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Authors Guidelines

Thank you for deciding to submit your article to the Ege Journal of Fisheries and Aquatic Sciences (EgeJFAS). The journal welcomes the submission of articles that are of interest and high scientific quality. Authors should check the "Author Guidelines" very carefully before submitting their manuscripts. The instructions given here will ensure that your article's evaluation process (referee, publication, etc.) can proceed smoothly. Make sure your article is prepared and submitted in accordance with journal rules.

Submitted manuscripts will be checked primarily for compliance with journal subjects and rules. Manuscripts not complying with required formatting will be returned for correction. Papers outside the scope of the journal will be rejected.

GENERAL INFORMATION

Aim & Scope

Ege Journal of Fisheries and Aquatic Sciences (EgeJFAS) is open access, international, double-blind peer-reviewed journal publishing original research articles, short communications, technical notes, reports, and reviews in all aspects of fisheries and aquatic sciences.

The journal does not charge any submission and publication fees.

All articles receive DOI, are citable, published in PDF format.

The journal focuses on interdisciplinary studies that present new and useful information to the international scientific community/readership, and contribute to scientific progress. Before submitting your article, make sure it is suitable for the journal scopes.

The main functional areas accepted into the journal are listed as follows:

Marine and freshwater fisheries, Aquaculture, Vertebrate and invertebrate aquaculture (marine/freshwater), Planktonology and plankton culture, Living resources, Management and economics, Aquaponic, Seafood processing technology, Feeding and feed technologies, Fishing technology, Fisheries management, Population dynamics, Disease and treatment, Aquatic microbiology, Biology, physiology, Macroalgae, Biotechnology, Conservation and sustainability, Environments and ecology, Biogeography, Biodiversity, Climate effects, Pollution studies.

Ege Journal of Fisheries and Aquatic Sciences (EgeJFAS) (Su Ürünleri Dergisi) published quarterly (March, June, September, December) by Ege University Faculty of Fisheries since 1984.

The journal is published only as an e-journal since the 1st issue of 2020.

Language

Although articles in English and Turkish are accepted, priority is given to articles prepared in English in order to increase international readability and citation. Limited Turkish articles are published in each issue.

Manuscripts should comply with the standard rules of grammar and style of the language (English or Turkish) with appropriate spelling and punctuation in which they are written.

Editorial Policy and Referee Process

Manuscripts should not be copied elsewhere or submitted to another journal for parallel evaluation. Only original manuscripts are considered. It is evaluated with the understanding that the content is approved by all co-authors. Submitted manuscripts are first checked in terms of journal scope, language, presentation, and style. Manuscripts that are not suitable for these aspects will be returned without review.

In order to evaluate the appropriate articles, at least 2 or 3 external and independent referees who are experts in their fields are appointed by a member of the editorial board/section editor. Each manuscript is reviewed through a double-blind peer-review process (identities of neither authors nor peer reviewers are disclosed). Manuscripts returned to authors with referee reports should be revised and sent back to the editor as soon as possible.

Editor-in-chief/editors take the final decision (Accept, Reject) of the manuscript in line with the reviewer's opinions. All responsibility for the scientific content and expressions in the published article belongs to the authors. In accordance with the publication policies of EgeJFAS, the plagiarism report for the relevant manuscript is requested to be uploaded to the submission system by the responsible author.

Article Types

The types of articles accepted include original research articles (priority), short communications, reviews, reports, and technical notes in all aspects, focusing on interdisciplinary studies in the field of fisheries and aquatic sciences.

Original research papers: These are the article type that the Journal gives the most importance and priority. Should contain data obtained from original studies such as experimental results, field data, and/or theoretical studies.

Short communication: It should include original results and headings, like research papers. Articles provide important new research results/methods or discoveries that do not possible to publish as a full research paper. These articles that are narrowly focused deserve to be published faster than other articles.

Review: Reviews may summarize current research areas of broad importance or provide the readers with an insightful introduction to new and groundbreaking areas of research. It should be examined and discussed in-depth and comprehensively written by the author(s) who have expertise in the subject area, not just the literature surveys. Only invited reviews (in English) are considered for publication. If you would like to submit an invited review, please contact the editor-in-chief (editor@egejfas.org) and upload a review cover letter containing the requested information. As of 2023, reviews in Turkish will not be accepted. Publication of those accepted in the previous year will be completed in 2023.

Reports

Case reports encourage the submission of reports containing feature novel findings or new management strategies. Well-written and illustrated reports are taken into account.

Brief reports are short, observational studies that report the initial results or completion of a study or protocol.

Technical notes: They are short articles that focus on a new technique, method or procedure. It should identify significant changes or unique applications for the method described.

MANUSCRIPT SUBMISSION

The manuscript, when submitted together with the Cover Letter (Submission declaration and verification) and Copyright Form signed by the corresponding author on behalf of all authors, warrants (confirms) that it is original and has not been published elsewhere, has been approved - tacitly or expressly - by all co-authors and the responsible authorities at the institute where the work was carried out. The publisher will not be held legally responsible in case of any claim for compensation.

Before you start submitting an article, please ensure that the article complies with the journal guidelines (instructions) and that you are ready to upload all requested documents (Article File, Similarity Report, Cover Letter, Copyright Release Form, Ethics Committee Approval (if necessary). Please note that submissions that do not contain the required documents/statements will be returned incomplete.

Authorship Contributions, Conflict of Interest Statement, Ethics Approval, Data Availability should be written in the article after Acknowledgements and Funding section.

While starting

For submission of your manuscript prepared in accordance with the guideline to EGEJFAS please click here and after logging into your account (if you don't have an account please register at https://dergipark.org.tr/en/ . Your default login ID is your email address. Use your existing account; do not create new accounts with new submissions) use the "Submit Article" button on the home page of the journal to start submission. Before submitting a manuscript, do not forget to check the Submission Checklist.

After log in, the article submission process is completed in 5 steps. Upload your article information, article file, and other necessary documents step by step correctly. There is no transition to the next step until a step is completed.

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Please see our information on Ethical Principles and Publication Policy. Before submission, do not forget to read the "Ethical Responsibilities of the Authors".

Please ensure that any manuscript you submit to this Journal conforms to the Committee on Publication Ethics (COPE) recommendations for ethics, Best Practice Guidelines and as well as to the rules of Egejfas.

PREPARATION OF MANUSCRIPTS

Papers must be clearly written in Turkish or English. Manuscripts should be typed double spaced on A4 size paper in 12-point Times New Roman font including the references, table headings and figure captions with standard margins (25 mm) all around. The author's name should appear centred under the title. Numbered (1) note should give the author's institutional address and an asterisked (*) note should indicate the corresponding author's e-mail address. Degrees and qualifications should not be included.

Line and page numbers should be given from the first page of the manuscript.

Please prepare your typescript text using a word-processing package (save in .doc or .docx).

The complete manuscript should be in a single file containing full text, references, figures and tables. Figures and tables should be inside the manuscript placed properly (not at the end of manuscript). The line number should be given to the whole manuscript.

- Research papers and reviews must not exceed 25 manuscript pages including tables and figures (except systematic checklists).
- Short communications, technical notes, and reports which are results of brief but significant work, must not exceed 10 manuscript pages including tables and figures.

Papers must be clearly written in Turkish or English. Manuscripts should be typed double spaced on A4 size paper in 12-point Times New Roman font including the references, table headings and figure captions with standard margins (25 mm) all around. The author's name should appear centered under the title. Numbered ([1]) note should give the author's institutional address and an asterisked (*) note should indicate the correspondence author's e-mail address. Degrees and qualifications should not be included.

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The complete manuscript should be in a single file containing full text, references, figures and tables. Figures and tables should be at the end of the manuscript file and the locations should be indicated in the text.

- Research papers and reviews must not exceed 25 manuscript pages including tables and figures (except checklists).
- Short communications, technical notes and reports which are results of brief but significant work, must not exceed 10 manuscript pages including tables and figures.

First Page

The title should be short concise and informative, and be a statement of the main result/conclusion presented in the manuscript. The title should not contain abbreviations. Do not forget to add English title for Turkish article. The title should be written in sentence order.

Author Names and Affiliation

The first name and surname of each author should be clearly listed together and separated by commas. Provide exact and correct author names (forenames-surnames) as these will be indexed in official archives. Occasionally, the distinction between surnames and forenames can be ambiguous, and this is to ensure that the authors' full surnames and forenames are tagged correctly, for accurate indexing online.

Present the authors' affiliation addresses should be indicated at the author's name with superscript numbers immediately after the author's name. The full postal address of each

affiliation at the time of research should be listed in order: Department, institution, city with postcode, and country name.

Please clearly indicate who will handle correspondence at all stages of refereeing and publication, also post-publication. Provide an active e-mail address of the corresponding author. It is editorial policy to list only one author for correspondence.

ORCID numbers of all authors should be listed on the article title page as of June 2017. Authors who do not have an ORCID number are required to register their number at www.orcid.org. The orcid number is mandatory. Articles that do not have an ORCID number or are incorrect will not be evaluated.

Please refer to the journal's "Ethical Responsibilities of Authors" policy in the Ethical Principles and Publication Policy section for details on eligibility for author listing.

Abstract

English and Turkish abstracts (contributors who are not native Turkish speakers may submit their manuscripts with an English abstract only) of a maximum of 300 words should be included in all submissions. The abstract should be comprehensible to readers before they have read the full paper, and reference citations must be avoided. In the abstract, the importance of the work should be clearly stated; what, why, how it was done should be answered and the contribution of the results to the scientific world should be expressed. It should not contain undefined abbreviations.

Abstract should clearly the importance of the work described in the paper and reflect what was done, why it was done and what important results were achieved. It should not contain any undefined abbreviations and not be written in the first person.

Keywords

Below the abstract, please provide 4-6 keywords related to the study that will help to increase the discoverability of your manuscript. It is especially important to include words that are fundamental to your manuscript but are not included in the manuscript title or abstract to increase discoverability by indexing services.

Following pages

Following pages should contain the rest of the paper and should be organized into an Introduction, Material and Methods, Results, Discussion, Conclusion(s), Acknowledgements and Funding, Authorship Contributions, Conflict of Interest Statement, Ethics Approval, Data Availability, References. These should be capitalized. Please note that submissions without required documents/statements will not be accepted.

Introduction

Provide clearly and an adequate background, avoiding a detailed literature survey or a summary of the results. State the specific objective or hypothesis of the study.

Material and Methods

Provide adequate detail to allow the work/experiment to be reproduced. Methods already published should be mentioned by references. Significant modifications of published methods and new methods should be described in detail.

If the study requires "Ethics Committee Permission Certificate", be sure to report after the "Acknowledgements" section that permission has been obtained from the relevant institution. A copy of the "Ethics Committee Permission Documents" should be uploaded to the system. A detailed explanation on this subject has been made in the "Ethics Approval" heading above.

Results

Results should be clear and concise. Results for different parameters should be described under subheadings or in separate paragraph. Present your results in a logical sequence in the text, tables, and figures.

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The discussion should not repeat the results, but should provide a detailed interpretation of the data. The discussion should highlight the importance of the work and the resulting new insights. Only in exceptional cases may the results and discussion be combined with the editor's consent. Avoid extensive citations and discussion of published literature.

Conclusions

This should briefly state the major findings of the study.

Acknowledgements and Funding

Acknowledgements including people, grants, funds, projects, etc. should be kept brief and placed after conclusion section. Names of contributing people should be written clearly and fully.

Examples:

"The authors are grateful to John Nare, for his friendly collaboration and hospitality during the lipid analysis."

"The authors would like to thank Ken More for language revision."

Please clearly and fully specify the relevant funding information (name) with the grant number or codes.

Financial support acknowledgwment should be written like the example given:

"This study was supported by the Turkish Scientific and Technological Research Institution (Grant number: .....)."

"This work was supported by Ege University Scientific Research Projects Coordination Unit. Project Number: …."

"Author Mary Lee has received research support from Company A."

If the research has no specific financial support, please include the following statement:

"This research has not received a specific grant, fund or other support from any funding agency in the public, commercial, or not-for-profit sectors."

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Identifying individual author contributions (CRediT - Contributor Roles Taxonomy, ICMJE-Defining the Role of Authors and Contributors, Transparency in authors' contributions) is important to reduce authorship disputes and facilitate collaboration. The publisher recommends that authors include statements of contribution stating each author's contribution to the work to promote transparency. This gives authors the opportunity to share an accurate and detailed description of their various contributions to the work. The corresponding author is responsible for ensuring that the disclosures are correct and accepted by all authors.

The roles of all authors should be listed. Authors may have contributed to more than one role. These contributions should be placed in the text with the heading of "Authorship Contributions", after the "Acknowledgements" section of the article. See below examples:

Example: All authors contributed to the idea and design of the study. Material preparation and investigation were performed by [full name], [full name] and [full name]. The writing/editing was carried out by [full name] and all authors have read and approved the article.

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Full name/s: Supervision

Full name/s: Software, Validation

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Full name/s: Writing- Reviewing and Editing

For review article; it should be stated whose idea, who did the literature survey and data analysis, who wrote the draft, and who revised the criticisms.

For articles produced from student's dissertations or thesis, it is generally recommended that the student is listed as the principal author (A Graduate Student's Guide-APA Science Student Council 2006).

Changes to Authorship

At the time of submission, the author (s) information, the corresponding author and the order of the authors must be correct. Changing the author order, adding/deleting are not allowed during the revision phases. However, in rare cases, it can be applied when detailed and acceptable reasons are presented. All authors must agree with any addition, removal or rearrangement and the reasons for changes should be explained in detail. After the article is accepted, no changes can be made to the authorships.

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Authors should declare if they have any financial or personal relationships with any institution/organization or person that may adversely affect their work. Conflict of interest statement should be attached to the article after the Acknowledgements section.

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In the event of a potential conflict of interest, the authors must state: "The following financial interests / personal relationships may be potential competitive interests."

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All animal and human experiments conducted in the manuscript research should comply with the ARRIVE guidelines, EU Directive 2010/63/EU, The Code of Ethics of the World Medical Association (Declaration of Helsinki), and National Ethics Committee for Animal Experiments (HADMEK, HADYEK). If there is a human study in the article, it must comply with The Code of Ethics of the World Medical Association (Declaration of Helsinki).

If the submitted article involves the use of animal (vertebrate) and human subjects, authors should prove that they have carried out the manuscript studies in accordance with the relevant laws and regulations and they have received the approval of the authorized institutional committee (s) (including the ethics committee name and reference number, if possible). If a study was granted exemption or did not require ethics approval, this should also be detailed in the manuscript.

Copies of approval should be uploaded to the system under the subheading "Ethics Committee Approval". In addition, an explanation should be added to the article with the title of "Ethics Approval" after the Acknowledgements section.

Examples:

"Approval was granted by the Ethics Committee of University B (Date.../No....)."

"This is an observational study. The ABC Research Ethics Committee has confirmed that no ethical approval is required."

"This article does not contain any human or animal studies performed by any authors."

"The authors declare that all applicable guidelines for sampling, care, and experimental use of animals in this study have been followed."

"Sampling and handling procedures of the fish were in accordance with an …… protocol approved by University of ……..".

"No specific ethical approval was necessary for this study."

Retrospective Ethics Approval

If necessary, an application should be made to the ethics committee and approval should be obtained before starting a study. Generally, retrospective ethical approval cannot be obtained. It may not be possible to consider such articles for peer review. In such cases, it is at the Editor's discretion to decide whether to proceed with the peer review.

Data Availability

Articles are open access and free to use. Published articles are archived permanently. Proper citation is required when using an article published in a journal.

In order for the datasets reflecting the results of the article should be accessible to the readers; the journal encourages that datasets may be stored in public repositories (where available and appropriate) and addressed in the article, provided in the article, or in supplementary files whenever possible, or available from the corresponding author upon request. Regarding data availability, authors can follow one of the ways described. Enquiries about data availability should be directed to the authors. This information should be placed in the text with the heading "Data Availability" after the "Acknowledgements" section of the article. See examples below:

Examples:

Data availability: All of the data summarized in the study are available in the (name) Data Repository, (link address).

Data availability: The data sets generated during and/or analysed during the current study will be provided by the corresponding author upon the request of the editor or reviewers.

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Data availability: All relevant data is in the article.

Scientific Style

In writing of systematic /biological papers, international terminology such as "International Codes of Zoological Nomenclature (ICZN), and International Code of Nomenclature for Algae Fungi and Plants (ICNAFP)(Formerly known as the International Code of Botanical Nomenclature - CBN) International Code of Botanical Nomenclature (ICBN)" must be strictly followed. The first mention in the text of any taxon must be followed by its authority including the year. The names of genera and species should be given in italics. Clearly write the full genus name at the first occurrence in the text, and abbreviate it when it occurs again. When

referring to a species, do not use the genus name alone; Be careful when using 'sp' (singular) or 'spp.' (plural).

Equations and units

Please ensure that equations are editable. Leave a space on both sides of the <, ±, =, etc. equations used in the text. For units and symbols, the SI system should be used.

Abbreviations

Please define non-standard abbreviations at first use in the text with full form followed by the acronym in parentheses. Use only the acronym for subsequent explanations.

Footnotes

Footnotes should be numbered consecutively. Those in tables or figures should be indicated by superscript lower-case letters. Asterisks should be used for significance values and other statistical data. Footnotes should never include the bibliographic details of a reference.

References

Full references should be provided in accordance with the APA style. The usage of reference managers as Mendeley© or Endnote© or an online reference manager as Citefast with the output style of APA 7th edition is advised in organizing the reference list.

Please ensure that every reference cited in the text is also present in the reference list (and vice versa) and avoid excessive referencing.

In-Text Citation

In-text citation to the references should be formatted as surname(s) of the author(s) and the year of publication (also known as the author-date system).

If a specific part of a source (book, article, etc) is cited directly, a page number should also be included after the date. If the full source is used, the citation page number is not displayed.

For example: Kocataş, 1978, p. 3

Citation can be shown in two ways: Parenthetical Citation or Narrative Citation.

References to be made at the end of the sentence should be shown in parentheses. If the cited reference is the subject of a sentence, only the date should be given in parentheses. There should be no parentheses for the citations that the year of the citation is given in the beginning of the sentence.

Citation examples according to the number of authors are given below.

One author:

Consider the following examples:

-…….(Kocataş, 1978)

- Kocataş (1978) states…….

- In 1978, Kocataş's study of freshwater ecology showed that….

Two authors:

If there are two authors, the surnames of both authors should be indicated and separated from each other by "and", (Geldiay and Ergen, 1972).

Consider the following examples:

-…….(Geldiay and Ergen, 1972)

- Geldiay and Ergen (1972) states……

- Similar results were expressed by Geldiay and Ergen (1972), Kocataş (1978).

More than two authors:

For citations with more than two authors, only the first author's surname should be given, followed by "et al." –in Turkish article 'vd.'- and the date (Geldiay et al.,1971; Geldiay vd., 1971).

See below examples:

-Geldiay et al. (1971) state…….

-……(Geldiay et al., 1971).

There are few studies on this subject (Geldiay et al.,1971).

Two or more works by different author:

When its needed to cite two or more works together, in-text citations should be arranged alphabetically in the same order in which they appear in the reference list and used semicolons to sparate citations.

For example: Several studies have reported similar results (Geldiay and Ergen, 1972; Kocataş 1978; Thurry 1987).

Two or more works by the same author:

If there are two or more works by the same author, list the years of publication in order, earliest first. For example: (Kocataş, 1978, 1979, 1981) or Kocataş (1978, 1979, 1981)

Citation to authors with more than one work in the same year:

The works should be cited as a, b, c, etc. after the date. These letters must be listed alphabetically according to the surname of the first author in the bibliography list.

For Example:

-Geldiay and Ergen, 1972a

-Geldiay and Ergen, 1972a, b

No authors:

If the author is unknown, the first few words of the source should be used and dated.

For example: (A guide to citation, 2017).

In some cases, "Anonymous" is used for the author, accept this as the name of the author (Anonymous, 2001). Use the name Anonymous as the author in the reference list.

No publication date:

If the publication date is unknown, write "n.d." (no date) in the in-text citation.

Example: (Geldiay, n.d.).

Citation to secondary sources:

In scientific studies, citation should be made to the original primary sources. Cite secondary sources when the original work is out of print, not available, or only available in a language you do not understand. If you want to cite a work that you can't find yourself, through a citation from another source, using the phrase "…….as cited in".

For Example:

(Geldiay and Ergen 1972, as cited in Kocataş, 1978)

Personal communication and unpublished results:

Personal communications, such as phone calls, emails, and interviews, are not included in the reference list because readers can't access them. The in-text citation is also formatted slightly differently as follow:

Example:

- Demands have been increasing lately. (A. Kale, personal communication, May 10, 2021).

General use of websites and software:

It should be showed as below.

-The website of Egejfas (www.egejfas.org) includes author guidelines.

-Statistical software SPSS (version 25) was used to analyze the data.

In References

All citations should be listed in the reference list, with the exception of personal communications and unpublished results.

All references must be written in English. If an article is written in a language other than English, give the title in English and indicate the language in which the article is in parentheses at the end of the source. Example: (in Turkish)

If the article has only an English abstract, indicate it in parentheses (English abstract) or (only English abstract)

References should be listed alphabetically ordered by the author's surname, or first author's surname if there is more than one author.

Hanging indent paragraph style should be used.

The year of the reference should be in parentheses after the author name(s).

The correct arrangement of the reference list elements should be in order as "Author surname, first letter of the name(s). (publication date). Title of work. Publication data. DOI

Article title should be in sentence case and the journal title should be in title case. Journal titles in the Reference List must be italicized and spelled out fully; do not abbreviate titles (For example; Ege Journal of Fisheries and Aquatic Sciences, not Ege J Fish Aqua Sci). Article titles are not italicized. If the journal is paginated by issue the issue number should be in parentheses.

DOI (Digital Object Identifier) information (if available) should be placed at the end of the reference as in the example. After added DOI information, "dot" should not be put. The DOI information for the reference list can be retrieved from CrossRef © Simple Text Query Form (https://doi.crossref.org/simpleTextQuery) by just pasting the reference list into the query box. After copying and pasting all the references of your article in the query box on this page, the DOI information is listed as added to the relevant reference. It is strongly recommended to provide DOI information of the references.

- For a reference with up to 20 authors, ALL authors (up to 20) are spelled in the reference list. When the number of authors is more than 21, "....." is used between the 19th author and the last author (APA 7th edition).

For example:

Bolotov, I.N., Kondakov, A.V., Konopleva, E.S., Vikhrev, I. V., Aksenova, O. A, Aksenov, A. S., Bespalaya, Y. V., Borovskoy, A. V., Danilov, P. P., Dvoryankin, G. A. Gofarov, M. Y., Kabakov, M. B., Klishko, O. K., Kolosova, Y. S., Lyubas, A. A., Novoselov, A. P., Palatov, D. M., Savvinov, G. N., Solomonov, N. M., ……..& Vinarski, M. M., (2020). Integrative taxonomy, biogeography and conservation of freshwater mussels (Unionidae) in Russia.Scientific Reports, *10*, 3072. https://doi.org/10.1038/s41598-020-59867-7

- In the reference list starting with the same surname and names (initials), works with a single author are put in chronological order first; Then, two-author works are taken into account in alphabetical order of the second author. Multi-author works are listed only chronologically.

For example:

Kocataş, A. (1978)

Kocataş, A., & Ergen, Z. (1972).

Kocataş, A., & Geldiay, R. (1972)

Kocataş, A., Ergen, Z., & Geldiay, R. (1980)

The citation of journals, books, multi-author books and articles published online etc. should conform to the following examples:

Journal Articles

Öztürk, B. (2010). Scaphopod species (Mollusca) of the Turkish Levantine and Aegean seas. Turkish Journal of Zoology, *35*(2), 199-211. DOI:10.3906/zoo-0904-23

Özbek, M., & Ulutürk, E. (2017). First record of Spongilla lacustris (Porifera: Demospongiae) from the Eastern Black Sea (Uzungöl Lake, Trabzon) (in Turkish with English abstract). Ege Journal of Fisheries and Aquatic Sciences, *34*(3), 341-346. https://doi.org/10.12714/egejfas.2017.34.3.14

Books

Parsons, T.R., Matia, Y., & Lalli, C.M. (1984). A manual of chemical and biological methods for seawater analysis. New York, Pergamon Press.

Kleiner, F.S., Mamiya, C.J., & Tansey, R.G. (2001). Gardner's art through the ages (11th ed.). Fort Worth, USA: Harcourt College Publishers.

Chapter in books

Gollasch, S. (2007). Is ballast water a major dispersal mechanism for marine organisms? In W. Nentwig (Ed.), Biological Invasions (pp. 29-57). Berlin: Springer.

E-books and chapter in e-books

Mitchell, J.A., Thomson, M., & Coyne, R.P. (2017). A guide to citation. Retrieved from https://www.mendeley.com/reference-management/reference-manager

Troy, B.N. (2015). APA citation rules. In S.T, Williams (Ed.). A guide to citation rules (2nd ed., pp. 50-95). Retrieved from https://www.mendeley.com/reference-management/reference-manager

Proceedings

Soultos, N., Lossifidou, E., Lazou, T., & Sergedilis, D. (2010). Prevalence and antibiotic susceptibility of Listeria monocytogenes isolated from RTE seafoods in Thessaloniki (Northern Greece). In Ş. Çaklı, U. Çelik, C. Altınelataman (Eds.), West European Fish Technologists Association Annual Meeting 2010 (pp. 94-98). İzmir, Turkey: Proceedings Book.

Websites

Mitchell, J.A. (2017, May 21). How and when to reference. https://www.howandwhentoreference.com

If the resource was written by a group or organization, use the name of the group/organization as the author. Additionally, if the author and site name are the same, omit the site name from the citation.

American Society for the Prevention of Cruelty to Animals. (2019, November 21). Justice served: Case closed for over 40 dogfighting victims. https://www.aspca.org/news/justice-served-case-closed-over-40-dogfighting-victims

Thesis

Acarli, S. (2005). Larval production of oyster. Doctoral dissertation, Ege University, Turkey.

