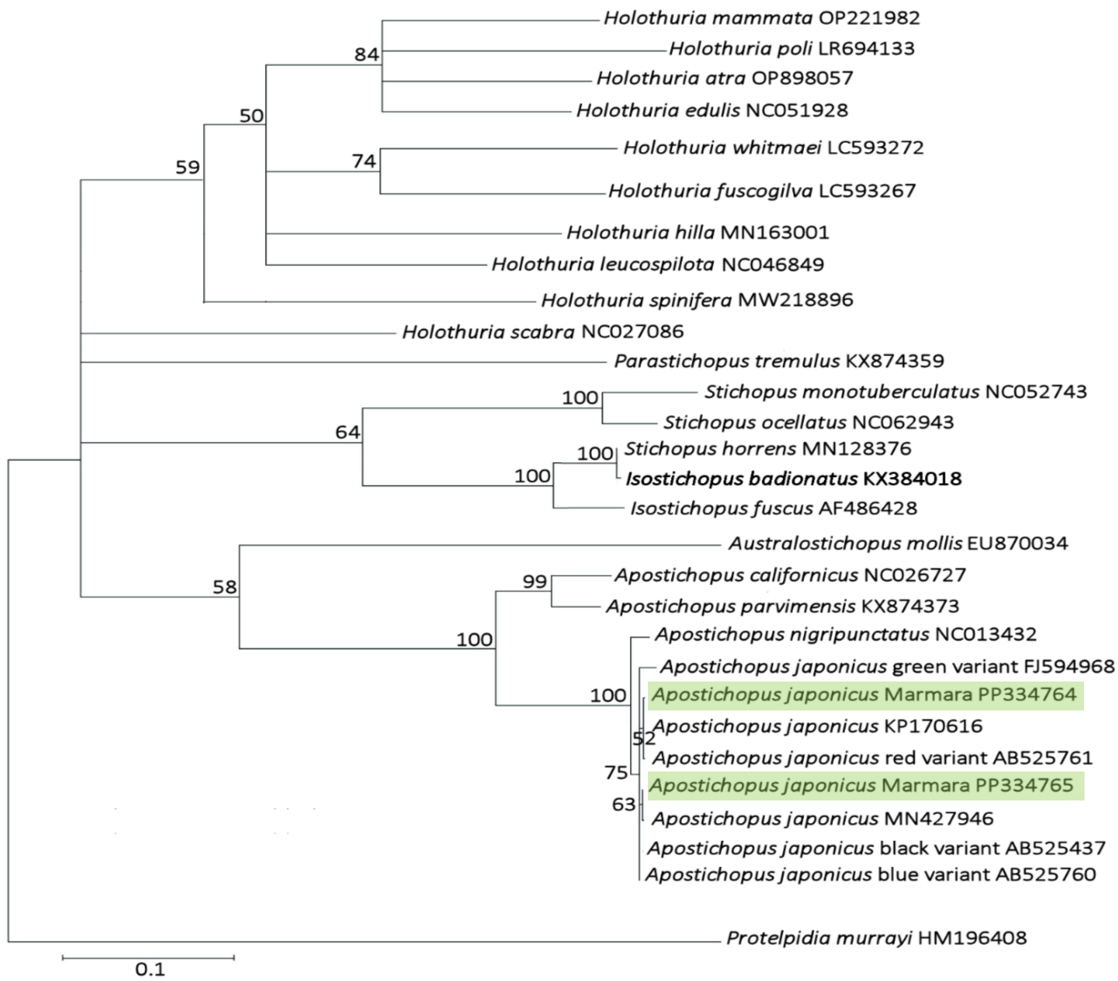

Figure 4. Maximum likelihood (ML) tree obtained by mitochondrial COI gene sequences of the samples from this study and related Holothuroidea spp. sequences deposited in NCBI GenBank. The sequences obtained in this study are painted in green. *Protelpidia murrayi* was used as outgroup. The condensed tree is shown with cut-off value at 50%. Branch support obtained after 1000 bootstrap replicates is indicated above lines. The scale bar is expected changes per site.

The average K value of the population was calculated as 2.32±0.08 (ranging from 0.94 to 4.62) and was significantly higher from optimal growth condition 1 (One-sample *t*-test; df = 66, t = 15.526, $p < 0.05$). The K value provides a holistic perspective of current ecological dynamics, and the higher the K value, the better the condition of the marine organism. Environmental conditions, including temperature, water quality, and habitat structure, may be potential determinants affecting the K value of the population (Froese, 2006). It also reflects the role of food availability, fishing pressure, predation, reproduction capacity, and the complex interaction of these factors (Nash et al., 2006; Aydın, 2020). A high K value of the population may indicate a resilient and thriving population in the SoM in the face of seemingly favorable environmental and social conditions.

The two genetically examined samples had different COI haplotypes, which showed the *A. japonicus* population inhabiting the Sea of Marmara may be genetically heterogenous, most probably due to multiple introductions. BLAST search revealed that the Marmara Sample 2675 (Accession no: PP334764) with a single mismatch showed 99.85% identity with *A. japonicus* from Vladivostok, Russia (Accession no: KP170616), whereas the Marmara Sample 2721 (Accession no: PP334765), again with a single mismatch, showed 99.85% identity with *A. japonicus* specimens from China (Accession no: MN427946) and Yamaguchi, Japan (Accession no: AB525437 and AB525760). The ML phylogenetic tree showed the genus *Apostichopus* is monophyletic and the species are genetically distinct (Figure 4). However, there is no significant genetic difference between the COI sequences of the color morphotypes of *A. japonicus*. These findings are in accordance with Jo et al. (2016).

Conclusion

The discovery of *A. japonicus* in the SoM constitutes a remarkable extension of its known distribution within the Mediterranean Sea, raising multifaceted ecological inquiries. Monitoring studies reveal a significant and successful colonization of *A. japonicus* in the Gulf of Izmit, with dense populations recorded at specific depths. The observed size distribution within the population, skewed towards juveniles, indicates ongoing reproduction and the potential for sustainability. They mature in a much shorter period of two years compared to other temperate climate species (Chen, 2003). The high reproductive capacity of *A. japonicus* (Kang et al., 2017; Zhang & Lai, 2024) guarantees the sustainability of stocks in the SoM. However, the sustainability of species in the SoM faces significant challenges, particularly from illegal hookah or SCUBA diving practices (Karadurmuş & Aydın, 2023). The species is frequently targeted and collected illegally, posing a substantial threat to the stability of stocks. Urgent measures need to be taken to prevent illegal harvesting of the species, especially during spawning periods that coincide with warm seasons (Park et al., 2007; Kang et al., 2017). In addition to the landing quota application, a regulation regarding the minimum landing size (MLS) is recommended to control the stock increase and to consider the sustainability of the species. The presence of this sea cucumber may have both positive and negative repercussions for cohabiting species. The presence of this alien species in the region may eventually lead to serious problems in terms of biodiversity and food competition in the Sea of Marmara. Further research and specific studies are needed to clarify these complex relationships.

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Compliance With Ethical Standards

Authors' Contributions

MA: Conceptualization, Methodology, Formal Analysis, Writing - Original Draft, Writing-Review and Editing, Data Curation, Visualization

UK: Conceptualization, Methodology, Validation, Resources, Writing - Original Draft, Writing-Review and Editing, Supervision

SÜK: Methodology, Writing-Review and Editing

MBY: Methodology, Formal Analysis, Writing - Original Draft, Writing-Review and Editing, Visualization

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.

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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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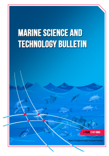

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RESEARCH ARTICLE

The fishery and utilization of flying fish (Exocoetidae) in Guiuan, Eastern Samar, Philippines

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Surface gillnet

ABSTRACT

The flying fish fishery in Guiuan, Eastern Samar, Philippines, serves as a valuable source of livelihood for the local community. This study used both survey methods through face-to-face interviews with the respondents (N=37) and actual catch sampling to assess the socio-demographic profile of the fishers, the fishery, and the utilization of the commonly landed flying fish species in the locality. The survey results showed that the flying fish fishers in Guiuan were male-dominated, showing no participation of women in the capture segment of the fishery. The average number of members of a flying fish fishing household was 5. The majority (68%) of the fishers earned <PHP 5,000.00. All fishers (100%) used surface gillnet made from monofilament netting with an 8.5 cm mesh size in targeting flying fish. The catch rates generally showed a monthly variation as affected by the fishing season of the species. The surface gillnet catch was composed of 8 valuable flying fish species, including: 1) intermediate flying fish *Cheilopogon intermedius* (60%), 2) manyspotted flying fish *Cheilopogon spilopterus* (10%), 3) stained flying fish *Cheilopogon spilonotopterus* (8.7%), 4) Sutton's flying fish *Cheilopogon suttoni* (0.4%), 5) margined flying fish *Cheilopogon cyanopterus* (0.3%), 6) Abe's flying fish *Cheilopogon abei* (0.1%), 7) yellowing flying fish *Cypselurus poecilopterus* (15.6%), and 8) tropical two-wing flying fish *Exocoetus volitans* (4.9%). In terms of usage, 80% of the flying fish catch in Guiuan was utilized for household consumption, with 10% as fresh and 70% as dried, while the remaining 20% served as bait by tuna fishers.

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Introduction

The Philippines, with its 2.2 million km^2 of highly productive seas endowed with diverse fishery resources, is recognized as among the top fish-producing countries in the world (Green et al., 2003; Licuanan et al., 2019; BFAR, 2022). In 2019, the Philippines landed 8th in the world fisheries ranking with a total production of 4.41 MT tons which represented a total of 2.07% of the total world production. The fisheries sector provides for the nutritional needs of the people, helps boost the country's economy, and provides livelihood to millions of fisherfolk. In 2021, the total fisheries production reached 4.25 million MT valued at PHP 302.44 billion. This contributed 12.70% to the country's gross value added (derived as the sum of the value added from agriculture, industry and services sector) in the same year. The 47.12% of the fisheries production which is equivalent to 2 million MT valued at PHP 173.90 billion came from the capture fisheries sector. From this, 26.64% equivalent to 1.13 million MT valued at PHP 112.1 billion came from municipal capture fisheries or small-scale fisheries (Perez et al., 2012; BFAR, 2022). The small-scale fisheries support over 1.1 million municipal or small-scale fishers representing 50.03% of the total number of fisherfolk nationwide (BFAR, 2022). One of the fish resources targeted by the small-scale fishers is flying fish.

Flying fish are small pelagic schooling species belonging to family Exocoetidae. This group of fish is comprised of 71 species belonging to 6 genera, namely: *Parexocoetus*, *Exocoetus*, *Hirundichthys*, *Prognichthys*, *Cypselurus*, and *Cheilopogon* (Indrayani et al., 2020; Tuapetel & Tupan, 2021). Flying fish are found in the tropical and sub-tropical waters (Chang et al., 2012; Lewallen et al., 2018; Gomez et al., 2019). In the Philippines, 11 species belonging to three genera including *Cheilopogon*, *Cypselurus*, and *Hirundichthys* were recorded in the west coast of Surigao del Norte (Gomez et al., 2019). On the other hand, five genera were recorded in Maitum, Sarangani Province namely: *Cheilopogon*, *Cypselurus*, *Hirundichthys*, *Parexocoetus*, and *Exocoetus* (Emperua et al., 2017). Flying fish are well-known for their aquatic gliding ability through their large and elongated pectoral and unsymmetrical caudal fins, in which, they use as mechanism to escape from their predators (Lewallen, 2012; Gomez et al., 2019).

Flying fish contribute significantly to the pelagic catch in coastal zones in tropical and subtropical countries (Emperua et al., 2017). These species are typically targeted for human consumption and as bait for the tuna fisheries (Jayawardane & Dayaratne, 1998; De Croos, 2009). In the Philippines, the fishery of flying fish is an important source of income particularly for the small-scale fishing households (Gomez et al., 2019). Flying fish are among the most common small pelagic species dominating the catch landed by the small-scale fishers in certain coastal areas in the country including the western portion of the Verde Island Passages in the West Philippine Sea, around the Camotes Sea in the Visayan Sea, and in the west coast of Surigao del Norte (Emperua et al., 2017; Gomez et al., 2019). Fishers commonly use surface gillnet, drift gillnet, and drive-in net to catch flying fish (Morales et al., 2016; Emperua et al., 2017; Molina et al., 2018). In Sta. Ana, Cagayan Valley, fishers begin the fishing operations at 5:00 or 6:00 in the morning and last for 3-12 hours (Molina et al., 2018). During the peak months from February to May, the catch is either sold at a very low price or processed into dried product, and sometimes given for free. On the other hand, flying fish catch in Maitum province is sold as fresh or processed through marinating which was said to be a potential business in the area (Emperua et al., 2017).

In Guiuan, Eastern Samar, Philippines, the fishery of the flying fish locally known as "iliw" is a valuable source of livelihood and one of the major species constituting the total fisheries production of the province. Flying fish landings in Eastern Samar in the last five years (2018-2022) reached 665.04 MT (PSA OpenStat, 2023). However, despite the importance of flying fish to the local fisheries of Guiuan, there has been limited scientific information about the fishery. To the best of the authors' knowledge, no studies have yet addressed the detailed information about the fishery. Thus, this study on the fishery and utilization of flying fish in Guiuan, Eastern Samar, Philippines was conducted to provide valuable information on the current profile and status of the fishery. Specifically, this study aimed to: (1) determine the general socio-demographic profile of the flying fish fishers, (2) determine and describe the fishing gear used, (3) describe the fishing practices employed by the fishers, (4) examine the catch composition and catch rate, and (5) assess the utilization of flying fish as a local commodity in Guiuan, Eastern Samar. The results may serve as a critical baseline that can be used by the concerned institutions in developing effective management strategies for the sustainability of the fishery in the area.

Materials and Method

Study Site and Duration

This study was conducted in the municipality of Guiuan, Eastern Samar, Philippines (Figure 1) from March to June 2023.

This research was primarily conducted at the two landing sites at Taytay, Guiuan namely: 1) Pangpang, and 2) Sabang. These are the only landing sites at Taytay which is one of the coastal communities in Guiuan with the highest population of flying fish fishers. According to the records of Taytay Fisherfolk Association, the community has 40 flying fish fishers representing 57% of the total flying fish fishers in the municipality.

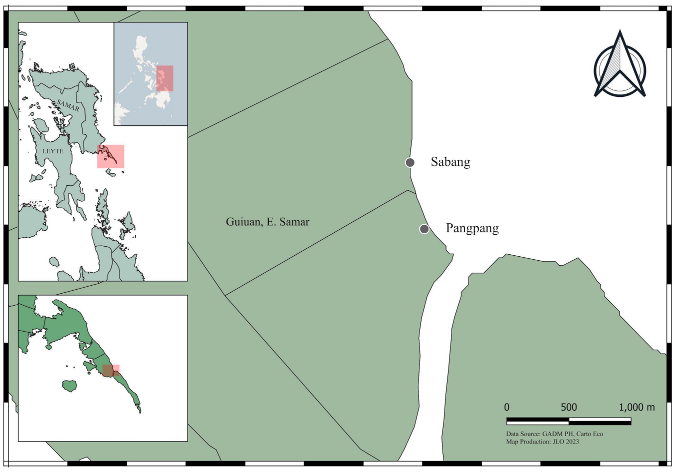

Figure 1. A map showing the study sites (Sabang and Pangpang) in Guiuan, Eastern Samar, Philippines

Study Design

This study involved both survey and actual catch sampling. The survey was conducted in-person with the 37 target respondents (flying fish fishers) using a semi-structured questionnaire. An actual catch sampling and on-site observation of the fishery were also carried out to validate the data collected during the interview (i.e., fishing gear and methods employed, catch rate and composition).

Survey Instrument and Respondents

The survey instrument consisted of several questions focusing on the general demographic and fishery profile of the respondents. The demographic profile included the respondent's gender, age, civil status, education and household information. On the other hand, the fishery profile concentrated on the fisher's experience in the fishery, income, type of fishing gear used, fishing practices, catch composition, catch rate, and catch utilization. The instrument was deployed through Kobo Collect, an open-source offline mobile application for collecting survey data. A total of 37 (92.5%) flying fish fishers of Taytay, Guiuan were successfully interviewed in this study. Prior to the interview, the fisher respondents were given a consent form to ensure their voluntary participation. Few (3) of the fishers were not able to participate in the survey due to the conflict of schedule.

Catch Sampling Procedure

Catch sampling was carried out on a weekly basis in the two landing sites (Pangpang and Sabang) from March to June 2023, to verify and expand the information acquired from the study. A total of 1,000 random flying fish samples were taken for the entire sampling duration. The sampling was done by the shore at around 3:00 PM, after the fishers had returned from their fishing operations. The samples were measured for their total length (cm) using a standard 150-cm tape measure, and weighed for their body weight (g) using a digital weighing scale with 1 g sensitivity. The catch rate was also verified during the actual catch sampling and onsite observation by directly obtaining the count and weight of the catch from the fishers when they are about to sell their catch. On the other hand, identification of the flying fish and other species were done using Carpenter & Niem (1999), White et al. (2013), and Froese & Pauly (2023).

Data Processing and Analysis

All data collected during the survey with the respondents were sent to the Kobo Toolbox server. From there, the data were downloaded in an excel file type. These were then processed accordingly and analyzed using descriptive statistics. The catch rate which was expressed as catch per unit effort (CPUE) was calculated as the number of individuals or pc/panel and pc/hour. The length-weight relationships (LWRs) were estimated using the log form of the growth equation (Ricker, 1973):

$$W = aL^b$$

wherein, W is the expected body weight (g), L is total length (cm); a (constant) is the intercept or initial growth coefficient, and b (constant) is the slope of the regression line. The analyses were performed in Microsoft Excel 2019. A product flow map was used to show how flying fish are utilized in the area.

Results and Discussion

The demographic and fishery data of the flying fish fishers of Guiuan, Eastern Samar, Philippines are presented in Table 1. The data show that the flying fish fishers in the locality were all males, showing no participation of women in the capture segment of the fishery. Typically, fishing is classified as predominantly male-oriented work, with women having a limited role in the fisheries industry. In the Philippine fishing communities, women are usually not involved in the fishing operations. They generally stay at home to do the traditional household chores such as meal preparation, and providing care for the children and the elderly members of the family (Mutia et al., 2020). This holds true in Guiuan, wherein, women have no knowledge and experience in the fishing operations at sea. They stay at home to do the household chores.

Table 1. Socio-economic and fishery profile of the flying fish fishers in Guiuan, Eastern Samar, Philippines

Respondent's Characteristics	Frequency of Response	Frequency Percentage (%)
Gender		
Male	37	100.00
Female	0	0.00
Total	**37**	**100**
Age structure		
21-25	3	8.11
26-30	4	10.81
31-35	8	21.62
36-40	4	10.81
41-45	1	2.70
46-50	1	2.70
51-55	5	13.51
56-60	9	24.32
61-65	1	2.70
66-70	1	2.70
Total	**37**	**100**
Civil status		
Married	18	48.65
Single	7	18.92
Separated	5	13.51
Live-in	5	13.51
Widowed	2	5.41
Total	**37**	**100**
Educational attainment		
No Formal Education	1	2.70
Elementary Level	11	29.73
Elementary Graduate	9	24.32
High School Level	4	10.81
High School Graduate	7	18.92
College Level	4	10.81
College Graduate	1	2.70
Total	**37**	**100**
Household size		
1-3	13	35.14
4-6	13	35.14
7-9	7	18.92
10-12	4	10.81
Total	**37**	**100**
Number of children		
0	8	21.62
1-3	17	45.95
4-6	7	18.92
7-9	5	13.51
Total	**37**	**100**

Table 1 (continued)

Respondent's Characteristics	**Frequency of Response**	**Frequency Percentage (%)**
Number of children still studying		
0	15	40.54
1-3	10	27.03
4-6	10	27.03
7-9	2	5.41
Total	**37**	**100**
Fishing experience (years)		
<5	6	16.22
6-10	7	18.92
11-15	8	21.62
16-20	3	8.11
21-25	2	5.41
26-30	4	10.81
31-35	4	10.81
36-40	1	2.70
>40	2	5.41
Total	**37**	**100**
Average monthly income derived from flying fish fishery		
<PHP 5,000	25	67.57
PHP 6,000-PHP 10,000	11	29.73
PHP 11,000-PHP 15,000	0	0.00
PHP 16,000-PHP 20,000	1	2.70
Total	**37**	**100**
Average number of fishing trip per month (days)		
10-15	4	10.81
16-20	11	29.73
21-25	20	54.05
26-30	2	5.41
Total	**37**	**100**
Membership in fisherfolk organization		
Member	19	51.35
Non-member	18	48.65
Total	**37**	**100**
Other source of income		
Tuna Fishing	13	35.14
Gillnet Fishing	3	8.11
Tuna Fishing and Gillnet Fishing	4	10.81
Tuna Fishing and Spear Fishing	3	8.11
Squid Fishing	4	10.81
Construction	5	13.51
Dried Fishing	1	2.70
Others	4	10.81
Total	**37**	**100**

The average age of the fishers in Guiuan was 57 years old, being dominated by older fishers in the same bracket at 51-60 years old (38%), followed by a younger generation with ages from 31-40 (32%). In terms of civil status, about half (49%) of the respondents were married, while others were single (19%), separated (14%), living together (14%), and widowed (5%) at the time of the study. It was observed that more than half of the respondents were either elementary level (30%) or graduate (24%). On the other hand, only four (11%) were able to attend college and only one (3%) earned a degree. In the study of

Molina et. al. (2018) in Sta. Ana Cagayan, it was also reported that 100% (n=21) of the flying fish fishers were males. The average age of the fishers in the study area was 41 years old. Many of the respondents were also married, but most finished high school.

This study found that the average number of household members among flying fish fishers was five, including three children. Meanwhile, an average of two children were still attending school. In terms of the respondents' length of involvement in the flying fish fishery, more than half (57%) had ≤15 years of fishing experience, while the others were already 16 to 50 years in the fishery. The average monthly income of the respondents ranged from <PHP 5,000.00 to PHP 20,000.00, with majority (68%) of them earning <PHP 5,000.00. The income of the fishers reaches PHP 20,000.00 during peak season but significantly drops when the catch become scarce. The results showed that the average monthly income (<PHP 5,000.00) of the flying fish fishers was basically less than the poverty threshold in Eastern Samar at PHP 12,052.00 for a family of five as reported by the Philippine Statistics Authority Eastern Visayas (2022). This simply implies that the flying fish fishers are generally living a poor life. The income of the fishers is generally low, and the opportunities available for them to have additional earnings are limited and are also mainly low-income generating activities as indicated in the other source of income (Table 1). In the study of Molina et al. (2018), the income derived from flying fish fishing ranged from PHP 20,000.00 to PHP 61,000.00 within 7 months which was equivalent to PHP 2,857.14 to PHP 8,714.29 monthly.

Most of the respondents in Guiuan were fulltime flying fish fishers (70%), while 30% were part-time in the fishery. Fishing of flying fish is being conducted in a daily basis. More than half of the fishers (54%) reported that they conduct fishing operations for 21-25 days in a month. These fishers with higher number of fishing trips were the fulltime fishers who highly depend on the fishery during its fishing season from March to December. And, due to the seasonal characteristics of the fishery, flying fish fishers diversify when flying fish become scarce to continuously sustain their daily needs. Majority of them shifted to other fishery and continue their fishing activities including tuna fishing or "pagbudlis" (35%), gillnet fishing or "pamukot" (8%), both tuna and gillnet fishing (11%), spearfishing or "pamana" and tuna fishing (8%), and squid fishing or "pagnoos" (11%). One fisher preferred fish drying as another source of income, while five (14%) were involved in the construction field. More than half (51%) of the respondents were members of the barangay's existing fisherfolk organization, the Taytay Fisherfolk Association which is registered at the Local Government of Guiuan. On the other hand, the remainder were non-members because they were not around during the creation of the organization and/or they were not interested to join due to personal reasons.

Fishing Gear Used in the Flying Fish Fishery

The bulk (97%) of the flying fish landings in the Philippines come from gillnet and little portion from drive-in nets (Dalzell, 1993). Consistently, all flying fish fishers in Guiuan use a surface gillnet in catching the species. Surface gillnet locally known as "pukot" is a type of gillnet that hangs vertically in the water and is not anchored to the seabed. Other regions in the Philippines including Maitum, Sarangani province also use the same gear for catching flying fish (Emperua et al, 2017). However, flying fish fishers in Danajon Bank in the Camotes Sea use floating drive-in-nets that are deployed from small motorized canoes (Dalzell, 1993). In Makassar Strait, Indonesia, drift gillnet is used in catching bony flying fish *Hirundichthys oxycephalus* (Palo et al., 2019; Najamuddin et al., 2020). The same gear is used in catching flying fish in the waters of Ambon Island, Indonesia (Tupamahu et al., 2023). On the other hand, three types of fishing gears are mainly used in catching flying fish which are associated with the Kuroshio current off Taiwan namely: drive-in net, set net, and gillnet (Chang et al., 2012).

The specifications of the gillnet used by the flying fish fishers in Guiuan is shown in Table 2. The gear is constructed with a monofilament knotted nylon netting with a twine diameter of 0.25 mm and a mesh size of 8.5 cm. The netting's depth is 100 meshes down. An ethylene-vinyl acetate (EVA) foam is used in the head rope while a lead sinker is fixed in the footrope, both at one piece per meter, to keep the net open right below the water surface.

The size of the floaters being used range from 5 to 8 cm weighing 10 to 15 g, while the sinkers' size varies from 4 to 5 cm weighing 20 to 21 g. A weighted buoy is fixed at each end of the finished fishing gear. The buoys which are similarly made from EVA foam are tied to a bamboo using a monofilament transparent nylon. A 3-m long multifilament nylon rope line then connects the buoys to the main gear. The buoys serve as markers and help maintain the desired position of the gear in the upper section of the water where flying fish occur. Each flying fish fisher owns 8 to 15 panels of nets configured into 1 unit with finished length of 800 to 1,500 m. Flying fish are primarily caught in the gear through gilling. The fish is caught through its gills as it tries to escape from the net. The mesh size

Table 2. Specifications of the surface gillnet commonly used in Guiuan, Eastern Samar, Philippines

Material/ Attribute	Specification
Netting	monofilament transparent nylon
	0.25 mm diameter twine size
Mesh	diamond-shaped knotted mesh with size of 8.5 cm
Floater	ethylene-vinyl acetate (EVA) foam and rubber
Sinker	lead (20-21 g)
Buoy	EVA foam or Styrofoam

of the gear is intended to catch the fish of desired size (marketable), making it generally size-selective. According to the survey, about 97-100% of the flying fish are caught through its gills, and that most of the catch are found near the headrope of the gear suggesting that flying fish are found at 0-5 meters from the water surface.

Aside from the surface gillnet used by fishers as the main gear, they also employ scoop net as accessory gear to aid in the fishing operation. The instrument is commonly made from a monofilament net fixed in a round-shaped metal frame and is attached to a handle. The frame's diameter ranges from 51 to 76 cm. The handle is typically made up of a 2-m long bamboo. Scoop nets are generally used to retrieve flying fish that fall onto the water during catch retrieval.

Fishing Practices

According to the survey, flying fish species landed in Guiuan are particularly caught in the areas of the West Pacific Ocean, about 2-4 km away from the shoreline. As early as 5:00 in the morning, flying fish fishers start to prepare for their fishing trip. They prepare their food and other things needed for the fishing operation, head to the docking site, unanchor their boats, and check the boat's engine. Their departure from the shore depends on the high tide hour which is usually between 05:00 AM to 07:00 AM. They reach the fishing ground at around 8:00 AM. In the fishing site, fishers start the actual fishing operation by setting the surface gillnet. This is done by deploying first the buoy followed by the main gear and the other buoy of the other end of the gear. On average, it takes about an hour to fully set the gear in the water. Once the gear is set, fishers stay in the boat just beside the buoy. The net is then left soaked in the water and the fishers utilize this time to talk with one another and nap. After 3 hours of soaking, fishers begin to check the net by pulling it towards the boat to check if there are already flying fish caught or gilled in the meshes. Whenever there are already gilled fishes, they will immediately get these and place on the deck of the boat and later place inside the bow. They will then have to wait for another 3 hours before the net is totally hauled. Thus, the net is soaked in the water for an average of 6 hours. At around 2:00 PM, fishers begin loading the net back to the boat, while concurrently taking the catch from the net. Finally, fishers are ready to land their catch and return home after a one-day fishing trip. Fishers usually have 1 haul per fishing operation. On the other hand, they add another haul for two reasons: (1) when the gear moved to an undesirable location due to the sudden change in the wind direction, thus change in the water current or, (2) when only few fish are caught during the first haul. In the second haul, the soaking time is reduced so that they can still return home on time. When catch is sold, income is usually divided to five, particularly for the three crew members who went to fishing, for the boat owner and the gear owner.

Emperua et al. (2017) reported that the flying fish in Maitum, Sarangani province were caught year-round. Though there were monthly variations of the catch, the seasonality of the fishery was not clearly observed during their 3-year study from 2013-2015. On the contrary, a peak season during the months of March to May was observed in Sta. Ana, Cagayan, and from February to May in the northeastern part of the country (Molina et al., 2018). In these periods, the water temperature is warmer which is expected to result to a higher primary productivity. In Guiuan, Eastern Samar, the flying fish fishers reported that the fishing for the species usually starts from late of March to early of December. In December, the northeast monsoon starts to precede, so the Pacific Ocean becomes rougher. The vulnerability of small-scale flying fish fishers to storms and greater water currents given that they use small pump boats and each of them fears the possibility of losing their gear result to the decrease in the number of fishing operations in the area. During this period, fishers shift to other fishing ground, particularly within Leyte Gulf. On the other hand, those who have commercial fishing vessels, such as those that are used for tuna fishing still continue to operate in the West Pacific waters since their fishing vessels are large enough to withstand stronger waves. Meanwhile, other fishers change fishing gear such as gillnets, spears, and hooks and lines locally known as "pukot", "pana", and "kawil", respectively, to sustain their daily needs.

Catch Rates

The survey results indicate that flying fish fishers typically spend 9 to 11 hours with an average of 10 hours on their daily fishing trips. On the other hand, the average soaking time of surface gillnet per fishing trip was 6 hours. This soaking time is similar to the report of De Croos (2009) in the flying fish fishery in Sri Lanka.

The estimated CPUE (pc/panel, pc/hour) of flying fish landed in Guiuan from March to June is presented in Table 3. The CPUE was calculated according to the number of individuals or piece (pc) because this is the unit used in the conventional trading of flying fish catch in Guiuan. The CPUE calculated as pc/panel was based on the average number of panels used during each fishing operation which was 15. Conversely, the pc/hour was based on the average soaking time of the fishing gear (6 hours). The CPUE was generally higher in the month of March with 29 pc/panel or 74 pc/hour, suggesting a peak month for the fishery. The CPUE then declined in the succeeding months. In Surigao del Norte, Philippines, Gomez et al. (2019) reported that CPUE of flying fish in the area was highest in November with 15.11 kg/boat/day and lowest in the month of August with 6.82 kg/boat/day. In Makassar Strait, Palo et al. (2019) showed that the CPUE of *H. oxycephalus* fishery during the months of April to June ranged from 0.23 to 2.90 kg/haul with an average of 1.38 kg/haul and 0.47 to 8.93 kg/haul with an average of 3.28 kg/haul per piece of drift gillnet with mesh size of 2.54 cm and 3.18 cm, respectively. In the northwestern coast of Sri Lanka, the mean CPUE using set gillnet varied from 102±37.8 kg/boat/day to 224±82.7 kg/boat/day, wherein the highest catch was recorded in November 2002 and lowest in March 2003 (De Croos, 2009). The seasonal differences are attributed to oceanographic processes.

Table 3. Estimated catch per unit effort of the flying fish fishery in Guiuan, Eastern Samar, Philippines at an average of 15 panels of surface gillnets and average of 6 hours soaking time per fishing trip

Month	Catch per Unit Effort	
	pc/panel	pc/hour
March	29	74
April	28	70
May	16	40
June	6	16

Catch Composition

The flying fish fishery in Guiuan, Eastern Samar is dominated by flying fish species belonging to three genera including: 1) *Cheilopogon*, 2) *Cypselurus*, and 3) *Exocoetus*. On the other hand, other non-targeted species are also incidentally caught in the gear. Nevertheless, the majority of the bycatch species of the fishery are of economic and/or commercial value.

Flying fish are one of the most common fish landed in certain regions of the Philippines including Sarangani, Cagayan, Surigao and Camotes Island (Emperua et al., 2017; Molina et al., 2018; Gomez et al., 2019). It is critical to have knowledge on the variety and composition of the flying fish catch in order to properly manage the fishery. In Guiuan, Eastern Samar, the catch of the flying fish fishery using surface gillnet is mainly comprised of the target species composing more than 95% of the total catch. Similarly, Harsha et al. (2017) reported that the gillnet used in catching flying fish in Tharuvaikulam coast, India, is highly species selective. In the present study, it was found that small-scale fishers in Guiuan catch eight valuable species of flying fish as presented in Table 4. Majority of the samples obtained were comprised of *Cheilopogon* species including intermediate flying fish *Cheilopogon intermedius* (60%), many spotted flying fish *Cheilopogon spilopterus* (10%), stained flying fish *Cheilopogon spilonotopterus* (8.7%), Sutton's flying fish *Cheilopogon suttoni* (0.4%), margined flying fish *Cheilopogon cyanopterus* (0.3%) and Abe's flying fish *Cheilopogon abei* (0.1%). The two other species recorded were the yellowing flying fish *Cypselurus poecilopterus* (15.6%) and the tropical two-wing flying fish *Exocoetus volitans* (4.9%). The results of the catch composition suggest that the flying fish fishery in Guiuan, Eastern Samar is dominated by *C. intermedius*. This further suggests that the aforementioned species is the most abundant species of flying fish in the area at present. On the contrary, *C. suttoni* and *C. abei* recorded to have the least quantities in the fishing ground. In Surigao del Norte, *C. poecilopterus* was observed as the most dominant and abundant flying fish species in the area constituting 37.80% of the total sample (Gomez et al., 2019). On the other hand, *C. abei* was observed to dominate the catch in Maitum, Sarangani comprising 21.45% of the total catch (Emperua et al., 2017). In Danajon Bank, two species of flying fish namely: *Cheilopogon nigricans* and *Cypselurus opisthopus*, and a halfbeak *Oxyporhamphus convexus* constituted about 90% of the landings using drive-in nets (Dalzell, 1993).

Table 4. Species and size composition of flying fish landed in Guiuan Eastern Samar, Philippines

Flying Fish Species	N	%	Total Length (cm)			Body Weight (g)		
			Range	*Mean*	*SEM*	*Range*	*Mean*	*SEM*
Cheilopogon intermedius	600	60	22.00-30.50	26.51	±0.06	87.00-202.00	130.57	±0.96
Cheilopogon spilopterus	100	10	25.70-33.50	28.60	±0.15	97.00-234.00	163.06	±2.51
Cheilopogon spilonotopterus	87	8.7	23.30-29.50	25.87	±0.12	92.00-165.00	114.21	±1.47
Cheilopogon suttoni	4	0.4	30.20-33.40	31.83	±0.64	170.00-207.00	185.50	±7.85
Cheilopogon cyanopterus	3	0.3	28.80-33.30	30.63	±1.11	150.00-219.00	174.67	±18.14
Cheilopogon abei	1	0.1	24.20	24.20	-	91.00	91.00	-
Cypselurus poecilopterus	156	15.6	20.80-28.50	23.80	±0.11	67.00-194.00	103.20	±1.43
Exocoetus volitans	49	4.9	25.20-30.00	27.09	±0.21	90.00-196.00	134.57	±4.63
Total	**1000**							

In the waters of Ambon Island, Indonesia, the flying fish drift gillnet catch was dominated by three species including *C. suttoni*, *C. abei* and *H. oxycephalus* (Tupamahu et al., 2023). However, the flying fish catch in Ceram Sea which is also part of Indonesian water was dominated by *H. oxycephalus* (Tuapetel et al., 2015). This simply shows that the species composition of the flying fish fishery differs from fishing ground to fishing ground.

The sizes and weights of the flying fish species caught in Guiuan are also presented in Table 4. In general, the sizes of the catch did not seem to vary much. The smallest flying fish measured 20.80 cm (*C. poecilopterus*) while the largest measured 33.50 cm (*C. spilopterus*). The highest range value of 8.5 cm was recorded from *C. intermedius* which comprised the bulk of the catch. On the other hand, the lowest range of just 3.2 cm was recorded from *C. suttoni*. The narrow size ranges of the flying fish catch implies that the fishing gear used (surface gillnet) in the locality is generally size selective.

Length and Weight Relationship

A length and weight relationship (LWR) analyses were conducted for the three species of flying fish including *C. intermedius*, *C. spilopterus* and *C. poecilopterus*. For other species, LWR was not conducted due to the limited number of samples taken during the actual sampling. The coefficient of determination (R^2) values obtained by *C. intermedius* (Figure 2), *C. spilopterus* (Figure 3) and *C. poecilopterus* (Figure 4) were 0.78, 0.75 and 0.64, respectively. The R^2 values suggest a positive relationship between the body length and weight of the species especially *C. intermedius* and *C. spilopterus*. The study of Gomez (2020) also showed a positive LWR for *C. poecilopterus* with R^2 value ranging from 0.877 to 0.963.

