MARINE SCIENCE AND TECHNOLOGY BULLETIN

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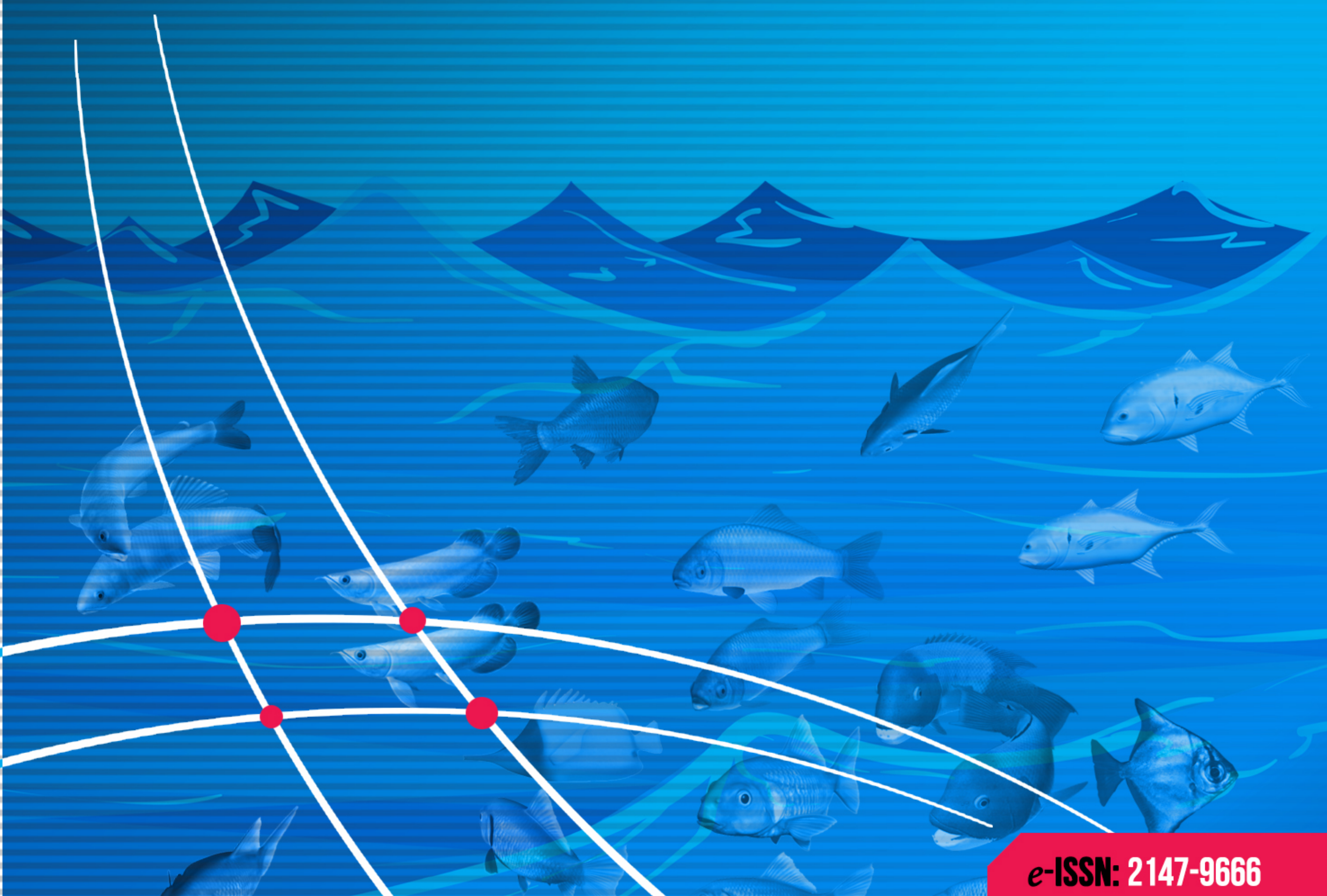

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Original Budapest Open Access Initiative Declaration

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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The views of referees have a decisive place in the publication quality of *Marine Science and Technology Bulletin*.

Marine Science and Technology Bulletin uses the double-blind review method, which means that both the reviewer and author identities are concealed from the reviewers, and vice versa, throughout the review process, in the evaluation process of all studies. For this reason, the authors are asked to erase their names while uploading the articles to the system.

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.

Referee Reports

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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RESEARCH ARTICLE

Comparative analysis of fish consumption habits in coastal and inland districts of Samsun province

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ABSTRACT

This study aimed to investigate the seafood consumption habits of individuals in Samsun Province, a region noted for its intensive fishing activities in the Middle Black Sea, and to determine the differences between coastal and inland districts. Primary data were gathered through online questionnaires. The analysis included descriptive statistics and chi-square tests. Among the participants, 53.7% considered fish prices to be expensive, 34.3% found them to be normal, 10.4% viewed them as very expensive, and 1.5% thought they were cheap. The most preferred fish type was anchovy, chosen by 48% of respondents, followed by sea bass at 18%. Coastal residents showed a higher frequency of weekly fish consumption, while inland residents had a higher rate of annual fish consumption. Significant differences were observed in fish consumption preferences, such as the type of fish and cooking methods, with coastal residents favoring fried fish and inland residents preferring grilled fish. Additionally, the study found that canned fish was significantly more preferred by inland residents (χ^2=55.49, $p<0.0001$). These findings highlight the impact of geographical location on seafood consumption habits and suggest the need for targeted interventions to promote healthier and more sustainable consumption patterns.

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Introduction

Aquatic foods have been a significant part of the human diet since ancient times. In the past, individuals were consumers who lacked knowledge about the nutritional composition of fish. Fish is now recognized as a significant protein source through the analysis of dietary constituents and the comprehension of the impact of nutrients on human well-being. Fish is an excellent source of high-quality proteins and is rich in omega-3 fatty acids. Additionally, it provides various vitamins and minerals, including vitamin D, vitamin B12, iodine, selenium, and zinc (Naeem & Selamoglu, 2023).

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In 2022, global fish production reached over 179 million tons, with 54% of it sourced from captured fishing, according to the FAO. The average per capita fish intake has steadily increased from 9 kg in 1961 to 20.5 kg in 2022, representing an annual growth rate of around 1.5% (FAO, 2022).

A significant portion of the fish caught in Türkiye comes from the Black Sea, accounting for approximately 76% of the country's total fish production. The types of fish caught in the Black Sea include red mullet, hake, anchovy, horse mackerel, whiting, turbot, sea bass, bluefish, haddock, and bonito. This high catch rate makes the Black Sea region the most intensive fishing area in Türkiye (Yücel et al., 2020a).

Samsun, situated in the Middle Black Sea region and the largest city in the area with a population of around 1.3 million, plays a significant role in Türkiye's fishery and aquaculture industries. According to 2023 data from the Samsun Agriculture and Forestry Directorate, 58,579 tons of fishing were conducted at sea, and 210 tons in inland waters. Additionally, 7,926 tons of aquaculture were carried out at sea, and 5,343 tons in inland waters. Production through fishing constitutes 81% of the total production, while production through aquaculture constitutes 18% (Anonymous, 2023; TUIK, 2024).

Türkiye sustains an important amount of fish output since fish is considered one of the most abundant sources of protein. Nevertheless, Türkiye's per capita fish consumption in 2022 has been recorded as 6.1 kg, which remains lower than the worldwide average (TUIK, 2023). The relatively low levels of fish consumption in Türkiye highlight the necessity for measures aimed at boosting fish consumption, while also addressing the underlying causes of this issue. The studies on seafood consumption habits in the Black Sea region are quite limited. This research aims to analyze the seafood consumption patterns of residents in both coastal and inland districts of Samsun Province, an area noted for its intensive fishing activities. The objectives of the research include understanding the priorities in fish consumption, identifying the reasons for non-consumption, determining which types of seafood are most consumed, and revealing the methods of consumption.

Material and Methods

In May 2024, a survey consisting of 26 multiple-choice questions was conducted with 403 randomly selected individuals from the inland districts (Asarcık, Ayvacık, Havza, Kavak, Ladik, Salıpazarı, Vezirköprü) and coastal districts (Alaçam, Atakum, Bafra, Canik, İlkadım, Tekkeköy, Yakakent, Terme) of Samsun province (Figure 1). The population of Samsun province is 1.377 million (Anonymous, 2024), and the number of participants was determined by the following Equation (1) according to proportional sampling (Cochran, 1977):

$$n = \frac{Z^2 \cdot p(1-p)}{E^2} \quad (1)$$

In this equation, n is the required sample size, Z is the value for the confidence level (for 95% confidence level, Z=1.96), p is the estimated probability of the event in the population (for example, 50% probability of fish consumption, so p=0.5 is used), E is the accepted margin of error (0.05 is used).

A higher sample size was preferred because the study covered 15 districts. The survey was conducted through face-to-face interviews or the Google Survey program. The pool can be reached at https://docs.google.com/forms/d/1xc89-p6zqM3MjReo3fxaH5NNeh2zKh66NzYHcumEAeA.

A chi-square test was performed to evaluate the differences in fish consumption preferences and frequencies between coastal and inland districts. The significance levels (p-values) were used to determine whether the observed differences were statistically significant.

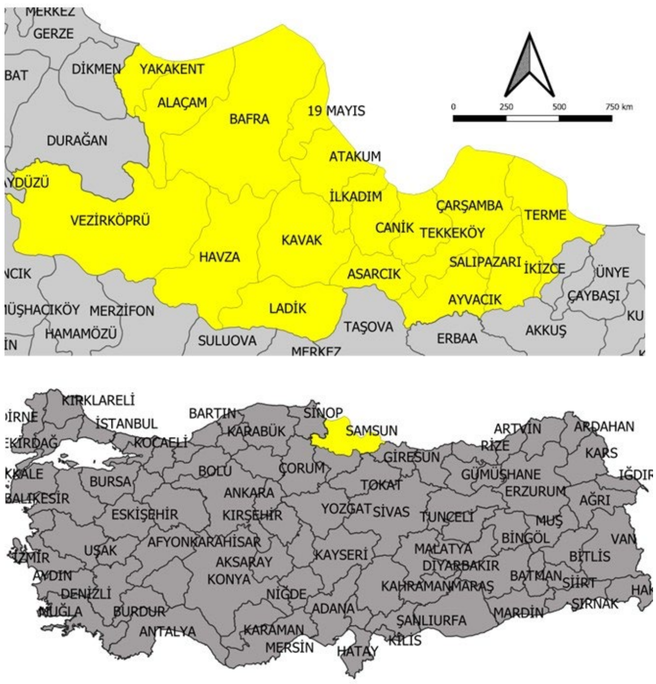

Figure 1. Location of Samsun and its districts

Results and Discussion

Based on the survey results, the distribution of participants in Samsun according to certain socio-economic and demographic characteristics is shown in Table 1. In the Samsun region, 50.9% of the participants were women, and 49.1% were men. The average age of the survey participants was primarily between 50-57 years (22.6%), with 30 and above age group comprising the majority.

Regarding educational background, most of the participants were university graduates (45.7%). When evaluating the profession, the public employee group ranked first (36.5%), followed by the self-employed. Considering income levels, a significant portion of the participants had an income between ₺41,000-50,000 (21.4%), followed closely by those earning ₺50,000 and above (18.7%). In the study conducted on the fish consumption habits of consumers in the Bursa region, 11.99% had postgraduate education, 38.9% had undergraduate education, 28.79% had high school education, and 21.49% had primary education. Additionally, 8.39% of participants had an income of ₺2,500 or less, 9.79% had an income between ₺3,500-4,250, 29.49% had an income between ₺4,250-8,000, 21.49% had an income between ₺8,000-10,000, and 31.19% had an income of over ₺10,000 (Bora Balaban, 2023). The increased monthly income in our study could be related to the high inflation rates, which affect consumers' purchasing power and financial stability.

When examining the individuals who participated in the survey, it was determined that the most preferred meat in the Samsun province is red meat, with a preference rate of 48.4%. Additionally, other preferences were found to be poultry meat at 44.4% and fish meat at 20.2%. Red meat was preferred more in inland areas (49%) than in coastal areas (31%). Poultry meat was more preferred in coastal regions (62%) than inland areas (49%). Fish meat was more commonly preferred in coastal regions (7%) than inland regions (2%) (Table 2). In inland areas, meat consumption is more preferred due to the barbecue culture and taste preferences. In a study conducted by (Yücel et al., 2020a), participants' meat consumption preferences were analyzed, revealing that red meat was preferred by 48%, poultry by 31%, and fish by 21%. Similar studies reported fish consumption rates as 5% in Adıyaman (Olgunoğlu et al., 2014), 25% in Giresun (Türkmen et al., 2016) and 22% in Tunceli (Yüksel et al., 2016) and %74 in Elazığ (Çiçek et al., 2014). Our results show similarities with Yücel et al. (2020a).

Examining the survey participants, it was found that in the Samsun province, 78% of the participants consumed 1-3 kg of fish per month on average, 20% consumed 4-7 kg, 1% consumed 8-10 kg, and 1% consumed 10 kg or more. In a comparison of coastal and inland regions, 79% of coastal participants and 83% of inland participants reported consuming 1-3 kg of fish per month, while 20% of coastal participants and 16% of inland participants consumed 4-7 kg. Only 1% of rural people consumed 8-10 kg, whereas 1% of coastal participants consumed 10 kg or more.

Table 1. Distribution of participants in Samsun based on socio-economic and demographic characteristics

Gender	**Women**	**Men**					
Total (%)	50.9	49.1					
Number of People	205	198					
Age	**18-25**	**26-33**	**34-41**	**42-49**	**50-57**	**58-64**	**65 and above**
Total (%)	16.3	13.1	15.6	19.3	22.6	11.4	1.7
Number of People	66	53	63	78	91	46	7
Education Level	**Primary School**	**Middle School**	**High School**	**University**	**Postgraduate**		
Total (%)	4.7	6.9	29.1	45.7	13.6		
Number of People	19	28	117	184	55		
Profession	**Public Employee**	**Private Sector**	**Self-Employed**	**Retired**	**Student**	**Housewife**	**Unemployed**
Total (%)	36.5	11.6	13.6	10.1	13.6	12.6	2.0
Number of People	147	47	55	41	55	51	8
Monthly Income (₺)	**5000-10000**	**11000-20000**	**21000-30000**	**31000-40000**	**41000-50000**	**Above 50000**	
Total (%)	8.3	14.2	21.1	16.3	21.4	18.7	
Number of People	33	57	85	66	86	75	

Table 2. Food preferences and consumption patterns between coastal and inland districts of Samsun

	Category	Coastal Districts (Counts)	Inland Districts (Counts)	Chi-Square (χ^2)	p-value
Most Preferred Meat Type	Red meat	62	99	8.18	0.0042
	Poultry	125	99	3.02	0.0822
	Fish	14	4	11.41	0.0007
	Total	201	202	22.61	0.0004
Monthly Fish Consumption Amount (Monthly)	1-3 kg	159	168	0.20	0.6507
	4-7 kg	40	32	0.93	0.3351
	8-10 kg	0	2	1.99	0.1583
	10+ kg	2	0	2.01	0.1563
	Total	201	202	5.13	0.1622
Fish Consumption Frequency	Once a week	47	6	31.92	< 0.0001
	Once a month	62	73	0.84	0.359
	Twice a month	46	48	0.03	0.855
	Once a year	8	50	30.21	< 0.0001
	Several times a year	24	22	0.10	0.755
	Do not consume fish	14	3	7.17	0.007
	Total	201	202	70.27	< 0.0001
Most Preferred Fish type	Seawater fish	163	115	8.0	0.0047
	Freshwater fish	16	85	47.6	< 0.0001
	Farmed fish	22	2	18.4	< 0.0001
	Total	201	202	74.0	<0.0001
Most Preferred Processed Fish Quality	Canned fish	62	178	55.49	< 0.0001
	Fish finger	7	0	7.03	0.00799
	Smoked fish	20	8	5.20	0.02255
	Marinated fish	7	0	7.03	0.00799
	Frozen fillet	14	0	14.06	0.000176
	None	91	16	52.94	< 0.0001
	Total	201	202	141.77	< 0.0001

The pool showed no significant differences in monthly fish consumption frequencies between coastal and inland districts for any specified ranges (1-3 kg, 4-7 kg, 8-10 kg, 10+ kg). The overall chi-square test also indicated that no significant difference was observed in the distribution of fish consumption frequencies between the two groups. This suggests that fish consumption patterns, in terms of quantity consumed monthly, are relatively similar across coastal and inland districts (Table 2).

Upon analyzing the survey participants, it was found that in the Samsun province, the most common frequency of consumption was once a month, accounting for 31.3% of the respondents, while the least common frequency was twice a week, representing just 0.5% of the participants. The analysis revealed highly significant differences in fish consumption frequencies between coastal and inland residents. Coastal residents consumed fish once a week significantly more frequently than inland residents. Conversely, inland residents consumed fish once a year at a significantly higher rate than coastal residents. Additionally, there was a significant difference in the number of individuals who did not like fish, with a higher percentage of coastal residents indicating a dislike for fish than inland residents (Table 2).

According to a survey study conducted in Uşak on fish consumption preferences, when the fish consumption frequency of the participants was investigated, it was found that 38.19% of consumers consumed fish once a week, 26.49% every fifteen days, 22.39% once a month, 11.39% more than once a week, and 1.29% did not consume fish at all (Kuşat & Şahan, 2021). A study by Karakaya & Kırıcı (2019) in Bingöl revealed that 18.5% of participants consumed fish weekly, while 35.1% ate fish every 15 days. Additionally, 33.2% of participants consumed fish once a month, and 13.2% reserved fish consumption for special occasions. In a survey conducted among 250 participants from Kırklareli, 52% indicated that they ate fish 1-2 times per month, 25% consumed it 3-5 times, 21% had fish 5 or more times, and 2% mentioned that they did not eat fish at all (Tozakçı & Bulut, 2021).

A comparison of fish consumption between the landlocked city of Ankara and the coastal city of Çanakkale was conducted. The chi-square test yielded a chi-square value of 3.21 with a p-value of 0.36, indicating no statistically significant difference in fish consumption frequency between Ankara and Çanakkale which is similar to our result (Bayraktar et al., 2019).

An examination of the survey participants revealed that in Samsun, the most consumed type of fish was saltwater fish (80%), followed by freshwater fish (15%) and farmed fish (5%). A significant preference for seawater fish among coastal district residents was observed compared to inland district residents (χ^2=8.0, p=0.0047). Inland district residents demonstrated a highly significant preference for freshwater fish compared to coastal district residents (χ^2=47.6, p<0.0001). Coastal district residents showed a significantly higher preference for farmed fish than inland district residents (χ^2=18.4, p<0.0001). The chi-square test revealed a highly significant difference in fish type preferences between coastal and inland districts (χ^2=74.0, p<0.0001) (Table 2). This indicated that the type of fish preferred varied greatly depending on whether the district was coastal or inland, highlighting the impact of geographical location on fish consumption patterns. In a study conducted in the Bursa region, when consumers were asked, "What type of fish do you prefer the most?", 62.2% of the consumers stated that they prefer sea fish, 13.7% stated that they prefer freshwater fish, and 24.2% stated that they consume both types of fish (Bora Balaban, 2023). In a study by Çadır & Duman (2013) performed in seven villages along the Keban Dam Lake, it was found that 80.59% of the consumers preferred freshwater fish, 3.69% preferred marine fish, and 15.8% consumed both. Another study in Elazığ revealed that 33% of consumers preferred freshwater fish, 16% preferred marine fish, and 44% consumed both types (Şen et al., 2008). In a study carried out in Sinop, it was found that nearly all participants consumed fish fresh, with 90% preferring saltwater fish and 48% specifically choosing anchovy (Yücel et al., 2020a). Inland residents tended to prefer freshwater fish due to their proximity to rivers or lakes, a pattern that aligned with our findings.

Among the survey participants in all the districts in Samsun, it was found that the most consumed processed seafood product was canned fish at 58.5%. This was followed by frozen fillet at 11.7%, marinated fish at 8.4%, fish fingers (breaded fish) at 3.1%, and smoked fish at 1.7%. Additionally, 16.7% of the participants reported not consuming any of these products. The pool revealed significant differences in processed fish quality preferences between coastal and inland districts. Canned fish was significantly less preferred by coastal district residents compared to inland district residents (χ^2=55.49, p<0.0001), while fish fingers were significantly more preferred. Smoked fish (χ^2=5.20, p=0.02255), marinated fish (χ^2=7.03, p=0.00799), and frozen fillet (χ^2=14.06, p=0.000176) were also significantly more preferred in coastal districts. Conversely, none of the processed fish options was significantly less preferred by coastal district residents compared to inland district residents (χ^2=52.94, p<0.0001) (Table 2). In a study made in Yozgat, it was found that 97.79% of consumers prefer to eat fish fresh, 1.39% consume it frozen, and 1.9% eat it canned (Erdoğan Sağlam et al., 2018). Meanwhile, a study in Burdur revealed that 99.29% of consumers prefer fresh fish, 11.39% consume canned fish, 9.49% eat frozen fish, and 0.89% prefer smoked fish (Orhan & Yüksel, 2010). In a study conducted in Isparta, it was found that individuals show different preferences for the form of fish they consume as food, choosing between fresh, frozen, salted, and canned fish (Gençler, 2024). According to the results, 70.00% of individuals prefer fresh fish, 18.60% opt for frozen fish, 7.70% choose canned fish, and 3.70% select salted fish. In Türkiye, approximately 70% of fish is consumed fresh. Globally, the consumption methods of seafood for human consumption are distributed as follows: 39.8% is consumed fresh, 19% is frozen or preserved, 7.1% is salted, and 8.29% is canned (Anonymous, 2002).

Among the survey participants in Samsun, anchovy was identified as the most consumed marine fish at 46.3%. This was followed by whiting at 23.3%, salmon at 10%, red mullet at 7.2%, bluefish at 4.2%, bonito at 3%, horse mackerel at 2%, and both bluefish and mullet at 1.5%. Sea bass was the least consumed at 1%.

The analysis of saltwater fish preferences between coastal and inland districts revealed significant differences for most of the fish types (Table 3) Coastal district residents showed a significant preference for anchovy (χ^2=25.66, p<0.0001), whiting (χ^2=7.22, p=0.0072), salmon (χ^2=20.01, p<0.0001), red mullet (χ^2=6.60, p=0.0102), bonito (χ^2=10.09, p=0.0015), horse mackerel (χ^2=9.22, p=0.0024), and sea bass (χ^2=12.05, p=0.0005) compared to inland district residents. Conversely, there were no significant differences for bluefish (χ^2=0.67, p=0.4107), mullet (χ^2=1.31, p=0.2518), and bluefish (small) (χ^2=0.00, p=0.9944).

In a study conducted in Bursa, when consumers were asked "Which fish do you consume the most?", the majority (39.4%) responded with anchovy. Sağlam & Samsun (2018) reported that the most preferred fish species for consumption was anchovy in Yozgat, with 94% of consumers favoring it. Siirt, located in the Southeastern Anatolia region, reported anchovy as the most consumed fish at 42.1%, consistent with our findings that anchovy is the most preferred fish across Türkiye, regardless of region (Karakaya et al., 2018). Saka & Bulut (2020) reported that Atlantic bonito (65%, 686 individuals) was the most consumed fish species, with Atlantic bonito being the second most consumed fish after anchovy in Çanakkale, while Tozakçı & Bulut (2021) determined that bonito was the most preferred fish species, followed by bluefish as the second most preferred. Anchovy is widely recognized as the most consumed fish in Türkiye, which corresponds with its status as the most frequently caught fish in the country. This high consumption rate is likely due to its abundant availability, cost-effectiveness, and cultural preference for dishes made with anchovy. The significant presence of anchovy in the Turkish diet underscores its crucial role in local fisheries and its importance in fulfilling the nutritional requirements of the population.

Among the survey participants in Samsun, it was found that the most consumed freshwater fish is trout at 77%. The other types of freshwater fish consumed are carp at 10%, catfish at 5.2%, mullet at 4.7%, silverfish at 1.7%, and pike at 1.2%.

Freshwater fish preferences varied significantly between coastal and inland districts for several fish types. Coastal residents showed a significant preference for gray mullet (χ^2=12.46, p=0.0004) and silverside (χ^2=12.80, p=0.0003). Additionally, catfish showed a significant difference (χ^2=6.00, p=0.0143). No significant differences were found for trout (χ^2=0.88, p=0.3482), carp (χ^2=3.00, p=0.0833), and pike (χ^2=0.00, p=1.0000) (Table 3). In the Süleymanpaşa district of Tekirdağ, trout emerged as the most consumed freshwater fish, accounting for 46.78% of the total consumption (Abdikoğlu et al., 2015). In a study conducted in Kayseri, 28.2% of consumers stated that they prefer trout, 15.5% prefer Norwegian salmon, 15.1% prefer sea bass, 9.8% prefer gilthead seabream, and 6.2% prefer horse mackerel (Sarıözkan & Deniz, 2020). The preference for rainbow trout can be attributed to its availability and affordability, making it a convenient and cost-effective option for consumers. Similarly, the preference for catfish can be linked to its prevalence in inland areas with rivers, where it is commonly caught.

Among the survey participants in Samsun, it was found that the most common place to purchase fish was from a fishmonger, accounting for 54.1%. Other places include marketplaces (18%), supermarkets (12%), fish markets (8.5%), and street vendors (4.2%). Additionally, 3.2% of the participants reported that they prefer to catch the fish themselves.