Tables and Figures

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RESEARCH ARTICLE ARAŞTIRMA MAKALESİ

Climate change awareness and potential risks in freshwater aquaculture sector in Türkiye: A survey-based evaluation

Türkiye'de tatlı su balık yetiştiriciliği sektöründe iklim değişikliği farkındalığı ve potansiyel riskler: Ankete dayalı bir değerlendirme

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Abstract: Aquaculture sector is vulnerable to climate change, which has adverse impacts on water resources such as floods, droughts, sea level rise, water scarcity and water pollution. In this study, climate change awareness of freshwater aquaculture producers and associated potential risks are investigated for Türkiye. A survey was applied to 257 trout producing plants out of 1440 active plants in 25 river basins in 2020. The results implied that 79% of producers mentioned their awareness of the negative impacts of climate change, where water quantity and quality was reported as the highest impact that would threat fish health. In terms of extreme weather events, floods and drought were experienced by 40% and 35% of respondents, respectively. Temperature increase poses a threat for the plant owners and affects trout production. One-third of the producers had a financial loss of €6500-30.000. There is water sharing problem for almost 40% of plants. Future concern on water allocation was higher than 70% and the rate of agricultural insurance was very low, i.e., 11%.

Keywords: Awareness, climate change, freshwater aquaculture, risk, survey

Öz: Su ürünleri yetiştiriciliği sektörü, sel, kuraklık, deniz seviyesinin yükselmesi, su kıtlığı ve su kirliliği gibi su kaynakları üzerinde olumsuz etkileri olan iklim değişikliğine karşı kırılgandır. Bu çalışmada, Türkiye için tatlısularda balık yetiştiriciliği yapan üreticilerin iklim değişikliği farkındalığı ve ilişkili potansiyel riskler araştırılmıştır. 2020 yılında 25 nehir havzasında 1440 aktif alabalık üreten tesisten 257'sine anket uygulanmıştır. Sonuçlar, üreticilerin %79'unun iklim değişikliğinin olumsuz etkileri konusunda farkındalıklarının olduğunu göstermiş, balık sağlığını tehdit edecek en yüksek etki su miktarı ve kalitesi olarak rapor edilmiştir. Aşırı hava olayları açısından, katılımcıların sırasıyla %40'ı sel ve %35'i kuraklık yaşamıştır. Sıcaklık artışının tesis sahipleri için bir tehdit oluşturduğu ve alabalık üretimini etkilediği belirtilmiştir. Üreticilerin üçte biri 6500-30.000 € arasında maddi kayıp yaşadığını belirtmiştir. Tesislerin yaklaşık %40'ında su paylaşımı sorunu vardır. Su tahsisinde gelecek kaygısı %70'in üzerinde çıkmış, tarım sigortası oranı ise %11 gibi çok düşük bir seviyede kalmıştır.

Anahtar kelimeler: Farkındalık, iklim değişikliği, tatlı su balık yetiştiriciliği, risk, anket

INTRODUCTION

Population growth, economic development and industrialization have induced a growing demand for natural resources. As a result, expanding emissions of greenhouse gases from burning fossil fuels have triggered the global problem of climate change. Among the consequences of climate change; global temperature rise, decreased snow cover, warming oceans, sea level rise, declining arctic sea ice, ocean acidification and extreme weather events such as floods and droughts can be listed (NASA, 2024).

One of the most noticeable impacts of climate change is perceived on the hydrological cycle and water resources. Intergovernmental Panel on Climate Change (IPCC) reports that global warming of 1.5°C and 2°C will be exceeded during the 21st century unless deep reductions in CO_2 and other greenhouse gas emissions occur in the coming decades (IPCC, 2021). One of the sectors to be adversely affected by climate change is the fisheries and aquaculture production, as they are directly linked to water.

Fisheries have an important role both in human diet and the economy. Fish provide high-quality protein, minerals and trace elements, fat-soluble vitamins and essential fatty acids (FAO, 2010). Hence, fish consumption leads to nutritional benefits. Worldwide recommended annual consumption of fish is 11.7 kg per capita (WWF, 2016). The average annual consumption of fisheries is 24.4 kg per capita in the European Union (European Council, 2024). On the other hand, with an annual consumption of 6.7 kg per capita consumption, Türkiye is below average compared to other countries and the EU (MoAF, 2021). Nevertheless, fish is expected to remain one of the highly preferred healthy foods in the human diet. With ever increasing population on earth, more fish will be required in coming years. However, due to overfishing and pollution, wild fish stocks have been decreasing, and the increasing demand has led to growth of aquaculture production (Hoque, 2021; World Bank, 2013).

Global fish production is estimated to have reached about 170 million tonnes in 2018 (FAO, 2020a, b). The latest available statistics shared by OECD demonstrate that China is the major fish producer, where more than 12 million tonnes of fish were captured in 2018. In capture, the rank is followed by Indonesia

and USA. In addition, China has produced more than 68 million tonnes of fish by aquaculture production, followed by Indonesia and India (OECD, 2022).

Fisheries and aquaculture production occur both in seas and inland freshwaters in Türkiye. Among a total of 2139 aquaculture production plants, 432 of them are produced at sea and 1707 of them are producing at inland freshwater. These numbers indicate that aquaculture production plants are mostly dependent on freshwater. Regarding the capacities, 1118 plants have small capacity of 0-50 tons/year, corresponding to 65% of total, and 99 plants have high capacity of 500-1000 tons/year; corresponding to 6% of total. By the year 2020, 1440 out of 1707 plants are active (84%) (MoAF, 2020). The most cultivated fish species in these plants are bass, trout and bream (TURKSTAT, 2021a). About 80% of the total production of the last 10 years was obtained from seas (Figure 1). Despite the fish consumption being deficient in Türkiye, the production occurred as 785.811 tonnes in 2020, where 364.400 tonnes of the total production were from capture fisheries and 421.411 tonnes were from aquaculture production, corresponding to 46% and 54% of total production, respectively (TURKSTAT, 2021a). These data imply that in recent years, growth in the capture fishing industry has slowed down and there has been a significant increase in the level of aquaculture production.

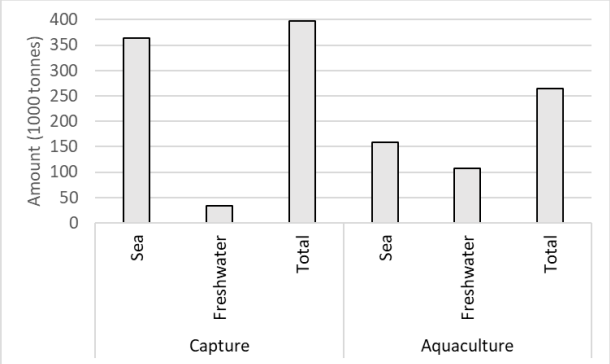

Figure 1. Fisheries and aquaculture production in Türkiye (2010-2020 average)

The fisheries and aquaculture sectors are highly vulnerable to climate change as investigated by researchers (Kainge el al., 2020; Sowman, 2020). Being located at the waterfront, fishing and fish farming communities are exposed to climate related extreme events and natural hazards, such as hurricanes, cyclones, sea level rise, ocean acidification, floods and coastal erosion (FAO, 2018). These negative impacts are not only affecting people who make their livelihood from this sector but also leading to global food insecurity. Türkiye has exported an average of 163.000 tons of aquaculture products to 80 countries worldwide from 2015 to 2019 (Figure 2). The Netherlands and Italy are the top two importing countries with an average rate of 13% (MoAF, 2020).

Climate change affects the aquaculture sector in different ways according to different countries or regions. A study on the impact of climate change on aquaculture in India reveals that the farmers in Sundarban region feels the negative impacts on the sector mainly because of the increasing frequency of cyclones and extreme weather events (Dubey et al., 2017). Similarly, another study, which investigated the possible impact of climate change on aquaculture in Indonesia shows that high density of rainfall causes decreasing water temperature and oxygen depletion that result in fish deaths (Sugama and Radiarta, 2012). There is also a case study which investigates the Mekong Delta in Vietnam. The study uncovers that climate change causes water level rise and saltwater intrusion, which creates a risk for the striped catfish production that makes huge contribution to the economy of Mekong Delta (Anh, 2014).

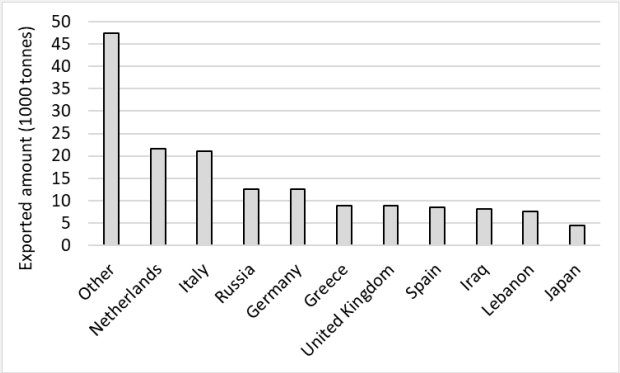

Figure 2. Aquaculture export of Türkiye (2015-2019 average) (MoAF, 2020)

Revealing the associated risks on different culture systems is important so that adaptation and resilience actions can be designed. For this, a framework was developed for assessing climate risk to aquaculture in Oman, where the overall climate risk was quantified as the combination of four risks: (1) species' temperature sensitivity, (2) flooding and storm surge exposure, (3) low-oxygen hazard and (4) disease vulnerability (Engelhard et al., 2022). They demonstrated that the framework was equally applicable at the regional, national or sub-national scale to support design of targeted resilience building actions and enhance food security.

Fisheries and aquaculture make a significant contribution to the economy of relevant countries, including Türkiye. The revenue generated by the export of fisheries and aquaculture products was about 1 billion dollars in 2020 (TURKSTAT, 2021b). The data discloses evidently that any factor that may adversely impact sustainable production will significantly harm the producers, the national economy as well as the food security of importing countries. The government has already prepared relevant adaptation strategies (MoAF, 2022). Awareness, participation and readiness of producers is vital within the context of climate change adaptation.

To contribute to the national and international strategies for adapting to climate change and in turn help sustainable production and exportation of aquaculture products, this study aims to assess the climate change awareness of freshwater aquaculture producers and associated potential risks in

Türkiye. To reach this aim, a survey was conducted with 257 production plants out of 1440 active plants from 25 river basins. Almost half of the surveyed plants were fed from rivers. The data obtained in the study was evaluated to identify river basins with high vulnerabilities. In addition, the dimensions of the threats and difficulties faced by the aquaculture sector have been revealed.

MATERIALS AND METHODS

Strategy of selecting freshwater aquaculture plants for the survey

The contact information of the freshwater aquaculture production plants was provided from the Republic of Turkey Ministry of Agriculture and Forestry (MoAF). Then, a province-based list of the plants was created based on the classification of the information in terms of the plant capacity, location, associated water resource and production model. It was aimed to sample the plants from each river basin, for which the hydrological layer of the MoAF Flood Management Information System was used. The survey was conducted in 2019. The following points were considered for plant selection:

- Different water resources such as rivers and lakes were represented.
- The distribution of plant capacities was represented; the survey covered small capacity plants to a high extent.
- The plants that use ponds on land (fed from the rivers mostly) and net cages in water bodies (reservoirs and lakes) were considered.
- The survey did not cover aquaculture production in closed loop systems and those fed by the treated drinking water (supplied by the municipality).
- In case there was a large number of plants on the same water supply, the number of plants surveyed was kept limited to avoid their impact on the results.
- For the basins whose water resources are used by different provinces or districts, it was aimed to represent producers with different economic and social conditions.

The inactive plants were eliminated and 257 active freshwater aquaculture production plants, corresponding to 18% of 1440 plants, were contacted. The number of plants to be covered by the survey was aimed to represent at least 10% of the total number of plants in each basin. As seen, the percentage of coverage varies between 11% to 100% (Table 1). The distribution of plants with respect to river basins is depicted in Figure 3.

The types of water resources used for fish production are given in Figure 4. As seen, 119 out of 257 plants use river waters (46%), followed by 61 plants fed by reservoirs (24%) and 53 plants fed by springs (20.6%). The number of plants engaged in production with water from lakes is relatively small, i.e., 23 (9%). In addition, there is only one plant that uses groundwater resource (0.4%). Considering all the plants surveyed in river basins and all types of water resources, the share of use are 11-88% for rivers, 5-56% for reservoirs, 10-100% for springs, 11-75% for lakes and 10% for groundwaters, respectively.

Table 1. Number and ratio of plants surveyed

River Basin	Number of plants surveyed	Total number of plants	Ratio (%)
01. Meriç-Ergene	10	28	36
02. Marmara	2	2	100
03. Susurluk	9	18	50
04. Northern Aegean	4	8	50
05. Gediz	6	15	40
06. Küçük Menderes	1	2	50
07. Büyük Menderes	10	43	23
08. Western Mediterranean	21	191	11
09. Antalya	26	133	20
10. Burdur	4	18	22
11. Akarçay	2	3	67
12. Sakarya	13	54	24
13. Western Black Sea	9	57	16
14. Yeşilırmak	13	82	16
15. Kızılırmak	6	50	12
16. Konya Closed Basin	3	10	30
17. Eastern Mediterranean	9	53	17
18. Seyhan	8	34	24
19. Asi	1	3	33
20. Ceyhan	7	45	16
21. Euphrates-Tigris	50	381	13
22. Eastern Black Sea	28	131	21
23. Çoruh	7	49	14
24. Aras	5	7	71
25. Van Lake	3	23	13
TOTAL	**257**	**1440**	**18**

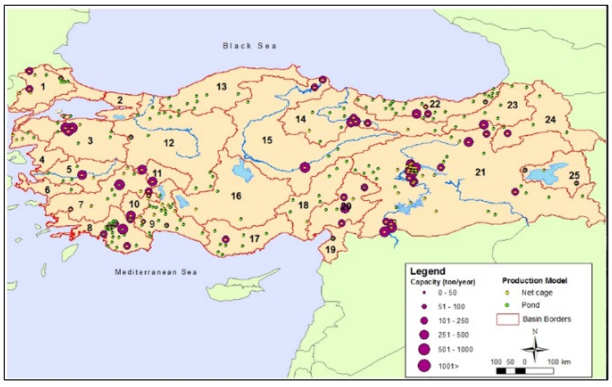

Figure 3. The distribution of plants participated in the survey with respect to river basins

Among the ones surveyed, the highest number of plants using river waters is 21 and they are in Eastern Black Sea Basin. On the other hand, the highest number of plants using reservoir waters is 28 and they are in Euphrates-Tigris Basin. This is quite expected because Eastern Black Sea Basin gets the highest precipitation compared to the country average, so the river flows are adequate for aquaculture production. On the contrary, Euphrates-Tigris Basin gets lower precipitation compared to the country average, and therefore storage of water in reservoirs becomes essential for sustainable production.

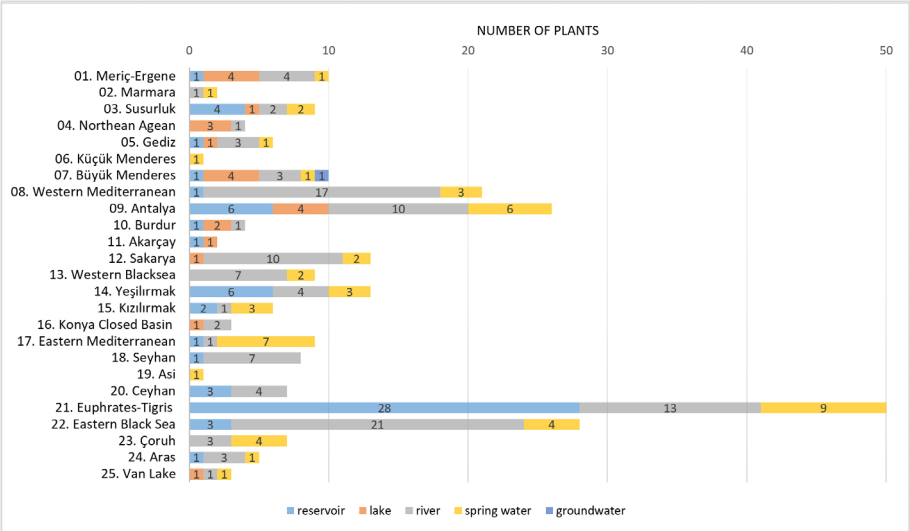

Figure 4. Types of water resources used for fish production

In this study, the production model of surveyed plants is either net cage for production in water source or ponds for inland production. Figure 5 depicts the distribution of production models; 33% of the plants were using net cages, 66% of plants were using ponds and 1% of plants were using both. As seen from Figure 6, the number of surveyed plants using ponds was highest in Antalya, Western Mediterranean, Eastern Black Sea and Euphrates-Tigris River basins.

Among the plants surveyed, 199 had small capacity of 0-50 tons/year, corresponding to 76%, followed by 10% of plants having a capacity of 101-250 tons/year. Only eight plants had a high capacity of 500-1000 tons/year, corresponding to 3% (Figure 7). These ratios well represented the situation in the country.

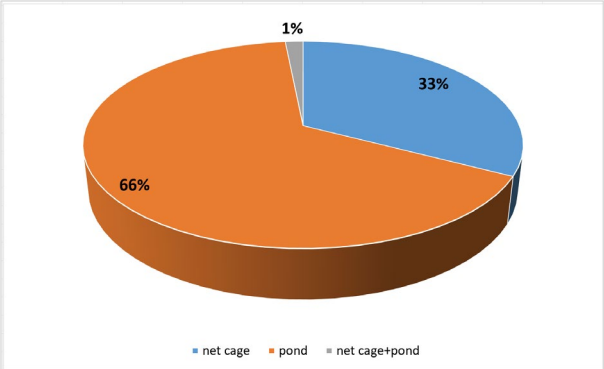

Figure 5. Share of production models

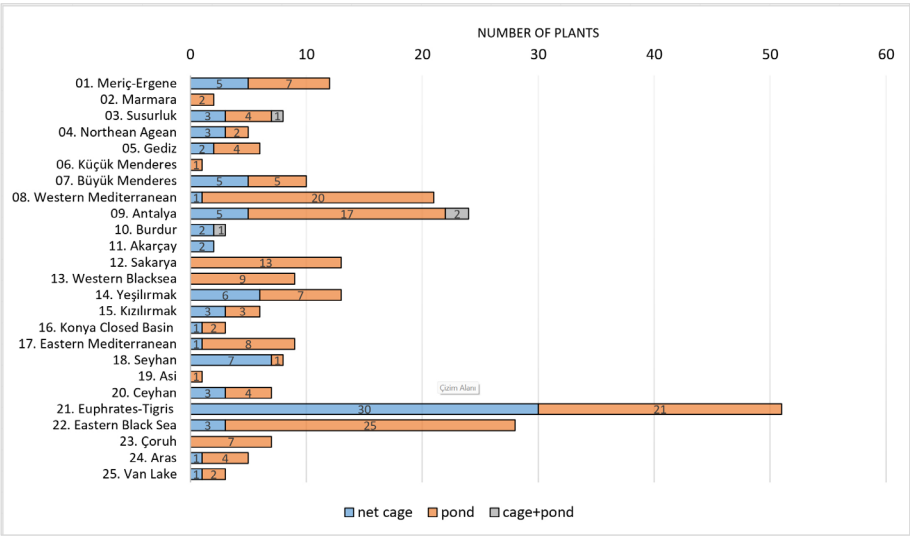

Figure 6. Distribution of production models among the river basins

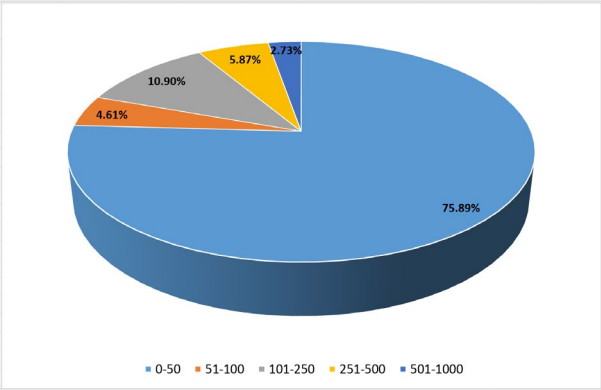

Figure 7. Capacity of plants surveyed (tons/year)

Content of the survey

The survey included one open-ended, three multiple responses and six multiple-choice questions (Table 2). The interviews were conducted by phone call and questions were answered by plant owners or authorized engineers. The results were evaluated on a basin basis.

Table 1. Survey questions

No	Question
1	Do you think that climate change affects the water resource that you use? If so, what is the severity of the impact? 1. No effect 2. Little effect 3. Some effect 4. Severe effect 5. No idea
2	In which of the following do you observe the impacts of climate change the most? 1. Production period and harvest 2. Water quality/quantity 3. Fish health 4. Reproduction performance 5. No idea
3	Have you experienced extreme weather events in the last five years? If so, which ones? 1. Storms 2. Drought 3. Flood 4. Frost 5. Others
4	Have you had any financial loss related to extreme weather events? Can you give a range for your approximate loss? 1. € 0-600 2. € 600-3500 3. € 3.500-6.500 4. € 6.500-30.000 5. € 30.000 and more
5	Do you have agricultural insurance? Yes/No
6	Do you have any problems with other sectors sharing water? Yes/No
7	Are you concerned with possible future problems on water allocation in the basin you are located? Yes/No
8	How would you be affected by a possible temperature increase of 1°C in the water supply? 1. Positive 2. Negative 3. No effect
9	Which of the following are the factors that you consider as a risk for the sustainability of your business? 1. Fish feed 2. Share of water 3. Climate change 4. Economy 5. Others
10	What is the most important problem that you think the freshwater aquaculture sector will face in the future?

RESULTS

Perceptions on the impacts of climate change on water resources and fish production stages

The respondents were asked whether the water resources they were using were negatively affected by climate change (Figure 8). The analysis of the answers on the basin level is shown in Figure 9.

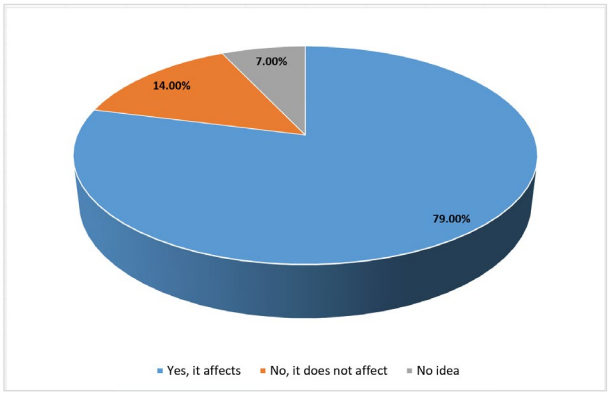

Figure 8. Producers' perception of climate change impacts on water resources

To figure out the fish production stages which were mostly affected by the climate change, the second question was directed to the respondents. They were allowed to give multiple answers (Figure 10).

Extreme weather events

The producers were asked which extreme weather events they have faced in the last five years (Figure 11). The occurrence of extreme weather events in each river basin is given in Figure 12.

Financial losses and agriculture insurance

The range of financial losses of the plants surveyed in this study are given in Figure 13 and their distribution with respect to the river basins is given in Figure 14.

Water sharing problems

The distribution of responses on water sharing problems with respect to river basins is given in Figure 15.

Impact of temperature increase

The distribution of producers' perceptions on 1°C temperature increase is shown in Figure 16 for all river basins.

Future risks

The future risks were asked to the respondents, and the results are given in Figure 17 and Figure 18. The distribution of possible risks is given in Figure 19.

The summary of all the responses is listed in Table 3.