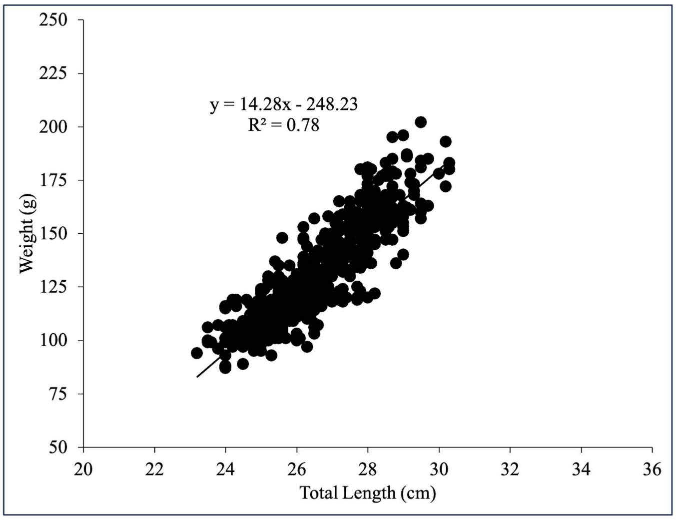

Figure 2. Scatter plot diagram showing the length-weight relationship of *Cheilopogon intermedius* (n=591)

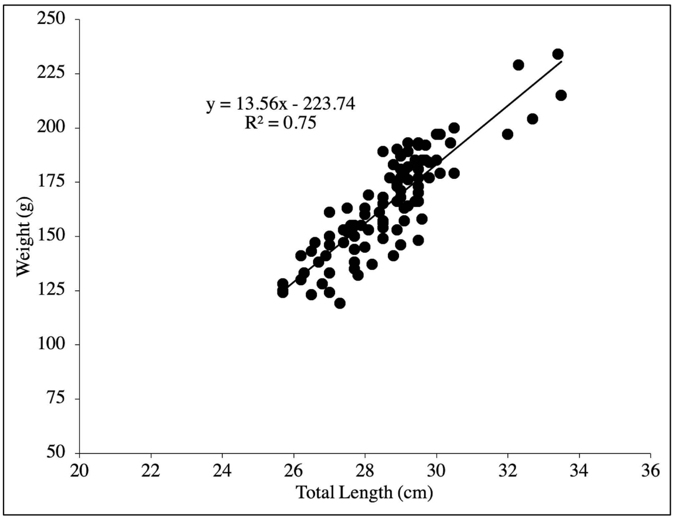

Figure 3. Scatter plot diagram showing the length-weight relationship of *Cheilopogon spilopterus* (n=97)

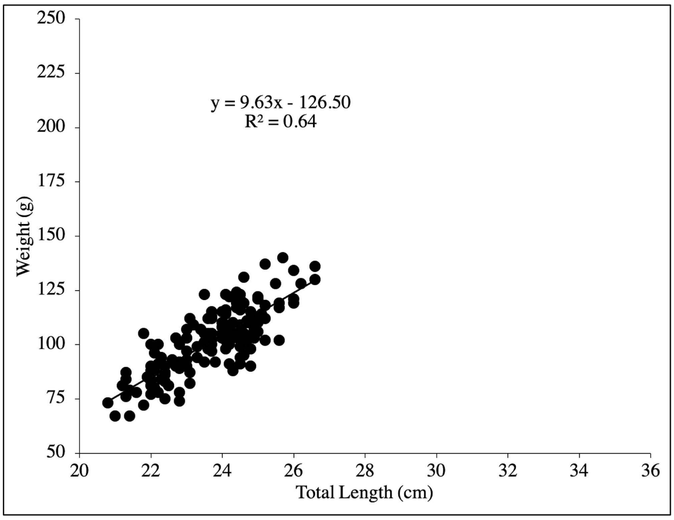

Figure 4. Scatter plot diagram showing the length-weight relationship of *Cypselurus poecilopterus* (n=150)

Bycatch Species

Based on the actual observation and reports of the fishers, bycatch in the flying fish fishery in Guiuan, Eastern Samar was relatively low, comprising of only 1-5 individuals per fishing operation representing only about 1% of the total catch. The recorded bycatch was comprised of seven species including needlefish *Tylosurus* sp., short mackerel *Rastrellliger brachysoma*, halfbeak *Hemiramphus* sp., Indo-pacific sailfish *Istiophorus platypterus*, skipjack tuna *Katsuwonus pelamis*, dolphinfish *Coryphaena hippurus* and common remora *Remora remora*.

Bycatch of the flying fish fishery in Guiuan except for *R. remora* are evidently economically and/ or commercially valuable species. These bycatch species are either sold or kept for household consumption by the fishers. Those large pelagic bycatch (i.e., sailfish, skipjack tuna, dolphinfish) are sold at the landing sites. Some fishers sell it to the middlemen present at the site, while others do sell it to the fish market.

Bycatch species caught in the flying fish fishery are observed to be all pelagic which proves that the fishery does not impact the bottom environment. On the other hand, some bycatch species generally cause damage to the target species, and the gear used particularly the large pelagic species such as swordfish and tuna which prey on flying fish. The gear gets damaged due to the heavy weight of these big fishes, especially that the gear is not designed to catch them. Molina et al. (2018), also recorded large bycatch species associated in the flying fish fishery in Cagayan which include dolphin, blue marlin, shark, and tuna. Contrarily, Harsha et al. (2017) reported no discards in the gillnet fishery targeting flying fish in Tharuvaikulam coast, India.

Product Flow and Catch Utilization of Flying Fish

The product flow of the fresh flying fish landed by the fishers in Guiuan, Eastern Samar, Philippines is simple and straightforward (Figure 5). The product basically goes to three routes — to the fish processors/ driers, tuna fishers, and middlemen as first-level buyers. After which, the product is finally distributed to two end users — the household consumers and tuna fishers.

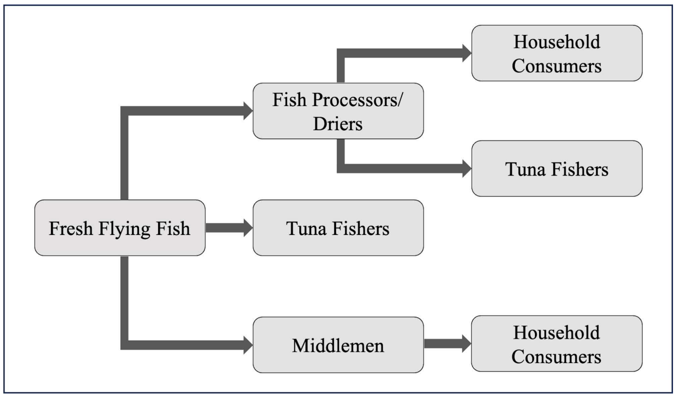

Figure 5. Product flow of the flying fish landed in Guiuan, Eastern Samar, Philippines

About 97% of the fresh flying fish are sold to fish processors/ driers. Since the bulk of the flying fish goes directly to the processors, the tuna fishers buy fresh flying fish from them to be used as bait for their tuna fishing. Processors provide to some fishers a capital for gasoline that they use in their fishing trips. So, in return, fishers are obliged to sell all their catch to them. As such, tuna fishers often cannot buy directly from the flying fish fishers. On the other hand, the processed/ dried flying fish are sold to the household consumers. In rare cases, usually during peak season when the flying fish catch is abundant, middlemen such as wholesalers and retailers from outside the municipality, as well as tuna fishers, buy directly from the fishers. The middlemen then sell the flying fish to the household consumers. In total, 80% are utilized by household consumers either fresh or dried (10% as fresh while 70% as dried fish and roe), and 20% as fresh (as bait for tuna fishing) by tuna fishers. In Sta. Ana Cagayan, 97-100 % of the flying fish catch is sold to the middlemen/ traders. Flying fish in the area are primarily utilized for human consumption (Molina et al., 2018). Similarly, the flying fish in Surigao del Norte are mainly used for local consumption. The catch is sold directly to the consumers as fresh or dried fishery product. The eggs particularly of the *Hirundichthys affinis* is also sold for the caviar production (Gomez et al., 2019). On the other hand, some fishers use the species as bait in line fishing. In Batanes, flying fish is also used for human food and as bait (Sui, 2013).

Socio-economic Importance of Flying Fish in Guiuan

Flying fish are primarily targeted for human consumption since they are a good source of protein. Its meat is an excellent source of amino acid, and its lipid contains high level of docosahexaenoic acid (Harewood et al., 1993). The fishery for flying fish is undeniably a valuable source of livelihood for specific areas in the Philippines such Sarangani province and Surigao del Norte (Emperua et al., 2017; Gomez et al., 2019). In Guiuan, Eastern Samar, flying fish, play an important role in the livelihood and sustenance of the municipal fishing households, who rely mostly on the flying fish fishery. Not only the fishers can benefit from the fishery but also the middlemen, vendors, peddlers and other fisherfolk who are engaged in the flying fish supply chain. The tuna fishers also benefit from the fishery where they use flying fish as bait.

The municipal fishers in Guiuan catch flying fish to meet their daily needs. According to the survey results, the average catch of fishers from their daily trips ranges from 200-500 pieces. Depending on the season, flying fish are sold per piece at varied costs. According to the interviewed fishers, the flying fish fishery in the area has two peak seasons. The first peak is from March to May, while the second is from September to November. Flying fish species are usually sold at a higher price during the first two months (March and April) of the first peak season because the demand is high. During these months, flying fish are usually priced between PHP 15.00 to PHP 20.00 per piece. In contrast, flying fish are sold at a lesser price, between PHP 8.00 to PHP 10.00 during the month/s of May and June, since supply is already abundant during the past months.

An average of 97% of the total flying fish catch are sold to fish processors being the direct buyers. Processors buy the catch at a wholesale price and pay the fishers at the agreed time, that is, when processors have already sold the dried flying fish, usually within a week. In the case of tuna fishers, they incur greater expenses as they typically purchase flying fish from processors. On the other hand, smaller-sized flying fish (<24 cm) caught in the fishery, which was observed during the data collection, are considered as rejects with no market value. These "rejects", which comprise only about 5% of the total catch, are brought home by the fishers and used for household consumption.

The "iliw" (dried flying fish) is undeniably starting to be known as a fishery commodity. In fact, it is one of the most wanted products in Guiuan, which tourists always look for, and Taytay specifically is the famous producer of dried flying fish in the region. The price of dried flying fish varies depending also on the season. For instance, during the first two months of the peak season, its usual price ranges between PHP 20.00 to PHP 25.00 per piece. But for the succeeding months, price drops to only PHP 10.00 to PHP 15.00 per piece.

Conclusion

The present study is the first comprehensive documentation of the flying fish fishery in Guiuan, Eastern Samar, Philippines. This provides significant information on the demographic profile of the fishers, the fish catch and fishing practices, the product flow, and the importance of the fishery to the socio-economic dimension of the local community. Being a valuable fishery in the area, particularly among the local municipal fisherfolk and tuna fishers, the results of this study may serve as an important scientific baseline information that may help in crafting sound local management plans specific for the flying fish fishery and for the sustainable utilization of the commodity in Guiuan, Eastern Samar.

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Compliance With Ethical Standards

Author's Contribution

NQB: Conceptualized and conducted the study, analyzed and interpreted the data, and prepared the draft of the manuscript.

RMPG: Helped in the conceptualization of the study, finalized the study design, helped in the data analysis and interpretation, reviewed and finalized the manuscript.

SAM: Helped in the conceptualization of the study, and reviewed the manuscript.

BBCS: Helped in the conceptualization of the study, and reviewed the 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.

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Data Availability Statement

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

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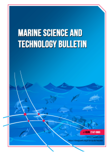

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RESEARCH ARTICLE

Phytoplankton species composition in the Turkish coast of the Aegean Sea between 2014 and 2016

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ABSTRACT

The research was carried out between 2014 and 2016, within the scope of the 'National Integrated Marine Pollution Monitoring Program,' in a total of five seasonal cruises at 22 stations along the Turkish coast of the Aegean Sea. A total of 296 phytoplankton species and one subspecies belonging to 12 classes were identified from samples collected during the five seasonal cruises. The highest diversity was observed in the summer of 2015, with 204 species recorded, while the lowest was 137 species in the summer of 2016. Dinoflagellates dominated the species composition, accounting for 51% of the species, followed by diatoms (44%), and other groups (5%). At the genus level, *Chaetoceros*, *Thalassiosira*, *Bacteriastrum*, and *Coscinodiscus* were the most dominant diatom genus, whereas *Protoperidinium*, *Tripos*, *Dinophysis*, *Oxytoxum*, and *Prorocentrum* were dominant among dinoflagellates. *Amphisolenia schauinslandii* Lemmermann 1899 and *Ceratoperidinium margalefii* A.R. Loeblich III 1980 were recorded for the first time along the Turkish coast of the Aegean Sea. This study provides a comprehensive assessment of the phytoplankton taxonomic diversity in the region from to 2014-2016.

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Introduction

The Aegean Sea, located between Greece and Turkey, is an intricate marine ecosystem with dynamic ecological interactions that significantly contribute to regional and global biodiversity. Phytoplankton, as primary producers, play a vital role in this ecosystem, influencing nutrient cycling and carbon sequestration, and supporting diverse marine life. The initiation of phytoplankton studies along the Turkish coast of the Aegean Sea in the 1950s marked an important milestone in understanding the ecological dynamics of this maritime region.

Traditionally, phytoplankton studies in this area have been characterized by short-term and regionally confined scopes. While these studies have provided valuable insights into local

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dynamics, a comprehensive understanding of the entire Turkish coast of the Aegean Sea necessitates a paradigm shift towards regular, systematic, and extensive monitoring initiatives. This shift is vital for several reasons rooted in the intricate nature of phytoplankton's role in marine ecosystems.

The Aegean Sea has significant economic importance for fisheries, tourism, and aquaculture. Regular phytoplankton monitoring is crucial for anticipating and mitigating potentially harmful algal blooms (HABs) that may pose threats to marine life, seafood safety, and economic activities dependent on the marine environment.

This study, which forms part of the "National Integrated Marine Pollution Monitoring Program," encompasses the entirety of the Turkish coast along the Aegean Sea. It presents the initial findings of a three-year taxonomic study conducted within the framework of the national monitoring initiative. The primary objective of this study was to lay the groundwork for a comprehensive reassessment, which was achieved by formulating a checklist that adheres to established taxonomic protocols. In particular, the study aimed to provide insights into the state of phytoplankton taxonomic composition between 2014 and 2016.

Materials and Method

Study Area

The Aegean Sea is separated from the Mediterranean by the islands of Crete, Karpatos, Kasos, and Rhodes to the south. The total surface area of the Aegean Sea, which has a rectangular appearance with indented coasts, a length of 660 km in the north-south direction, a width of 270 km in the east-west direction in the north, 150 km in the central part, and 400 km in the south, is approximately 214,000 km^2. The Aegean Sea is located within the borders of Turkey. The coastal length was determined to be 2833 km, and the average depth was 350 m (Senirkentli, 2003).

The research was carried out between 2014 and 2016, within the scope of the "National Integrated Marine Pollution Monitoring Program," in a total of five cruises (2014: Summer, 2015: Winter-Summer, 2016: Winter-Summer) implemented with R/V TÜBİTAK MARMARA at 22 stations along the Turkish coast of the Aegean Sea (Figure 1).

Figure 1. Sampling stations

Sampling and Identification

A total 268 phytoplankton samples were collected using 10-liter Teflon Niskin type bottles attached to a CTD (SeaBird SBE 25Plus/SBE 27 pH Sensor) Rosette System in sampling stations. 1-liter samples were fixed onboard in 3 ml L-1 alkaline Lugol's solution and concentrated by the sedimentary method. Qualitative analyses of the samples were performed with a light microscope (Nikon Eclipse Ni with DS-Fi2 cam-NIS Imaging System) in the counting cell Sedgewick Rafter using standard methods (Moncheva & Parr, 2010).

The species identified in the literature were taxonomically updated by examining both the AlgaeBase (Guiry & Guiry, 2023) and the World Register of Marine Species (WoRMS Editorial Board, 2023) online databases.

For the identification of species, printed and digital sources were used, including Kiselev (1950), Proshkina-Lavienko (1955), Trégouboff & Rose (1957a, 1957b), Cupp (1977), Sournia (1978), Rampi & Bernhard (1980), Sournia (1986), Balech et al. (1988), Tomas (1997), Faust & Gulledge (2002), Hoppenrath et al. (2009), and Kraberg et al. (2010), as well as online databases such as "AlgaeBase", "nordicmicroalgae.org", "planktonnet.avi.de", and "WoRMS". The species obtained in this study were classified using the AlgaeBase database (Guiry & Guiry, 2023).

Results

In total, 296 species and one subspecies belonging to 12 phytoplankton classes were identified. Their distribution in phytoplankton classes: 25 genus and 46 species belonging to the Bacillariophyceae, 10 genus and 23 species belonging to the Coscinodiscophyceae, 17 genus and 62 species belonging to the Mediophyceae, 38 genus, 149 species and 1 subspecies belonging to the Dinophyceae, 4 genus and 4 species belonging to the Cyanophyceae, 1 genus and 1 species belonging to the Thecofilosea, 2 genus and 2 species belonging to the Cryptophyceae, 1 genus and 1 species belonging to the Noctilucophyceae, 2 genus and 3 species belonging to the Dictyochophyceae, 1 genus and 1 species belonging to the Coccolithophyceae, 1 genus and 1 species belonging to the Chlorophyceae, two genus and two species belonging to the Euglenophyceae were identified (Table 1).

Table 1. Taxonomic list of the phytoplankton species

Cyanobacteria
Cyanophyceae
Anabaena* sp.**; ***Merismopedia glauca (Ehrenberg) Kützing 1845; ***Trichormus variabilis*** (Kützing ex Bornet & Flahault) Komárek & Anagnostidis 1989; ***Oscillatoria* sp.**
Cercozoa
Thecofilosea
Ebria tripartita (Schumann) Lemmermann 1899
Cryptista
Cryptophyceae
Chroomonas* sp.**; ***Hillea fusiformis (J.Schiller) J.Schiller 1926
Dinoflagellata
Dinophyceae
Akashiwo sanguinea (K.Hirasaka) Gert Hansen & Moestrup 2000; ***Alexandrium minutum*** Halim 1960; ***Amphidinium* sp.**; ***Amphisolenia bidentata*** B.Schröder 1900; ***Amphisolenia schauinslandii*** Lemmermann 1899; ***Brachidinium capitatum*** F.J.R.Taylor 1963; ***Blixaea quinquecornis*** (T.H.Abé) Gottschling 2017; ***Ceratocorys armata*** (Schütt) Kofoid 1910; ***Ceratocorys gourretii*** Paulsen 1937; ***Ceratocorys horrida*** Stein 1883; ***Ceratoperidinium margalefii*** A.R.Loeblich III 1980; ***Cochlodinium* sp.**; ***Corythodinium constrictum*** (F.Stein) F.J.R.Taylor 1976; ***Corythodinium diploconus*** (F.Stein) F.J.R.Taylor 1976; ***Corythodinium milneri*** (G.Murray & Whitting) F.Gómez 2017; ***Corythodinium tesselatum*** (F.Stein) Loeblich Jr. & Loeblich III 1966; ***Dinophysis acuta*** Ehrenberg 1839; ***Dinophysis acuminata*** Claparède & Lachmann 1859; ***Dinophysis amandula*** (Balech) Sournia 1973; ***Dinophysis caudata*** Kent 1881; ***Dinophysis fortii*** Pavillard 1924; ***Dinophysis hastata*** F.Stein 1883; ***Dinophysis odiosa*** (Pavillard) Tai & Skogsberg 1934; ***Dinophysis ovum*** F.Schütt 1895; ***Dinophysis sacculus*** F.Stein 1883; ***Dinophysis schuettii*** G.Murray & Whitting 1899; ***Dinophysis tripos*** Gourret 1883; ***Dinophysis* sp. 1**; ***Dinophysis* sp. 2**; ***Diplopsalis lenticula*** Bergh 1882; ***Gonyaulax digitale*** (Pouchet) Kofoid 1911; ***Gonyaulax monacantha*** Pavillard 1916; ***Gonyaulax polygramma*** F.Stein 1883; ***Gonyaulax scrippsae*** Kofoid 1911; ***Gonyaulax spinifera*** (Claparède & Lachmann) Diesing 1866; ***Gymnodinium* sp.**; ***Gyrodinium fusiforme*** Kofoid & Swezy 1921; ***Gyrodinium fusus*** (Meunier) Akselman 1985; ***Gyrodinium lacryma*** (Meunier) Kofoid & Swezy 1921; ***Gyrodinium spirale*** (Bergh) Kofoid & Swezy 1921; ***Gyrodinium* sp.**; ***Heterocapsa rotundata*** (Lohmann) Gert Hansen 1995; ***Histioneis elongata*** Kofoid & J.R.Michener 1911; ***Histioneis* sp.**; ***Karenia brevis*** (C.C.Davis) Gert Hansen & Moestrup 2000; ***Karenia mikimotoi*** (Miyake & Kominami ex Oda) Gert Hansen & Moestrup 2000; ***Karenia* sp.**; ***Kapelodinium vestifici*** (Schütt) Boutrup, Moestrup & Daugbjerg 2016; ***Kryptoperidinium triquetrum*** (Ehrenberg) Tillmann, Gottschling, Elbrächter, Kusber & Hoppenrath 2019; ***Lebouridinium glaucum*** (Lebour) F.Gómez, H.Takayam, D.Moreira & P.López-García 2016; ***Lingulodinium polyedra*** (F.Stein) J.D.Dodge 1989; ***Margalefidinium polykrikoides*** (Margalef) F.Gómez, Richlen & D.M.Anderson 2017; ***Oblea rotunda*** (Lebour) Balech 1964; ***Ornithocercus magnificus*** F.Stein 1883; ***Ornithocercus quadratus*** Schütt 1900; ***Oxytoxum curvatum*** (Kofoid) Kofoid & J.R.Michener 1911; ***Oxytoxum longiceps*** Schiller 1937; ***Oxytoxum longum*** J.Schiller 1937; ***Oxytoxum minutum*** Rampi 1941; ***Oxytoxum rampii*** Sournia 1973; ***Oxytoxum reticulatum*** (Stein) Schütt 1899; ***Oxytoxum scolopax*** F.Stein 1883; ***Oxytoxum viride*** Schiller 1937; ***Oxytoxum* sp.**; ***Phalacroma doryphorum*** F.Stein 1883;

Table 1 (continued)

Dinophyceae
Phalacroma favus Kofoid & J.R.Michener 1911; ***Phalacroma mitra*** F.Schütt 1895; ***Phalacroma ovatum*** (Claparède & Lachmann) Jørgensen 1923; ***Phalacroma rapa*** F.Stein 1883; ***Phalacroma rotundatum*** (Claparéde & Lachmann) Kofoid & J.R.Michener 1911; ***Podolampas bipes*** F.Stein 1883; ***Podolampas curvatus*** Schiller 1937; ***Podolampas elegans*** F.Schütt 1895; ***Podolampas palmipes*** Stein 1883; ***Podolampas spinifera*** Okamura 1912; ***Polykrikos kofoidii*** Chatton 1914; ***Polykrikos schwartzii*** Bütschli 1873; ***Prorocentrum balticum*** (Lohmann) Loeblich III 1970; ***Prorocentrum cordatum*** (Ostenfeld) J.D.Dodge 1976; ***Prorocentrum gracile*** F.Schütt 1895; ***Prorocentrum lima*** (Ehrenberg) F.Stein 1878; ***Prorocentrum micans*** Ehrenberg 1834; ***Prorocentrum redfieldii*** Bursa 1959; ***Prorocentrum scutellum*** B.Schröder 1900; ***Prorocentrum triestinum*** J.Schiller 1918; ***Protoperidinium bipes*** (Paulsen) Balech 1974; ***Protoperidinium brevipes*** (Paulsen) Balech 1974; ***Protoperidinium brochii*** (Kofoid & Swezy) Balech 1974; ***Protoperidinium cerasus*** (Paulsen) Balech 1973; ***Protoperidinium claudicans*** (Paulsen) Balech 1974; ***Protoperidinium conicoides*** (Paulsen) Balech 1973; ***Protoperidinium conicum*** (Gran) Balech 1974; ***Protoperidinium crassipes*** (Kofoid) Balech 1974; ***Protoperidinium curtipes*** (Jørgensen) Balech 1974; ***Protoperidinium depressum*** (Bailey) Balech 1974; ***Protoperidinium diabolus*** (Cleve) Balech 1974; ***Protoperidinium divergens*** (Ehrenberg) Balech 1974; ***Protoperidinium elegans*** (Cleve) Balech 1974; ***Protoperidinium grande*** (Kofoid) Balech 1974; ***Protoperidinium granii*** (Ostenfeld) Balech 1974; ***Protoperidinium latidorsale*** (P.J.L.Dangeard) Balech 1974; ***Protoperidinium leonis*** (Pavillard) Balech 1974; ***Protoperidinium oblongum*** (Aurivillius) Parke & Dodge 1976; ***Protoperidinium obtusum*** (Karsten) Parke & J.D.Dodge 1976; ***Protoperidinium oceanicum*** (Vanhöffen) Balech 1974; Protoperidinium pallidum (Ostenfeld) Balech 1973; ***Protoperidinium pellucidum*** Bergh 1882; ***Protoperidinium pentagonum*** (Gran) Balech 1974; ***Protoperidinium pyriforme*** (Paulsen) Balech 1974; ***Protoperidinium pyriforme* subsp. *breve*** (Paulsen) Balech 1988; ***Protoperidinium solidicorne*** (Mangin) Balech 1974; ***Protoperidinium steinii*** (Jørgensen) Balech 1974; ***Protoperidinium* sp.**; ***Pseliodinium fusus*** (F.Schütt) F.Gómez 2018; ***Pyrocystis fusiformis*** C.W.Thomson 1876; ***Pyrocystis lunula*** (F.Schütt) F.Schütt 1896; ***Pyrocystis obtusa*** Pavillard 1931; ***Pyrocystis robusta*** Kofoid 1907; ***Pyrocystis* sp.**; ***Pyrophacus horologium*** F.Stein 1883; ***Pyrophacus steinii*** (Schiller) Wall & Dale 1971; ***Scrippsiella acuminata*** (Ehrenberg) Kretschmann, Elbrächter, Zinssmeister, S.Soehner, Kirsch, Kusber & Gottschling 2015; ***Sourniaea diacantha*** (Meunier) H.Gu., K.N.Mertens, Zhun Li & H.H.Shin 2020; ***Torodinium robustum*** Kofoid & Swezy 1921; ***Tripos arcuatus*** (Gourret) F.Gómez 2021; ***Tripos arietinus*** (Cleve) F.Gómez 2021; ***Tripos brevis*** (Ostenfeld & Johannes Schmidt) F.Gómez 2021; ***Tripos candelabrum*** (Ehrenberg) F.Gómez 2013; ***Tripos carriensis*** (Gourret) Hallegraeff & Huisman 2013; ***Tripos extensus*** (Gourret) F.Gómez 2021; ***Tripos furca*** (Ehrenberg) F.Gómez 2013; ***Tripos fusus*** (Ehrenberg) F.Gómez 2013; ***Tripos gibberus*** (Gourret) F.Gómez 2021; ***Tripos gracilis*** (Pavillard) F.Gómez 2013; ***Tripos hexacanthus*** (Gourret) F.Gómez 2013; ***Tripos limulus*** (Pouchet) F.Gómez 2021; ***Tripos lineatus*** (Ehrenberg) F.Gómez 2021; ***Tripos longipes*** (Bailey) F.Gómez 2021; ***Tripos longissimus*** (Schröder) F.Gómez 2013; ***Tripos macroceros*** (Ehrenberg) Hallegraeff & Huisman 2020; ***Tripos massiliensis*** (Gourret) F.Gómez 2021; ***Tripos muelleri*** Bory 1826; ***Tripos pavillardii*** (Jørgensen) F.Gómez 2021; ***Tripos pentagonus*** (Gourret) F.Gómez 2021; ***Tripos pulchellus*** (Schröder) F.Gómez 2021; ***Tripos setaceus*** (Jørgesen) F.Gómez 2013; ***Tripos symmetricus*** (Pavillard) F.Gómez 2021; ***Tripos teres*** (Kofoid) F.Gómez 2013; ***Tripos trichoceros*** (Ehrenberg) Gómez 2013; ***Tripos vultur*** (Cleve) Hallegraeff & Huisman 2020
Noctilucophyceae
Pronoctiluca pelagica Fabre-Domergue 1889
Heterokontophyta
Bacillariophyceae
Achnanthes adnata Bory 1822; ***Achnanthes armillaris*** (O.F.Müller) Guiry 2019; ***Amphora marina*** W.Smith 1857; ***Amphora ovalis*** (Kützing) Kützing 1844; ***Amphora* sp. 1**; ***Amphora* sp. 2**; ***Asterionella formosa*** Hassall 1850; ***Asterionellopsis glacialis*** (Castracane) Round 1990; ***Bacillaria paxillifera*** (O.F.Müller) T.Marsson 1901; ***Cocconeis scutellum*** Ehrenberg 1838; ***Cocconeis* sp.**; ***Coronia decora*** (Brébisson) Ruck & Guiry 2016; ***Cylindrotheca closterium*** (Ehrenberg) Reimann & J.C.Lewin 1964; ***Diploneis bombus*** (Ehrenberg) Ehrenberg 1853; ***Diploneis crabro*** (Ehrenberg) Ehrenberg 1854; ***Diploneis* sp. 1**; ***Diploneis* sp. 2**; ***Entomoneis alata*** (Ehrenberg) Ehrenberg 1845; ***Entomoneis gigantea*** (Grunow) Nizamuddin 1983; ***Entomoneis* sp.**; ***Fragilaria crotonensis*** Kitton 1869;

Table 1 (continued)

Bacillariophyceae
Fragilaria* sp.**; ***Grammatophora marina (Lyngbye) Kützing 1844; ***Gyrosigma balticum*** (Ehrenberg) Rabenhorst 1853; ***Gyrosigma fasciola*** (Ehrenberg) J.W.Griffith & Henfrey 1856; ***Gyrosigma* sp.**; ***Licmophora abbreviata*** C.Agardh 1831; ***Licmophora flabellata*** (Greville) C.Agardh 1831; ***Licmophora gracilis*** (Ehrenberg) Grunow 1867; ***Navicula* sp. 1**; ***Navicula* sp. 2**; ***Nitzschia longissima*** (Brébisson ex Kützing) Grunow 1862; ***Nitzschia tenuirostris*** Manguin 1952; ***Pinnularia* sp.**; ***Pleurosigma angulatum*** (J.T.Quekett) W.Smith 1852; ***Pleurosigma elongatum*** W.Smith 1852; ***Pleurosigma formosum*** W.Smith 1852; ***Pseudo-nitzschia delicatissima*** (Cleve) Heiden, 1928; ***Pseudo-nitzschia pungens*** (Grunow ex Cleve) Hasle 1993; ***Striatella unipunctata*** (Lyngbye) C.Agardh 1832; ***Surirella* sp.**; ***Synedra* sp.**; ***Thalassionema frauenfeldii*** (Grunow) Tempère & Peragallo 1910; ***Thalassionema nitzschioides*** (Grunow) Mereschkowsky 1902; ***Tryblionella compressa*** (Bailey) Poulin 1990; ***Ulnaria ulna*** (Nitzsch) Compère 2001
Coscinodiscophyceae
Actinoptychus splendens (Shadbolt) Ralfs 1861; ***Actinoptychus* sp.**; ***Asterolampra marylandica*** Ehrenberg 1844; ***Asterolampra* sp.**; ***Coscinodiscus centralis*** Ehrenberg 1839; ***Coscinodiscus granii*** L.F.Gough 1905; ***Coscinodiscus janischii*** A.W.F.Schmidt 1878; ***Coscinodiscus perforatus*** Ehrenberg 1844; ***Coscinodiscus radiatus*** Ehrenberg 1840; ***Coscinodiscus wailesii*** Gran & Angst 1931; ***Dactyliosolen fragilissimus*** (Bergon) Hasle 1996; ***Guinardia flaccida*** (Castracane) H.Peragallo 1892; ***Guinardia striata*** (Stolterfoth) Hasle 1996; ***Melosira moniliformis*** C.Agardh 1824; ***Melosira varians*** C.Agardh 1827; ***Neocalyptrella robusta*** (G.Norman ex Ralfs) Hernández-Becerril & Meave 1997; ***Pseudosolenia calcar-avis*** (Schultze) B.G.Sundström 1986; ***Rhizosolenia castracanei*** H.Peragallo 1888; ***Rhizosolenia hebetata*** J.W.Bailey 1856; ***Rhizosolenia imbricata*** Brightwell 1858; ***Rhizosolenia styliformis*** T.Brightwell 1858; ***Sundstroemia pungens*** (Cleve-Euler) Medlin, Lundholm, Boonprakob & Moestrup 2021; ***Sundstroemia setigera*** (Brightwell) Medlin 2021
Dictyochophyceae
Dictyocha fibula Ehrenberg 1839; ***Octactis octonaria*** (Ehrenberg) Hovasse 1946; ***Octactis speculum*** (Ehrenberg) F.H.Chang, J.M.Grieve & J.E.Sutherland 2017
Mediophyceae
Bacteriastrum biconicum Pavillard 1916; ***Bacteriastrum comosum*** Pavillard 1916; ***Bacteriastrum delicatulum*** Cleve 1897; ***Bacteriastrum elongatum*** Cleve 1897; ***Bacteriastrum furcatum*** Shadbolt 1853; ***Bacteriastrum hyalinum*** Lauder 1864; ***Biddulphia biddulphiana*** (J.E.Smith) Boyer 1900; ***Cerataulina pelagica*** (Cleve) Hendey 1937; ***Chaetoceros affinis*** Lauder 1864; ***Chaetoceros anastomosans*** Grunow 1882; ***Chaetoceros atlanticus*** Cleve 1873; ***Chaetoceros borealis*** Bailey 1854; ***Chaetoceros brevis*** F.Schütt 1895; ***Chaetoceros coarctatus*** Lauder 1864; ***Chaetoceros compressus*** Lauder 1864; ***Chaetoceros constrictus*** Gran 1897; ***Chaetoceros costatus*** Pavillard 1911; ***Chaetoceros curvisetus*** Cleve 1889; ***Chaetoceros dadayi*** Pavillard 1913; ***Chaetoceros danicus*** Cleve 1889; ***Chaetoceros debilis*** Cleve 1894; ***Chaetoceros decipiens*** Cleve 1873; ***Chaetoceros densus*** (Cleve) Cleve 1899; ***Chaetoceros diadema*** (Ehrenberg) Gran 1897; ***Chaetoceros didymus*** Ehrenberg 1845; ***Chaetoceros diversus*** Cleve 1873; ***Chaetoceros insignis*** Müller Melchers 1955; ***Chaetoceros laciniosus*** F.Schütt 1895; ***Chaetoceros lorenzianus*** Grunow 1863; ***Chaetoceros messanensis*** Castracane 1875; ***Chaetoceros peruvianus*** Brightwell 1856; ***Chaetoceros pseudocurvisetus*** Mangin 1910; ***Chaetoceros radicans*** F.Schütt 1895; ***Chaetoceros similis*** Cleve 1896; ***Chaetoceros simplex*** Ostenfeld 1902; ***Chaetoceros socialis*** H.S.Lauder 1864; ***Chaetoceros tenuissimus*** Meunier 1913; ***Chaetoceros teres*** Cleve 1896; ***Chaetoceros tetrastichon*** Cleve 1897; ***Chaetoceros* sp.**; ***Climacosphenia moniligera*** Ehrenberg 1843; ***Detonula confervacea*** (Cleve) Gran 1900; ***Detonula pumila*** (Castracane) Gran 1900; ***Detonula* sp.**; ***Ditylum brightwellii*** (T.West) Grunow 1885; ***Eucampia zodiacus*** Ehrenberg 1839; ***Hemiaulus chinensis*** Greville 1865; ***Hemiaulus hauckii*** Grunow ex Van Heurck 1882; ***Lauderia annulata*** Cleve 1873; ***Lennoxia faveolata*** H.A.Thomsen & K.R.Buck 1993; ***Leptocylindrus danicus*** Cleve 1889; ***Planktoniella sol*** (G.C.Wallich) Schütt 1892; ***Proboscia alata*** (Brightwell) Sundström 1986; ***Skeletonema costatum*** (Greville) Cleve 1873; ***Thalassiosira allenii*** H.Takano 1965; ***Thalassiosira angustelineata*** (A.W.F.Schmidt) G.Fryxell & Hasle 1977; ***Thalassiosira eccentrica*** (Ehrenberg) Cleve 1904; ***Thalassiosira gravida*** Cleve 1896; ***Thalassiosira subtilis*** (Ostenfeld) Gran 1900; ***Thalassiosira* sp. 1**; ***Thalassiosira* sp. 2**; ***Trieres mobiliensis*** (Bailey) Ashworth & E.C.Theriot 2013

Table 1 (continued)

Haptophyta
Coccolithophyceae
Gephyrocapsa huxleyi (Lohmann) P.Reinhardt 1972
Chlorophyta
Chlorophyceae
***Scenedesmus* sp.**
Euglenophyta
Euglenophyceae
Euglena viridis (O.F.Müller) Ehrenberg 1830; ***Eutreptia lanowii*** Steuer 1904

The research study found that the highest number of species was recorded in the summer of 2015 with 204 species, while the lowest number was recorded in the summer of 2016 with 137 species. The average number of species recorded annually throughout the entire study period was 173.

When the study period from 2014 to 2016 was examined, the number of diatom species identified was 131, the number of dinoflagellate species was 150, and 14 species belonged to other phytoplankton groups. Throughout the entire research period, dinoflagellate species constituted 51% of the total number of species, diatom species constituted 44%, and other groups constituted 5%. Dinoflagellates were always dominant in the species composition, making up 50-55% of the species during the sampling periods. Diatoms were the second most important group, making up 39-45% of the species composition.

The study found that diatoms were represented by 52 genera, with *Chaetoceros*, *Thalassiosira*, *Bacteriastrum*, and *Coscinodiscus* making the biggest contribution to the number of species in the diatom group. These genera dominated 39% of the total species composition. In addition, 52% of the genus belonging to the diatom group were represented by a single species.

Dinoflagellates were represented by 39 species, with *Protoperidinium*, *Tripos*, *Dinophysis*, *Oxytoxum*, and *Prorocentrum* making the biggest contribution to the species composition. These genera dominated 56% of the total number of dinoflagellate species. 54% of the genus belonging to the dinoflagellate group were represented by only a single species.

Other groups, apart from dinoflagellates and diatoms, were represented by only 13 genus and made up 13% of the total number of genera.

Amphisolenia schauinslandii Lemmermann 1899, sampled in the summer of 2016, and *Ceratoperidinium margalefii* A.R.Loeblich III 1980, sampled in the summer of 2014, were reported for the first record species in the Turkish coast of Aegean Sea.

Discussion

The Turkish coast of the Aegean Sea was studied for the first time in the Gulf of Izmir. The first scientific investigations into the phytoplankton of the Izmir Bay, which encompasses the research area, were conducted by Numann (1955) and Acara & Nalbantoğlu (1960). Ergen (1967) carried out an initial qualitative examination of microplankton species in Izmir Bay, and Geldiay & Ergen (1968) subsequently built on this research.

Türkoğlu (2015) reported that a total of 88 studies were conducted along the Turkish coast of the Aegean Sea between 1950 and 2015. The majority of these studies were carried out in the Izmir Gulf region. Koray (2001) reported a list of 491 phytoplankton species found on the Turkish coast, while Koray et al. (2000) identified 243 phytoplankton species in the Turkish Aegean Sea. Türkoğlu (2015) examined the studies conducted in the Turkish seas, it was reported that the highest species diversity was in the Aegean Sea. According to the findings of the studies, dinoflagellates accounted for 54.7% of the dominant group, while diatoms accounted for 42%. Other phytoplankton groups made up 3.3% of the total phytoplankton composition. Although dinoflagellates were dominant over diatoms in studies conducted in the south of the Aegean Sea, the composition of phytoplankton groups varied in studies conducted in the north, with diatoms being the dominant group (Turkoglu & Yenici, 2007; Güreşen & Aktan-Turan, 2014). Furthermore, Altuğ et al. (2011) reported in their study that in the northern Aegean Sea, dinoflagellates accounted for 51% of the species composition and diatoms accounted for 37%. Aglaç & Balkis (2014) reported in their study in Edremit Bay that dinoflagellates (53.7%) were more dominant than diatoms (43.9%). This study is consistent with other research in terms of high species diversity and dominant phytoplankton groups.

As in this study, it has been revealed in studies that *Dinophysis*, *Prorocentrum*, *Protoperidinium*, and *Tripos* genera are dominant in the dinoflagellate species composition, and *Chaetoceros*, *Thalassiosira*, and *Bacteriastrum* genera dominate the diatom group (Koray et al., 2000; Senirkentli, 2003; Turkoglu & Yenici, 2007; Altuğ et al., 2011).

Conclusion

The importance of the Aegean Sea as an important corridor in the wider Mediterranean system linking the Mediterranean Sea to the Marmara-Black Sea highlights the need for ongoing monitoring and assessment. The dynamic nature of Aegean phytoplankton species composition requires continued taxonomic research to understand its ecological complexity. Traditional classification methods, while valuable, can be improved by incorporating advanced methods such as DNA barcoding (molecular methods). Furthermore, recognizing the ecological role of picoplankton and understanding their contribution to the overall phytoplankton composition is crucial for a comprehensive understanding of Turkish coast of the Aegean marine ecosystem.