Table 3. Comparative analysis of most preferred fish and shellfish species between coastal and inland districts

	Category	Coastal Districts (Counts)	Inland Districts (Counts)	Chi-Square (χ^2)	p-value
Most Preferred Saltwater Fish	Anchovy	43	105	25.66	< 0.0001
	Whiting	30	55	7.22	0.0072
	Salmon	30	4	20.01	< 0.0001
	Red mullet	22	8	6.60	0.0102
	Bonito	30	10	10.09	0.0015
	Horse mackerel	22	6	9.22	0.0024
	Bluefish	4	2	0.67	0.4107
	Mullet	4	8	1.31	0.2518
	Sea bass	12	0	12.05	0.0005
	Bluefish	4	4	0	0.9944
	Total	201	202	92.88	< 0.0001
Most Preferred Freshwater Fish	Trout	139	156	0.88	0.3482
	Carp	18	30	3.00	0.0833
	Catfish	0	6	6.00	0.0143
	Gray mullet	22	4	12.46	0.0004
	Silverside	18	2	12.80	0.0003
	Pike	4	4	0	1.0000
	Total	201	202	35.14	< 0.0001

Table 4. Comparative analysis of fish purchase places, cooking methods, consumption locations, and seasonal preferences between coastal and inland districts

	Category	Coastal Districts (Counts)	Inland Districts (Counts)	Chi-Square (χ²)	p-value
Fish Purchase Place	Fishmonger	87	121	5.39	0.0202
	Market place	26	57	11.42	0.0007
	Fish market	38	6	23.43	< 0.0001
	Supermarket	42	4	31.58	< 0.0001
	Street vendor	4	2	0.67	0.4107
	Self-caught	4	12	3.96	0.0466
	Total	201	202	76.46	< 0.0001
Cooking Method	Baked	64	60	0.14	0.6989
	Grilled	18	74	33.80	< 0.0001
	Fried	80	34	18.79	< 0.0001
	Steamed	22	2	16.76	< 0.0001
	Electric grill	12	2	7.19	0.0073
	Air fryer	5	30	17.73	< 0.0001
	Total	201	202	94.44	< 0.0001
Fish Consumption Places	At home	129	91	6.75	0.094
	Bought as cooked	26	34	1.02	0.3108
	Picnic	12	73	43.47	< 0.0001
	Restaurant	34	4	23.83	< 0.0001
	Total	201	202	75.08	< 0.0001
Fish Consumption Season	Winter	141	155	0.59	0.4407
	Autumn	53	34	4.24	0.0394
	Spring	4	9	1.89	
	Summer	3	4	0.13	0.7103
	Total	201	202	6.87	0.0760
Fish Price	Very expensive	12	8	0.82	0.3652
	Expensive	121	91	4.40	0.0360
	Normal	56	101	12.68	0.0004
	Cheap	12	2	7.19	0.073
	Total	201	202	25.08	< 0.0001

The analysis of fish purchase places between coastal and inland districts implied significant differences for several categories. Residents in coastal districts showed a strong preference for buying fish from supermarkets (χ^2=31.58, p<0.0001), fish markets (χ^2=23.43, p<0.0001), and marketplaces (χ^2=11.42, p=0.0007). The preference for fishmongers was notably higher in coastal regions (χ^2=5.39, p=0.0202) (Table 4). There was a notable preference for catching fish oneself in inland regions compared to coastal districts (χ^2=3.96, p=0.0466). This may be attributed to the relative ease of fishing in lakes and rivers, which is common in Samsun.

In another study, when evaluating the responses of survey participants regarding their sources of seafood, it was found that in Ordu, 32.6% preferred fish markets, while in Samsun, 20.4% did. Conversely, 21.4% of participants in Ordu and 34.9% in Samsun preferred fishmongers (Güvenin & Sağlam, 2020). Bolat & Cevher (2018) reported that 53% preferred fish markets, (Temel & Uzundumlu, 2015) found 80% preferred fish markets. The preference for fishmongers in Samsun and its districts may be attributed to the ease of access and lower prices.

Among the survey participants in Samsun, it was found that when cooking fish, 31% use an oven, 26% use a grill, 25% fry it, 11% use an air fryer, 4% steam it, and 3% use an electric grill.

Significant differences were determined in cooking methods between coastal and inland districts. Coastal residents significantly preferred frying, steaming, and using an electric grill. In contrast, inland residents favored grilling and using an air fryer. In many previous studies, it has been found that frying is the preferred method for cooking fish (Orhan & Yüksel, 2010; Aydın & Karadurmuş, 2013; Olgunoğlu et al., 2014; Baydede, 2018; Sivri, 2018). In Samsun, cooking fish in the oven was the most preferred method. Additionally, the newer method of using an air fryer has started gaining popularity due to its time efficiency and the need for less oil.

Analyzing the survey participants from the Samsun region, it was observed that 51% of them eat fish at home, 26% during picnics, 16% have it cooked outside but eat it at home, and 7% consume it in restaurants. The analysis of fish consumption between coastal and inland districts revealed significant differences in several locations. Coastal residents significantly preferred consuming fish at home (χ^2=6.75, p=0.0094) and in restaurants (χ^2=23.83, p<0.0001), while inland residents significantly preferred consuming fish at picnics (χ^2=43.47, p<0.0001). No significant difference was observed for buying fish as cooked (χ^2=1.02, p=0.3108) (Table 4).

In a study conducted in Bursa, consumers were asked where they prefer to eat fish. It was found that 63.9% prefer to eat fish at home. Additionally, 23.6% of respondents indicated a preference for eating fish at fish restaurants, while 13.4% preferred to eat it outdoors (Bora Balaban, 2023). In their study carried out in Erzurum and Van (Güngör & Ceyhun, 2017) found that frying was the most preferred cooking method. Other studies on fish consumption methods also found that frying was generally preferred (Aydın & Karadurmuş, 2013; Çadır & Duman, 2013). Yüksel et al. (2016) concluded that baking (42%) was slightly more preferred than frying (37%) in Tunceli. The decline in dining out in our study can likely be attributed to recent economic challenges, leading people to prefer eating at home.

Examining the survey participants, it was found that in the Samsun province, 87% of the participants consume fish in winter, 11% in autumn, 1% in spring, and 1% in summer. The analysis of fish consumption seasons between coastal and inland districts reveals significant differences for some seasons. Inland residents significantly preferred consuming fish in autumn (χ^2=4.24, p=0.0394). No significant differences were found for winter (χ^2=0.59, p=0.4407), spring (χ^2=1.89, p=0.1692), and summer (χ^2=0.13, p=0.7103) (Table 4).

Although the income levels in our study were not particularly low, most participants perceived fish prices as high (Table 1). Specifically, 53.7% of participants considered fish as expensive, 10.4% believed prices were very expensive, and only 1.5% thought the prices were cheap. This indicates that even with relatively moderate to high-income levels, there is a general perception that fish prices are high in Samsun. The analysis of fish price perceptions between coastal and inland areas reveals several significant differences. Coastal residents are significantly more likely to perceive fish as being "expensive" and "cheap" compared to inland residents. The perception of fish prices as "normal" is also significantly different, with inland residents more likely to view fish prices as normal.

These findings suggest that geographical location influences how residents perceive fish prices, possibly due to factors such as availability, transportation costs, and local market dynamics. The significant difference in the "cheap" category might indicate that coastal residents have better access to fresh fish at lower prices, while inland residents may face higher prices due to transportation and limited supply. The overall highly significant difference (p=0.000015) underscores the impact of these geographical factors on consumer perceptions of fish prices.

The "Very expensive" category, however, does not show a significant difference, indicating that the perception of fish being very expensive is relatively consistent between the two areas. This might suggest that both coastal and inland residents experience similar pricing for high-end fish products.

In a study conducted in Uşak in 2021, 42.2% of the survey participants found fish prices to be normal, 29.5% considered them expensive, 12.3% thought they were cheap, and 16% had no opinion (Kuşat & Şahan, 2021) In Malatya, 29% of the respondents stated that fish prices are reasonable, 18% considered them expensive, and only a small fraction, 2%, thought they were cheap (Yücel et al., 2020b). Kızılaslan & Nalinci (2013) found that among consumers residing in the central district of Amasya, 60.61% considered fish prices to be normal, while 30.91% found them to be expensive. In our results, the higher percentage of respondents considering fish prices to be expensive is attributed to the changes in economic conditions and persistent inflation in recent years.

Conclusion

This study provides a comprehensive analysis of fish consumption habits in both coastal and inland districts of Samsun province, revealing significant differences in consumption patterns, preferences, and socio-economic factors. Coastal residents exhibit higher fish consumption frequencies, particularly for saltwater fish, and show a preference for processed seafood products. In contrast, inland residents prefer freshwater fish and consume fish less frequently.

Among the 403 survey participants in Samsun, it was determined that 78% consume an average of 1-3 kg of fish per month, 20% consume 4-7 kg, 1% consume 8-10 kg, and 1% consume over 10 kg. Considering the 5-month fishing ban season, the average annual fish consumption in Samsun is about 19.96 kg per person. This value is significantly higher compared to the national average of 6.22 kg per person per year, as reported by the Turkish Statistical Institute (TUIK, 2020) in 2020, but lower than the European average of 24 kg per person annually (EUMOFA, 2024). Most of the consumed products were fresh fish, indicating that fish is predominantly eaten during specific seasons. However, to encourage fish consumption throughout the entire year, there is a need to further promote and support processed fish products.

The study highlights the need to increase knowledge about the nutritional advantages of fish and make educational efforts to promote increased consuming of fish. Studies performed at a regional level, such as this one, provide useful insights that may inform policies and activities focused on promoting higher fish consumption and enhancing public health.

To promote fish consumption, it is crucial to engage families, educational institutions, public organizations, and non-governmental organizations in accomplishing public awareness initiatives. Enhancing the availability of diverse, reasonably priced seafood and promoting local fishing and fish farming will play a crucial role in boosting fish consumption and attaining improved health outcomes within the community.

Compliance With Ethical Standards

Conflict of Interest

The authors declare that there is no conflict of interest.

Ethical Approval

This study was approved by the Social and Human Sciences Ethics Committee of Ordu University (Ethics approval number: 2024-139, Date: 30/09/2024).

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Data Availability

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

Hydrodynamic performance improvement of a tirhandil yacht by Stern form modifications

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ABSTRACT

This paper presents a comprehensive investigation to improve the hydrodynamic performance of a Tirhandil hull form by modification efforts on the stern region. The form improvement approach combines computational fluid dynamics (CFD) methods with computer-aided design (CAD) systems. The design process for the reference and modified models was carried out by using CAD systems. The hydrodynamic characteristics of the reference hull form were evaluated by employing CFD methods and it was determined that form improvements should be concentrated on the stern region. The modification process was conducted by considering constraints on the design variables in the stern region and the main dimensions of the reference model. A grid independence study was performed to evaluate various grid structures to determine the optimal mesh configuration for the numerical analyses. The SST k-Omega turbulence model was used for the numerical analyses to simulate turbulence structure around the hull form. Achieving around a 13.4% reduction in the total resistance coefficient, the modified model also exhibited decreased wave amplitudes, smoother wave transitions, and a significant reduction or cancellation of shoulder and stern waves.

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Introduction

Yachts have long held a significant place in maritime culture, offering not only cultural and economic value but also substantial touristic benefits. Their influence on local economies is substantial, particularly in industries such as tourism, boat building, and marine services, where they generate income and employment. Beyond their cultural and economic impact, yachts contribute meaningfully to environmental sustainability efforts within the maritime sector. In recent years, the focus on improving yacht designs has gained momentum, driven by the need for both economic efficiency and environmental protection. These modifications are essential, as they enhance hydrodynamic performance, resulting in reduced fuel consumption and lower emissions.

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This is particularly important given the rising global demand for greener shipping practices, which seek to balance operational cost savings with environmental responsibility. Therefore, modifying yacht designs plays a crucial role in meeting both economic and environmental goals, helping the industry adapt to the challenges of sustainable development more efficiently.

Tirhandil yachts, an important part of our maritime culture, hold significant potential for form improvement efforts with their traditional and unique designs. Tirhandils, known for their rich historical backgrounds and aesthetic forms, are widely used in the Aegean and Mediterranean regions. As one of the oldest boat forms originating from the Aegean, Tirhandils are distinguished by their symmetrical bow and stern design. Tirhandils have found broad applications in the fishing and sponge diving industries of Greece, Italy, and Turkey (Ozen, 2017). The term 'Tirhandil', derived from the Greek word 'trea-kena', meaning 'one-third', emphasizes that these boats have a one-third width-to-length ratio (Koyagasioglu, 2014). Tirhandil boats, with historical roots dating back to ancient times including the Phoenicians, have documented records from as early as 1658 by G. D. Kriezis (Koyagasioglu, 2014; Gür, 2020). According to historian Dentes, the first Tirhandil boats were constructed in the 17th century on the island of Hydra. Used historically for fishing, transportation, and military purposes, 20 Tirhandil boats were part of the Ottoman Navy in 1790 (Gencer, 2001). Production of Tirhandil boats began in Bodrum in the 1950s and by the 1960s, they had also found their place in the waters of Istanbul (Mahmuzlu, 2019). Today, they are also used for private and tourism purposes along the Aegean and Mediterranean coasts. The literature review reveals limited studies on Tirhandils, primarily using semi-empirical methods, and lacking any research focused on form improvements through CFD analyses. When the literature is reviewed, it becomes evident that there are limited studies on Tirhandils, mostly conducted using semi-empirical methods, and no studies have been found that involve form improvements using CFD analyses. Ganos & Loukakis (1986) conducted model tests on Tirhandil-type boat hulls. A limited number of models were used, and the resistance characteristics of Tirhandil boats were examined. Damianidis (1989) studied the production history and main features of various boat types within Greece, including Tirhandils. Turan & Akman (2021) developed parametric models to analyze the hull form characteristics of Bodrum Gulets with round and transom sterns, comparing their hydrostatic and resistance performances. Turan et al. (2021) analyzed the forms of Gulet and Tirhandil boats, presenting their hydrostatic and hydrodynamic characteristics. Turan (2022) compared the hull forms of Tirhandil and Piyade boats, highlighting their performance differences in terms of resistance and deck space utilization. Turan (2023) introduced a parametric design framework for trawler-type motor yachts, providing resistance estimation values using only the LOA in the early stages of the design process. Turan et al. (2024) proposed a conceptual design framework for Tirhandil yachts, focusing on hull form, resistance, and sailing performance.

The modification of hull forms holds the promise of enhancing the flow structures around the yachts and improving resistance characteristics. Traditionally, such modifications were tested using physical models in towing tanks, but with advances in computer technology and Computational Fluid Dynamics (CFD) methods, these processes can now be simulated with greater efficiency and accuracy. However, simulations conducted in the field of form improvement using CFD methods also involve certain challenges, such as the prediction of complex turbulent structures around the form, computational load, accurate boundary condition representation, grid sensitivity, and the coupling of multiple physical phenomena like fluid-structure interaction. Especially the bow and stern regions of the hull present specific challenges due to their high-pressure fluctuations, large wave amplitudes, and higher resistance values. These regions are often the focus of modifications, as they can greatly influence the overall performance of the yacht. Improving the flow and reducing resistance in these regions is essential for enhancing both fuel efficiency and operational performance.

The modification studies of aft hull forms have gained increasing attention in recent years due to the significant impact that the stern shape has on a yacht's hydrodynamic performance. Improvements to the stern region can reduce resistance, improve fuel efficiency, and enhance overall boat performance. Several studies in this area have focused on improving the stern forms using various methods and approaches to achieve better results in terms of hydrodynamic characteristics. Küкner & Mamur (2016) conducted a study exploring the effects of various bow and stern form combinations on vessel resistance, generating 252 different boat models for analysis. Their results showed that the plumb bow form, combined with other optimized stern forms, exhibited the lowest resistance, primarily due to the longer waterline length and improved water separation. Ali & Ali (2016) proposed a novel stern shape concept using radial crenellated-corrugated sections and reverse piezoelectric effects to reduce total forward resistance. Their study demonstrated that this new stern design significantly reduced propeller cavitation, improving overall vessel performance. Song et al. (2018) assessed the impact of stern flaps and interceptors on the drag resistance, trim, and sinkage of a high-speed deep-vee ship using experimental and CFD methods. Results showed that both devices reduced drag resistance, with interceptors performing better at higher speeds and stern flaps at lower speeds, achieving drag reductions of 3–9%. Various studies have also explored the effects of different stern configurations and appendages on total vessel resistance and hydrodynamic performance, yielding significant improvements in resistance reduction and overall performance (Maki et al., 2016; Mansoori & Fernandes, 2016, 2017; Deng et al., 2020; Lena et al., 2021; Song et al., 2024). Duy & Hino (2015) focused on optimizing the transom stern shape to minimize the pressure resistance coefficient using a CFD solver based on the Reynolds-Averaged Navier-Stokes equations. Reductions in pressure resistance of approximately 5–6% were observed, with total resistance reductions of 1.9–2.3%, depending on the test case. Marcu & Robe-Voinea (2024) investigated the stern flow hydrodynamics around a manoeuvring ship by using CFD techniques. Their findings revealed that stern vortices and turbulent flow patterns significantly affect the propeller inflow and contribute to increased ship resistance. Lu et al. (2019) proposed a methodology for the synchronous optimization of bow and stern hull forms across the entire speed range of the KRISO Container Ship (KCS). An average drag reduction of over 4.0% was achieved across various speeds, with the best performance at mid-range Froude numbers. Anggriani & Baso (2020) investigated the performance of a ship by optimizing the stern hull form to match the propeller diameter and engine power for high-speed operations. It was observed that the U-shape stern outperformed the V-shape stern, with reduced total resistance and lower power requirements at a Froude number of approximately 0.22. Mutsuda et al. (2013) conducted a numerical investigation using Computational Fluid Dynamics (CFD) and Particle Image Velocimetry (PIV) to examine the effects of stern part modifications on reducing drag resistance in fishing boats. The study revealed that the optimized designs reduced water resistance by 15–20% compared to the original form, primarily by controlling separated flow and vortex formation around the stern. Baso et al. (2019) examined the effects of stern part improvements on the heave and pitch motions of a fishing boat using a hybrid scheme of Eulerian grid-Lagrangian particles. Stern modifications resulted in a 5% to 10% rise in heave amplitude and a 5% to 9% rise in pitch amplitude, with a more significant impact on heave motion, highlighting the method's effectiveness for preliminary ship design. Several researchers also worked on reducing resistance in the stern part of fishing boats, including studies by Masuya (2007), Karafiath (2012), and Suastika et al. (2017). Solak (2020) focused on optimizing the stern form using a Kriging-based high-fidelity method combined with genetic algorithms to minimize viscous pressure drag. This approach resulted in at least a 5% reduction in viscous pressure drag, improving the hydrodynamic performance of the vessel.

In this study, form modifications were performed, focusing on the stern region to improve the hydrodynamic performance of a Tirhandil hull form. The reference model and modified model were designed using CAD systems. The hydrodynamic characteristics of the reference Tirhandil model were determined through flow simulations using Computational Fluid Dynamics (CFD) methods. Based on the hydrodynamic characteristics of the reference form, it was determined that form improvement efforts should be concentrated on the stern region of the hull form. The modification process was carried out by considering the constraints applied to the design variables defined in the stern region. Additionally, constraints related to the main dimensions of the reference model were also considered in the form improvements. A grid independence study was performed using various grid structures to determine the optimal mesh configuration for the numerical analyses. The SST k-Omega turbulence model was used to simulate the turbulence around the hull form in the numerical analyses. The hydrodynamic characteristics of the reference and modified models were comparatively investigated. The modified model achieved approximately a 13.4% reduction in the total resistance coefficient, featuring reduced wave amplitudes, smoother wave transitions, and a significant reduction or cancellation of shoulder and stern waves. A review of the literature reveals that no previous work has offered such a hydrodynamic performance improvement study on the stern region for Tirhandil yachts. Through the modification process, a unique Tirhandil design with improved hull form characteristics was developed. This research also provides a framework that can guide form optimization studies for sailing yachts.

Material and Methods

Governing Equations

The evaluation of flow patterns in this study is based on the governing Navier-Stokes and continuity equations. The continuity and momentum equations in Cartesian coordinates are formulated as:

$$\frac{\partial \rho}{\partial t} + \frac{\partial (\rho u_i)}{\partial x_i} = 0 \tag{1}$$

$$\rho\left(\frac{\partial u_i}{\partial t} + u_j \frac{\partial u_i}{\partial x_j}\right) = -\frac{\partial P}{\partial x_i} + \mu \frac{\partial^2 u_i}{\partial x_j^2} + f_i \tag{2}$$

In these equations, ρ signifies fluid density, u_i indicates velocity components, P stands for the pressure field, μ is the dynamic viscosity, and f_i represents external forces.

Flow structures and turbulence distribution are modelled using the RANS-based SST k–Omega model (Menter, 1994). The methods of Reynolds averaging and filtering are commonly applied to convert the Navier-Stokes equations into a resolvable form, preventing the direct modelling of smaller turbulent scales. Reynolds averaging divides a flow variable into a mean value, $\bar{\theta}(x,t)$, and a fluctuating component, $\theta'(x,t)$.

$$\theta(x,t) = \bar{\theta}(x,t) + \theta'(x,t) \quad (3)$$

Equation 4 shows the RANS equations derived from the incompressible Navier-Stokes equations.

$$\frac{\partial}{\partial t}(\rho\overline{u_i}) + \frac{\partial}{\partial x_j}(\rho\overline{u_i u_j}) = -\frac{\partial\bar{p}}{\partial x_i} + \frac{\partial}{\partial x_j}\left[\mu\left(\frac{\partial\overline{u_i}}{\partial x_j} + \frac{\partial\overline{u_j}}{\partial x_i}\right)\right] + \frac{\partial R_{ij}}{\partial x_j} \quad (4)$$

In this equation, $\bar{u}_i$ and $\bar{u}_j$ refer to the Reynolds-averaged velocity, and $\bar{p}$ represents the Reynolds-averaged pressure field. The Navier-Stokes and RANS equations differ primarily due to the presence of the Reynolds stress tensor (Equation 5), introduced by the Boussinesq hypothesis (Boussinesq, 1877).

$$R_{ij} = -\rho\overline{u_i u_j} = \mu_t\left(\frac{\partial\overline{u_i}}{\partial x_j} + \frac{\partial\overline{u_j}}{\partial x_i}\right) - \frac{2}{3}k\delta_{ij} \quad (5)$$

RANS-based turbulence models calculate eddy (turbulent) viscosity, μ_t, using different approaches. The SST k-Omega model (Wilcox, 1988) employs a blending function that combines a k-Omega model near the wall with a k-Epsilon model in the outer flow region. This model also incorporates an innovative approach to eddy viscosity, which accounts for the transport of the primary turbulent shear stress. The k-omega model calculates turbulent viscosity based on turbulent kinetic energy (k) and the specific dissipation rate (ω) (Equation 6).

$$\mu_t = \alpha^* \frac{\rho k}{\omega} \quad (6)$$

Numerical Setup

This part outlines the numerical setup employed in the simulations. The flow around the ship hull was modelled using numerical solutions of the continuity and Navier-Stokes equations. The URANS solver was applied, with the finite volume method used to discretize the Navier-Stokes equations. The simulation of turbulent flow structures was achieved using the SST k-Omega model in CFD analyses. Each momentum equation was solved sequentially in the numerical simulations using a segregated flow solver. The solver integrates an algebraic multigrid approach for efficient computation. For spatial discretization of the convection and diffusion terms, a second-order upwind scheme was applied in the governing equations. The discretization of temporal terms in the governing equations was achieved through a first-order unsteady implicit method. ITTC's guidelines (ITTC, 2011) for Reynolds stress models were followed in the simulations, which use a time-step of 0.004 seconds and 10 inner iterations. The free surface effects of a floating ship were modelled using multiphase flow simulation. The Volume of Fluid (VOF) approach was used to represent free surface effects, considering two or more immiscible fluid phases and tracking the interface between them.

The accuracy of the solutions depends heavily on the placement of domain boundaries and the appropriate selection of boundary conditions. The computational domain has boundaries positioned 3 LOA forward from the bow, 8 LOA aft of the stern, 3 LOA on the sides from the symmetry plane, 2 LOA below the keel, and 1 LOA above the deck. ITTC recommendations (ITTC, 2011, 2014) were taken into account when defining the computational domain. For the boundary conditions, velocity inlets were applied at the inlet, top, and bottom surfaces, a pressure outlet was set behind the hull, symmetry conditions were imposed on the sides, and a no-slip condition was used on the hull. Figure 1 provides a visual representation of the computational domain and the boundary conditions.

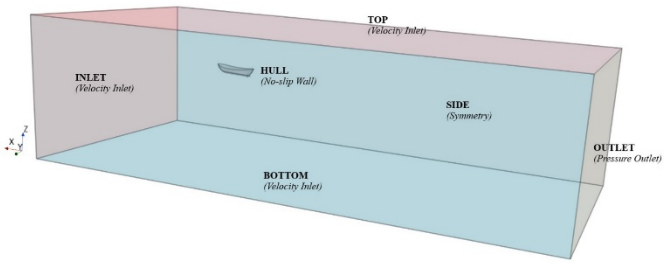

Figure 1. Overview of the computational domain and boundary conditions

The accuracy of fluid flow simulations and the rate of convergence are heavily influenced by the mesh generation process. Mesh quality was enhanced in certain critical regions of the computational domain. Refinement volumes were defined to apply local improvements to the mesh within the domain. Local mesh improvements were concentrated around the hull form, stern, bow, wake region, and free surface. The trimmed cell mesher technique was used to create a robust and efficient mesh structure. According to ITTC recommendations (ITTC, 2011, 2014), 10 prism layers with a 1.2 expansion ratio were employed. To provide the optimal mesh configuration for flow analysis, a grid independence study was performed. The refined regions enabled a gradual and smooth connection between the prism layers and the outer mesh. A y+ value of around 30 was implemented for the SST k-omega model as part of the All y+ wall treatment, providing accurate resolution of the buffer layer and inertial sublayer. Figure 2 presents a detailed presentation of the mesh configuration used in the flow analysis from different viewpoints.