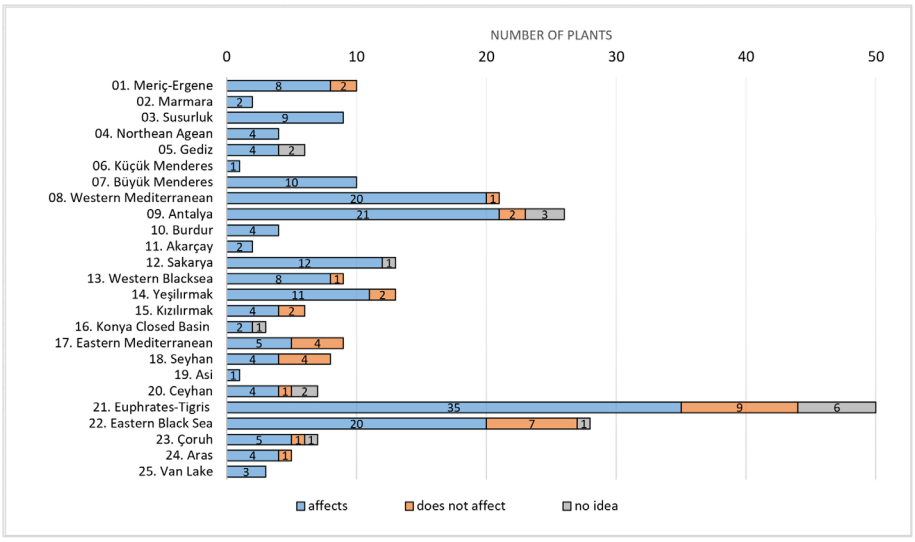

Figure 9. Replies for awareness on climate change impacts with respect to river basins

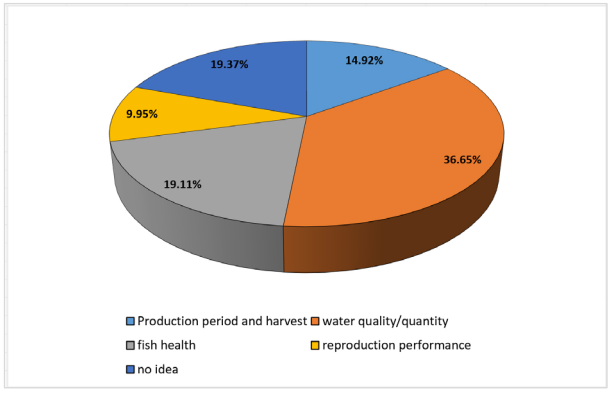

Figure 10. Impacts of climate change on fish production stages

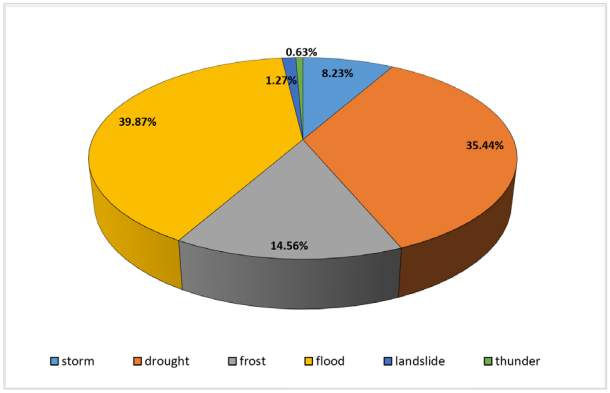

Figure 11. Extreme weather events that plants had faced in the last 5 years

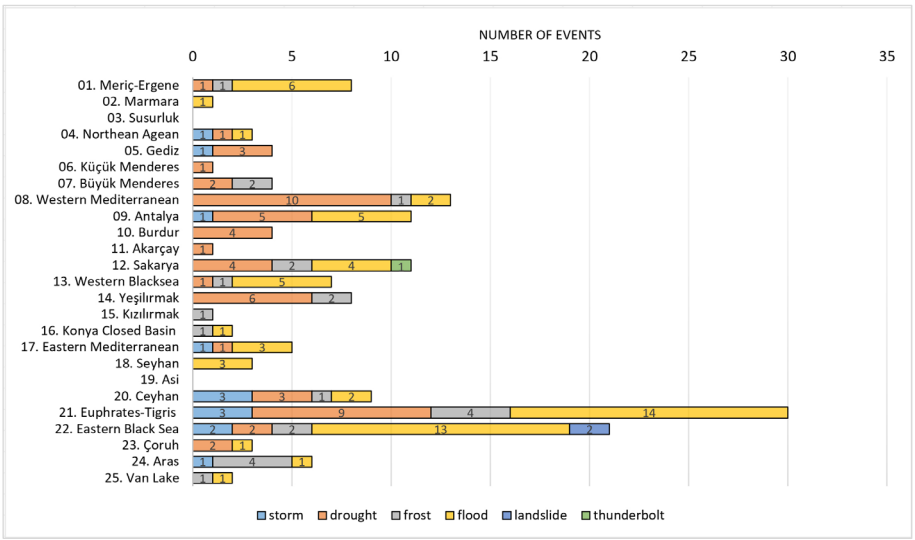

Figure 12. Occurrence of extreme weather events in river basins

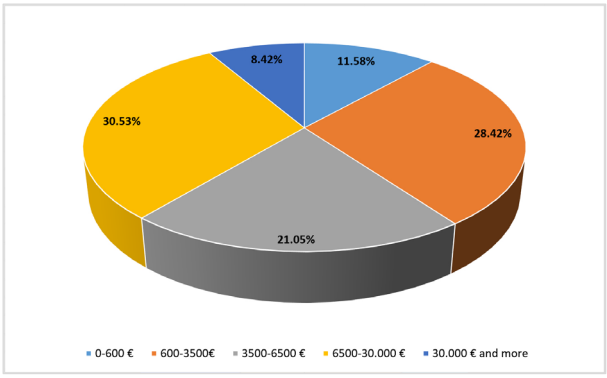

Figure 13. Financial losses of the plants

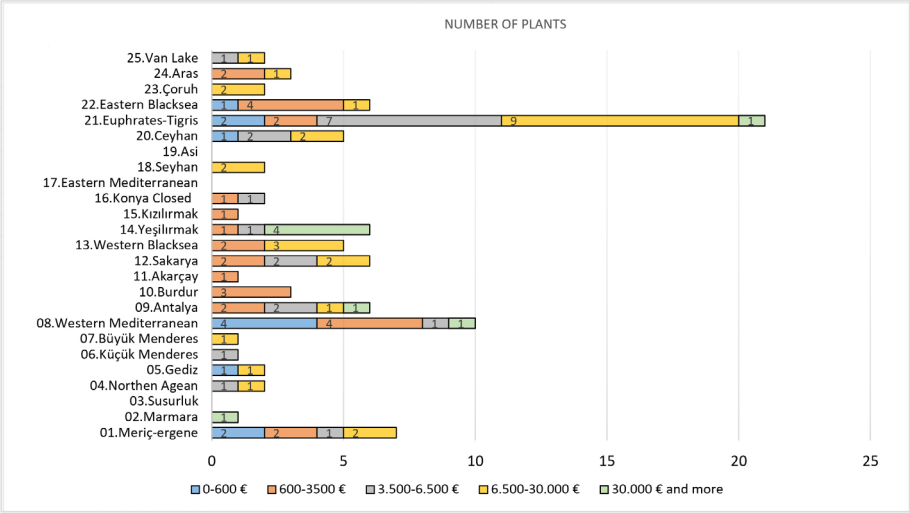

Figure 14. Distribution of financial losses among river basins

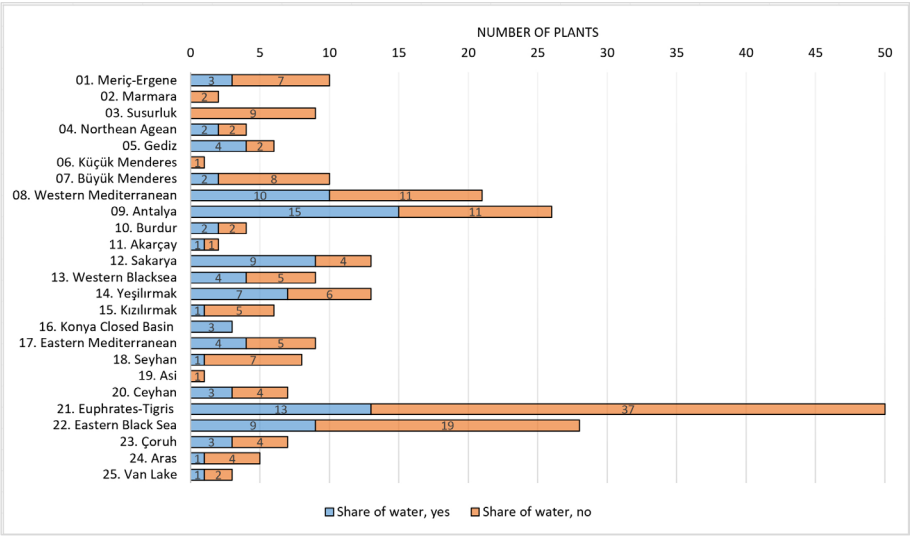

Figure 15. Distribution of responses on water sharing problems in river basins

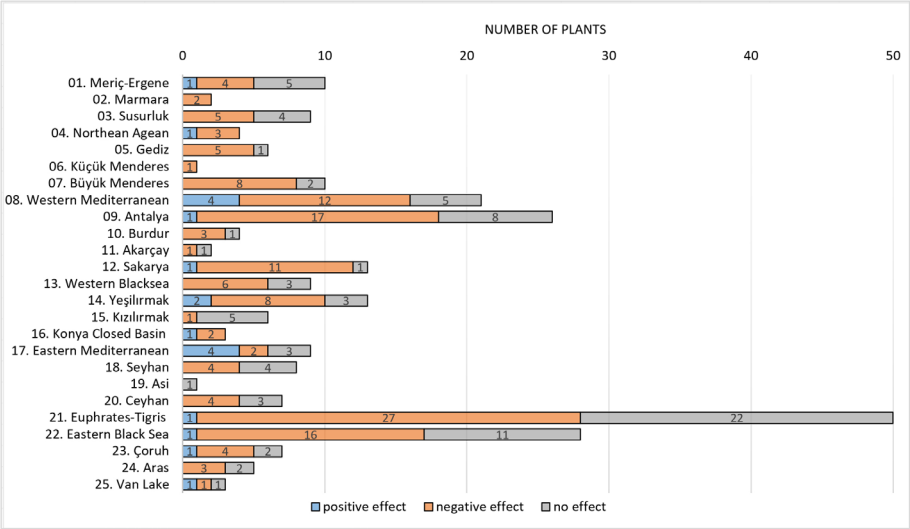

Figure 16. Distribution of producers' perceptions on 1°C temperature increase

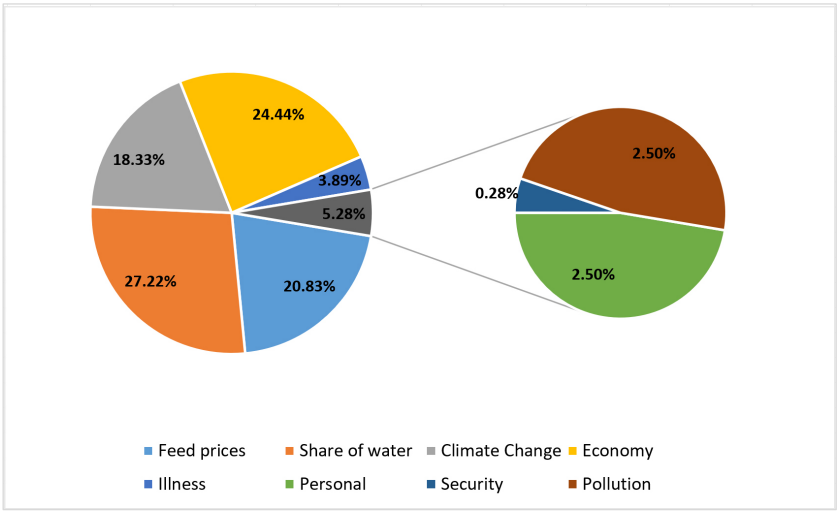

Figure 17. Possible future risks for the aquaculture sector

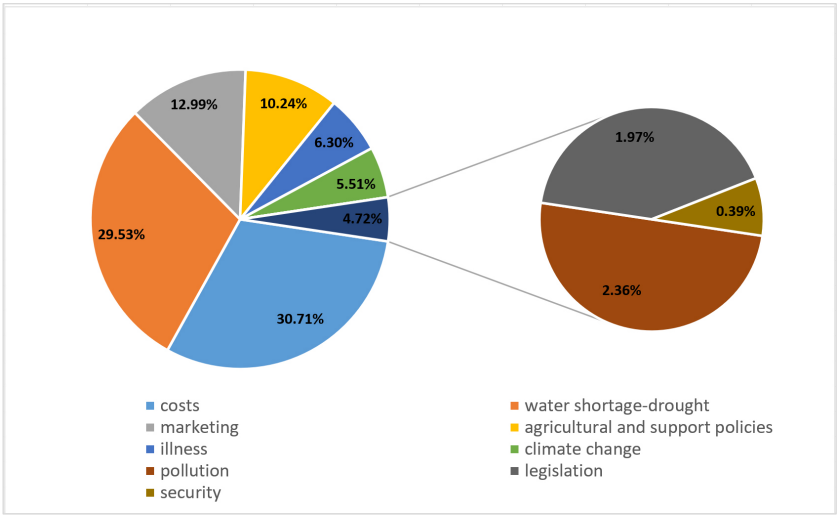

Figure 18. Future problems of aquaculture sector

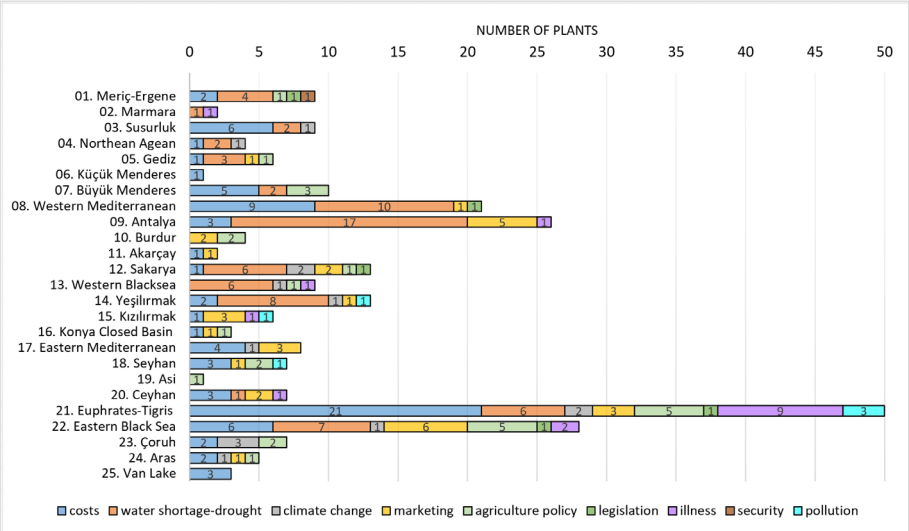

Figure 19. Distribution of future problems among river basins

Table 3. Summary of all the responses

Question	Result	Response	Most affected river basin
Climate change awareness	High	79%	All basins
Impact of climate change on production stages	Water quality/quantity Fish health	37% 19%	All basins
Extreme weather events	Floods Drought	40% 35%	Floods; Eastern Black Sea, Western Black Sea, Meriç-Ergene
Financial losses	€6500 - €30.000 €600 - €3500	31% 28%	Yeşilırmak, Euphrates-Tigris
Agricultural insurance	Low	11%	Euphrates-Tigris
Problem of water sharing	There is conflict	38%	Konya, Euphrates-Tigris and Antalya
Future concern on water allocation	High	> 70%	Sakarya and Konya
Temperature increase	Negative impact expected	58%	Western Mediterranean, Antalya, Euphrates-Tigris and Eastern Black Sea
Possible future risks and problems	Costs Water shortage/drought	31% 30%	Costs; Çoruh, Küçük Menderes and Susurluk Water shortage/drought; Western Black Sea,

DISCUSSION

Perceptions on the impacts of climate change on water resources and fish production stages

As evidenced from the survey study, 79% of the respondents said that the water resources they were using were negatively affected by climate change (Figure 8). These data imply that aquaculture producers are aware of the climate change and its impacts on water resources. This is quite expected since recent studies point to the fact that Türkiye, being in the Mediterranean Basin, is predicted to be severely affected by the adverse effects of global climate change, particularly in terms of water resources (Aktaş, 2014; ClimaHydro Project - MoAF, 2016a). According to ClimaHydro projections, temperature increase of at least 1-2,5C° is expected in Türkiye. Annual precipitation rates are expected to decrease except Black Sea Basin. All projection periods predict a serious water deficit in Euphrates-Tigris and Konya Closed Basin while excess water is predicted in Eastern Black Sea and Çoruh Basins (MoAF, 2016a).

The analysis of the answers on the basin level shows that 50-100% of the plants in all river basins realize the climate change impacts on water resources; where 100% reply belongs to the producers from Northern Agean, Susurluk, Burdur, Marmara, Büyük Menderes, Küçük Menderes, Akarçay, Van Lake and Asi basins (Figure 9). The ratio of respondents who said that climate change had no effect on their water resources was as high as 44-50% in Eastern Mediterranean and Seyhan basins. The corresponding number of plants in this category was 4 out of 9 and 8, respectively. The numbers were even higher in Euphrates-Tigris and Eastern Black Sea basins, i.e., 9 out of 50 plants and 7 out of 28 plants, respectively, had the idea that no impact of climate change was observed. However, most respondents in these

basins also agreed with the impact of climate change on water resources.

Regarding the evaluation of water resources with respect to the level of impact; 40% of the respondents indicated that they were moderately affected while 37% said that they were strongly affected. The remaining stated that there was little effect. By the analysis of the answers on river basin level, Burdur is the only river basin that all respondents indicated that the water resources were strongly affected by climate change (Tatma, 2020). The climate change related future projections support this information as it was revealed that water resources of Burdur basin currently cannot meet the water demand and the basin is expected to have the worst scenario in terms of gross water availability in all periods from 2015 to 2100, where 80-90% decrease is expected (Burdur Report - MoAF, 2016b).

As seen from Figure 10, the most preferred answers were water quality/quantity (37%) and fish health (19%) as the production stages mostly affected by climate change in almost all river basins. On the other hand, reproduction period/harvest option was preferred more by producers from Aras, Sakarya, Antalya, Euphrates-Tigris and Western Mediterranean River basins. It is interesting to note that the ratio of those who have no idea was as high as 19%. On the other hand, only 7% of respondents had no idea about the impact of climate change on water resources. This difference may imply that some producers are aware of water-related problems but not aware of the production problems in their plants. On the other hand, it is also known that some producers having water related problems have been trying to find different water resources and make changes in their production plans. These efforts seem to lessen the possible negative effects on production stages.

Extreme weather events

According to recent research, the severity and number of extreme climatic and meteorological events such as storms, heavy rains, floods, tornadoes, heat waves and forest fires are expected to increase in Türkiye in relation to the climate change (Demircan et al., 2017). In the current state, 54% of the respondents in this study stated that they had faced extreme weather events in the last five years (Tatma, 2020).

The producers were mostly exposed to floods (40%) and drought (35%) (Figure 11), which may indicate evidence of a change in precipitation patterns. Frost, by 15%, is the third most observed extreme event. The respondents also indicated that there had been an increase in the number of days without rain and extreme precipitation rates after severe drought and this situation resulted in floods, especially for the last three years. Some of the respondents claimed that another reason for the floods was the structures which prevent rainwater from reaching rivers and watersheds. In addition, producers in Eastern Black Sea River basin stated that the construction of dams reduced floods by regulating flow regimes.

The number of extreme weather events was reported to be between 15-30 in Euphrates-Tigris and Eastern Black Sea River basins, with a majority of floods. This was followed by 10-15 extreme weather events in Western Mediterranean, Antalya and Sakarya river basins, with a majority of drought. This outcome is supported by the findings of ClimaHydro project, where Western Mediterranean is among the basins that is expected to have the highest decrease of precipitation (25-30%) in the period of 2071-2100 (MoAF, 2016a). The survey results show that the occurrence of frost was highest in Aras and Euphrates-Tigris River basins (Figure 12). Floods were also observed in Meriç-Ergene, Antalya and Western Mediterranean basins. All these information need to be handled carefully since extreme weather events due to climate change might severely harm the sector in Türkiye.

Financial losses and agriculture insurance

The plants' authorized staff were asked whether they had any financial loss in the last five years due to extreme weather events and 95 out of 257 plants (37% of the respondents) replied positively. The amount of losses was grouped into five ranges (Figure 13). It was noticed that the producers did not consider the decreased production capacity (due to drought) as a financial loss. This means their financial losses are very likely to be higher than the reported values. As seen from Figure 13, 8% of the plants had the highest loss of €30.000 or more, whereas 31% of them had losses between €6500-30.000, followed by 21% of plants with losses of €3500-6500 and 28% of them with losses of €600-3500.

The interviews showed that most of the financial losses were caused by floods and drought. By its nature, production plants are located nearby water resources, and they are exposed to danger of floods. Overflow of the production pools results in both fish stocks to escape to the natural environment and turbidity problem. Floodwater causes blockage of fish gills and fish deaths. It can lead to a complete loss of the production season and significant financial losses. The financial losses are high in Yeşilırmak and Euphrates-Tigris River basins (Figure 14). The financial losses were mostly due to droughts and floods (Figure 12). The total financial loss of all affected plants was estimated as €950.000. This is equivalent to the income that can be earned from almost 300 tons of trout, given that one kg of trout costs approximately €3. This amount of fish can be produced in six small sized plants (0-50 tons/year).

Although the sensitivity of the aquaculture sector to extreme weather events and natural disasters was shown explicitly by the survey, it has been observed that the number of plants which had agricultural insurance is very low, i.e., only 28 out of 257 (11%).

Some of the respondents stated that they had tried but failed to meet the requested conditions for insurance. Some of them who had insurance indicated that they had to use a loan to complete the process for agricultural insurance. In addition, a large part of the plants which had insurance were the ones that had large production capacities and using reservoirs as the water resource. The plants located in/nearby rivers stated that

the required conditions for insurance were too hard and it was not possible for them to fulfill.

Kızılırmak river basin, with a number of 5 insured plants out of 6, had the highest level of agriculture insurance. On the other hand, Euphrates-Tigris River basin, having intense aquaculture production at high-capacity plants shows the least number of insured plants, that is 3 out of 50. Insurance seems to be an option for producers in talking the climate related risks, however it is not valid for most plants due to financial issues.

Water sharing problems

Türkiye is a water-stressed country with a water potential of around 1300 m3/cap/year and 77% of water resources are used for agricultural production. Therefore, fair water allocation for all sectors at river basin scale is of utmost importance. According to the Regulation on Water Allocation (Official Gazette of the Republic of Turkey, 2019), sectors are ranked with respect to their priority. The first two are human consumption and environmental flow requirement. Irrigation and aquaculture production are in the third row, followed by energy and industry sectors. However, in some basins problems may occur in allocating water according to the priority rank as sectors compete for the same water resource. Water is generally not used efficiently in agriculture as modern irrigation techniques cannot be applied widely yet.

In relation to this issue, the respondents were asked if they were having any conflicts about the share of water resources with other sectors. A total of 159 respondents (62%) answered that they had not had any conflicts and 98 of them (38%) answered that they had conflicts. They also stated that they mostly had conflicts with irrigation unions, municipalities and the people in the region. Besides, the producers had conflicts with the energy sector. Water shortage and controlled release of water during and after the construction of hydroelectric power stations aggrieve the producers and they are forced to reduce their capacity to overcome this problem, which in turn causes economic losses.

All producers in Konya closed basin stated that they had problems while all producers from Marmara, Susurluk and Asi River basins indicated that they had not had any conflict about sharing water resources (Figure 15).

Although 62% of the plants did not report any problem on share of water, 54% of the respondents had concerns about possible problems in the future on water allocation. They had primarily cited drought periods as the reason for their concern. The producers also had concerns about the water allocation priority of other sectors such as drinking water, agriculture, energy and industry. This issue is a good example to recall the work of Zeitoun (2011) on the web of water security, where it is mentioned that water security for some rests on the water insecurity of others.

The analysis of the answers on the basin level demonstrates that there is a concern about water allocation in 23 out of 25 river basins, excluding Marmara and Asi. The concerns were high; 70-77% in Çoruh, Yeşilırmak, Sakarya, Western Mediterranean and Meriç-Ergene river basins, and as high as 85% and 100% in Sakarya and Konya closed river basins, respectively. Although the rate of concerned plants was 34% for Euphrates-Tigris basin, it is among the three basins that are projected to have water deficiency in 2071-2100 period, followed by Eastern Mediterranean and Konya Closed basins (MoAF, 2016a, b). These results clearly imply that reduced water availability in the future due to pressures such as population growth and climate change will most probably lead to serious risks for the aquaculture sector.

Impact of temperature increase

Water temperature has a great influence on the initiation and course of several fish diseases. The immune system of most fish species has an optimum performance at water temperatures of about 15°C (Svobodová et al., 1993). While warm climate species naturally grow better between 20ºC and 28ºC, their ability to live decelerates as they approach 0ºC. Cold climate species show better development at water temperatures below 20°C, and when the temperature rise above 25°C, they can die (Dikel, 2009).

There are a number of studies investigating the impacts of climate change on cold-water fish. Williams et al. (2015) investigates the existing and future impacts of climate change on salmonids in North America. Native salmonids in western North America are facing mounting stressors because of climate change and the resulting warmer streams, higher variability in precipitation, and reduced snowpack (Westerling et al., 2006). Similarly, a study evaluating the impacts of climate change on brown trout in Central Europe shows an increase of temperature-related risk for proliferative kidney disease and a decrease of suitable thermal habitat for brown trout (Borgwardt et al., 2020).

The optimum temperature for the growth of *oncorhynchus mykiss* is 16.5°C and maximum temperature for taking the feed is 19.5°C. Regarding the temperature tolerance, it can be said that the critical lower limit is 5°C, the optimum temperature is 10-16°C and the critical upper limit is 20-22°C. Besides its impact on fish growth and death, global warming may impose severe risks for aquatic animal health if increasing water temperature leads to an increase in the incidence of parasitic diseases (Karvonen et al., 2010).

According to the ClimaHydro project, at least 1°C temperature rise is expected for all river basins in Türkiye after the year 2050, which is projected to be even higher; 2-6°C in 2091-2100 period (MoAF, 2016a). The survey shows that 1°C temperature increase in water supply would negatively affect the aquaculture production plants. Among all the respondents, 58% of them thought that they would be negatively affected by a possible temperature increase of 1°C while 34% of them said they would not be affected. On the other hand, 8% of them mentioned that they would be positively affected. Regarding the responses with respect to river basins, it was seen that plants in Western Mediterranean, Antalya, Büyük Menderes,

Küçük Menderes, Gediz, Sakarya, Yeşilırmak, Euphrates-Tigris and Eastern Black Sea River basins mentioned they had low tolerance to temperature increase (Figure 16).

Considering the importance of trout production in Turkish aquaculture sector, it is inevitable that a possible temperature increase will negatively affect the producers because of the thermal tolerance of trout and increased costs for the aquaculture production sector. Because in such a case, the temperature in the ponds might need to be reduced by providing cooling. Furthermore, oxygen deficiency might need to be compensated by providing oxygen to the ponds to maintain optimum growth conditions. These practices would increase the costs of fish production, which in turn would increase the fish prices on the market.

Future risks

As the study aims to assess the possible future risks, the respondents were asked which factor(s) they considered as risk(s) to their businesses for the future (multiple answers allowed). The most preferred answer was the share of water with a rate of 27%, followed by the economy with a rate of 24% and feed prices with a rate of 21%. Climate change was in the fourth raw among the expected risks (Figure 17).

Considering the basin-based assessment of operating risks, producers in Antalya, Gediz, Küçük Menderes and the Western Black Sea basins consider the share of water as a risk in the future, while the risk for producers in the Akarcay, Van Lake and Küçük Menderes basins is the climate change and that for producers in Asi and Burdur basins is the economy.

In the last question, the participants were asked "What is the most important problem that you think the freshwater aquaculture sector would face in the future?" Although the question was open-ended, the answers were very similar. For that reason, the answers were grouped after the survey was completed.

According to the respondents, the major problems that the producers expect are the high production costs (31%) and water shortage-drought (30%) (Figure 18). Since feed prices are high, it also affects the production costs. As seen, climate change is ranked as 6th in the list of nine problems asked to the producers. Indeed, the second most voted problem, that is water shortage-drought is also related to climate change. The data shows that most of the producers don't expect marketing, legislative issues and illness as high risks.

Producers in Western Black Sea, Antalya and Yeşilırmak river basins were mostly concerned about water shortage and drought while the producers in Çoruh, Küçük Menderes and Susurluk river basins were mostly concerned about costs (Figure 19).

As given in Table 3, climate change awareness is high in the sector. The major impact of climate change on production stages is mentioned as water quality and quantity. The front runner extreme weather events are floods and droughts. The highest financial losses belong to Yeşilırmak and Euphrates-Tigris River basins, where the agricultural insurance is also low. The conflict of water sharing was pronounced in Konya, Euphrates-Tigris and Antalya River basins. And finally, the future water allocation risks were mentioned highest for Sakarya and Konya River basins.

CONCLUSION

This study has carried out a survey for the freshwater aquaculture producers in Türkiye to assess their level of awareness on climate change and possible risks for their businesses. The results showed that producers have a high awareness on climate change and its impacts on water resources. Producers find production costs and water sharing problems as the most likely future challenges.