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Compliance With Ethical Standards

Conflict of Interest

The author declares that there is no conflict of interest.

Ethical Approval

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

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Data Availability 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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RESEARCH ARTICLE

Structure design and strength analysis of the glass reinforcement plastic (GRP) Malay traditional "Perahu Bedar"

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ABSTRACT

The Perahu Bedar, a traditional fishing boat in the Terengganu region of Malaysia, has been historically crafted from Cengal wood. In response to challenges posed by wood scarcity and limitations in skilled craftsmen, this study pioneers the exploration of Glass Reinforced Plastic (GRP) as a novel alternative material for constructing the traditional Perahu Bedar, measuring 4.32 meters in length. Through a rigorous analysis, the research delves into the structural design intricacies and strength attributes of the GRP Perahu Bedar, marking a significant departure from conventional wood-based construction methods. The study conducts a comprehensive analysis of the structure design and strength characteristics of the GRP Perahu Bedar. The weight, buoyancy force, and load distribution along the boat are analyzed. The data shows varying weight and buoyancy forces along the stations, with positive load values indicating upward forces contributing to buoyancy and negative load values representing downward forces. This analysis provides insights into the boat's stability and distribution of forces. The sheer force and bending moment along the Perahu Bedar are evaluated. The sheer force values gradually increase or decrease along the boat, while the bending moment is highest at the midsection and decreases towards the ends. These results indicate the distribution of forces and stress on the boat's structure, aiding in understanding its integrity and stability. The Factor of Safety (FoS) analysis demonstrates a FoS value of 2.2368, indicating a safety margin greater than 1. This suggests that the GRP Perahu Bedar design meets safety requirements and can withstand applied

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stresses without exceeding yield strength. The FoS value provides assurance of structural integrity and safety during normal operating conditions. In summary, this study underscores the groundbreaking potential of Glass Reinforced Plastic (GRP) as a viable alternative to traditional wooden Perahu Bedar due to very high cost of Cengal Wood (wood that been used to build Peahu Bedar). By meticulously analyzing critical factors such as weight, buoyancy, load, shear force, bending moment, and Factor of Safety (FoS), the research offers invaluable insights into the structural integrity and safety aspects of GRP Perahu Bedar. These revelations not only herald a new era of sustainable and cost-effective boatbuilding practices but also serve as a crucial step towards safeguarding and perpetuating the rich maritime heritage of the region.

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Introduction

The Perahu Bedar, a traditional fishing boat with a rich maritime heritage, has been an integral part of the coastal communities in the Terengganu region of Malaysia for centuries. Traditionally crafted from Cengal wood, these boats have played a vital role in the livelihoods of local fishermen, enabling them to navigate the shallow coastal waters and venture into the open sea for fishing and pearl diving expeditions. However, the increasing scarcity and high cost of Cengal wood, coupled with the diminishing availability of skilled boat craftsmen, have prompted the need for exploring alternative materials and construction methods. Some research from Bahri et al. (2022) and Abd Wahab et al. (2023) has been conducted about the diminishing availability of skilled boat craftsmen. For the purpose of preservation of the traditional boat, Rahman et al. (2021) has constructed the blueprint for the traditional boat using the reverse engineering methods. Kamaruddin & Rosli (2023) attempts to discover how traditional boats are made in Terengganu.

The present study aims to investigate the use of Glass Reinforced Plastic (GRP) as a potential substitute for Cengal wood in the construction of the Perahu Bedar. GRP, commonly known as fiberglass, is renowned for its high strength-to-weight ratio, corrosion resistance, and ease of molding into complex shapes. Its advantageous properties make it an appealing candidate for boat construction, especially in regions where traditional boatbuilding materials face limitations.

The research will involve a comprehensive analysis of the structural design and strength characteristics of the GRP Perahu Bedar. By leveraging modern engineering techniques, the study seeks to ensure that the GRP version retains the essential features and performance of its traditional wooden counterpart. Special attention will be given to factors such as buoyancy, stability, and load-bearing capacity, which are critical for the safety and seaworthiness of the boat.

The Perahu Bedar has been the subject of various studies, primarily focusing on its historical significance, traditional construction techniques, and cultural importance within the Terengganu region. Abd Wahab et al. (2021) explored the historical evolution of the traditional boat and highlighted its role in shaping the maritime identity of the local communities. Similarly, Kamaruddin & Rosli (2023) documented the traditional boatbuilding techniques used by skilled craftsmen to construct the wooden boat.

Figure 1. Measurement of Perahu Bedar on dry land

In the search for alternative boatbuilding materials, researchers have turned their attention to composite materials like GRP. Chalmers (1994) conducted a study on the mechanical properties of GRP composites and emphasized their potential for marine applications. Furthermore, Sen (2003) investigated the durability and corrosion resistance of GRP materials in marine environments. The aspects of composite material evolution have been covered by Pasăre et al. (2019), and a review of the marine application of GRP was conducted by Rubino et al. (2020).

To ensure the structural integrity of the GRP Perahu Bedar, strength analysis becomes imperative. Ruzuqi (2020) performed analysis to study the tensile strength of fiberglass boat structures with variations in the amount of fiberglass lamination. Additionally, Iqbal & Shifan (2018) presented a comprehensive modelling and simulation of finite element techniques in boat design, emphasizing their application in optimizing hull structures.

Methodology

The research study on the structure design and strength analysis of the GRP traditional Perahu Bedar boat was conducted through several sequential phases. The initial phase involved precise boat measurement, which included assessing various components such as the stem profile, stern profile, and cross-sections at multiple locations. The measurements were performed on dry land at a boat maker yard, ensuring the keel's levelness. To facilitate accurate measurement, reference lines were established, with the keel line serving as the baseline. The distance between the forward perpendicular and aft perpendicular was divided into ten sections, known as stations, with equal lengths. Figure 1 showed the measurement activity on dry land.

The design specifications of the Perahu Bedar, as measured on dry land, provide valuable insights into the boat's physical dimensions and characteristics as shown in Table 1. The overall length (LOA) of the boat is determined to be 4.32 m, while the length between perpendiculars (LBP) measures 3 m. The boat's overall breadth (B) is recorded as 0.83 m, and the overall depth (D) is measured at 0.29 m. The draft (T) of the boat is found to be 0.2 m, indicating the depth of the boat below the waterline. The common interval for station measurements (h) is set at 0.432 m, ensuring consistent and uniform data collection along the boat's length. Additionally, the water density (ρ) is estimated to be 1025 kg/m^3, which is crucial for accurate buoyancy and stability calculations. These design specifications serve as a foundation for further analysis and design considerations, enabling a comprehensive understanding of the Perahu Bedar's structural characteristics and performance.

Table 1. Design specification of Perahu Bedar

Overall Length, LOA	4.32 m
Length Between Perpendicular, LBP	3 m
Overall Breadth, B	0.83 m
Overall Depth, D	0.29 m
Draught, T	0.2 m
Common interval for station, h	0.432 m

Digitalization Phase

In the digitization phase, the shape of the Perahu Bedar hull was digitally rendered using Rhinoceros 5, a 3-D modeling software. This involved placing the stem and stern profiles in the profile view to determine the overall length of the boat. The measured cross-sections were then positioned along the length, and the deck line was created by connecting the edges of each cross-section, terminating at the stem and stern as shown in Figure 2. Subsequently, a surface was generated by lofting along the measured cross-sections, and the software automatically generated the ten stations as shown in Figure 3.

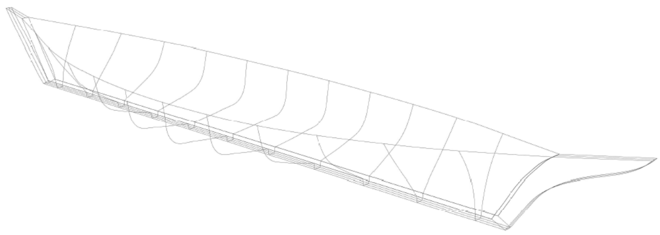

Figure 2. 3-D wireframe modelling of Perahu Bedar

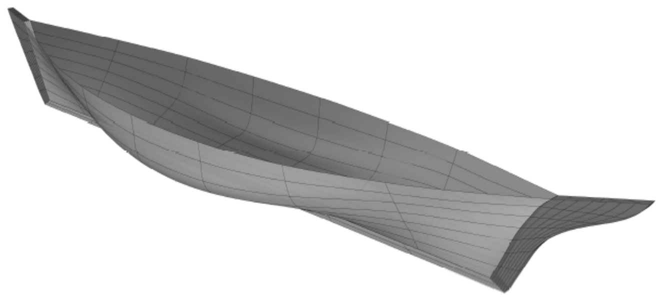

Figure 3. 3-D surface modelling of Perahu Bedar

Structure Design Phase

Moving on to the structure design phase, several crucial aspects were determined. This included calculating the cubic numeral and loaded displacement, estimating the weight of the hull laminate based on the framing system, panel width, thickness, and weight, and evaluating the weight of the deck laminate if applicable. Additionally, the study considered the weight and width of additional reinforcement on the keel, stem, chine, and deck edge. The determination of section modulus was performed for both the hull and deck stiffeners, considering the spacing and span of the stiffeners. The sizing of top hat stiffeners involved assessing the appropriate section modulus, stiffener glass weight, plating thickness, and the dimensions of the stiffeners.

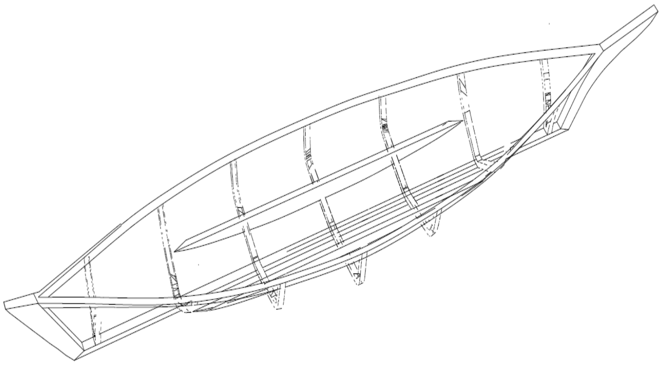

Figure 4. Perspective view of the structure and framing system of Perahu Bedar

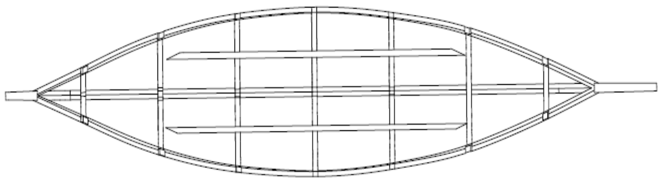

Figure 5. Top view of the structure and framing system of Perahu Bedar

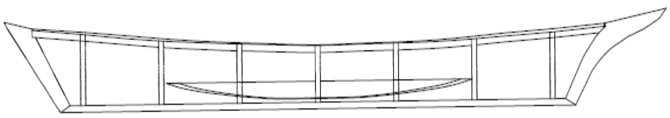

Figure 6. Side view of the structure and framing system of Perahu Bedar

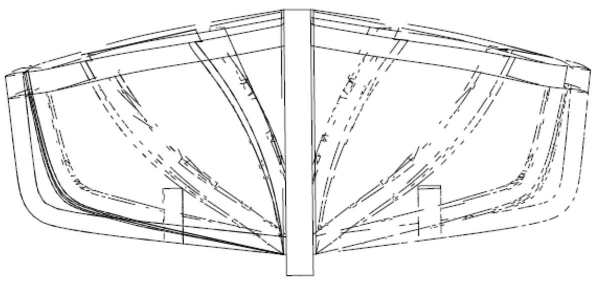

Figure 7. Front view of the structure and framing system of Perahu Bedar

In the crucial phase of structural design, where precision is paramount, a key determinant for ensuring the structural integrity of the vessel is the section modulus of the top hat stiffeners. This value serves as a critical guide in establishing the correct size of the top hat stiffeners, playing a pivotal role in fortifying the overall framework of the boat. The section modulus, derived from meticulous considerations of stiffener spacing and span, holds particular significance in navigating the complex interplay of forces and stresses that the vessel may encounter during its operational life.

The chosen values for stiffener spacing and span, set at 500mm each, are foundational parameters in this design framing system. These dimensions contribute directly to the calculation of the section modulus. This, in turn, aids in precisely determining the appropriate size of top hat stiffeners required for optimal structural support. The section modulus essentially acts as a compass, guiding the design team to strike a balance between the vessel's weight distribution, the imposed loads, and the intended performance. This careful calibration ensures that the top hat stiffeners are not only robust enough to withstand external pressures but are also streamlined to the specific demands of the vessel's design, enhancing both safety and functionality.

The scantling of the framing system has been design based on the standard rules from McVeagh et al. (2010). Figure 4 showed the perspective view of the structure and framing system of Perahu Bedar. Figure 5 showed the top view of the structure and framing system of Perahu Bedar. Meanwhile Figure 6 showed the side view of the structure and framing system of Perahu Bedar and Figure 7 showed the front view of the structure and framing system of Perahu Bedar.

Structure Analysis Phase

In the structure analysis phase, the study focused on strength calculations, constructing various diagrams, and conducting stress analysis. The strength calculations involved determining buoyancy, weight, load, shear force, and bending moment distributions along the ship or boat. Diagrams such as the weight and buoyancy diagram, load diagram, shear force diagram, and bending moment diagram were constructed accordingly. Stress analysis was carried out by considering parameters such as moment of inertia, section modulus, yield stress, and factor of safety.

In the intricate phase of structural analysis, the comprehensive evaluation of buoyancy, weight, load, shear force, and bending moment distributions along the ship or boat stands as a cornerstone in ensuring not only the structural robustness but also the seaworthiness of the vessel. The determination of buoyancy, encapsulating the vessel's ability to stay afloat, is fundamental. It provides essential insights into the equilibrium between the weight of the vessel and the supporting buoyant force exerted by the water. This critical parameter forms the basis for subsequent analyses, guiding in design a vessel with optimal stability.

Simultaneously, the calculations of weight, encompassing the overall mass of the vessel, contribute to a comprehensive understanding of the load dynamics the vessel will undergo. Understanding the weight distribution is pivotal for not only balancing the vessel during operation but also for effective load management and stress distribution across the structure. The load analysis further refines this understanding, delving into the diverse forces acting on the vessel, aiding in designing a structure that can efficiently withstand these forces.

Moving to the shear force and bending moment distributions, these factors play a pivotal role in understanding how different sections of the vessel will bear the applied loads. Shear force, representing the internal forces trying to slide one part of the vessel past another, and bending moment, depicting the forces causing the vessel to bend, offer intricate insights into potential stress points. These distributions are critical for pinpointing areas of vulnerability and ensuring that the structure can resist deformation, guaranteeing the vessel's overall strength.

This research methodology provided a systematic approach to investigate the structure design and strength analysis of the GRP traditional Perahu Bedar boat. It facilitated accurate boat measurement, digital representation, structure design considerations, and comprehensive analysis. The findings from this study will contribute to enhancing the understanding of using GRP in the construction of the traditional Perahu Bedar, opening up new possibilities for sustainable and cost-effective boat building practices.

Results and Discussion

Weight, Buoyancy Force and Load

The weight and buoyancy forces of the Perahu Bedar vary along the different stations, indicating variations in the distribution of weight and buoyancy along the boat's length as shown in Figure 8. As the station number increases, there is a trend of increasing weight and buoyancy forces. This can be observed in the data where the weight gradually increases from 68.7583 N/m at station 0.5 to 981.0491 N/m at station 4.5. Similarly, the buoyancy force also increases from 46.54845 N/m at station 0.5 to 1024.1444 N/m at station 4.5.

From the weight and buoyancy force along the Perahu Bedar, the load along the Perahu Bedor has been obtained. The load as shown in Figure 9, which is calculated as the product of (buoyancy force - weight) and the station length (0.432 m), provides insights into the net force acting on the boat at each station. Negative load values indicate that the buoyancy force is less than the weight, resulting in a downward force. Conversely, positive load values indicate that the buoyancy force exceeds the weight, creating an upward force.

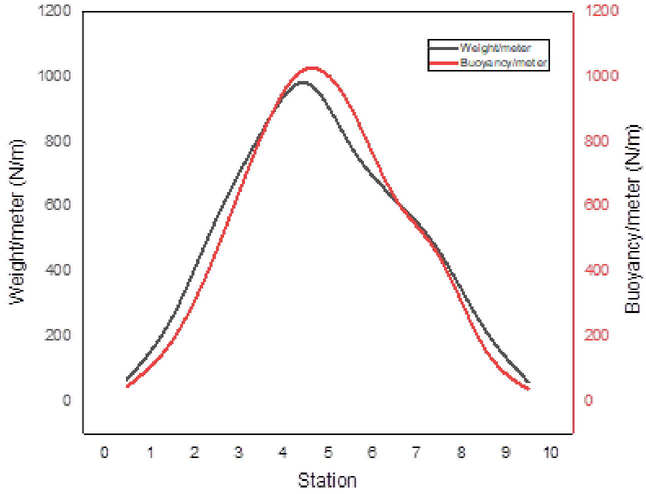

Figure 8. Weight and buoyancy force along the Perahu Bedar

Based on the load data, it can be observed a varying pattern along the stations. At some stations, such as station 4.5, the load is positive (18.6172 N), indicating an upward force that contributes to the boat's overall buoyancy. This suggests that the buoyancy force exceeds the weight, resulting in a net upward force at that particular station. On the other hand, at stations like 1.5 and 2.5, the load values are negative, indicating a net downward force. This suggests that the weight of the boat exceeds the buoyancy force at these stations.

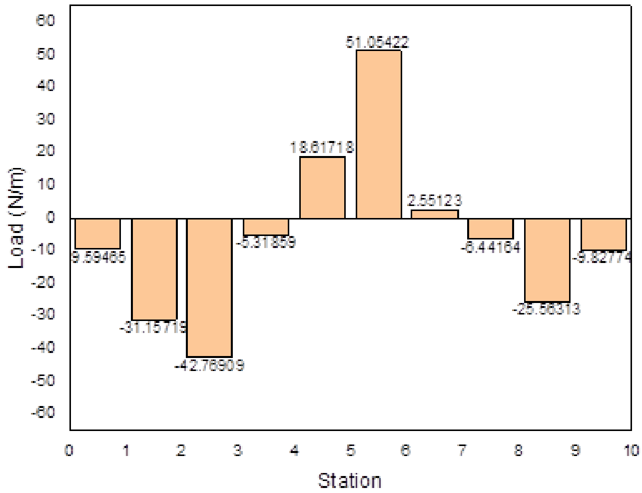

Figure 9. Load along the Perahu Bedar

The variation in load along the stations signifies the distribution of forces and the stability characteristics of the Perahu Bedar. Positive load values contribute to the boat's stability and the ability to remain afloat, while negative load values indicate a potential for instability and a tendency for the boat to sink. These scientific results highlight the significance of considering weight, buoyancy, and load distributions when assessing the stability and performance of the Perahu Bedar.

Sheer Force and Bending Moment

The sheer force is a measure of the internal force experienced by a structure in response to external loads. It indicates the intensity and direction of the force acting perpendicular to the longitudinal axis of the boat. From the Figure 10, it can be observed varying sheer force values at different stations along the Perahu Bedar. At stations 0 and 10, the sheer force is zero, indicating that there is no perpendicular force acting on the boat at these locations. This is expected as these stations represent the extreme ends of the boat. At intermediate stations, such as stations 1 to 9, the sheer force values are negative and gradually increase or decrease along the length of the boat. Negative sheer force indicates that the force is acting downward or in the negative direction along the longitudinal axis of the boat.

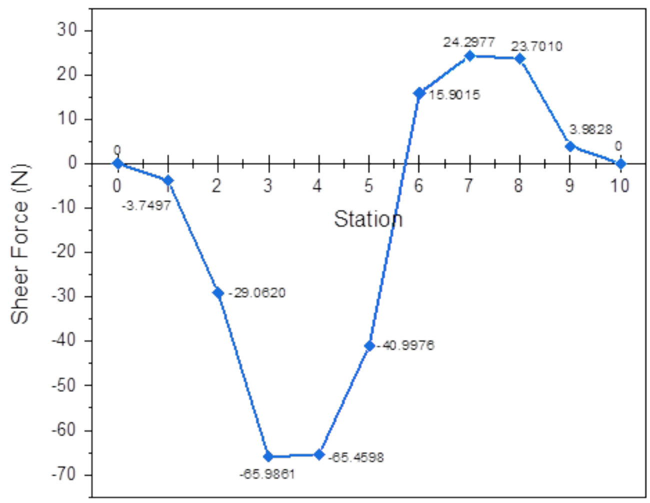

Figure 10. Sheer force along the Perahu Bedar

The bending moment, on the other hand, is a measure of the internal bending force experienced by a structure. It indicates the intensity and direction of the force causing the structure to bend. The bending moment values are influenced by both the sheer force and the distance from the point of measurement. From the Figure 11, it can be observed varying bending moment values along the stations of the Perahu Bedar. The bending moment is negative throughout the boat, indicating that the structure is subject to compression on the upper side and tension on the lower side. This is expected for the analyzed boat's configuration and the downward sheer force distribution. The bending moment values are highest at the midsection of the boat, represented by station 5, where the values reach -3482.1082 N. This indicates the maximum bending force experienced by the boat at this location. As it moves towards the ends of the boat, the bending moment decreases, reaching zero at stations 0 and 10.

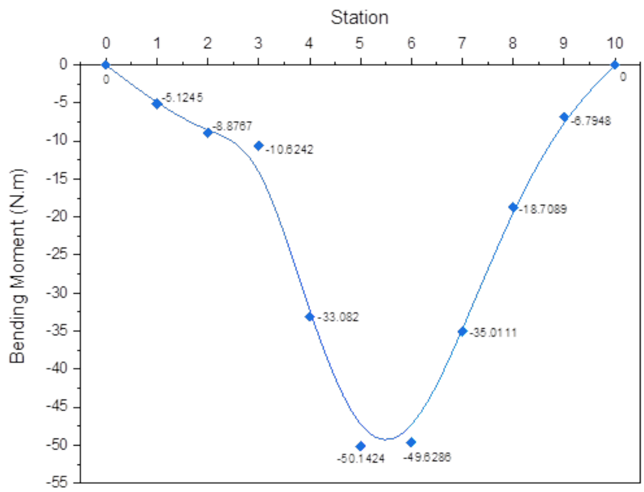

Figure 11. Bending moment along the Perahu Bedar

These scientific results highlight the distribution of sheer force and bending moment along the Perahu Bedar. The negative sheer force values indicate that the structure experiences downward forces, while the negative bending moment values suggest compression on the upper side and tension on the lower side of the boat's structure. Understanding the distribution of sheer force and bending moment is crucial for assessing the structural integrity and stability of the Perahu Bedar. It provides insights into the areas of maximum stress and deformation, allowing for further analysis and optimization of the boat's design to ensure adequate strength and safety. It is important to note that these results should be interpreted in the context of the specific Perahu Bedar under study and the assumptions made during the analysis.

Factor of Safety (FoS) Analysis

The FoS is a measure of the structural safety margin, indicating the ratio of the applied stress to the allowable stress. A higher FoS value indicates a greater safety margin, while a lower value suggests a reduced margin and potential for failure. In this analysis, the FoS is determined based on various parameters, including the maximum bending moment, area of midship scantling, neutral axis position, second moment of area, vertical distances from the keel and deck to the neutral axis, section moduli at the keel and deck, longitudinal bending stress at the keel and deck, yield stress for the material, and the calculated FoS value. The FoS is calculated using the Equation (1):

$$FoS = \frac{\sigma_y}{\sigma_{keel}\, or\, \sigma_{deck}} \quad (1)$$

In Equation (1);

σ_y: yield stress for the material;

σ_{keel} : longitudinal bending stress at keel

σ_{deck}: longitudinal bending stress at deck

The maximum longitudinal bending stress at the keel, σ_{keel} and deck, σ_{deck} has been determined by using the Equation (2) and Equation (3):

$$\sigma_{keel} = \frac{MI}{Y_{keel}} \quad (2)$$

In Equation (2);

M: Maximum bending moment at midship;

I: Second moment of area at natural axis (N.A);

Y_{keel}: Vertical distance from keel.

$$\sigma_{deck} = \frac{MI}{Y_{deck}} \quad (3)$$

In Equation (3);

M: Maximum bending moment at midship;

I: Second moment of area at natural axis (N.A);

Y_{deck}: Vertical distance from deck.

The section modulus at keel, Z_{keel} and deck, Z_{deck} has been determined by using the Equation (4) and Equation (5):

$$FoS = \frac{\sigma_y}{\sigma_{keel}\, or\, \sigma_{deck}} \quad (4)$$

In Equation (4);

I: Second moment of area at natural axis (N.A);

Y_{keel}: Vertical distance from keel.

$$FoS = \frac{\sigma_y}{\sigma_{keel}\, or\, \sigma_{deck}} \quad (5)$$

In Equation (5);

I: Second moment of area at natural axis (N.A);

Y_{deck}: Vertical distance from deck.

From the Table 2, it can be observed that the maximum bending moment, M is 50.1424 N.m, and the total area of midship scantling is 0.119 m^2. The neutral axis, $N.A$ is positioned at 0.145 m from the base line, and the second moment of area, I is calculated as 1.798 m^4. The vertical distance from the keel, Y_{keel} to the neutral axis is 0.1556 m, while the vertical distance from the deck, Y_{deck} to the neutral axis, N.A is 0.1344 m. The section modulus at the keel, Z_{keel} and deck, Z_{deck} are determined as 11.5553 m^3 and 13.3780 m^3, respectively. The longitudinal bending stress at the keel, σ_{keel} is calculated as 579.4089 N/m^2, while the longitudinal bending stress at the deck, σ_{deck} is 670.8083 N/m^2. The yield stress, σ_y for the material is given as 1500 N/m^2. Based on these values, the Factor of Safety (FoS) is calculated as 2.2361.

Table 2. Factor of Safety (FoS) Analysis of Perahu Bedar

Maximum Bending Moment, M	50.1424 N.m
Total Area of Midship Scantling	0.119 m^2
Neutral Axis (N.A)	0.145 m from Base Line
Second Moment of Area, I at N.A	1.798 m^4
Vertical distance from Keel to N.A, Y_{keel}	0.1556 m
Vertical distance from Deck to N.A, Y_{deck}	0.1344 m
Section Modulus at keel, Z_{keel}	11.5553 m^3
Section Modulus at Deck, Z_{deck}	13.3780 m^3
Longitudinal Bending Stress at Keel, σ_{keel}	579.4089 N/m^2
Longitudinal Bending Stress at Deck, σ_{deck}	670.8038 N/m^2
Yield Stress for the Material, σ_y	1500 N/m^2
Factor of Safety, FoS	2.2361

The result can emphasize that the calculated FoS value of 2.2361 indicates a safety margin greater than 1, which suggests that the structural design of the Perahu Bedar meets the safety requirements and exhibits a satisfactory level of structural integrity. The FoS value above 1 indicates that the structure can withstand the applied stresses and loads without exceeding the material's yield strength. A FoS greater than 1 provides a safety margin, ensuring that the Perahu Bedar can safely operate under normal operating conditions, accounting for uncertainties and variations in loading.

Conclusion

The scientific analysis conducted on the GRP Malay traditional Perahu Bedar reveals promising potential for the use of GRP as a substitute material for the traditional Cengal wood in boat construction. The accurate boat measurement and digitization phases provided precise dimensions and a virtual model of the Perahu Bedar, enabling reliable structural evaluations. The structure design phase, encompassing considerations of weight, laminate properties, and reinforcement, ensured the strength and integrity of the GRP structure. The structure analysis phase, including stress distribution, load diagrams, and section moduli calculations, offered insights into the boat's structural behavior and stability. The factor of safety analysis demonstrated a satisfactory safety margin, indicating that the GRP Perahu Bedar can withstand applied stresses and loads without exceeding yield strength. Overall, the utilization of GRP presents a viable solution for preserving the Malay region's maritime heritage, addressing wood scarcity, and maintaining the performance and safety of the Traditional Bedar boat. Further research and validation can refine the design and construction techniques, ensuring the continued sustainability and success of the Perahu Bedar in modern contexts.

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Compliance With Ethical Standards

Author's Contribution

NMKNI: Conducted precise measurements of the Perahu Bedar on dry land, capturing stem profiles, stern profiles, and cross-sections and also contributed to the structure design phase, estimating weights, determining laminate weights, and calculating additional reinforcement;

MAJ: Utilized 3-D modeling software to create an accurate digital representation of the Perahu Bedar hull;

NAAR: Contributed to assisted the structure design phase, estimating weights, determining laminate weights, and calculating additional reinforcement;

ANR: Reviewed and edited the research findings, ensuring accuracy and clarity in the structure analysis phase;

SA: Oversaw the project, coordinating efforts, and supervising the research process;

MSM: Provided valuable insights into the historical and cultural significance of the Perahu Bedar as a representative from the museum.

All authors read and approved the final manuscript.

Conflict of Interest

The authors declare that there is no conflict of interest.

Ethical Approval

The research conducted on the Perahu Bedar in this study has received official ethical approval and permissions from the Museum Negeri Terengganu, State of Terengganu, Malaysia. The authors like to express the gratitude to the Museum for their invaluable support and cooperation, which has allowed to access the Perahu Bedar and conduct the measurements and analyses. Their commitment to preserving and promoting the maritime heritage of the Terengganu region has been integral to the success of the research, and the authors have ensured that all activities involving the Perahu Bedar align with the ethical standards and guidelines established by the Museum.

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Data Availability Statement

All datasets generated during and/or analyzed during the current study are available from the corresponding author upon reasonable request. The authors are committed to promoting transparency and scientific collaboration.

Therefore, the authors encourage researchers and interested parties to reach out to the corresponding author to access the datasets, ensuring that the findings of this research can be further examined, validated, and utilized for future studies and advancements in the field of boat design and construction.

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REVIEW ARTICLE

Contribution and prospect of marine fisheries in the economy of Bangladesh and sustainable blue economy challenges: A review

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ABSTRACT

Marine resources of Bangladesh are abundant, both in terms of huge sea area and its biological richness. The marine water area supports a large number of commercially important fin fish, mollusks, crustaceans, and seaweeds, offering significant economic potential due to their diversified use and high demand in the international market. Therefore, the current review comprehensively examines both the contribution and potentials of marine fisheries resources to the economy, as well as the challenges involved in marine fisheries sectors in attaining a sustainable blue economy in Bangladesh. The study revealed that, the marine fisheries plays an important role in national economy and has huge prospect in employment generation and ensuring food security of Bangladesh. The expansion of mariculture and effective utilization of marine resources will open a new window for the economic development of Bangladesh. Marine fisheries production of Bangladesh has increased over the last two decades, but its relative share in total fisheries production has declined. Despite being rich in marine living resources, commercial mariculture has been developed only for shrimp, prawn, and mud crab. Challenges hindering mariculture expansion includes limited research, technological deficiencies, inadequate skilled workforce, underdeveloped domestic seafood markets, and financial constraints. Concerted efforts including exploring new fishing grounds, conducting stock assessments, implementing scientific management strategies, enacting a national marine fisheries policy, enforcing legislation, and establishing robust surveillance and monitoring mechanisms are required to foster a sustainable blue economy in Bangladesh.

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Introduction

Marine fisheries is an important sector for the economy of Bangladesh. As a leading fish producing country in the world, Bangladesh was positioned 14th among top 30 marine aquatic animal producers in 2021-22 (FAO, 2024). The contribution of the fisheries sector to the gross domestic product (GDP) of the country is 3.57% which is almost one-fourth (26.50%) of the agricultural GDP (DoF, 2022). More than 10 million coastal fishers directly depend on the fisheries sector for their livelihood (Hoque et al., 2021). The coastal and marine environment of Bangladesh is highly productive due to warm climate, heavy rainfall, and abundance of nutrient that supports diverse marine life (Hossain, 2001; Islam, 2003). A large part of the coastal area of Bangladesh is the habitat for commercially important finfish, shrimp, prawn, crab, and seaweed species (Ahmed & Glaser, 2016; AftabUddin et al., 2021). These resources support a vibrant fishing industry that ranges from small-scale artisanal fishing operations to larger commercial enterprises (Hoq et al., 2013). The coastal aquaculture (shrimp/prawn and crab culture) has become a multimillion-dollar industry in Bangladesh due to huge demand in global markets (& and Glaser, 2016). Expansion of mariculture, sustainable utilization of marine fisheries resources, and promotion of blue economy can open a new window for the economic growth of Bangladesh (Hussain et al., 2018).

Blue Economy is a popular term in modern marine and ocean governance (Voyer et al., 2018) however, it is a quite new and emerging concept in Bangladesh. It is a marine-based economic development that increases social and human well-being while preserving the health of the ocean ecosystem (Smith-Godfrey, 2016; Lee et al., 2020). The establishment of a blue economic transformation ensures food and energy security while safeguarding marine ecosystem (Çoban & Ölmez, 2017). The concept of the blue economy was first introduced by Professor Gunter Pauli in 1994 and earned global attention during the United Nations Conference on Sustainable Development held in Rio de Janeiro in 2012 (Roberts & Ali, 2016). Blue economy became an important issue in Bangladesh after the settlement of the maritime boundary with Myanmar and India in 2012 and 2014, respectively (Hussain et al., 2018; AftabUddin et al., 2021). The Blue Economy holds significant potential for boosting economic growth, employment opportunities, food security, and thereby contributing to human welfare (Sarker et al., 2018). It has been estimated that, it will be possible for Bangladesh to obtain 5% of its GDP from marine resources by 2030 (Rashid, 2014). The country has immense potential to be a developed country by 2041, if the expanded coastal and marine resources can properly be explored, extracted, and utilized (Mukit, 2019).

Considering the huge potential, Bangladesh has adopted 17 development goals known as sustainable development goals (SDGs), which have a direct relationship with the development of the blue economy (Bari, 2017). The country has identified 26 sectors to exploit the marine resources where marine fisheries is one of the most promising sectors (Alam, 2019). The government of Bangladesh has embraced the concept of the blue economy (Sarker et al., 2018) and an inter-ministry coordination unit called the "blue economy cell" has also been established to promote blue economy (Patil et al., 2018). Proper planning and development in any production sector need up to date information on available resources, prospect, current states, and problems. The implementation of the developmental program often turns out unsuccessful due to the lack of proper information.

There are studies focusing marine fisheries resources of Bangladesh (Sarkar et al., 2016; Shamsuzzaman et al., 2017a, 2017b; Chakraborty, 2018; Habib & Islam, 2020), their culture potentials (Hoq, 2016; Dhar et al., 2020; Lahiri et al., 2021; Mondal et al., 2021; Chakraborty, 2021; Chowdhury et al., 2022), and constrains of mariculture development (AftabUddin et al., 2021; Sarker et al., 2021) in Bangladesh. There are also studies emphasizing opportunities and limitations in utilizing ocean resources for blue economy development in Bangladesh (Hussain et al., 2017, 2018; Sarker et al., 2018). However, literature focusing contribution of marine fisheries resources as a component of the blue economy, its prospects, and sustainability challenges is still scanty. Therefore, this review aimed to figure out the contribution and prospects of marine fisheries resources in the economy of Bangladesh. This paper also focuses on the challenges involved in marine fisheries sectors in attaining a sustainable blue economy in Bangladesh.

Maritime Area and Marine Fisheries Resource Diversity in Bangladesh

After the settlement of the maritime boundary, Bangladesh now has sovereign rights over 118,813 square kilometers (equivalent to the land mass of Bangladesh) of waters extending up to 12 nautical miles of territorial sea and 200 nautical miles of exclusive economic zone (EEZ) into the Bay of Bengal (BoB) (Figure 1) (Hussain et al., 2017). It is the nursery and breeding ground of a diverse range of marine living organisms such as fishes, shrimps, mollusks, crustaceans, seaweeds, reptiles, amphibians, mammals etc. However, there are disagreement in number of existing species in published reports (Table 1). Very little is known about cephalopods (squid, octopus, and cuttle fish), marine mammals (dolphin and whales), and reptiles (turtles and crocodiles) of Bangladesh. In addition, 11 sharks, 24 rays, 3 sponges, 3 starfish's, 10 frogs, 24 snakes, 66 corals, and 3 species of otter have so far been recorded in marine water area of Bangladesh (IUCN, 2015; Sarker et al., 2019). Many of these species are commercially important and have export potential besides having high demand in the domestic market. A detail investigation on species diversity needs to carry out to update the number of different species present and to find out the relative abundance of each of those species in the marine environment of Bangladesh.

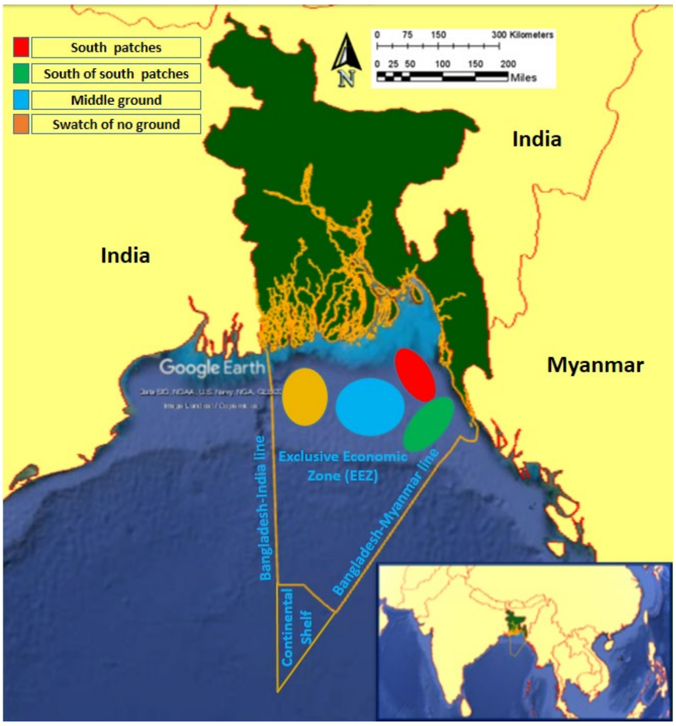

Figure 1. Maritime area of Bangladesh

Contribution of Marine Fisheries to Total Fish Production of Bangladesh

In spite of having a rich biodiversity and a large marine water area, the relative share of marine fisheries in total fish production is very low compared to inland fisheries production. The inland fisheries production of Bangladesh has increased more than double by the last two decades, but marine production has not tumid that much (Figure 2). In 2010-11, the total fish production of Bangladesh was 3261782 MT where inland (capture and culture) fisheries contributed 2683112 MT (82.26%) and marine fisheries from marine capture contributed 578620 (17.74%) MT (Shamsuzzaman et al., 2017a). After 10 years in 2020-21, the total fish production increased to 4621228 MT where the contribution of inland (capture and culture) fisheries was 3939989 (85.26%) MT and marine capture fisheries contributed 681239 (14.74 %) MT (DoF, 2022). Regardless the slow increase in production, the relative share of marine fisheries in total fisheries production has declined (from 17.74% to 14.74%) because no marine aquaculture is currently practiced in Bangladesh (Shamsuzzaman et al., 2017a) and marine fisheries production is completely dependent on marine capture. The reasons behind low marine capture production are lack of modern fishing knowledge and equipment, irrational harvesting of marine resources, inadequate information on pelagic stock, and high levels of capital required to exploit resources of the deep sea (Islam, 2003; Shamsuzzaman et al., 2017b).