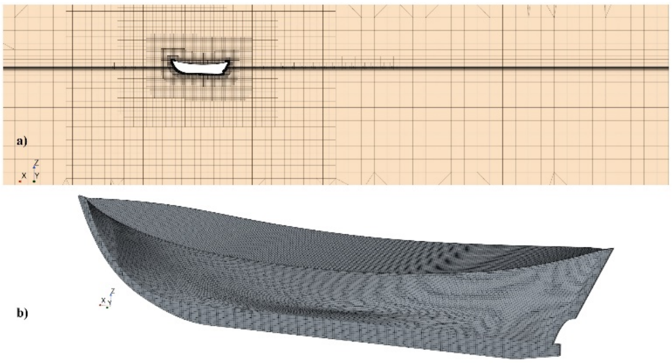

Figure 2. Mesh configuration: a) Side view b) Hull surface

Results and Discussion

Grid Independence Studies

The accurate modelling of the boundary layer, along with satisfying the conditions of turbulence models, is essential for providing precise results in the flow analyses. A proper mesh setup ensures an effective trade-off between accuracy and computational efforts. The GCI method (Celik et al., 2008) was used to assess discretization errors, contributing to establish a suitable mesh configuration. Mesh discretization errors were determined using the total resistance coefficient (C_T) as a reference parameter. The GCI parameters for the coarse, medium, and fine mesh configurations, with 2.4, 1.7, and 1.2 million cells respectively, for the reference model at Froude number of 0.38 were presented in Table 1. The grid refinement factor, *r*, was calculated as the ratio of the finer mesh element size to that of the coarser mesh. As outlined below, the apparent order of accuracy was calculated from the corresponding definitions.

$$p = \frac{1}{\ln(r_{21})} |\ln|\varepsilon_{32}/\varepsilon_{21}| + q(p)| \tag{7}$$

$$q(p) = \ln\left(\frac{r_{21}^p - s}{r_{32}^p - s}\right) \tag{8}$$

$$s = 1 \times sgn\left(\frac{\varepsilon_{32}}{\varepsilon_{21}}\right) \tag{9}$$

Here, $\varepsilon_{32} = \theta_3 - \theta_2$, $\varepsilon_{21} = \theta_2 - \theta_1$ and θ_k corresponds to the solution on the *kth* grid. A negative ratio $\varepsilon_{32}/\varepsilon_{21} < 0$ are a possible indication of oscillatory convergence (Celik et al., 2008). The following definition was used to derive the extrapolated values:

$$\theta_{ext}^{21} = (r_{21}^p \theta_1 - \theta_2)/(r_{21}^p - 1) \tag{10}$$

θ_{ext}^{32} can also be calculated similarly Equations 11 and 12 were used to calculate the approximate relative error (e_a^{21}) and extrapolated relative error (e_{ext}^{21}), respectively.

$$e_a^{21} = \left|\frac{\theta_1 - \theta_2}{\theta_1}\right| \tag{11}$$

$$e_{ext}^{21} = \left|\frac{\theta_{ext}^{12} - \theta_1}{\theta_{ext}^{12}}\right| \tag{12}$$

The definition for determining the grid convergence index for the fine-to-medium grids is as follows:

$$GCI_{fine}^{21} = \frac{1.25 . e_a^{21}}{r_{21}^2 - 1} \tag{13}$$

Grid refinement progressively decreased the GCI ($GCI_{fine}^{21} < GCI_{med}^{32}$) or the total resistance (R_T). A considerable reduction in GCI from the coarser to the finer grid was achieved, as shown in Table 1. According to the results, the grid-independent solution was almost obtained, and further refining the grid would not lead to substantial changes. Thus, given both accuracy and computational cost, the medium mesh with 1.7 million cells was preferred for the numerical simulations, as indicated by the grid convergence analysis.

Table 1. Parameters of the grid convergence method

GCI Parameters	Values
N_1, N_2, N_3 ($\times 10^6$)	2.4, 1.7, 1.2
G_1, G_2, G_3 ($\times 10^3$)	8.409, 8.575, 9.271
φ_{ext}^{21}	0.84
e_a^{21} (%)	1.97
e_{ext}^{21} (%)	0.62
GCI_{fine}^{21} (%)	0.77
GCI_{med}^{32} (%)	3.18

Comparison With Reference Model and Modified Model

In this section, a detailed comparison of the hydrodynamic characteristics between the reference and modified models was examined. Flow simulations for the reference and modified models were performed at a speed of 4.12 m/s, which corresponds to a Froude number of 0.38, using CFD methods. The numerical analysis covered a comprehensive investigation of resistance results, pressure coefficients, and wave patterns. The simulations were performed through the use of the commercial software STAR-CCM+ (StarCCM+ User Guide, 2023). The computational process was conducted on PC clusters, each featuring 24 Intel Core (64-bit, 3.0 GHz to 5.8 GHz) processors, with funding provided by TUBITAK.

The modified model (MDF) was generated by implementing improvements in the stern region of the reference model (REF) using CAD systems. Design splines were defined on the stern form, and design variables were positioned on these splines (Figure 3). The modification process was performed by considering the constraints applied to these design variables. Constraints are also applied to form characteristics such as draft (T), beam (B), length (L), displacement (∇), and wetted surface area (SW). The dimensional ratios of L/B and B/T for the Tirhandil form were maintained. The variation allowed in displacement and wetted surface area was limited to below 1%. The difference in draft values between the reference model and the modified model is also below 1%. Hydrostatic analyses were conducted for both models, and no significant differences were observed in the changes to the hydrostatic values. Figure 4 presents the hull forms of the reference and modified models in detail.

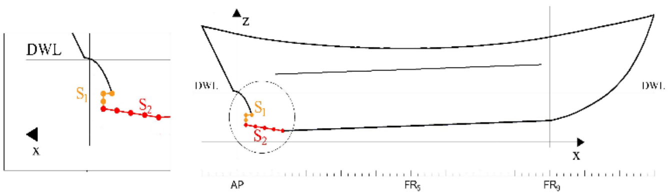

Figure 3. Design splines and design variables

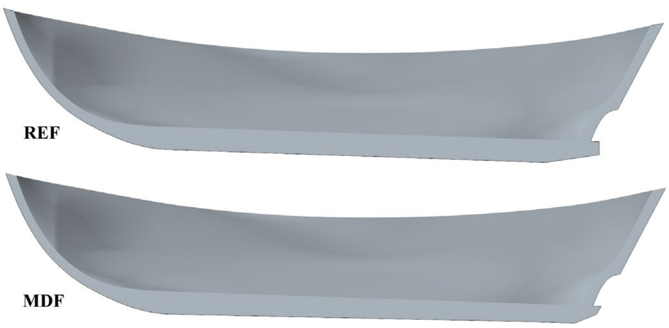

Figure 4. Hull forms of reference and modified models

Turan et al. (2024) conducted field studies on 23 different Tirhandil boats. They created 3D models of the Tirhandils using CAD software, performed engineering analyses on these models to determine the boats' characteristics, and applied regression analyses on the data to determine the design criteria and hull form parameters for Tirhandils. The reference Tirhandil form used in this study was developed based on the data presented in the work of Turan et al. (2024). The general dimensions of the reference model are presented in Table 2.

Table 2. General dimensions of the reference model

Specifications	**Reference Model**
Waterline length (LWL)(m)	11.41
Waterline width (BWL) (m)	3.53
Draft (m)	1.39
Displacement (tonnes)	11.35

A comparison of the total resistance coefficient between the reference model (REF) and the modified model (MDF) is shown in Table 3. The modified model achieved a 13.4% reduction in the total resistance coefficient, along with a 15.5% reduction in the pressure resistance component. The results of the modification studies reveal that the modified model provides considerable reductions in total resistance. The reduction in resistance is generally considered important, as it also directly affects wake characteristics (Hamed, 2022; Nazemian & Ghadimi, 2022). The wave patterns of the reference and modified models were investigated as well to understand the causes of resistance reduction.

Table 3. Total resistance coefficient values for reference model and modified model

	Reference Model	**Modified Model**
Total Resistance Coefficient ($C_T \times 10^3$)	7.984	6.914

The pressure coefficient distribution on the reference and modified models at a cruising speed of 4.12 m/s, corresponding to a Froude number of 0.38, is shown in Figure 5. The pressure coefficient distribution results reveal that there is a significant reduction in high-pressure values in the stern regions where improvements were applied in the modified model (MDF). The maximum pressure coefficient in the stern regions decreases from 0.75 in the reference model to 0.56 in the modified model. The modified model shows a uniform pressure distribution in the lower stern region. The reduction in pressure values and their smoother distribution are expected to result in a decrease in the amplitude and intensity of radiated waves from the stern regions.

Figure 6 provides a comparative analysis of the reference and modified models, focusing on wave transition and propagation, wave amplitude, and the formation of shoulder and stern waves. It is noted that a smoother wave transition is observed in the modified form. The modified model features more regular wave propagation and less pronounced stern and shoulder waves, contributing to smoother flow separation and reduced turbulence. A noticeable decrease in wave amplitude

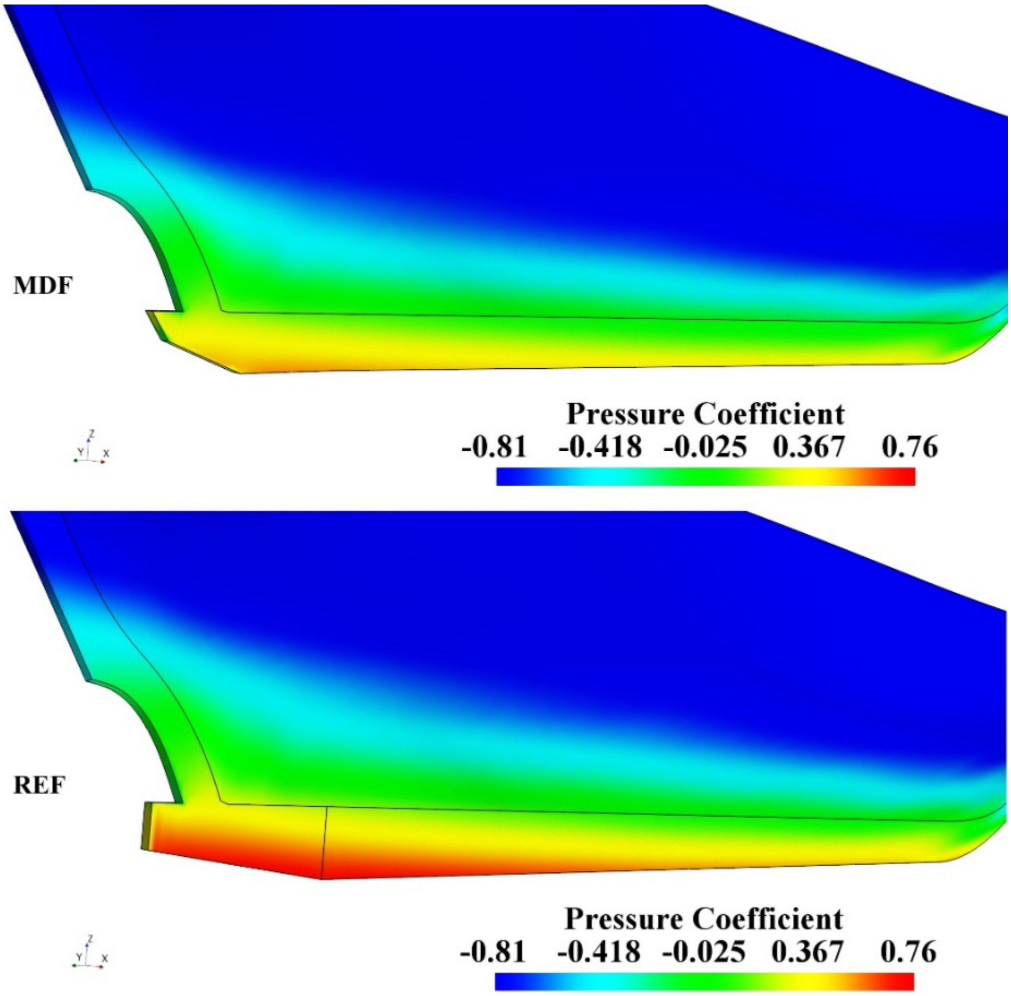

Figure 5. Pressure coefficient distribution of the reference and modified models

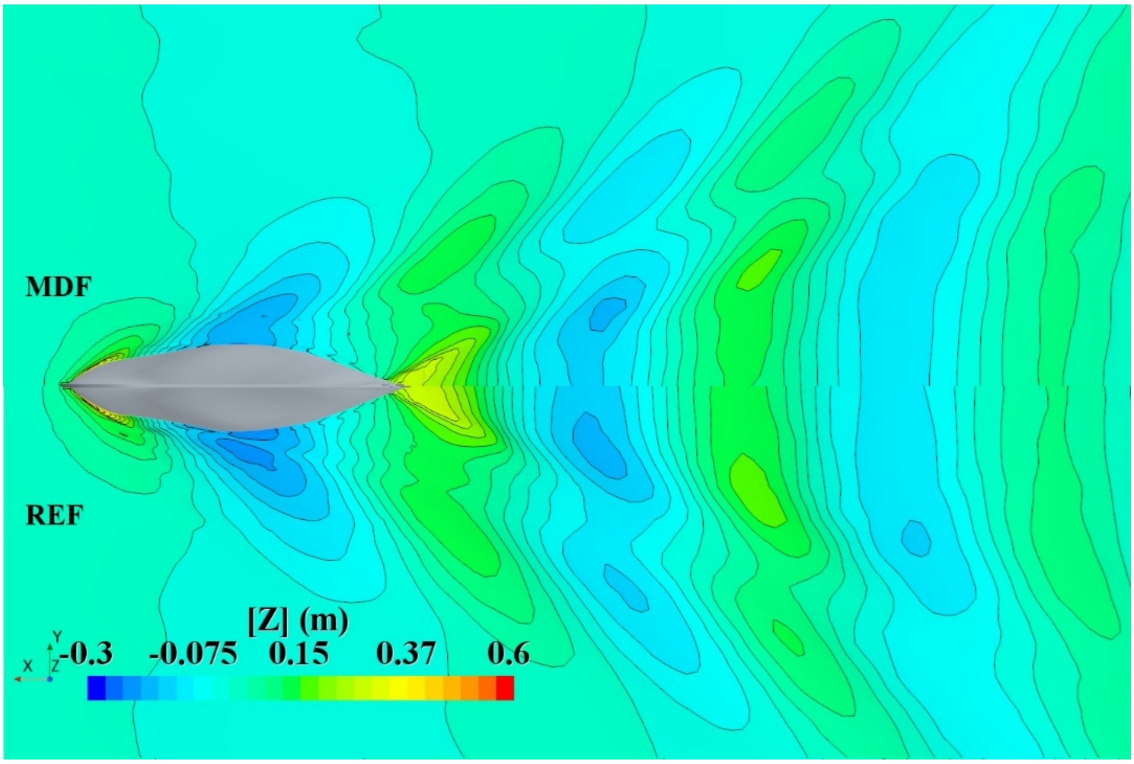

Figure 6. Wave pattern comparison between the reference (REF) and modified models (MDF)

by approximately 0.04 m is observed in the lower stern regions of the modified model. The decrease in wave amplitudes means that the water around the hull moves with less energy, resulting in a reduction in total resistance (Hamed, 2022; Nazemian & Ghadimi, 2022). It can be observed that the modified model experiences a reduction or cancellation of shoulder and stern waves compared to the reference model. The wave pattern improvements result in enhanced flow stability and reduced wave resistance, which in turn lead to better hydrodynamic performance and lower energy consumption for the modified model (Tezdogan et al., 2018; Hamed, 2022; Nazemian & Ghadimi, 2022).

Conclusion

A detailed investigation was conducted in this study to improve the hydrodynamic performance of a Tirhandil yacht by modification efforts on the stern region. The design of the reference and modified models was performed using CAD systems. The hydrodynamic characteristics of the reference Tirhandil model were determined through CFD analyses, and it was then concluded that form improvement efforts should focus on the stern region. The modification process was performed considering constraints on the design variables in the stern region and the main dimensions of the reference model. Various grid structures were analyzed in a grid independence study to determine the most suitable mesh configuration for the numerical analyses. In the numerical analyses, the SST k-Omega turbulence model was applied to simulate the turbulence around the hull form.

The reference model (REF) and the modified model (MDF) were comparatively investigated in terms of hydrodynamic characteristics. It was revealed that the modified model provided a 13.4% decrease in the total resistance coefficient and a 15.5% reduction in the pressure resistance component. The distribution of pressure coefficients indicates that high-pressure values were reduced in the stern region where improvements were implemented in the modified model (MDF). The maximum value of the pressure coefficient in the stern regions was decreased from 0.75 in the reference model to 0.56 in the modified model. The modified model features more regular wave propagation and experiences a reduction or cancellation of both shoulder and stern waves compared to the reference model. In the lower stern regions of the modified model, a significant decrease in wave amplitude of about 0.04 m is detected.

The literature review shows that there has been no previous study on improving hydrodynamic performance specifically in the stern region of Tirhandil yachts. This study presents a pioneering approach through the development of a unique Tirhandil hull design, with advanced hydrodynamic characteristics. This research also offers a framework for guiding future form optimization studies on sailing yachts. In future studies, the hydrodynamic characteristics of the hull form could be improved even more by applying form modification approaches to various regions of the hull form. Furthermore, similar research could be extended to consider harsh water conditions.

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

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RESEARCH ARTICLE

Determination of the amount of bilge waste generated by motorized fishing vessels in Türkiye

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ABSTRACT

When bilge water from ships is illegally discharged into the sea, it causes severe damage to the marine and coastal ecosystem. MARPOL Annex-1 does not cover many fishing vessels since it only covers vessels over 400 GT (gross tonnage). According to Turkish Statistical Institute (TURKSTAT) data, only 174 of the 14064 fishing vessels registered in Türkiye are above 400 GT. In our country, only 63 of 325 fishing harbors have waste reception facilities to control and collect bilge water. In this study, the amount of bilge waste that fishing vessels can produce was calculated using engine power information, and it was determined that a fishing vessel can produce an average of 155 L/day of bilge waste. It was also calculated that the bilge waste from fishing vessels could be at least 463872 m^3/year, which is more than the 416370 m^3 bilge waste collected from all vessels in 2021 according to the data of the Ministry of Environment, Urbanization and Climate Change. As a result, it is assessed that this risk can be reduced by increasing the number of waste reception facilities, the legal responsibility of waste reception facilities for bilge waste of fishing vessels, and strict inspections.

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Introduction

The discharge of bilge and wastewater from ships into the sea poses severe threats to the marine ecosystem. Bilge waste accumulates on the bottom of ships and contains substances such as detergent, oil or fuel that can cause severe damage to the ecosystem. One of the main anthropogenic inputs of hydrocarbons in marine waters is the dumping of bilge waste, estimated to be even higher than accidental oil spills (Pavlaski et al., 2001; National Research Council (NRC), 2003; GESAMP, 2007). One of the most important causes of anthropogenic pollution in the coastal ecosystem is petroleum hydrocarbon discharges from two-stroke and stationary engine oils (Beyrem et al., 2010). A study on bilge wastes from fishing vessels in the

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coastal area of Thailand reported that the discharge of bilge in the sea may have an important share in the formation of oil pollution (Lin et al., 2007).

The study conducted in Taiwan estimated that 3215 small vessels under 100 GT with engines below 300 HP (Horse Power) could generate up to 321700 L of oily waste per year. According to MARPOL, if the oil content in bilge waste is more than 15 mg/L, it is prohibited to be discharged into the sea. However, since this rule does not cover fishing vessels, most of which are under 400 GT, these vessels discharge a significant amount of bilge water into the sea (Lin et al., 2007). In a study on the content of bilge produced by small fishing vessels in Thai harbors, it was determined that the oil content ranged from 58 to 976 mg/L, which is much higher than the oil content of 15 mg/L determined by MARPOL (Chanthamalee et al., 2013). The rules in Annex-1 of the MARPOL convention contain the regulations on bilge waste. These regulations cover tankers larger than 150 GT and all ships larger than 400 GT. Only 174 of the fishing vessels in Türkiye are larger than 400 GT (TURKSTAT, 2022).

Parks et al. (2019) determined that a fishing vessel can produce 1.36 liters of bilge waste daily by assuming that 0.5% of the amount of fuel consumed daily constitutes oily bilge waste, using AIS data in the Bering Sea between 2014 and 2017. However, the amount of bilge waste produced by fishing vessels smaller than 15 meters without AIS system could not be calculated.

In a study conducted in Indonesia, an island country in the Pacific Ocean, on the management of wastes from fishing vessels between 30-100 GT in Nizam Zachman fishing harbor, it was calculated that 60% of the waste produced by fishing vessels was bilge waste and this was calculated to be 0.55 kg/day (Riyanto et al., 2023). A study on wastewater from ships in the Baltic Sea determined that fishing vessels produced 222 L of wastewater (grey water) per person per day (Ytreberg et al., 2020). In the Barents Sea, which is a cold sea close to the North Pole, the plastic wastes of fishing vessels were examined by surveying the stakeholders of the fishing sector on waste management in 2017-2018, and it was determined that there is a need for port waste receiving facilities and legal regulations in this regard (Finska et al., 2022). A study observing 1023 beaches on the coasts of England between 1999-2007 determined that plastic litter largely originated from fishing harbors (Unger & Harrison, 2016).

In the Middle East, in a study conducted in 2010 on the effect of fishing vessels on heavy metal pollution in the Oman Sea of Iran, it was stated that the primary source of heavy metal pollution in the harbors was bilge wastes from fishing vessels and wastewater with high organic matter content. However, no industrial activities were around the harbors (Hamzeh et al., 2013). It was also stated that the high organic matter content in the sediments in Cabahar Bay of the same country may be caused by fishing vessels' discharge of fuel and wastewater (Keshavarzi et al., 2015). In Vietnam, bilge and wastewater discharge of fishing vessels were shown as the primary source of pollution in harbors by Xuan et al. (2023).

In a study conducted in the Pacific Ocean between 2003 and 2015, it was reported that 71% of the pollution sources from fishing vessels between 2003 and 2015 were garbage thrown from the deck, 9% of these were waste oils, and 16% of the remaining pollution rate was oil spills. As a result of this study, it is seen that 25% of the pollution from fishing vessels is bilge waters, which we define as waste oil. (Richardson et al., 2017).

Ortiz-Ojeda & Rázuri-Esteves (2021) examined bilge waste samples from fishing vessels between 300 GT and 400 GT in the Gulf of Ancón in Peru, which have 9-200 HP engine power. The amount of bilge wastes these ships can produce annually is determined according to the waste oil that may be generated from machinery maintenance. As a result of this study, it was determined that a fishing vessel with 9 HP engine power produced 2.6 L of waste oil annually, a fishing vessel with 200 HP engine power produced 200 L of waste oil annually, and fishing vessels in the studied region produced a total of 4319 L of waste oil annually.

The study conducted in our country on bilge wastes originating from ships in Lake Van determined that oily bilge wastes caused by machinery maintenance or regular operation of the machinery in fishing vessels are discharged into the lake offshore. It has also been reported that the oil content of bilge wastes from fishing vessels exceeds the MARPOL standard of 15 mg/L (Akman &Atıcı, 2022). The study covering the years 2015-2016 in Sinop fishing shelters reported that the pollution may be caused by bilge water from fishing vessels due to seawater analyses (Arıcı, 2017). Our country's coastal fisheries are generally carried out daily with 5-12 m long motorized vessels and 10-70 HP power (Mısır, 2008). The engine power of purse seine vessels in the Central and Eastern Black Sea is between 9HP and 2270 HP, the engine power of trawlers is between 24-886 HP, and the average engine power of vessels using general extension net is 19.9 HP (Zaman, 2011).

The global fishing fleet doubled between 1950 and 2015, from 1.7 million vessels to 3.7 million. This is mainly due to the increasing number of motorized fishing vessels; by 2015, 68%

of the world's fishing fleet was motorized (Rousseaua et al., 2019).

The world fishing fleet has remained relatively stable since 2008, reaching approximately 4.6 million vessels in 2016, 75 percent in Asia. In terms of the number of ships, Asia is followed by Africa, Latin America, the Caribbean, North America, and Europe. In 2016, 61 percent of the world's ships were motorized. Approximately 86 percent of motorized fishing vessels have a vessel length of less than 12 m. Fishing vessels with 24 m and larger vessel lengths account for approximately 2% of the total fleet (FAO, 2018).

The number of fishing vessels globally decreased to 4.1 million in 2020. China has the largest fishing fleet, with approximately 564000 fishing vessels (FAO, 2022). Although fishing vessels decreased by 47% from 2013 to 2020, they could fish more by increasing engine power and capacity (Di Cintio et al., 2022). Between 1950 and 2015, the number of non-motorized fishing vessels decreased by 0.2 million, while the number of motorized fishing vessels increased more than six-fold over the same period (Rousseau et al., 2019).

As in the world, the production of aquaculture products obtained by catching in our country is limited. For this reason, the primary approach recognized by scientists in catching is to maintain production by protecting stocks. The fishing fleet has grown and developed in power, number, technology, and fishing gears until the 2000s. According to TURKSTAT data, while the number of active fishing vessels in our seas was 13381 in 2000, this number increased to 18396 in 2005. It decreased to 14064 in 2022 (Ministry of Environment, Urbanization and Climate Change (MEUC), 2024a).