From the river basin perspective, producers from all river basins have common views about the impacts of climate change on water resources. In terms of extreme weather events, floods occurred in Eastern Black Sea, Western Black Sea and Meriç-Ergene river basins, droughts in Western Mediterranean and frost in Aras basin. More than half of the attendees have been exposed to extreme weather events in the last five years. Total financial losses of the plant owners as a result of the extreme weather are estimated as €950.000. Although the fact that more than half of the plants have been exposed to extreme weather events, there is only a small number of plants which have insurance. Insurance should be regarded as part of the possible solutions in tackling the risks associated with climate hazards.

The survey shows that most of the plants did not have problems with water allocation in the past. However, 54% of the plant owners have concerns about water allocation problems that may occur in the future.

At least 1.0 – 2.5^{o}C temperature increase in Türkiye is expected in the future. Increasing temperature is also expected to affect fish health and especially trout production which holds an important place in Turkish aquaculture sector. As a result of temperature increase, 30% of the attendees think that water shortage/drought will be a future problem.

The study clearly figures out that aquaculture sector in Türkiye needs immediate action to build capacity for climate resilience. The future of the sector is important for the national economy as well as international trade in relation to food security. Some recommendations and adaptation options are given below:

- There are still few studies in Türkiye on the impact of climate change on aquaculture sector and determining the sectoral vulnerability is the most priority issue.
- It should be determined which impacts climate change will have on the aquaculture sector (water temperatures, drought, floods, heat waves, etc.) and which stage of production is more sensitive to it. Aquaculture production takes place in different types of water sources such as

lakes, streams, dams, and spring water. For this reason, priorities will vary according to the different water resources. Pollution may be a priority for still-waters while drought may be a priority problem for streams.

- The applicability of production systems that will enable more efficient use of water resources in aquaculture should be evaluated such as closed-circuit production.
- The rate of insurance should be increased via legislative and financial instruments.

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AUTHOR CONTRIBUTIONS

Ayşe Tatma has collected data, conducted the survey in 2019 and evaluated the results. Gökşen Çapar has supervised the study (as the master thesis of Ayşe Tatma), evaluated the results, wrote the manuscript.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

ETHICAL APPROVAL

Ethical approval is not required for this study. This study was conducted in 2019. The journal requests an ethical approval document for studies conducted as of 2020.

DATA AVAILABILITY

The corresponding author should be contacted regarding any questions.

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RESEARCH ARTICLE ARAŞTIRMA MAKALESİ

Impact of dietary gallic acid on growth indices and the expression of antioxidant, stress, and immunity-related genes in rainbow trout (*Oncorhynchus mykiss*)

Gallik asidinin gökkuşağı alabalığında *(Oncorhynchus mykiss*) büyüme endeksleri ve antioksidan, stres ve bağışıklık ilgili genlerin ekspresyonu üzerindeki etkisi

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Abstract: This study investigates the effects of dietary gallic acid (GA) supplementation on growth performance and the expression of genes linked to antioxidant, stress, and immune functions in rainbow trout (*Oncorhynchus mykiss*). Fish with an average body weight of 2.84 ± 0.25 g were fed diets containing 0 mg/kg (control), 300 mg/kg (G300), 450 mg/kg (G450), and 600 mg/kg (G600) of GA over 60 days. The results revealed significant improvements in growth indices, including weight gain, specific growth rate, and feed conversion ratio, in GA-supplemented groups compared to the control ($P<0.05$). At the molecular level, GA supplementation significantly upregulated the expression of antioxidant-related genes (SOD, CAT, GPX), stress-related genes (HSP70), and immune-related genes (TNF-α, IL-1β). The G300 group consistently exhibited the most pronounced transcriptional responses, while higher doses (G450 and G600) showed diminished or inconsistent effects. These findings suggest that a dietary inclusion of 300 mg/kg GA optimally enhances fish health and productivity by modulating key molecular pathways. This dosage is recommended as an effective feed additive for improving the performance and resilience of rainbow trout in aquaculture.

Keywords: Feed supplement, organic acid, growth, gene expression

Öz: Bu çalışmada, gökkuşağı alabalığında (*Oncorhynchus mykiss*) diyet gallik asit (GA) takviyesinin büyüme performansı ve antioksidan, stres ve bağışıklık fonksiyonlarıyla bağlantılı genlerin ifadesi üzerindeki etkileri araştırılmıştır. Ortalama vücut ağırlığı 2,84 ± 0,25 g olan balıklar, 60 gün boyunca 0 mg/kg (kontrol), 300 mg/kg (G300), 450 mg/kg (G450) ve 600 mg/kg (G600) GA içeren diyetlerle beslenmiştir. Sonuçlar, GA takviyeli gruplarda kontrole kıyasla kilo alımı, özgül büyüme oranı ve yem dönüşüm oranı da dahil olmak üzere büyüme endekslerinde önemli iyileşmeler olduğunu ortaya koymuştur ($P<0,05$). Moleküler düzeyde, GA takviyesi antioksidanla ilişkili genlerin (SOD, CAT, GPX), stresle ilişkili genlerin (HSP70) ve bağışıklık ile ilişkili genlerin (TNF-α, IL-1β) ifadesini önemli ölçüde artırmıştır. G300 grubu sürekli olarak en belirgin transkripsiyonel tepkileri sergilerken, daha yüksek dozlar (G450 ve G600) azalan veya tutarsız etkiler gösterdi. Bu bulgular, 300 mg/kg GA'nın diyete dahil edilmesinin, temel moleküler yolları düzenleyerek balık sağlığını ve üretkenliğini en iyi şekilde artırdığını göstermektedir. Bu dozaj, su ürünleri yetiştiriciliğinde gökkuşağı alabalığının performansını ve dayanıklılığını iyileştirmek için etkili bir yem katkı maddesi olarak önerilmektedir.

Anahtar Kelimeler: Yem takviyesi, organik asit, büyüme, gen ifadesi

INTRODUCTION

Aquaculture is one of the fastest-growing industries globally, playing a critical role in addressing the increasing demand for food (Verdegem et al., 2023; Obirikorang et al., 2024). Among farmed fish species, rainbow trout (*Oncorhynchus mykiss*) stands out as a key species due to its rapid growth, adaptability to diverse environmental conditions, and high economic value (Vasdravanidis et al., 2022; Alkan et al., 2025). However, achieving optimal growth performance and resilience in rainbow trout requires precise nutritional strategies to support health and counteract environmental stressors (Ciji and Akhtar, 2021; Toomey et al., 2024). Enhancing growth and health in rainbow trout is not only vital for the sustainability and profitability of aquaculture but also aligns with the broader goals of efficient and sustainable food production.

In recent years, organic acids have garnered considerable attention as feed additives in aquaculture due to their potential to improve growth, enhance nutrient utilization, and modulate immune responses in fish. Research indicates that organic acids can promote fish health by increasing nutrient absorption, regulating intestinal microbiota, and stimulating digestive enzyme activity (das Neves et al., 2021; Ghafarifarsani et al., 2023; Yousefi et al., 2023). Moreover, these compounds have been shown to boost antioxidant capacity and enhance immune function in fish (Duan et al., 2018; Yilmaz, 2019; Zhang et al., 2020; Jin et al., 2023; Zhang et al., 2023).

Gallic acid (GA), a naturally occurring phenolic acid found abundantly in plants and fruits (Sousa et al., 2024; Xiang et al., 2024), has gained attention as a promising dietary supplement due to its potent anti-inflammatory, antimicrobial, and

antioxidant properties (Hadidi et al., 2024; Zhao et al., 2024). Research conducted on terrestrial animal species has shown that the inclusion of dietary GA supplementation leads to notable enhancements in growth performance and overall health status (Wei et al., 2016; Samuel et al., 2017; Zhao et al., 2021; Xu et al., 2022). However, despite its proven efficacy in terrestrial species, the application of GA in aquaculture remains underexplored.

Emerging research has begun to highlight the potential of GA in aquaculture species. For instance, Ghafarifarsani et al. (2023) reported significant enhancements in growth indices, antioxidant status, and immune function in common carp (*Cyprinus carpio*) subjected to crowding stress when supplemented with dietary GA. Similarly, Zhao et al. (2024) demonstrated that GA alleviates fish enteritis by suppressing immune cell activation, cytokine release, apoptosis, and oxidative stress while promoting anti-inflammatory intestinal metabolites with immunomodulatory and antioxidant effects. Despite these promising findings, the specific effects of GA on rainbow trout a globally significant aquaculture species remain largely unexplored.

This research seeks to fill the existing knowledge gap by examining how dietary supplementation with GA influences growth indices, feed efficiency, and the expression of critical antioxidant genes (SOD, CAT, GPX), immune-related genes (IL-1β, TNF-α, and IL-8), and stress-related gene (HSP70), in rainbow trout. The study also aims to identify the optimal dosage of GA that maximizes its beneficial effects by evaluating various levels of incorporation. Ultimately, this investigation explores the potential of GA as a feed additive to enhance growth performance and promote the expression of antioxidant, immune, and stress-related genes in rainbow trout. By providing critical insights into nutritional strategies that foster healthier and more resilient fish populations, this research aspires to contribute to the advancement of sustainable aquaculture practices and improve production outcomes.

MATERIALS AND METHODS

Experimental fish

Rainbow trout were obtained from a local aquaculture facility located in Van Province, Turkey. Following their collection, the fish were transported to the Aquatic Animals Experiment Unit at Van Yüzüncü Yıl University in Van, Turkey, where they were placed in individual tanks. Before the commencement of the experiment, the fish underwent a 15-day acclimatization period to adapt to the experimental conditions and were fed a standard control diet twice each day.

Experimental diets

Experimental diets were prepared by incorporating gallic acid (Sigma-Aldrich, Germany) into a basal diet (composition: 54% crude protein, 15% crude fat, 1% crude fiber, 8.9% crude ash, 1.3% phosphorus, 1.5% calcium, and 0.3% sodium; Skretting, Milas-Muğla, Turkey) at concentrations of 0 (Control), 300, 450, and 600 mg/kg. The inclusion levels were based on the study by Ghafarifarsani et al. (2023). To prepare the diets, 300 mL of water was added per kilogram of the basal diet to form a smooth dough. The required amount of gallic acid was thoroughly mixed into the dough, which was then shaped into sticks using a mincer and dried by fan air (22°C). The dried sticks were pelleted (2 mm diameter) and stored in airtight plastic bags at 4°C until use (Hoseinifar et al., 2017; Ghafarifarsani et al., 2021).

Experimental design and feeding protocols

Four experimental diets containing varying levels of gallic acid (0 mg/kg as Control, 300 mg/kg as G300, 450 mg/kg as G450, and 600 mg/kg as G600) were tested. A total of 360 healthy fish with an initial average weight of 2.84 ± 0.25 g were randomly assigned to four dietary treatments, with three replicates per group (30 fish per tank). The feeding trial lasted 60 days, during which fish were fed 3% of their body weight three times daily (Karataş, 2025). Feed amounts were adjusted biweekly based on average fish weight. The 12 tanks (400 L each) were aerated using a central air pump, and 20% of the water in each tank was exchanged daily with dechlorinated water to maintain optimal water quality. Uneaten feed and feces were removed from the tanks each morning before feeding. Key water quality parameters were monitored and maintained at 7.64 ± 0.39 mg/L dissolved oxygen, 15.35 ± 0.19°C temperature, and pH 8.2 ± 0.05. Artificial lighting provided a 12-hour light and 12-hour dark photoperiod.

Growth indices and sampling

At the start and end of the trial, fish were individually weighed to calculate growth indices. Growth parameters were determined using standard formulas.

Weight gain (WG; g/fish) = Final weight (g) − Initial weight (g),

Daily weight gain (DWG; g/fish) = (Final weight (g) − Initial weight (g)) / days,

Specific growth rate (SGR; % / day) = ((ln (final weight) – ln (initial weight)) / days) x 100,

Thermal growth coefficient (TGC) = ((final weight)1/3 – (initial weight)1/3) / temperature in ^{o}C x time in days) x 1000,

Feed conversion ratio (FCR) = Total feed given (g) / Weight gain (g),

Survival rate (SR; %) = (Final number of fish / Initial number of fish) x 100.

Before sampling, the fish were subjected to a fasting period of 24 hours and were anesthetized using clove powder at a concentration of 200 mg/L (Karataş, 2024). Body weight was recorded using a digital scale (Sartorius/0.01 g). For the purpose of gene expression analysis, liver tissues were extracted from six randomly chosen fish within each treatment group, with two fish selected from each replicate tank. Liver

samples (25–50 mg) were collected and preserved in RNAlater solution until the RNA extraction process.

Gene expression analysis

Total RNA was isolated using the DiaRex® Total RNA Isolation Kit (TR-0877-100, Diagen, Ankara, Turkey) in accordance with the manufacturer's guidelines. The concentration and purity of the isolated RNA were evaluated with a QIAxpert nanospectrophotometer (Qiagen) at a wavelength of 260/280 nm. cDNA synthesis was performed using the Solver ArGe cDNA Synthesis Kit (SLV-M-2021-10-100, Van, Turkey), following the methodology outlined by Önalan (2019). Quantitative real-time PCR (qRT-PCR) was conducted using the Solver ArGe qPCR Master Mix (SLV-M-2021-01-0.5ML, Van, Turkey) on a Rotor-Gene Q 9000 thermal cycler (Qiagen). A total of eight genes were analyzed, including seven target genes and one reference gene. Each 25 µL PCR reaction contained 12 µL SybrGreen qPCR Master Mix, 4 µL cDNA, 4 µL H_2O, and 2.5 µL of forward and reverse primers (Table 1). The PCR protocol included an initial denaturation at 95°C for 15 minutes, followed by 45 cycles of 95°C for 30 seconds and 60°C for 60 seconds. Beta-actin served as the reference gene for normalization purposes. Gene expression data were analyzed using the ΔΔCt method (Livak and Schmittgen, 2001), with results presented as fold changes relative to the control group.

Statistical analysis

Data analysis was conducted using SPSS v20 (IBM, Chicago, IL, 2011), with results expressed as mean ± standard error of the mean (SEM). A one-way analysis of variance (ANOVA) was utilized to assess differences between treatment groups, followed by Duncan's multiple range test for subsequent pairwise comparisons. A significance level of $P < 0.05$ was established for statistical relevance.

Table 1. Details regarding the sequences of forward and reverse primers, accession numbers, and the conditions for the genes chosen for real-time PCR

Target gene	Primer sequence (5´ to 3´)	Amplicon size(bp)	Annealing Tm (°C)	Accession no.
β-actin (Beta-actin)	F:GGAGGCTCCATCTTGGCTTC R:GAAGTGGTAGTCGGGTGTGG	158	61	AJ438158.1
CAT (Catalase)	F:TGATGTCACACAGGTGCGTA R: GTGGGCTCAGTGTTGTTGAG	195	58	XM_021557350.2
GPx (Glutathione peroxidase)	F:CGAGCTCCATGAACGGTACG R: TGCTTCCCGTTCACATCCAC	183	60	HE687022.1
SOD (Superoxide dismutase)	F:TGGTCCTGTGAAGCTGATTG R:TTGTCAGCTCCTGCAGTCAC	201	58	AF469663.1
IL-1β (Interleukin-1 Beta)	F:AGCAGGACTACACCAAACCG R:TCCTGATCGTAGAGGCCCAA	184	59	AJ004821.1
TNF-α (Tumor Necrosis Factor-Alpha)	F:GGCTGTGTGGCGTTCTCTTA R: AAATGGATGGCTGCTTTCGC	190	58	NM_001124374.1
IL-8 (Interleukin-8)	F:CACAGACAGAGAAGGAAGGAAAG R:TGCTCATCTTGGGGTTACAGA	162	60	NM_001124279.1
HSP 70 (Heat Shock Protein 70)	F:CTGCTGCTGCTGGATGTG R:GCTGGTTGTCGGAGTAAGTG	135	59	AB062281.1

RESULTS

Table 2 displays the growth performance metrics for rainbow trout fed the experimental diets. Throughout the 60-day feeding trial, no mortality occurred in either the control or gallic acid (GA) groups. The inclusion of gallic acid in the diet significantly enhanced final weight (FW), weight gain (WG), specific growth rate (SGR), daily weight gain (DWG), and thermal growth coefficient (TGC) compared to the control group ($P<0.05$). Among the treatment groups, the G450 diet yielded the highest growth indices, while the most efficient feed conversion ratio (FCR) was observed in the G300 group ($P<0.05$).

Table 2. Effects of dietary gallic acid on growth performance in rainbow trout

Growth performance	Experimental diets			
	Control	G300	G450	G600
Initial weight (g)	2.84 ± 0.03	2.84 ± 0.02	2.84 ± 0.04	2.84 ± 0.04
Final weight (g)	9.82 ± 0.07^{c}	10.68 ± 0.12^{ab}	10.79 ± 0.05^{a}	10.41 ± 0.06^{b}
WG (g)	6.97 ± 0.07^{c}	7.83 ± 0.12^{ab}	7.93 ± 0.05^{a}	7.57 ± 0.06^{b}
DWG (g)	0.12 ± 0.00^{c}	0.13 ± 0.00^{ab}	0.13 ± 0.00^{a}	0.13 ± 0.00^{b}
SGR (%/day)	2.06 ± 0.01^{c}	2.20 ± 0.02^{ab}	2.21 ± 0.00^{a}	2.16 ± 0.00^{b}
TGC	0.79 ± 0.00^{c}	0.85 ± 0.00^{ab}	0.86 ± 0.00^{a}	0.83 ± 0.00^{b}
FCR	1.04 ± 0.02^{d}	0.89 ± 0.00^{s}	0.94 ± 0.00^{b}	0.98 ± 0.01^{c}
SR (%)	100	100	100	100

Data are presented as means ± SEM (n = 3). Different lowercase letters in each row indicate significant differences among groups ($P<0.05$). G300, diet supplemented with 300 mg/kg gallic acid; G450, diet supplemented with 450 mg/kg gallic acid; G600, diet supplemented with 600 mg/kg gallic acid; WG, weight gain; DWG, daily weight gain; SGR, specific growth rate; TGC, thermal growth coefficient; FCR, feed conversion ratio; SR, survival rate.

The expression levels of SOD, CAT, and GPX, are shown in Figure 1. CAT gene expression was significantly upregulated in the G300 and G450 groups compared to the control, whereas it was significantly downregulated in the G600 group (P<0.05). For the SOD gene, expression was upregulated in the G300 group but downregulated in both the G450 and G600 groups relative to the control (P<0.05). Likewise, GPX gene expression was significantly upregulated in the G300 group, while downregulation was observed in the G450 group (P<0.05). No notable difference in GPX expression was detected between the G600 group and the control group (P>0.05).

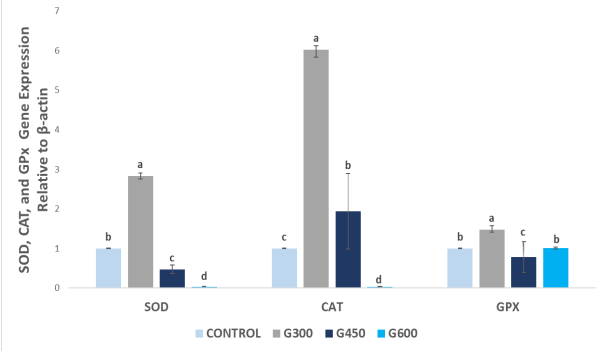

Figure 1. Effect of dietary gallic acid on the expression of antioxidant-related genes (SOD, CAT, GPX) in rainbow trout (n = 6)

The expression levels of IL-1β, TNF-α, IL-8, and HSP70, are depicted in Figure 2. The IL-1β gene showed increased expression in the G300 group compared to the control, although this difference was not statistically significant (P>0.05). Downregulation of IL-1β was observed in both the G450 and G600 groups relative to the control (P<0.05). For TNF-α, expression was elevated in the G300 group and decreased in the G600 group compared to the control (P<0.05), with no significant difference between the G450 and control groups (P> 0.05). The expression of IL-8 was significantly downregulated in all gallic acid-treated groups compared to the control (P<0.05). The stress-related HSP70 gene was significantly upregulated in the G300 group and downregulated in the G600 group compared to the control (P<0.05). No notable difference was detected between the G450 and control groups (P> 0.05).

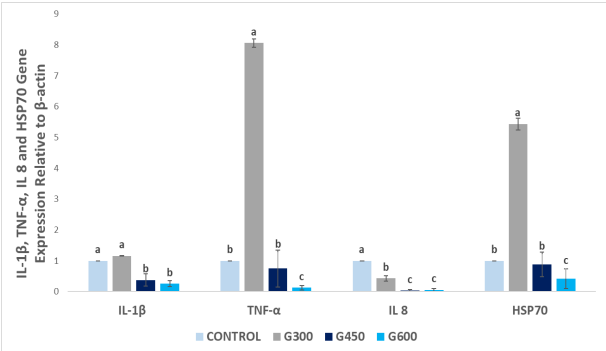

Figure 2. Effect of dietary gallic acid on immune response-related genes (IL-1β, TNF-α, IL-8) and stress-related HSP70 gene expression in rainbow trout (n = 6)

DISCUSSION

The use of organic acids as feed additives to enhance fish growth and health has gained considerable attention in recent years (Ghafarifarsani et al., 2023; Yousefi et al., 2023). The performance of growth is a vital aspect influencing the economic viability of aquaculture production (das Neves et al., 2021). This study found that diets enriched with gallic acid (GA) led to significant enhancements in growth metrics, including weight gain (WG), specific growth rate (SGR), and daily weight gain (DWG) in rainbow trout, when compared to the control group, regardless of the level of supplementation. Additionally, feed conversion ratio (FCR) was significantly enhanced across all GA-treated groups, reflecting more efficient feed utilization. These results align with previous findings demonstrating the positive effects of dietary organic acids on the growth indices of different fish species (Yilmaz, 2019; Zhang et al., 2020; Ghafarifarsani et al., 2023; Zhang et al., 2023).

The observed improvements in growth indices may be attributed to enhanced nutrient utilization facilitated by gallic acid (Ghafarifarsani et al., 2023). Organic acids are recognized for their ability to enhance the secretion and function of digestive enzymes, which in turn facilitates more efficient digestion, absorption, and utilization of vital nutrients (das Neves et al., 2021; Hassaan et al., 2018; Huan et al., 2018). Furthermore, the antimicrobial properties of organic acids and their protective effects on the intestinal epithelium contribute to improved gut health, which may further enhance growth performance (Shah et al., 2015; das Neves et al., 2021).

The antioxidant capacity of aquaculture species is influenced by various factors, including dietary practices and environmental conditions (Zhang et al., 2020; Karataş, 2024). In this research, the dietary addition of 300 mg/kg GA (G300 group) significantly upregulated the expression of antioxidant enzyme-related genes, such as superoxide dismutase (SOD), catalase (CAT), and glutathione peroxidase (GPX), compared to the control and other GA-treated groups. These findings suggest that GA supplementation enhances the antioxidant defense system, protecting fish from oxidative damage. The results are consistent with the reported antioxidant properties of gallic acid and its ability to prevent oxidative DNA damage in both animals and humans (Ferk et al., 2011). Similar effects of other organic acids, such as succinic acid, chlorogenic acid, and malic acid, on the antioxidant capacity of aquatic organisms have been reported (Duan et al., 2018; Safari et al., 2021; Ghafarifarsani et al., 2023; Jin et al., 2023). The effectiveness of GA supplementation, particularly at 300 mg/kg, underscores the importance of optimizing dosage levels to achieve the desired antioxidant effects. While gene expression analysis provides valuable insights, further studies are needed to confirm these findings through enzymatic activity assays and direct assessments of oxidative stress markers.

Immune-related genes, including TNF-α, IL-1β, and IL-8, are essential components of the innate immune response in fish and are frequently influenced by dietary modifications

(Safari et al., 2021; Karataş, 2025; Kaya et al., 2025). In this study, supplementation with 300 mg/kg GA significantly upregulated TNF-α and IL-1β expression levels, suggesting immunostimulatory effects. However, no significant changes were observed in IL-8 expression across the treatment groups. These findings are consistent with studies reporting that organic acid-enriched diets enhance the expression of immune-related genes (Yilmaz, 2019; Zhang et al., 2020; Safari et al., 2021; Yousefi et al., 2023). Nevertheless, it is important to note that gene expression does not necessarily translate to functional immune enhancement due to potential post-transcriptional regulatory mechanisms (Vogel and Marcotte, 2012; Karataş, 2025). Future studies should include functional assays, such as assessments of lysozyme activity, phagocytic activity, and tests for disease resistance, to confirm these molecular findings.

Heat shock proteins (HSPs), such as HSP70, serve as biomarkers of biological stress and play a protective role under stressful conditions (Zhang et al., 2020; Jiang et al., 2016). In this study, dietary GA at 300 mg/kg increased HSP70 expression, suggesting enhanced cellular stress resilience. Similar effects of organic acids on HSP70 expression have been documented in previous research (Duan et al., 2018; Yilmaz, 2019; Yousefi et al., 2023). However, the specific role of GA in modulating stress and HSP70 pathways in rainbow trout remains unclear, necessitating further investigation.

CONCLUSION

This research indicates that the addition of gallic acid to the diet notably improves growth performance, boosts antioxidant capacity, and enhances immune responses in rainbow trout. Specifically, 300 mg/kg GA proved to be the optimal dose, leading to improved growth indices, feed conversion efficiency, and upregulation of key antioxidant and immune-related genes. These findings highlight the potential of gallic acid as an effective feed additive in aquaculture. However, further research is warranted to confirm these molecular observations through functional assays and to explore the long-term impacts of GA supplementation on fish health and productivity.

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ETHICAL APPROVAL

The experiment was approved by the Van Yuzuncu Yil University Aquatic Vertebrates Local Ethics Committee (protocol no: 2024/04-05) and conducted in accordance with standard ethical guidelines.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

DATA AVAILABILITY

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

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RESEARCH ARTICLE ARAŞTIRMA MAKALESİ

Detection of moving fish schools using reinforcement learning technique

Takviyeli öğrenme tekniği kullanarak haraketli balık sürülerinin tespiti

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Abstract: In this study, it is aimed to contribute to the fishing sector by determining the locations of moving fish schools. With the Q-Learning algorithm, areas where fish schools are frequently seen were marked and autonomous ships were able to reach these areas faster. With the Q-Learning algorithm, one of the machine learning techniques, areas where fish schools are abundant were determined and reward and penalty points were given to each region. In addition, the fish density matrix of the region was extracted thanks to the autonomous systems. Moreover, the algorithm can be automatically updated according to fish species and fishing bans. A different Q-Gain matrix was kept for each fish species to be caught, allowing autonomous ships to move according to the gain matrix. In short, high gains were achieved in terms of time and travel costs in finding or following fish schools by recognizing the region by autonomous ships.