Fin Fish

Hilsa (*Tenualosa ilisha*) is the dominant species captured from marine water area (Figure 3). Its production has increased from 339845 MT in 2010-11 to 565183 MT in 2020-21, contributing 46.03% of total marine capture production and 12.23% of total fish production of Bangladesh (DoF, 2022). The declaration of marine protected area (MPA), marine managed areas (MMA), marine reserves, fish sanctuaries, and ban on fishing during the reproduction period under the Protection and Conservation of Fish Act of 1950 has increased hilsa and other fish production in inland and marine water. However, illegal fishing due to lack of alternative income source and insufficient government compensation during the restricted season is undermining the success (Hoq et al., 2013; Talukdar et al., 2022). Despite the high potential for developing commercial mariculture industry in Bangladesh, no marine fin fishes are farmed (Shamsuzzaman et al., 2017a). Only the traditional culture of seabass (*Lates calcarifer*) and mullet (*Chelon subviridis*) is being reported on a small-scale basis in shrimp and prawn *ghers* (modified rice field) that are connected with coastal rivers. Seabass and mullet fry are stocked into the *ghers* collected from the wild or they enter into the *ghers* during water filling from river (Hoq et al., 2014; Chakraborty, 2021; Mondal et al., 2021). Domestication and export oriented commercial culture of high-valued marine finfish species in coastal ponds/enclosures and marine cages have high potential to boost up fish production of Bangladesh (AftabUddin et al., 2021).

Table 1. Marine fisheries resources in Bangladesh

Category	Sarker et al. (2019)	IUCN (2015)	Rahman (2015)	Hoq et al. (2013)	Islam (2003)	Hossain (2001)
Fish	475	442	442	475	475	475
Shrimp	36	36	36	36	24	25
Crab	50	16	15	15	50	15
Lobster	5	3	3	5	-	5
Mollusk	301	336	336	400	301	301
Seaweed	165	168	168	-	22	56
Squid, octopus, and cuttle fish	9	-	-	7	7	-
Dolphin/whales	11	11	11	11	-	11
Turtles and tortoise	-	7	31	5	-	4
Crocodiles	-	3	3	1	-	1

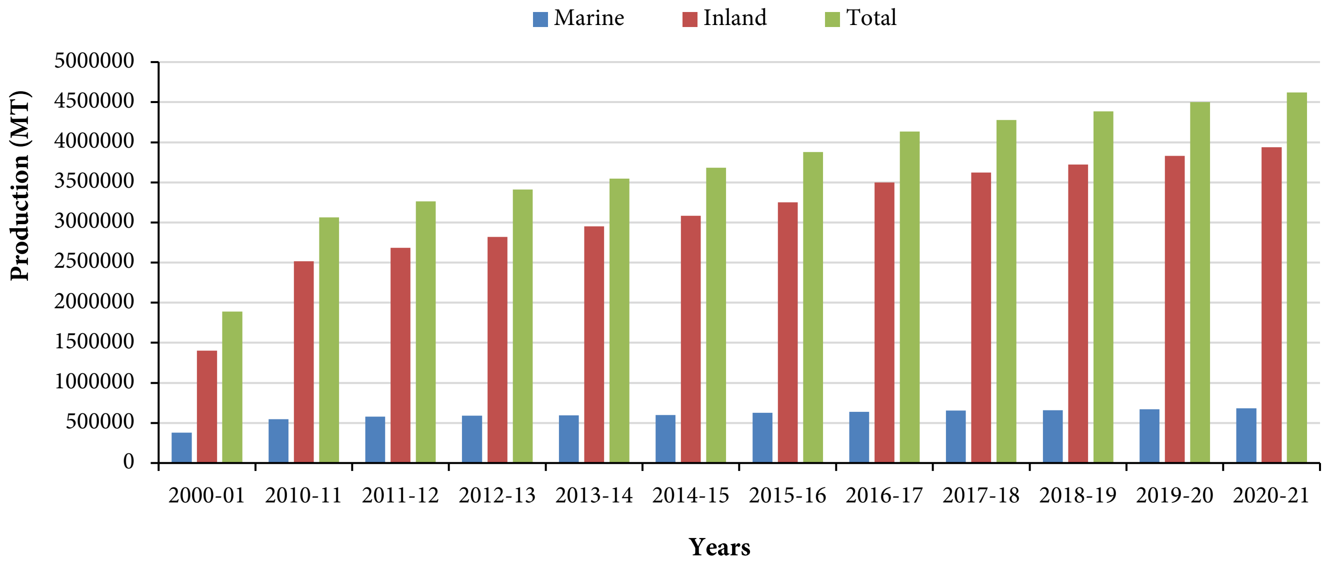

Figure 2. Inland and marine fisheries production in Bangladesh from 2000-01 to 2020-21 (Adapted from DoF (2018))

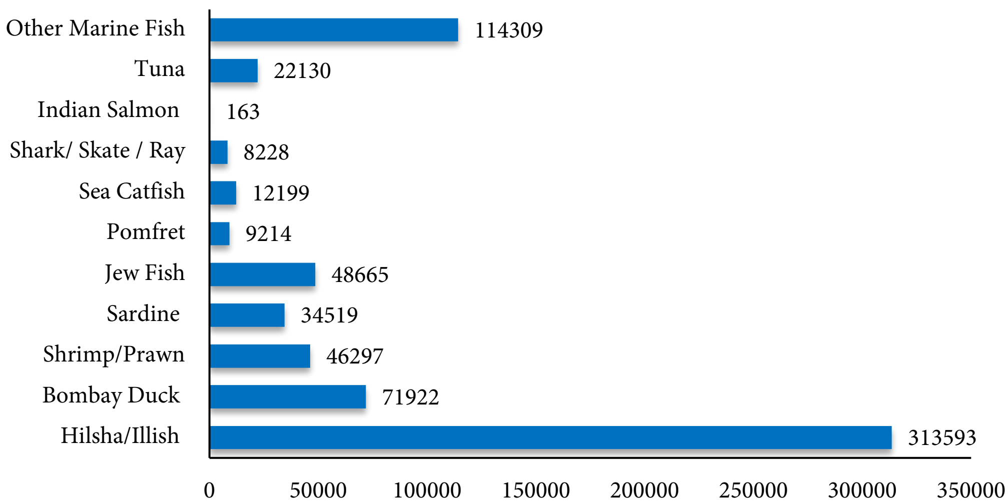

Figure 3. Species-wise annual capture (MT) in marine fisheries in 2020-21 (Adapted from DoF (2022))

Crustaceans

Shrimp and prawn

Shrimps and prawn are captured from both inland and marine water bodies (rivers, ponds, beels, floodplains, and mangroves etc.); however, commercial culture of shrimp and prawn is only carried out in inland shrimp and prawn farms (*gher*) (Ahmed, 2013; Dhar et al., 2020). The coastal aquaculture of Bangladesh mainly refers to the culture of shrimp (*Penaeus monodon*) and prawn (*Macrobrachium rosenbergii*) (Shamsuzzaman et al., 2017a) and about half of the total production of shrimp and prawn comes from shrimp and prawn farms (Figure 4). The southwest region including Khulna, Satkhira, Bagerhat, and the southeast region including Noakhali, Chattagram, and Cox's bazar cover more than 95% of the shrimp and prawn farming areas of Bangladesh (Ahmed, 2013). Shrimp and prawn farming developed in these areas because of the availability of wild post-larvae and suitable biophysical resources like salinity and low-lying agricultural land (Ahmed, 2013; Dhar et al., 2020). The culture area has expanded in the last two decades from 141352 ha in 2000-01 to 263026 ha in 2020-21 (Figure 4). Many farmers converted their rice fields into *ghers*, because *gher* farming is more profitable than rice cultivation due to its multiple cropping systems (Islam et al., 2017a, 2017b). Moreover, shrimp and prawn have very high demand in national and international market. Country's total shrimp and prawn production has increased from 152520 MT in 2001-02 to 251964 MT in 2020-21; however, the average production of the shrimp farms is 1059 kg ha^{-1} which is still very low compared to Australia (4000 kg ha^{-1}), Thailand (3116 kg ha^{-1}) and Malaysia (1500 kg ha^{-1}) (Kumar et al., 2004; Rahman & Hossain, 2013). The adoption of intensive farming in 30-40% of farms and semi-intensive farming in 60-70% of farms boosted up the production in Australia and Thailand. Bangladesh also needs to introduce intensive culture system, advanced technologies, and proper management strategies to increase per unit yield in shrimp and prawn farms (Rahman & Hossain, 2013).

Frozen shrimp and prawn is the second largest export earning sector of Bangladesh (Karim et al., 2019). However, in the last couple of years export earnings from shrimp fell both in term of value and volume (Figure 5). Rahman (2019) reported that Bangladesh is falling behind in competition with *Vannamie* shrimp because of its low price and high productivity. Many Asian countries have started *Vannamei* culture; however, not yet been reported in Bangladesh. Moreover, the major importing countries are not satisfied with the quality control and food safety assurance of Bangladesh and imposing difficult conditions to enter into their market. Now, international trade is more regulated and Bangladesh needs to introduce hazards analysis critical control point (HACCP) and traceability to survive the high competition in the international market (Islam et al., 2017b; Rahman & Hossain, 2009).

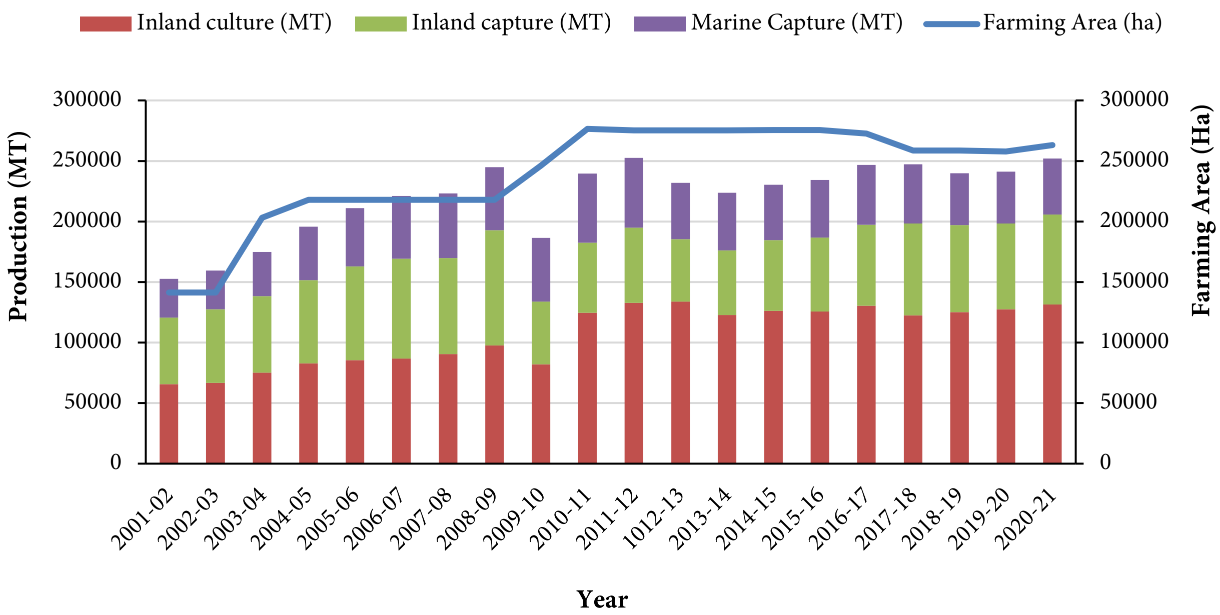

Figure 4. Farming area (Ha) and production (MT) trends of shrimp/prawn from 2001-02 to 2020-21 (Adapted from DoF (2022))

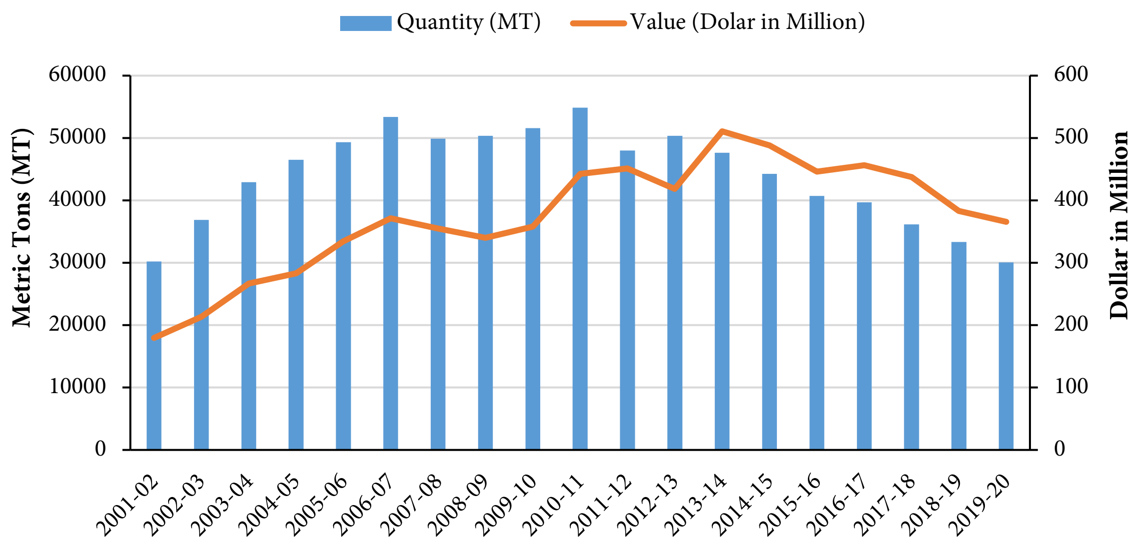

Figure 5. Export earning of frozen shrimp/prawn from 2001-02 to 2019-20 (Adapted from DoF (2020))

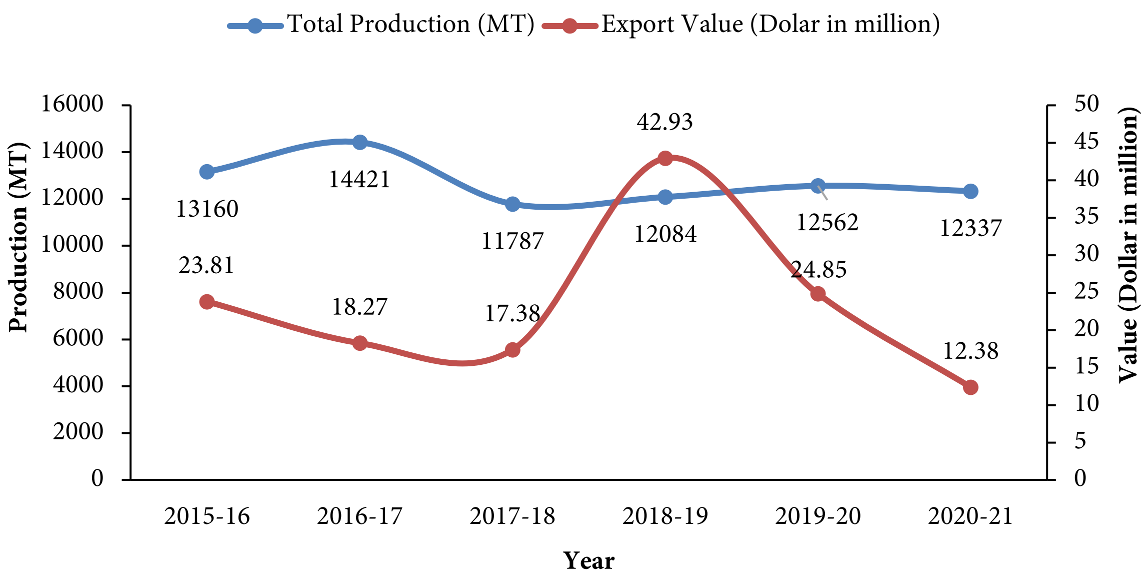

Figure 6. Annual production (MT) and export earnings (USD in million) from crab (Adapted from EPB (2022))

Crab

Crab is the second most important shellfish species in terms of the export earning in Bangladesh (Hoq et al., 2014). The availability of saline water with temperature condition promoted mud crab farming in the mangrove forests of the Sundarban area and coastal districts in Satkhira, Khulna, Bagerhat, and Cox's Bazar regions. Crab farming has bright prospects due to its low susceptibility to disease, high resistance to environmental conditions, and growing demand in the international market (AftabUddin et al., 2021). Crab species belonging to genera *Scylla*, *Portunus*, *Charybdis*, *Matuta*, *Varuna*, and *Sartorina* are available in the coastal and marine habitats of Bangladesh; however, the mud crab (*Scylla serrata*) is considered the most commercially important species (Rahman et al., 2020). Mud crab is the only species that is cultured in Bangladesh on a small scale. Mud crabs are collected from nature, shrimp farms, coastal pens, and cages. About 70% of mud crab for export comes from Khulna and the rest from Chottagram, Barishal, and Noakhali regions (Istiak, 2018). In Bangladesh, the total production of crab was 12337 MT and the total export value was USD 12.38 million in 2020-21 (Figure 6). Crabs are mainly exported to China, Thailand, the USA, the UK, Australia, Taiwan, Singapore, Hong Kong, Malaysia, and Europe in live and frozen conditions. Despite having huge economic importance due to small market structure, buyer-driven value chains, poor governance, and most importantly inadequate wild seed supply the crab industry is suddenly collapsing in Bangladesh (Lahiri et al., 2021). There is no commercial crab hatchery reported in Bangladesh and crab farming is completely dependent on wild stock (Ali et al., 2020). The indiscriminate collection of crab from natural sources is depleting the crab population in the wild (Chakraborty, 2018). Hatchery production of crablet, adoption of advanced culture technologies, introduction of value-added products, expansion of new markets, balance between local and global market, and good governance are possible options for developing a sustainable mud crab industry in Bangladesh (Lahiri et al., 2021).

Lobster

Lobster is a high-valued and popular seafood with an increasing global demand in Asia, Europe, and America. The hatchery technology is yet to be developed and almost the entire global lobster production is from capture fisheries. Recently, the sea cage culture of wild-caught lobster has been expanding in many parts of the world (Petersen & Phuong, 2010). Wild-caught juvenile lobsters are stocked in floating, suspended, and submerged cages and fed with fresh seafood (crabs, mollusks, and fish) (Jones et al., 2019). The total global production of lobster was 308664 ton in 2019 with an estimated value of USD 3920 million (FAO, 2021). Four species of lobster under the families Palinuridae known as spiny lobsters (*Panulirus homarus, P. ornatus, P. polyphagus* and *P. versicolor)* and two species of the family Scyllaridae known as slipper lobsters (*Thenus orientalis* and *Scyllarus depressus*) has so far been identified from Saint Martin's Island and other shallow rocky coastal areas of Bangladesh. Among them, spiny lobsters are the most popular and highly-priced crustacean in the domestic and international market (Ahmed et al., 2022a). The availability of naturally settling lobsters indicates that these areas are suitable for lobster grow-out. The commercial culture of lobster in Vietnam is successful with a production of 1600 tons of premium-grade lobster and the industry is valued at over USD 120 million (Jones et al., 2019). Bangladesh also has a huge prospect in farming lobster using wild collected seed from natural resources. The marine cage culture of lobster can significantly improve the livelihood and socio-economic position of the coastal people.

Seaweed

Seaweeds are marine autotrophic multi-cellular macroalgae that grow attaching to rock or other hard substrates down to the lower limit of the photic marine ecosystem (Sarker et al., 2021). Seaweeds are important due to their nutritive value, bioactive compounds, medicinal properties, pharmaceutical, and industrial uses for human welfare. Moreover, it has the potential to be used as an effective bio-fertilizer and source of renewable bioenergy (AftabUddin et al., 2021; Pradhan et al., 2022). In 2019, the global production of seaweed was 36 million tons (value of USD 14.85 billion) of which 97% was from mariculture and only 3% was from wild exploitation (Sarker et al., 2021). The coastline of BoB, Sundarban, and Saint Martin's Island was found suitable for seaweed culture (Hoq et al., 2013; Hoq, 2016; Sarkar et al., 2016). *Hypnea sp.* was found suitable to culture in Bakkhali River estuary, Inani Beach, and Saint Martin's Island in the winter season (Hoq, 2016). However, still no large-scale commercial culture of seaweed in marine water has been reported yet in Bangladesh. Local collectors collect seaweed from April to May and then exported to China, Myanmar, and Singapore (Ahmed & Taparhudee, 2005). According to Sarkar et al., (2016) about 5000 MT of seaweed biomass is naturally available from the coast of Bangladesh annually. The present production from natural habitat is still very low. Seaweed cultivation could be an alternative source of livelihood for coastal people (Ahmed & Taparhudee, 2005). However, existing seaweed farming is unplanned and farmers are facing problems due to environmental challenges (pollution, turbidity, heavy wave, bio-fouling) due to poor site selection, lack of seed supply and seaweed nursery, lack of technical and financial support for farming, harvesting and processing of seaweed, limited market, and weak supply chain (Ahmed et al., 2022b). A research and development (R&D) based roadmap is required to transform small-scale seaweed culture into a large-scale agribusiness industry. Zoning of seaweed farming areas, seed bank development for commercial seaweed species, integrated and intensive farming practice, value-added product development, post-harvest processing, and seaweed-based industry are the key to developing the seaweed industry in Bangladesh (Chowdhury et al., 2022).

Mollusk

Mollusk, a diverse group including bivalves (oysters, clams, and mussels), gatropods (snails and slugs), cephalopods (cuttlefishes, squids, and octopuses), etc. is available in the marine water of Bangladesh (Islam, 2003). Mollusk meat and shells are used for different purposes like human consumption, poultry and aquaculture diet preparation, lime production, paint making, and ornamental usage (Solaiman et al., 2006). Marine bivalve can produce pearl and a total of 7 species of pearl-bearing oyster has been identified in the BoB which has very high culture potential (Rahman et al., 2015). Marine cephalopods are caught by trawl net or set bag net from up to 20 m deep and they contribute 4-5% of total marine fish landing (Siddique et al., 2016). No published report on mollusk catch and stock size is available; however total usage by different stakeholders involved in the mollusk industry was estimated to be 1130 MT per year (Solaiman et al., 2006; Shahabuddin et al., 2010). Mollusk culture is a very low-investment activity with very good returns. Bangladesh earned USD 5.51 million the 2017–2018 by exporting oysters, mussels, and scallops (AftabUddin et al., 2021). Considering water quality, transport, and market facilities the south eastern coast of Bangladesh including Moheskhali channel, Kutubdia, Coxes Bazar, and Teknaf was found to be the most suitable place for mollusk culture while the south western coast was moderately suitable (Salam et al., 2005; Shahabuddin et al., 2010; Hossain et al., 2013). Due to lower salinity and muddy substrate the middle part of the coast was not found suitable for mollusk culture (Salam et al., 2005). Although we have suitable site for marine mollusk culture, no commercial culture of mollusk is reported yet in Bangladesh. Mollusk aquaculture can generate alternative livelihood and employment opportunities in Bangladesh (Hossain et al., 2013). There is considerable potential for future development of the mollusk culture industry in Bangladesh.

Marine Fisheries Products

Marine fisheries products are the important export item in Bangladesh. Producing marine dry and dehydrated fish is a very common practice in the coastal regions and isolated coastal islands (Hoq et al., 2014). About 20% of the total marine catch is dried round the year and marketed in the UK, the US, the Middle East, and domestic markets (Hoq et al., 2014). In the 2017-18 fiscal year, Bangladesh earned USD 4.19 and 2.62 million by exporting 3144 MT of dried and salted fish, and 214 MT of dehydrated fish, respectively (DoF, 2018). Shark and shark products like shark fins, tails, skin, bone, meat, liver, jaw, etc. are other exportable items from Bangladesh. Shark products are mainly exported to Myanmar directly from Cox's Bazar through border. During 2017-18, different shark products exported from Bangladesh were around 0.50 MT with an estimated value of USD 11817 (DoF, 2019). Major shark hunting grounds in Bangladesh include areas of Patuakhali, Barguna, the Sunderbans, Sandwip, Kutubdia, Moheshkhali, and Elephant Point in Teknaf (Roy et al., 2015). There is a good opportunity to earn foreign currency from exporting shark products through proper channels. There is also a high demand for marine mollusk shell especially in Cox's Bazar where there is a mollusk market. The empty shells are used as raw material in making shell craft products, showpieces, ornaments and home decorative item (Rahman et al., 2015). Around 1,000 households were involved in ornament marketing and about 250 MT of mollusk shells were used in this industry annually in Cox's Bazar (Solaiman et al., 2006). Proper planning and government support are required to get more output from these prospective sectors.

Non-Conventional Marine Fisheries Resources

Non-conventional marine fisheries resources such as sea cucumber, sea urchin, skates and rays, horseshoe crab, marine sponge, and coral possess huge economic prospect due to their diversified use and high demand in the international market. Sea cucumber and sea urchin collection and culture can also be initiated in Bangladesh. In the Asia-Pacific region (e.g., China, Japan, Korea, Singapore, and Malaysia), sea cucumber and sea urchin have significant importance as a high nutrient food item (AftabUddin et al., 2021). Horseshoe crab has huge prospect in biomedical and pharmaceutical utilization such as endotoxin detection. It is also used for human consumption and as bait for fishing (Gorman, 2020). Skates and rays are not considered as primary food fish; however, are consumed as dietary supplements (cartilage supplement), making traditional Chinese medicine, and used in cosmetics industries (Tiktak et al., 2020). Marine sponges are considered as a treasure house of drugs in response to the potential of their secondary metabolites. Many of these biologically active compounds have shown a wide range of pharmaceutical activities such as antibacterial, antifungal, antitumor, anticancer, antimalarial, antiprotozoal, anti-inflammatory, immunosuppressive, cardiovascular, and antifouling activities (Hassan & Shaikh, 2017). Saint Martin's Island has potential for coral farming, which is better suited to small-scale artisanal production with the help of exporters of aquarium products (AftabUddin et al., 2021). Thus, the exploitation and culture of non-traditional fish, shellfish, mollusk, and crustacean species can significantly contribute to the economy of Bangladesh.

Challenges Toward Sustainable Blue Economy

Challenges in Developing Mariculture

The geographical position and climate condition of Bangladesh is suitable for mariculture however, there have been limited attempts to promote mariculture due to many constraints (Figure 7). The scarcity of seed-producing hatcheries for commercially important marine species is a vital constraint for mariculture development in Bangladesh. Wild-caught juvenile and brood stocks need to be domesticated in captive conditions prior to initiating breeding and culture. In this regard, full-fledge technical education and research institutes are required to develop expertise and new technologies. Lack of capital is another vital problem in developing mariculture in Bangladesh. Commercial mariculture infrastructures like inshore coastal ponds and raceways, offshore floating net cages, mollusk and seaweed culture rack and rafts, etc. require a lot of investment. Access to institutional credit operated by commercial banks in Bangladesh is very limited and complicated. Moreover, the country does not have enough domestic consumer for mariculture products like crab, shellfish, seaweed, and others. Hence, modern seafood processing plants are required to export mariculture products to the international markets (Hussain et al., 2019; AftabUddin et al., 2021).

Limited Survey to Identify Fishing Grounds and Stock Assessment

According to Hoq et al. (2013), a total of 26 surveys were carried out in the BoB from 1857 to 2007. Early surveys were for identification of fishing grounds and later surveys were for fisheries stock assessment. Four fishing grounds namely South patches, South-west of south patches, Middle ground, and Swatch of no ground were identified in the BoB (Figure 1) through the survey of Sagar Sandhani and Meen Sandhani (research vessel) from 1968 to 1971 (Hoq et al., 2013; Sarker et al., 2018). Since that, no survey was conducted to find new fishing grounds in the BoB. DoF procured a research vessel from Malaysia in 2016 to conduct survey of demersal fish stock assessment, shrimp stock assessment, and pelagic fish stock assessment in the BoB (Hoq et al., 2013). The stock surveys are about 8 years old and no recent or comprehensive knowledge is available on the fisheries stocks, systematics, biological, and ecological aspects of marine fisheries of Bangladesh (Shamsuzzaman et al., 2017b). Standing stock evaluation and maximum sustainable yield values are necessary knowledge for sustainable resource management (Islam & Shamsuddoha, 2018). Fishing without adequate information on the status of the stock leads to over-exploitation or under-exploitation of fishery resources (Hussain & Hoq, 2010). Several studies reported that the distribution of fish stock shifts over time due to various reasons like climate change or intensive fishing pressure (Katikiro, 2014). Therefore, to identify new fishing ground and assess standing stock for sustainable exploitation, survey needs to be carried out in the extended maritime boundary.

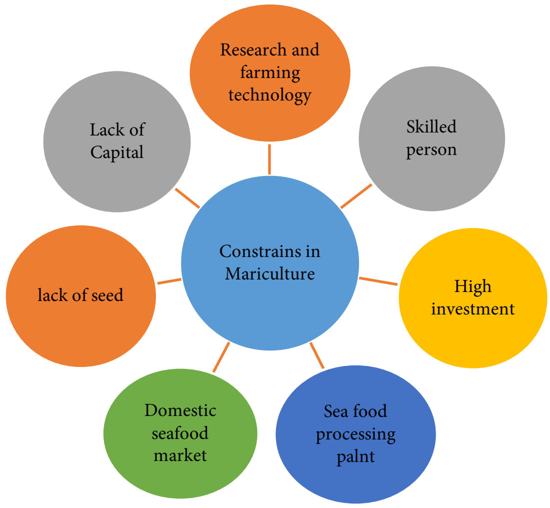

Figure 7. Constraints in developing mariculture in Bangladesh

Fishing Pressure

Bangladesh Fisheries Development Corporation (BFDC) started commercial exploitation of these fishing grounds in 1972 with only 11 fishing trawlers (Islam, 2003). As there is no updated stock assessment report, it is hard to maintain the maximum sustainable yield of our marine fisheries resources. In the last twenty years, industrial (fish and shrimp trawler) and artisanal (mechanized and non-mechanized boat) fishing has increased in the BoB (Figure 8). The number of fish and shrimp trawlers has increased from 21 in 1999-20 to 216 in 2020-21 which is more than ten times higher. At present, 32,859 mechanized and 34,810 non-mechanized boats are exploiting mainly for demersal fishes (DoF, 2022). Pelagic and deep-sea marine fisheries resources are still unexploited (Shamsuzzaman et al., 2017b). Both industrial and artisanal fisheries are exploiting fishery resources without any appropriate management plan due to the unavailability of scientific information and management strategies (Hoq et al., 2013). Therefore, a multidisciplinary baseline research program needs to be developed in the BoB.

Illegal Fishing

The use of illegal fishing gear and illegal fishing by outsider and domestic fishers made the scenario more difficult to maintain responsible fishing. Some destructive fishing gears like estuarine set bag net (ESBN), gill net, and their indiscriminate uses are destroying fry and juveniles of fish and other marine resources (Hoq et al., 2013). Besides, illegal fishing by domestic and foreign fishing trawlers are now a great concern too. Illegal fishers from Myanmar, India, Thailand, and

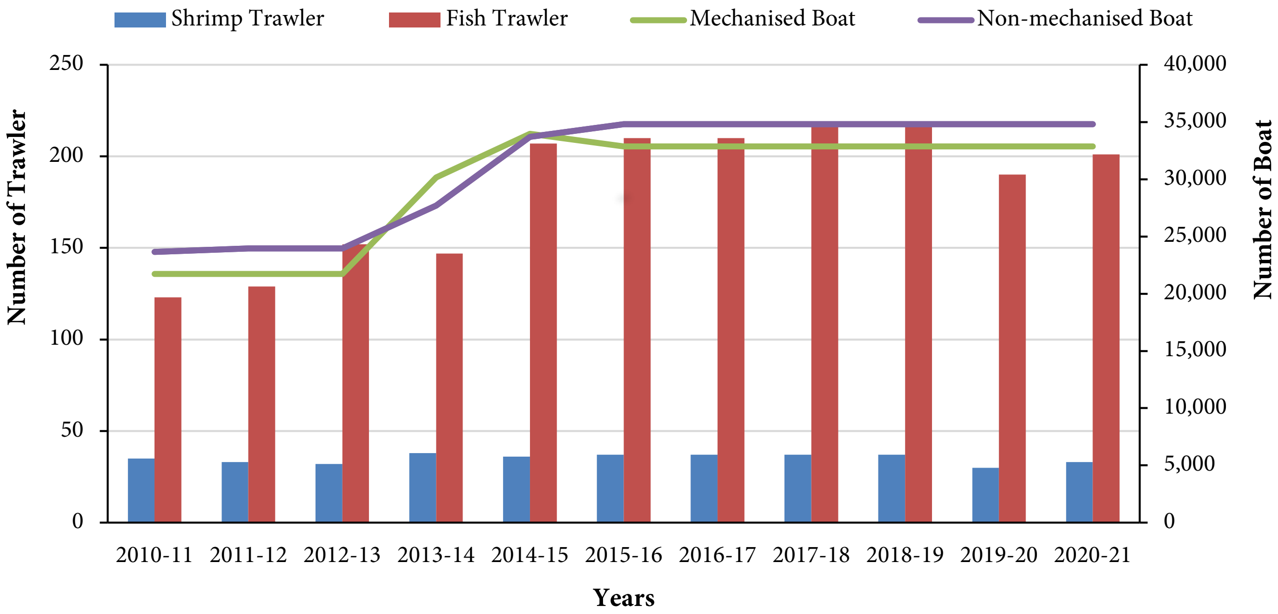

Figure 8. Fishing crafts used in the Bay of Bengal from 2010-11 to 2020-21 (Adapted from Hoq et al. (2013) and DoF (2018))

Sri Lanka trespass the maritime boundary and enter into the Bangladeshi maritime zone (Hussain et al., 2018). An effective surveillance and monitoring system needs to be established to prevent illegal fishing pressure.

Marine Pollution

Marine pollution is another concerning issue in BoB that pollutes the marine environment and degrades marine biodiversity. Industries, ship-breaking yards, sewage, tourism, and trans boundary depositions are the main sources of pollution. Moreover, major river systems (Ganges, Meghna, Jamuna, and Brahmaputra) of Bangladesh carry land-based wastes from urban areas (Biswas et al., 2021). Ocean acidification also threatens blue economy and causes adverse biological effects on marine organism (Tayyar, 2023). Without appropriate control measures, coastal and marine ecosystems are largely unprotected and pollution can cause devastating impact on marine biota including human health (Alam & Xiangmin, 2019). Being a maritime nation, as well as one of the top biodiversity-rich country, Bangladesh needs to take the marine pollution issue seriously. At present, Bangladesh has no act or law to protect the coastal and marine resources from pollution. To conserve and protect the ecosystem and environment Bangladesh has enacted a number of conservation and protection laws but they do not have any direct relation with marine pollution (Alam & Xiangmin, 2019; Alam et al., 2021). Bangladesh can draw lessons from international marine pollution control regulations and set up marine pollution protection law in the present context of blue growth.

Inadequate Government Rules, Policies, Regulations, and Poor Implementation

Economic activities in the ocean may cause threats to the biodiversity and the environment, therefore it is important to implement environmentally compatible policies (Suluk, 2022). There are about twelve old-fashioned fisheries regulations for the management of fisheries resources in Bangladesh. Major features of these regulations are protection, conservation, restriction, management, exploitation, monitoring, supervision, quality control, licensing, and development (Shamsuzzaman et al., 2016). Unfortunately, most of the laws are not implemented properly and surveillance in the coastal and marine areas is very poor. The implementation of these laws and policies often faces conflicts among the stakeholders due to coastal poverty, the inadequate and improper distribution of incentives, insufficient logistic support, limited alternative occupations, political interference, and a lack of awareness regarding fishery regulation (Islam et al., 2017c). Moreover, the lack of clear policy guidelines and strategy and the absence of regular law review and updating mechanisms are also limiting the success in the implementation of these laws (Shamsuzzaman et al., 2016). There is a need to adjust the existing laws and legislation of the country to achieve the goal of sustainable coastal and marine fisheries resource management. An integral, coherent, and comprehensive legal framework is required to formulate consulting with all the fishery stakeholders (Islam et al., 2017c).

Conclusion

The marine fisheries resources in Bangladesh hold immense potential for boosting fisheries production and driving economic growth. Expansion of mariculture and effective utilization of marine resources can play a part in developing a sustainable blue economy in Bangladesh. To increase marine fisheries production, it is imperative to address the existing challenges comprehensively. This entails not only conducting further scientific investigations for stock assessment, exploring new fishing grounds, and advancing culture technologies but also prioritizing the development of skilled personnel, leveraging advanced technology, expanding the domestic seafood market, enhancing the supply chain, and implementing effective management strategies. Moreover, to overcome the limitations hindering marine fisheries performance, it is crucial to strengthen policy interventions. This includes formulating specialized government policy for marine fisheries, and ensuring their robust implementation. By strengthening policy frameworks, Bangladesh protects its marine fisheries resources efficiently, drive the blue economy forward, and make a substantial contribution to sustainable development.

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Compliance With Ethical Standards

Authors' Contributions

MRI: Conceptualization, Data analysis, Writing - Original Draft, Writing-Review and Editing
TA: Conceptualization, Data analysis
AH: Writing - Original Draft
ATT: Writing - Original Draft
SSM: Writing - Original Draft
MAH: Writing-Review and Editing
MMH: 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.

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Data Availability Statement

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

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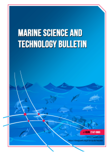

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RESEARCH ARTICLE

A bibliometric analysis of mental health and wellbeing of seafarers

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ABSTRACT

The present study aims to analyse the output of mental health and wellbeing studies on seafarers. The necessary data from the Web of Science database was retrieved and processed using the visualisation and mapping programme VOSviewer 1.6.19. The study maps seafarers' mental health and wellbeing research published from 2004 to 2023. The findings indicate that the most common topic of seafarers' mental health and wellbeing was the International Maritime Health Journal was the most prominent. The United States of America was the most productive country. The outcomes of this present study can assist researchers in conducting more effective studies on the mental health and wellbeing of seafarers by providing insights into potential journals for reference, contributing authors, emerging patterns, nations, and relevant keywords.

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Introduction

World Health Organisation (WHO) defines health as "a full condition of physical, mental, and social wellbeing, not only the absence of sickness or disability". Mental health is an essential component of overall health; in fact, there is no health without mental health. One significant matter is that a variety of social, biological, and environmental factors have an impact on mental health (WHO, 2023). The physical and psychological environmental conditions of workers while working and their mental health interact (Belloni et al., 2022). Specifically, seafarers can be vulnerable because of the nature of the profession for mental health. The ship is a working environment where the conditions of the working and living environment are intertwined with noise, vibration exposure, long work hours, trouble sleeping, contract length, long time away from the family and social environment, isolation supervisor demands and intense workload (International Labour Organization, 1997; Blackburn, 2020).