When the national and international literature is examined, very few studies on bilge waste from fishing vessels were found. Among these studies, the bilge water of fishing vessels was calculated in the research efforts made in the world. Still, the formula used in this study was not used, and it was observed that risk assessment and waste reception facilities in the harbors where fishing vessels are located were not considered. In the studies conducted in Türkiye, risk assessment and waste reception facilities in the harbors where fishing vessels are located have not been examined, including calculating the amount of bilge waste from fishing vessels. In this study, bilge waste from fishing vessels in Türkiye was calculated, risk assessment was made for the first time, and the needs for waste reception facilities in the harbors where fishing vessels are located were tried to be determined. In addition, it is hoped that this study will contribute to the literature as the first study to evaluate the waste reception facility facilities of fishing harbors or harbors for other studies conducted worldwide.

Material and Methods

Data Collection

The bilge wastes from fishing vessels were determined with the number and engine power of fishing vessels, the amount of waste collected, and fishing times taken from the open sources of the relevant institutions are summarized below.

Determination of the Number of Fishing Vessels and Motor Power

The number of fishing vessels in Türkiye and their changes over the years are given in Figure 1. As of 2022, there are 14064 fishing vessels, and the total machinery power of these vessels is 1559300 KW (kilowatt) (MEUC, 2024a). The distribution of fishing vessels according to engine power ranges is given in Table 1.

Although the number of fishing vessels tends to decrease over the years, it is seen in Figure 1 that their engine power has increased. According to TURKSTAT data, the number of fishing vessels and engine power range are given in Table 1.

Table 1. Distribution of fishing vessels according to engine power range (TURKSTAT, 2022)

Motor Power Range (HP)	Black Sea	Marmara Sea	Aegean Sea	Mediterranean Sea
1- 9.9	1621	559	1204	211
10-19.9	367	164	326	144
20-49.9	1178	717	995	445
50-99.9	1081	448	743	425
100-199.9	817	310	475	173
200-499.9	377	320	165	213
>500	351	156	46	33
Total	5792	2674	3954	1644

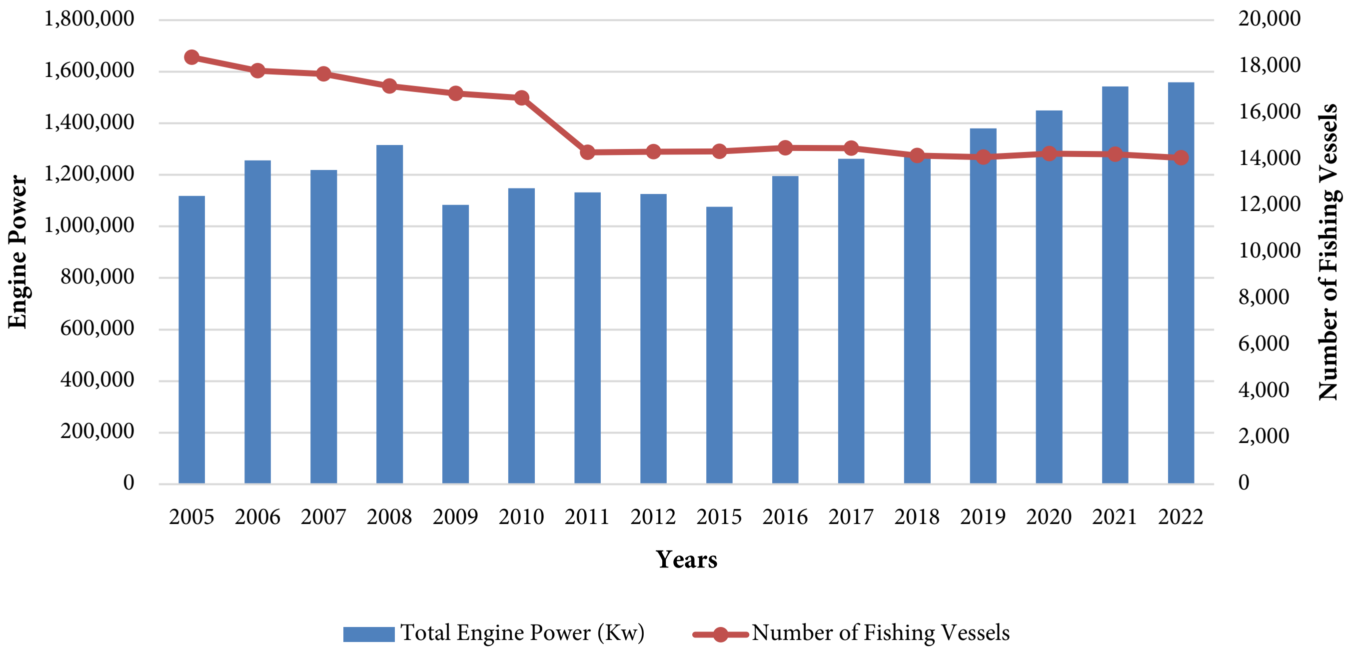

Figure 1. Changes in the number and engine power of fishing vessels by years (TURKSTAT, 2022)

Table 2. Amount of waste from ships collected by year (M.E.U.C.,2024b)

Waste	2015	2016	2017	2018	2019	2020	2021
Oil Derived Waste (m^3)	240046	388311	236004	524031	315325	504797	416370
Wastewater (m^3)	206429	58950	81585	27331	85413	37903	13332
Litter (m^3)	40067	33872	24514	37494	163989	76527	52034

Table 3. The time intervals in which fishing vessels can fish at sea

Fishing Vessel Type	Mediterranean Sea	Black Sea	Marmara Sea	Aegean Sea
Troll	16 September-15 April	1 September-15 April	1 September-15 April	1 September-15 April
Seiner	16 September-15 April	1 September-15 April	1 September-15 April	1 September-15 April
Carrier	16 September-15 April	1 September-15 April	1 September-15 April	1 September-15 April
Other	Free	Free	Free	Free
Extension vessel	Free	Free	Free	Free
Beam trawl	Forbidden	1 September-15 April	1 September-1 January 1 February -15 April	Forbidden
Bank line and fishing rods	Free	Free	Free	Free
Slewing and Volley Nets	16 May -15 April	16 May -15 April	16 May -15 April	16 May -15 April
Drag Nets	Forbidden	Forbidden	Forbidden	Forbidden
Collapsing Nets	Free	Free	Free	Free
Tunnel net	Free	Free	Free	Free

Table 4. The number of days fishing vessels can fish at sea is determined by region

Fishing Vessel Type	Mediterranean Sea	Black Sea	Marmara Sea	Aegean Sea
Troll	212	227	227	227
Seiner	212	227	227	227
Carrier	212	227	227	227
Other	365	365	365	365
Extension vessel	365	365	365	365
Beam trawl	Forbidden	227	196	Forbidden
Bank line and fishing rods	365	365	365	365
Slewing and Volley Nets	334	334	334	334
Drag Nets	Forbidden	Forbidden	Forbidden	Forbidden
Collapsing Nets	365	365	365	365

Table 5. Distribution of the amount of bilge waste that can be generated by fishing vessels according to the lowest engine power

Motor Power Range (KW)	Black Sea (L/day) (min)	Marmara Sea (L/day) (min)	Aegean Sea (L/day) (min)	Mediterranean Sea (L/day) (min)
0.75	250312.43	86319.96	185919.90	32582.31
7.5	56732.79	25351.98	50394.79	22260.28
14.91	182317.03	110968.85	153994.44	68871.88
37.3	167902.34	69583.95	115403.73	66011.56
74.6	127650.22	48435.21	74215.24	27029.97
149.2	59598.14	50587.28	26084.06	33672.16
>372.9	57427.33	25523.26	7526.09	5399.15
Total	901940.27	416770.49	613538.26	255827.30

Determination of the Amount of Waste Collected

Wastes collected from ships in ports and marinas in Türkiye between 2015 and 2021 are classified according to waste types and given in Table 2. It is seen that the amount of petroleum-derived wastes, also defined as bilge waste, doubled in 2018 and was approximately the same amount in the following years. The amount of waste in this table includes vessels other than fishing vessels and covers all vessels (MEUC, 2024b).

Determination of the Catching Season

According to the Communiqué No. 5/1 on the Regulation of Commercial Fisheries, the time intervals in which fishing vessels can carry out fishing activities regionally according to their fishing gear and types are given in Table 3. By calculating the days shown in this table as free time for fishing, the amount of bilge that can be produced by the fishing vessels was calculated using the information of being able to go fishing for 212 days, the minimum number of days.

According to the data of the Ministry of Environment, Urbanization and Climate Change in Türkiye, the number of licensed waste reception facilities serving in ports is 298 as of 2024, and the number of waste reception facilities in fishing harbors serving fishing vessels is 62 (MEUC, 2024c). The total number of fishing harbors in Türkiye is 385 (Ministry of Agriculture and Forestry, 2024).

Calculation of Bilge Quantity Risk

The following formula was used to calculate the amount of bilge produced by a ship (Jalkanen et al., 2020);

$$b = 0.0247p \text{ (kW)} + 154.4 \quad (1)$$

Here, the daily amount of bilge waste (b) (L/day) that a ship can produce is calculated as a function of the engine power (p). This study tried to determine the amount of bilge waste that a fishing vessel can produce in one day using this formula.

The minimum amount of bilge that can be formed in each region is calculated with the smallest value in each engine power range, and the largest value in the formula for calculating the maximum amount of bilge is used as engine power. Then, the amount of bilge waste calculated according to the engine power range in each region was multiplied by the number of ships in the calculated engine power range in each region, and the amount of bilge waste that may occur in a day was calculated. The amount of bilge waste that may occur daily for a year, at least the days when there is no fishing ban specified in Table 4 were calculated and the lowest value of 212 days was used in the calculations. For each engine power range, the lowest and highest bilge waste amounts were calculated separately for each region. As a result, the following formula was used in the calculations;

$$S = (b \times N) \times 212 \quad (2)$$

Here, the annual amount of bilge waste (S) (L/year) that fishing vessels can produce was tried to be determined by multiplying the amount of bilge waste (b) (L/day) with number of ships (N) that a vessel can produce by 212 days.

Results and Discussion

Determination of the Number of Days to Be Used in Calculations

The number of days fishing vessels sailed outside the fishing ban periods was calculated using the information given in Table 3 and shown in Table 4. Here, it is seen that the minimum number of days at sea is 212 days, and the minimum number of days is used in the calculations. In addition, since the number of drift gillnet vessels, which are mentioned in TURKSTAT data but are completely prohibited according to the Communiqué No. 5/1 on the Regulation of Commercial Fisheries is 21, and the total number of beam trawl vessels in the Mediterranean Sea and Aegean Sea regions is 4, they were not considered in the calculation of the number of days.

Determination of Bilge Waste Amount

Using the information on the number of fishing vessels given in Table 1 according to the engine power range, the minimum amount of bilge waste that may occur in the regions according to the lowest engine power was calculated and given in Table 5. The engine power unit shown in Table 1 was converted to kW, the engine power unit in the HP formula, by the formula given in the materials and methods section. Then, the minimum amount of bilge waste generated according to the regions was calculated with the formulae 1 and 2 in the materials and methods section. In this study, the amount of waste produced by unregistered and unregistered fishing vessels could not be calculated. The number of days fishing vessels could not go out when a storm at sea was not considered in the bilge waste amount calculations.

Using the information on the number of fishing vessels given in Table 1 according to the engine power range, the highest amount of bilge waste that may occur in the regions according to the highest engine power is calculated and given in Table 6. The engine power unit shown in Table 1 is converted to kW. Then, the minimum amount of bilge waste generated according to the regions was calculated according to the formulae 1 to 3 given in the materials and methods section. The engine power of purse seiners, which was stated as the highest engine power value in the study conducted by Zaman (2011), was between 9HP and 2270 HP, and the engine power of trawlers was between 24-886 HP. The maximum machine power was calculated by converting the average 886 HP and 2270 HP values into kW using the information here. In our study, the average amount of bilge waste produced daily by fishing vessels was 155 L/day.

Comparison of the Calculated Bilge Waste Amount With the Collected Amount

The annual amount of the daily minimum and maximum amount of bilge waste calculated according to the regions is calculated using the 2nd formula. The sum is converted from L to m^3 and given in Table 7. In 2021, the amount of bilge waste collected by waste reception facilities in Turkish ports is 416000.37 m^3 as shown in Table 2. However, it is seen in Table 7 that the risk of bilge waste amount that may occur only for fishing vessels is at least 463872.18 m^3. Considering that 1 liter of oil can pollute 1000 liters of water, bilge waste severely threatens the marine ecosystem. This situation shows a need for legal regulations on the inspection of waste reception facilities and the implementation of strict supervision in this regard. However, as it is known, although the MARPOL regulation on marine pollution internationally includes regulations on waste reception facilities in ports, it includes rules for ships in the prevention of marine pollution from ships. Similarly, in Türkiye, the Environmental Law No. 2872, the Regulation on Waste Collection from Ships and Waste Control, the Regulation on Environmental Inspection and the Circular on Maritime Wastes Implementation impose legal obligations on ships regarding ship wastes.

Table 6. Distribution of the amount of bilge waste that can be generated by fishing vessels according to the highest engine power

Motor Power Range (KW)	Black Sea (L/day) (max)	Marmara Sea (L/day) (max)	Aegean Sea (L/day) (max)	Mediterranean Sea (L/day) (max)
7.38	250605	86421	186138	32620
14.89	56812	25388	50465	22291
37.21	183067	111425	154628	69155
74.5	168896	69996	116086	66402
149.1	129153.62	49005.66	75089.32	27348.32
372.8	61680.28	52354.61	26995.35	34848.54
1176.7 <	64396.04	28620.46	8439.37	6054.33
Total	914609.98	423209.99	617841.08	258720.26

Table 7. The sum of the minimum and maximum annual bilge waste amounts is calculated according to the regions

Bilge Waste Amount	Black Sea (m^3/year)	Marmara Sea (m^3/year)	Aegean Sea (m^3/year))	Mediterranean Sea (m^3/year))
Bilge Quantity Range	191211.34-193897.31	88355.35-89720.51	130070.12-130982.30	54235.39-54848.7
Total	463872.18- 469448.84			

Although the number of fishing harbors serving fishing vessels in Türkiye is 385 (Ministry of Agriculture and Forestry, 2024), only 62 have waste reception facilities (MEUC, 2024c). In this case, the discharge of bilge waste in the sea by fishing vessels becomes inevitable. In addition, there are waste reception facilities in only 10 of 165 fishing harbors in the Black Sea region, with approximately 60% of the fishing vessels registered in Türkiye (Table 1). Although the waste reception facilities in the fishing harbors are so inadequate and legally deficient, the obligation to give waste within 48 hours was increased to 10 days by the Ministry of Environment, Urbanization, and Climate Change with the Maritime Waste Application Circular (2022/14), since it was seen that the adequacy of the waste tank volumes of fishing vessels with a crew of more than 12 people was sufficient for this period. In this case, it is evaluated that the inadequacy of the sanctions by loosening the control of the situation where the waste collection facilities are already inadequate leads to the discharge of more bilge waste into the sea. In addition, according to MARPOL, the oil content in the bilge waste of ships over 400 GT can be reduced below 15 mg/L with the treatment systems installed on the ships and discharged into the sea at a certain distance from the shore. However, when it is evaluated that only 174 fishing vessels in Türkiye are over 400 GT (TURKSTAT, 2022), it can be seen that legal regulations are insufficient in this regard.

In this study, the amount of bilge waste that all types of fishing vessels can produce was calculated between 463.9 and 469.4 m^3/day by using machine power information. However, a study conducted in Taiwan determined that only fishing vessels with engine power below 300 HP can produce up to 321700 L of bilge waste annually (Lin et al., 2007). A similar study conducted in Indonesia observed that the waste produced by fishing vessels between 30-100 GT was 0.55 kg/day (Riyanto et al., 2023). In Türkiye, the average daily bilge water that can be generated based on engine power is 155 liters. In the study conducted in the Gulf of Ancón, Peru, it was found that fishing vessels with lower (9 HP) engine power produced 2.6 L of bilge waste per year and fishing vessels with 200 HP engine power produced 200 L of bilge waste per year (Ortiz-Ojeda & Rázuri-Esteves, 2021).

A study conducted in the Bering Sea using AIS data determined that the amount of bilge waste produced daily by fishing vessels was 388 L of bilge waste per day, assuming 0.5% of the amount of fuel consumed (Parks et al., 2019).

The wastes generated by fishing vessels are bilge water but also grey and black water, fishing nets, and plastic wastes. In other studies, it has been reported that fishing vessels produce 222 L of wastewater (gray water) per person per day (Ytreberg et al., 2020). However, in this study, only bilge waste from fishing vessels was considered and analyzed.

Among the limited number of studies on bilge waste from fishing vessels in Türkiye, it was determined that the oil content of the bilge waste of fishing vessels in Lake Van was above 15 mg/L determined by MARPOL (Akman & Atıcı, 2022) and in the study conducted in Sinop fishing harbors, it was determined that marine pollution may be caused by bilge water from fishing vessels (Arıcı, 2017). As seen from the literature, in this study, the bilge waste of fishing vessels was calculated based on engine power, and the risk of bilge water that could be produced in Türkiye was emphasized.

Conclusion

As a result of the study, there is a need to ensure that the amount of bilge waste received from fishing vessels is recorded by the waste reception facilities. Thus, as a priority, the waste reception facilities in the fishing harbors should be brought to an adequate level, and legal arrangements should be made. As a result, it is clear that by increasing the harbor waste reception facilities and waste reception facility responsibilities in the fishing harbors it will be an easier and more effective method than the detection of bilge waste discharged into the sea by fishing vessels in sea areas where it is challenging to control.

Bilge wastes discharged from fishing vessels to the sea intentionally or accidentally may be caused by inadequate personnel training on the spilled environment. However, the most important reason may be insufficient waste reception facilities and capabilities and ineffective legislation. In addition, although the number of waste reception facilities in fishing harbors and the types of wastes received are known the lack of information on how much waste is obtained from which vessel, as in other harbors, is a significant lack of follow-up.

In future studies, analyses of bilge water from fishing vessels and determination of the substances, such as oil ratios, heavy metals, etc., that may cause serious harm to the marine ecosystem and human health will contribute to understanding the extent of this risk. In addition, it is thought that a similar study for wastewater from fishing vessels will be helpful to in correctly determining the waste reception facility facilities.

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

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

The small-scale tuna fishery in Leyte, Philippines: Fishing gears, practices, catch rate and composition

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ABSTRACT

The Philippines is a significant tuna producer globally and ranks among the major tuna-fishing nations. One of the various areas where tuna fishery occurs in the country is the province of Leyte in Eastern Visayas. However, available information on the fishery in the province is limited. Thus, this study aimed to provide comprehensive information on the current status of small-scale tuna fishery in selected municipalities in Leyte, particularly on the types of fishing gears used, practices employed by fishers, and the catch rate and composition of the gears. This study used a purposive sampling method, and data were gathered through face-to-face interviews with a total of 68 small-scale tuna fishers, and actual catch sampling. The respondents' involvement in tuna fishing ranged from 3 to 60 years with a mean of 26±13 years. A total of three different types of hook and line gear used in the fishery were recorded, namely: 1) paired troll line, 2) single troll line, and 3) single hook and line with float. The paired troll line is the most commonly used gear among tuna fishers. The mean catch per unit effort varies depending on the fishing gear type. The catch composition of the three gears based on the actual catch sampling was comprised of four tuna species including longtail tuna *Thunnus tonggol* (50.48%), big-eye tuna *T. obesus* (21.90%), eastern little tuna *Euthynnus affinis* (18.10%), frigate tuna *Auxis thazard* (3.81%), and two other species including *Megalapis cordyla* (3.81%) and *Scomberomorus commerson* (1.90%). The current major issues in the fishery include catch seasonality, illegal fishing, and border restriction.

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Introduction

The fishery of tunas is one of the most important marine fisheries in the Philippines. In the global scale, the country ranks among the major tuna-fishing nations (Llanto et al., 2018; Nepomuceno et al., 2020). Tuna consistently ranks first among the top commodities from both marine municipal and commercial fisheries (BFAR, 2023). In 2022, the overall tuna landings reached 475,313.47 mt, representing 23.90% of the total capture fisheries production in the country valued at PHP 54.32 billion. In the commercial fisheries subsector, tuna landings contributed 335,210.21 mt (38.86%) valued at PHP 35.42 billion. In terms of the marine municipal fisheries subsector, tuna landings contributed 140,103.26 mt (12.44%) valued at PHP 18.90 billion. Tuna also remained as the top exported commodity with a total value of USD 403.51 million. However, despite the economic importance of tuna resources in the Philippines, detailed documentation on the fishery in the various areas of the country is limited (Yutuc et al., 2018; Nepomuceno et al., 2020). In terms of regulations and fisheries management, Republic Act No. 10654, an Act to prevent, deter and eliminate illegal, unreported and unregulated fishing, amending Republic Act No. 8550, otherwise known as "The Philippine Fisheries Code of 1998," and for other purposes, sets out the general framework for the management of fisheries sector in the county including tuna fisheries (DA-BFAR, 2018). The Department of Agriculture-Bureau of Fisheries and Aquatic Resources is designated as the lead government agency responsible for the conservation and management of the fisheries beyond the municipal waters (>15 km from coastline). On the other hand, the local government units through Republic Act No. 7160 known as the "Local Government Code of 1991" are given the jurisdiction and responsibility to manage the fisheries within their municipal waters (municipal fisheries, within 15 km from the coastline).

The province of Leyte in Eastern Visayas, Philippines is one of the areas where tuna fishery occurs. It was reported that Leyte is one of the major sources of tunas caught by hook and line gears that are channeled to General Santos City in Mindanao – the center of tuna industry in the Philippines (DA-BFAR, 2018). From 2018-2022, the collective average tuna landings from the province ranged from 705.53 mt to 1,011.26 mt with a value of PHP 82.79 to PHP 130.37 million. The contribution of the municipal fisheries to the province's tuna landings varied from 17% to 55%.

The available updated data about the tuna fishery in the province is limited to the total production and the target species. A more comprehensive data about the fishery such as the various types of fishing gears used to include the designs, and the fishing practices employed is imperative to better understand the current status of the fishery in general. Records on the catch rate and composition are also an important input needed for the evaluation of the fishery's exploitation level and potential. This study aimed to provide an information about the current status of the small-scale tuna fishery in the selected municipalities in Leyte including the types of existing fishing gear used, the practices employed by the fishers, and the catch rate and composition of the gears to fill the information gap concerning the fishery. The results of this study may serve as baseline information that can be used by the concerned government agencies and other institutions in formulating better management plans for the said fishery resource.

Material and Methods

Study Area and Duration

This study was conducted in the three selected coastal municipalities in Leyte, Eastern Visayas, Philippines where small-scale tuna fishery occurs, namely: Tolosa, Dulag, and Mayorga from February to May 2023. The interviews with the tuna fishers started in February, while the actual catch sampling in March to coincide with the local tuna fishing season from March to June. These neighboring municipalities are geographically located along San Pedro Bay (Tolosa) and Leyte Gulf (Mayorga and Dulag), which are among the major fishing grounds in Eastern Visayas (Figure 1).

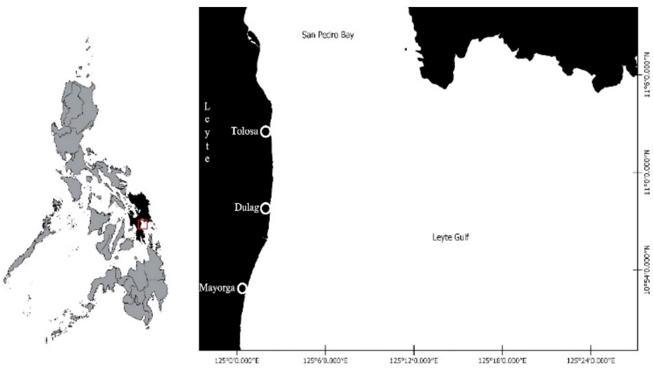

Figure 1. Map showing the study sites in the selected coastal municipalities of Leyte, Eastern Visayas Philippines

Study Design

A purposive sampling method was used in this study. The data were collected through face-to-face interviews with the target respondents using a semi-structured questionnaire. An actual catch sampling and field observation were also conducted for validation of the data gathered from the tuna fishers particularly on the catch rate and composition.

Before the interview, a consent form was provided to the target respondents to ensure their voluntary participation in the study. The fishing gears were photographed for proper identification and description. Gear illustrations and layouts featuring the gear design and structure based from the photographs taken during the conduct of the face-to-face interviews and actual field observation were also provided through AutoCAD –a computer aided design software.

The Survey Instrument

The survey instrument used in this study was mainly comprised of the respondent's fishery profile focusing on their involvement in the fishery, fishing gear/s used, methods employed, catch rate, and the size and species composition. The instrument was deployed through Kobo Collect, an offline android-based application that was used during the survey.

Catch Sampling Procedure and Species Identification

Catch sampling was done weekly from March to May 2023. Sampling was done as soon as the catch was landed. Collected data included the individual body weight to the nearest "g" using a 10,000-g capacity weighing scale. Fishing effort data including the number of hooks used, number of hours spent every fishing operation, and the total catch were also recorded though direct interviews with the fishers after landing. The different species composing the catch were determined on site with the direct assistance from the National Fisheries Research Development Institute—National Stock Assessment Program (NFRDI—NSAP) personnel (data enumerator) assigned in the three selected sites. A cross verification of the identification was done based on the taxonomic characters of each species following the identification guide of Froese and Pauly (2024) and White et al (2013).

Data Processing and Analysis

The gathered data from both the face-to -face interviews and the actual catch sampling were uploaded to the Kobo Toolbox server then downloaded in an excel format, and were processed accordingly. Data were further analyzed using descriptive statistics and results were presented in tables or charts. Catch rate was expressed through catch per unit effort in terms of kilogram per fishing hour (kg/h) and kilogram per hook (kg/hook) depending on the fishing gear type.