Keywords: Fish school finding, multi-agent systems, reinforcement learning, Q-Learning algorithm

Öz: Bu çalışmada toplu halde hareket eden balık sürülerinin yerlerinin tespit edilerek, balık endüstrisine katkı sağlamaya odaklanılmıştır. Takviyeli öğrenme tekniğini kullanan Q-Learning algoritması ile balıkların sıkça rastlandığı bölgeler işaretlenip, otonom gemilerin bu bölgelere daha hızlı ulaşması sağlanmıştır. Makine öğrenmesi tekniklerinde olan Q-Learning algoritmasıyla, küçük karelere ayrılmış her bir bölgeye verilen ödül ceza puanlarıyla, balık sürülerinin bol olduğu bölgeler tespit edilmiştir. Ayrıca istenen bölgenin balık sürüsü yoğunluk matrisi çıkartılıp, avcı ya da araştırmacılar tarafından daha hızlıca tanınması sağlanmıştır. Sonuç olarak, bölgenin otonom gemiler tarafından tanınmasıyla birlikte, balık sürülerini bulma veya takip etmede zaman ve yol maliyeti açısından yüksek kazançlar elde edilmiştir.

Anahtar kelimeler: Balık yuvası bulma, çoklu etmenler, takviyeli öğrenme, Q-Learning algoritması

INTRODUCTION

Machine learning technique, which is one of the sub-branches of artificial intelligence, is a heuristic algorithm that analyzes the data sources of the machine and produces appropriate solutions to new problems it may encounter(Angiuli et al., 2022; Gümüş, 2016) The network structure of the machine, called artificial intelligence, updates itself according to the expected and obtained results and aims to get better results. Machine learning technique is divided into three types: supervised, unsupervised and reinforcement learning. Reinforcement learning technique works by observing the rewards in the environment. This technique achieves more successful results, especially in cases where the environmental space is very large and cannot be expressed briefly. Q-Learning algorithm is one of the methods that works using the reinforcement learning technique. In the reinforcement learning method, the aim is to trend towards the step with the highest gain by using reward and penalty points. By calculating reward and penalty at every step taken, the profit is brought closer to the best. There is no need for expert or competent instructor knowledge in this type of learning management. Generally, the trained agent (player, robot, etc.) tries to reach its goal by taking random steps. This algorithm keeps the transition matrix between steps and the gain value information of these transitions. The gain matrix values perform the learning process by updating themselves with a certain learning coefficient at each step taken.

Q-Learning is a learning method, one of the sub-learning techniques of the machine learning system, was first proposed by Watkins (Watkins,1989). In 1993, it was used by Peter Dayan in calculating return prediction and finding suitability depending on time (Dayan, 1993). At similar times, it was proposed as a method in the field of reinforcement learning in the training and development of agent robots (Lin, 1992). Towards 1995, the algorithm was combined with dynamic programming logic and benefited from real-time application studies (Barto et al., 1995).

This method performs the learning process with a specific function value. By using the Monte Carlo method and the advantages of dynamic programming, it is aimed to predict future steps with current values without creating a model (Jones and Qin, 2022; Liu et al., 2019). The Q-Learning method works by updating the reward value of each step and the step values that can be taken. The aim of this method is to maximize the reward or minimize the punishment in the long term (Watkins and Dayan 1992).

The Q-Learning method, as a type of reinforcement learning, works by updating the reward value of each action taken and the possible future actions based on the current state of the system. This approach helps in making decisions that will maximize rewards or minimize penalties over time, focusing on long-term outcomes rather than immediate feedback. One of the key features of Q-Learning is its ability to perform learning tasks without needing a model of the

environment. Instead, it uses the Monte Carlo method and dynamic programming principles to predict future actions and refine decisions based on the values of the current state (Jones and Qin, 2022; Liu et al., 2019). The learning process relies on a specific function value, where the goal is to optimize the sequence of decisions to achieve the best possible results in the future.

In essence, Q-Learning is designed to operate by updating its understanding of the environment step by step, refining its choices through continuous learning, and aiming to maximize the cumulative reward over time. This makes it a powerful tool in fields where decisions must be made sequentially, and long-term optimization is key (Watkins and Dayan, 1992). As its usage continues to grow, Q-Learning is playing an increasingly important role in both theoretical and applied research, driving innovations in various sectors.

In recent years, the Q–Learning algorithm has contributed to science, especially in areas such as marketing (Jogunola et al. 2021), autonomous robot control systems (Elallid et al. 2022), economy (Meng and Khushi, 2019) and health (Aydındağ Bayrak et al. 2022). Moreover; it has been presented as a suggestion to find solutions to problems in many fields such as information and game theory, operations research, statistics and optimization (Chapman and Kaelbling, 1991). With the reinforcement learning method, it is aimed to predict the next step without labeling the environment or data in the environment, adhering to the reward function (Jordan and Mitchell 2015; Kober et al., 2013), and the use of the algorithm has increased day by day (Parisotto, 2021).

This study aims to enhance fishing operations by combining machine learning techniques with autonomous systems, fostering cost-effective, time-efficient, and sustainable practices. It contributes to the fishing industry by utilizing the Q-Learning algorithm to streamline the identification and tracking of fish schools. Additionally, it determines areas with frequent fish activity and assesses their density. Furthermore, it enables autonomous ships to navigate to high-density fish regions more rapidly and efficiently, minimizing both time and travel expenses.

MATERIALS AND METHODS

'Q-Learning Algorithm', one of the reinforcement learning methods, is a common algorithm that performs the learning process using the reward-punishment system as mentioned above. This algorithm keeps the inter-region transition matrix and the gain value information of the transitions. It is aimed to improve the learning process by updating the gain matrix values with a certain learning coefficient when each step is taken, or a result is reached.

In this model, a fishing ship is considered to start fishing from any point in the sea or lake. It assumes that the ship is casually trying to locate and hunt fish areas. For each position the ship changes, it gives a reward value for transitions between zones. Thus, each other ship that sets out to sea updates the gain values in the location, creating a training network that can optimally find fish areas. In this way, ships use smart systems that detect fish schools autonomously.

Q-Learning algorithm, the training process is based on rewarding or punishing the values in the Q-Gain matrix. This process will be achieved by determining the region where the fish flock is located and increasing the profit value of the region that allows reaching it (Nykjaer, 2022).

$$Q_G[start, end] = (R_N[start, end] + (LCV * max))$$

Q_G: Q_{Gain}; R_N: $R_{Neighborhood}$; LCV: Learning coefficient value

As seen in the equation; “QGain[start, end]” represents the "gain" or reward for taking a certain path (from start to end) in the Q-learning algorithm. It tracks how valuable that path is based on prior experience and learning. “RNeighborhood[start, end]” matrix is the reward for being in the current "neighborhood" or region. It could represent how close the path is to the fish school. “LearningCoefficientValue” is a factor that influences how much the algorithm values past experiences versus the current observation. It helps control the learning rate. “Max” value refers to the maximum value of the Q-Gain for all possible actions from the end state. Essentially, this term captures the best possible future reward from that point (after taking action). By increasing the gain value of the roads leading to the location of the fish schools, faster discovery of the schools is ensured. This process can be compared to the process of increasing the efficiency of that path by ants in the ant swarm algorithm by constantly secreting phenomena. Thus, as the amount of gain/phenomenon increases, many of the ants will use this path, and many of the ships will move using the profitable path.

Matrix model representation of an area

The area where fishing ships hunt can be represented with squares of 50 or 100 meters in length. In this way, the autonomous ship can determine the fish density in the region every time it changes location. Thus, the gain value in that location is updated for each step taken. In fact, this is done in a similar way by ship captains. With his previous experience, the captain moves towards areas where fish are concentrated and determines the fish value in that location. However, while the captain uses his own or his immediate surroundings' experiences when making this evaluation, autonomously moving ships will have the opportunity to progress with more experience by updating the gain/learning data they receive from the common learning matrix.

In Figure 1, the sea is shown as a matrix space and the regions where fish are found are expressed representatively. Using this matrix, autonomous ships start hunting from any point and try to find the location of fish schools. Ships randomly sail around the sea while the learning process is taking place. When they reach the position where the fish schools are, they increase the gain values of that position and the positions that help them reach that position, thus creating a Q-Gain matrix.

Establishing neighborhoods between determined regions

In order to represent the search space, transitions and gain information between each region must be determined. Thus, information on inter-regional neighborhood and its earnings value can be obtained.

First of all, with the expression 'RNeighor[i,j] = 0', the permissions for passage from all regions to other regions are disabled. Then, by using certain mathematical conditions, the upper neighbor, lower neighbor and diagonal neighbor numbers are determined and the adjacency matrix value is set to 1, and you are informed that the transition can be made. As seen in Figure 2, in order to define the transition to the right (right neighborhood), it is sufficient to meet the "i==j-1" condition to define the neighborhood from the active area (i) to the area one number higher (j). However, this code makes all consecutive fields neighbors. However, as can be seen from Figure 1, although square 15 and square 16 have consecutive values, they are not neighbors. Therefore, it is necessary to remove the neighborhood for all elements to the right of the sea space, even if they are consecutive. In this case, it will be sufficient to meet the condition " (j % numberofelements) != 0) " (Figure 2).

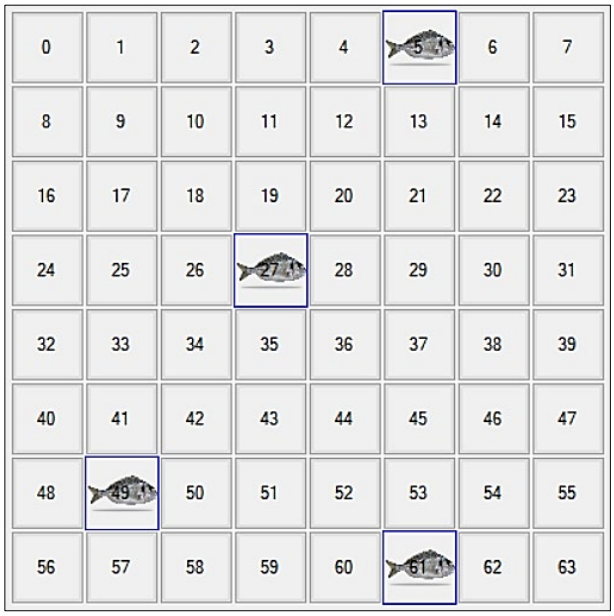

Figure 1. Representative illustration of sea space and schools of fish

```
private void NeighborhoodTransitions(int matrixSize, int i, int j)
{
    if (i == j)//no transition
    {
        RNeighbor[i, j] = 0;
    }
    if (i == j - 1 && ((j % matrixSize) != 0))// transition right,
    {
        RNeighbor[i, j] = 1;
    }
    if (i == j - matrixSize)//transition down
    {
        RNeighbor[i, j] = 1;
    }

    if ((i == j + 1 && (i % matrixSize) != 0))//transition left,
    {
        RNeighbor[i, j] = 1;
    }
```

Figure 2. Defining interregional neighborhood

Development of the interface and application

The program was developed as a desktop application in C Sharp programming language, using the Visual Studio IDE (integrated development environment). The aim is that the ship left in a random location will find schools of fish using the optimal path, looking at the earnings updated by the learning method. As seen in Figure 3, the sea the ships navigated was represented as a 7*7 array.

The location of the fish schools was determined dynamically by the person using the application. Thus, a ship departing from any point will try to find schools of fish by moving randomly (Figure 3).

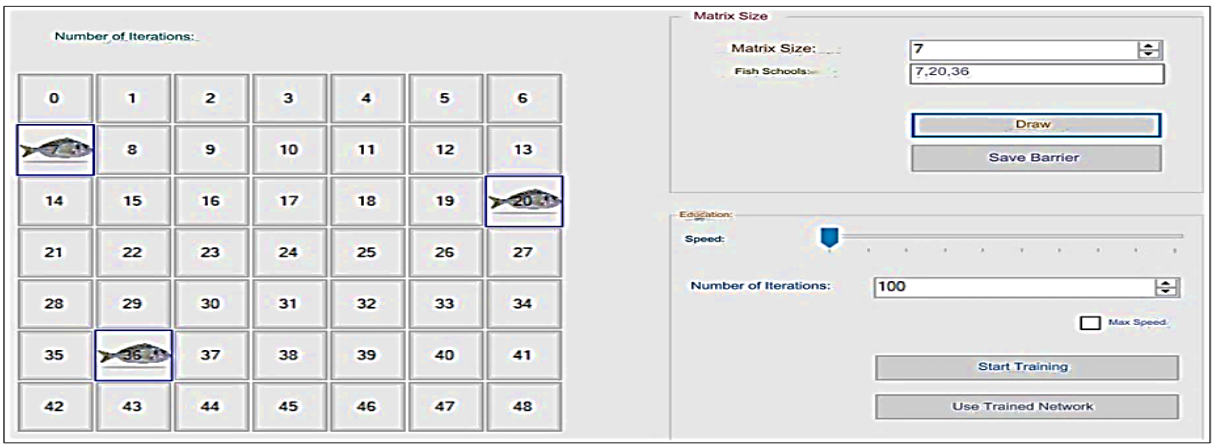

Figure 3. Application interface and training phase

Application speed

In order to make the visual of the application understandable, it would be meaningful to show the steps taken with a painting tool. Thus, people running the application will have more information about how the application works by following the steps taken. However, since the learning process will be long and laborious, you will need to accelerate after seeing a few steps in slow motion. In this way, results can be achieved quickly, without waiting too long. At the same time, since it takes a long time to update the drawing and matrix visual, the processing time will be much reduced by using the max speed control.

Uses of the trained network

Once the training process is repeated a certain/sufficient number of times, the training process is completed and ready to be used. In this case, the earnings values have reached a certain coefficient and the process of finding the school of fish is easily completed by sailing a new ship. Figure 4 shows how the ship placed in area 18 after the training found the school of fish (Figure 5). Since the herd in area 46 was closer, an orientation towards that area was quickly achieved.

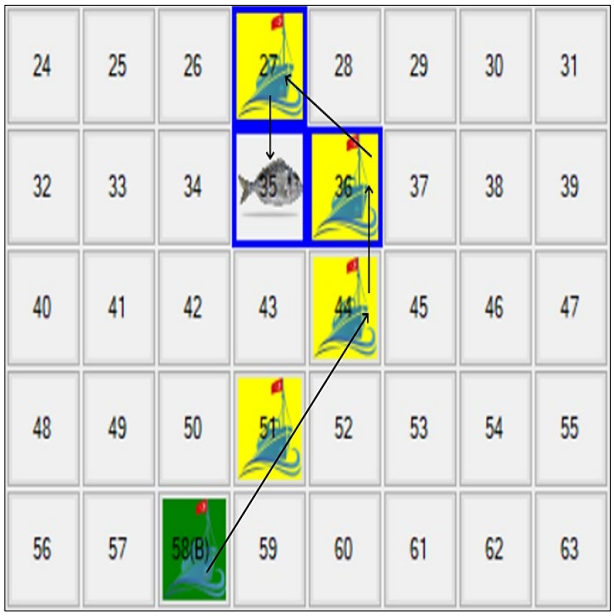

Figure 4. Fish shoal movement situation

Movement of the fish school

Generally, fish do not stay in a fixed place but move around a certain nest or area. In this sense, updating the determined fish points in certain steps will allow us to characterize the real fish schools a little better. The school of fish seen at number 35 has been allowed to pass to areas number 36 and 27 (Figure 4). Although the fish school changed location during the training process, the density of the gain matrix towards that area helped control and step in other areas where the fish roamed.

However, if the schools of fish move quickly and do not focus on a certain point, it will become more difficult for the schools to be caught by autonomous ships.

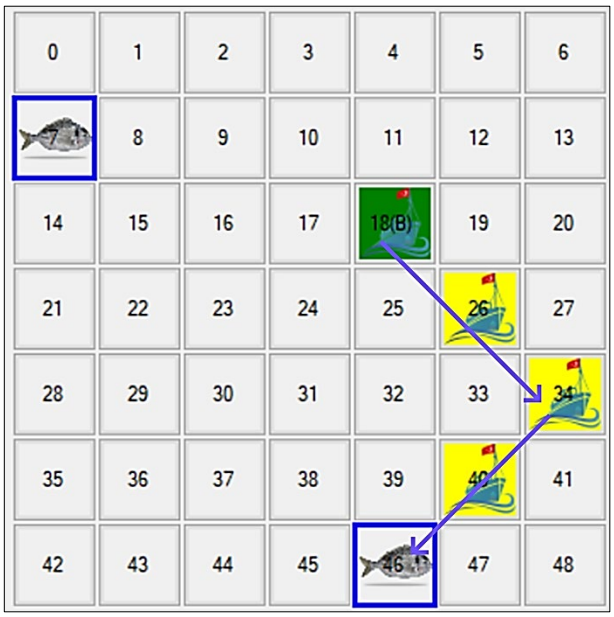

Figure 5. Finding schools of fish using trained network

Fish school density matrix

The matrix-represented region will be recognized by autonomous ships and the creation of a density matrix showing areas where fish density may be high will be beneficial for hunters. In this sense, a representative matrix showing fish density was created in Figure 6. In this matrix, the red color represents the region where fish are abundant, while the areas close to black represent the regions where fish are rare. Thanks to this density matrix, fishermen or researchers who know little or nothing about the region will have information about the region.

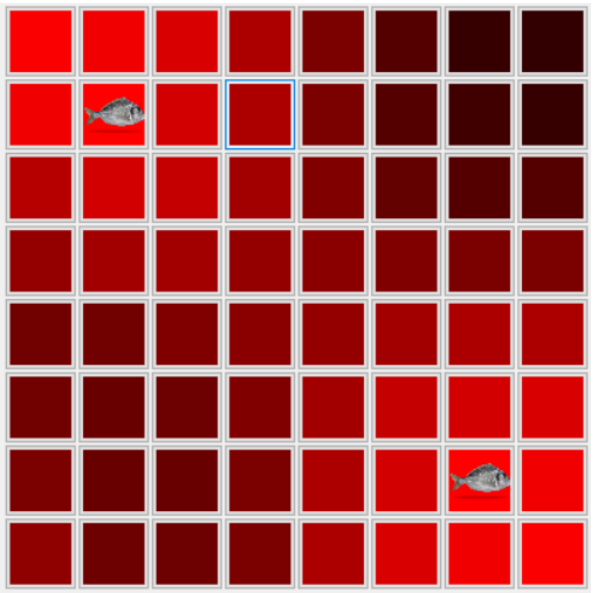

Figure 6. Fish school density matrix

RESULTS

Since fishing vessels do not know where the fish are, it will be time-consuming for them to locate the school. The vessels will have to visit almost every area one by one and detect the schools of fish. Moreover, if the school has moved a little when the fish nests are reached, it will cause the school of fish not to be found. In this sense, autonomous vessels- which are used Q-learning algorithm- will helped to detect both the area where the school is located and its movement area.

In Figure 7, the average number of steps to be taken for a region according to the matrix size is given statistically. A ship newly included in the system can reach the fish shoal in approximately 75 steps by taking random steps in an 8*8 matrix array, while autonomous ships moving with a trained network data can find the fish area in approximately 4.6 steps. These results show that defining the region with a trained network is approximately 20 times more advantageous. In addition, as the matrix size increases, the number of steps taken by ships moving with an untrained network increases exponentially, while a linear increase is observed when the trained network is used (Figure 7).

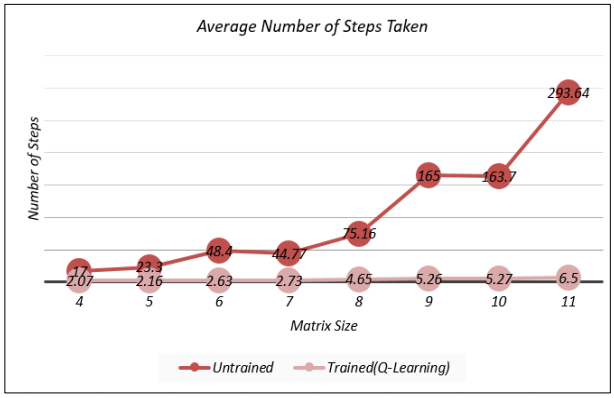

Figure 7. Average number of steps to find schools of fish

DISCUSSION

In the Q-Learning algorithm, the decision-making process is evaluated based on the reward function. The step to be taken is preferred according to the size of the profit in the reward function. In the relative Q-Learning algorithm, the step with the highest instant reward is selected by taking the previous step into account (Pandey et al., 2010).In some cases, problems caused by over-learning can occur in the Reinforcement Learning algorithm (D'Eramo et al. 2017; 2021). In addition, as stated in the article, due to events such as the movement of fish schools, the reward function may need to be corrupted or updated (Everitt et al., 2017). A solution to these problems was proposed by expanding the reward and penalty functions (Wang et al., 2020). Moreover, studies were conducted to identify potential new rewards and focus on different rewards, and the flexibility of the Q-Learning algorithm was improved (Devlin et al., 2014).In this article, by using the Q-Learning algorithm, in addition to detecting moving fish schools, it has been ensured that obstacles and areas forbidden to fish are avoided. In addition, it has been used in ATARI games, and the steps taken by the player have been optimized (Christiano et al., 2017; Van Seijen et al., 2017).

Additionally in this article, a density matrix has been obtained that will allow them to go to the nearest school in a short time. Moreover, by updating the matrix according to the school and fish type, suitable schools will be reached during suitable fishing periods. In particular, the areas prohibited from fishing will be removed from the matrix, and the protection of endangered schools will be ensured.

CONCLUSION

So, the process of discovering fish shoals, which is a difficult and time-consuming process for fishing vessels, has been made fast and effective thanks to autonomous ships. In addition, the detection of herds that may not be detected due to movement was ensured. With this method, it has become possible to quickly identify areas that are not known to fishermen or captains or that have not yet been discovered.

With the Q-Learning algorithm, areas such as seas or lakes in a region are represented in a matrix and the areas where fish schools and varieties are located are marked. In addition, the algorithm can update itself according to fish types and hunting prohibitions. By keeping a different Q-Earning matrix for each type of fish to be caught, the Q-Total-Earning matrix was obtained according to the types of fish desired to be caught, and autonomous ships were enabled to act according to this matrix. In addition, the region was recognized by autonomous ships and the fish density matrix representing that region was created.

For more complex and high-dimensional state spaces, such as large areas with fluctuating conditions, Deep Q-Learning (DQN) can be utilized. This method leverages deep neural networks to approximate the Q-value function, allowing autonomous ships to process greater volumes of data and perform more effectively in diverse settings.

Furthermore, autonomous ships can collaborate by sharing information about fish shoals and successful fishing regions. This cooperative strategy would enable a more comprehensive and dynamic understanding of fish movements, helping the ships to operate more efficiently and work together.

The Q-Learning algorithm can also be improved by incorporating adaptability, adjusting strategies based on the real-time behavior of various fish species, which may exhibit different movement patterns influenced by their environment, season, and other factors.

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AUTHOR CONTRIBUTIONS

The data collected and findings obtained for this article were provided by Mehmet Yaşar Bayraktar.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

ETHICAL APPROVAL

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

DATA AVAILABILITY

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

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RESEARCH ARTICLE ARAŞTIRMA MAKALESİ

Determination of marine environmental awareness level of Turkish SCUBA divers

Türk aletli dalıcıların denizel çevre bilinç düzeylerinin belirlenmesi

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Abstract: Human beings have been benefiting from ecosystem services for a long time. Recreational diving, as a Cultural Ecosystem Service, engages millions of divers worldwide. Because divers have a strong motivation to support biodiversity conservation, they have been involving in ecosystem assessment studies. In this study, an online survey was conducted to investigate on the marine environment awareness of people who actively dive on the coast of Türkiye. The collected responses of the divers were evaluated according to the participants' demographic characteristics and diving experiences. The questionnaire was conducted with 111 people, 32% of them were female divers. Divers' certificates vary from 1 star (1*) diver to 3 star (3*) instructor diver. On the questionnaire, we presented photographs of 13 fish species that are frequently encountered at diving areas and/or have ecological importance in our country's waters were asked to identify the species with their Turkish names. It was determined that there was no significant difference between genders, ages and the levels of education in species identification ($p>0.01$). However, there was a significant relationship between the identification of *Coris julis*, *Epinephelus marginatus* and *Chromis chromis* and the level of diving ($p<0.01$). Participants were asked which of the 13 fish species given in the survey is completely prohibited to catch in our country's waters. More than half (61%) of divers know that fishing for dusky grouper is prohibited in the coasts of Türkiye. Within the scope of this study, divers were asked "What tools do you use to get to know marine life better?". Thirty-five percent of the divers responded by watching documentaries and 33% by following some social media accounts. It is very important for divers to obtain accurate information about marine life and disseminate it to society with appropriate tools for the protection, planning and management of our seas.

Keywords: Recreational diving, SCUBA, cultural ecosystem service, environmental consciousness, awareness, Türkiye

Öz: İnsanoğlu uzun zamandır ekosistem hizmetlerinden faydalanmaktadır. Kültürel Ekosistem Hizmeti olan rekreasyonel dalış, dünya çapında milyonlarca insanı cezbetmektedir. Dalıcılar biyoçeşitliliği korumada güçlü bir motivasyona sahip olduklarından, ekosistem değerlendirme çalışmalarının bir parçası olmuşlardır. Bu çalışmada, Türkiye kıyılarında aktif olarak dalış yapan kişilerin denizel çevre bilinçlerini araştırmak için çevrimiçi bir anket çalışması yürütülmüştür. Dalıcılardan toplanan yanıtlar, demografik yapıları ve dalış tecrübelerine göre değerlendirilmiştir. Anket 111 kişi ile yürütülmüştür, katılımcıların %32'si kadın dalıcılardan oluşmaktadır. Dalıcıların bröveleri 1 yıldız (1*) dalıcıdan 3 yıldız (3*) eğitmen dalıcıya kadar çeşitlilik göstermektedir. Ankette, ülkemiz sularındaki dalış alanlarında sıklıkla karşılaşılan ve/veya ekolojik öneme sahip olan 13 balık türünün fotoğrafı gösterilmiş ve dalıcılardan bu türleri Türkçe isimleri ile tanımlamaları istenmiştir. Dalıcıların cinsiyetlerine, yaşlarına ve eğitim seviyelerine göre tür tanımlamada önemli bir farkın olmadığı belirlenmiştir ($p>0.01$). Ancak *Coris julis*, *Epinephelus marginatus* and *Chromis chromis* türlerini tanımlama ve dalış brövesi arasında önemli bir ilişki vardır ($p<0.01$). Katılımcılara, ülkemiz sularında 13 balık türü içinden hangisinin avcılığının tamamen yasak olduğu sorulmuştur. Dalıcıların yarısından fazlası (%61) Türkiye sularında orfoz balığının avcılığının yasak olduğunu bilmektedir. Bu çalışma kapsamında, dalıcılara "Denizel yaşamı daha iyi tanımak için hangi araçları kullanıyorsunuz?" sorusu sorulmuştur. Dalıcıların %35'i belgesel izleyerek ve %33'ü bazı sosyal medya hesaplarını takip ederek cevabını vermiştir. Denizlerimizin korunması, planlanması ve yönetimi açısından dalgıçların deniz canlıları hakkında doğru bilgilere ulaşmaları ve bunu uygun araçlarla topluma yaymaları büyük önem taşımaktadır.