In the context of seafarers' mental health studies, it is apparent that seafarers' mental health and wellbeing are associated with variables such as stress (Nielsen et al., 2013; Akamangwa, 2016), workplace violence and mobbing (Mayhew

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& Chappell, 2007; Sampson et al., 2018, 2019; Uğurlu et al., 2022), fatigue (Bal et al., 2015; Lefkowitz & Slade, 2019), job satisfaction (Yuen et al., 2018), wellbeing (Stannard et al., 2015; Slišković, 2020; Brooks & Greenberg, 2022), depression and suicide (Mayhew & Chappell, 2007; Sampson et al., 2018, 2019; Uğurlu et al., 2022), fatigue (Bal et al., 2015; Lefkowitz & Slade, 2019), job satisfaction (Yuen et al., 2018), wellbeing (Brooks & Greenberg, 2022; Slišković, 2020; Stannard et al., 2015), and similar with other fields. Anxiety, disruptive thinking and behaviour, and addiction to alcohol and drugs are also defined as elements compromising the mental health of seafarers (ISWAN, 2015). Although research concerning seafarers' mental health is arising but limited in the literature, Lefkowitz and Slade's study holds great significance for the findings: It shows that 17% of the seafarers who participated in the study reported generalised anxiety disorder, 20% reported having suicidal ideation and 25% reported symptoms of depression (Lefkowitz & Slade, 2019).

A bibliometric study of publications from time period is required in order to help us arrange enormous amounts of data, evaluate the state of a particular research subject state-of-art, and offer suggestions or guidance for future research (Han et al., 2019). In the study, it is used a bibliometric analysis to analyse the development of research for mental health of seafarers and wellbeing. This study aims to provide insight into the subject of seafarers' mental health and wellbeing. The purposes of this study are to (1) identify the contributing countries and the most influential journals, (2) determine the most frequently appearing keywords on the topic; (3) to identify the distribution of contributing affiliations, (4) co-cited authors.

Materials and Method

Bibliometrics analysis is a study methodology called academic outputs quantitatively and statistically. Further, network analysis of keywords, texts, citations, authors, institutions, and their relationships is part of this methodology (Liang & Liu, 2018). Well-executed bibliometric studies can lay the groundwork for advancing a field in fresh and significant ways by giving scholars the ability to (Donthu et al., 2021): (1) obtain a comprehensive overview; (2) identify knowledge gaps; (3) derive fresh ideas for research; and (4) put their planned contributions to the area of study. There are bibliometric studies on different subjects in the maritime field such as maritime transport literature (Solak Fiskin & Güldem Cerit, 2019), maritime accidents (Cao et al., 2023; Yurt & Cenk, 2023), oil spill (Buber & Koseoglu, 2022a, 2022b), inspection analysis (Bicen & Celik, 2023), safety management (Rinaldy, 2023), seafarers' health research (Jiang et al., 2023), Automatic Identification System (Meyers et al., 2021).

Table 1. Searching Strategy for seafarers' mental health and wellbeing research in the WoS database

	Categories	Applied Filters
1	Keywords	(Mental health or wellbeing or well-being or depression or suicidal ideation or suicidal thoughts or anxiety or stress* fatigue or burnout* or aggression* or sense of isolation* or substance misuse or alcohol misuse or alcoholism or hazardous drinking or problematic drinking* or bullying or harassment or workplace violence or mobbing*) and (seafarer* or seafaring or navy personnel or mariners or maritime personnel or sailor* or seamen*)
2	Publication Time	2004-2023
3	Document Types	Articles and review articles
4	WOS Index	Social Sciences Citation Index (SSCI), Science Citation Index Expanded (SCI-E), and Emerging Sources Citation Index (ESCI).
5	WOS Categories	Public Environmental Occupational Health; Psychiatry; Psychology Multidisciplinary; Psychology Clinical;; Transportation; Psychology; Engineering Marine, Engineering Industrial; Psychology Applies; Oceanography; Ergonomics; Engineering Ocean; Operations Research Management Science; Psychology Experimental; Psychology Social; Engineering Civil; Management; Psychology Developmental; Engineering Mechanical; Industrial Relations Labour; Women S Studies; Behavioural Science; Business; Psychology Educational; Psychology Psychoanalysis.
6	Citation Topics Meso	Safety and Maintenance; Psychiatry and Psychology; Psychiatry; Sleep Science and Circadian Systems; Management; Social Psychology; Substance Abuse; Gender and Sexuality Studies; Operations Research and Management Science; Health Literacy and Telemedicine; Healthcare Policy, Communication.
7	Language	English

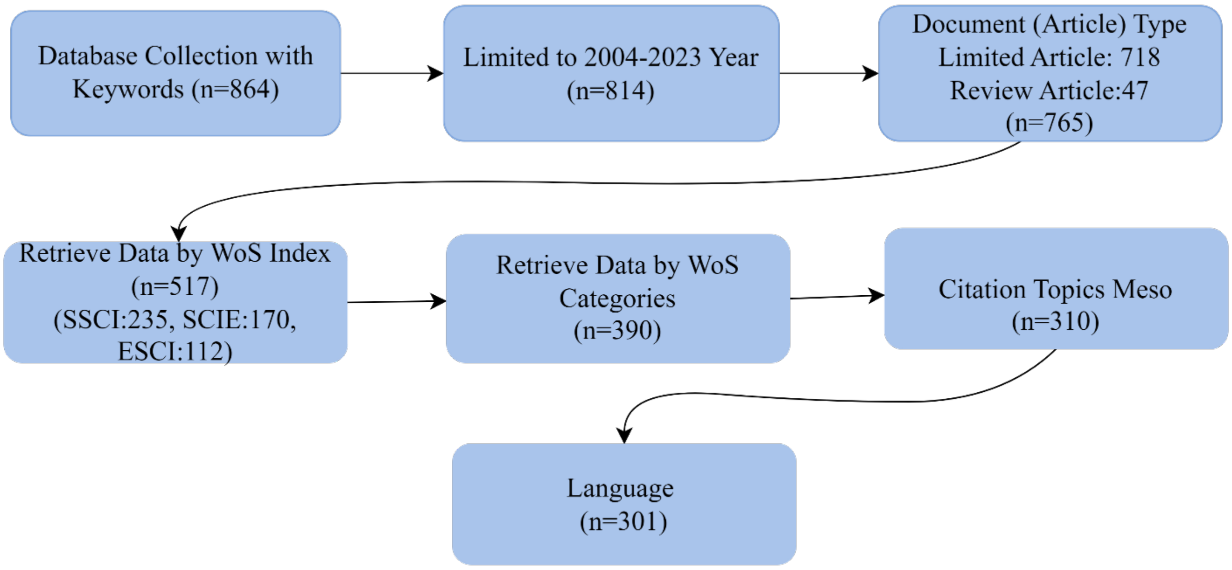

Figure 1. Data collection process

In order to have comprehensive data we used the Clarivate Analytics ISI Web of Science (WoS) website served as the major source of worldwide research data for this article. The dataset was created using the WoS database and analysed using visualisation and descriptive statistics in this article. The data used in this study was retrieved on 22nd November 2023 with search strategy shown in Table 1:

The data collection process is illustrated in Figure 1. Initially, a database query was conducted using specific keywords. The search was initiated from publications dating back to 1981. Subsequently, the time frame was restricted to the years 2004–2023, and proceedings papers were excluded from the dataset. Only articles and review articles were considered for inclusion. Following this, the data was retrieved from publications indexed in SSCI, SCIE, and ESCI. The Web of Science (WOS) database was then filtered by categories and topics. Lastly, the language was restricted to English only. A total of 301 articles were retrieved by employing this searching strategy. The titles, keywords, and abstracts of the studies included in the databases were examined first, manually. Then, the studies that were outside the scope of the search were eliminated from the results. Finally, 209 articles were found to be relevant to seafarers' mental health and wellbeing.

Findings and Results

From 2004 to 2023, all review and research articles on seafarers' mental health and wellbeing were examined as follows. The data of 209 articles were evaluated according to the number of articles and citations by years and the journals that accepted the publications. Figure 2 depicts the scientific production of papers with citation analysis from 2004 to 2023, in total 209 articles.

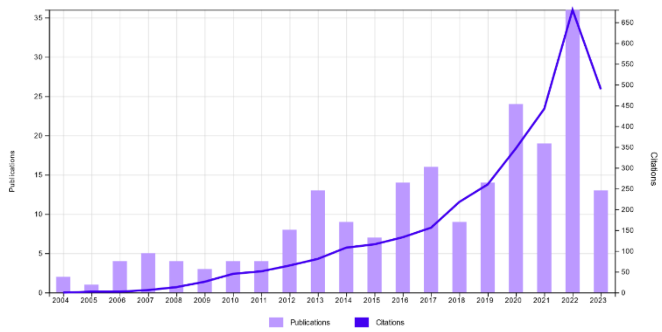

Figure 2. Publications and times cited over time

As seen in Figure 2, there have been fluctuations in the number of publications and citations in the last 20 years. For instance, there is only one publication in 2005, while in 2022, 22 publications are produced. In this period (2004-2023), the number of citations has experienced fluctuations over time. In 2004, no studies were cited, whereas 2022 marked the most cited year with 680 citations. There are 20 publications addressing the mental health and wellbeing of seafarers that have yet to receive citations. Among these uncited studies, the oldest dates back to 2017, while the rest are relatively recent, published in subsequent years after 2017.

The journals that have published the highest number of articles publishing the highest number of articles mental health and wellbeing of seafarers are summarized in Figure 3.

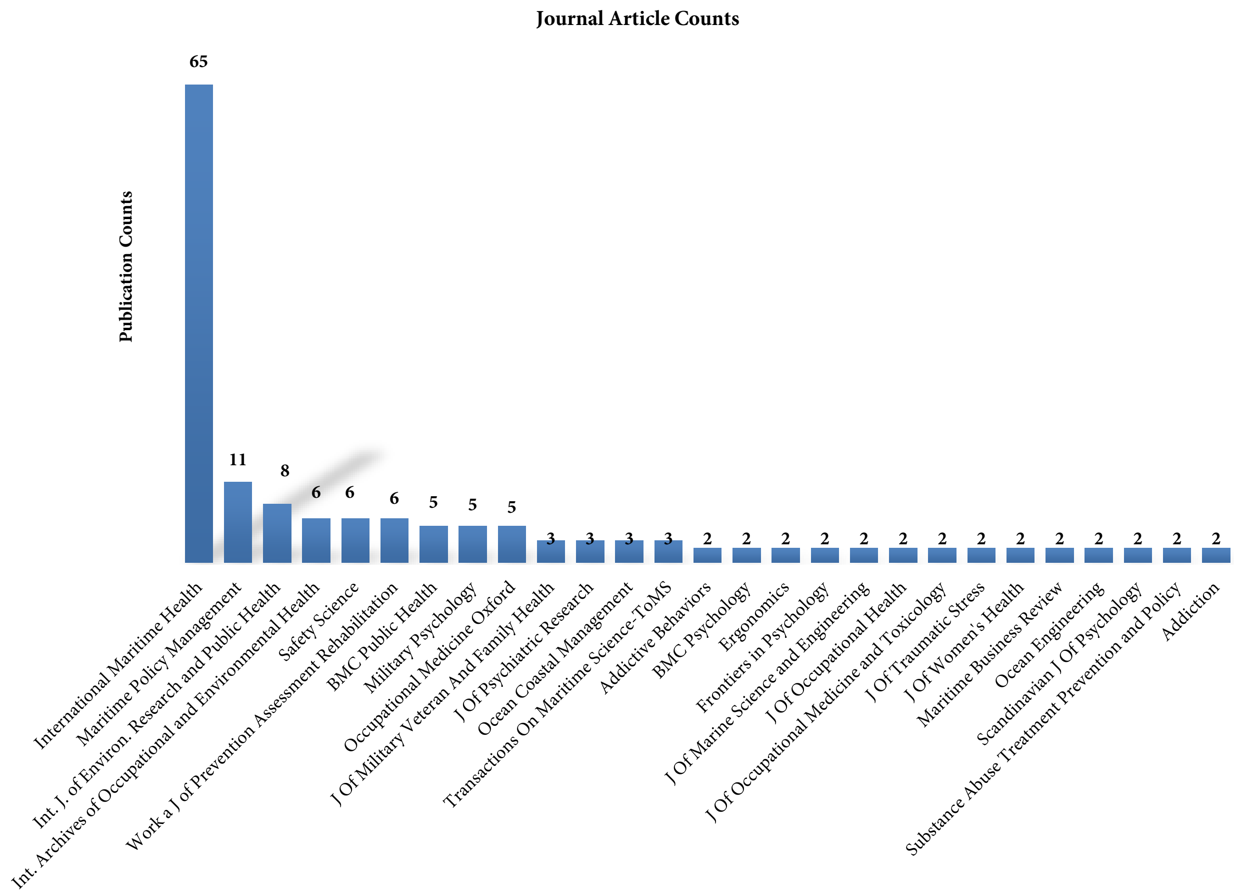

Figure 3. Most productive journals for mental health and wellbeing of seafarers'

Table 2. Most impactful articles for seafarers' mental health and wellbeing

Rank*	Authors	Journal	Doc. Type	Times Cited, WoS Core	Times Cited, All Dbs	Pub. Year
1	Hetherington et al. (2006)	J. of Safety Research	Review	411	421	2006
2	Oldenburg et al. (2010)	J. of Occupational Health	Review	138	141	2010
3	Carotenuto et al. (2013)	Int. Maritime Health	Review	118	127	2013
4	Iversen (2012)	Int. Maritime Health	Review	88	91	2012
5	Jepsen et al. (2015)	Int. Maritime Health	Review	80	85	2015
6	Rohsenow et al. (2007)	Addictive Behaviors	Article	73	78	2007
7	Hystad & Eid (2016)	Safety And Health at Work	Article	73	76	2016
8	Oldenburg et al. (2013)	Int. Archives of Occupational and Environmental Health	Review	68	72	2013
9	Nielsen (2013)	Scandinavian J. of Psychology	Article	68	70	2013
10	Wadsworth et al. (2006)	American J. of Industrial Medicine	Article	47	51	2006

Note: *Ranking by Times Cited All Databases; Doc. Type refers to Document Type; Times Cited, All Dbs refers to Times Cited All Databases; Pub. Year refers to Publication Year.

A total of 81 journals, each with a minimum of two publications, were examined based on the number of articles. "International Maritime Health" (n= 65, 31.10%), "Maritime Policy and Management" (n=11, 5.26 %), and "Journal of Environmental Research and Public Health" (n= 8, 3.83%) were the most productive journals. The top 5 journals with the highest number of publications represent 56% of total publications. The highest number of the research areas in the publications are respectively Public Environmental Occupational Health (n=123, 58.85%), Psychology (n=33, 15.79%), Engineering (n=22, 10.53%), Psychiatry (n=20), 9.57%), and Transportation (n=14, 6.70%). Table 2 summarizes the most cited articles related to seafarers' mental health and wellbeing between 2004 to 2023.

As seen in Table 2, there are 6 Review articles in the top 10 most cited publications. We can infer that the review article is prominent among the most cited publications. The most cited article (421 total citations) is by Hetherington et al. (2006), that individual factors such as fatigue, health and stress may have a role in accident causation (Hetherington et al., 2006). The second (141 total citations) is Oldenburg et. al (2010) that primary and secondary prevention of work-related hazards, psychological stress and lifestyle risks, and all factors contributing to fatigue and isolation have been expressed as the most fundamental approach to reducing the occupational health risks of seafaring (Oldenburg et al., 2010). The third one (127 total citations) is by Carotenuto et al. (2013) who evaluated the 162 seafarers by The Psychological General Well-being lndex. Engineer officers expressed a great deal more anxiety than the deck and engine crew did (Carotenuto et al., 2013).

The most cited articles are also most leading ones in the topic of research. The highest number of citation topics meso in the publications are respectively Safety & Maintenance (n=118, 56.46%), Psychiatry & Psychology (n=39, 18.66%), Sleep Science & Circadian Systems (n=15, 7.18%), Management (n=13, 6.22%), and Social Psychology (n=7, 3.35%). Likewise, the highest number of citation topics micro in the publications are respectively Safety climate (n=112, 53.59%), post-traumatic stress disorder (n=38, 18.18%), insomnia (n=15, 7.18%), job satisfaction (n=12, 5.72%), and alcohol, maritime safety, and subjective well-being (n=4, 1.91%).

Co-citation analysis is a science mapping technique that presupposes those articles frequently cited together share similar thematic content (26). The co-citation networks of references are visualised in Figure 4. A co-citation analysis of 209 references with at least 20 citations between 2004 and 2023 revealed 28 authors and four clusters. The four main clusters and related themes are denoted by orange, green, blue, and yellow. The number of publications connected to seafarers' mental health and wellbeing by corresponding writers is shown by the size of the nodes in Fig. 4, and the thickness of the connecting lines reflects the closeness of the ties between the authors. The colour of the lines and nodes represents the author's topic similarity. Oldenburg et al (2010) was the most co-cited article in these 4 clusters (Oldenburg et al., 2010). In the article, seafaring is characterized by several occupational risks, including high stress levels, fatigue, and isolation.

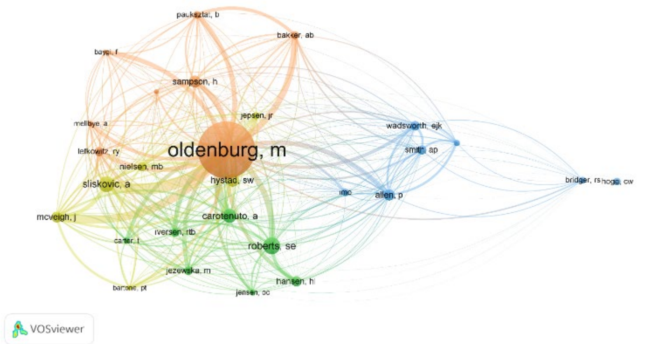

Figure 4. Network map of co-cited references

Figure 5. Co-authorship network among the authors

Figure 5 depicts a network of co-authorship author analysis related to the mental health and wellbeing of seafarers. As seen in Figure 5, there is no network connecting all available authors. There is limited collaboration between authors with at least 4 papers, with many authors publishing their papers as single authors. To produce better quality publications, there is a need for collaboration between authors with different methods and different perspectives.

The most frequently used keywords and the relationship between the keywords are shown in Figure 6. "seafarers", "stress", "mental health", and "fatigue" are the most commonly used keywords. This study shows that the studies on seafarers' mental health and wellbeing are mostly done on stress, mental health, and fatigue. The colours blue, orange, green, and yellow represent the four major clusters of co-cited articles and connected themes. The keywords stress, fatigue, sleepiness, sleep quality, job satisfaction, maritime industry, seafaring, seafarers, mental health, Covid-19 and wellbeing are in Cluster 1 (orange colour) and Cluster 2 (blue colour). The top ten words with the highest number of co-occurrences, each repeated at least five times, were identified. With the keywords in the Cluster 1 and 2, anxiety, depression, military, military personnel, navy, resilience, wellbeing, maritime, and seafarer in Cluster 3 (green colour) in Cluster 4 (yellow colour) keywords clearly indicate that they stand for the main conceptual frameworks in the literature on the mental health and wellbeing of seafarers.

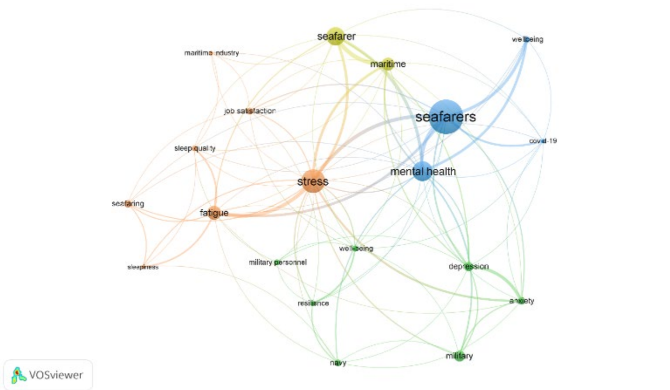

Figure 6. Keyword co-occurrence network visualization

Table 4. Countrywide citation

	Country	Total Articles (TA)	Total Citations (TC)	Citation Impact
1	USA	35	483	13.80
2	England	30	395	13.17
3	Norway	17	331	19.47
4	China	15	232	15.47
5	Denmark	14	221	15.79
6	Wales	14	141	10.07
7	Germany	12	301	25.08
8	Australia	11	248	22.55
9	Türkiye	11	90	8.18
10	Sweden	10	159	15.90
11	France	10	48	4.80
12	Italy	10	197	19.70
13	Croatia	8	106	13.25
14	Poland	8	90	11.25

Figure 7 shows the collaboration network on the country based. The most effective countries are the United States of America (USA), England, and Norway, as in Table 4. When the four clusters are investigated, the most effective and collaborative countries are the US, China, and Wales which are shown in yellow. And second order, England, Norway and Türkiye are effective and collaborative countries which are shown in green colour. The US has the highest number of articles with 35 publications, followed by the England and the Norway with 30 and 17 publications. There are several reasons USA and the England have the highest publicity. USA has civil and military research institutes, and England and Norway have universities with maritime research centres. In Figure 8 and Table 5 show the network of affiliations and distribution.

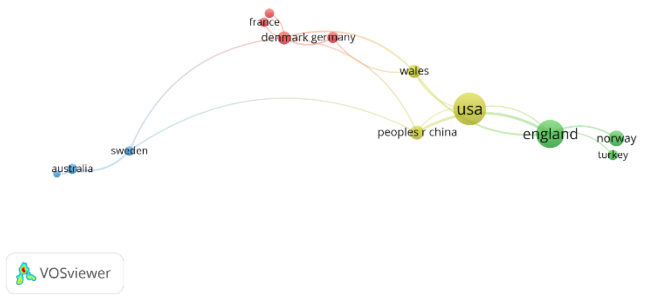

Figure 7. Country Collaboration Network

The 209 articles identified come from 42 different countries. Two articles were produced in 35 countries, three articles in 25 countries, four articles in 18 countries, and five articles in 14 countries. USA has the highest number of publications (30 articles) and a citation impact of 13.8. On the other hand, although Germany and Australia have 12 and 11 publications respectively, their citation impact is quite high with 25.08 and 22.5.

As seen in Table 5, University of Southern Denmark and Cardiff University are the institutions with the highest number of publications and collaborative (13 articles). Figure 8 shows the affiliation networks, providing a visual representation of the articles. The blue, red, yellow, and green colours indicate the four primary clusters. Cluster 1 (blue colour) includes 23 publications from Cardiff University, İstanbul Technical University and University of Zadar. 23 publications produced at University of Bergen, Shanghai Maritime University, Liverpool John Moores University, University of Queensland and Flensburg University Applied Science in Cluster 2 (red colour). Cluster 3 (yellow colour) comprised of 22 publications by University of Southern Denmark and University Medical Centre Hamburg Eppendorf. Cluster 4 (green colour) includes 19 publications produced at Kings College London, Medical University Gdansk, University of Camerino.

Table 5. Affiliation distribution

	Affiliations	Total Articles (TA)	Total Citations (TC)	Citation Impact
1	University of Southern Denmark	13	218	16.77
2	Cardiff University	13	128	9.85
3	University of Bergen	9	242	26.89
4	Kings College London	9	127	14.11
5	Naval Health Research Center	9	123	13.67
6	University Medical Center Hamburg Eppendorf	9	73	8.11
7	University of Camerino	6	165	27.50
8	University of Zadar	6	102	17.00
9	Shanghai Maritime University	6	43	7.17
10	Liverpool John Moores University	4	60	15.00
11	Istanbul Technical University	4	56	14.00
12	University of Queensland	4	54	13.50
13	Leidos	4	50	12.50
14	Medical University Gdansk	4	23	5.75
15	Flensburg University Applied Science	4	11	2.75

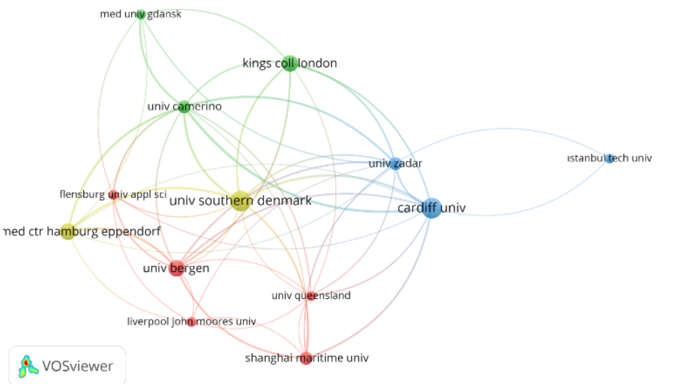

Figure 8. Affiliation network visualization

209 articles were produced by 275 different institutions. In total, 275 institutions produced only one article, 69 institutions produced two articles, 37 institutions produced three articles and 15 institutions produced only four articles. The University of Southern Denmark and Cardiff University had the most publications and collaborations (13 articles). Their citation effects are 16.77 and 9.85, respectively. On the other hand, "University of Bergen" has 9 publications, but very high number of citations.

Conclusion

This study presents the findings of a bibliometric analysis of articles on seafarers' mental health and wellbeing. In this study, which analyses search queries on mental health and wellbeing of seafarers, some significant worldwide research trends were gathered from publications from WoS from 2004 to 2023, November. This study evaluated the publications related to searching query, maps of the author and citation, linkages of co-occurrence and author keywords, country and affiliations network and the most impactful journals and articles. We discovered that the most influential publication was International Maritime Health journal. The country with the highest level of production was USA. This is because in the USA, not only universities but also the leading institutions such as the Department of Defence, the Navy and the Naval Health Research Centre, and Naval Medical Research Centre focused on the mental health and well-being of seafarers. These institutions are considered pioneers not only in terms of civilian seafarers, but also in prioritizing the health and well-being of naval personnel.

We found that the most frequently used keywords are "seafarers", "stress", "mental health", and "fatigue" are the most used keywords. Dr. Marcus Oldenburg emerged as the most co-cited author. Occupational risks and challenges of the maritime profession are presented in the article (Oldenburg et al., 2010). The article focussed on fatigue, isolation, multinational crews, limited possibilities for recreation and environmental stress. It is thought that this is a result of the fact that it contains the most used keywords that revealed in the present study, which correspond to the occupational risk and challenges discussed in the Oldenburg's article.

It has been identified which countries have undertaken comprehensive research on the topic of seafarer's mental health and wellbeing around the world. In addition to its contributions to the field, the study has certain limitations. Since English-language publications were filtered, the words used in the query and the findings overlap with each other. Another limitation is that the bibliometric research was conducted only on the Web of Science database. In addition, only articles were analysed in the study. In future research, all types of publications can be expanded by including different databases and languages other than English.

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.

Funding

Not applicable.

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

Floating ports as support for port relocation measures on sea level rise

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ABSTRACT

Ports are one of the structures where the effects of global warming are most severe and intense in atmospheric, oceanic, and geographical terms. According to the Intergovernmental Panel on Climate Change (IPCC)'s assessment reports, although it is possible to slow down global warming by reducing greenhouse gas (GHG) emissions, it is not foreseen to stop global warming and sea level rise (SLR) in any scenario. The rising sea level, an inevitable consequence of global warming, is a clear threat to conventional port facilities. In summary, SLR triggered by climate change, which is today's hot topic, may cause conventional port infrastructures to be flooded and lose their functionality. To cope with this threat, port facility planning, and design stages must be carried out by referring to the updated threshold values in Shared Socioeconomic Pathway (SSP) scenarios defined by the Working Groups of the IPCC. However, the uncertainty about the scale, timing, and location of SLR makes definitive solution-oriented approaches more prominent. One of these approaches is floating port structures. This study aims to reveal the role of floating port structures in the implementation of the relocation measure emphasized in the IPCC Sixth Assessment Report (AR6) for conventional ports under the threat of SLR. Initially, in this study, regions with higher SLR risk were identified by considering SSP scenarios contributed by Sixth Phase of the Coupled Model Intercomparison Project (CMIP6) data. Afterwards, the dynamic downscaling model was used to determine the regions with higher regional sea level rise (RSLR) risk and the Marine Traffic database was used to determine the ports in these regions. Thus, it is evaluated whether floating ports can be a suitable alternative in the relocation decision of ports under SLR risk. It is expected that maritime transport will be maintained at adequate security and operational levels by revealing the pros and cons of floating ports.

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Introduction

Ports are strategically located to feed supply chains for the sustainability of global trade on coastlines, riverbanks, low-lying areas, and deltas. Asariotis et al. (2018) state that the locations of ports make them vulnerable to a range of hydro-meteorological hazards resulting from climate change, and 72%

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of ports are negatively affected by these hazards. Considering the role of ports in global trade, which is an essential component of maritime transportation that responds to more than 90% of global cargo flows by volume (Sirimanne et al., 2019), disruption of port operations can cause regional and international economic shocks. Therefore, well-targeted response measures are required to reduce climate change impacts on port operations, infrastructure, and assets.

UNCTAD (2011), which provides a platform with an ad hoc expert meeting on climate change subject, is looking for ways to develop policies on how best to improve the understanding of the impacts of climate change on ports and develop effective and appropriate adaptation response measures. Savonis et al. (2008) state that sea level rise (SLR) can cause floods, damaging ports, terminals, intermodal facilities, storage areas, port-connected transportation systems, and, of course, cargo, rendering them unusable, thus disrupting supply chains and transportation. Esteban et al. (2017) underline that the consequences of mean sea level rise (MSLR) will be much more serious if precautions are not taken, especially in regions experiencing rapid subsidence. Reports presented by organizations such as Intergovernmental Panel on Climate Change (IPCC), World Meteorological Organization (WMO), and United Nations Environment Program (UNEP) constantly revise SLR projections upwards (Prestrud, 2007; IPCC, 2023; WMO, 2023). A continuous MSLR, combined with future extreme storm surges, waves, and tides, could result in devastating extreme sea level rise (ESLR) events that pose a serious threat to ports.

The importance of port authorities' contributions to the sustainability of supply chains by taking short-medium-long-term measures against SLR risks is increasing day by day. However, alternative solutions play a critical role as existing long-lasting and strong measures impose high financial burdens on ports. At this point, low-cost floating ports that can support the solution of port relocation where the risk of SLR is absent (maybe valid for a short period) or relatively low should be considered.

Most studies in the field of floating ports have only focused on increasing the capacity or operational flexibility of existing conventional ports (Kim & Morrison, 2012; Baird & Rother, 2013). In other words, the use of floating ports to port relocations to cope with SLR has not been investigated. Therefore, it is still not known whether floating ports can cope with the SLR. Therefore, this paper attempts to show the general technical features of floating ports and analysis the pros and cons of floating port alternatives for SLR that can impact supply chain sustainability.

Sea Level Rise Projection

Studies show that the rate of global SLR since the early 20th century has been sharply above the stable historical course of the previous 2000 years (Church & White, 2006, 2011; Engelhart et al., 2009; Gehrels & Woodworth, 2013; Stocker, 2014). Kemp et al. (2011) showed a consistency between sea level change and global warming using extended semiempirical modeling. In IPCC Sixth Assessment Report AR6, human activities are seen as the main cause of SLR (IPCC, 2023). There has been a dramatic acceleration in the rate of average SLR from the past to the present due to the impact of humans on global warming as is seen in Table 1.

Table 1. Historical MSLR rates

Years	SLR range (mm/year)	Average rate of SLR (mm/year)
1901-1971	0.6 to 2.1	1.3
1971-2006	0.8 to 2.9	1.9
2006-2018	3.2 to 4.2	3.7

Note: (Source: Adapted from IPCC (2023))

For years from 1901 to 2018, the average global sea level increased by 15–25 cm, corresponding to an average of 1–2 mm per year (IPCC, 2019, 2023). The apparent reason for SLR is the thermal expansion of seawater and the melting of temperate glaciers (Wouters & van de Wal, 2018). These apparent reasons are triggered by climatic factors such as increase in temperatures, desertification, decrease in precipitation, loss of biodiversity, and degradation of land and forests. If global warming continues in its current form, it has been revealed by the National Research Council (2011) that SLR will accelerate until 2050. After 2050, different SLR rates may be encountered in the light of scenarios produced depending on the amount of emitted greenhouse gas. However, SLR is predicted to occur even in the most optimistic scenario which includes deep emission cuts.

The Intergovernmental Panel on Climate Change's (IPCC) prediction for 2100 was that there will be an MSLR in almost all different emission scenarios (Church et al., 2013). The IPCC's fifth assessment report (AR5) predicted an MSLR of 0.4-0.6 m in the strongly reduced emissions scenario Representative Concentration Pathway (RCP) 2.6 by 2100. According to the high warming scenario (RCP 8.5) of the same report, it was argued that MSL may exceed 1 m and cause more serious consequences. With a comparison between IPCC's AR5 and

AR6, it is seen that MSL is revised upward direction in all defined scenarios due to the expectation of an increase in the frequency of climatic factors such as sharp changes in temperatures, desertification, decrease in precipitation, loss of biodiversity, degradation of land and forests, and retreat of glaciers (IPCC, 2014, 2023). In Table 2, the revised MSLR rates in IPCC AR6 as of 2100 are given so that they can be compared with IPCC AR5.

Unfortunately, research shows that SLR in the future is certain. However, how long and to what extent this increase will occur depends on GHG emissions. Some predictions are made in the scenarios produced (from very low to very high as a five-scale range in IPCC AR6) to understand this projection and be prepared for future SLR risks. Taking 1900 as a reference point, observations, and projections for the years 2100, 2150 and 2300 are given in Figure 1. Kopp et al. (2019) describes the risks of unpreventable SLR as follows: (1) losses to coastal ecosystems and ecosystem services, (2) damage to coastal structures, including ports, and (3) extreme and permanent flooding. In addition, it is expected that more than 1 billion people in the low-lying coastal zone to be affected and extreme sea level events can increase 20-30 times (Hauer et al., 2020; IPCC, 2023). Realization of GHG emissions as in the high scenarios can lead to a larger and faster SLR, requiring earlier and stronger measures to be taken. Protection sets, protection barriers, and planned relocation that can be taken for higher scenarios can be seen as stronger, longer-lasting measures (IPCC, 2023), but on the other hand, these are high-cost.

Table 2. A comparison of the revised MSLR in IPCC AR6 according to IPCC AR5

		Assessment Report 6 (AR6)[1]		**Assessment Report 5 (AR5)**[2]	
Category in WGIII[3]	***Category description***	***GHG emissions scenarios (SSPx-y)***[4] ***in WGI***[5] ***& WGII***[6]	***Global MSLR***[7] ***by 2100***	***RCPy***[8] ***in WGI & WGII***	***Global MSLR by 2100***
C.1	limited warming to 1.5°C (>50%)	Very low (SSP1-1.9)	28-55 cm		
C.2	returned warming to 1.5°C (>50%) after a high overshoot				
C.3	limited warming to 2°C (>67%)	Low (SSP1-2.6)	32-62 cm	RCP2.6	28-61 cm
C.4	limited warming to 2°C (>50%)				
C.5	limited warming to 2.5°C (>50%)				
C.6	limited warming to 3°C (>50%)	Intermediate (SSP2-4.5)	44-76 cm	RCP4.5	36-71 cm
C.7	limited warming to 4°C (>50%)	High (SSP3-7.0)	55-90 cm	RCP6.0	38-73 cm
C.8	warming exceed to 4°C (>50%)	Very high (SSP5-8.5)	63-101 cm	RCP8.5	52-98 cm

Note: *(*Source: Adapted from (Arias et al., 2021; Church et al., 2013; Field & Barros, 2014; Stocker, 2014; Edenhofer, 2015; Fox-Kemper et al., 2021; IPCC., 2022a, 2022b))

[1] Intergovernmental Panel on Climate Change's Sixth Assessment Report - The contributions of Working Groups I, II and III were released on 9 August 2021, 28 February, and 4 April 2022 respectively. The Synthesis Report was also released on 20 March 2023.

[2] Intergovernmental Panel on Climate Change's Fifth Assessment Report – The contributions of Working Group I, II and III were released in September, March, and April 2013 respectively. The Synthesis Report was also released in October 2014.

[3] The working group III is about Mitigation of Climate Change.

[4] Shared Socio-economic Pathways

[5] The working group I is about The Physical Science Basis.

[6] The working group II is about Impacts, Adaptation and Vulnerability.

[7] Mean Sea level Rise

[8] Representative Concentration Pathways

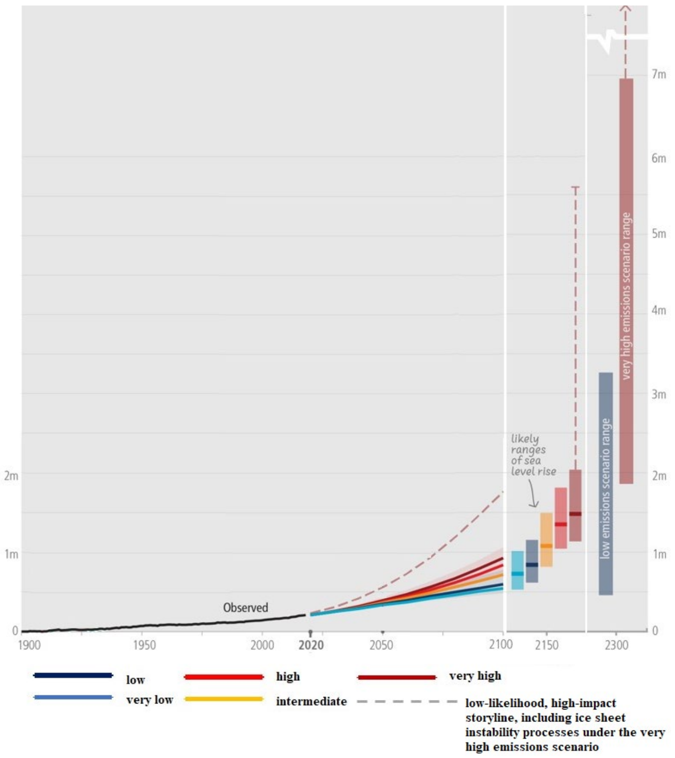

Figure 1. Observed and projected MSL change (Source: Adapted from IPCC, 2023))

Sea Level Rise Risks for Ports and Floating Ports

There is a growing body of literature that is concerned with the potential risk of SLR for ports from different perspectives. Karl et al. (2009) argued that an average sea level rise of 1.2 m would permanently flood more than 70% of existing port facilities on the US Gulf coast, whereas SLR of 5.5 m above the current mean sea level (MSL) to cause temporary flooding of 98% of port facilities. The study conducted on Small Island Developing States (SIDS) reveals that some ports in the Caribbean may be affected even by global warming below 1.5°C (Mycoo, 2018). In the study providing a wider focus on the effects of SLR on ports, Christodoulou et al. (2019) discuss the critical scenario in which approximately 450 ports in Europe may be affected when SLR exceeds 7.5 meters. Hanna et al. (2013) suggest that the change in MSL rise for this worst-case scenario could occur due to a combination of (i) ocean thermal expansion due to increased ocean heat content; (ii) increased ocean water mass due to melting of continental ice sheets, mantles, and glaciers; and (iii) isostatic adjustment, anthropogenic coastal subsidence, and changes in land water storage. Karim & Mimura (2008) argue that SLR leads to higher water levels in rivers and estuaries, increasing the risk of flooding for inland water ports. Pickering et al. (2012) state that the tidal regime affected by SLR may cause some changes in port infrastructure and operational planning. Hallegatte et al. (2011) address SLR risk and storm surge for the port city of Copenhagen, demonstrating a methodology for assessing the climate change's economic impacts at city and port scales and the benefits of adaptation.

Becker et al. (2016) and Radfar et al. (2021) state that ports in sensitive regions where SLR impacts can be seen need high-cost technical interventions. Defense methods against SLR include raising port walls and even relocating the port. Nicholls et al. (2008) claim that the costs of precautions taken by rich port cities against SLR are unaffordable for poor countries. While the cost of building an international port is approximately four billion Euro (Schade et al., 2013), the cost of a kilometer-long embankment that can provide protection for one-meter-high water can vary between one and four million Euros (Hippe et al., 2015). In other words, raising the port wall (which has an upper limit) or relocating the port can be a very burdensome solution.