Results and Discussion

A total of 68 small-scale tuna fishers who were all males were interviewed from the three selected coastal municipalities of Leyte, Eastern Visayas, Philippines, in which, 16 where from Tolosa, 25 from Dulag, and 27 from Mayorga. These numbers represent about 27% to 100% of the total number of small-scale tuna fishers in the three municipalities who were available and had voluntarily participated during the face-to-face interviews.

The Small-scale Tuna Fishery in Leyte

According to the face-to-face interviews with the small-scale tuna fishers and from the actual field sampling, the tuna fishing season in Leyte starts in March but with limited catch. Later on, during the month of April until May, abundant catch of tuna species is observable. At the beginning of June, tuna landings in the three different sampling stations started to decline. The major fishing areas where tuna fishers operate were mostly in the waters between Leyte and Samar Islands, particularly in the Leyte Gulf and San Pedro Bay. According to the fishers, they operate in the waters of the municipalities of Tolosa, MacArthur and Abuyog in Leyte, Marabut in Samar, and Balangiga, Lawaan, Giporlos, Homonhon and Guiuan in Eastern Samar. They also fish as far as Dinagat Islands in Surigao.

Most of the respondents had their preferred "lab-asero" or "postor" or so-called middlemen to whom they sell their catch as soon as they land. The price of tuna at the landing site when catch is abundant during the fishing season ranges from PHP 150.00 – PHP 180.00, while up to PHP 200.00 – PHP 240.00 when catch is lesser.

Fishery Profile of Small-scale Tuna Fishers

The fishery profile of the small-scale tuna fishers is shown in Table 1. Out of the 68 respondents, a total of 52 (76.47%) were full-time while 16 (23.53%) were part-time tuna fishers. When the tuna fishing season in the localities is off, full-time fishers engaged in other fishery activities targeting other species such as *Caesio* spp. On the other hand, part-time tuna fishers are involved in either of the following: 1) fishery law enforcement; 2) fisheries, particularly fish peddling, and repair and production of fishing boat accessories such as propeller; 3) agriculture, particularly butchery, coconut harvesting and wine production, and rice production; 4) small retail of variety of goods; 5) labor and construction; 6) public transportation; and 7) local government unit as contractual worker. One tuna part-time fisher receives pension from his retirement as a policeman.

Table 1. Fishery profile of small-scale tuna fishers in Leyte, Eastern Visayas, Philippines

Variables	Frequency of Response	Frequency Percentage (%)
Status as tuna fisher		
Full-time	52	76.47
Part-time	16	23.53
Total	68	100
No. of years in tuna fishing		
≤10	12	17.65
11 – 20	16	23.53
21 – 30	18	26.47
31 – 40	12	17.65
41 – 50	8	11.76
51 – 60	2	2.94
Total	68	100
Type of fishing vessel used		
Motorized	64	94.12
Non-motorized	4	5.88
Total	68	100
Fishing vessel material		
Fiberglass Reinforced Plastic	8	11.76
Wood	60	88.24
Total	68	100
No. of crew per vessel		
1 person only	50	73.53
2 persons	18	26.47
Total	68	100
Role in the fishing operation		
Captain/Operator	67	98.53
Crew	1	1.47
Total	68	100
Frequency of the conduct of fishing operation (days)		
5 – 10	8	11.76
11 – 15	17	25.00
16 – 20	15	22.06
21 – 25	20	29.41
25 – 30	8	11.76
Total	68	100
Average duration of fishing operation/trip (h)		
1 – 5	3	4.41
6 – 10	21	30.88
11 – 15	44	64.71
Total	68	100

Table 2. Recorded tuna-fishing gears used in Tolosa, Dulag and Mayorga in Leyte, Eastern Visayas, Philippines, the local names, and the number of users

Common Name	TOLOSA		DULAG		MAYORGA		Total No. of Users	% No. of Users per Fishing Gear Type
	Local Name	*No. of Users*	*Local Name*	*No. of Users*	*Local Name*	*No. of Users*		
Paired troll line	Sahid	8	Pakaras	20	Bahan	20	48	70.59%
Single troll line	Limbag/ Singgol/ Solo-solo	3	Limbag/ Singgol/ Solo-solo	4	Limbag/ Singgol/ Solo-solo	5	12	17.65%
Single hook and line with float	Palutaw	5	Palutaw	1	Palutaw	2	8	11.76%

The fishers' length of involvement in small-scale tuna fishing ranged from 3 to 60 years with a mean of 26±13.00 years. It can be noted that most of the fishers (82.35%) were already >10 years in the fishery. Most of the respondents stated that they started to join fishing operations at an early age of at least 10 years old together with their late fathers. According to the respondents, they preferred to go fishing instead of going to school since they perceived that tuna fishing provides them income and sustain their needs rather than studying.

Tunas are typically found in deeper areas farther than the shore. Allain et al. (2016) reported that tuna species including yellowfin and bigeye are usually found at depths of 250 m and 300-500 m, respectively. Thus, the use of powered vessels is critical in the fishing operations. In this study, 94.12% of the fishing boats used were motorized powered by 5.50 to 18 HP engine. The most common type of fishing boats used were made from wood (88.24%) while a few (11.76%) were made from fiberglass reinforced plastic. Almost all (98.53%) of the respondents were either boat captains or operators. The frequency of fishing operations ranged from 5 to 30 days monthly with a mean of 19±5.00 ($\bar{x}$±SD) days. The duration of the daily fishing operation lasts from 5 to 15 hours with a mean of 10.91±2.58 hours.

Fishing Gears Used

This study recorded a total of three different fishing gears used in catching tuna species in the municipalities of Tolosa, Dulag, and Mayorga, Leyte. These include: 1) paired troll line, 2) single troll line, and 3) single hook and line with float (Table 2). All of these fishing gears are basically hook and line. Similarly, Mendoza et al. (2023) recorded four types of fishing gear used in Infanta, Pangasinan in catching tuna species, which are also all hook and line gears including: 1) simple handline (*surrate*), multiple hook and line (*sibid-sibid*), troll line (*paguyod*) and bottom set long line (*kitang*). In Zambales Coast (part of the West Philippine Sea), Yutuc et al. (2018) recorded ten different types of fishing gears used in catching tuna species including three commercial (i.e., purse seine, ring net and Danish seine) and seven municipals (i.e., multiple handlines, handline, trammel net, bagnet, bottom set longline, otter trawl, and gillnet). Multiple handline and troll line are also used in Tawi-Tawi, Southern Philippines particularly for frigate tuna *Auxis thazard* and skipjack tuna *Katsuwonus pelamis*, respectively (Ajik & Tahiluddin, 2021; Mohammad et al., 2022). Hook gears locally known as "pasol/ taga" along with fish aggregating device known as "payao" are used in catching *A. thazard* in Sogod Bay, Southern Leyte (Ratilla et al., 2016).

The local names of the fishing gears reported are actually the same in all the municipalities except for the paired troll line. The paired troll line is locally termed as *sahid* in Tolosa, *pakaras* in Dulag and *bahan* in Mayorga. This gear is the most widely used (70.58%) among the three municipalities.

Paired Troll Line

The structure of the paired troll line gear is shown in Figure 2, and its specifications are presented in Table 3. Its mainline is made from a polyamide with a twine size ranging from 0.50 to 1 mm Ø and length ranging from 60 to 200 m. It consists 10 to 15 branch lines with twine size of 0.30 to 0.80 mm Ø and length of 0.50 to 1 m. The distance between branch lines measures 1.00 to 1.50 m. The line is coiled in a spool made from bamboo, or polyvinyl chloride (PVC) pipe. The sizes of the hooks vary from number 15, 16, and 17. The type of lures used varies in each municipality, and depends upon the preference of the fisher. Materials for the lures can be made from crystallite (metallic cloth) or silicone hose. Lures are typically customized to mimic the shape of small fishes that are preyed by tunas such as anchovies and sardines (Figure 2). Some specifications include metallic cloth being inserted inside the silicone hose to create a more attractive lure. Metallic cloth has various colors in order to lure tuna species. Some tuna fishers also prefer to buy ready-made lure from online shops.

Single Troll Line

Single troll line locally called as “limbag”, “singgol” or “solo-solo” is also a type of troll line that consists of only a single hook operated in a single boat (Figure 3). The spool is typically made from either wood, plastic, or polyethylene (PE) pipe. As indicated in Table 4, the main line is made from a polyamide with a thickness of 0.15 to 0.60 mm Ø and length of 50 to 200 m. A swivel is attached between the main line and branch line for the purpose of allowing the lines to rotate independently and prevent undesirable tangling. Furthermore, the branch line is made from either stainless-steel wires or polyamide with a size of 0.10 to 0.30 mm Ø and length of 7 to 45 m. The lure is made from a metal which is shaped by the fishers into fish-like.

Single Hook and Line with Float

Single hook and line with float are a type of a passive fishing gear that is widely used in targeting large pelagic species including tunas. An illustration of the gear is shown in Figure 4. The gear is composed of a spool which also serves as the floater, a mainline, a branch line (but sometimes no branch lines are attached), a single hook, sinker, and a swivel. The spool which also serves as floater is made from various materials such as styrofoam, empty plastic bottles and galloons — which preference depends on the fisher. The specifications of the single hook and line with float are shown in Table 5. The main line is made from polyamide measuring from 0.40 to 0.50 mm in size and up to 110 to 140 m long. The branch line can be made from stainless-steel wires or polyamide with a measurement of 0.40 to 0.50 mm Ø in size and about 0.30 to 40 m in length. A lead sinker is also attached to set the gear vertically in the water column. A swivel is also attached connecting the main line and the branch line in order to prevent tangling. The most unique feature of this gear among the different types of hook and line gears recorded in this study is its utilization of live fish as a natural bait.

Fishing Practices

Fishing practice depends on the type of fishery, geographic location, and the technology used, among others. In Leyte, tuna fishing involves both active and passive fishing gears. Active fishing gears are the type of gears used to capture the fish based on an aimed chase to the target species (Bjordal, 2002). On the other hand, passive fishing gears also known as stationary fishing gears are those type of gears that generally depend on the behavior and movement of the target species towards the gear. In this study, paired troll line and single troll line are identified as active fishing gears, while the single hook and line with float is considered as passive. The first two gears use a trolling method while the last one employs attracting and setting. Dickson & Natividad (2000) reported that the introduction of fish aggregating device locally known as “payao” in tuna fishing in 1975 resulted to the rapid development of tuna and small pelagic fisheries in the country. However, the current study observed that fishers at the selected study sites in Leyte do not use payaos in the small-scale tuna fishery.

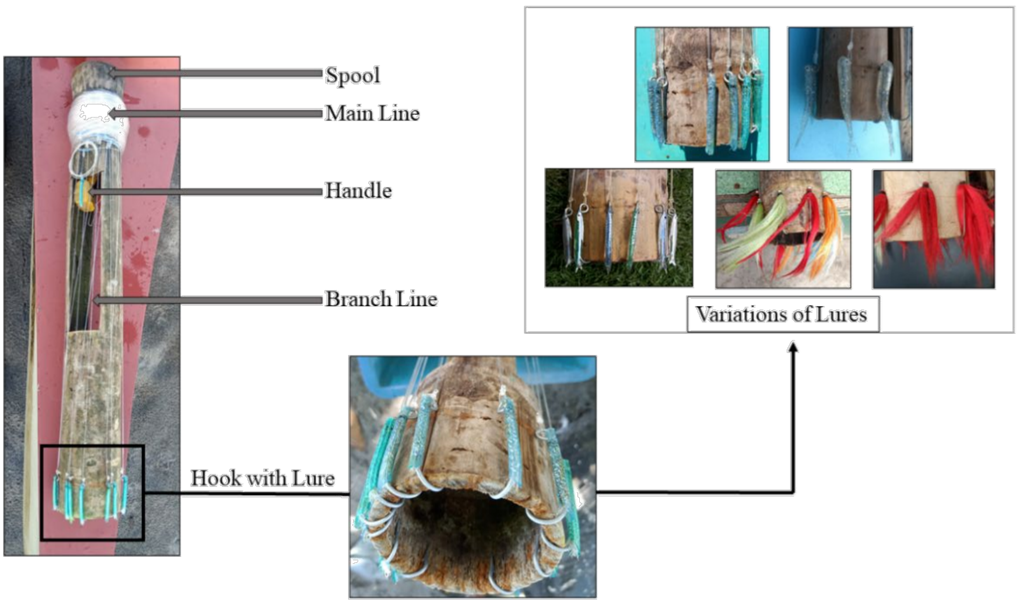

Figure 2. An illustration showing the parts of a paired troll line and the different types of lures used for the gear

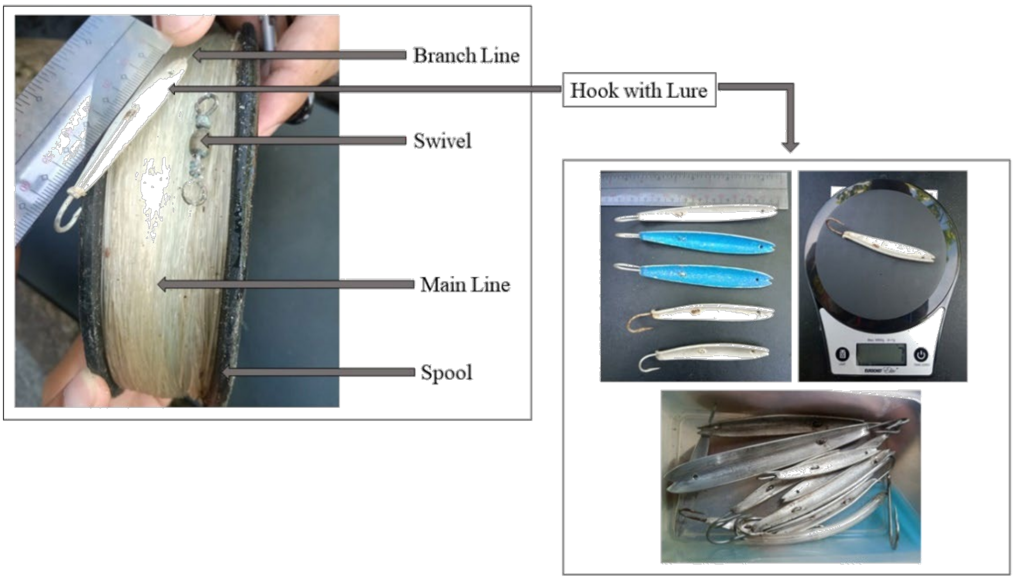

Figure 3. An illustration showing the parts of a single troll line

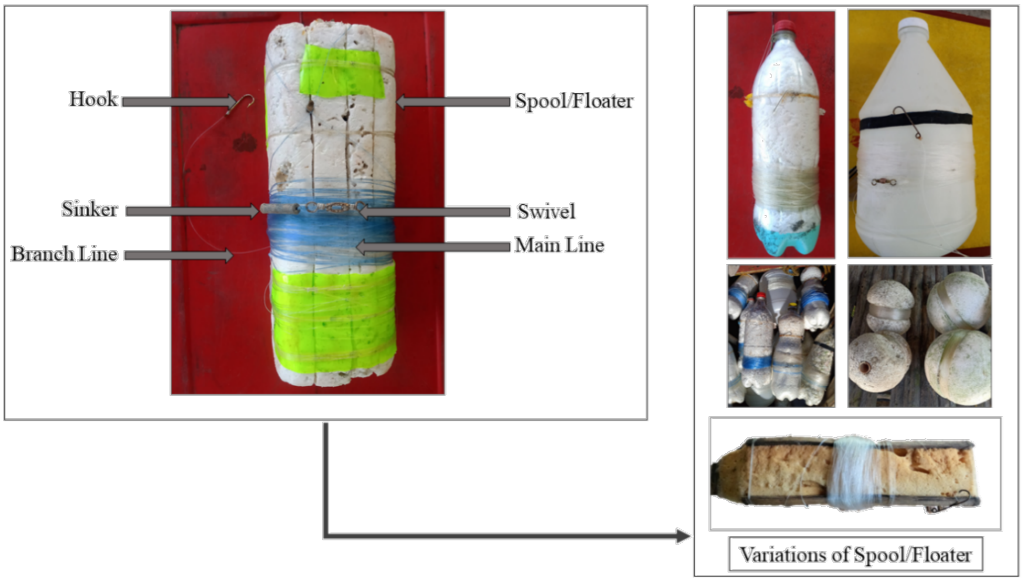

Figure 4. An illustration showing the single hook and line with float and its parts

Table 3. Parts and specifications of paired troll line used in tuna fishing

Parts	Materials	Description	Function
Spool	Bamboo, PVC pipe	2-3 feet long	It is where the entire line is being coiled.
Main line	Polyamide	Size: 0.50-1 mm Ø Length: 60-200 m	Serves as primary line where the branch lines containing the hooks with lures are attached.
Handle	Rubber, Styrofoam	Part of the gear held by fishers during fishing operations.	This is used in order to prevent hand abrasions/ injury to the fishers during operations.
Branch line	Polyamide	Size: 0.30-0.80 mm Ø Length: 0.50-1 m	It is where the hook with lure is attached.
Hook	Metal	Hook size: #15, #16, #17	Part of the gear where tunas and other species are actually caught.
Lure	Silicone hose, Crystallite (metallic cloth), Rubber	2-3 inches long	Used in attracting or luring tunas.

Table 4. Parts and specifications of a single troll line

Parts	Materials	Description	Function
Spool	Wood, Plastic, PE pipe	Cylindrical	It is where the entire line is being coiled.
Main line	Polyamide	Size: 0.15-0.60 mm Ø Length: 50-200 m	It is the primary line.
Swivel	Metal	Barrel swivel	Used to prevent undesirable tangling.
Branch line	Stainless-steel wires, Polyamide	Size: 0.10-0.30 mm Ø Length: 7-45 m	It is where the hook is attached.
Hook	Metal	Hook size: #14, #15, #16, #17, #19, #20, #22, #23, #60, #62, #64	Main part of the gear where tuna and other species are actually caught.
Lure	Metal (customized)	2-6 inches long	Used in attracting or luring tunas.

Table 5. Parts and description of single hook and line with float

Parts	Materials	Description	Function
Spool/Floater	Styrofoam, Plastic bottle, Galloon	Structure varies depending on the preference of the fisher.	It is where the entire line is being coiled. It also serves as the gear's floater when deployed.
Main line	Polyamide	Size: 0.40-0.50 mm Ø Length: 110-140 m	It is the primary line.
Swivel	Metal	Barrel swivel	Used to prevent undesirable tangling.
Sinker	Lead	Elongated, cylindrical	Used to make the line sink to the water column vertically.
Branch line	Stainless-steel wire, Polyamide	Size: 0.40-0.50 mm Ø Length: 0.30-40 m	It is where the hook is attached.
Hook	Metal	Hook size: #15, #16, #17	Used to catch large pelagic species including tuna.
Bait	Smaller fishes such mackerel and scads	Alive	Used to bait large pelagic species such as tunas.

Paired Troll Line/Two-Boat Troll Line

Paired troll line or two-boat troll line is operated using a pair of boats as shown in Figure 5. The fishers depart early in the morning at 4:00 AM to 5:00 AM, and travel for almost 2-3 hours to reach the fishing ground particularly in San Pedro Bay or the contiguous waters of Leyte Gulf. Both fishers scout for schools of feeding tunas on the surface of the water. Fishers use visual cues to detect the presence of tuna school locally termed as "bakal". One of the most common cues is the presence of birds gathering above the water. Once a school of tuna is found, the gear will be set and the pair of boats maneuver toward the school while maintaining considerable distance from each other to stretch the gear completely. When the gear is stretched on both ends, the two boats then continuously travel parallel to each other until the school of tuna passes between them. When there is already a catch, the pair of boats slow down and maneuver close to each other to retrieve the line by either one of them. After collecting the catch, they set out for another run and repeat the process for more trials as long as there are still school of tunas in the area. Later in the afternoon, if there is enough catch, the fishers may decide to travel back to the landing site in order deliver their catch as fresh as they can and also for them to land while it is still daytime -since their travel time from the landing site to the fishing area and vice versa ranges from 1-4 hours (depending on the location where the tunas are schooling). However, some fishers land late at around 6:00 PM to 8:00 PM especially when catch is lean. At the landing site, their preferred middleman locally known as "lab-asero" or "postor" are regularly waiting for them to purchase their catch at a set price. The profit will be divided fairly between the pair.

In the absence of a boat partner which happens rarely, paired troll line is operated with a floater/buoy. This trolling method is locally known as "surfing" (Figure 6). In this method, one end of the main line is tied to a floater/buoy while the other end is held by the fisher. As the boat is continuously moving, the gear tied to the buoy is dragged along. The advantage of this practice is it can be operated by a single fisher without depending on a partner. Also, the total catch of this operation is solely owned by the operator. However, since there is only a single boat involved, it moves slower and the gear is not towed parallel to the boat. Another disadvantage is that the fisher cannot totally control the stretched gear to where he wants it to be. Thus, catch could be lesser than the two-boat troll line.

Single Troll Line

Single troll line is operated by towing just like the paired troll line. However, this gear has only a single hook and only one boat does the fishing operation (Figure 7). Similar with the paired troll line, the fishing gear operation involves scouting for school of tunas. When a school is sighted, the gear is deployed and soaked to the water. After which, the gear is towed as the boat continuously chase the target school of tunas. This practice is used most often when the fisher departs and operates alone. This type of fishing practice along with the paired troll line is usually done during the peak season of tuna fishing (mostly from April to May). Once their contacts from nearby municipalities and from Samar area notify them that schools of tuna are already present, most of the small-scale tuna fishers in Leyte set out together the following day.

Single Hook and Line with Float

Compared to the previously mentioned fishing gears, the structure of single hook and line with float is much simpler (Figure 8). After the fisher departs from the shore at around 4:00 AM to 5:00 AM, he will first catch smaller fish species such as mackerel and scads that will be used as live bait using a multiple hook and line while still in shallower waters. The smaller fish catch will be hooked in its dorsal part to be used as bait while it is still alive. After which, the gear is deployed and is left in place while the floater remains on the surface of the water. As the live bait continuously moves, it may attract large pelagic species including tunas. While waiting for fish catch from the main gear, the fisher may use another type of gear to augment the catch. The fisher then comes back after some time of at least 30 minutes to check the single hook and line with float. The presence of catch is detected by the irregular movement of the gear's floater. When there's already catch the fisher then retrieves the gear.