Anahtar kelimeler: Rekreasyonel dalış, aletli dalış, kültürel ekosistem hizmeti, çevre bilinci, farkındalık, Türkiye

INTRODUCTION

Ecosystem Services (ES) are "the benefits that people obtain from nature." In broader terms, they can be thought of as resources and conditions provided by nature that enhance human well-being, ranging from water resources, food, and materials to opportunities for enjoyment or exercise in a recreational area (M.E.A. A Report of the, 2005).

Humanity has long benefited from ecosystem services. These services are necessary to ensure human health, maintain social stability, promote economic growth, and support human well-being (Costanza et al., 1997). Millennium Ecosystem Assessment (MEA) categorized the ES in four principal types as provisioning, regulating, supporting, and cultural services. Cultural Ecosystem Service (CES), encompasses a society's values, needs, and habits, considering its socio-political, economic, and environmental dimensions. With CES, people provide benefits from the ecosystem and which directly influence their quality of life (M.E.A. A Report of the, 2005). Assessing cultural ecosystem services is essential for effectively planning and managing an ecosystem, and being aware of the diversity within the environment (Gee et al., 2017).

As an important Cultural Ecosystem Service, recreational diving involves millions of divers (De Brauwer et al., 2017; Huveneers et al., 2017; Arcos-Aguilar et al., 2021). In marine

tourism activities, PADI (Professional Association of Diving Instructors) reported that each year, more than one million newly certified divers engage in this association. (PADI, 2019). According to PADI 2019 Worldwide Corporate Statistics, more than 28 million people in the world have received diving certification since 1967. The United States Sports and Fitness Industry Association reported that 3.1 million Americans engaged in diving at least once in 2013 (Denoble, 2016). According to the President of the Turkish Underwater Sports Federation, there are approximately 150 thousand certified active divers in Türkiye (Ş. Özen, personal interview, 2018). There is no comprehensive official statistic on the number of divers and dives worldwide. However, Schuhbauer et al. (2023) have estimated every year, 8.9–13.6 million divers and snorkelers participate in marine dive tourism activities worldwide. Several studies have been conducted to estimate the value of ecosystem services related to recreational diving (Ruiz-Frau et al., 2013; Failler et al., 2015; Rees et al., 2015; Zunino et al., 2020), focusing particularly on evaluating nature-based solutions such as habitats, species, and marine protected areas.

SCUBA (Self-Contained Underwater Breathing Apparatus) diving contributes to the economic growth of coastal regions (Ha et al., 2020). Its economic contribution to in establishing a Blue Economy make it an important sector (Schuhbauer et al., 2023). Furthermore, diving industry has an important role in the enhancement of biodiversity awareness (Oliveira et al., 2018). Also, divers are progressively participating in marine conservation efforts, often integrating these activities into their recreational pursuits (Hammerton et al., 2012).

To understand the relationship between our daily lives and a healthy coastal environment is important for the development of coastal communities (Fletcher and Potts, 2007). To understand this relationship requires increasing awareness of marine environmental problems. It is also very important to understand the role of personal behaviour in creating and solving marine environmental problems (McKinley and Fletcher, 2012).

In the current study, we were interested in examining the level of marine environmental awareness of individuals who actively dive on the coast of Türkiye. The collected responses of the divers within the scope of the study were evaluated according to the participants' demographic characteristics and diving experiences. We presented photographs of 13 fish species on the questionnaire. We compared the participants' responses on ecological issues of these fishes, such as correctly identifying them and whether there were any fishing bans on them, according to their diving experiences and demographic characteristics.

MATERIALS AND METHODS

A questionnaire (QA) survey accompanied by Google Forms was conducted with divers at different levels from different cities in Türkiye in April and May 2024. To access more respondents, the survey was shared through the social media accounts of some of the diving centers, which are hosted by many divers, on the coast of the country and student communities of universities from different cities such as İzmir, Antalya, Muğla, İstanbul and Kocaeli.

The QA gathered information which contains demographic attribute, diving experiences and ecological knowledge (species identification, fishing bans, etc.). In the ecological knowledge section, photographs of 13 fish species were presented, considering fishes that divers may frequently encounter in the regions where they dive (Figure 1). In the survey, divers were asked the names of these fishes in Turkish. In the last part of the QA, divers were asked about the tools they use to satisfy their curiosity about marine life (such as documentaries, social media accounts, popular science magazines, etc.). The full questionnaire can be found in the Supplementary Material section.

The data from the multiple-choice questions in the survey were analysed using the Statistical Package for the Social Sciences (SPSS, Version 25) software. Chi-square and sign tests were applied to categorical variables to assess differences in responses to ecological knowledge questions.

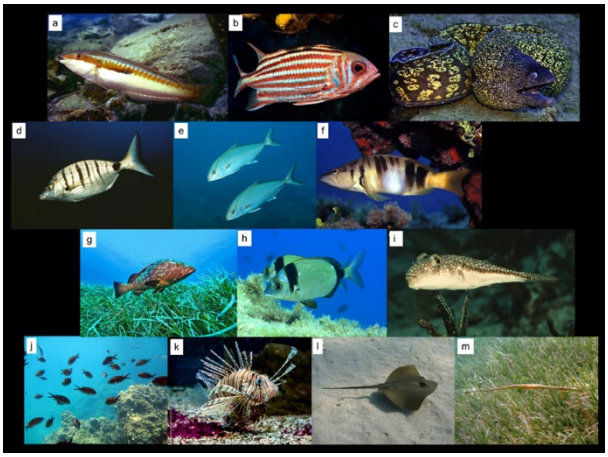

Figure 1. Fish species frequently encountered in diving areas off the Turkish coast: (a) *Coris julis* (Linnaeus, 1758) (gün balığı) (b) *Sargocentron rubrum* (Forsskål, 1775) (asker balığı), (c) *Muraena helena* Linnaeus, 1758 (müren), (d) *Diplodus puntazzo* (Walbaum, 1792) (sivriburun karagöz), (e) *Seriola dumerili* (Risso, 1810) (akya), (f) *Serranus scriba* (Linnaeus, 1758) (hani balığı), (g) *Epinephelus marginatus* (Lowe, 1834) (orfoz), (h) *Diplodus vulgaris* (Geoffroy Saint-Hilaire, 1817) (karagöz), (i) *Torquigener hypelogeneion* (Bleeker, 1852) (balon balığı), (j) *Chromis chromis* (Linnaeus, 1758) (papaz balığı), (k) *Pterois miles* (Bennett, 1828) (aslan balığı), (l) *Dasyatis pastinaca* (Linnaeus, 1758) (vatoz), (m) *Syngnathus typhle* Linnaeus, 1758 (deniz iğnesi)

RESULTS

The survey was conducted with 111 divers, all of whom were suitable for further analysis. The majority of divers participating in the survey were from Izmir (44%), followed by participants from Muğla (24%) and Antalya (16%). The

proportion of female participants was smaller (32%). The majority of the respondents (66%) were in their 30s and 40s. Only 4 divers (all male) were over 60 years old. The participants' education level revealed that 87% held a higher education degree with 47% having bachelor's degree, and 23% and 17% having completed a master's degree and doctoral degree, respectively. More than half of the participants (52%) were private sector workers, and 32% were employed in the public sector. Only two percent of the participants were unemployed. Only 2 participants reported having no income, while the biggest proportion of the participants (37%) reported an income ranging from 1072 to 1607 US$ (Reference average exchange rate of April and May 2024: US$ 1 = 31.74 TL) (TCMB, 2024). Table 1 presents the demographic variables and the divers' career.

Table 1. Divers' sociodemographic characteristics and diving background (n = 111)

Sociodemographic characteristics	No. of divers		Dive experience	No. of divers	
Age	Female	Male	***Level of certification***	Female	Male
20s	8	10	1* diver	6	10
30s	18	23	2* diver training	1	2
40s	7	25	2* diver	7	13
50s	2	14	3* training	0	1
>60	0	4	3* diver	12	14
Level of education			Guide diver	0	2
Middle school	1	0	1* instructor	5	14
High school	1	8	2* instructor	2	12
Undergraduate school	0	5	3* instructor	0	3
Bachelor degree	16	36	Other	2	5
Master degree	11	14	***Years diving***		
Doctoral degree	6	13	0	1	1
Occupation			1-10	19	28
Student	1	3	11-20	14	29
Unemployed	1	2	>21	1	18
Civil servant	11	25	***Annual number of dives***		
Private sector	22	36	1-20	13	26
Retired	0	10	21-40	11	11
***Monthly income* (US$)**			41-60	4	5
0	0	2	61-80	3	5
<536	1	4	>81	4	29
537-1071	6	9	***Experience level***		
1072-1607	15	26	Inexperienced	14	25
1608-2143	8	15	Experienced	21	51
>2144	5	20			

All participants in the study have diver certificates obtained from different diving organizations (PADI, SSI, CMAS etc.). The divers' certification levels ranged from beginner [CMAS 1 star (1*)] to master instructor [CMAS 3 star (3*) instructor]. While the participants hold various diving certifications, 3* (equal to dive master in PADI), 2* (equal to advanced open water in PADI) and 1* instructor (equal to open water diver instructor in PADI) divers account for 23%, 18%, and, 17% respectively. The experience duration of certified divers ranged from below 1 year (2%) and above 21 years (17%). Thirty-five percent of participations reported the number of dives per year as below 20, while 30% of divers stated having above 81 logged dives. In this study, recreational divers were at the various diving levels, therefore they were categorized into two groups, namely "experienced" and "inexperienced" for better analysis. Inexperienced divers included 1* and 2* divers and divers who were in training for 2* level (N=39), while experienced divers included 3* divers, dive masters, and instructors (N=72).

In this study, 111 divers were shown photographs of 13 fish species commonly encountered and/or of ecological importance at Turkish Seas, and they were asked to identify the species by their Turkish names (Table 2). Majority of divers identified fish species correctly except for *Diplodus puntazzo* and *Sygnathus typhle*. *Diplodus puntazzo* was identified by only 14% of female and %29 of male divers, and *Sygnathus typhle* was identified by 29% of female and 41% of male divers. Regardless of the fish species, there were no significant differences in fish species identification according to divers' socio-demographic characteristics (gender, age and level of education) and diving location of them ($p>0.01$).

As diving experience increases, it is expected that marine life will become better known. As expected, experienced divers accurately identified fish species more than inexperienced divers in this study. Lionfish (*Pterois miles*) and puffer fish (*Torquigener hypelogeneion*) were the most known fishes for divers. The level of diving certificate, the length of dive career, and the number of annual logged dives have no affect to know these two fish species ($p>0.01$). A significant relationship between the diving experience of divers and species identification was found the identification of *Coris julis*, *Epinephelus marginatus*, and *Chromis chromis* according to the diving level ($p<0.01$). These three fish species were identified significantly more by experienced divers than inexperienced divers (Table 2). The duration of diving experience and the number of logged dives per year reflect the divers' experience (Stolk et al., 2005). Additionally, the number of dives shows how are divers active in scuba diving. In this study, except identify *C. chromis and C. julis*, there is no significant relationship between fish species identification and divers' experience. While the length of dive career enlarged, the rate of divers who identified the damsel fish increased significantly ($p<0.01$). Similar with former finding, while the number of annual logged dives increase, the rate of divers who identified *C. julis* increased significantly.

In the survey, there were three exotic fish species (*Sargocentron rubrum*, *Torquigener hypelogeneion*, *Pterois miles*) among 13 fishes. Most divers (63%) identified pufferfish and lionfish as exotic fish, while 24% identified these three fish correctly. A significant relationship was not found between the dive level category and identify exotic fishes. Both experienced and inexperienced divers identify exotic fishes at the same rate (~24%, $p>0.01$). Besides the ecological knowledge question, we asked the fishing regulation question to divers. More than half of divers (61%) stated that "fishing of *E. marginatus* is prohibited in the coasts of Türkiye". The knowledge about fishing regulations on fishes was not changed according to dive level category either. More than half of experienced (67%) and inexperienced (51%) divers have correct knowledge of the fishing regulations ($p>0.01$).

Table 2. Percentages of divers on fish species identification according to dive experience

Fish species	Diving levels		Length of diving career (year)				The number of annual logged dives				
	Inexp. (n=39)	Exp. (n=72)	0 (n=2)	1-10 (n=47)	11-20 (n=43)	>21 (n=19)	1-20 (n=39)	21-40 (n=22)	41-60 (n=9)	61-80 (n=8)	>81 (n=33)
C. julis	41	69	50	49	60	84	41	50	89	63	79
S. rubrum	59	72	100	60	77	63	62	68	78	75	70
M. helena	92	100	100	96	98	100	92	100	100	100	100
D. puntazzo	15	29	0	15	23	53	23	36	11	0	27
S. dumerili	77	88	100	79	81	100	72	86	78	100	94
S. scriba	51	74	100	55	65	89	51	59	67	63	88
E. marginatus	77	99	100	83	95	100	82	91	89	100	100
D. vulgaris	74	82	100	68	84	95	69	86	89	50	91
T. hypelogeneion	90	94	100	89	93	100	90	95	89	88	97
C. chromis	44	72	100	45	67	89	51	50	56	88	79
P. miles	92	99	100	96	95	100	95	95	100	88	100
D. pastinaca	97	97	100	98	98	95	95	100	100	100	97
S. typhle	33	39	0	26	42	58	31	41	44	25	42

To learn more information about marine life, 35% of the respondents watch documentaries, and 33% follow regarding social media accounts. Both groups use their mobile phones to obtain the information. To identify a species to which respondents encountered it, 42% use “search engine", and almost half of the divers ask the species to a person (instructor; 24%, dive buddy; 25%) in their social surroundings.

DISCUSSION

This study was conducted with recreational divers who dive in the waters of our country and possess various levels of diving certifications. The percentage of female divers (32%) is aligned with the finding from previous research on recreational divers (Musa et al., 2006; Edney and Spennemann, 2015; Şensurat-Genç et al., 2022). The age of the divers in the study is younger than in previous studies (Ditton et al., 2002; Shani et al., 2012; Kirkbridge-Smith et al., 2013).

The majority of participants (86%) have completed high levels of education. The study’s respondents have higher education level than previous studies (Ditton et al., 2002; Stolk et al., 2005; Edney, 2012; Polak and Shashar, 2013; Edney and Spenneman, 2014). Consistent with previous study findings, the majority of recreational divers have incomes above the minimum wage (Stolk et al., 2005; Shani et al., 2012; Edney and Spenneman, 2014; Şensurat-Genç et al., 2022). Eighty percent of the divers surveyed have monthly incomes exceeding 30.000 TL. This amount is higher than the approximately 7.000 TL (US$221), which is the annual average disposable income per capita for households (TÜİK, 2023). While two participants reported no income, five individuals have monthly incomes less than the minimum wage (US$536). In this study, results consistent with previous studies conducted with recreational divers were found, suggesting that our sample properly reflects the diving community of Türkiye.

Participants presented a wide range of certification levels, from 1* divers to 3* instructors. The largest dive group was 3* divers accounting for 23%, followed by 2* divers at 18%. In previous studies conducted with recreational divers, 2* divers were the most numerous certification level (Stolk et al., 2005; Shani et al., 2012; Polak and Shashar, 2013). To analyze the responses such as species identification, ecological knowledge, divers were categorized into two groups as experienced and inexperienced.

Recreational diving, by definition, makes the diver a part of the marine ecosystem. The presence of a diver underwater impacts ecosystem directly and/or indirectly. These impacts can be either positive or negative. The main negative impact is that diver contact with corals and cause damage (Hawkins et al., 1999). To reduce this effect, some solutions have been implemented such as giving brief information to divers before diving (Camp and Fraser, 2012; Webler and Jakubowski, 2016; Giglio et al., 2018), providing better negative buoyancy dive training (Hammerton, 2017), limiting the number of dives and creating closed areas.

"The exact information" is crucial for the preservation of the marine ecosystem and all living creatures in it. The most important requirement for the protection of a species is for the diver to identify the species who encounters and to know its ecological and economic importance. It is especially important for instructor-level divers (herein experienced) to have known well of the common species and habitats in their region. Research on the motivations of SCUBA divers shows that when diving development improves, the level of environmental concern, or ethic increases (Todd et al., 2002). In this study, our hypothesis was that experienced divers (N: 72) would be able to identify all the thirteen species who frequently encounter in their regions. The experienced divers identified moray eels (100%), dusky groupers (98%), lionfish (98%) and pufferfish (94%) at high rates, while the other 9 species were identified by professionals better than the inexperienced divers, but not at the high rates we expected. Among 13 species, only 24% and 67% of experienced divers were able to identify exotic species and fishing prohibited species, respectively.

“Pufferfish and lionfish” were chosen by divers as exotic species in this study (63%). These two species, which are in

the news, talked about, and given information about their ecology and even biology in many broadcasting channels and social media in Türkiye, However, 24% of all divers stated that "squirrel fish, pufferfish and lionfish" are not native species. So, they completely answered the exotic species question in the QA. Additionally, in this study, it was found that to "better understand marine life" and "research a species they couldn't identify underwater" the divers mostly utilized the internet. While 33% of divers follow social media accounts to "better understand marine life," 42% of them research online to "research a species they couldn't identify underwater". It's already known that people today use social media to support environmental campaigns and to bring people together on small and large environmental issues locally and globally (Mallick and Bajpai, 2019).

CONCLUSION

"What was that fish?" is one of the most common question heard after a dive. The training systems of diving organizations are more or less the same. There is no special section in basic diver training programs that introduces the marine environment and/or fish species. Organizations give speciality courses named as Environment Specialty Programs, Fish Identification, Coral Identification etc. We believe that instead of such speciality courses, short briefings before and after diving will be a more useful and cheaper way to get to know the marine environment and raise awareness on related issues. Social media has become a part of today's lifestyle. It is also used as a tool to reach people's awareness about current environmental issues to a wider audience much faster and in a very short time. In this study, it is noted that the majority of divers surveyed are aware that lionfish and pufferfish are exotic species. It is believed that the extensive coverage of these species in social and mainstream media may have had a significant impact. In this context, it is thought that informative posts with plenty of photos from the social media accounts of environmental organizations, relevant university faculties, and/or related academics could make a difference in creating environmental awareness and consciousness.

Today, as one of the fastest tools for sharing information, social media needs to be used for a healthy marine environment and its effects need to be evaluated in the future.

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AUTHOR CONTRIBUTIONS

Tuğçe Şensurat-Genç: Conceptualization, Data analysis, Methodology, Writing-Review and Editing; Kaan Kırşan: Investigation, Formal analysis, Writing Original Draft

CONFLICTS OF INTEREST

The authors declare that there are no financial interests or personal relationships that could have appeared to influence the work reported in this paper.

ETHICS APPROVAL

The ethical approval of this study was received from the Board of Scientific Research and Publishing Ethics of İzmir Katip Çelebi University.

DATA AVAILABILITY

For any questions, both authors should be contacted.

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RESEARCH ARTICLE ARAŞTIRMA MAKALESİ

Genotoxicity assessment on presence of metal(loid)s in drinking water source and tap water

İçme suyu kaynağı ve musluk suyunda metal(loid)lerin varlığına bağlı genotoksisite değerlendirmesi

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Abstract: It is important to quantify the concentrations of metalloids and heavy metals (metal(oid)s) in drinking water sources and tap water due to contamination of drinking water sources by natural processes and anthropogenic activities. In this study, the genotoxicity of drinking water sources (Kacalı River) and tap water (Perşembe district) was mainly investigated by comet assay. The effect of metal(loid)s was monitored *in vivo* using erythrocyte cells of *Cyprinus carpio*. The eight heavy metals (aluminium, nickel, cadmium, lead, manganese, iron, copper, zinc) and one metalloid (arsenic) were found in the water samples and the total content of metal(loid)s was determined seasonally. In general, the total metal(loid)s content of the Perşembe tap water was higher than that of the Kacalı River in all seasons. Especially in summer, tap water causes higher DNA damage in *C. carpio* erythrocytes. Water samples from the Kacalı River showed significantly higher genotoxicity compared to control groups in all seasons. Careful management of water supplies is needed to reduce the health risks associated with genotoxicity in drinking water.

Keywords: Comet assay, drinking water, DNA damage, metal(loid) content, tap water, *Cyprinus carpio*

Öz: İçme suyu kaynaklarının doğal süreçler ve antropojenik aktivitelerle kirlenmesi nedeniyle içme suyu kaynakları ve musluk sularındaki metaloid ve ağır metal (metal(oid)lerin) konsantrasyonlarının ölçülmesi önem kazanmıştır. Bu çalışmada esas olarak içme suyu kaynağı (Kacalı Deresi) ve musluk suyunun (Perşembe İlçesi) genotoksisitesi comet analizi yöntemi ile araştırılmıştır. Metal(oid)lerin etkisi *Cyprinus carpio*'nun eritrosit hücreleri kullanılarak *in vivo* izlenmiştir. Su örneklerinde sekiz ağır metal (alüminyum, nikel, kadmiyum, kurşun, manganez, demir, bakır, çinko) ve bir metaloid (arsenik) bulunmuş ve toplam metal(oid) içerikleri mevsimsel olarak belirlenmiştir. Genel olarak Perşembe musluk suyunun toplam metal(oid) içeriği tüm mevsimlerde Kacalı Deresi'nden daha yüksek bulunmuştur. Özellikle yaz aylarında musluk suyu *C. carpio* eritrositlerinde daha fazla DNA hasarına neden olmuştur. Kacalı Nehri'nden alınan su örnekleri, tüm mevsimlerde kontrol gruplarıyla karşılaştırıldığında önemli ölçüde daha yüksek genotoksisite göstermiştir. İçme suyundaki genotoksisite ile ilişkili sağlık risklerini azaltmak için su kaynaklarının dikkatli bir şekilde yönetilmesi gerekmektedir.

Anahtar kelimeler: Comet analizi, içme suyu, DNA hasarı, metal(loid) içeriği, musluk suyu, *Cyprinus carpio*

INTRODUCTION

Chemical elements whose properties are classified between those of non-metals and metals are called metalloids (Batley, 1998). Heavy metals, such as mercury, lead, and cadmium, are metals with a density greater than 4.5 g/cm^3 (Mao et al., 2022). In the earth's crust, atmosphere, and water, heavy metals occur naturally (Jannetto and Cowl, 2023). Heavy metals lead to pollution in water resources (Kılıç, 2021). Water pollution is one of the most important environmental problems today and pesticides, fertilizers, mining, sewage waste, domestic wastewater, eutrophication, thermal pollution, oil spills, acid rain, and radioactive waste are among the main factors of water pollution (Hussain et al., 2018; Kontaş, 2022; Altunkaynak et al., 2023). These pollutants in water bodies can come from both natural sources such as erosion, corrosion and precipitation, and anthropogenic activities such as mining, agricultural spraying, industrial and domestic wastewater (Zeng et al., 2019).

Heavy metals can enter organisms directly from water or indirectly via the food chain. Heavy metals are known for their many negative properties such as persistence, bioaccumulation, and cellular, structural and environmental toxicity potential in aquatic systems and organisms (Zhang et al., 2014). Heavy metals, which have a high dispersal potential in aquatic systems due to such different factors, can maintain their presence in tap water as well as surface water and even drinking water (Zhang et al., 2014).

The detection of pollutants in aquatic systems and their possible genotoxic effects on organisms is important to study the effects on organisms and especially on fish (de Lapuente et al., 2015). Heavy metals are potentially genotoxic and carcinogenic and are known to induce oxidative stress in organisms. These genotoxic contaminants cause DNA damage in organisms and can even cause cell death by stimulating the production of reactive oxygen species (ROS) in cells (Lushchak, 2011). The complexity of contaminants in water samples leads to the preference of different genotoxicity

tests in studies. In this sense, the use of the comet assay test on different model organisms such as animal cells (*Onchorhynchus mykiss*, *Danio rerio*) for sensitive assessment of genotoxic effects of surface water samples is a very popular and accepted approach (Žegura and Filipič, 2019). The comet assay is a genotoxicity test that is generally applicable to all cell types and can be used on both prokaryotic and eukaryotic organisms. The comet assay can be used to assess water quality both *in vitro* and *in situ*. It is a reliable, rapid and cost-effective test for DNA damage susceptibility (Glei et al., 2016; Kontaş, 2022). The comet test allows the damaged DNA to be seen in the 'comet' structure and the damage in the cell increases as the calculated percentage of DNA in the tail increases and decreases as it decreases. (Doğan et al., 2022). Heavy metals are often found in trace amounts in aquatic environments, but human activities have the potential to release large amounts of these substances into water sources (Matos et al., 2017). Water is used for many human activities, and the quality of water needed for life is important (Mawari et al., 2022). Contamination of freshwater sources can result from human activities. The use of herbicides and pesticides causes an increase in metals in the water of Kacalı Stream. The differences in total metal content between seasons may be an indicator that surface waters are more polluted by different means in the respective seasons.

There is also the potential for contamination from corrosion of pipes used in plumbing fixtures and water distribution systems. The soft, acidic water can cause some complications in pipelines due to its contact with pipes, taps, and water fittings. In addition, if the source and drinking water contain high concentrations of sulfate and/or chloride, these corrosive chemicals can dissolve the lime in the water transmission system and cause the release of some undesirable heavy metals. These situations can cause corrosion in water transmission and installation pipes and increase the concentration of some heavy metals such as Fe, Cu, Pb, and Ni in tap water (WHO, 2005; U.S.EPA, 2011). Many studies have reported that lead is often used for soldering purposes in water distribution and plumbing systems. As a result, Pb concentrations in tap water may increase (Sorlini et al., 2014; Ghoochani et al., 2023). Drinking water sources and tap water containing metals and other contaminants are a major environmental problem that threatens human health.