In addition to its economic and financial dimensions, Thoresen (2010) emphasizes that building a port is a challenging process, starting from the planning stage and extending to the calculation of environmental forces and determining its technical and operational properties. This challenging process also includes an in-depth analysis of possible increases in the severity of ecological forces that ports may face with the impact of global warming. Reducing the margin of error in practical applications depends on more precise analysis by supporting assumptions with real data whenever possible. However, Gallivan et al. (2009) emphasize a major deficiency by stating that the data generally used in the planning phase of ports does not include climate change predictions. Although port planning processes do not have specific features to account for impacts associated with climate change, SLR is one of the more definitive consequences of climate change. Headland et al. (2011) draw attention to the responsibilities of relevant coastal management institutions in new project development permits by addressing SLR. The fact that there are various scenarios about SLR and its uncertainty in terms of scale, timing, and location causes hypothetical prediction thresholds to be considered particularly high. A scheduled maintenance/upgrade/adaptation is suggested by maintaining the desired security and operation standards in scenarios with varying risk levels to prevent seaports from being affected by SLR. On the other hand, alternative port structures that can support SLR measures can be considered as an approach to ensure the sustainability of maritime transport.

Floating ports which are suggested to support port relocation measures for SLR risks are used for various purposes in maritime transport. Kim & Morrison (2012) presented a study that includes the classification of floating ports that provide flexibility for various operational challenges thanks to their technical advantages. Kurt et al. (2021) suggest that larger-capacity floating container port systems can be considered as an alternative to conventional ports and can also be used to increase capacity in ports experiencing land shortages. Pachakis et al. (2017) analyzed the structural and operational implementations of the Venice Offshore-Onshore Port System (VOOPS), proposed by the Venice port authority to both increase the port cargo capacity and reduce the impact of SLR on Venice. The floating ports featured in Ali (2005) and Lau & Ng (2017) studies show that some tailor-made solutions can be developed with both complex and simple designs. Since SLR will increase land scarcity and make it difficult to afford the land needed for new port investments and port relocation, the lack of land purchase costs for floating ports, as stated by Baird & Rother (2013) and Kurt et al. (2015) brings these structures to the fore once again. Waals (2017) states that innovative floating structures proposed as an alternative solution to sea level rise will be more effective than raising dikes and sandblasting.

In the light of the data obtained from the past about SLR, and depending on three drivers (policy, technology, and consumer preferences) that affect how and how much energy will be used, the current situation shows that SLR is one of the consequences of climate change that must be combated in the future. However, studies conducted to date show that floating ports have not been examined to deal with the impacts of SLR on ports. Therefore, examining floating ports and contributing to their development to combat SLR may be a valuable step towards reducing the effects of SLR, if not eliminating it.

Methodology

The analysis focused on identifying ports likely to be affected by SLR in 2050 and 2100, based on global sea level changes according to GHG emission scenarios produced in IPCC AR6. For this analysis, IPCC's SSP emissions scenarios, from SSP1-1.9 to SSP5-8.5 (low confidence), were used to generate SLR projections. The CMIP6 (Coupled Model Intercomparison Project Phase 6) climate models were integrated under some SSP scenarios to project future SLR associated with increasing concentrations of greenhouse gases. The CMIP6 data underpins IPCC AR6, can be accessed through the Program for Climate Model Diagnosis and Intercomparison (PCMDI) (LLNL, 2023). Also, a dynamic downscaling model was applied to reveal regional sea level increases in 2050 and 2100 for ports. In this way, a higher-resolution coastal climate model was obtained. The coastal climate model integrates the effects of the region's atmospheric, oceanic, and geographical features on sea level change.

With this model, predictions of ports' exposure to SLR risk are made by determining SLR projections in port regions around the world. Therefore, a regional sea level rise (RSLR) was defined. RSLR includes geophysical sources that drive long-term changes, such as ice components, oceanic components, and glacier isostatic regulation, but does not account for local subsidence caused by human activities. RSLR is calculated from sea level elevation obtained from global climate models, including ocean, atmosphere, land, and cryosphere components. According to RSLR, major port areas at risk are identified and associated with floating ports that are expected to support the relocation measure emphasized in IPCC AR6. The sequential steps of the methodology are given in Figure 2.

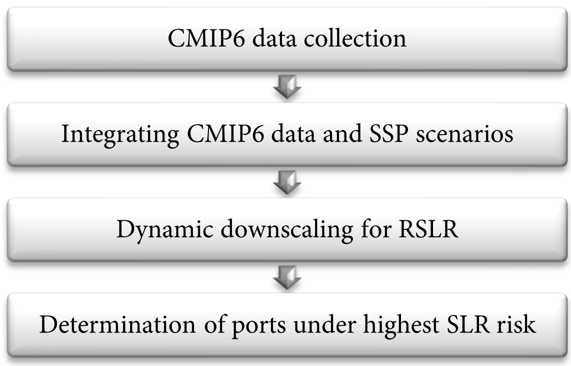

Figure 2. The sequential steps of the methodology

First, coastal areas at risk of SLR were determined by applying the defined model. Afterwards, the existing ports in these regions were determined with the data obtained from the Global Satellite Plan of the Marine Traffic. In the light of the data obtained, regions at risk of SLR were associated with countries and at least one port was defined for each country at risk of SLR. Accordingly, around 150 port areas that are likely to face the SLR threat have been identified. The data received from Marine Traffic includes characteristics of port area, port facilities, and berthing area, but also provides the operational characteristics and capacities of the ports. Thus, if these ports resort to a relocation solution when faced with SLR risk, a projection can be presented regarding the scope and size of the relocation operation.

The second stage is to determine the advantageous and disadvantageous aspects of suitable floating port systems that can provide operational sustainability for port regions whose RSLR was calculated. Thus, it can be discussed whether a floating port can respond to the relocation problem when a conventional port faces SLR risk, and the role of floating ports as a possible alternative port system was revealed. In determining the advantages and disadvantages of floating ports, the features highlighted in floating port projects and the positive and negative aspects mentioned in the existing literature are presented by applying strategic management tools.

Results

Figure 3 provides six sea level projections for 2050 calculated based on IPCC's AR6 generated scenarios (from SSP1(a) to SSP5 (low confidence) (f)).

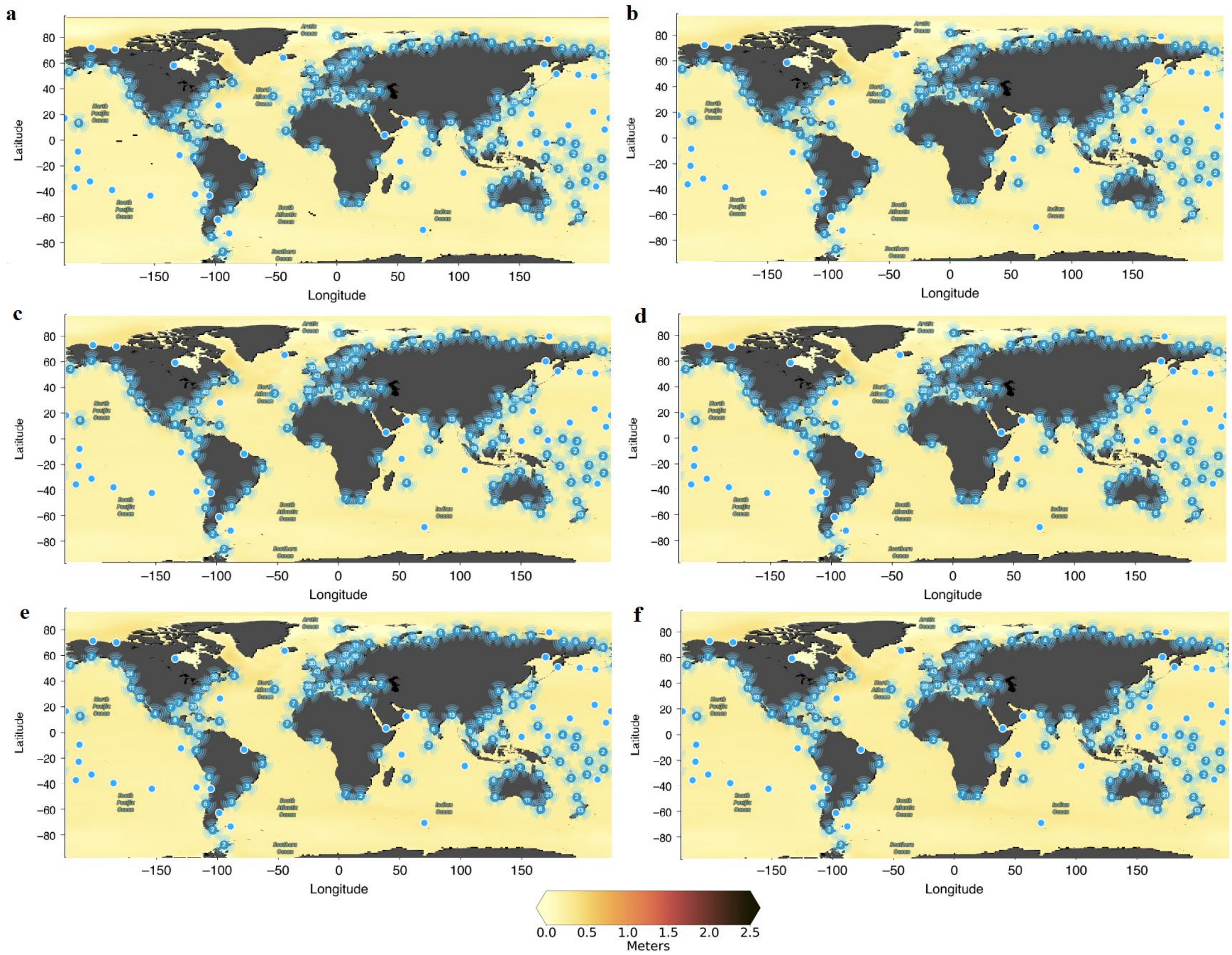

Figure 3. Sea level projections by 2050 according to SSPs based on IPCC AR6.[1]

[1] These SLR2050 projections are based on the assessment presented in the IPCC Sixth Assessment Report. Sea level projections considering processes for which projections can be made are provided, relative to the period 1995–2014, for five Shared Socioeconomic Pathway (SSP) scenarios. SSP scenarios affecting the six SLR2050 projections are as follows. The maps:

- **a.** Represents the SSP1-1.9 scenario.
- **b.** Represents the SSP1-2.6 scenario.
- **c.** Represents the SSP2-4.5 scenario.
- **d.** Represents the SSP3-7.0 scenario.
- **e.** Represents the SSP5-8.5 scenario.
- **f.** Represents the SSP5-8.5 (low confidence) scenario.

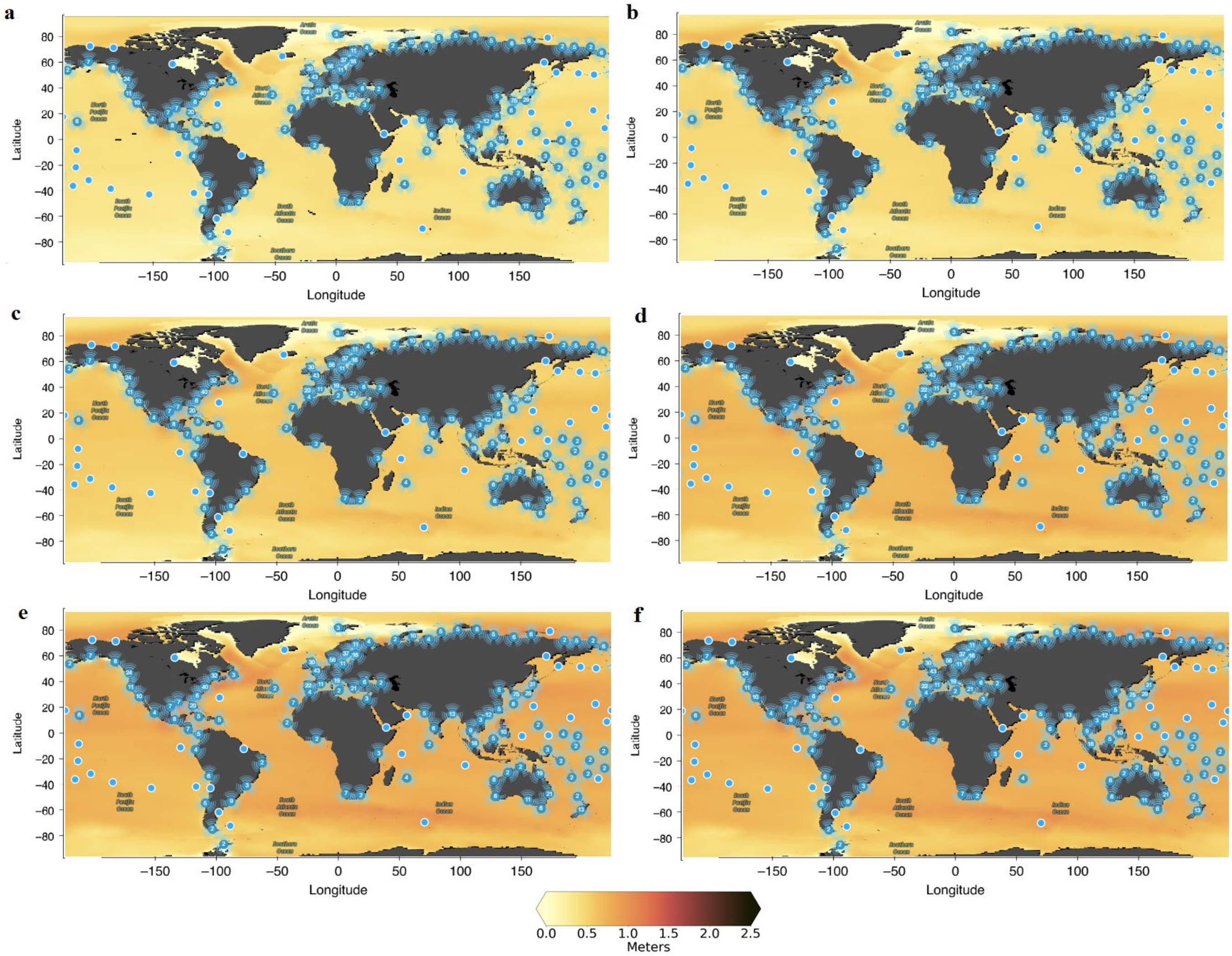

Figure 4. Sea level projections by 2100 according to SSPs based on IPCC AR6.[1]

Figure 4 provides six sea level projections for 2100 calculated based on IPCC's AR6 generated scenarios (from SSP1(a) to SSP5 (low confidence) (f)).

When the described methodological approach is applied, an overlap between SSP scenarios is observed in both 2050 and 2100 projections for most coastal areas. However, while the highest threshold of RCP2.6 calculated in the IPCC AR5 report overlaps with the lowest threshold of RCP8.5, it is seen that the SLR ranges in the SSP1-2.6 scenario do not overlap with those of SSP5-8.5 (see Table 2). Overlap between SSP scenarios is observed in SSP2, SSP3 and SSP5 scenarios. The overlap of SLR ranges in these scenarios explains that the continuum across the scenarios should be considered, especially in the short and medium term, since the future emission trajectory is uncertain. However, while the separation of this continuum spectrum in SSP scenarios, unlike the RCP scenarios, gives an idea that future projections are now more clearly observed, the upward revision of the SLR ranges also shows that the size of the threat has increased.

[1] These SLR2100 projections are based on the assessment presented in the IPCC Sixth Assessment Report. Sea level projections considering processes for which projections can be made are provided, relative to the period 1995–2014, for five Shared Socioeconomic Pathway (SSP) scenarios. SSP scenarios affecting the six SLR2100 projections are as follows. The maps:

- **a.** Represents the SSP1-1.9 scenario.
- **b.** Represents the SSP1-2.6 scenario.
- **c.** Represents the SSP2-4.5 scenario.
- **d.** Represents the SSP3-7.0 scenario.
- **e.** Represents the SSP5-8.5 scenario.
- **f.** Represents the SSP5-8.5 (low confidence) scenario.

According to the first evaluation of the RSLR, the highest value is obtained under the SSP5-8.5 scenario. Ports where SLR due to the SSP5-8.5 scenario is further deteriorated by land subsidence will have the highest RSLR values in 2050 (see Table 3 (a)). In the RSLR evaluation conducted for the year 2100, while the land subsidence factor loses its impact, the highest values are observed in ports where the effect of large ocean currents is observed (see Table 3 (b)).

In Table 3 (a), port areas where the RSLR effect will be most intense are required to take positions according to the RSLR of at least 0.5 m or more by 2050. In this scenario, more serious measures should be sought for port areas that are likely to be exposed to 0.92 m RSLR in 2050. For this reason, the authorities of the ports at the top in the maximum RSLR list should operate their decision mechanisms based on 0.5-0.92-meter RSLR in their plans targeting 2050.

For the year 2100, all world ports must plan to be prepared for an RSLR of at least 0.28 m, even in the very low scenario SSP1-1.9. Looking at Table 3 (b), the situation is likely to become inextricable for major ports that may be exposed to RSLR of 1.5 m and above. Although the quay wall elevation is higher than the maximum RSLR, eliminating freeboard requirements for port operability pushes port authorities to take some measures (Gracia et al., 2019; Wijayanti et al., 2023). The findings suggest that it would be more beneficial and economically feasible for port authorities to plan according to the maximum RSLR in the medium and long term, rather than resorting to a series of SLR measures. According to the very high scenario, significant changes were seen in the port area rankings in the period from 2050 to 2100 in Table 3, as the impact of land subsidence in 2100 decreased on the port areas at the highest RSRL and the impact of ocean currents intensified. This global distribution is expected to change from Northern Europe, North Sea, and Black Sea regions to the Eastern American coasts, as shown in Figure 5 and Figure 6.

The lower and upper limit SLR calculated based on the emission scenarios produced by IPCC, RSLR projections including atmospheric, oceanic, and geographical characteristics of the regions and their changes over time determine the flexibility range for new port planning and adaptation of existing ports.

The findings show that floating port systems, which are proposed with a mission to support the relocation measure for existing ports to cope with the effects of RSLR, stand out as a more flexible measure compared to sets and barriers that protect existing ports against RSLR.

Table 3. Top ports with high RSRL in SSP5-8.5 scenario – 2050 (a) and 2100 (b) projections

(a) Maximum RSLR (SSP5-8.5) in 2050		**(b) Maximum RSLR (SSP5-8.5) in 2100**	
Port Region	***(m)***	***Port Region***	***(m)***
Calcutta (India)	0.92	Calcutta (India)	2.28
New Orleans (USA)	0.65	New Orleans (USA)	1.71
Alexandria, Port Said, Damietta (Egypt)	0.63	Mobile (USA)	1.69
Mobile (USA)	0.63	Toyohashi, Honshu (Japan)	1.69
Novorossiysk (Russia)	0.63	Alexandria, Damietta (Egypt)	1.66
Samsun (Turkey)	0.61	Port Said (Egypt)	1.65
Odesa, Illichivsk, Sevastopol (Ukraine)	0.60	Tianjin (China)	1.63
Haydarpasa, Istanbul (Turkey)	0.60	Hampton Roads, Norfolk (USA)	1.57
Varna (Bulgaria)	0.60	Brooklyn, New York (USA)	1.54
Gdansk, Gdynia (Poland)	0.56	Halifax (Canada)	1.54
Toyohashi, Honshu (Japan)	0.56	Baltimore (USA)	1.54
Rotterdam, Amsterdam (Netherlands)	0.54	Chester (USA)	1.53
London (UK)	0.54	Philadelphia (USA)	1.53
Tianjin (China)	0.53	Shanghai (China)	1.52
Immingham (UK)	0.51	Boston (USA)	1.51

Figure 5. Global distribution of top ports with the highest RSRLs based on SSP5-8.5 by 2050

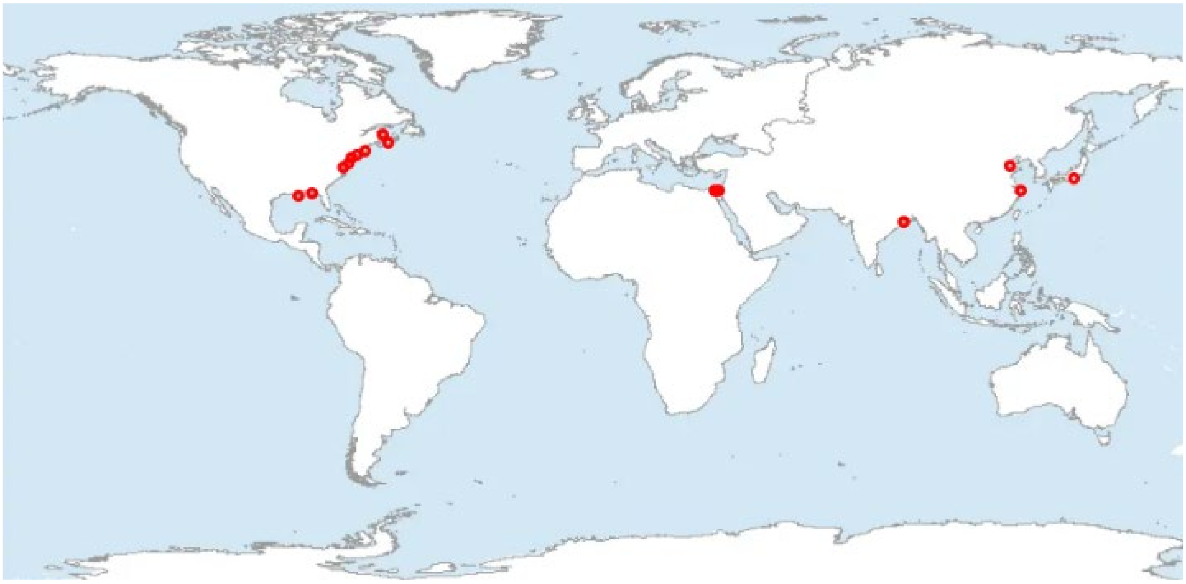

Figure 6. Global distribution of top ports with the highest RSRLs based on SSP5-8.5 by 2100

In regions where some functions or port facilities may become completely dysfunctional due to the SLR effect, the floating port concept is being evaluated to serve especially larger ships and sectors seeking flexibility through transfer, supply, and logistics solutions. It is not possible to mention a uniform floating port design, as there may be a tailored-made design approach according to the location, operational, and technical needs of the ports in the regions shown in Figure 6. For example, the offshore port concept defined in the Portunus Project focuses on safer, greener, and more efficient transportation (Martin, 2021). In some examples, the functionality, flexibility, and economy of floating ports are highlighted by emphasizing land scarcity (BFSA, 2024; SeaTech, 2024). This functionality and flexibility are supported by modular designs whose arrangement can change according to the specific requirements of the port structure (Waals, 2017; National Ports, 2024). Additionally, floating ports can be moved to more protected areas by tugboats or their propulsion system, thanks to a design feature that allows short-distance relocations. Floating breakwaters to protect ships calling at the port from mild sea conditions (Dai et al., 2018) and modular port solutions that allow capacity increase will add dynamism to the structure (RINA, 2024). However, some concerns about the use of floating ports act as a barrier to implementation. Concerns about floating ports in general and possible floating port features in response to these concerns are given in Table 4.

Table 4. Concerns for floating ports and the given response

Floating Port Systems	
Motivation to Propose Floating Port Systems	
Floating port systems provides flexibility against sea level rise thanks to their floating feature.	
Concerns	**Responses for Concerns**
It may be more affected by extreme weather due to its offshore location.	It offers the opportunity to relocate to a region where the weather is more stable, thanks to its floating feature.
As the capacity of the floating port increases, the floating flexibility for relocation may decrease or even disappear.	The capacity can be limited so as not to lose its ability to relocate by floating. Modular feature can be provided to increase portability.
It may require complex machinery and navigation equipment for portability.	Portability can be achieved without internal machinery power or by supporting existing machinery and propulsion equipment via tugboats.
Cargoes will need extra handling to reach the hinterland.	Thanks to the extra handling, cargoes can be transferred to the hinterland from locations where the SLR effect is less observed, with marine vehicles designed for different coastal characteristics (such as coastline, inland water).

Table 5. Main pros and cons of floating port systems

Floating Port Systems	
Pros	**Cons**
No dredging required for water draft	Storage yard is restricted
Bridges on navigation route are not a constraint	Personnel facilities are limited
Canals on navigation route are not a constraint	Energy supply should be provided from shore or need extra investment for self-service
Land is not required for port facility	A stability system can be required
Provides higher operation and cargo safety due to not directly contact with land	Require higher equipment technology so needs costly equipment investment
Construction cost is lower	Require higher personnel qualification so more salary budget
Shorter payback period	
Higher internal return rate	

Floating ports, which promise a systematic approach to the relocation measure offered for SLR, also have the potential to attract attention with their short payback period. Floating ports, with their low investment cost, high return rate, and other techno-physical advantages compared to conventional ports, can be considered as an alternative against the SLR threat (Kim & Morrison, 2012; Baird & Rother, 2013; Kurt et al., 2015, 2021, 2023). Creating a sheltered area for a floating port may require the construction of a breakwater, which can cause a significant increase in cost and may negatively affect the economic feasibility of floating ports. However, Zhao et al. (2019) highlighted the advantages of floating breakwaters, such as relatively low construction costs, less dependence on marine geological conditions, low environmental impact, and flexibility. A system in which floating breakwaters and floating ports are integrated can stand out in terms of operational flexibility and economic benefit. In addition, positioning floating ports in sheltered areas against harsh sea conditions or moving them to a sheltered area by tugboats or their propulsion system can increase operational and economic benefits. The advantages and disadvantages of floating ports can be compiled with the aspects discussed in this study as in Table 5.

It can be said that the advantages of floating ports, compared to their concerns and disadvantages, bring these structures to the fore. Floating port structures can be considered not only to reduce the risk of SLR but also to support the sustainability of the maritime transport sector, which is constantly growing and technically exceeds the limits of conventional ports (Kurt et al., 2023). In addition, the fact that the ports in Table 3 are in densely populated locations makes floating port systems an important alternative in case of relocation of conventional ports, as they are not affected by land scarcity and land costs (Waals, 2017). Apart from these, while the modular and portable features of floating ports provide operational functionality and flexibility, at the same time it is possible to escape from atmospheric and oceanic challenging situations to more sheltered sea areas (Kim & Morrison, 2012; Baird & Rother, 2013; Pachakis et al., 2017; Waals, 2017).

Conclusion

According to the scenarios put forward by the IPCC in AR6, all ports in the world are expected to be affected by SLR. However, it has been observed that this effect may vary with atmospheric, oceanic, and geographical components with regional analysis of SLR. This study examines the possibilities of ports facing SLR by considering the effects of RSLR on port areas with 2050 and 2100 projections. As a result of this examination, two ways are recommended to deal with SLR in IPCC AR6: mitigation and adaptation.

Reducing SLR effects is possible by reducing emission values. However, SLR is an inevitable outcome in all scenarios produced by the IPCC. That is, even if the lowest scenario is realized with strict emission reduction measures, adaptation, upgrading, or reconstruction are methods that should be considered as other options for ports to reduce the potential impacts of SLR. In scenarios where emission reduction measures are implemented more strictly, it is preferred to provide port structure protection with sets and barriers. However, if emission reduction cannot be achieved, ports will have to resort to relocation measures by acting according to the high tolerance limit due to the increase in the RSLR.

The floating port option, which offers a systematic approach to relocation measures, is evaluated in this study. The reason why floating port structures are proposed as a systematic approach for relocation measures is that the ability to physically float makes floating structures more flexible in adapting to SLR. The fact that the floating port system can respond to the concerns in physical and technical aspects reveals the flexibility of floating structures. However, the fact that existing conventional ports have not yet faced a serious SLR threat and that floating port systems have not been proposed before to cope with the SLR threat can be defined as the limit of this study. Therefore, performing static and dynamic analyses of a high capacity floating port and determining tailored floating port structures considering regional atmospheric, oceanic, geographical, and operational factors can be recommended for future works.

Compliance With Ethical Standards

Conflict of Interest

The author declares that there is no conflict of interest.

Ethical Approval

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

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Not applicable.

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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RESEARCH ARTICLE

Evaluation of port state control inspections in Türkiye

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ABSTRACT

With technological developments, transportation has become easier and maritime trade between countries has reached very important dimensions, but this situation has led to the emergence of various risks in terms of both environment and maritime safety due to accidents or other reasons. The most important factor threatening the environment and maritime safety is the continued operation of substandard ships. There are various inspection mechanisms to prevent the operation of these ships and one of these mechanisms is port state control inspections. In this context, in this study, Port State Control inspections carried out in Türkiye between 2018 and 2022 were statistically examined and frequency analysis was performed and Pearson Chi-Square Independence test was utilized to analyse the hypotheses and the degree of relationship between the hypotheses was analysed by Phi- Cramer's V test. The study contributes to the literature in terms of statistical analysis of PSC Inspections in Turkish Ports within the scope of Black Sea Memorandum and Mediterranean Memorandum.

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Introduction

Maritime transportation is one of the foundations of globalisation, where most of the world trade takes place, and many ships call at ports in various countries of the world (Öztürk et al., 2016; Akpınar & Şahin, 2020; Bolat & Alpaslan, 2021; Prieto et al., 2021). However, since it is a type of transport that involves various risks for the marine environment and people (Emecen Kara, 2022), the lack of safety, security and/or pollution protection on ships causes marine accidents (Demirci & Çiçek, 2023). The majority of these accidents are caused by substandard ships (Demirci & Çiçek, 2023). Substandard ships can pose serious hazards to both personnel safety and marine life (Karahalios, 2021) and have a negative effect on both the maritime security and sustainability of international trade (Chuah et al., 2023). In this context, to decrease the risks posed by maritime transportation in the world seas and to preserve both environment of marine and human life, there are many legal regulations and sanctions for ships to navigate in

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compliance with international standards and these are implemented by international organisation, port state and flag state (Öztürk & Gökdemir Işık, 2016; Öztürk et al., 2016; Akpınar & Şahin, 2020).

"The International Maritime Organization (IMO)" and the "International Labour Organization (ILO)", which are fundamental rule makers in maritime sector, are the determinants of important environmental, security and safety conventions (Bang & Jang, 2012; Öztürk et al., 2016; Akpınar & Şahin, 2020; Emecen Kara et al., 2020; Kostović et al., 2022; Maşalacı & Çakır, 2023). Apart from IMO and ILO, stakeholders such as, insurance companies, ship owners, cargo owners, classification societies, port states and flag states also have responsibilities in the proper enforcement and supervision of all these rules and conventions (Demirci & Çiçek, 2023; Nwokedi et al., 2023).

The first control mechanism that can prevent substandard ships from circulating in the world seas is the flag state (Farag, 2016). However, since this inspection mechanism is not sufficiently operated in some flag states, ships that endanger maritime safety may continue to carry out their international activities (Farag, 2016). Classification societies are the organisations secondarily responsible for safety inspections of ships periodically (Farag, 2016; Emecen Kara, 2018); they provide technical surveys as well as annual, interim and additional surveys (Demirci & Çiçek, 2023). Ship owners, management companies, masters and crew are also responsible for substandard ships (Farag, 2016). The other control mechanism is insurance companies and P&I clubs (Farag, 2016). Since these inspection mechanisms mentioned above are insufficient to prevent substandard ships, it has become necessary to establish a new inspection mechanism as Port State Control in order to prevent these substandard ships (Farag, 2016).

Port states continue to inspect foreign flag ships arriving at the ports in line with the regional agreements they have established. (Bang & Jang, 2012; Öztürk & Gökdemir Işık, 2016). Port State Control, which was established after the tanker accidents in the 1960s and 1970s (Torrey Canyon-1967, Amoco Cadiz-1978, etc.), has its roots in the "1978 Hague Memorandum" (Nooramin & Sadjadi Parsa, 2010; Arslan & Eyigün, 2016; Şanlıer, 2020, 2021; Uygur & Bolat, 2021; Wang et al., 2021; Chuah et al., 2023). Later, the "Memorandum of Understanding on Port State Control" was signed between Western states at the "Balkans Conference" held in Paris in 1982 and "the Paris Memorandum of Understanding (Paris MoU)" was established (Knapp & Franses, 2007; Şanlıer, 2021; Bolat & Alpaslan, 2021; Demirci et al., 2022). Paris MoU is the first PSC system to be implemented (Bang & Jang, 2012; Bolat & Alpaslan, 2021; Chuah et al., 2023). There are currently nine main regional MoUs (Paris, Vine Del Mar, Tokyo, Caribbean, Mediterranean, Indian Ocean, Abuja, Black Sea, Riyadh) in the world (MedMoU, 2023a). Moreover, "the United States Coast Guard (USCG)" also conducts inspections of PSC on its shores (Bang & Jang, 2012; Emecen Kara, 2018, 2022; Uygur & Bolat, 2021; Demirci et al., 2022; Kostović et al., 2022).

Türkiye carries out port state control under "Black Sea MoU" and "Mediterranean MoU". Port State Controls are carried out in Turkish ports on Black Sea coast under the "Black Sea MoU" agreement (BSMoU, 2023) and other Turkish ports under Mediterranean MoU agreement. The geographical scope of the "Black Sea MoU", signed in 2000 by six Black Sea countries, includes ports on Black Sea coast, namely Bulgaria, Georgia, Romania, the Russian Federation, Türkiye and Ukraine (Eyigün, 2013). The observers of "the Black Sea MoU" are "IMO", "ILO", "Commission on the protection of the Black Sea against pollution", "USCG", "Mediterranean MoU", "Paris MoU", "Riyadh MoU" and "Republic of Azerbaijan". "Black Sea MoU" is an observer in "Paris MoU", "Viña del Mar", "Tokyo MoU", "Mediterranean MoU", "Indian Ocean MoU", "Abuja MoU" and "Riyadh MoU" (MedMoU, 2023a). In addition, "The Mediterranean Memorandum of Understanding on Port State Control" was signed by Algeria, Tunisia, Cyprus, Türkiye, Israel, Egypt, Morocco and Malta in 1997. At the end of 1997, Lebanon and Jordan ratified the agreement in 1999 (Eyigün, 2013). The observers of the Mediterranean MoU are "IMO", "ILO", "EC", "Paris MoU", "Black Sea MoU" and "USCG" and "Mediterranean MoU" is an observer in "Paris MoU", "Black Sea MoU", "Abuja MoU" and "Riyadh MoU" (MedMoU, 2023a).

Purpose of the article is to investigate the port state controls in Türkiye. It is aimed to provide a holistic perspective by considering "Mediterranean MoU" and "Black Sea MoU" together in Turkish Port State controls. In this context, statistical analysis of the inspections carried out in Turkish Ports in the Mediterranean and Black Sea Memorandums between 2018 and 2022 has been carried out. In this context, firstly, frequency analyses were made and it was defined whether there was an important relationship between the two independent groups with "Pearson Chi-Square test". Then, "Phi/ Cramer's V test" was utilized to define the degree of relationship between the accepted hypotheses.

Literature Review

With the increase in technology and ships' size, the risks in terms of safety and environment in maritime transportation have increased and maritime safety has become an important issue to be solved with major marine accidents occurring over time. One of the most important reasons for the occurrence of maritime accidents has been substandard ships. The primary responsibility for ensuring maritime safety belongs to flag states and flag state inspections have been insufficient due to the fact that some flag states have not acted responsibly enough over time. Although marine stakeholders are also responsible, all these organizations have been insufficient over time and the concept of port state control has occurred (Nwokedi et al., 2023). Many academic papers have been conducted on port state controls, which have a major influence on maritime safety.

Looking at the academic research on port state control, it can be seen that the research is mainly on risk and performance analysis (Emecen Kara, 2018; Akpınar & Şahin, 2020; Karahalios, 2021). Studies on risk and performance analysis include "Failure Mode and Effects Analysis (FMEA)" (Akyüz et al., 2016) "Fuzzy Cluster Analysis (FCA)" (Demirci et al., 2022), "Fault Tree Analysis (FTA)" (Akpınar & Şahin, 2020), "Bayesian" (Yang et al., 2018, 2020; Wang et al., 2021; Chuah et al., 2023), "Grey Relation Analysis (GRA)" (Lai et al., 2023), "Entropy Based Gray Relationship Analysis (GRA)" (Maşalacı & Çakır, 2023), "Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS)" (Emecen Kara, 2022; Lai et al., 2023), Excess Factor (EF) (Emecen Kara, 2016; Yılmaz, 2020). Akyüz et al. (2016) analysed the maritime safety of the Black Sea MoU, focusing on the compliance of certain aspects of "SOLAS Chapter II-2" regarding fire protection, detection and extinguishing regulations in ships using the FMEA method. Demirci et al. (2022) focused on the estimation of the risk level of ships for inspections of port state using an analytical method that integrates a fuzzy rule-based system with a machine learning method with the parameters of ship's type, flag and age, number of deficiencies and detention. Wang et al. (2021) found that the biggest deficiencies in ship detentions during Tokyo MoU PSC inspections were caused by fire safety and navigational safety, using a Bayesian network model. Yang et al. (2018) examined Paris MoU PSC inspections to calculate the cargo taking rate of bulk carriers using a real-time Bayesian network model and found that the main risk factors are recognised organisation (RO) and ship age. Furthermore, Yang et al. (2020) used Key Performance Indicators and Bayesian Network to examine PSC inspections before and after NIR under Paris MoU and found that NIR improved maritime safety and ship quality.

In addition, data mining (Tsou, 2019; Xiao et al., 2021; Sevgili & Töz, 2022) and statistical analysis studies (Arslan & Eyigün, 2016; Farag, 2016; Bolat, 2019; Ukić Boljat et al., 2020; Mantoju, 2021; Prieto et al., 2021; Şanlıer, 2020, 2021; Kostović, et al., 2022, Turna & Öztürk, 2023; Uçar & Boran, 2023) have also been carried out. Tsou (2019) used "big data analysis" to investigate the implicit relationships related to detention shortages and determined that there is an implicit relationship between Fire Training and ISM resources and manpower. Xiao et al. (2021) reached that ship's type, age, flag state performance and number of deficiencies considered significant by NIRs are important criteria for calculating ship risk. Kostović et al. (2022) compared the inspections' number and detained container ships for each area and for the same timeframe, the inspection statistics (overall) and the proportion of ships detained. Mantoju (2021) made a statistical study of MARPOL deficiencies in PSC inspections in all the MoUs and found that the most significant deficiencies were related to Annex I and Annex V. Ukić Boljat et al. (2020), using chi-square test and correlation analysis, explained that the highest number of deficiencies were found in Marpol Annex I, followed by Annex V, IV and VI, respectively. Prieto et al. (2021) found that a direct relationship between age of ship and deficiencies' number and ship size, and substandard ships are smaller and older ships. Şanlıer (2021) analysed the Paris MoU inspections and stated that the deficiency areas that affect the detentions most are ISM, fire doors - openings in fire-resistant compartments, emergency fire pumps/pipes, fire drills and the most difficult conventions are STCW, SOLAS and ILO conventions.