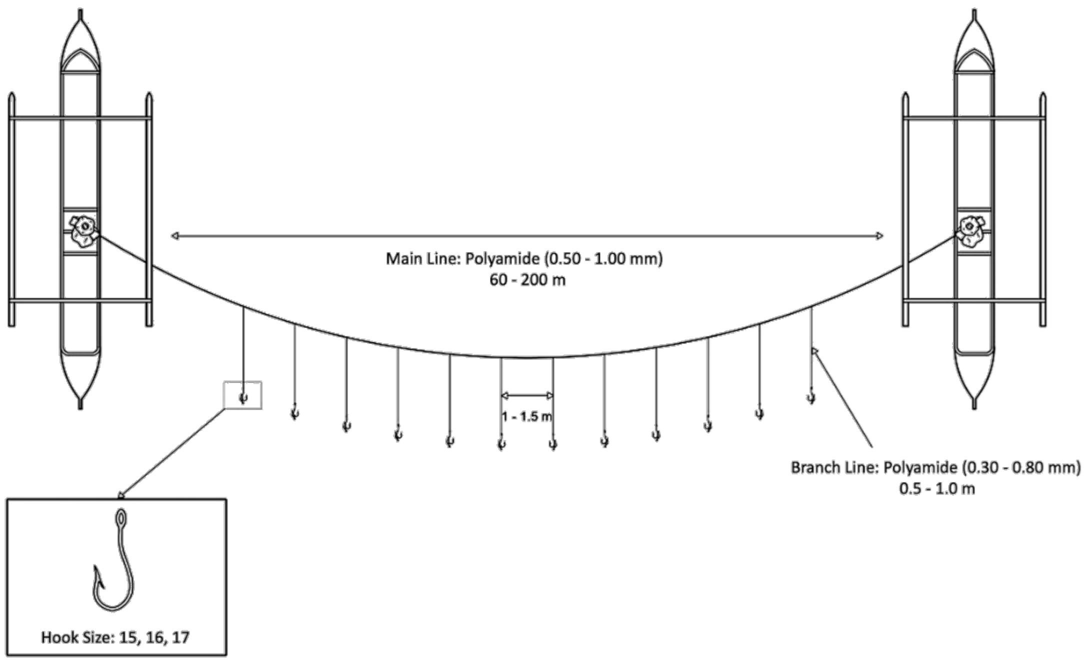

Figure 5. An illustration showing the operation and specifications of paired troll line/two-boat troll line

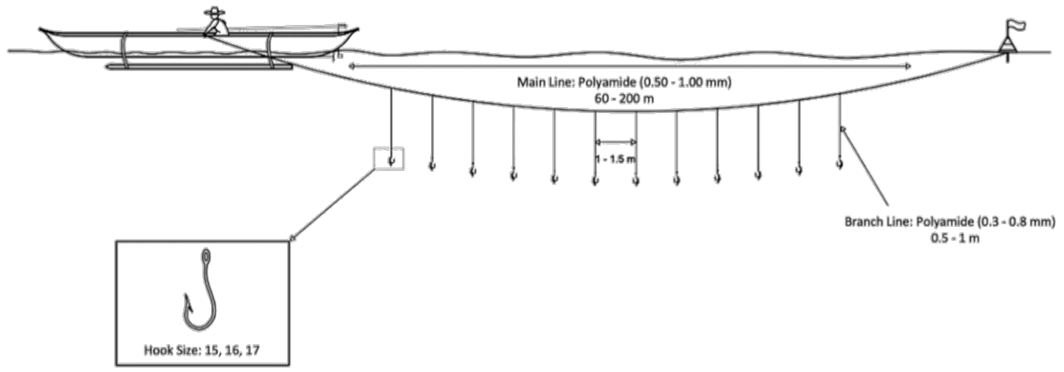

Figure 6. An illustration showing the operation and specifications of a paired troll line with a buoy/floater

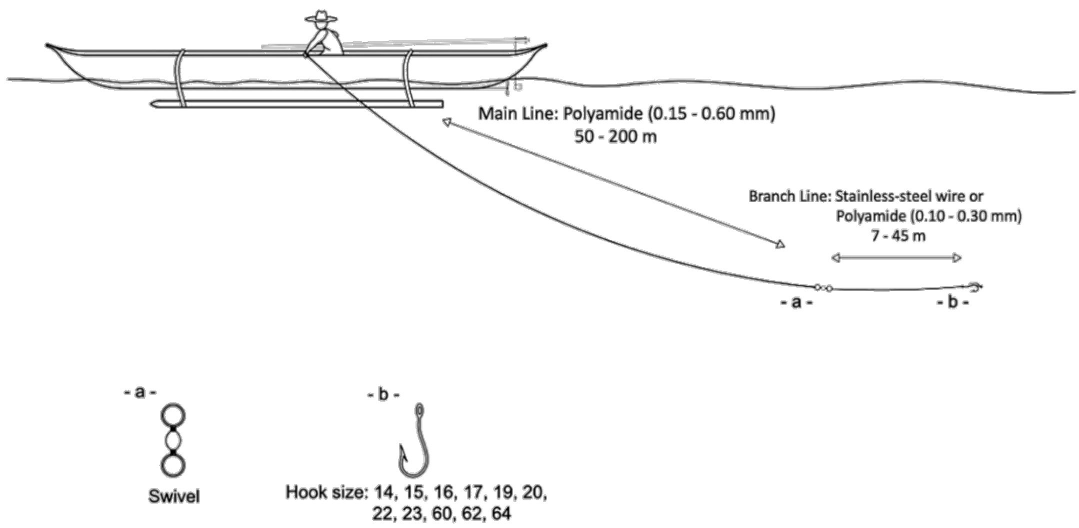

Figure 7. An illustration showing the operation and specifications of a single troll line

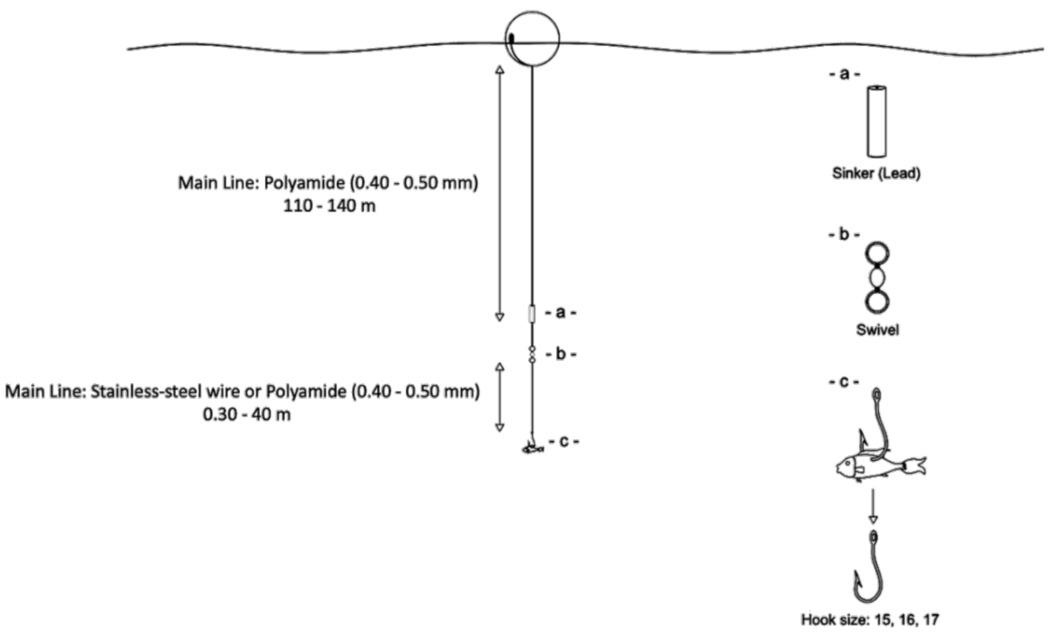

Figure 8. An illustration showing the operation and specifications of a single hook and line with float

Catch Rate

The catch rate of the small-scale tuna fishery in the selected study sites was expressed through catch per unit effort (CPUE) in terms of kilogram per hook (kg/hook) for the paired troll line, and kilogram per fishing hour (kg/h) for the single troll line. The most commonly used CPUE for hook and line gears is kg/h, however, kg/h is used for the latter gear since it has only one hook. Records on the fishers' fishing efforts which included the number of boats used, size and number of hooks used, number of hours spent every fishing trip, and their total catch (kg) were gathered through regular weekly field visits to the landing sites. Sampling was done randomly and data were recorded as soon as the fisher has landed from the fishing trip. The data on the fishing effort as well as the CPUE of the two fishing gears (paired troll line and single troll line) are shown in Table 6.

Table 6. Fishing effort and average catch per unit effort of small-scale tuna fishery in the selected landing sites in Leyte, Eastern Visayas, Philippines

Variables	**Municipality**		
	Tolosa	**Dulag**	**Mayorga**
Paired troll line			
Number of hooks used			
Average	11±1.00	12±0.00	13±1.00
Range	10 – 12		11 – 15
Number of hours spent			
Average	7±1.05	8±0.00	8.33±0.52
Range	6 – 8		8 – 9
Total Catch (kg)			
Average	24.90±13.23	5.88±0.53	15.83±9.09
Range	4 – 49	5.5 – 6.25	5.5 – 25.25
CPUE (kg/hook)			
Average	2.31±1.39	0.49±0.04	1.29±0.80
Range	0.33 – 4.70	0.46 – 0.52	0.46 – 2.16
Single troll line			
Number of hooks used	-		
Average	-	1±0.00	1±0.00
Range	-	1	1
Number of hours spent	-		
Average	-	6±0.00	8±.1.00
Range	-	6	7 – 9
Total Catch (kg)	-		
Average	-	2.25±0.00	7.25±3.85
Range	-	2.25	3 – 10.5
CPUE (kg/h)	-		
Average	-	0.38±0.00	0.89±0.44
Range	-	0.38	0.43 – 1.31

Table 7. Catch species composition recorded during the actual sampling

Local Name	Common Name	Scientific Name	Number of Individuals	Percentage Composition (%)
Tuna species				
Baragsikol	Longtail Tuna	*Thunnus tonggol*	53	50.48
Baragsikol	Bigeye Tuna	*Thunnus obesus*	23	21.90
Turingan/Bagaongon	Eastern Little Tuna	*Euthynnus affinis*	19	18.10
Mangko/Lison	Frigate Tuna	*Auxis thazard*	4	3.81
Sub-total	99	94.29		
Other species				
Kalapion	Torpedo Scad	*Megalaspis cordyla*	4	3.81
Tangige	Narrow-barred Spanish Mackerel	*Scomberomorus commerson*	2	1.90
Sub-total	6	5.71		
Total	105	100		

Catch Composition

Dickson & Natividad (2000) reported that the local tuna fishery in the Philippines is comprised of six major species including yellowfin tuna *Thunnus albacares*, skipjack tuna *Katsuwonus pelamis*, bigeye tuna *T. obesus*, bullet tuna *Auxis rochei*, eastern little tuna *Euthynnus affinis*, and frigate tuna *A. thazard*. This study recorded a total of six species during the entire actual catch sampling which included four tuna species and two other fish species (Table 7). The tunas which are the primary target species of the fishers included: 1) longtail tuna *T. tonggol*, 2) *T. obesus*, 3) *E. affinis*, and 4) *A. thazard*. The other two species included: 1) torpedo scad *Megalaspis cordyla* and 2) narrow-barred Spanish mackerel *Scomberomorus commerson*. However, it shall be noted that these samples were only from the paired and single troll line gears since during peak seasons, these gears are widely used for fishing tunas. No catch from single hook and line with float were recorded since this was not used by the fishers during the actual sampling period.

In the collective data during the actual sampling from the three municipalities regardless of the type of gear used, the samples were dominated by *T. tonggol* (50.48%) followed by *T. obesus* (21.90%) and *E. affinis* (18.10%). The least caught tuna species was *A. thazard* (3.81%). The remaining 5.71% was comprised of *M. cordyla* (3.81%) and *S. commerson* (1.90%). In a pole and line fishery in Indonesia, Nainggolan et al. (2017) reported that the catch was comprised of *K. pelamis* (72.7%), *T. albacares* (24.5%), *A. rochei* (2.8%). The *K. pelamis* was also the most dominant species caught in the Zambales Coast, followed by *T. albacares*, and *T. obesus* (Yutuc et al., 2018).

Though there were only two non-tuna species recorded during the actual sampling, fishers mentioned during the face-to-face interviews other species that are also caught by tuna fishing gears which include dolphin fish, blue marlin and shark. These results show that most of the bycatch species of the tuna fishery in the small-scale tuna fishery in Leyte are of commercial value.

Perceptions and Current Perceived Issues in Tuna Fishery

According to the face-to-face interviews with the respondents, tuna fishing is equally profitable in comparison to other fishery since tunas have high market value and are much larger. Thus, it has more weight and sells more expensive per piece. However, the most common challenge in tuna fishing is the seasonality of these species. Since these are migratory species, they do not occur permanently in a specific fishing area for a longer period of time. Recently, seasons of tunas are unpredictable since they depend on the availability of their food particularly smaller fishes such as anchovies and sardines. If preys are not available, so as tunas. One of the major reasons to such decline in the preys of tunas according to the fishers is the operation of illegal fishing particularly seining, trawling, as well as the operation of bag nets which target these smaller-sized fishes. Unfavorable weather conditions also hinder their fishing operation. Further, the continuous oil price hike affects the frequency of their fishing trips since they cannot afford to buy expensive fuel.

Border restriction is also one of the issues raised by the tuna fishers since some reach to other municipal waters. Thus, these small-scale tuna fishers suggest to lift the strict ordinance about the border restriction of municipal waters. This ordinance restricts fishers to enter the municipal waters under other local government unit or municipality. The fishers added that they only have limited fishing areas due to this restriction, thus, they have lesser catch. They also suggested to strengthen the policies that prohibits illegal fishing in their localities. Minimal assistance on providing of materials for their fishing gear is also of great help for them. Similar issues were reported in the tuna fishing in Pangasinan wherein the high cost of fuel is also considered the primary issues of the fishers (Mendoza et al., 2023). Other issues included decline in fish catch, increasing number of fishers, illegal fishing activities, among others. In Sogod Bay, Southern Leyte, various issues and concerns in the frigate tuna industry including the presence of large-scale commercial fisheries, illegal fishing, pollution, and poor implementation of the fisheries laws were reported (Ratilla et al., 2016).

Conclusion

This study is the first to present a comprehensive information about the municipal or small-scale tuna fishery in the province of Leyte, Eastern Visayas, Philippines. The fishery can be regarded as selective and non-destructive, based on the types of fishing gear and practices employed by the fishers. The results may serve as a baseline for monitoring and understanding the status and performance of the fishery, aiding in the formulation of management plans for the development and sustainability of the small-scale tuna fishery in the province, and region-wide eventually. Continuous monitoring is necessary to better comprehend the dynamics of the fishery. Additionally, recognizing the migratory behavior of tuna species, adjacent municipalities and provinces surrounding the tuna fishing grounds particularly San Pedro Bay and Leyte Gulf are encouraged to collaborate in crafting and implementing a harmonized and holistic management strategy that ensures effective resource management and promotes equity among tuna fishers and other stakeholders.

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Compliance With Ethical Standards

Authors' Contributions

COR: Conceptualization, Investigation, Data curation, Formal analysis, Writing – original draft

RMPG: Conceptualization, Data curation, Formal analysis, Writing – review & 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

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

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RESEARCH ARTICLE

Investigation of the use of hops (*Humulus lupulus*) and calendula (*Calendula officinalis*) as disinfectants on the hatching efficiency of rainbow trout (*Oncorhynchus mykiss*)

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ABSTRACT

This study investigates the potential application of plant-based resources with antimicrobial properties, namely hops (*Humulus lupulus*) and calendula (*Calendula officinalis*), as viable alternatives to commercial disinfectants for the prevention of fungal growth during the incubation period of rainbow trout (*Oncorhynchus mykiss*) eggs. Fertilized eggs were examined with daily 20-minute baths in 0.25 mg, 0.5 mg, and 1 mg concentrations throughout the incubation period (33-35 days). Control group, commercial formaldehyde, hops, and calendula groups were examined in triplicate for each concentration. As a result, the lowest hatching ratio was observed in the control group with 84.77%, while the hatching ratios in the other groups were as follows: commercial disinfectant group with 86.22%, hops group with 87.44% (0.25 mg), calendula group 88% with (0.25 mg), calendula group with 89% (0.5 mg), calendula group with 89.33% (1 mg), hops group with 89.55% (0.5 mg), and the highest hatching ratio was found in the hops group with 90.66% (1 mg). The lowest survival rate was observed in the control group with 85.22%, with the survival rates of the other groups were 86.44% in the commercial disinfectant group, 87.55% (0.25 mg) in the hops group, 88.55% (0.25 mg) in the calendula group, 88.88% (0.5 mg) in the calendula group, 89.33% (1 mg) in the calendula group, 89.55% (0.5 mg) in the hops group, and the highest survival rate was 90.11% (1 mg) in the hops group. In conclusion, it was specified that plant-based by-products (hops and calendula) could be used as alternative disinfectants to commercial chemicals in the disinfection of rainbow trout eggs and fry, and the most appropriate concentration was 1 mg.

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Introduction

In recent years, trout farming has a magnificent increase in interest, becoming one of the top ventures in aquaculture globally with an accompanying rise in demand for trout fry, which in turn made the production of healthy eggs and fry crucial to enhancing both productivity and quality in trout aquaculture. During the hatching, fish eggs are placed rather densely on incubation racks, creating a high risk of fungal contamination, which can rapidly spread from a single infected egg to other healthy ones. Such a contamination often results in the death of a substantial portion of healthy eggs, and in some severe cases, may lead to the loss of whole batches. This stage of the hatching is when the most significant losses in egg and pry production occur. While a loss rate of 10-20% is during incubation is tolerable, 20-30% is unacceptable (Çelikkale, 1988).

Controlled environmental conditions are required to minimize mortality during the incubation period, and different doses of various disinfectants are used to prevent mortality during the incubation period and larval stages, especially to prevent losses due to fungal and other diseases. The disinfectant substances used are selected because they are abundant, economical and effective. For this purpose, chemicals such as malachite green, formalin, iodine, iodophor, methylene blue, etc. are used in hatcheries (Yanik et al., 2009).

Hatchers can implement various preventive measures to minimize the loss rate during the incubation phase in trout farming. These measures primarily focus on preventing fungal infections during the mentioned period and the subsequent larval phase, all of which include the application of a variety of treatments and chemical disinfectants at different concentrations to some extent. In the context of trout farming, some of the common chemical disinfectants that help protect the eggs during the incubation period and the subsequent fries are malachite green, formalin, iodine, iodophor, methylene blue, bronopol, wescodyne, buffodine, sulformerthiolate, merthiolate, acriflavine, gentian violet, sodium and calcium hypochlorite, chloramine, potassium permanganate, copper sulfate, and salt etc. (Çelikkale, 1988; Barnes et al., 1997; Emre & Kürüm, 1998; Hekimoğlu, 2001; Arda et al., 2002; Timur & Timur, 2003; Alpbaz, 2005; Çağıltay, 2007; Güner et al., 2007; Yılmaz, 2010; Ural et al., 2011a).

However, some reports indicate that some of the chemical substances used to disinfect eggs as a preventive measure in incubation systems may have harmful effects on healthy eggs as well (Alderman, 1984). For instance, due to its harmful effects and potential risks to human health, many countries have banned the use of malachite green (Emre & Kürüm, 1998; Timur & Timur, 2003; Güner et al., 2007; Yılmaz, 2010). Furthermore, the environmental impact and safety of these chemical substances continue to be subjects of debate. Thus, the research on and the promotion of the natural disinfectants with no harmful effects on the environment, fish, or human health is vital, with researchers worldwide continuing to explore alternative medical plants for use in aquaculture (Cline & Post,1972; Lio-Po et al., 1982; Bayley, 1984).

Hops (*H. lupulus L.*), belonging to the Cannabaceae family, is a dioecious perennial climber native to temperate climates in the Northern Hemisphere. Although it is primarily known as one of four ingredients required to make beer, Hops was initially used as medicinal herb (Bocquet et al., 2018). Nearly all parts of the plant are rich in bioactive compounds. The strong antimicrobial, antioxidant, and antifungal properties of its bitter acids and flavonoids, combined with the growing interest in natural health-promoting substances, offer new and intriguing perspectives on the use of hops beyond brewing. With its recognition as a medicinal plant since ancient times, humanity's cultivation of Hops requires a revisit to with an emphasis on its health-enhancing attributes (Lukešová et al., 2019).

Calendula *(C. officinalis)* is a plant native to the Mediterranean region, with centuries worth of history in ancient medicine, and is commonly referred to as 'aynısafa' in Turkish (Ramos et al., 1998). The English herbalists Gerard and Culpeper were first to discover the medicinal properties of the plant in the 16th and 17th centuries. Another English herbalist Grieves, in the early 20th century, recommended the use of Calendula flowers, nothing that applying the ligulate flowers directly to insect bites could reduce pain and swelling (Della Loggia et al., 1994). In light of these properties, our study investigates the effects of hops and Calendula, which have the potential to serve as natural antimicrobial agents, in preventing fungal growth on trout eggs and their impact on hatching efficiency (Alderman, 1984; Emre & Kürüm, 1998; Timur & Timur, 2003; Güner et al., 2007; Yılmaz, 2010).

Material and Methods

This study was carried out at the Freshwater Fish and the Inland Fish Research and Application Centers at Atatürk University between December 2022 and February 2023, using 2 female and 4 male broodfish, each 3 years old (Table 1). In this research, female and male broodstock fish were stripped according to the standard dry stripping method and the eggs were fertilized under optimal conditions using male sperm. Afterwards, the washed, intact, and fertilized eggs were placed in pre-sterilized incubation baskets according to the volumetric method, each carrying 100 eggs. These included: 24 fiberglass baskets (15×10 cm) placed in 8 all-fiberglass incubation trays (50×40 cm), in 8 aquariums with a capacity of 240 liters each, at the end of which rainbow trout eggs were treated with hops and calendula extract.

In the study, hops and calendula collected naturally and stored under airtight conditions were provided from a herbalist named İpekyolu (Muratpaşa, Haşil Efendi, No: 32, 25100 Yakutiye/Erzurum). Plants were extracted using ethanol as solvent (plant-ethanol ratio, 1:20) and the solutions were filtered using a vacuum pump. A rotary evaporator set at 65°C concentrated the filtered solutions to obtain the extracts. From the beginning of incubation until hatching, eggs were given daily hop and marigold extracts in single doses of 0.25 mg, 0.50 mg and 1.00 mg after the water flow in each aquarium was stopped for 20 min and then the water flow was restarted immediately. Dead and/or bleached eggs were removed with sterilized siphons. In addition, eggs were monitored daily throughout the study. No dose of extracts obtained from yolk sacs was given to the subjects until the larval stage and monitoring continued until the larvae reached 1 gram in weight. Before the completion of the study, the fish subject to the study were stored frozen at -80°C in the Atatürk University Inland Fish Research and Application Center.

$$\text{Incubation Efficiency (\%)} = \frac{\text{Number of live offspring}}{\text{Total number of eggs}} \times 100 \qquad (1)$$

$$\text{Survival Rate (\%)} = \frac{\text{Number of fish at the end of the trial}}{\text{Number of fish at the beginning of the trial}} \times 100 \qquad (2)$$

Water quality parameters (including water temperature, dissolved oxygen, and pH) were measured during study period.

Data Analysis

In this study, the significance of the difference data of all groups determined as hatching efficiency (%) and survival rate (%) of different concentrations of hops and calendula in egg, eyed egg, and larval stages was determined using One Way ANOVA and DUNCAN tests.

Results

The eggs turned into eyed eggs between days 16 and 19, and the larvae hatched between days 33 and 35. In the two female and four male broodstock used in the study, the average weight and length of the females reached 0.790 kg and 37 cm respectively, and the average egg yield was 1.576 per kg, while the average weight and length of the males were 0.735 kg and 39 cm, respectively (Table 1).

Table 1. The brood stock in the study (Mean±SD)

Gender	Value	Weight (kg)	Length (cm)	Egg yield/kg
FEMALE	N	2	2	2
	Min - Max.	0.755 – 0.825	33-41	1479 – 1673
	Mean±SD	0.790±0.3	37±1.8	1576±217
MALE	N	4	4	
	Min-Max.	0.674 – 0.796	36 - 42	
	Mean±SD	0.735±0.2	39±1.7	

Table 2. Change in hatchability rate depending on groups (Mean±SD, %)

Groups	Hatching efficiency of the groups (%)
Hops 0.25 mg	87.33±2.08 ^{C*}
Hops 0.5 mg	89.00±1.00 ^{B}
Hops 1 mg	90.33±0.58 ^{A}
Calendula 0.25 mg	87.67±0.58 ^{C}
Calendula 0.5 mg	88.67±0.58 ^{B}
Calendula 1 mg	89.00±1.00 ^{B}
Commercial Disinfectant	86.33±0.58 ^{D}
Control	84.67±0.58 ^{D}

Note: $^{*\ A,\ B}$: Uppercase letters denote significant differences in hatchability rates between groups. Groups within the same row that are marked by different uppercase letters exhibit statistically significant differences (p<0.05).

The results indicated significant differences among the groups ($p<0.05$), with the control group having the lowest hatching efficiency at 84.67%, while the hops group had the highest efficiency at 90.33% (1 mg). The hatching efficiency of the remaining groups was as follows: commercial disinfectant group 86.33%, the hops group 87.33% (0.25 mg), the calendula group 87.67% (0.25 mg), the calendula group 88.67% (0.5 mg), the calendula group 89% (1 mg), the hops group 89% (0.5 mg) (Figure 1 and Table 2).

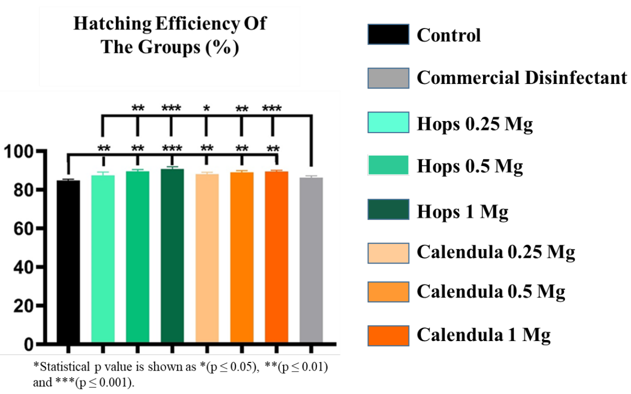

Figure 1. Hatching efficiency of the groups (%)

The analysis of survival rate (%) revealed significant differences between the groups ($p<0.05$), with the control group having the lowest survival rate of 85.22%, while the hops group had the highest survival rate. The survival rates of the other groups were as follows: commercial disinfectant group 86.44%, the hops group 87.55% (0.25 mg), the calendula group 88.55% (0.25 mg), the calendula group 88.88% (0.5 mg), the calendula group 89.33% (1 mg), the hops group 89.55% (0.5 mg) (Figure 2 and Table 3).

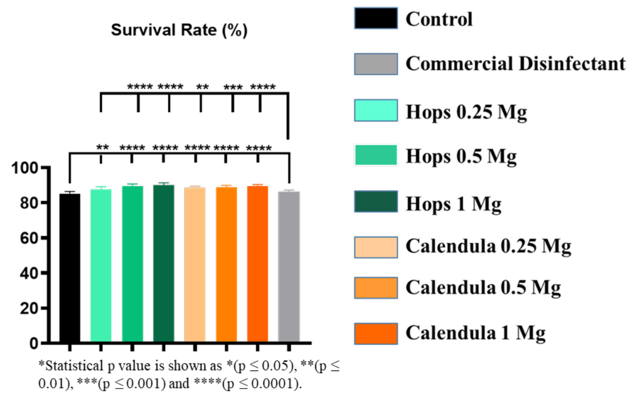

Figure 2. Survival rate (%)

The average water temperature, pH, and dissolved oxygen (DO) values measured during the incubation period are given in Table 2. The changes between these parameters measured daily were found to be statistically insignificant ($p>0.05$), and the means values of water temperature, pH, and dissolved oxygen (DO) were measured 10, 8.65 and 7.1, respectively.

Table 3. Change in survival rate depending on groups (Mean±SD, %)

Groups	Survival rate (%)
Hops 0.25 mg	87.33±2.08 ^{C*}
Hops 0.5 mg	89.00±1.00 ^{B}
Hops 1 mg	90.33±0.57 ^{A}
Calendula 0.25 mg	87.67±0.57 ^{C}
Calendula 0.5 mg	88.67±0.57 ^{B}
Calendula 1 mg	89.00±1.00 ^{B}
Commercial Disinfectant	86.33±0.57 ^{D}
Control	84.67±0.57 ^{D}

Note: $^{*\ A,\ B}$: Uppercase letters denote significant differences in hatchability rates between groups. Groups within the same row that are marked by different uppercase letters exhibit statistically significant differences ($p<0.05$).