With increasing interest in the genotoxicity of contaminants in water, sensitive biological assays such as the comet assay have become an important tool for determining genotoxicity (Scalon et al., 2010). Understandably, given the current water shortage and the need for clean water for human consumption, there is growing concern about the genotoxicity of contaminants. For this reason, the genotoxicity of contaminated rivers, surface water resources and tap water can be more effectively revealed by combining the use of more sensitive biological assays with other supporting techniques.

There are many studies on this subject (Boucard et al., 2017; Turan et al., 2020; Altunkaynak et al., 2023). No detailed study was found investigating the genotoxicity of both surface and tap water in the city of Ordu. This study aims to provide reliable data for the future safe use of the drinking water resource (Kacalı River) in Ordu province and to help implement the necessary policies to improve the aquatic system. In this study, the total metal content (eight heavy metals (aluminium (Al), nickel (Ni), cadmium (Cd), lead (Pb), manganese (Mn), iron (Fe), copper (Cu), zinc (Zn)) and a metalloid (arsenic (As)) in river and tap water were determined. In addition, we used the comet assay to evaluate the genotoxicity of tap water (Perşembe district) and surface water of the Kacalı River, an important water source that supplies drinking water to the local community of Ordu City.

MATERIALS AND METHODS

Water sampling areas

The Middle Black Sea region of Turkey includes the coastal district of Perşembe, which is located in the province of Ordu (Figure 1).

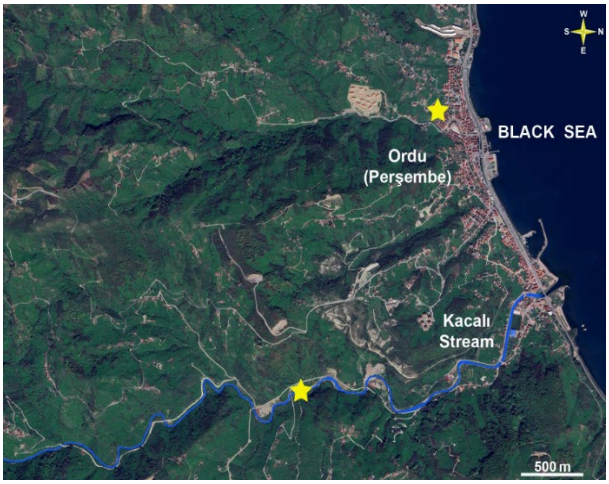

Figure 1. The sampling area (Kacalı Stream-Perşembe)

Perşembe was designated as a "Cittaslow" town, which is an international movement that is in favour of a high quality and peaceful way of life on 21 October 2012 (Şengür and Atabeyoğlu, 2018; Matcar, 2025). This study was conducted in the Kacalı stream, which flows from the Perşembe district of Ordu (Turkey) into the Black Sea, and the Perşembe tap water. Water samples were collected seasonally (winter, spring, summer and autumn seasons) from January 2020 to December 2020 from the entrance to the water intake points (in Kacalı stream) and tap water (Perşembe district). Samples were collected in three replicates to represent the study area (for surface and tap water). The water samples were collected in 10 L sterile bottles and taken to the laboratory.

Experimental design

Cyprinus carpio individuals were obtained from the Suluova Yedikır Aquaculture Production and Research Station (Amasya, Turkey). The experimental procedures of this study were approved by the Local Ethics Committee for Animal

Experiments, Ordu University (approval number: 82678388/5). The length and weight of *C. carpio* samples were selected between 4.5 - 5.5 cm and 1.00 - 1.70 g, respectively. Fish were acclimated to laboratory conditions for one month. The aquariums were aerated with air stone diffusers and sponge air pumps. The temperature, pH, and oxygen concentration of the aquarium water were maintained at 24-26°C, 7-8 and 80-90% during the day and night, respectively. Fish samples were fed commercial feed without additives twice a day during the experimental period. In this study, the experimental setup was designed as three main groups: (a) Kacalı stream (surface water), (b) Perşembe district (tap water) and (c) control groups (containing dechlorinated clean water). Fish samples (n=20) were placed in each tank. Five fish samples were randomly collected from each tank for comet assay on day 10, 20 and 30 of the experiments. All experiments were performed in three replicates.

Heavy metal analysis

The water in the tanks did not change throughout the experiment. Water samples (50 mL) were taken from each tank at the end of the 10th, 20th, and 30th day. The water samples (three replicates) were taken into 50 mL of Falcon tubes and acidified with 2M HCl (pH 2). Before the analysis, the water samples were filtered with Whatman GF/C type membrane filter (0.45 µm) (Alam et al., 2001). The heavy metals (Al, Cd, Cu, Fe, Mn, Ni, Pb, and Zn) and metalloid (As) concentrations (µg/L) of the water samples were determined by inductively coupled plasma mass spectrometry (ICP-MS) at the Scientific and Technological Research Application and Research Centre of Sinop University (SUBITAM). Since heavy metals were found as a mixture in the water samples taken from the stations, the toxicological effect of heavy metals was made on the total metal concentration (As, Al, Cd, Cu, Fe, Mn, Ni, Pb, and Zn).

Comet assay

Five fish samples from each tank were anesthetized with clove oil and blood samples were immediately taken from the hearts of these samples with heparinized syringes and the comet assay procedure was immediately performed at the end of the 10th, 20th, and 30th day. The comet assay was performed under alkaline conditions with some modifications (Kontaş, 2022; Chatha et al., 2024). For each fish, 300 µL of 1% low melting point agarose and 1 µL of blood were mixed and the slides were coated with 150 µL of this mixture. The slides were placed on a cooled layer for 30 minutes and then carefully placed in cold lysis buffer (pH 10) for one hour at 4°C. The stock solution for the lysis solution was prepared with 10 mM Tris, 2.5 M NaCl and 100 mM EDTA. Lysis buffer was prepared with 10 mL DMSO, 1 mL Triton and 89 mL stock solution. After one hour, the slides were placed in a cold electrophoresis buffer (pH> 13, prepared with 200 mm EDTA and 10 N NaOH). Electrophoresis was performed at 1 V/cm for 20 min at 4°C. After the electrophoresis phase, the slides were placed in a neutralization buffer (pH 7) for 15 min. Each slide was stained with ethidium bromide and examined under a fluorescence microscope attached to a TXR filter. One hundred erythrocytes were randomly counted for each fish sample. In genotoxicity studies, the tail DNA value (tDNA%), tail moment (TM), and olive tail moment (OTM) are the most reliable comet assay parameters used to determine DNA strand breaks (Kumaravel and Jha, 2006; Jiang et al., 2023). Therefore, in this study, tail DNA% (tDNA%), tail moment (TM), and olive tail moment (OTM) values were evaluated using CometScore software (Tritec Corp, Sumerduck, VA, USA).

Statistical analysis

Descriptive statistics of tDNA%, TM, and OTM parameters used to determine DNA damage in fish erythrocytes were calculated for each group. Groups (surface water, tap water, control), exposure periods (10th, 20th, 30th day), and seasons (spring, summer, autumn, winter) were compared by one-way ANOVA. A statistically significant P value is one less than 0.05. All tests were performed using the statistical analysis program MINITAB 17.0 (Minitab, Inc., State College, PA).

RESULTS

The total metal content is presented seasonally for the surface and tap water samples in Figure 2. In this study, the total metal content in the water of fish exposed to surface and tap water decreased during the exposure periods (10th, 20th, and 30th day).

The average total heavy metal content in Kacalı stream surface water and Perşembe tap water on days 10, 20, and 30 in the spring season were 112.71±8.25, 40.73±5.2, 19.92±3.23 and 166.77±8.57, 48.09±5.12, 18.34±2.47, respectively (Figure 2A). The average total heavy metal content in Kacalı stream surface water and Perşembe tap water on days 10, 20, and 30 in summer season were 136.65±7.35, 110.57± 6.27, 29.61±4.12 and 202.27±9.24, 63.68±4.89, 45.85±4.32, respectively (Figure 2B). The average total heavy metal content in Kacalı stream surface water and Perşembe tap water on days 10, 20, and 30 in autumn season were 35.31±3.14, 21.62±2.75, 16.27±2.13 and 85.65±5.24, 45.70±4.47, 11.26±1.16, respectively (Figure 2C). The average total heavy metal content in Kacalı stream surface water and Perşembe tap water on days 10, 20, and 30 in winter season were 47.93±5.78, 22.21±2.86, 13.37±1.47 and 79.58±5.11, 30.54±2.95, 11.82± 1.24, respectively (Figure 2D). In general, the total metal content of the Perşembe tap water was higher than that of the Kacalı Stream surface water in all seasons. The Kacalı stream had the highest total heavy metal concentration in the summer season ($P<0.05$). The water of the Kacalı River showed a high concentration of metal content especially in summer on the 30th day (Figure 2).

The present study investigated the genotoxicity of surface and tap water samples from the drinking water source of the Perşembe district. The comet assay was used to measure DNA

damage. The results of the comet assay are presented in Table 1. In summer, samples from Kacalı Stream caused a significant increase in DNA damage in erythrocytes on day 30, and water samples showed marked toxicity on day 10 (P<0.05). Regarding surface water, water samples from Kacalı River showed significantly higher genotoxicity in all seasons (P<0.05) compared to controls. In addition, significantly higher levels of DNA damage were found in the summer, autumn, and winter seasons in the tap water (P<0.05).

Tap water samples from the Perşembe district showed a statistically significant increase in genotoxicity compared to controls (P<0.05). Tap water samples also showed genotoxic activity in the spring season, but the toxicity was lower than that of surface water on all exposure days (P<0.05). Tap water showed significantly higher levels of DNA damage on all exposure days than surface water in the other seasons except spring (P<0.05) (Table 1).

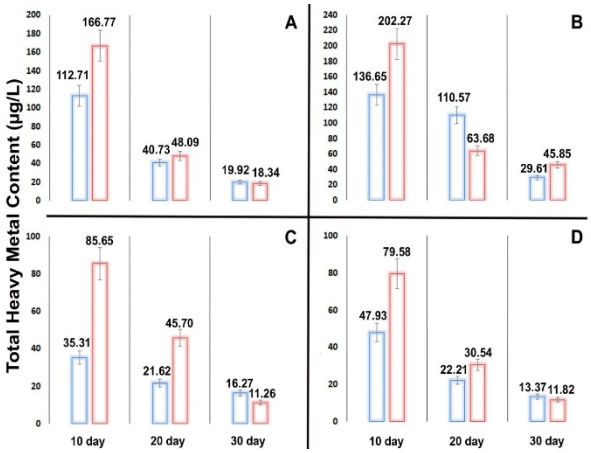

Figure 2. Seasonal total heavy metal content of Kacalı Stream water (Blue) and Perşembe tap water (Red). A: Spring, B: Summer, C: Autumn, D: Winter

Table 1. The comet assay on erythrocyte cells in *C. carpio* by surface and tap water effect in different seasons (tDNA%: tail DNA%, TM: tail moment, and OTM: olive tail moment) (Mean±S.D.) (Sp: spring, S: summer, A: autumn, W: winter, KSSW: Kacalı Stream Surface Water, PTW: Perşembe Tap Water)

	Groups (n=15)	Exposure Times (day)	tDNA (%)	TM	OTM
Sp	KSSW	10	13.72 ± 0.370^{xBa}	0.202 ± 0.011^{xAb}	0.505 ± 0.027^{xAd}
		20	14.69 ± 0.387^{xABa}	0.217 ± 0.013^{xAab}	0.498 ± 0.026^{xAb}
		30	15.94 ± 0.398^{xAab}	0.239 ± 0.013^{xAab}	0.469 ± 0.027^{xAb}
	PTW	10	12.51 ± 0.331^{yCb}	0.177 ± 0.009^{xBa}	0.529 ± 0.027^{xAc}
		20	14.31 ± 0.342^{xBa}	0.221 ± 0.011^{xAa}	0.511 ± 0.026^{xAb}
		30	15.71 ± 0.431^{xAb}	0.257 ± 0.015^{xAab}	0.470 ± 0.032^{xAb}
	Control	10	3.60 ± 0.132^{zAa}	0.042 ± 0.001^{yAa}	0.236 ± 0.013^{yAa}
		20	3.44 ± 0.131^{yAa}	0.040 ± 0.002^{yAa}	0.214 ± 0.012^{yAa}
		30	3.58 ± 0.136^{yAa}	0.041 ± 0.001^{yAa}	0.235 ± 0.013^{yAa}
S	KSSW	10	13.57 ± 0.417^{xBa}	0.264 ± 0.015^{xAa}	1.091 ± 0.035^{xAa}
		20	13.85 ± 0.435^{xBab}	0.242 ± 0.015^{xAa}	0.924 ± 0.031^{yBa}
		30	16.33 ± 0.465^{yAa}	0.269 ± 0.016^{xAa}	0.914 ± 0.028^{xBa}
	PTW	10	14.01 ± 0.380^{xBa}	0.218 ± 0.013^{yAa}	0.958 ± 0.026^{yAa}
		20	14.79 ± 0.422^{xBa}	0.247 ± 0.016^{xAa}	1.025 ± 0.031^{xAa}
		30	17.95 ± 0.429^{xAa}	0.279 ± 0.015^{xAa}	0.940 ± 0.023^{xAa}
	Control	10	3.90 ± 0.136^{yAa}	0.045 ± 0.001^{zAa}	0.260 ± 0.012^{zAa}
		20	3.83 ± 0.161^{yAa}	0.046 ± 0.001^{yAa}	0.267 ± 0.013^{zAa}
		30	3.77 ± 0.131^{zAa}	0.044 ± 0.001^{yAa}	0.238 ± 0.012^{yAa}
A	KSSW	10	10.14 ± 0.388^{yCc}	0.161 ± 0.012^{xBb}	0.795 ± 0.030^{xBc}
		20	12.63 ± 0.374^{yBb}	0.194 ± 0.011^{yABb}	0.910 ± 0.027^{yAa}
		30	13.99 ± 0.393^{xAc}	0.209 ± 0.014^{xAb}	0.870 ± 0.026^{xABa}
	PTW	10	12.49 ± 0.354^{xBb}	0.183 ± 0.012^{xBa}	0.852 ± 0.029^{xBb}
		20	13.66 ± 0.321^{xABa}	0.229 ± 0.012^{xAa}	1.020 ± 0.022^{xAa}
		30	14.58 ± 0.399^{xAb}	0.212 ± 0.011^{xABb}	0.859 ± 0.023^{xBa}
	Control	10	3.80 ± 0.164^{zAa}	0.046 ± 0.001^{yAa}	0.265 ± 0.013^{yAa}
		20	3.77 ± 0.132^{zAa}	0.044 ± 0.001^{zAa}	0.240 ± 0.012^{zAa}
		30	3.88 ± 0.145^{yAa}	0.046 ± 0.001^{yAa}	0.261 ± 0.013^{yAa}
W	KSSW	10	12.02 ± 0.331^{yBb}	0.211 ± 0.012^{xAb}	0.967 ± 0.027^{xAb}
		20	13.77 ± 0.379^{xAab}	0.208 ± 0.011^{yAab}	0.888 ± 0.025^{yAa}
		30	14.78 ± 0.371^{xAbc}	0.240 ± 0.014^{xAab}	0.932 ± 0.024^{xAa}
	PTW	10	13.04 ± 0.335^{xBab}	0.200 ± 0.011^{xBa}	0.907 ± 0.024^{xABab}
		20	14.11 ± 0.367^{xBa}	0.265 ± 0.015^{xAa}	0.963 ± 0.024^{xAa}
		30	15.74 ± 0.384^{xAb}	0.243 ± 0.014^{xABab}	0.884 ± 0.023^{xBa}
	Control	10	3.78 ± 0.130^{zAa}	0.044 ± 0.001^{yAa}	0.240 ± 0.012^{yAa}
		20	3.82 ± 0.160^{yAa}	0.046 ± 0.001^{zAa}	0.266 ± 0.013^{zAa}
		30	3.89 ± 0.141^{yAa}	0.045 ± 0.001^{yAa}	0.262 ± 0.012^{yAa}

Different A, B, C superscripts indicate statistical differences between exposure times (P<0.05), different x, y, z superscripts in a column indicate statistical differences between groups (P<0.05), and different a, b, c, d superscripts indicate statistical differences between seasons (P<0.05).

DISCUSSION

In the current study, the heavy metal concentration of tap water detected an unexpected positive genotoxic effect on *C. carpio* erythrocytes. However, there was no previous study on the genotoxicity of tap water in Ordu province. The genotoxic potential of metalloids and heavy metals has been reported in *Oreochromis niloticus* erythrocytes (Barbosa et al., 2010), and *Clarias gariepinus* gill and liver cells (Turan et al., 2020). The comet assay has also been proposed to monitor the genotoxicity and toxicity of surface water samples in many countries (Žegura et al., 2009; Chakrabarty and Sarma, 2011; Kontaş and Bostancı, 2020; Lovinskaya et al., 2022; Picinini et al., 2022).

The potential genotoxic effects of these contaminants in fish are also not fully understood. According to the results, both surface water and tap water interacted with the erythrocyte cells of *C. carpio*. For the first time, the genotoxicity of surface water from the Kacalı stream, one of the main drinking water sources in Ordu province and tap water from Kacalı districts were evaluated *in vivo* using the comet assay. The present study revealed that heavy metals were present in surface water and tap water analysis results. Heavy metals in water systems may act alone or in combination with other heavy metals. Heavy metal may not be effective at low doses but may become effective when combined with other low doses of heavy metals (Dağ and Arıcı, 2021; Mitra et al., 2022). Since this possible effect was taken into account in our study, the effects of heavy metals were evaluated in a combined manner and it was found that although the metal concentrations were not very high, the total metal content in waters had the potential to cause genotoxic damage to *C. carpio*.

It is difficult to identify the compounds that may be responsible for the possible adverse effects associated with exposure to mixed forms of environmental contaminants in the aquatic environment and to attribute the genotoxic effect directly to another factor. In addition, the interactions of the relevant heavy metals with each other are quite complex. These substances can exhibit different effects when mixed together in the same environment, as well as when they are present alone (Kontaş, 2022; Mitra et al., 2022).

Previous studies have shown the presence of numerous heavy metals in drinking water (Yeo et al., 2021; Luo et al., 2022). These harmful compounds originate not only from pollution but also from disinfection processes, especially when surface water is chlorinated. The majority of chlorinated compounds found in drinking water are non-volatile and difficult to identify (Ceretti et al., 2016). In many studies, genotoxic effects in tap water are mostly associated with the presence of disinfection by-products (Richardson et al., 2003; Cortés and Marcos, 2018). Drinking water contamination may originate from point sources of drinking water and other non-point sources of pollution or materials used in distribution systems (Žegura et al., 2009; Bozzo et al., 2013). One of the main causes of heavy metals contamination in tap water was the pollutants released from pipe sediments, especially in Ordu. The various factors can cause microbial and chemical changes in water distribution systems. The increase in microorganisms can also lead to corrosion of water pipes in these systems (Song et al., 2023). In addition, the properties of the water (temperature, oxygen content, particulate matter, and pH), as well as the age, type, structure (deposits and corrosion) and quality of the pipe materials can contribute to biological degradation.

Untreated industrial and domestic wastewater had genotoxic potential in aquatic ecosystems in Serbia, which could be effectively monitored by comet assay (Sunjog et al., 2012). Similarly, da Silva et al. (2020) found that *Astyanax lacustris* may suffer genetic damage when urban water contains high concentrations of certain metals. According to the WHO (2022), disinfecting water from surface sources may produce hazardous substances. Contamination of tap water can result from both water distribution systems and these disinfection treatments. In general, the most effective way to manage a drinking water distribution system is to reduce the possibility of contamination and quality degradation during transport, particularly by safeguarding water quality. Previous study has reported waterborne disease outbreaks in the UK (Cairncross, 2003) as a result of water contamination in the distribution system.

The current study results were consistent with previous data showing an increase in DNA damage in fish exposed to different types of contaminants and were also supported by exposure time and season, which has been highlighted in many genotoxicity studies (de Flora et al., 1993; Rocco et al., 2012). As in the current study, the comet assay sensitively detected DNA damage induced by different genotoxic agents in a dose-dependent manner. The comet assay has been successfully used in many studies, including our study, to investigate the effects of genotoxic pollutants on DNA integrity (Ternjej et al., 2010; Kontaş and Bostancı, 2020; Jiang et al., 2023). Due to its sensitivity to water contamination, the comet assay has recently been recognized as an efficient test to be used in genotoxicity studies. The comet assay has been applied to several pollutants in different types of water, such as drinking water, industrial effluents, lake and river water (Jiang et al., 2023). The comet assay is based on the assessment of DNA damage in different cell types (Žegura and Filipič, 2019).

There were significant seasonal variations in tail DNA percentage, tail moment, and olive tail moment. The variations of tDNA% were highly significant when comparing the values obtained in summer with those obtained in other seasons. Furthermore, the differences between surface and tap water samples were specified in all seasons. tDNA% values at three exposure times varied between 13.57-16.33 in Kacalı surface water and 14.01-17.95 in Perşembe tap water in summer. These values were between 12.02-14.78 in surface water and 13.04-15.74 in tap water in the same season. The differences in tDNA% values in the water samples may be affected by the significant temperature fluctuations in Ordu. DNA damage in

Mugil sp. and *Netuma* sp. was significantly higher in spring and summer compared to autumn and winter. Higher temperatures in surface waters were associated with higher levels of DNA damage than seasons with lower temperatures (Andrade et al., 2004). Exposure time caused an increase in DNA damage in erythrocyte cells of *C. carpio*. A positive relationship between DNA damage and exposure time has also been described previously (Kontaş and Bostancı, 2020; Kontaş, 2022).

The results of heavy metal analysis combined with the results of genotoxicity tests would provide a more robust basis for assessing the risks to human health associated with the use of drinking water. Low levels of genotoxicity, which are typical of drinking water samples, can be detected using genotoxicity tests. The present study did not attempt to directly identify which heavy metals in surface and tap water are responsible for genetic damage. These waters are likely to contain other pollutants as well as heavy metals. Aquatic organisms and humans are exposed to all heavy metals simultaneously. For this reason, it was considered more appropriate to calculate the genotoxic potential of surface and tap water based on the total load. Furthermore, heavy metals with complex chemical combinations can cause genotoxic effects in aquatic systems, even at very low concentrations (Hemachandra and Pathiratne, 2017).

In order to assess the mutagenic and/or genotoxic hazards of drinking water, a series of short-term in vitro analyses were performed on different drinking water samples before and after distribution. It has been reported that these waters can cause genetic damage in various organisms (Lan et al., 2018; Kontaş and Bostancı, 2020; Jiang et al., 2023). Although water is treated in drinking water facilities, tap water may have different metal concentrations due to contamination and corrosion during transport from the water facility through the supply system (Khan et al., 2015; Hossain et al., 2022). A similar case was observed in Perşembe tap water, where the total metal content in water samples was higher than in surface water samples. This situation shows the presence of genotoxic pollutant(s) in tap water, which still need to be identified and removed, even though they are purified in network treatment stations.

CONCLUSIONS

In this study, the toxic effects presumably caused by heavy metals in the surface water of Kacalı River and the tap water of Perşembe were observed. The present study showed that additional knowledge is needed about the potential toxicity of the drinking water source (Kacalı River) and the tap water (Perşembe district). The quality of the tap water consumed by humans needs to be investigated in relation to the dissolved metal composition and the possible health risks associated with it need to be assessed. The contamination of the drinking water in this area is likely to increase, with adverse consequences for organisms and humans. During the installation, operation and maintenance phases of the water treatment system, potential threats to the receiving environment and public health can be reduced by implementing an efficient drinking water management program. Strict enforcement of regulations and regular monitoring are also essential during the operational phase.

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AUTHOR CONTRIBUTIONS

Seda Kontaş Yalçınkaya, Derya Bostancı, Serdar Yedier: Conceptualisation, methodology; Derya Bostancı: Project management; Seda Kontaş Yalçınkaya, Serdar Yedier: Research, sample collection, observation; Seda Kontaş Yalçınkaya: Preparing an original draft; Seda Kontaş Yalçınkaya, Derya Bostancı, Serdar Yedier: Data analysis, writing, revising, reviewing and editing.

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

ETHICS APPROVAL

All experimental procedures were approved by Animal Experiments Local Ethics Committee, Ordu University (Approval number: 82678388/5).

DATA AVAILABILITY

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

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RESEARCH ARTICLE ARAŞTIRMA MAKALESİ

Evaluating the socio-economic conditions of fishers and sustainability of small-scale fisheries in the Kalni River, Bangladesh

Bangladeş Kalni Nehri'ndeki balıkçıların sosyo-ekonomik koşullarının değerlendirilmesi ve küçük ölçekli balıkçılığın sürdürülebilirliği

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Abstract: Small-scale fisheries play a vital role in the economy of Bangladesh, especially in providing livelihood to fishers and foreign exchange. A study on the socio-economic assessment of small-scale fishing and fish availability in the Kalni River in Habiganj district was conducted for four months from May to August 2023. A total of 58 fishers were randomly selected and interviewed for information gathering and pre-checklisting in focus group discussions (FGDs). Of these, 93% were male and the mean age was 36.89 ± 6.43 years. The results showed that the monthly income of fishers ranged from 10,000-20,000 BDT, 20,000-30,000 BDT, and less than 10,000 BDT. The study collected information on various aspects including the type of fishing gear used and the availability of small indigenous fish (SIS). The main fishing method, 'Ber jal' gear, accounted for 80% of the catch, while 'Dhormo jal' gear accounted for the remaining 20%. During this period, 1-3 types of Puti (*Puntius* sp.) and (*Nandus nandus*) Gobiidae family is the most abundant species. Various SISs were caught in the river; some rare species were also identified. Community-based management approach and management of fish sanctuaries, as well as public awareness of fishery resources, could be effective in minimizing anthropogenic impacts on fishers' livelihood.