There are also studies on the legal dimension of port state control (Keselj, 1999; Stoyanov & Terlemesian, 2004; Bang & Jang, 2012; Öztürk et al., 2016) and studies on stakeholders (Piniella et al., 2020; Nwokedi et al., 2023). Keselj (1999) examined the notion of port State jurisdiction under UNCLOS and the development of the MoU on Ports. Stoyanov & Terlemesian (2004) provide an overview of Bulgarian and international law on management of environmental in port regions. Nwokedi et al. (2023) analysed the classification society performance of ships inspected and arrested under the Abuja PSC and found that ships classed by Germanisher Lloyds (GL) had fewer safety defects and deficiencies in inspections, while shipowners preferred NipponKaiji Kyokai the most.

There have been studies on the analysis of the status of the Turkish flag in the MoUs (Bolat, 2019; Yılmaz, 2020; Uygur &

Bolat, 2021; Sevgili & Töz, 2022; Kan, 2023), and some studies on the Black Sea and Mediterranean MoUs (Emecen Kara, 2016; Öztürk & Gökdemir Işık, 2016; Öztürk et al., 2016; Şanlıer, 2020; Akpınar & Şahin, 2020; Maşalacı & Çakır, 2023; Uçar & Boran, 2023). Looking at studies on Turkish flag ships, Bolat (2019) deficiencies were identified especially in the areas of navigational safety, fire safety and life-saving equipment of Turkish flagged ships, throughout the inspections of Tokyo MoU. Kan (2023) aimed to identify and address the deficiencies of Turkish flag ships under the "MLC Convention" in the Paris MoU and concluded that a sustainable and conscious management approach should be adopted, working and seafarers' living conditions should be improved, trade union rights should be developed and grievance mechanisms should be established. Sevgili & Töz (2022) found that the main deficiencies causing the arrest of Turkish flagged ships in PSC inspections are navigation safety, documentation and documentation and emergency systems. Uygur & Bolat (2021) aimed to analyse the performance of Turkish flag ships in Paris MoU inspections and concluded that deficiencies have an impact on the detention decision of the ship, but the age of the ship has no effect on the detention decision. Yılmaz (2020) used the excess factor and arrest rate indicators to measure merchant vessels of Turkish flagged in the Paris MoU inspections. Looking at the studies on the Mediterranean and Black Sea MoUs, Akpınar & Şahin (2020) aimed to calculate the probability of a ship being detained during Black Sea MoU PSC inspections and evaluated it using "Fault Tree Analysis (FTA)". Emecen Kara (2016) analysed the risks related to the ships passing through the Bosporus Strait by utilizing the "Black Sea MoU" inspection data and concluded that the highest risk flags are Sierra Leone, Tanzania, Cambodia, Turkey, Georgia, Togo and Moldova. Maşalacı & Çakır (2023) found that the most important deficiency type in ship detentions during PSC inspections in the Black Sea was Fire Safety and Emergency Systems. Şanlıer (2020) resulted that the root cause for detentions in Black Sea MoU PSC inspections is the age of the ship and the flag, ship type, inspection authority and recognised organisation are other reasons. Uçar & Boran (2023) analysed that there is a meaningful relationship between the cause for detention based lack of machinery within the scope of Black Sea PSC inspections and classification society, ship's age, flag, gross tonnage, and inspection country; however, there is no meaningful relationship between the ship type and the causes for detention statistically. In a study conducted by Öztürk & Gökdemir Işık (2016) for port state officers conducting port state inspections in Türkiye, the aim was to determine the operations of the ship that should be considered before the ship to be inspected. Öztürk et al. (2016) stated that the greatest problem of the Turkish PSC system in the implementation of 1982 UNCLOS is the lack of branching, while the problem of inter-departmental supervision is not a significant problem.

Our study discusses port state control in Turkish ports in "Black Sea MoU" and "Mediterranean MoU", and this study contributes to the literature since there are not enough studies in the literature in terms of statistical analysis of Turkish port state control in both MoUs.

Material and Method

The paper's aim is to analysis the inspections carried out in Turkish Ports in the Mediterranean and Black Sea Memorandums between 2018 and 2022. Firstly, frequency analyses were performed and Pearson Chi-Square independence test is utilized to assign whether there is a relationship of significant between two independent groups. Then, Cramer's V test is used to determine the degree of relationship between the accepted hypotheses.

Chi-Square independence analysis is one of the most useful statistics used to test hypotheses when variables are nominal (Bayar & Akan, 2022). Chi-Square independence analysis is a statistical analysis used to perform independence analyses on categorical data (Turhan, 2020; Bayar & Akan, 2022). In cases where the p value is less than 0.05, it is accepted to be significant and there is a relationship between variables (Baradan et al., 2016).

The Pearson Chi-square independence test compares the observed values with the values that will be expected if there is no relationship between the two variables, and in order to apply the Pearson Chi-square independence test that each case must be included in a cell in the cross-tabulation for the test to be meaningful (Baradan et al., 2016). In addition, the cross-tabulation can have at most 20% cells with an expected frequency below 5, and expected frequencies below 1 are unacceptable (Baradan et al., 2016).

Phi Cramer's V test is performed to identify the level of relationship between variables that have relationship of significant with chi-squared test; Phi coefficient is used for 2×2 dimensional tables and Cramer's V coefficient for tables larger than 2×2 (Bölükbaşı & Yıldırtan, 2009; Çolak & Ergün, 2020; Akan et al., 2022). The relationship levels of Phi Cramer's V values are as follows (Rea & Parker, 1992; Kotrlik et al., 2011; Akan et al., 2022):

- "Negligible association" (0.00 and under 0.10)

- "Weak association" (0.10 and under 0.20)
- "Moderate association" (0.20 and under 0.40)
- "Relatively strong association" (0.40 and under 0.60)
- "Strong association" (0.60 and under 0.80) and
- "Very strong association" (0.80 and under 1.0).

Application

In the study, 11080 inspections with Türkiye as the Port State between 2018 and 2022 were analysed and the data were taken from "Black Sea MoU" and Thetis-Med (for Mediterranean MoU) websites (BSMoU, 2023; EMSA, 2023). SPSS programme was used for data analysis. As can be seen in Table 1; 80.3% of the data belong to the inspections in the "Mediterranean MoU" and 19.7% in the Black Sea MoU". In terms of year, the most inspections were carried out in 2022 (f: 3249, 29.3%) and the least in 2020 (f: 1530, 3.8%).

Moreover, the most detailed inspection (f:7758, 70,00%) and the least expanded inspection (f:232,2,1%) were carried out. Of the inspected vessels, 52,5% were without deficiencies, 3,1% with deficiencies were detained, 44,32% had only deficiencies but no detention. Most of the inspections took place in Mersin (f:1571, 14.2%) and the least in Other Mediterranean and Aegean Ports (f:373, 3.4%). (Table 1).

In the study, a total of 34 hypotheses were established to evaluate the existence of a relationship between them (Table 2). Pearson's chi-square independence test was utilized to measure the accuracy of these hypotheses, and Cramer's V test was used to identify the effect rate of the hypotheses that were accepted to have a relationship of significant according to the results of the chi-square test (Table 3). In this context, hypotheses H_{10} and H_{27} were rejected and no significant relationship was found between "result" and "month" and between "flag" and "month". In order to identify the relationship level between the hypotheses accepted as a result of Pearson Chi-Square Independence test, Cramer's V coefficient was examined in Phi Cramer's V test. H_1 ("type of inspection" and "year") (v:0.236), H_{11} ("result" and "flag") (v:0.220), H_{12} ("result" and "ship type") (v:0.243), H_{13} ("result" and "port") (v:0.230), H_{15} ("result" and "ship's age") (v:0.263), H_{18} ("MOU" and "flag") (v: 0.228), H_{19} ("MOU" and "ship type") (v:0.301), H_{25} ("port" and "deficiency") (v:0.201), H_{28} ("flag" and "ship type") (v:0.332), H_{30} ("flag" and "ship's age") (v:0.205), H_{33} ("ship type" and "deficiency") (v: 0.207) and H_{34} ("ship type" and "ship's age") (v:0.322) are "moderate association". Finally; H_6 ("type of inspection" and "port") (v: 0.456), H_8 ("type of inspection" and "MOU") (v: 0.579) and H_{24} ("port" and "ship type") (v: 0.403) are "relatively strong association" (Table 3).

Results and Discussion

Port State control is carried out in order to determine whether the port state meets the safety and pollution prevention requirements of foreign flagged ships entering their ports or coastal facilities and whether they are suitable for the related international conventions, whether there are appropriate people who they are working on board (Bang & Jang, 2012; Farag, 2016; Öztürk et al., 2016; Akyüz et al., 2016; Akpınar & Şahin, 2020; Yılmaz, 2020; Uygur & Bolat, 2021; Kostovic et al., 2022).

Turkish port state control inspections are performed within the scope of "Black Sea MOU" and "Mediterranean MOU"; Black Sea Region ports within the borders of Türkiye are inspected under "Black Sea MOU" and ports on the other coasts are inspected under "Mediterranean MOU". In this context, in 2022, a total of 4972 PSC inspections were conducted on 3501 individual ships in "Black Sea MoU" and deficiencies were found in 2981 of these inspections. The inspection rate was 74.25%. 162 individual ships were detained total 174 times in the inspections. The detention rate was 4.63% (BSMoU, 2022). Within the scope of the "Black Sea MoU", 523 individual ships were inspected with 568 inspections totally in Turkish ports and deficiencies were found in 340 of these inspections. The inspection rate was 40.39%. 8 individual ships were detained total 9 times in the inspections. The detention rate was 1.53% (BSMoU, 2022). However, the countries with the greatest PSC inspection rate were Russia, Ukraine and Georgia, while the countries with the greatest rate of detention were Romania, Russia and Bulgaria, respectively (BSMoU, 2022). Also, in 2022, 6132 PSC inspections were conducted in the "Mediterranean MoU". In these inspections, inspection with deficiencies was 2909, with a deficiency rate of 47.44%. As a result of these inspections, 921 detentions were made and the detention rate is 15.02%. However, the country with the biggest inspections number in 2022 is Türkiye; in 2021, 2711 inspections were conducted in Turkish Ports and the inspection rate is 37.30%. In Türkiye, inspection with deficiencies was 1290 and the deficiency rate is 47.58%. However, 89 detentions were carried out and the detention rate was 3.28%. The countries with the greatest inspection rate are Jordan (79.86%), Lebanon (38.88%), Egypt (31%) and Türkiye (37.3%). The countries with the greatest rate of detention were Israel (4.43%), Cyprus (3.94%), Türkiye (3.28%) and Jordan (3.00%) (MedMoU, 2023b).

Table 1. Frequency table for port state inspections in Türkiye

	Frequency	Percent		Frequency	Percent
MOU			**Flag**		
Mediterranean	8897	80.3	Liberia	1094	9.9
Black Sea	2183	19.7	Malta	1043	9.4
Year			Marshall Islands	1050	9.5
2018	1841	16.6	Panama	1930	17.4
2019	1979	17.9	Russia Federation	1130	10.2
2020	1530	13.8	China/Hong Kong /Singapore	786	7.1
2021	2481	22.4	Other	4047	36.5
2022	3249	29.3	**Port**		
Month			Ceyhan	564	5.1
January	1006	9.1	Mersin	1571	14.2
February	972	8.8	Aliağa	1498	13.5
March	944	8.5	Kocaeli	1357	12.2
April	734	6.6	Iskenderun	1267	11.4
May	560	5.1	Izmir	699	6.3
June	834	7.5	Samsun	690	6.2
July	732	6.6	Istanbul/Ambarlı/Tuzla	626	5.6
August	793	7.2	Trabzon	422	3.8
September	1010	9.1	Other Black Sea Ports	1071	9.7
October	1193	10.8	Other Marmara Ports	942	8.5
November	1178	10.6	Other Mediterranean and Aegean Ports	373	3.4
December	1124	10.1	**Deficiency Area in Detentions**		
Week Day			Certificate and Documentation	232	66.9
Monday	2426	21.9	Structural Conditions	115	33.1
Tuesday	2364	21.3	Water/Weathertight Conditions	117	33.7
Wednesday	2272	20.5	Emergency Systems	182	52.4
Thursday	2042	18.4	Radio Communication	115	33.1
Friday	1864	16.8	Cargo Operation including Equipment	15	4.3
Saturday	75	0.7	Fire Safety	229	65.7
Sunday	37	0.3	Alarms	51	14.7
Type of Inspection			Living and Working Conditions	189	54.5
Initial Inspection	3090	27.9	Safety of Navigation	223	64.3
Detailed Inspection	7758	70.0	Life Saving Applications	212	61.1
Expanded Inspection	232	2.1	Dangerous Goods	6	1.7
Result			Propulsion and auxiliary machinery	124	35.7
Detention	347	3.1	Pollution prevention	127	36.6
Only Deficiencies	4913	44.3	ISM	125	36.0
Without Deficiency	5820	52.5	ISPS	67	19.3
Ship Type			Labour Conditions	57	16.4
Bulk Carrier	3415	30.8	Others	17	4.9
Tanker	1172	10.6	**Ship's Age**		
General Cargo /multi purposes	4859	43.9	0-5	839	7.6
Other	1634	14.7	6-10	2064	18.6
Deficiency			11-15	2199	19.8
0	5820	52.5	16-20	1234	11.1
1-5	3632	32.8	21 and up	2561	23.1
6-10	1108	10.0	n/a	2183	19.7
11 and up	520	4.7			

Table 2. Research hypotheses

Hypothesis	Statement
H_1	"Type of inspection" and "year" have a relationship of significant
H_2	"Type of inspection" and "month" have a relationship of significant
H_3	"Type of inspection" and "result" have a relationship of significant
H_4	"Type of inspection" and "flag" have a relationship of significant
H_5	"Type of inspection" and "ship type" have a relationship of significant
H_6	"Type of inspection" and "port" have a relationship of significant
H_7	"Type of inspection" and "deficiency" have a relationship of significant
H_8	"Type of inspection" and "MOU" have a relationship of significant
H_9	"Result" and "year" have a relationship of significant
H_{10}	"Result" and "month" have a relationship of significant
H_{11}	"Result" and "flag" have a relationship of significant
H_{12}	"Result" and "ship type" have a relationship of significant
H_{13}	"Result" and "port" have a relationship of significant
H_{14}	"Result" and "MOU" have a relationship of significant
H_{15}	"Result" and "ship's age" have a relationship of significant
H_{16}	"MOU" and "year" have a relationship of significant
H_{17}	"MOU" and "month" have a relationship of significant
H_{18}	"MOU" and "flag" have a relationship of significant
H_{19}	"MOU" and "ship type" have a relationship of significant
H_{20}	"MOU" and "deficiency" have a relationship of significant
H_{21}	"Port" and "year" have a relationship of significant
H_{22}	"Port" and "month" have a relationship of significant
H_{23}	"Port" and "flag" have a relationship of significant
H_{24}	"Port" and "ship type" have a relationship of significant
H_{25}	"Port" and "deficiency" have a relationship of significant
H_{26}	"Flag" and "year" have a relationship of significant
H_{27}	"Flag" and "month" have a relationship of significant
H_{28}	"Flag" and "ship type" have a relationship of significant
H_{29}	"Flag" and "deficiency" have a relationship of significant
H_{30}	"Flag" and "ship's age" have a relationship of significant
H_{31}	"Ship type" and "year" have a relationship of significant
H_{32}	"Ship type" and "month" have a relationship of significant
H_{33}	"Ship type" and "deficiency" have a relationship of significant
H_{34}	"Ship type" and "ship's age" have a relationship of significant

In the study, it was observed that the total number of Turkish Ports' inspections affiliated to the Black Sea MoU and Mediterranean MoU in 2018 (f:1841, 16.6%) and 2019 (1979, 17.9%), while it decreased in 2020 (f:1530, 13.8%). The reason for this decrease was that the Covid pandemic started to spread around the world. After this pandemic process, it was observed that Port State Controls in Türkiye increased more and more compared to the previous years, in 2021 (f: 2481, 22.4%) and 2022 (f: 3249, 29.3%), However; in terms of days, 63.7% of the inspections took place in the first three days of the week (Monday, Tuesday, Wednesday), while only 1% of the inspections took place at the weekend.

In the study, 34 hypotheses related to inspections have been established and only H_{10} (""result" and "month" have a significant relationship") and H_{27} (""flag" and "month" have a significant relationship") hypotheses have been rejected, while the degree of association between H_2 ("type of inspection and "month"), H_{17} ("MoU" and "month"), H_{22} ("port" and "month") and H_{32} ("ship type" and "month)" hypotheses related to "month" has been "negligible association". H_6 ("type of inspection" and "port") (v: 0.456), H_8 ("type of inspection" and "MOU") (v: 0.579) are "relatively strong association". In this context, although most of the inspections in Turkish ports within the scope of "Black Sea MoU" (Samsun (f: 599), Trabzon (f: 294), other Black Sea Ports (f: 723)) are "initial inspection"; in Turkish ports within the scope of "Mediterranean MoU" (Mersin (f: 1383), Aliağa (f: 1147), Kocaeli (f: 1070), İskenderun (f: 943), Izmir (f. 605), Ceyhan (f: 486, Istanbul/Ambarlı/Tuzla (f: 563), other Marmara Ports (f: 831) and other Aegean and Mediterranean Ports (f: 352) are detailed inspection. Despite being the same port state, different inspection types were preferred in MoUs. "Expanded inspection" was performed at very low rates in both MoU ports. In this context, although the texts of all MoUs are almost the same, the MoU parties in some areas shortage of the technology, financial capacity, infrastructure, action plans and policies required for an effective agreement (Bang & Jang, 2012). Furthermore, Piniella et al. (2020), using both stakeholder perceptions and information from the "European Maritime Safety Agency (EMSA)", "Paris Memorandum of Understanding (Paris)", concluded that PSC controls are not perceived consistently and vary by the same state operator, port, even port state control operator.

Table 3. Research hypotheses test results

Hypothesis	Value	P	Result of Hypothesis	Cramer's V Value	Degree of Relationship
H_1	1237.187	0.000	Accept	0.236	"Moderate association"
H_2	121.117	0.000	Accept	0.074	"Negligible association"
H_3	159.239	0.000	Accept	0.085	"Negligible association"
H_4	234.153	0.000	Accept	0.103	"Weak association"
H_5	143.097	0.000	Accept	0.080	"Negligible association"
H_6	4604.900	0.000	Accept	0.456	"Relatively strong association"
H_7	227.402	0.000	Accept	0.101	"Weak association"
H_8	3713.054	0.000	Accept	0.579	"Relatively strong association"
H_9	17.381	0.026	Accept	0.028	"Negligible association"
H_{10}	30.087	0.116	Reject	-	-
H_{11}	1075.122	0.000	Accept	0.220	"Moderate association"
H_{12}	1309.234	0.000	Accept	0.243	"Moderate association"
H_{13}	1171.549	0.000	Accept	0.230	"Moderate association"
H_{14}	201.361	0.000	Accept	0.135	"Weak association"
H_{15}	1536.090	0.000	Accept	0.263	"Moderate association"
H_{16}	31.118	0.000	Accept	0.053	"Negligible association"
H_{17}	34.543	0.000	Accept	0.056	"Negligible association"
H_{18}	574.165	0.000	Accept	0.228	"Moderate association"
H_{19}	1000.558	0.000	Accept	0.301	"Moderate association"
H_{20}	279.699	0.000	Accept	0.159	"Weak association"
H_{21}	805.636	0.000	Accept	0.135	"Weak association"
H_{22}	371.661	0.000	Accept	0.055	"Negligible association"
H_{23}	1525.174	0.000	Accept	0.151	"Weak association"
H_{24}	5396.020	0.000	Accept	0.403	"Relatively strong association"
H_{25}	1337.633	0.000	Accept	0.201	"Moderate association"
H_{26}	114.492	0.000	Accept	0.051	"Negligible association"
H_{27}	69.279	0.367	Reject	-	-
H_{28}	3665.830	0.000	Accept	0.332	"Moderate association"
H_{29}	1165.782	0.000	Accept	0.187	"Weak association"
H_{30}	2328.602	0.000	Accept	0.205	"Moderate association"
H_{31}	137.382	0.000	Accept	0.064	"Negligible association"
H_{32}	50.609	0,026	Accept	0.039	"Negligible association"
H_{33}	1425.553	0.000	Accept	0.207	"Moderate association"
H_{34}	3449.389	0.000	Accept	0.322	"Moderate association"

H_{24} ("port" and "ship type") (v: 0.403) are "relatively strong association". The most inspected vessels were general cargo/multi purposes (f:4859, 43.9%) and Bulk Carrier (f:3415, 30.8%), respectively. In the scope of the "Mediterranean MoU", the most inspected ship types in Turkish Ports were general cargo/multi purposes (f: 3283, 36.9%) and bulk carrier (f: 2916, 32.78%) respectively, while the most inspected ship types in Turkish Ports within the scope of the Black Sea MoU were general cargo/multi purposes (f: 1576, 72.19%) and bulk carrier (f: 499, 22.86%), respectively. This situation is due to the different proportions of ships arriving at the ports of these MoUs. Şanlıer (2020) analysed the inspection data of the Black Sea MoU between 2012 and 2017 and stated that while the rate of general cargo, which is the most inspected vessel, was 44.79% in 2012, it decreased over the years and decreased to 37.48% in 2017, and the rate of bulk carrier, which was the second, was 25.99% in 2012 and increased to 34.81% in 2017.

As a result of our analyses, H_{11} ("result" and "flag"), H_{12} ("result" and "ship type"), H_{13} ("result" and "port") and H_{15} ("result" and "ship's age) have "moderate association". In this context, in our study, the flags of the ships that were most frequently detained in the inspections were found to be Panama, Marshall Islands and Liberia with approximately 16.71%, 4.61% and 3.46%, respectively. However, while the detention rate of Panama flag was 3.01%, Marshall Islands was 1.52% and Liberia was 1.11%. It was observed that these flags with the highest detention rate were easy flags. In addition, among the inspections, the most common type of vessels detained were "general cargo/multipurpose" (68.58%), "bulk carrier" (16.14%) and "tanker" (3.17%). The detention rate of "general cargo/multipurpose" was approximately 4.90 %, while that of "bulk carrier" was 1.64 % and that of "tanker" was 1.03 % according to our paper's result. In this context, the ports where the ships were detained the most in inspections were Iskenderun (approximately 13.54%), Mersin (approximately 12.97%), and Kocaeli (approximately 8.07%), respectively. In addition, Other Marmara Ports (approximately 14.12%), Other Black Sea Ports (approximately 12.10%) and Istanbul/Ambarlı/Tuzla (approximately 8.36%). However, while the rate of detention of vessels in Samsun Port was approximately 3.91%, it was 3.71% in Iskenderun Port and 3.55% in Ceyhan Port. Moreover; this rate was 7.24% in Other Aegean and Mediterranean Ports, 5.20% in Other Marmara Ports and 4.63% in Istanbul /Ambarlı/Tuzla. In addition, the age range of the most detained vessels in the inspections is 21 and up; this ratio covers approximately 67.90% of all detained vessels. This is followed by 16-20 with approximately 9.23%. In addition, approximately 8.43% of 21 and up and 1.95% of 16-20 vessels entered into detention. Only about 0.36% of the vessels in the 0-5 range were detained. In this context, Chuah et al. (2023) analysed the factors of risk for ship detention and found that the flag state is the biggest factor, followed by type of ship, recognized organization inspection authority and age of ship. In addition, Emecen Kara (2022) measured the flag states performance and stated that only 49% of the flag states have substandard performance and especially Panama and Indonesia are the countries with the lowest performance. Öztürk & Gökdemir Işık (2016) found that ship age, ship type, ship structure, cargo type, voyage intensity and ship flag also affect the inspection status of ships.

In PSC inspections, ships, the general condition of the ship; certificates and documents, preparedness for emergencies and the quality of the crew and familiarity with the task are examined (Demirci et al., 2022). When a PSC inspection is carried out, the first procedure after checking the external appearance of the ship under general conditions is to control the ship's certificates and documents, and if no obvious deficiencies are found as a result of the impression obtained, the inspection is terminated. If an obvious defect is found, control all levels of the deck and associated cabin area equipment etc. by visiting; a more comprehensive inspection is made (Tsou, 2019; Şanlıer, 2020; Prieto et al., 2021). If serious defects are found as a result of the detailed inspection, the ship is detained until all deficiencies are eliminated, and if the ship goes though the PSC inspection after the deficiency is eliminated, the detention of the ship is lifted (Tsou, 2019; Şanlıer, 2020; Chuah et al., 2023). In the inspections carried out in Turkish Ports between 2018 and 2022 the most common deficiency areas in the detentions were "Certificate and Documentation" (66.9%), "Fire Safety" (65.7%), "Safety of Navigation" (64.3%), and the least deficiency areas were "Dangerous Goods" (1.7%), "Cargo Operation including Equipment" (4.3 %), "Other" (4.9 %), respectively.

Conclusion

Evaluating the performance of the flag state are important to ensure the life, property and the environment safety for the coastal state in PSC inspections (Xiao et al., 2021; Uygur & Bolat, 2021). Therefore, the paper is examined PSC inspections in Türkiye between 2018 and 2022. The frequency and relationship analyses with the hypotheses were made. According to the results, it was observed that 98.99% of the inspections were carried out on weekdays and the vessels with the highest detention rate were easy flag states. In addition, the month of inspection was either not correlated with other variables or the degree of association was "negligible association". The most correlation was observed between type of inspection and MoU between port and type of inspections and ship type. The study contributed to the literature in terms of statistically examining the inspections carried out in Turkish Ports between 2018 and 2022 within the scope of "Black Sea MoU" and "Mediterranean MoU". In future studies, a general risk analysis of PSC inspections and detentions in Turkish Ports can be carried out, as well as a risk analysis of any deficiency area that causes detention.

Compliance With Ethical Standards

Conflict of Interest

The author declares that there is no conflict of interest.

Ethical Approval

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

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Data Availability Statement

All data generated or analysed during this study are included in this published article and its supplementary information files.

Supplementary Materials

Supplementary data to this article can be found online at https://doi.org/10.33714/masteb.1402896

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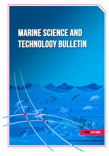

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REVIEW ARTICLE

Application of the MALDI-TOF MS method for identification of *Vibrio* spp. in aquaculture

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Vibriosis

ABSTRACT

Aquaculture is developing rapidly and plays an important role in providing animal protein to the world's growing population. However, increasing mortality from bacterial disease outbreaks in important species poses a challenge to production progress in this sector. In order to reduce the impact of these diseases, rapid and accurate pathogen identification is essential for disease management, early detection and the continued health of aquaculture. The aim of this review is to summarise studies on the identification and diagnosis of *Vibrio* pathogens in aquatic organisms by MALTI-TOF MS (Matrix-Assisted Laser Desorption Ionisation Time-of-Flight Mass Spectrometry), a rapid identification method based on protein profiling of bacteria. The profiles of bacterial protein obtained are compared with a global microbial protein library for identification. This study demonstrates the potential of using MALDI-TOF MS for the detection of *Vibrio* pathogens in aquaculture in studies published between 2015 and 2024. While purchasing a time-of-flight mass spectrometer is expensive when compared to conventional and molecular identification methods. It also appears to be much more efficient in terms of time spent on identification. MALDI-TOF MS has been shown to be simple to use in fish identification laboratories.

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Introduction

Aquaculture, a rapidly growing sector, suffers tremendous financial losses every year due to fish deaths caused by disease outbreaks and treatment expenses (Woo & Bruno, 2011). There are numbers of gram-negative, halophilic, flagellated and facultative anaerobic *Vibrio* species in Vibrionaceae family such as *V. parahaemolyticus*, *V. vulnificus* and *V. cholerae* cause diarrheal disease, septicaemia and serious wound infections in humans (Malainine et al., 2013; Burbick et al., 2018; Boonstra et al., 2023). *V. alginolyticus*, *V. anguillarum*, *V. parahaemolyticus*, *V. harveyi*, *V. splendidus* and *V. ordalii* are also known to be the causative agent of Vibriosis that causes symptoms of haemorrhagic septicaemia in various marine fish and freshwater fish (salmon, rainbow trout) (Silva-Rubio et al.,

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2008) as well as shellfish, crustaceans and bivalves (Tanrikul, 2007; Mougin et al., 2020). Lastly, bacterium *V. tapetis* causes Brown Ring Disease (BRD) in Manila clam (Paillard et al., 2006). Since bacterial infections are a major contributor to fish mortality in aquaculture, mitigating their impact is of great importance to the aquacultural and fisheries industry. It is essential to monitor these diseases by surveillance and quick bacterial detection in order to diagnose and treat aquatic animal diseases before they pose major hazards to animal welfare and country economies that depend on marine and inland aquaculture (Ashfaq et al., 2022).

Traditionally, bacterial fish pathogens have been identified and characterized using conventional microbiological, immunological and molecular biological approaches (Ruiz-Zarzuela et al., 2005; Altinok et al., 2008; Timur et al., 2009; Austin, 2019; Duman et al., 2022). Although these classical methods are frequently used in the identification of bacterial fish diseases, they also have the disadvantages of requiring too much effort and time and not being able to distinguish between some closely related species.

Consequently, the emphasis has been to develop quick, affordable substitute methods that have a significant level of sensitivity and specificity for identifying *Vibrio* agents. In the identification of bacterial disease pathogens, mass spectrometry with Matrix Assisted Laser Desorption/Ionization Time of Flight (MALDI-TOF) is a recent breakthrough. By examining bacterial protein profiles, this proteomics-based method offers rapid and precise identification. It can be applied in supplementary to and as a validator of other microbial identification techniques (Lauková et al., 2018).

In this review, a brief overview of the general principles, applications and history of MALDI-TOF MS is provided, followed by an evaluation of the studies on the detection of *Vibrio* spp. by this method.

History, Applications and General Principles of MALDI-TOF MS

MALDI-TOF MS was first developed by Karas et al. (1985) and after Tanaka won the Nobel Prize in Chemistry for this development in 2002, MALDI-TOF MS has made significant advances in proteomics research, enabling rapid identification of many different microorganisms in medical microbiology research (Tanaka, 2003). In the following years, open access protein mass spectrum libraries were created to facilitate microbial (virus, bacteria, fungi and yeast) characterization for clinical studies (Böhme et al., 2012).

MALDI-TOF was first used in clinical microbiology (Seng et al., 2010; Erler et al., 2015; Patel, 2015; Anwer et al., 2022), followed by veterinary, soil, plant, food and water microbiology (Popović et al., 2017; Chun et al., 2022) and more recently for the aquatic pathogens (Jansson et al., 2020; Piamsomboon et al., 2020).

The basic principle of the MALDI-TOF MS method works by ionising and measuring the mass to charge ratios (*m/z*) of ribosomal proteins of microorganisms, resulting in a mass spectrum with a unique fingerprint (Singhal et al., 2015). The obtained microbial peptide mass fingerprints are compared with the mass spectral library database of pre-existing reference samples and identification is performed (Brauge et al., 2021). Figure 1 summarize the MALDI-TOF MS procedure steps for different *Vibrio* identification. Step A is sample preparation from *Vibrio* culture, step B individual colonies on MALDI-TOF device and step C is the analysis and step D is identification (Sandalakis et al., 2017; Kazazić et al., 2019a, 2019b). In the first step, a single colony is selected from culture petri dishes with *Vibrio* and spread on the target plate. The sample plate of the device is then coated with a matrix solution of 70% formic acid and allowed to dry at room temperature. As the matrix dries, it crystallises together with the sample and is then placed in the MALDI-TOF device and the analysis is initiated (Popović et al., 2017). Once the matrix plate is placed in the instrument, ionised *Vibrio* peptides are converted by laser beams into protonated ions which are accelerated by an electric field towards a detector with the time required to travel along the flight tube under vacuum and measured according to their mass to charge ratio (*m/z*). Smaller proteins, followed by progressively larger analytes, arrive at the detector, creating a characteristic mass spectrum, which allows molecules present in samples to be identified based on their unique mass fingerprint. The distinctive spectrum obtained for each species is recorded and compared with a reference spectrum database. Species identification is achieved by comparing *Vibrio* species with reference mass spectra in databases based on peaks and ranking them on a logarithmic scale from 0 to 3.0 The criteria for a reliable identification at the species level should be a number higher than 1.7 (Puk et al., 2018).

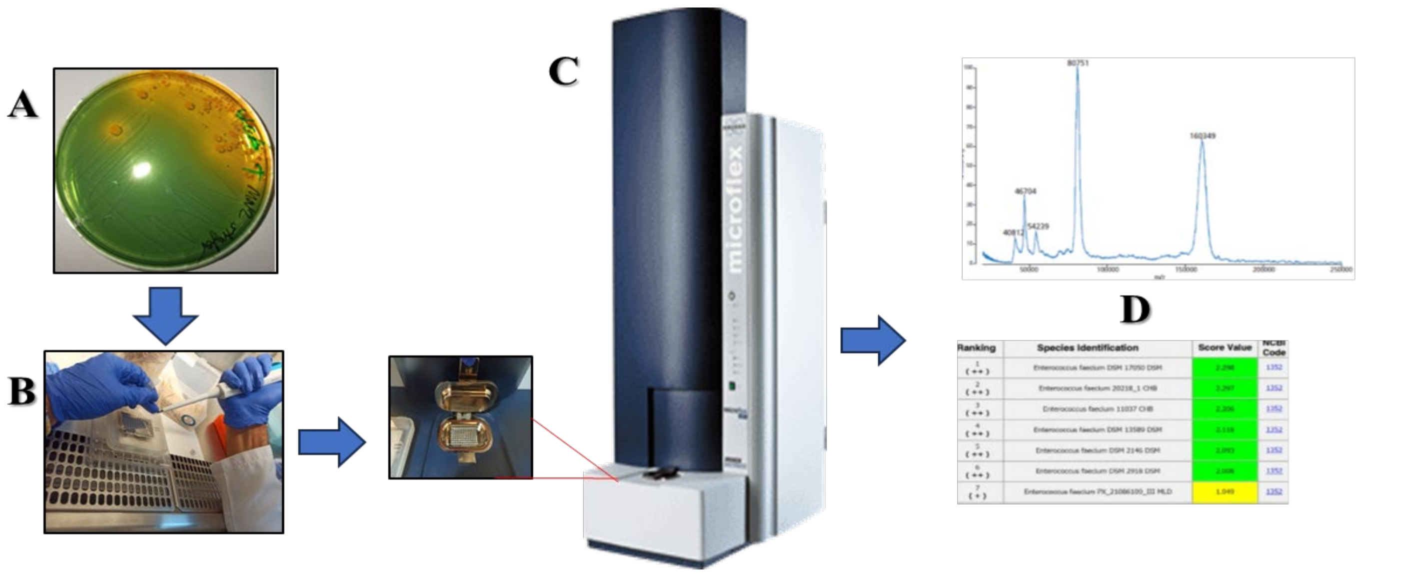

Figure 1. Schematic steps for MALDI-TOF MS **A)** Preparation of bacterial sample; **B)** Application of samples; **C)** MALDI-TOF MS analysis; **D)** Identification of *Vibrio* spp.

MALDI-TOF MS Analysis for Identification of *Vibrio* spp. and Other Fish Pathogens

Research has shown that the MALDI-TOF MS technique is capable of identifying a single bacterial disease agent or co-infectors, which is important for fish species used in both inland and marine aquaculture (Piamsomboon et al., 2020; Nissa et al., 2021; Moreira et al., 2021; Duman et al. 2022; Saticioglu et al., 2023). Besides Vibrionaceae (Burbick et al., 2018), several bacterial families of Mycobacteriaceae, Aeromonadaceae and Pseudomonadaceae, Enterobacteriaceae, Streptococcaceae that cause disease in aquaculture have been shown to be identified by MALDI TOF (Singhal et al., 2015; Popović et al., 2017; Assis et al., 2017; López-Cortés et al., 2017).

This section reviews research articles on the identification of *Vibrio* species by MALDI-TOF MS from 2015 to 2024 retrieved using "MALDI-TOF MS" and "each *Vibrio* spp. separately" as keywords in the Google Scholar search engine (Figure 2). The bar graph in Figure 2 shows the number of research studies that utilised MALDI-TOF MS for the identification of *Vibrio* spp. during this period has been gradually increasing.

The reported applications and results of MALDI-TOF MS to identify *Vibrio* pathogens causing common vibriosis in fish, shellfish and shrimp are summarised in Table 1. A study by Dieckmann et al. (2010) showed that *Vibrio* spp. were identified from different samples by RNA polymerase beta subunit gene (*rpoB*) sequencing and compared with MALDI-TOF MS, which was shown to give a score mass of 4200 to 6500 Da for accurate identification. Bauer et al. (2018) identified eleven pathogenic *Vibrio* species from Pacific white shrimp samples (*Litopenaeus vannamei*) by protein spectrum MALDI-TOF MS analysis and compared these data with 16S rRNA sequencing and sequencing of the uridylate kinase encoding gene (*pyrH*). Burbick et al. (2018) reported that 29 out of 35 *Vibrio* spp. (83%) from different fish such as *Hippocampus abdominalis* (Big-belly seahorse), *Seriola lalandi* (yellowtail kingfish), *Atractoscion nobilis* (white seabass), *Pterapogon kauderni* (Banggai cardinal fish), *Paralichthys californicus* (California halibut) were correctly identified at species level using MALDI-TOF MS. *V. fluvalis* and *V. vulnificus* were identified by analysing peptide mass score values between 1.750 and 2.41 obtained from seawater (Haider et al., 2023) and *Anguilliformes* species (eels) (Boonstra et al., 2023), respectively. *V. anguillarum*, another important vibriosis causing bacterium, was identified from *Dicentrarchus labrax* (European sea bass) and *Sparus aurata* (sea bream) by MALDI-TOF MS with an average mass score of 2.12-2.50 (Kazazić et al., 2019b; Jansson et al., 2020; Mougin et al., 2021). Low et al. (2014) reported the identification of *V. alginolyticus* from *Epinephelus fuscoguttatus* (brown-marbled grouper) using MALDI TOF. Additionally, Rahmani et al. (2021) also came to the conclusion that *V. tapetis* isolated from Manila clams, were found as pathogenic based on the protein profiles which demonstrated the presence of a virulence gene. *V. parahaemolyticus*, the causative agent of vibriosis, was reported to be identified from *D. labrax*, *Haliotis tuberculata* (green ormer) and *Crassostrea gigas* (Pacific oyster) by Malainine et al. (2013) and Mougin et al. (2020) using MALDI TOF method. Finally, Yavuzcan et al. (2022) showed that *V. harveyi* from *Sarpa salpa* (dreamfish) was identified by the same method with a score of 2.248.