Table 4. Water quality parameters in the hatching aquariums (Mean±SD)

Parameter	Control Group	Commercial Disinfectant Group	Hops Group	Calendula Group
Water Temperature (°C)	9.8±0.2	9.9±0.2	10.1±0.1	10.3±0.3
pH	8.74±0.4	8.73±0.4	8.65±0.2	8.63±0.2
DO (mg/L)	7.0±0.3	7.61±0.8	7.08±0.3	6.70±0.5

Discussion

Hatchers use a wide variety of chemical agents during the incubation phase of rainbow trout for the disinfection of eggs and fry. However, there are significant variance in the methods of applications and concentrations of these chemical substances, with persisting debates on their safety on water and living organisms. Therefore, the importance of the use of entirely natural disinfectants and preventive measures that do not cause any harmful effects – either respiratory or acute and chronic – on the environment and other living beings has become increasingly recognized (Can et al., 2012).

Many studies indicate the destructive effects of plant extracts, their main components and essential oils on fish eggs or fish egg-preserved *Saprolegnia parasitica* fungi (in vitro) (Khallil, 2001; Mori et al., 2002; Udomkusonsri et al., 2007; Ghasemi Pirbalouti et al., 2009; Khosravi et al., 2012; Xue-Gang et al., 2013).

In this study, the extracts of the two plants mentioned were extracted and applied to the eggs of rainbow trout immediately after fertilization. The concepts of time in the embryonic stages were examined on the trout eggs. As a result; the embryological development, fertilization and survival rates of the experimental groups after short-term preservation were examined. When the obtained data were examined, it was reported that no difference was observed in the fertilization rate after storage for up to 6 hours compared to the control group, that lemon balm (*Melissa officinalis*) showed a protective effect without losing the ability of the eggs to be fertilized after short-term storage, and that it reduced losses due to fungus by 10%, and that coriander (*Coriandrum sativum*) showed a mortal effect at the applied concentration and should be used at a lower concentration (Özdemir, 2018).

In the study, the number of eggs that died due to infection in the control group was determined as 635.00±54.049. The number of these dead eggs was 325.00±31.943, 393.67±3.283 and 420.00±80.829 in the groups which garlic peel extract was applied at concentrations of 0.4, 0.8 and 1.6 g/L, respectively. Similarly, the number of eggs that died in the 0.8 and 1.6 g/L garlic stalk groups were reported as 370.67±24.333 and 166.00±28.478, respectively. The findings suggest that garlic peel extract used at concentrations of 0.4, 0.8 and 1.6 g/L reduced the number of eggs that died due to fungus compared to the control group ($p<0.05$). It was also reported that although there was a slight increase in the number of dead eggs in the 3.2 g/L group compared to the control group, this increase was not statistically significant ($p>0.05$) (Özçelik, 2019).

In research examining the effects of vinegar disinfection following the fertilization of trout eggs through milking, it was reported that the application of a 12 mL/L vinegar solution produced favorable results (Ural et al., 2011b). The study employed various concentrations of vinegar and was conducted in a controlled hatchery environment where water temperature was kept at 8.4±0.2°C in fiberglass tank systems. The pH of the water in the control group was measured at 7.6±0.4, while the pH in the group treated with 12 mL/L vinegar decreased to 4.0±0.1. As a result of these data, the mortality rate in the control group was recorded at 20.2%, whereas the group exposed to vinegar treatment exhibited a significantly lower mortality rate of 12.1%.

In this study, 35 mL/L of vinegar stock solution was applied, resulting in a pH of 5.9 in the incubation water. The expert posited that the differences in mortality rates observed in both studies could be attributed to the variations in pH levels and water temperatures, indicating a potential correlation between these factors and the effectiveness of vinegar as a disinfectant in egg incubation.

Recent works in the field show that there are very few studies focusing on the use of completely natural substances in combating fungal infections in trout eggs. The studies, or lack thereof, inspired the study on the potential use of hops and calendula, both medicinal plants, as disinfectants. The use of hops dates back to ancient times and it is a well-known preservative. In addition to its antimicrobial properties, it has widespread industrial uses because almost all parts of the plant are rich in bioactive compounds. The strong antimicrobial, antioxidant, and antifungal properties of its bitter acids and flavonoids, combined with the growing interest in natural health-promoting substances, offer new and intriguing perspectives on the use of hops beyond brewing. The cultivation of hops by humanity, which has been considered a medicinal plant since ancient times, should be reconsidered by emphasizing its positive effects on health (Lukešová et al., 2019).

In light of these properties, our study investigated the effects of hops and calendula, which have the potential to be natural antimicrobial agents, on preventing fungal growth in trout eggs and their impacts on hatching efficiency (Alderman, 1984; Emre & Kürüm, 1998; Timur & Timur, 2003; Güner et al., 2007; Yılmaz, 2010).

During the incubation stages of trout eggs, it is crucial to use entirely natural products, which have no adverse effects, as alternatives to chemical disinfectants. The works in the field so are insufficient to explore the potential of the availability of plant-based medicinal disinfectants, and warrants further research. In this context, the study investigated the feasibility of using hops and calendula, known for their antifungal disinfectant properties, on trout eggs.

Conclusion

This study involved the application of hops and calendula to trout eggs in doses of 0.25 mg, 0.50 mg, and 1.00 mg/L. The results showed that the group with the 1.00 mg concentration of hops had the best hatching efficiency (%), while the control group had the lowest hatching efficiency. Similarly, in terms of survival rate, the same group with the 1.00 mg concentration of hops had the highest survival rate, with the control group having the lowest, thus revealing significant statistical differences between the groups ($p<0.05$). This research showed that increasing the concentration values gave positive results in hatching efficiency and survival rate. Therefore, it is recommended to determine the best rate by trying concentrations above 1 mg on future researches.

The water temperature in the incubation system during the study was at approximately 9.9°C. Maintaining the optimal levels for water temperature and other parameters is crucial during the incubation phase, since water quality, particularly the water temperature, are variables that can result in fungal growth in eggs. Meanwhile, the groups in the study had no significant fungal growth during the study. The findings suggest that the results may be applicable to facilities with similar water temperatures and quality. Higher or lower concentrations of hops and calendula can neutralize fungal growth in eggs that might occur due to changes in water temperature. Given that hops and calendula are entirely natural, readily available, this study recommends these medicinal plants for the disinfection of trout eggs.

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This study was based on MSc thesis of the first author under supervision of the second author.

Compliance With Ethical Standards

Authors' Contributions

MUN: Investigation, Methodology, Data curation, Formal analysis, Writing – original draft, Writing – review & editing

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

All authors read and approved the final manuscript.

Conflict of Interest

The authors declare that there is no conflict of interest.

Ethical Approval

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

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Data Availability

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

Unraveling the link: Examining the influence of dollar strength on dirty tanker freight rates

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ABSTRACT

This study explores the asymmetric relationship between the U.S. dollar index (DXY) and dirty tanker freight rates, a largely unexamined area within maritime economics despite the dollar's profound influence on global oil prices and economic stability. Tanker shipping, the primary mode of transportation for global oil and a capital-intensive sector, plays a crucial role in oil supply chains. Given that oil prices are quoted in U.S. dollars, fluctuations in dollar strength directly impact oil costs, demand for tankers, and the operational costs of tanker shipping. This study employs an asymmetric model, recognizing that dollar value changes affect the tanker market differently depending on whether the dollar is strengthening or weakening. Findings reveal that decreases in the DXY drive up tanker freight rates, while increases do not correspondingly decrease rates, highlighting the unique non-linear dynamics between currency strength and freight costs. This asymmetric approach provides a more accurate framework for understanding these interactions than traditional linear models.

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Introduction

Oil is an indispensable element of production processes. However, oil is exploited from different parts of the world and often has to be transported from these areas to production centers (Stopford, 2009). Today, crude oil is usually transported by pipeline, barge or tanker (Rodrigue et al., 2013; Coles & Watt, 2009). The tanker, one of these transport vehicles, emerged in the 1940s and 1950s to meet this need. Tanker is defined as a ship designed to transport liquid cargoes (Grammenos, 2010). The most transported cargo by tanker is crude oil. Tanker transport is divided into two as "clean tanker" and "dirty tanker". Clean tankers refer to product tankers carrying clean oil products such as diesel fuel and jet fuel, while

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dirty tankers refer to crude oil and black products (Stopford, 2009). Dirty tankers carrying crude oil and other unrefined petroleum oil products are an integral part of the global supply chain. Data on dirty tanker freight rates is provided through the Batic Dirty Tanker Index (BDTI). The other concept that we will evaluate the relationship between dirty tanker freight rates is dollar strength. United States Dollar (USD) is an important currency due to its effects on the world economy (Hakkio & Whittaker, 1985). The concept of dollar strength refers to the relative value of the U.S. dollar compared to other currencies. Since oil prices are quoted in dollars, fluctuations in the dollar's value directly impact the cost of oil in international markets. Consequently, the price of oil in import and export transactions is effectively determined in U.S. dollars (Farley, 2024). Similarly, oil exporters are paid in dollars, meaning that shifts in the dollar exchange rate influence the effective price of oil for all countries outside the United States. Consequently, fluctuations in the dollar's value can impact global oil prices by driving adjustments in both supply and demand (Coudert & Valérie, 2016). The price of oil significantly influences dirty tanker freight rates, affecting both the demand for oil and the operational costs of tanker shipping. When the dollar weakens, oil becomes relatively cheaper, potentially boosting demand and lowering transportation costs. However, as demand for tanker shipping rises in response, freight rates may not decrease proportionately with costs. Conversely, in a stronger dollar scenario, these dynamics may play out very differently. This generates an asymmetric and non-linear relationship between the dollar index and tanker freight rates, making asymmetric models a more suitable choice for analyzing the interactions between these variables than traditional linear models.

Leading indicators play a critical role in the tanker shipping industry by providing foresight into future market conditions, allowing stakeholders to make informed decisions (Karamperidis et al., 2013). These indicators help in anticipating changes in demand, operational costs, and overall market dynamics. In terms of shipowners: (i) Indicators like the dollar index help shipowners forecast fuel costs, allowing for better budgeting and operational planning; (ii) Understanding economic trends aids in implementing hedging strategies to manage financial risks associated with currency and fuel price fluctuations. In terms of shippers: (i) Shippers use indicators to anticipate changes in shipping costs, enabling better pricing strategies and contract negotiations; (ii) Predictive indicators help in planning shipment schedules and routes, ensuring timely delivery and cost-efficiency; (iii) By monitoring economic indicators, shippers can anticipate disruptions and adjust their supply chain strategies accordingly. In terms of countries: (i) Governments use indicators to forecast trade volumes and balance of payments, essential for economic planning and policy formulation; (ii) Economic indicators guide policies on import/export tariffs, subsidies, and trade agreements to enhance national economic stability; (iii) Anticipated changes in shipping demand influence national decisions on port development and transportation infrastructure investments.

Although the U.S. dollar is widely recognized for its significant impact on the global economy, and its influence on global oil prices has been extensively studied and confirmed in the literature (Sadorsky, 2000; Lizardo & Mollick, 2010; Beckmann & Czudaj, 2013; Couder & Valérie, 2016; Kisswani et al., 2019), to the best of the authors' knowledge, no study has specifically examined its impact on the tanker shipping market, which plays a critical role in oil transportation. Tanker shipping is the primary mode of transportation for global oil and is a capital-intensive sector due to the high costs associated with ships. Presenting findings that can serve as decision-support mechanisms for this sector is therefore highly valuable. Furthermore, examining the potential relationship through an asymmetric approach offers a distinctive contribution by aligning with the inherent characteristics of tanker transportation. This method acknowledges that external factors, such as currency fluctuations and oil price shifts, do not affect the tanker market symmetrically.

Our findings suggest that policymakers and industry participants should focus on robust hedging strategies to manage currency risk, revise contractual terms for flexibility, and invest in fuel-efficient technologies to mitigate the impacts of currency fluctuations. This research not only contributes to the nuanced understanding of maritime economics but also offers practical recommendations for enhancing operational stability in the shipping industry. In the second part of the study, the theoretical framework of the research was drawn, in the third part, the data set and method were introduced, and the characteristics of the series were examined, in the fourth part, the results were presented, and in the last part, conclusions and recommendations were made.

Background of the Study

Since the US Dollar is one of the main exchange rates of international trade, the strengthening and weakening of its value has significant effects for countries, companies and individual investors (Bertaut et al., 2021). The strengthening and weakening of the dollar primarily affect the American economy. Export volumes could decline as a stronger dollar makes American exports more expensive for foreign buyers. Similarly, since this situation makes international products cheaper, there may be an increase in import levels of the country. The weakening of the US dollar may increase exports because it will make the country's products cheaper, while it may reduce imports because international products will become more expensive (Eguren Martin et al., 2017).

For other countries, especially developing countries, the strengthening of the dollar may generate financial stress and inflationary effects as it will increase import and energy costs (Boz et al., 2017). On the other hand, if their economies are dependent on export revenues, positive effects such as their products being cheaper in the international market and increased demand may also be seen. However, if the country borrows from international markets at the exchange rate, it will need a lot of money to pay these debts, which may trigger a depreciation in its own currency and therefore inflation (Nguyen et al., 2024). In terms of international commodity markets, a stronger dollar could reduce demand for commodities by making them more expensive (Reboredo, 2012).

In terms of investment, the strengthening of the dollar will increase foreign investments in American assets as it will cause higher returns, while the weakening of the dollar may cause investments to outflow from American assets to other countries (Klein & Rosengren, 1994). Therefore, the strengthening of the dollar may result in accelerated money outflows from developing countries and further depreciation of local currencies. Due to the strengthening dollar, the growth of developing countries is also decreasing (Druck et al., 2018). As can be seen, since the global economy's dependence on the dollar is high, the effects of increases and decreases in the value of the dollar are very large and widespread.

Some indicators were needed to follow the change in the value of the dollar and to develop proactive measures and policies according to its situation. DXY, which is used to measure whether the dollar is strengthening or weakening in global markets, stands out as an important indicator (Euromoney, 2012). Countries, companies and individuals make their monetary and fiscal policies, hedging strategies and commercial decisions according to the movement of the index (Köse & Yılmaz, 2022).

The effect of the strengthening or weakening of the dollar on crude oil tanker freights can occur in two ways: (i) its effect on oil demand by affecting international oil price, (ii) its effect on tanker transportation demand by affecting international tanker shipping price. The final price of oil for countries and companies can be simplified into the sum of the price of the product and transportation costs. The dollar's impact on the demand for oil will also affect the demand for tanker ships, which have a derived demand structure (Lun et al., 2013). More oil demand could lead to more ship demand. On the other hand, since international transportation is priced in dollars, the change in the value of the dollar may cause tanker transportation to become more expensive or cheaper (Chen et al., 2014). However, the relationship becomes complicated because the tanker freight price also depends on the balance of supply and demand in the tanker market. For this reason, a network of relationships that can be captured with linear models may not be established.

In order to determine the effects of the dollar on the global economy and therefore on the tanker market, it would be useful to draw a framework using the literature on subjects such as exchange rate & oil, oil & gold, exchange rate & international trade, and oil & global economy. Of course, there are hundreds of studies on these subjects, but only those that fit our theoretical framework will be selected and included. The relationship between oil prices and exchange rates has been extensively studied, revealing a complex and dynamic interaction. Lizardo & Mollick (2010) found an inverse relationship between the variables. Since the US is a country that imports a large amount of oil, the increase in oil prices has a depreciation effect on the value of the dollar. Based on the fact that this relationship can change over time, Beckmann & Czudaj (2013) identified that there is a time-varying pattern among the variables and that the effect is mainly formed from the exchange rate to the oil price, although it varies according to the country's economic profiles. Another study revealed that relations vary according to the economic profiles of countries, Kisswani et al. (2019) found asymmetric effects in ASEAN countries. While there is a causality from exchange rates to oil prices in some countries, the opposite relationships have been found in some other countries. Couder & Valérie (2016) found that an increase in the dollar strength leads to a decrease in the oil price by decreasing the demand for oil and increasing its supply, which implied the causality running from the dollar to the oil price. Sadorsky (2000), on the other hand, examined the relationship between exchange rates and oil prices through the prices of energy products in future markets and revealed that exchange rates have an impact on energy future prices. Since the interaction between variables may also differ depending on whether the country is a net oil exporter or importer, the study conducted by Nandi et al. (2024) on Bangladesh, a net importer country, has shown that the exchange rate and oil price interact and that the shock from the oil price has a long-term effect on the exchange rate. The findings of these studies suggest that policymakers and industry participants should consider the time-varying and asymmetric nature of the oil-exchange rate interaction. For oil-importing countries, monitoring and managing currency strength is crucial to mitigate the adverse effects of oil price volatility on the exchange rate. Although the direction of the effect varies from country to country, it is of great importance to follow hedging strategies to stabilize the effect of exchange rates on oil prices and the effect of oil prices on exchange rates. Since the impact of the US dollar on oil prices is primarily demand-driven, studies on oil demand are also common. A stronger dollar index could negatively affect demand as it would make oil more expensive for other countries. A study by Chen et al. (2016) identified that a stronger US dollar causes less oil demand globally. For oil-exporting countries, a strong dollar can reduce demand for oil exports, necessitating policies to diversify their economies and reduce dependency on oil revenues. Conversely, oil-importing countries might benefit from a strong dollar by facing lower oil import costs. Strategic reserves and alternative energy investments can mitigate the impacts of dollar index fluctuations on oil demand.

Since the price of gold is closely related to the global economic situation, it also interacts with oil. In an environment where the dollar strengthens, demand for gold may decrease because it will be relatively expensive, or vice versa. On the other hand, global uncertainties may increase demand for gold, which is seen as a safe-haven investment instrument. In addition, not only gold but also other precious metals such as silver, platinum and palladium are used as alternative investment tools. In its study, Sari et al. (2010) identified the relationship between precious metals and oil prices and determined that the two sectors have positive effects on each other. Since gold is considered a safe-haven investment, Reboredo (2013) examined whether it can be used as a hedge against fluctuations in oil prices. The results show that it cannot be used as a hedge because there is a positive dependence on the average between gold and oil prices, but since the tail values are independent, gold can only be used as a hedge against extreme oil prices. The information flow between oil price and gold price was examined by Zhang & Wei (2010) and it was found that the oil price Granger causes the gold price in linear sense. In the research conducted by Mensi et al. (2021), based on the fact that there are relationships between variables in the current period and that there may be interactions in future markets, it was determined that while precious metals and oil commodities are risk takers in the bear market, oil prices are risk givers in the bull market. The source of risk may differ depending on the market type. In addition, the relationship between variables may differ depending on whether any of them is too low or too high, and this was determined in the study conducted by Alomari et al. (2022). When general studies are evaluated, oil prices and gold prices are related to each other. Policymakers and investors should recognize the co-movement between oil and gold prices when designing investment portfolios and economic policies. Additionally, understanding the influence of the US dollar on these commodities can aid in making more informed financial decisions.

Since a stronger or weaker dollar will affect international trade, it will also affect the demand for oil, which is used as a raw material and energy source, and therefore the tanker market. So, the dollar index significantly influences international trade dynamics. A study by Goldberg & Tille (2008) found that a stronger US dollar contributes to the trade deficit because it makes US exports more expensive and imports cheaper. In addition, since the exchange rate is a determining factor not only in exports or imports of goods but also in exports and imports of services, the study conducted by Eichengreen & Gupta (2013) found that the increase in the real exchange rate increased service exports more than goods exports. Gopinath et al. (2020) investigated that dollar index movements influence global trade patterns, affecting both advanced and developing economies. An increase in the value of the dollar causes a decrease in global trade volume. Considering the effects of the dollar on trade, policymakers should monitor the dollar index to understand its impact on trade balances. For the US, managing the dollar's strength can help balance trade deficits and surpluses. For other countries, currency strategies, such as pegging or floating exchange rates, can be adjusted to mitigate adverse impacts on trade balances due to dollar index fluctuations.

The situation in the global economy also directly affects oil demand since oil is used as raw material, energy source and fuel in many sectors. The relationship between oil demand and the global economy is intricate and has significant implications for both macroeconomic stability and policy-making. In his study, Hamilton (2009) explored the effects of increasing oil prices on the global economy and determined that there were downturns in the global economy because the increase in prices also caused an increase in costs and decrease in disposable income. Another study by Joo et al. (2020) examined the impact of the global financial crisis on the crude oil market, finding that economic slowdowns lead to decreased oil demand, which in turn affects global oil prices negatively. Stock exchanges are also one of the important indicators for the economic situation of countries and the positive and negative situations in the economy can be felt directly. In this context, He et al. (2022), which examined the effects of oil prices on stock exchanges, determined that the asymmetric effects of oil price uncertainties on the stock exchanges of oil exporting countries are stronger than the importer countries. In addition, since the main oil producing and consuming countries are geographically located in certain regions, geopolitical events and energy security-related situations also affect oil demand and supply and spread to the economic structure. The research conducted by Khan et al. (2023) examined the effects of disruptions in the oil supply chain caused by such factors on national economies. These studies underscore the significant impact of oil demand on the global economy and vice versa. Policymakers should consider strategies to stabilize oil demand, such as promoting energy efficiency and investing in alternative energy sources. Diversifying energy portfolios can help mitigate the economic risks associated with oil price volatility. Additionally, understanding the geopolitical factors that influence oil demand is crucial for developing comprehensive energy policies that enhance economic resilience.

The relationship between dollar strength and crude oil also has an effect on dirty tanker freight rate. An increase in the dollar strength will lead to a decrease in the demand for crude oil and thus a decrease in the demand for maritime transport of crude oil, i.e., transport by dirty tanker. With the decrease in demand, dirty tanker freight rate will decrease. As a result, an increase in dollar strength may cause a decrease in the dirty tanker freight rate. Increasing dollar strength makes oil more expensive globally, reducing demand and this effect may cause dirty tanker freight rates to decrease. However, a decrease in dollar strength due to reasons such as economic conditions and operational costs does not necessarily mean that dirty tanker freight rates will increase. Considering all these, it can be assumed that as the dollar strength increases, the dirty tanker freight rate will decrease. This hypothesis is based on the relationship between dollar strength and the dirty tanker freight rate, which enables the transport of crude oil by sea.

Material and Methods

In order to assess the relationship between dirty tanker freight rates and dollar strength, a comprehensive data set covering different market conditions and more than twenty-one years is used. The monthly dataset covers the dates between August 2002 and April 2024 and consists of 261 observations. We used US Dollar Index (DXY) and Baltic Dirty Tanker Index (BDTI) variables to investigate the relationship between US dollar and tanker freight rates.

DXY, which was developed in 1973, is defined as the US Dollar Index and allows to measure the relative value of the United States dollar against the values of exchange rates in a basket of currencies of 6 countries (Parboteeah & Cullen, 2018). The weights of the exchange rates in this basket are as follows: 57.6% EURO, 13.6% Japanese Yen, 11.9% British Pound, 9.1% Canadian Dollar, 4.2% Swedish Krona, and 3.6% Swiss Franc (ICE, 2024). Instead of using the value of a single currency against the dollar, we chose to use the U.S. Dollar Index (DXY). A single currency comparison is insufficient to capture the relative strength of the dollar globally. In contrast, the DXY, with its comprehensive basket of currencies, better represents the dollar's global strength. This makes it a more effective indicator for analyzing international demand for dollar-denominated products.

BDTI is a freight index published by Baltic Exchange, developed to measure freight rates on the main routes where crude oil and heavy oil products are transported (Alizadeh & Nomikos, 2009). By following this index, it becomes possible to analyze global crude oil demand, tanker fleet utilization rate, seasonal factors and the cost of transportation of the crude oil. It is currently calculated by taking the weighted average of the values of 16 frequently used routes (Baltic Exchange, 2024). The BDTI is a comprehensive representation of the crude oil freight market. Published daily, the index enables industry stakeholders to respond promptly to market fluctuations. While it is somewhat limited in its route representation, covering only specific routes, and can be influenced by market sentiment, it remains a highly useful index for monitoring conditions in the crude oil market through a single indicator.

Descriptive statistics of the data set used in the study are presented in Table 1. Both variables are indices generated by weights of different components. Descriptive statistics are presented both as raw data and as log returns. Thus, detailed evaluations can be made about the characteristics and distributions of the variables. During the period under consideration, the average growth rate of BDTI is positive, while that of DXY is negative. In other words, while tanker freight rates increased on average, the strength of the dollar decreased. The skewness of both return distributions is positive, which shows that the effects of positive news were higher in the period under consideration. In addition, this shows that extreme positive news is more than negative news, that is, sudden increases are more than sudden decreases, especially in the BDTI as it has a higher skewness. In addition, the fact that the returns do not have a normal distribution indicates the asymmetry in the variables when evaluated together with the long tail effects. The distribution characteristics of the variables also confirms the difficulty of finding a meaningful relationship with linear modeling. When monthly changes are examined, it is seen that the biggest increase in BDTI is 66.6% and the biggest decrease is 55.1%, while the biggest increase in DXY is 7.7% and the biggest decrease is 7.4% in 1 month. This is also important in terms of understanding how volatile and risky the BDTI market is. When the coefficients of variation of the raw data are examined (standard deviation/mean), the coefficient is calculated as 43% for BDTI and 10.3% for DXY, indicating how volatile the maritime sector is.

The graphical illustration of the relationship between dollar strength and dirty tanker freight rate is presented in Figure 1. DXY value dropped to its lowest value of 71.80 in March 2008. This situation resulted from events during the 2008-2009 global economic crisis such as the decrease in the demand for the dollar, lowering interest rates to support the economy, injecting cash into the market through security purchases (Quantitative Easing), and economic support packages (FED History, 2024). As a result, the stable fluctuation in the value of the dollar continued until 2014, and then the increasing trend of the dollar began. The reason for this increase after 2014 was the announcement by the FED that the Quantitative Easing program was concluded (FED, 2014).

BDTI fell to its lowest value in October 2020. At that time, the decrease in oil demand due to the global economic slowdown due to COVID-19 also reduced the demand for tankers and freight rates hit the bottom level. In addition, the drop in oil prices due to falling demand also reduced transportation costs, and this supported the further decline in freight rates. In fact, at that time, oil prices were negatively priced for the first time in history (MOL, 2020). However, compared to other shipping markets, tanker freight rates were in better shape. The main reason for this is that tanker ships have been chartered and used by countries and large companies to store excess oil supply (Marine Insight, 2020). A similar decrease in demand was experienced after the 2008 global crisis, and as the demand for tankers decreased, freight rates dropped to low levels. As a result, since the demand for crude oil transportation is a derived demand, any developments in the economy due to global events are directly reflected in freight rates (Lun et al., 2013).

When the relationship between the variables is examined in Figure 1, no significant linear relationship can be seen. In addition, the applied correlation analyzes also give insignificant results. The main reasons for this are that oil is both a customer burden and a source of cost for tankers, and the supply in the tanker market is affected by the ship construction period. In other words, market supply consists of the orders accumulated from previous periods being delivered at that moment rather than instant demand. This delay may vary between 1-4 years depending on the market situation and the ship type (Tsolakis, 2005).

Table 1. Descriptive statistics of the variables

Parameters	BDTI	DXY	Dln BDTI	Dln DXY
Mean	1002.280	89.72667	0.001540	-6.83E-06
Median	855.0000	90.03000	-0.001441	4.19E-05
Maximum	3008.000	112.1200	0.666120	0.077353
Minimum	411.0000	71.80000	-0.551870	-0.074127
Std. Dev.	431.8196	9.294691	0.170817	0.022073
Skewness	1.487712	0.080314	0.142807	0.010348
Kurtosis	5.728688	2.039517	4.485708	3.938621
Jarque-Bera	177.2504	10.31308	24.79646	9.548899
Probability	0.000000	0.005762	0.000004	0.008443
Observations	261	261	260	260

Note: Source: Trading View (2024); Investing (2024)

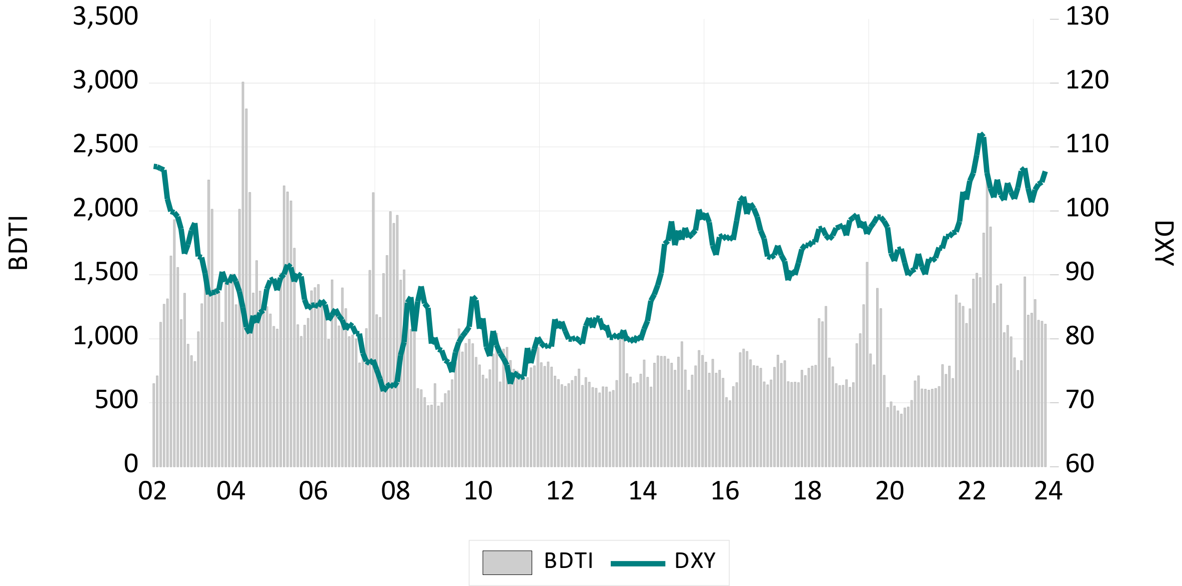

Figure 1. Relationship between Dollar Strength and Dirty Tanker Freight Rate (Source: Trading View (2024); Investing (2024))

The asymmetric causality test we preferred in our study was developed by Hatemi-J (2012). Traditional Granger (1969) causality analysis assumes a symmetric relationship between variables. However, this scenario is slightly simplified to explain the relationship between variables in the real world. In order to eliminate this limitation, asymmetric causality method tests the relationship from one variable to another in 4 different combinations by decomposing the variables into positive and negative components. In this way, it is possible to determine whether positive shocks in one variable affect positive shocks, negative shocks, or both positive and negative shocks in the other variable. In the real world, information spreads very quickly and there are many different players in the market, and each player's reactions to similar shocks may vary. Traditional symmetric causality tests may be inadequate to capture such asymmetric relationships. Asymmetric causality test has a similar logic to the traditional Granger (1969) method. It is based on the logic of applying the logic of the Granger test, which reaches its conclusion by testing whether the past values of one variable explain the current value of the other variable in a significant way, through the shocks in the series.

In real-world dynamics, assuming symmetric interaction between variables oversimplifies the complexity of market reactions, as responses to shocks vary widely. In fast-paced global markets, traders, fleet managers, financial institutions, and policymakers may react differently to similar shocks due to unique positions, risk profiles, and strategic goals. By adopting an asymmetric approach, we aimed to capture this diverse reactivity and potential differences in responses within the tanker market. This approach allows us to better align the intricate relationship between DXY and BDTI with real-world market behavior, compared to other symmetric methods.

In this method, the series do not have to be stationary. The maximum integration degrees (dmax) of the variables included in the analysis must be known. This can be determined by unit root tests. If one or both two analyzed variables contain a unit root, dmax is set as 1, and if neither of them contains a unit root, it is set as 0. We preferred to apply augmented Dickey-Fuller (ADF) (Dickey & Fuller, 1981) and Phillips and Perron (PP) (Phillips & Perron, 1988) tests to the series to determine the maximum degree of integration. The null hypotheses of these tests indicate the existence of a unit root in the series. PP test is an improved version of ADF, and it becomes robust to serial correlation and heteroscedasticity in error terms (Enders, 2004) by making non-parametric considerations in the test statistics (Das, 2019). Therefore, PP test was also applied as a complement to ADF test.

Logarithmic transformations were applied to the series in our analysis. To remove potential seasonal effects, we first used Seasonal-Trend decomposition using Loess (STL) method, producing seasonally adjusted series. This method allows time series to be separated into seasonal, trend, and irregularity components (Chen et al., 2021). This was particularly relevant for the BDTI variable, which likely experiences seasonal fluctuations driven by demand shifts. Unit root tests were then conducted on the seasonally adjusted series to determine their maximum degrees of integration. Additionally, we assessed whether shocks to these series had temporary or permanent effects. After establishing the degrees of integration, we proceeded with the asymmetric causality test to evaluate the relationship between the variables.

Results

In analyses of the relationship between the dollar and the dirty tanker freight rate, it is essential to seasonally adjust the data. By adjusting the data for seasonality, seasonal effects are eliminated, and thus more appropriate comparisons can be made between different periods.

Seasonal demand, policy and spending changes in exchange rates may cause exchange rates to follow seasonal patterns. At the end of the year, multinational companies may increase the demand for other currencies in order to take their profits to home countries, causing a downward trend in the US dollar. Similarly, increased import spending during holiday seasons may increase demand for foreign exchange rates and cause a decline in the local currency. In addition, since tourism activities in countries vary seasonally, the local currency may gain value due to tourism-related foreign exchange expenditures in the country. Since agricultural exports also increase in certain seasons, foreign currency inflow to the country may increase in the relevant calendar period. Similarly, since the demand for raw materials such as coal increases in certain months, there may be seasonal fluctuations in the exchange rates of the exporting and importing countries of the relevant product. In short, it is inevitable that there will be seasonal effects in the DXY variable.

In order to correctly interpret the seasonality in BDTI, it is necessary to understand the seasonality in oil prices. There may be increases in oil demand for heating purposes in winter and for fuel purposes in summer. Demand for oil for fuel purposes may also increase during periods when agricultural activities are at their peak. In addition, seasonal hurricanes and storms in some important oil production and refining regions may cause disruptions in the oil supply chain, so seasonal changes may occur at certain times of the year. These changes in oil demand may affect the price of oil and therefore the demand and cost of tanker shipping, thus causing seasonal patterns in freight rates.

For these reasons, seasonal effects must be determined, and the variables must be studied in a seasonally adjusted manner. The monthly averages of the seasonal adjustment factor obtained as a result of the STL decomposition method applied are presented in Figure 2. When the seasonality in BDTI is examined, it is seen that while freight rates experience a seasonal decrease in the summer period, they experience a seasonal increase in the winter period. A seasonal peak occurs at the beginning of the winter period due to the increase in demand for oil because of the need for heating in the Northern Hemisphere. This seasonal increase continues in the first 3 months of the new year. Towards the end of the fall season, refineries and distributors begin to stockpile oil in anticipation of increased demand, which leads to a rise in demand for oil transport. With the arrival of spring, there is often a decrease in demand, particularly in regions where oil is used for heating, resulting in lower freight rates. Additionally, during summer, demand for oil may decrease as refineries increase their maintenance activities to prepare for the busy fall and winter seasons.

When the DXY seasonal adjustment factor is examined, it is seen that it generally follows a stable course, while there are seasonal significant decreases in January and April, the dollar strengthens seasonally in November. The decline in the DXY, particularly in April, is largely attributed to tax season in the U.S. During this period (IRS, 2024), individuals and companies make substantial tax payments, which can lead to a temporary decrease in dollar demand and, consequently, a drop in its value. The seasonal increase in November may be driven by heightened dollar demand as companies and institutions engage in budget balancing and year-end financial planning. These activities often require increased dollar reserves and adjustments to dollar-denominated assets, contributing to a rise in the Dollar Index (DXY).

Unit root analysis is one of the methods applied to evaluate the analyses more accurately. Unit roots are nonstationary autoregressive (AR) or autoregressive moving average (ARMA) time series processes that may include an intercept or trend. These processes are common in economics and finance, and also appear in other scientific fields. Unit root tests address whether a series has a unit root (nonstationary) or is stationary (or trend stationary).

Since the series do not have to be stationary in the asymmetric causality test, ADF and PP unit root tests were applied to the series to determine the maximum order of integration value (dmax) in the models and the results are presented in Table 2. According to the ADF test, the unit root null hypothesis was rejected at the 5% confidence level for BDTI, but not for DXY. Similarly, according to the PP test, the unit root null hypothesis was rejected at the 5% confidence level for BDTI, but not for DXY. It was rejected only for DXY at the 10% confidence level in Intercept & Trend. When the 5% confidence level is taken as the basis for both tests, the results are exactly the same. Accordingly, the maximum integration degree was determined as 1 by assuming that BDTI is I(1) and DXY is I(0).

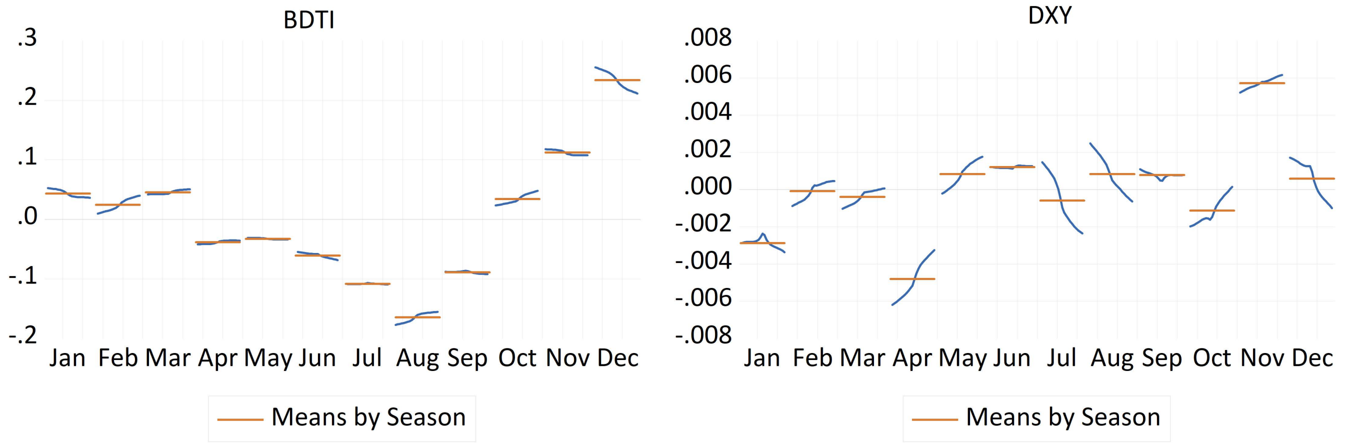

Figure 2. Seasonal factors in BDTI and DXY

Table 2. Unit root analysis result

Test	Variable	Level		First Difference		
		Intercept	Intercept & Trend	Intercept	Intercept & Trend	Conclusion
ADF	BDTI	-3.8017***	-4.1018***	-13.671***	-13.645***	I(0)
	DXY	-1.7291	-3.1105	-15.564***	-15.716***	I(1)
PP	BDTI	-3.7859***	-4.1408***	-16.236***	-16.201***	I(0)
	DXY	-1.9016	-3.1592*	-15.599***	-15.736***	I(1)

Note: Schwarz information criterion was selected in ADF test for optimum lag selection. ADF and PP critical values -3.455387 for ***1%, -2.872455 for **5%, -2.572660 for *10% at Intercept; ADF and PP critical values -3.993746 for ***1%, -3.427203 for **5%, -3.136898 for *10% at Trend and Intercept.

Table 3. Asymmetric causality test results

				Dollar =>	Freight	
			D+F+	D+F-	D-F-	D-F+
Optimal Lag; Var(p)			1	1	1	1
Additional Lags			1	1	1	1
Test Stat (MWALD)			0.066	0.292	2.255	4.533**
Asym. chi-sq. p-value			0.798	0.589	0.133	0.033
Critical Value	**1%*** **		6.398	7.534	9.431	8.075
		5%**	3.691	4.0.41	4.449	4.026
		10%*	2.575	2.940	2.829	2.724

Note: **Significant at %5*

The econometric meaning of the unit root is related to whether the effects of shocks are permanent. In other words, a unit root shows that statistical properties such as mean, and variance change over time. Since the BDTI variable contains a unit root, it can be said that it carries the shocks it was exposed to in the period under consideration and does not tend to return to its mean in the long run. In other words, the effects of the shocks the sector is exposed to are permanent in freights. On the other hand, the shocks in the DXY variable have a temporary effect and the variable tends to return to its mean in the long term. These results also show that BDTI moves randomly and is unpredictable, while DXY is predictable. The reason why BDTI is difficult to predict is because it is affected by many factors such as global trade, supply chain disruptions, oil prices, economic cycles, geopolitical events, ship orders, and inelastic supply in the short term. Any of these factors can significantly affect freight rates. On the other hand, DXY is mainly affected by limited factors such as interest rates, inflation expectations, and geopolitical risk. Although these factors also have a relatively volatile effect, it can be said that DXY is on a more stable course because their effects are more predictable compared to freight.

The analyses were carried out using GAUSS software codes. Since there is a unit root in the BDTI variable from the series, the dmax value is determined as 1. Since the data set frequency is monthly, the maximum lag is determined as 12 to determine the lag in causality estimation. The number of bootstrap simulations for calculating critical values was determined as 1000. The Schwarz information criterion value was taken into account to determine the optimum value within the maximum lag. The test results for the asymmetric causality relationship from DXY to BDTI are presented in Table 3. The null hypothesis of no causality could be rejected for only 1 case, where negative shocks in DXY were determined as the cause of positive shocks in BDTI. No causality relationship could be determined in other combinations. Accordingly, a decrease in the dollar strength has an increasing effect on the dirty tanker freight rate. However, it was not found that an increase in dollar strength has a decreasing effect on dirty freight rate.

Discussion

Tanker transport, which is one of the most common methods preferred for the transport of oil, is also affected by the fluctuations in the oil price and therefore the dollar. This research paper provides a unique contribution to existing literature by exploring the asymmetric relationship between the dollar index and tanker freight rates, a topic not extensively covered in previous studies. While significant research has been conducted on the interactions between oil prices, exchange rates, gold price, and global economic factors, the specific focus on tanker freight rates adds a new dimension to the discussion. The paper builds on the foundational work in the field by examining how fluctuations in the dollar index uniquely affect tanker freight rates, highlighting an asymmetric relationship that has been observed.

In the asymmetric causality test, our unit root tests, applied to determine the maximum order of integration, indicated that BDTI is I(1) while DXY is I(0). These findings carry practical significance. BDTI's unit root implies that shocks impart lasting effects, causing the series to move unpredictably. This necessitates accounting for the permanence of shocks in forecasting models. Key factors contributing to this include the shipbuilding process, which spans 1-4 years and complicates rapid supply adjustments; unexpected supply chain disruptions; direct ties to global trade volumes and geopolitical tensions; and the impact of oil supply decisions, often influenced by political agendas. This inherent unpredictability underscores the need for stakeholders in the crude oil sector to adopt more complex and diversified risk management strategies. These strategies include hedging through derivative markets, diversifying routes and suppliers, securing long-term contracts with built-in flexibility, conducting real-time market analysis, managing exchange rate risk through currency hedging, and fostering strategic collaborations. The other variable, DXY, being I(0), indicates that shocks have only temporary effects, making long-term forecasts relatively more reliable and predictable. This allows stakeholders to base strategies on trends and expectations in indicators like interest rates and inflation. Consequently, simpler hedging strategies are likely sufficient for managing DXY-related risks compared to the more complex strategies required for BDTI.

The study's findings on the asymmetric causality between the dollar index (DXY) and tanker freight rates underscore a critical dynamic in maritime economics: currency fluctuations affect the tanker market in complex and uneven ways. A decrease in the dollar index leads to an increase in tanker freight rates, while an increase in the dollar index does not correspondingly decrease the freight rates. This asymmetry suggests that factors influencing tanker freight rates are more sensitive to decreases in the dollar index. This finding contributes to the broader understanding of how currency fluctuations impact the maritime shipping industry, particularly in the context of tanker operations.

The observed asymmetries in the relationship between the dollar index and tanker freight rates can be attributed to several potential causes: (i) Tanker operations are heavily dependent on fuel costs, which are influenced by oil prices (Alizadeh & Nomikos, 2009). When the dollar index decreases, oil prices typically rise, leading to higher operational costs for tankers. This increase in costs is directly passed on as higher freight rates. Conversely, when the dollar index increases, the reduction in oil prices may not proportionally lower operational costs due to fixed operational expenses and other non-variable costs. (ii) Freight rates are often determined through long-term contracts (Lyridis & Papleonidas, 2019). These contracts may not be immediately adjusted to reflect short-term fluctuations in the dollar index, leading to an asymmetric response. (iii) The demand for tanker shipping services may be more elastic in response to decreases in the dollar index. A weaker dollar can stimulate global trade by making US goods cheaper internationally, increasing the demand for shipping services. However, an increase in the dollar index might not result in an immediate decrease in trade volume, especially if global economic conditions are strong. (iv) Companies involved in tanker operations may employ hedging strategies to manage currency risk (Karatzas, 2016). These strategies could mitigate the impact of an increasing dollar index on operational costs, thereby dampening the expected decrease in freight rates.

Our research reveals that only decreases in the DXY are responsible for increases in the BDTI. This relationship can be understood by examining how changes in U.S. exchange rates influence oil prices. Literature by Lizardo & Mollick (2010), Beckmann & Czudaj (2013), and Kisswani et al. (2019) has demonstrated the immediate effect of exchange rates on oil prices, while Sadorsky (2000) highlighted this impact in futures markets. According to our findings, a decrease in the DXY signifies a depreciation of the U.S. dollar, making it cheaper in international markets. This lower dollar value makes oil relatively more affordable, boosting demand for oil and, consequently, raising oil prices. Since the tanker market operates on derived demand, this rise in oil demand translates into increased demand for tankers, driving up tanker freight rates. Additionally, a secondary effect arises from the calculation of tanker freight rates in U.S. dollars; as oil prices increase, transportation costs also rise, further benefiting tanker rates. Conversely, our findings indicate that increases in the DXY do not result in lower tanker freight rates. Couder & Valérie (2016) observed that an increase in DXY typically reduces oil prices by making it relatively more expensive. However, this effect may not translate directly to tanker markets due to the prevalence of long-term contracts among tanker stakeholders, which buffer freight rates from short-term currency fluctuations.

The findings of this research have important implications for policymakers and industry stakeholders: (i) Stakeholders should develop robust hedging strategies to manage the impact of currency fluctuations on operational costs. (ii) Revising contractual terms to allow for more flexibility in response to currency changes can help mitigate the impact of asymmetries. (iii) Investing in more fuel-efficient technologies and alternative energy sources can reduce dependency on oil prices and mitigate the effects of a decreasing dollar index on operational costs.

By foreseeing changes in freight rates due to fluctuations in the US dollar, these companies can make informed decisions on when to deploy more vessels or adjust charter rates, thereby increasing profitability and operational efficiency. Industry stakeholders can better navigate the complexities of the relationship between the dollar index and tanker freight rates, ensuring more stable and predictable operational outcomes. This paper's originality lies in its detailed analysis of these asymmetric effects and its contribution to a more nuanced understanding of maritime economics.

Conclusion

In our current study, we employed a method focused on two-variable modeling to precisely capture the interactions between dollar strength and tanker freight rates. Consequently, other potential influencing factors on tanker freights could not be directly included in our model. Future research can enhance the comprehensiveness of these findings by adopting multivariable modeling approaches that incorporate additional relevant variables, such as oil prices, active fleet size, average fleet speed, and average haul distances, etc. to provide a more robust understanding of the determinants impacting tanker freight rates.

Compliance With Ethical Standards

Authors' Contributions

HOS: Writing – original draft, Writing – review & editing
AA: Conceptualization, Formal analysis, Data curation, Supervision
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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Not applicable.

Data Availability

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

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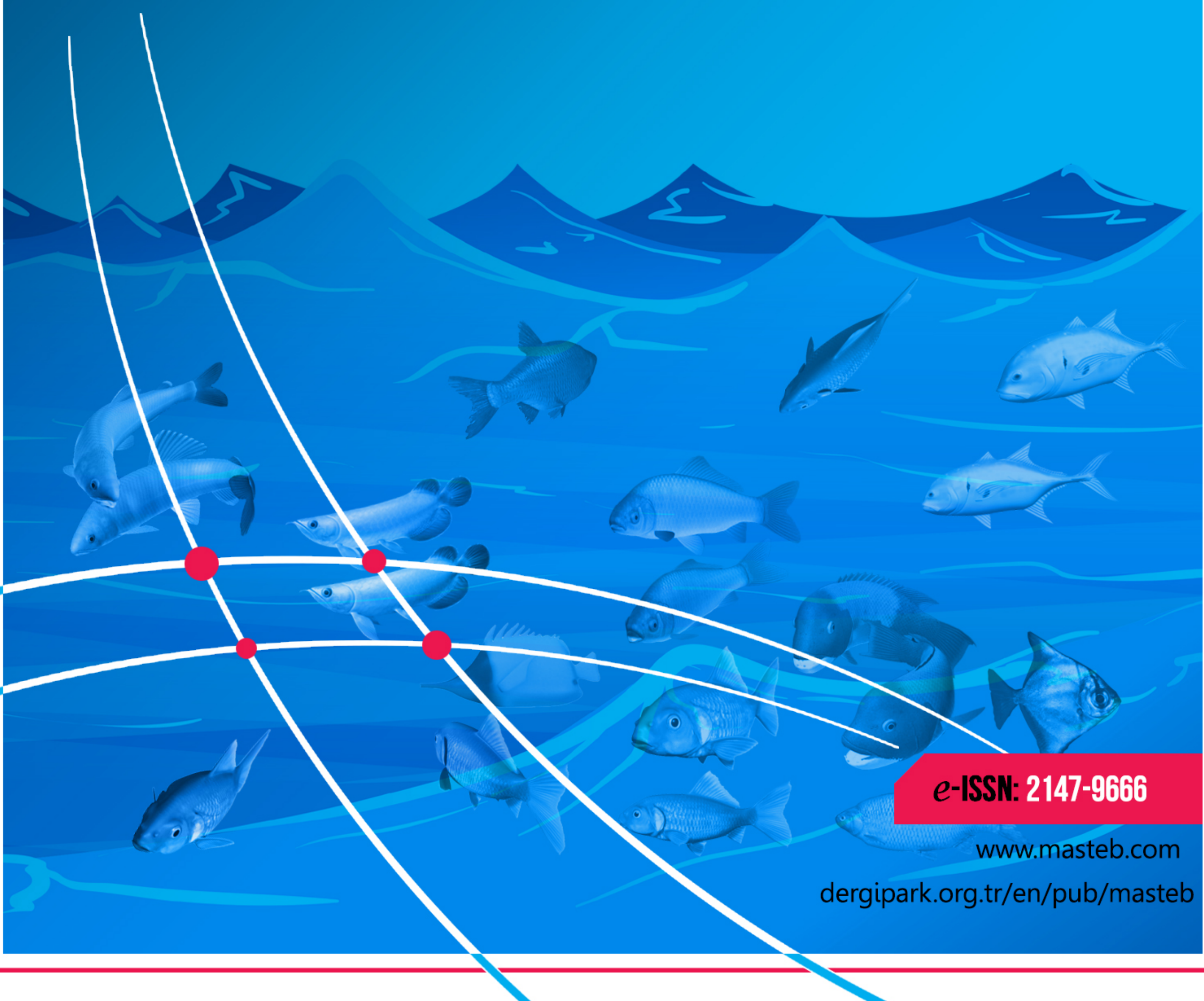

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