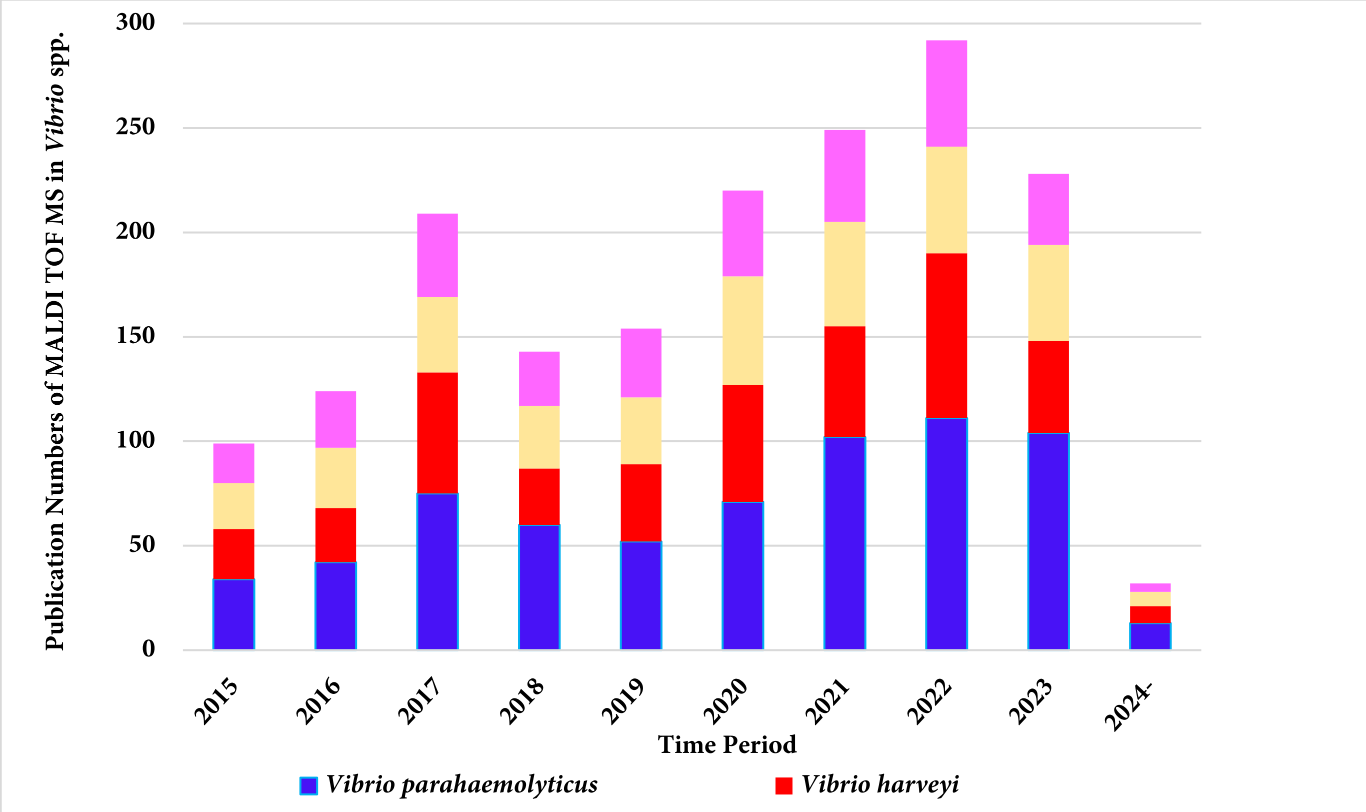

Figure 2. The number of publications over ten years related to found identification *Vibrio* pathogens with MALDI-TOF MS. The bar indicates the number of Web of Science search associated with *Vibrio* pathogens

Table 1. A list of *Vibrio* spp. identified with MALDI-TOF MS

Bacteria	Hosts	MALDI-TOF MS Peaks (Da)/Scores	References
Vibrio spp.	Molluscs	Scores 4200 to 6500	Dieckmann et al. (2010)
	Hippocampus abdominalis (big-belly seahorse), *Seriola lalandi* (yellowtail Kingfish), *Atractoscion nobilis* (White seabass), *Pterapogon kauderni* (Banggai cardinalfish), *Paralichthys californicus* (California halibut)	Scores 1.700 to 3.010	Burbick et al. (2018)
	Litopenaeus vannamei (Pacific white shrimp)	Scores 1.600 to 2.440	Bauer et al. (2018)
V. vulnificus	*Anguilliformes* spp. (Eels)	Score 2.000	Boonstra et al. (2023)
	Fish	Scores 2.218 to 2.418	Jansson et al. (2020)
V. anguillarum	Marine fish	Scores 2.123 to 2.318	Jansson et al. (2020)
	Dicentrarchus labrax (European seabass)	Score 2.500	Mougin et al. (2021)
	D. labrax, *S. aurata* (gilthead seabream)	Score 2.232	Kazazić et al. (2019b)
V. alginolyticus	*Epinephelus fuscoguttatus* (brown-marbled grouper)	Scores 910 to 2000 Da	Low et al. (2014)
V. fluvalis	Sea water	Score 1.750	Haider et al. (2023)
V. splendidus	Marine fish	Scores 1.780 to 2.030	Jansson et al. (2020)
V. harveyi	*Sarpa salpa* (dreamfish)	Score 2.248	Yavuzcan et al. (2022)
	D. labrax	Score 2.480	Mougin et al. (2021)
V. parahaemolyticus	*D. labrax, Haliotis tuberculate* (green ormer), *Crassostrea gigas* (Pacific oyster)	Scores 2.290 to 2.400	Mougin et al. (2020)
	shellfish, sea water and sediments	Scores 3000 to 11000 Da	Malainine et al. (2013)

Advantages, Limitations and Future Perspectives of MALDI-TOF MS for the Identification of Bacterial Fish Diseases

In terms of aquatic health, MALDI-TOF MS serves as a state-of-the-art diagnostic tool for identification of fish pathogens affecting aquatic organisms. There are a number of advantages to using MALDI-TOF MS analysis for identifying those pathogens, promoting sustainable practices in aquaculture and healthier fish populations. First of all, it provides rapid and accurate identification of the bacterial species causing fish disease, facilitating rapid detection of diseases affecting aquatic organisms. Furthermore, since MALDI-TOF MS has a high throughput and minimal sample preparation requirements, it can effectively screen a large number of field samples. Moreover, it is also an advantageous system as it reduces the need for costly reagents and labour-intensive steps involved in traditional techniques.

However, there are some limitations to take into account. The initial high cost of purchasing a MALDI-TOF MS device is a significant disadvantage that may prevent farming companies from using this technology. Alternatively, it can be suggested that instead of purchasing device, users who wants to bacterial identification, can obtain services from the devices available in clinical microbiology laboratories.

Another limitation of the current devices is that bacteria cannot be sampled directly from the diseased fish sample and identified in the equipment. Although MALDI-TOF MS can accurately identify most of the bacterial species, its inability to detect some species not found in proteomic databases may be one of the limitations of this method.

Overall, MALDI-TOF MS technology has ongoing innovations and system refinement for future user convenience. Efforts to optimise sample preparation protocols and streamline data analyses can make MALDI-TOF MS more accessible and user-friendly for aquaculture practitioners and hold great promise for advancing disease diagnosis and promoting sustainable aquaculture practices in the future. Nevertheless, more fish pathogens' score values and peak data should be uploaded to global protein databases for accurate discrimination and identification of fish pathogens.

Conclusion

In conclusion, the number of published papers between 2015 and 2024 applying MALDI-TOF MS increased significantly, demonstrating the technique's effectiveness and efficacy regarding the management of fisheries and aquatic health. With distinct fingerprints (spectral protein peaks) and mass score values obtained from cellular ribosomal proteins in *Vibrio*s, MALDI-TOF MS has demonstrated the ability to quickly and accurately detect, identify, and differentiate pathogens at the species level through comparison with reference mass spectrum databases. The use of this method in the aquaculture disease sector promotes sustainable practices and healthier fish populations in aquaculture by contributing to early detection of disease and the development of timely and effective intervention strategies.

Compliance With Ethical Standards

Authors' Contributions

İTÇ: Conceptualization, Writing - Original Draft, Writing-Review and Editing, Data Curation, Formal Analysis, Supervision

KG: Writing - Original Draft, Data Curation, Visualization

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.

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Data Availability Statement

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

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RESEARCH ARTICLE

Impacts of Brent crude oil price fluctuations on global aquaculture production during World economic crises

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ABSTRACT

This study evaluates the linkage between brent crude oil prices and volatility spillover on the global aquaculture volume -and values during world economic crises. Besides the main variable costs comprising feed expenses with over the half of total costs in aquaculture facilities, the energy expenditures are among the important operational costs that influence farm profits through feed costs overall, but also with direct effects in recirculating systems as electricity use. Findings in this study evidenced that global aquaculture volume and value is closely related to global brent crude oil price variations during the periods of crises, as a result of increase in production costs. The correlations between brent crude oil prices and percent changes in volume -or values of farmed fish covering the crises periods between 2008 and 2021 were highest as 0.798 (R=0.798134676) and 0.716 (R=0.715832960), respectively, which are close to zero "0", showing strong correlations between the investigated structures. However, no correlation was found between the investigated structures during the pre-crisis, post-crisis or inter-crisis periods. Over the last ten years, there were three periods when brent oil prices dropped remarkably, with interrelated effects on world aquaculture production volume or values with severe price dip following the brent oil trends. Hence, the results from this study reveal that any severe change in the energy sector will in turn hit the aquaculture industry with significant influences on both production volume -and values. Therefore, information regarding the interrelation of brent crude oil price variations and global aquaculture production provided in this study, may support building management strategies for sustainable fish farming business with foresights to world economic crises.

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Introduction

Energy resources are one of the most important factors affecting production that shape global economies. In developing economies with high external dependency for energy, the cost of production is directly affected by any fluctuation, especially in oil and its derivatives (Taghizadeh-Hesary et al., 2018). Crude oil has strong impacts on life and may influence the quality standards of people's life and livelihoods during imbalance of crude oil prices (Jahangir & Dural, 2018), because of its broad use of area such as the transportation industry, or production of all kinds of commodities, including food and animal production or agricultural activities. Energy resources are indispensably in use in all levels of industrial process. It has been stated that fluctuations in oil prices directly affect animal production (Fabiosa, 2009), or products obtained from animals, such as the butter prices and volatility influenced by the changes in oil prices (Bergmann et al., 2016). Also, strong linkages between agricultural commodity prices and oil prices in the U.S. were reported by McFarlane (2016) in their study conducted over long-term comprising two consecutive periods of 1999–2005 and 2006–2012. Similarly, López Cabrera & Schulz (2016) evaluated the price and volatility risks generated by the energy and agricultural commodity prices, and underlined that the variations in prices were closely related between energy -and agriculture commodities in Germany in long-term, and strong positive correlations were noted with severe shock effects on markets. This was also reported from Nigeria, where Nwoko et al. (2016) revealed a positive and significant short-term relation between oil price and food price volatility between 2000 and 2013. In another study, Al-Maadid et al. (2017), the relations between food and energy prices have been investigated and the authors underlined that there were strong relations between food and both oil prices. It has been reported that the food crises in 2006 and financial crisis in 2008 caused significant impacts on the volatility of the prices for food and oil. El Montasser et al. (2023) also evidenced strong relations between the presence of volatility in brent oil prices and agricultural commodities. Although investigations on the relationship between energy resources and agricultural activities or livestock sector has increased recently, it should be noted that this relationship is not unidirectional, many factors play a role in the interaction and there is a more complex connection than it seems (El Montasser et al., 2023). Unexpected developments, such as the recent Covid-19 pandemic, or events that started as a regional dispute between Russia and Ukraine but turned into a war in a short time, cause serious problems not only in the regional economies, but also in the inter-country trade network with severe shock waves on both developed or emerging economies worldwide. Despite the fact that a number of research efforts focused on the interrelation of brent crude oil prices with a variety of commodities and price volatilities, including agricultural commodities (López Cabrera & Schulz, 2016; McFarlane, 2016; Aye & Odhiambo, 2021), food production (Nwoko et al., 2016; Al-Maadid et al., 2017; Roman et al., 2020), and livestock production (Fabiosa, 2009), there is no published report available to our knowledge so far regarding the possible volatility spillover from brent crude oil price variations on global aquaculture activities, which is in a rapid expansion with remarkable growth over the last decades, providing an important share of the food demand of the growing world population.

In the aquaculture sector, especially in closed recirculating facilities and hatcheries, the energy factor comes to foreground in terms of electricity costs, while the share of energy use in the production of feed required for fish feeding is also significant. Hence, this study aimed to fill this gap by evaluating the interrelated nature or even the co-explosivity between Brent crude oil prices and the production level or sales value for the global aquaculture industry, that in turns may provide important foresights for farm managers to overcome future crisis periods with best aquaculture management strategies.

Material and Methods

Data Description

For the evaluation of interrelations between brent crude oil prices and aquaculture production in terms of volume and value, actual prices for both measures were used with the sample period between 2005 and 2021, covering the three global economic crises occurred in 2009, 2015 and 2020, that hit global economies of both developed and emerging countries. These three incidences were chosen to figure the two shock waves happened in five-years intervals over the past fifteen years by the dip price of brent crude oil, that remarkably affected the world aquaculture production and global aquaculture markets, overlapped and potentially showed a co-explosivity effect. Among the three severe price drops of brent crude oil, the shock wave in 2009 was called as "Housing market bubble" (Loo, 2020), the crisis in 2015 was called as "the oil shale revolution 2014-2015" (Mănescu & Nuño, 2015), whereas the third was the Great Lockdown (Panneer et al., 2022), that occurred in 2020 due to the recent Covid-19 pandemic. Data used in this study were retrieved from statistical data base of Statista (2023), and FAO (2023a, 2023b). Data for global aquaculture production volume and value represent the total sum of finfish aquaculture covering diadromous fishes + freshwater fishes + marine fishes. Plants and other aquatic animals are excluded.

The data for global finfish aquaculture production in volume and international trade values in $US covered the periods between 2005 and 2021, which were collected from online statistical query panels of FAO (2023a, 2023b), have been used in the equations given below, according to Yigit & Kusku (2022):

$$PIVOL\% = \frac{(PVOL(y2) - PVOL(y1))}{PVOL(y1)} \times 100$$

where,

PIVOL%: percent increase of production volume (tons)

PVOL(y2): production volume (tons) in year-2

PVOL(y1): production volume (tons) in year-1

$$PIVAL\% = \frac{(PVAL(y2) - PVAL(y1))}{PVAL(y1)} \times 100$$

where,

PIVAL%: percent increase of production value ($US)

PVAL(y2): production value ($US) in year-2

PVAL(y1): production value ($US) in year-1

The unit sales price for the global finfish aquaculture harvests were estimated via dividing the production values by production volumes using following equation provided by Yigit et al. (2023).

$$SPunit = \frac{PVAL}{PVOL}$$

where,

SPunit: unit sales price

PVAL: production value ($US)

PVOL: production volume (tons)

Description of the Interrelation Via Correlation and Statistical Analyses

With the mathematical estimations in this study, it was aimed to understand to which extent price changes for the brent crude oil and global aquaculture in both volume and value correlate positively with each other. Correlations were assessed for data covering the crisis periods, as well as no-crisis periods in order to understand the variations of coefficients with possible influences by crisis. In terms of timely perspective, the total span of years investigated in this study (2005-2021) was divided into period groups, following the reports of Al-Maadid et al. (2017), Vo et al. (2019), and Roman et al. (2020). The three period groups in this study were assessed as (a) no-crises and (b) crisis periods. Then, each of these periods were divided into three subperiods, where the no-crisis period group consisted of (i) 2005-2008 (pre-crisis period of the housing market bubble crisis in 2009), (ii) 2010-2014 (post-crisis period after 2009-crisis, pre-crisis period before the oil shale revolution in 2015), and (iii) 2016-2019 (post-crisis period after 2015-crisis, pre-crisis period before the Covid-19 pandemic crisis in 2020), while the crisis period group consisted of (i) 2005-2021 (all times combined with three world crisis in 2009, 2015, 2020), (ii) 2008-2021 (three world crisis periods combined with one year before and after the crisis), and (iii) 2009-2020 (three world crisis combined, covering the year of crisis only.

The correlation coefficient range between minus one (-1) and one (1) indicate how the variations of the two evaluated parameters are related to each other. When the value obtained is close to “-1”, this indicates a strong negative relation, which shows that the variables move in opposite directions, whereas a coefficient value close to “1” gives a strong positive relation between the variables, underlining a trend motion to the same direction. When the correlation coefficient is found as “0”, this gives an indication that the trends of the two variables are not linearly related (Camp, 2019). The correlation coefficient between brent crude oil price volatilities and global aquaculture value has been investigated in the present study. Mathematical calculations were assessed by using a Microsoft Excel program for Mac MacBook Pro, macOS Big Sur (11.7.3), and the correlation coefficients were estimated by the following equation:

$$Correl\ (X,Y) = \frac{\sum(x - \bar{x})(y - \bar{y})}{\sqrt{\sum(x - \bar{x})^2 \sum(y - \bar{y})^2}}$$

where, $\bar{x}$ and $\bar{y}$ indicates the mean value of the sample for two different series, which were set as the brent crude oil price, global aquaculture value changes, and global aquaculture production volumes in this study.

Results

The main three severe price drops of brent crude oil occurred during the devastating crises in 2009, 2015, and 2020 are presented in Figure 1. The variations of average annual brent crude oil price, global finfish aquaculture production in volume and value, and the precent volatility rates over the previous year during the study period from 2005 to 2021 have been summarized in Table 1.

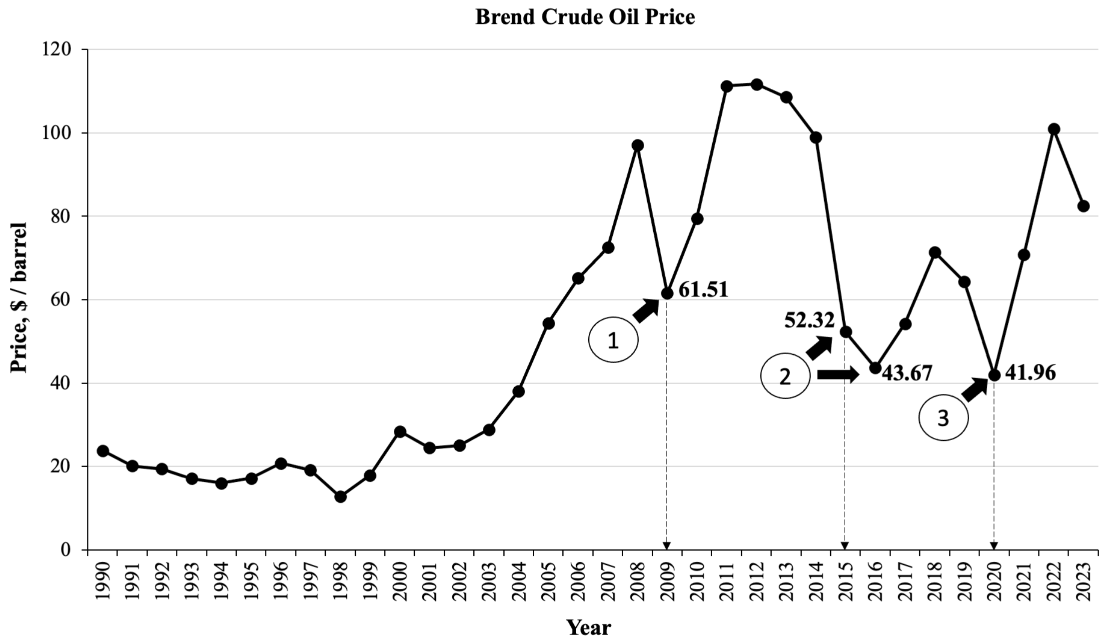

Figure 1. Variations in brent crude oil prices between 1990 and 2023. Price drops during the three global crises are noted with arrows. Year of brent crude oil crises indicated with vertical arrows. Figure produced using data provided by Statista (2023).

Table 1. Average annual brent crude oil price ($ per barrel), and global aquaculture sales average per kg fish and percent value changes between 2005 and 2021.

Year	BCOP * $/barrel	ΣPVOL** Tons	PIVOL % increase	ΣPVAL*** $, ×1000	PIVAL % increase
2005	54.38	27,949,129.8	-	39,424,645.9	-
2006	65.14	29,772,563.5	6.52	45,031,777.4	14.22
2007	72.52	31,572,500.5	6.05	56,487,942.5	25.44
2008	96.99	34,239,736.7	8.45	65,482,730.8	15.92
2009	**61.51**	**35,697,108.7**	**4.26**	**69,674,113.7**	**6.40**
2010	79.47	37,683,870.0	5.57	80,681,414.1	15.80
2011	111.26	39,385,612.1	4.52	94,937,258.5	17.7
2012	111.63	42,269,689.2	7.32	104,160,284.8	9.71
2013	108.56	44,863,659.3	6.14	115,747,156.0	11.1
2014	98.97	47,129,646.2	5.05	126,406,719.3	9.21
2015	**52.32**	**48,994,863.6**	**3.96**	**122,950,881.8**	**-2.73**
2016	43.67	50,978,555.5	4.05	132,105,854.9	7.45
2017	54.25	52,594,116.2	3.17	138,945,076.9	5.18
2018	71.34	54,436,545.0	3.50	140,537,402.4	1.15
2019	64.30	56,195,538.6	3.23	143,645,756.6	2.21
2020	**41.96**	**57,506,702.8**	**2.33**	**144,912,753.2**	**0.88**
2021	70.86	59,271,218.1	3.07	154,902,873.6	6.89

Note:

BCOP: brent crude oil price

ΣPVOL: global aquaculture production, total

PIVOL: global aquaculture production, percent increase over previous year

ΣPVAL: global aquaculture value, total

PIVAL: global aquaculture value, percent increase over previous year

*Statista (2023), **FAO (2023a), ***FAO (2023b)

The three shock waves of crises with brent crude oil price dips in 2009, 2015 and 2020 have been highlighted in grey color and bold numbers.

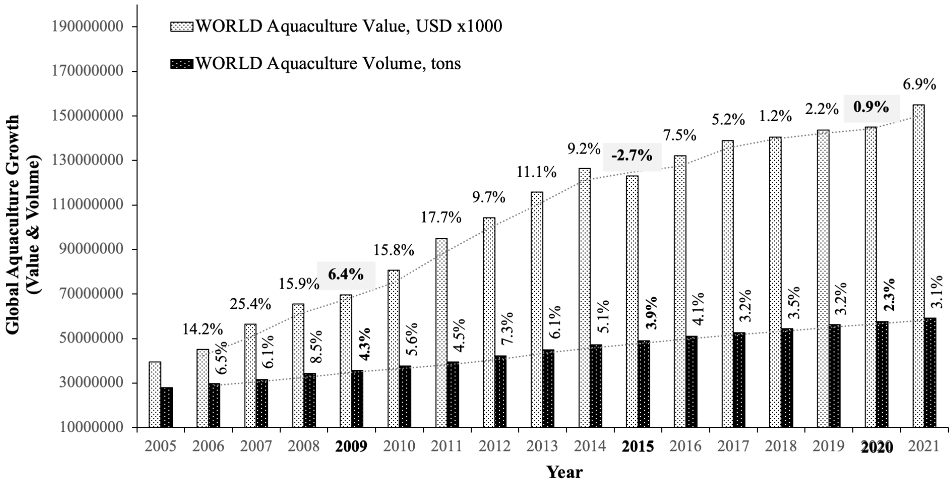

Figure 2. Global finfish aquaculture growth in value ($, x1000) and volume (tons) from 2005 to 2021, with indications of world crisis in 2009, 2015 and 2020. Values on bars present percent increase over previous year. Figure produced by statistical data provided by FAO (2023a, 2023b).

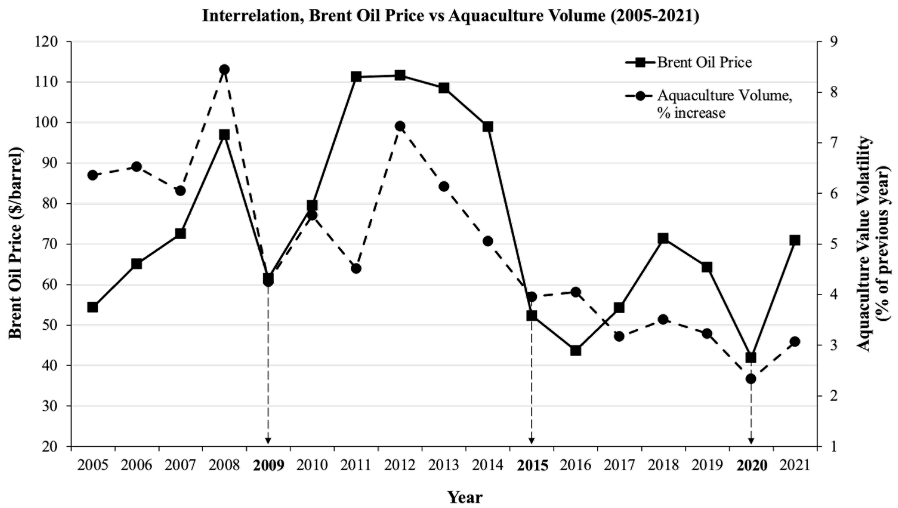

Figure 3. Superimposed illustration for the interrelation of brent crude oil price versus global aquaculture production volume between 2005 and 2021. Year of brent crude oil crises indicated with vertical arrows. Figure produced by statistical data provided by Statista (2023) and FAO (2023a, 2023b).

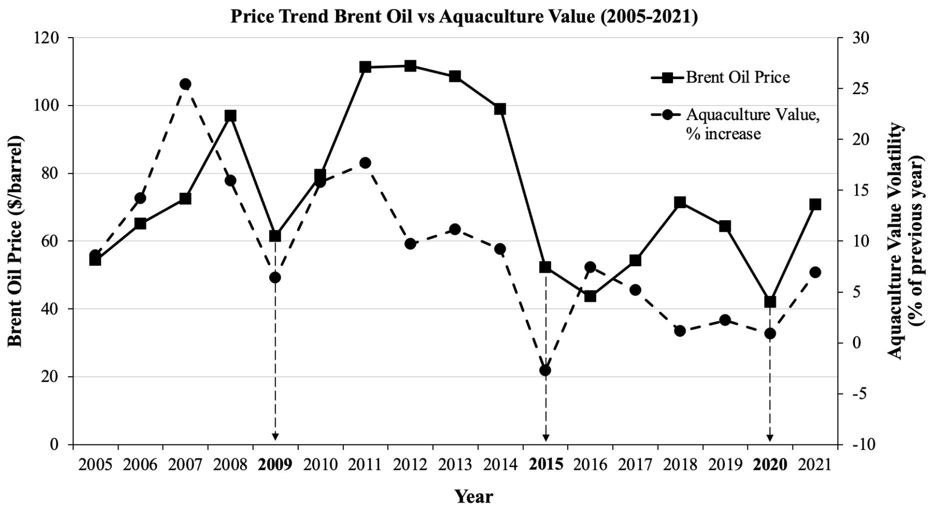

Figure 4. Superimposed illustration of brent crude oil price trend versus global aquaculture value volatility between 2005 and 2021. Year of brent crude oil crisis indicated with arrow. Figure produced by statistical data provided by Statista (2023) and FAO (2023a, 2023b).

Table 2. Correlation coefficients between brent crude oil prices and global aquaculture volume -and value volatilities during no-crisis and crisis periods.

Brent Crude Oil			
Crisis: NO	**Inter-crisis periods**		
	2005-2008[a]	**2010-2014[b]**	**2016-2019[c]**
GA-VOL	0.146297890	0.213407087	-0.569037484
GA-VAL	0.057705678	-0.252998166	-0.995184679
Crisis: YES	**Time of crisis periods**		
	2005-2021[d]	**2008-2021[e]**	**2009-2020[f]**
GA-VOL	0.566464994	0.730856035	0.790843781
GA-VAL	0.498279004	0.715832960	0.696991266

Note:

GA-VOL: global aquaculture volume

GA-VAL: global aquaculture value

No-crisis periods;

[a]2005-2008: before the housing market bubble crisis in 2009

[b]2010-2014: after 2009-crisis, before the oil shale revolution in 2015

[c]2016-2019: after 2015-crisis, before the Covid-19 pandemic in 2020

Crisis periods;

[d]2005-2021: all times combined with three world crises in 2009, 2015, 2020

[e]2008-2021: three world crisis periods combined with one year before and after the crisis [f]2009-2020: three world crisis periods combined covering the year of crisis only

Table 2 shows the results of Pearson's correlation with two main period groups with three divisions of subperiods in each group. Data in table reflect the relationship between brent oil price variations and both the percent volatility of both aquaculture volume -and value during the inter-crisis periods, that explains the "before, between and after" crisis terms (no-crisis periods).

Discussion

The results in this study evidenced no relationship with price variation in brent crude oil and global aquaculture volume or value during the no-crisis periods, since no correlation or even negative (-) correlation was found between brent oil price variations and percent volatility of both aquaculture volume -and value during the inter-crisis periods, that explain the "pre-crisis, between-crisis, and post-crisis" terms (no-crisis periods). This was in line with the report of Nazlioglu & Soytas (2011), who did not find any relationship between agriculture commodities and crude oil prices, which is an indication that during a no-crisis period, the brent oil price trend is not directly linked to the price of agricultural commodity. Also, Zhang et al. (2010) noted that the increase in crude oil prices have not direct linkage or relation to the food prices, but other factors influencing price volatilities may get in charge, such as demand shocks (Vo et al., 2019), that in turn may be coupled with a demand increase for crude oil according to Baumeister & Kilian (2014). In contrast to these reports with incompatible and even contradictive findings, there are clear evidences for significant linkages between food and oil prices during periods of crisis such as the food crisis in 2006, and financial crisis in 2008, that led to remarkable volatilities between their price series (Al-Maadid et al., 2017).

Since there is a lack of research on the spillover of crude oil prices into aquaculture production volume -or values, earlier investigations on a variety of food and agriculture commodities have been compared with the findings in this study regarding global aquaculture impacts. A number of researchers have pointed on the increasing crude oil prices as a strong reason for significant shock effects on agricultural markets. For example, El Montasser et al. (2023) reported that the relationship between crude oil and agricultural commodity is a complex issue that is linked to a variety of factors, however the authors underlined that the linkage between crude oil and agricultural commodities increased drastically during the global 2007-2008 food crisis and the recent Covid-19 pandemic crisis, which was in agreement with Du et al. (2011), who reported volatility spillovers from crude oil prices to the prices of agriculture commodities during the post-crisis period of 2006. Also, Nazlioglu et al. (2013) underlined that there was no risk transmission between crude oil and agriculture commodity prices during the pre-crisis period, but the oil market volatility showed a spillover into the agricultural markets during the post-crisis period. In contrast to these reports, findings in the present study showed evidence that the correlation coefficients for the evaluated structures of brent crude oil price and volatility spillover on global aquaculture volume -or value had no linkage in the pre-crisis or post-crisis periods during the three crises encountered in 2009, 2015, or 2020. However, at the time of the crises, the correlation coefficients increased in the positive direction close to one "1", underlining a strong relationship between brent crude oil price changes and the volatility of both global aquaculture volume -and value, with highest coefficients of 0.731-0.791, and 0.697-0.716 during the periods covering all three severe crises occurred in 2009, 2015, and 2020. Similar findings were also addressed by Roman et al. (2020) with high correlation coefficients between prices of oil and food indices. The results of this study with crisis-driven volatility spillover of crude oil prices into global aquaculture volume -and value, is also in close agreement with the report of Fabiosa (2009), who noted negative correlation coefficients between crude oil and grain prices, but the relationship increased during the ethanol bloom period, with elevated correlation coefficients from -0.117 to 0.876 for corn, from 0.182 to 0.909 for soymeal, and from -0.252 to 0.834 for distiller soluble dried grains. The correlation between crude oil and feed prices increased from a weak correlation of 0.020 to 0.890 during the ethanol bloom period between 2005-2008, that severely influenced the feed costs and as a consequence the livestock sector was affected during the crisis period.

Over the last fifteen years, three main crises were observed globally with five-years intervals that severely affected economies of developed as well as emerging economies of world countries. Among the three severe price drops of brent crude oil, the shock wave in 2009 was called as "Housing market bubble" (Loo, 2020), the crisis in 2015 was called as "the oil shale revolution 2014-2015" (Mănescu & Nuño, 2015), whereas the third was the Great Lockdown (Panneer et al., 2022), that occurred in 2020 due to the recent Covid-19 pandemic. In 2009, the average annual price of brent crude oil dropped suddenly to 61.51 $/barrel from its peak of 96.99 $/barrel in its history. After the recovery of 2009 crisis, it peaked again to the highest level of 111.63 $/barrel, that declined slightly to 108.56 $/barrel and 98.97 $/barrel over the following two years and suddenly dropped to 52.32 $/barrel in 2015 and 43.67 $/barrel in 2016. Political instabilities in certain countries or regional conflicts such as the Russia-Ukraine conflict, that turned to a flame of war by February 20th, 2014, limiting the world food trade routes and lowered food security around the globe (Ben Hassen & El Bilali, 2022). Russia's economy is most dependent on the energy sector, however, the sharp decline in global oil prices in 2014 brought the price of a barrel of oil down 60% from the $100 band, resulting in a severe dip in 2015. Mănescu & Nuño (2015) analysed the collapse in oil prices in the second half of 2014 and underlined that the sudden drop of the price was mainly because of unexpected supply shocks by the energy industry, which was in agreement with Baffes et al. (2015), who also noted that supply shocks were more responsible than the demand shocks in the decline of brent crude oil prices occurred late 2014. An increasing trend was seen thereafter which averaged around 70 $/barrel in the years of 2018-2019. However, a similar sudden decline was seen again in 2020 during the Covid-19 pandemic crisis, with a hit to its lowest rate of 41.96 $/barrel (Statista, 2023).

Based on earlier investigations evaluated above, fluctuations in crude oil prices are strongly related to commodity prices that affect operational costs through the production stages and consequently increase the prices of goods that is delivered to the consumers. Hence, it is advisable that political instabilities in certain countries especially those with high food supply for the global markets need strong attention to develop rapid solutions immediately in order to hinder any possible food security problems in the world.

The correlation structure between brent crude oil and global aquaculture prices volatility has increased dramatically in the present study, during the main three economic crisis in 2009, 2015, and 2020, which is in line with earlier reports on grain prices as discussed above. The depreciation in the aquaculture sector coincides with the downward trend in brent oil prices observed in 2009, 2015 and 2020. The decrease of aquaculture value during the crises could be explained by the cessation of purchases from Russia, but on the other hand, reduced prices could also be linked to the efforts of melting the stock in hand as a result of high-volume production as a challenge to encourage the sales immediately after the shock wave and closure of borders that was also the case during the lock-downs of Covid-19 pandemic period. The sharp decline in crude oil prices due to the recent Covid-19 pandemic crisis, together with the significant variations in global economies in the last decade, resulted an even more careful evaluation of the effects of crude oil, as an important indicator for food securities (Xu et al., 2020). The slow move of economic recovery after the pandemic can be linked to the nature of the Covid-19 that hit many countries, including emerging countries and developed economies. Despite the strong measures, the spread of the Covid-19 virus affected all sectors and consumers, with slow-down of various production facilities, that eventually reduced the need and consumption of oil, which in turn resulted in an over-supply of crude oil. This was also the case for the global aquaculture production volume, which indeed continued with increasing quantities during the pandemic period from 2019 to 2020. However, the percent increase of price in 2020 over the previous year of 2019 was less than the normal trend in the pre-crisis period of the Covid-19 virus. This again, similar to the case for the over-supply in crude oil, the global aquaculture production led to an over-supply of aquaculture harvest from fish farms, as a result of the lock downs and chain cut of the trade flow due to limited border passages in most countries during the Covid-19 pandemic. This again shows the sensitively close tides of intercontinental trade linkage in the world.

Conclusion

Considering that variations in brent crude oil price influence global aquaculture value during crises, the diversification of the energy consumption in the aquaculture industry could be an important measure for the slow-down of shock waves and volatility spillover from crude oil price into aquaculture values. Both renewable and non-renewable energy sources, like solar energy in hatcheries, and current -or wind energy resources in offshore cage farming systems can be combined for the improvement of food security, that is much dependent on fossil fuels. Further, in the context of policy efforts for reducing foreign dependency on energy sources, the interrelation of brent crude oil price variations and volatility spillover on global aquaculture enterprises need more attention and is encouraged in future investigations.

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.

Funding

Not applicable.

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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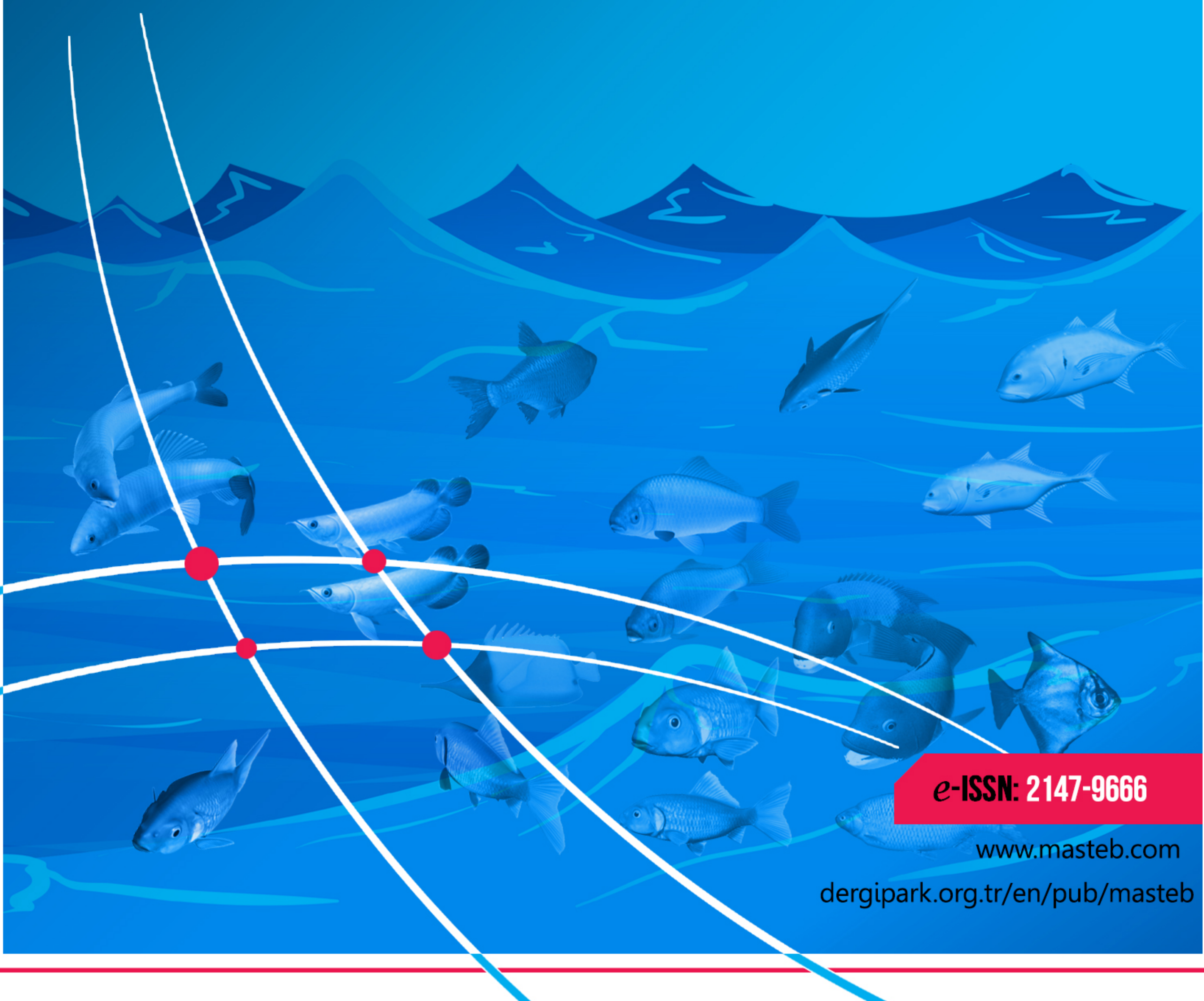

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