Keywords: Bangladesh, *Puntius* spp., small indigenous species, socio-economic, small scale fisheries

Öz: Küçük ölçekli balıkçılık, özellikle balıkçılara geçim kaynağı ve döviz sağlaması açısından Bangladeş ekonomisinde hayati bir rol oynamaktadır. Habiganj bölgesindeki Kalni Nehri'nde küçük ölçekli balıkçılığın ve balık mevcudiyetinin sosyo-ekonomik değerlendirmesi üzerine olan bu çalışma, Mayıs-Ağustos 2023 tarihleri arasında dört ay boyunca yürütülmüştür. Toplam 58 balıkçı rastgele seçilmiş ve bu balıkçılarla odak grup tartışmalarında (FGD'ler) bilgi toplama ve ön kontrol listesi oluşturmak için görüşülmüştür. Bunların %93'ü erkek ve yaş ortalaması 36,89 ± 6,43 yıldır. Sonuçlar, balıkçıların aylık gelirinin 10.000-20.000 BDT, 20.000-30.000 BDT ve 10.000 BDT'den az arasında değiştiğini göstermiştir. Çalışmada, kullanılan balıkçılık araçlarının türü ve küçük yerli balıkların (SIS) mevcudiyeti de dahil olmak üzere çeşitli yönler hakkında bilgi toplanmıştır. Ana balıkçılık yöntemi olan 'Ber jal' avcılık yöntemi, avın %80'ini oluştururken, 'Dhormo jal' yöntemi kalan %20'yi oluşturmuştur. Bu dönemde, 1-3 tür Puti (*Puntius* spp.), meni (*Nandus nandus*) ve Gobiidae familyası türü en bol bulunan balıklardır. Nehirde çeşitli SIS'ler yakalandı; ayrıca bazı nadir türler de belirlendi. Topluluk temelli yönetim yaklaşımı ve balık koruma alanlarının yönetimi ile balıkçılık kaynaklarına ilişkin kamuoyunun farkındalığı, balıkçıların geçim kaynakları üzerindeki antropojenik etkileri en aza indirmede etkili olabilir.

Anahtar kelimeler: Bangladeş, *Puntius* spp., küçük yerli türler, sosyo-ekonomik, küçük ölçekli balıkçılık

INTRODUCTION

Fish and fisheries have long dominated the lives and livelihoods of Bangladeshis people. According to "Maache-Bhate Bangali," which translates to "Fish and rice make a Bengali," the majority of Bangladeshis consume fish in their diets (Alam and Thomson, 2001; Rashed-Un-Nabi et al., 2011). Initially, viewed primarily as a means of subsistence, the fisheries industry has developed into a significant contributor to the national GDP, job creation, and foreign exchange earnings (Njaya, 2007; Mozumder et al., 2023). Bangladesh contains a wide variety of fishery assets, enveloping many local and outlandish sea-going species. As the fourth-largest producer of inland fisheries worldwide, Bangladesh's freshwater bodies are home to 260 native fish species, 12 exotic fish species, and 24 prawn species (DoF, 2018; Das et al., 2024). The fisheries sector is crucial to the nation's economy because it provides food, employment, and earnings in foreign exchange. It has a significant impact on the supply of animal protein, the GDP of the nation (3.52%), export revenue (1.39%), and so on (DoF, 2020). Aquaculture will be worth approximately 264 billion US dollars in 2022, accounting for 49.2% of global fish production (Sidiq et al., 2024). In addition, this amount is 87.5 million tons of fish

(Shamsuzzaman et al., 2020). Bangladesh is the third-largest producer of inland open-water capture water, making it one of the top aquaculture producers worldwide (Azad et al., 2023). Small-scale fisheries are traditional fishing methods that use limited resources such as capital and energy (Gunakar and Bhatta, 2023). Moreover, small-scale fisheries frequently self-regulate to safeguard nearby assets by enforcing closed seasons, restricting fishing gear, and controlling fishing access (Mozumder et al., 2023). These methods could be as straightforward as those used in less developed nations or as sophisticated as larger vessels such as trawlers and long liners in more developed regions. Small-scale fisheries are an essential component of global fishing activities and are a vital source of income for millions of people worldwide in developed as well as developing nations (Mohsin and Emdadul Haque, 2009). As Bangladesh's fisheries area has a high potential to contribute to the country's financial turn of events, these issues can be addressed by mindful and cost-effective fisheries executives (Murshed-e-Jahan et al., 2009).

Bangladesh, which is also a developing nation, has a similar percentage of small-scale fishing. This industry provides numerous advantages, including national employment, food security, and economic expansion (Islam et al., 2017a). This is especially true for the Sylhet region, which is in the country's northeastern region and contains a large area of natural water bodies and low-income fisher groups. The potential of small-scale fisheries to alleviate poverty has been largely overlooked despite their crucial role in supporting a significant portion of the population (Islam et al., 2017b). Small-scale fishermen lack protection from a wide range of crises, which eventually leads to poor socioeconomic conditions (Islam and Chuenpagdee, 2013). Floods and market issues pose particular difficulties for those living in the Sylhet region (Mawa et al., 2023), as does a lack of hospitals, sanitary living conditions, and waterborne diseases such as dysentery and diarrhea (Ashbolt, 2004; Hridoy et al., 2025). Inadequate collaboration between specialists and neighborhood partners is primarily to blame for the unfortunate outcomes brought about by the devaluation of fisheries assets, which necessitates adequate support from Bangladeshi educators for those affected (Emdad and Salim, 2013).

Fishermen have a high rate of illiteracy due to a lack of access to education, which is exacerbated by a lack of schools and inadequate transportation and communication infrastructure (Khanum, 2013). The Sunamganj region faces challenges as a result of high population pressure and an increase in the number of households with landless fishermen. Because the government does not have a sufficient understanding of the small-scale fisheries (SSF) industry, it is ill-equipped to address the potential effects on society and the environment. The lives of small-scale fishermen in floodplain areas are ignored in the material that is currently being published, highlighting the urgent need for additional research. According to a study that examined the factors that influence these fishermen's income, it is evident how important it is to increase their income to develop policies that will improve their well-being (Anna et al., 2019). To achieve social-ecological sustainability and ensure future livelihoods, novel methods are required to comprehend fisheries in their environments and create efficient policies (Andrew et al., 2007). The National Fisheries Policy (1998) is a crucial framework that prioritizes sustainable fisheries management, the advancement of aquaculture, and the reduction of poverty. Furthermore, Co-Management Policies are designed to enhance collaboration among government bodies, non-governmental organizations (NGOs), and fishers. These policies seek to promote shared responsibilities and inclusive decision-making, ensuring a balanced strategy for resource management and active community participation. The present study seeks to offer insights into the diversity, availability, current status, population trends, threats, and household circumstances of SISs in the northern part of the Kalni River region in Bangladesh. The study also considered the socioeconomic conditions of stakeholders to assess the future potential of SSFs.

MATERIALS AND METHODS

The research utilized a mixed-method approach, integrating both qualitative and quantitative techniques. This strategy facilitates a thorough analysis by merging numerical data with detailed contextual insights, providing a well-rounded understanding of the research subject.

Study area

This research was carried out in the designated area of the Kalni River (24°25'36"N 91°12'08" E) in the Habiganj district of Bangladesh to evaluate the livelihoods of local fishermen (Figure 1). The banks of the Kushiyara-Kalni River in the Ajmiriganj upazila of the Habiganj district have been eroding over time. The Kalni River is a tributary of the Surma River, which originates from the Manipur state in India.

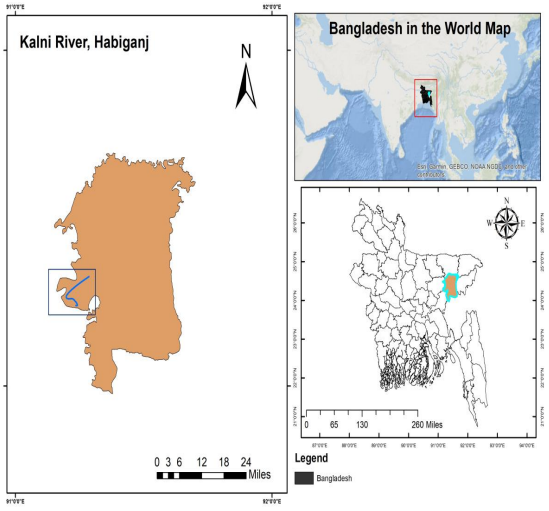

Figure 1. Geographical Representation of the Kalni River in Habiganj, Bangladesh, and Its Global and National Context: Developed Using ArcGIS 10.8

Data collection process

Primary data were collected and used for this study. The data collection period was conducted for four months from May to August 2023. The data were collected through the administration of questionnaires. This data collection process by a research team focused on 58 small-scale fishers and women who had life-led many problems in their household assessments. A previous check was made via focus group discussion (FGD). The illiterate respondents did not understand English, so the questionnaire was explained in the Bangla language; thus, they answered properly and were notified. Face-to-face questionnaire interviews were conducted with the chosen fishers; the sample size was established at 60 (Rahman et al., 2018). On the other hand, a total of 50 fishers were randomly selected from three villages, Mohonganj upazila, in the Netrokona district (Alam et al., 2023). In their study, 70 households were identified as being particularly susceptible to riverbank erosion (Ali and Khan, 2023).

Data analysis

The data were examined using the R programming language (R Studio 4.3.2) for data cleaning and analysis preparation, after which the frequency distribution, percentage, mean, and standard deviation (SD) were determined using descriptive statistics.

RESULTS

The data were collected for close examination of the respondents' livelihood; personal, communicational, socioeconomic, and situational characteristics; and other factors.

Gender distribution across different age groups

The review showed that 93% of the males and 7% of the females were aged between 27 and 50 (36.89±6.43) years (Figure 2), which demonstrated that the angler networks were ruled by the middle-aged bunch. Their exercises are fish-related, and some additional work includes family.

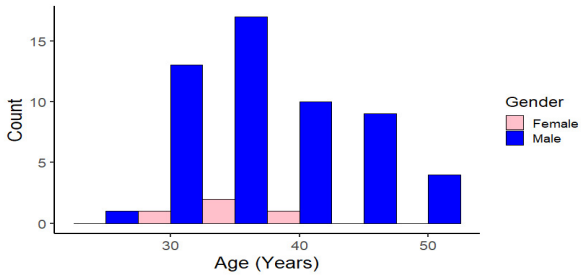

Figure 2. Age-related performance across different genders

Main occupation related to monthly income

The month-to-month pay of anglers was ordered into three gatherings under 10000, 10,000-20,000 and 20,000-30,000 BDT. A greater percentage of the respondents (41.51% under 10,000) (13.21% are 20,000-30,000) had a high BMI of 10,000-20,000 (45.28%) (Figure 3).

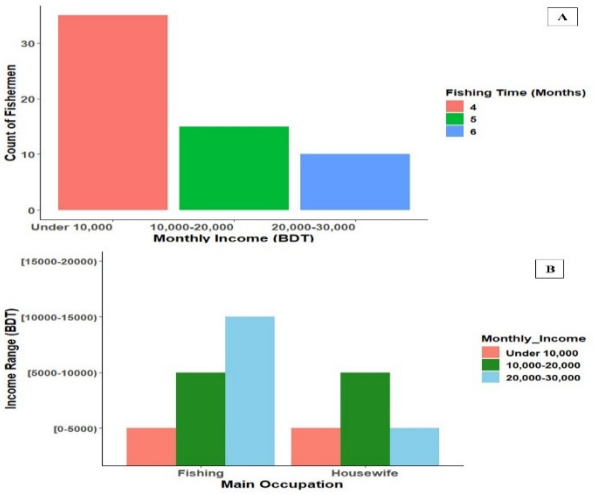

Figure 3. Presents bar charts illustrating: A. The relationship between monthly income and fishing time, and B. The association between monthly income and occupation

Relationship between daily engagement in fishing and monthly income

According to the study intensity map, there is a relationship between month-to-month pay and fishing length within a 24-hour time frame. The information reveals that anglers invest in shifting measures of energy fishing: 1-6 hours, 6-7 hours, 7-8 hours, 8-9 hours, and more than 10 hours. The most widely recognized fishing term is between 8 and 9 hours, representing 25% of the commitment, followed by 7 and 8 hours, which represents 23.75% of the commitment (Figure 4).

The peak season of fishing generates monthly income

In this study, the pinnacle fishing season for little fish occurred from December to February, during which anglers acquired the most noteworthy extent of their month-to-month pay, totaling 67.19%. In particular, December to January contributes 23.44%, and November to February contributes 9.38% to the general pay. Anglers procuring between 10,000 and 20,000 normally experience this pinnacle from November through February.

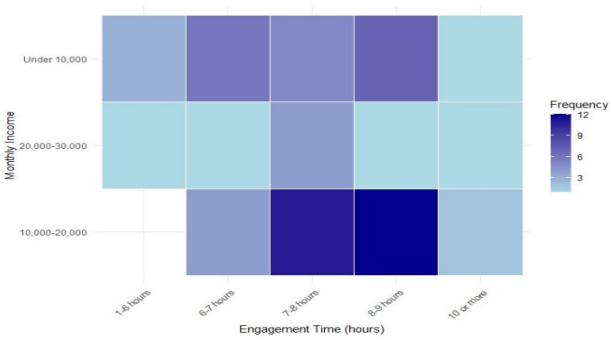

Figure 4. Amount of time spent fishing and relate to their monthly income

Types of gear use and amount of fish caught

This study on the different fishing strategies utilized to catch Puti fish. The essential strategy, the "Ber jal" gear, represented 80% of the catch, while the "Dhormo jal" gear contributed more than 20% of the total (Figure 5).

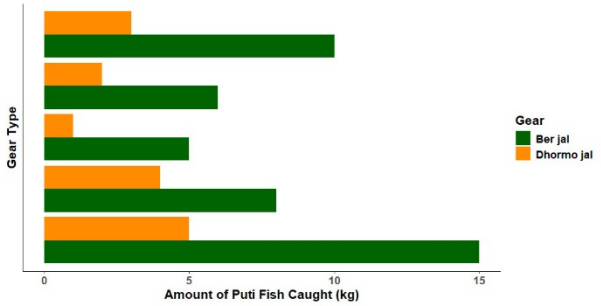

Figure 5. The utilization of gear for catching Puti (*Puntius* spp.) was measured per kilogram

Types of Puti fish

The pie chart provides the division of answers with regard to the range of Puti species they were familiar with. The majority (50%) were familiar with 2-3 species, reinforcing the fact that this was the most prevalent range known to them. An approximate 33.3% were familiar with 1-2 species, revealing very low awareness when it comes to species diversity. A very minimal percentage (1.9%) were familiar with 3-4 species, reinforcing the fact that exposure to more diversified Punti species is negligible (Figure 6).

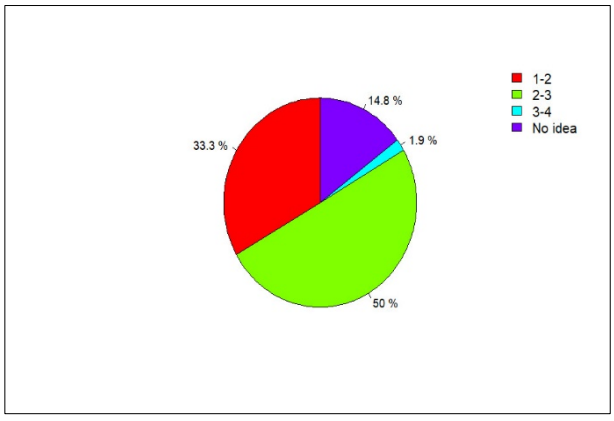

Figure 6. Distribution of respondents based on the number of puti fish species identified

Availability of small indigenous species (SIS)

This study looks at the limited scale fisheries working along the Kalni Waterway, zeroing in on the variety of fish species present. Among the species reviewed, Meni (*Nandus nandus)* was the most common, accounting for 17% of the complete fish populace. Less habitually experienced species include Baim (*Mastacembelus armatus*), Shol (*Channa striata*), Chapila (*Gudusia chapra*), and Gutom (*Lepidocephalichthys guntea*). Despite these overflow varieties, the review highlights the assorted scope of fish species inhabiting the Kalni Waterway ecosystem. Three percent of the Anguillidae family contains freshwater eels. Meni, from the Gobiidae family, is the most common species, accounting for 17%. Shoal from the Channidae family was associated with the most unbountiful species (1%), and Rani, which is from the Cyprinidae family, was associated with 14% of the unbountiful species (Figure 7). Additionally, the occasional overflows of Kholisha (*Trichogaster fasciata*) and Kakila (*Xenentodon cancila*) are accessible in this riverside neighborhood market (Figure 8).

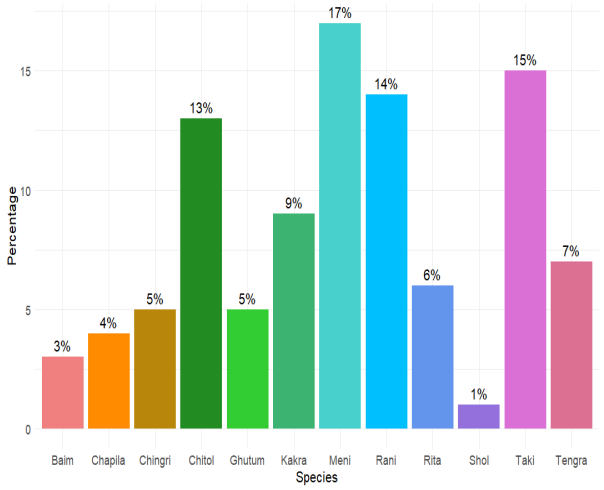

Figure 7. Percentage distribution of respondents' knowledge on different fish species

Figure 8. Some fish species in the Kalni River, Bangladesh

DISCUSSION

The demographics and socio-economics of fishing communities in South Asia are heterogeneous. In Barpeta, Assam, most anglers (49.3%) were aged 31–40 years and 23.91% were from the 41–50 age group (Kalita et al., 2015). In Tamil Nadu's Kanyakumari district, 46% of mussel fishers were between the ages of 40–50 years, followed by 24% who were aged between 50 and 60 years,18%between the ages of 30 and 40 years old, 8 under 30 years old, and 4 over 60 years old (Mary et al., 2015). About three-fifths of the total fishing labor force in Karnataka comprised small-scale fishers, 36% with ages between 21–30 years, followed by 25% each in the age brackets of 31–40 and 41 –50 years, while another

9% of fishers were under the age of twenty and only again just five percent above fifty (Islam et al., 2016). In a different study, the 31-40 age group comprised about 52% (Sidiq et al., 2024).

Earning power among fishers is another indicator of inequality in the economy. In Bangladesh, a four-month study found that most fishers earned below 10,000 BDT ($125) per month. 72%, 16% and only 12% of them annually earned in the group categories:15,000–25,000 BDT; the medium income (25,001–35,000 BDT) and between 35,001–50,000BDT respectively (Rashed-Un-Nabi et al., 2011). While 68.8% sold their catch in local markets, they were largely caught using traditional fishing gears which contributed to the total catch (80 and 20% of Ber jal and Dhormo jal catches, respectively) (Afrad et al., 2019).

On the Shari-Goyain Waterway in Sylhet, fishers used different gears such as gill nets, seine nets, lift nets, cast nets, and hauled nets (Ahmed, 2008; Das et al., 2022). Mono-fiber gill nets, traps (139.48 kg), line nets (66.37 kg), and seine nets (31,130 kg) were the most -preferred with high catches (Njaya, 2007). *Puntius* spp. is another important freshwater cyprinid inhabiting the region with high nutritional values (Gupta, 2015). Nevertheless, environmental hazards threaten species such as *Puntius sarana* which is critically endangered in the lower Ganges region (Sarkar et al., 2012).

Aquatic ecosystems are a prominent highlight of biodiversity studies across Bangladesh. For example, 36% of fish from the Cyclinidae family were recorded from the Bhairab River along with other families namely Bagridae, Channidae, and Mastacembelidae. In Sylhet, other surveys recorded a total of 79 fish species, while the specific Kusiara River has been reported to yield as many as 74 species in one sampling survey and generic sub-basins such as Sylhet-Mymensingh have yielded over 92 species in total across sites within land-use types (Hossain et al., 2009). Nevertheless, these values often are dependent on habitat conditions and the scope of research.

This diversity, the fishing sector in Bangladesh is one of the most affected by issues such as labor shortages, pollution, and habitat destruction due to flooding (Mustafi et al., 2022; Kawsar et al., 2023). These issues should be addressed as awareness raising, skill development, and creation of access to credit programs offered through government offices, and microcredit organizations in northeastern Bangladesh (Hridoy et al., 2021; Sunny et al., 2021; Dey and Ghosh, 2022). Furthermore, there is a lack of comprehensive research on the long-term impacts of habitat destruction and pollution on fish diversity and fisher livelihoods. Addressing this gap requires integrating ecological studies with socio-economic assessments to develop sustainable fisheries management strategies.

Challenges faced by the fishing industry

Insufficient protein intake among fishermen can result in the sale of their catch in local markets to earn a living, with additional income sometimes coming from the sale of two pieces of Snell, Clams, or Oysters for 1.00 Tk. Poor sanitation systems can also negatively impact people's livelihoods. These issues are significant concerns for river stakeholders and can sometimes involve local businesses and vendors. However, the fishermen's passion for fishing not only properly utilizes their time but also engages them in fishing for 4-6 hours daily. Unfortunately, many of their family members lack education due to the difficulties in maintaining their families' needs. Other fishermen have noted that rivers are becoming increasingly polluted, which is affecting their livelihoods and leading to the spread of waterborne diseases (Hridoy et al., 2025). Fisher women often process small, unsold fish to create semifermented fish products, which can serve as an additional source of income. However, they also face challenges related to the local fisheries syndicate, which can limit their ability to harvest open-water fish. In addition, their gear is not always protected, which can result in damage and hinder their ability to fish effectively. Furthermore, the use of chemicals in agricultural lands can lead to the accumulation of toxic sediments in waterways, which can negatively impact fish populations and the livelihoods of fishermen.

CONCLUSION

This study presents important insights into the socio-economic conditions and fish diversity in the Kalni River, underscoring the reliance of small-scale fisheries on traditional methods. The research found that middle-aged male fishers constitute the main workforce, utilizing gear like "Ber jal" to catch small indigenous species such as *Puntius* spp. and *Nandus nandus*. Although these species are commonly found, fish diversity is severely threatened by overfishing, environmental degradation, and inadequate management practices. The socio-economic assessment indicated that fishers encounter several challenges, including low income, seasonal fluctuations in fish availability, and restricted access to modern fishing technologies. These issues have a profound effect on their livelihoods and food security. To tackle these challenges, it is essential to implement collaborative management strategies, which may include the creation of fish sanctuaries, as well as providing financial and technical assistance to fishers. Policymakers must focus on sustainable fishing practices and community-led conservation efforts to safeguard the fish diversity of the Kalni River and enhance the welfare of its fishing communities.

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AUTHORSHIP CONTRIBUTIONS

Md. Abdullah Al Mamun Hridoy**:** Conceptualization, Methodology, Data Analysis. Md. Abdullah Al Mamun Hridoy, Shuvo Saha, Tanvir Ahmed Chowdhury**:** Data Curation, Writing - Original Draft Preparation. Md. Abdullah Al Mamun Hridoy, Puspendu Biswas Paul**:** Visualization, Investigation. Md. Thashin Rahman, Md. Abdullah Al Mamun Hridoy**:** Software, Validation. Kazi Shiam, Md. Mahedee Hasan, Rafi-Ul-Islam, Mohammad Fahim, Abdullah Al Mizan, Tanvin Yeasin Tanay**:** Data Collection, Writing - Reviewing and Editing.

CONFLICT OF INTEREST STATEMENT

The authors declare that they have no known financial or personal conflicts that could have influenced this research.

ETHICS APPROVAL

All human-animal care and experimental procedures were conducted following guidelines set by the Sylhet Agricultural University Ethical Committee Board, which were strictly followed (protocol no. APR2023004).

DATA AVAILABILITY

For any questions regarding the datasets used in this study, please get in touch with the corresponding author.

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RESEARCH ARTICLE ARAŞTIRMA MAKALESİ

Investigation of the effect of various pretreatments on the freeze-drying process of blue mussel (*Mytilus edulis)*

Mavi midyenin (*Mytilus edulis*) dondurularak kurutma işleminde çeşitli ön işlemlerin etkisinin araştırılması

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Abstract: In this study, freeze-drying of blue mussels with various pretreatments was investigated, the effective moisture diffusion value was determined, and mathematical models were applied to the drying data. Pretreatments were applied as: 1- and 5-min ultrasonication (US), 30- and 60-sec blanching (BW), 30- and 60-sec blanching in 10% salt water (BSW); 1- and 5-min osmotic dehydration (OD)in 10% salt water and 1- and 5-min OD in 20% salt water. Blue mussel samples were freeze-dried until the final moisture content dropped below 7%. The OD pretreatment provided the lowest final moisture content, while the BW had the highest final product moisture content. The highest coefficient of determination (R^2), the lowest root mean square error (RMSE), and reduced chi-square (χ^2) values were used to select the most appropriate mathematical model. The best fitting mathematical models were Alibas, Midilli & Kucuk, and two-term exponential.

Keywords: Blue mussel, *Mytilus edulis*, freeze-drying, lyophilization, mathematical modelling

Öz: Bu çalışmada, mavi midyelerin çeşitli ön işlemlerle dondurularak kurutulması incelenmiş, etkin nem difüzyon değeri belirlenmiş ve kurutma verilerine matematiksel modeller uygulanmıştır. Ön işlemler şu şekilde uygulanmıştır: 1 ve 5 dakikalık ultrasonikasyon (US), 30 ve 60 saniyelik haşlama (BW), %10 tuzlu suda 30 ve 60 saniyelik haşlama; %10 tuzlu suda (BSW) 1 ve 5 dakikalık ozmotik dehidratasyon (OD) ve %20 tuzlu suda 1 ve 5 dakikalık OD. Mavi midye örnekleri, son nem içeriği %7'nin altına düşene kadar dondurularak kurutulmuştur. OD ön işlemi en düşük son nem içeriğini sağlarken, BW en yüksek son ürün nem içeriğine sahipti. En uygun matematiksel modeli seçmek için en yüksek belirleme katsayısı (R^2), en düşük ortalama karekök hatası (RMSE) ve indirgenmiş ki-kare (χ^2) değerleri kullanılmıştır. En iyi uyum sağlayan matematiksel modeller Alibas, Midilli & Küçük ve iki terimli üstel'dir.

Anahtar kelimeler: Mavi midye, *Mytilus edulis*, dondurarak kurutma, liyofilizasyon, matematiksel modelleme

INTRODUCTION

Drying is a crucial process in food preservation, involving the removal of moisture from substances to prevent spoilage. The primary cause of food deterioration over time is its moisture content, which fosters microbial growth and enzymatic activity. By reducing moisture to specific levels, the shelf life of foods can be significantly extended through drying processes (Dweh et al., 2024). Drying methods are broadly classified into two categories: traditional and modern. Among traditional methods, sun drying has been practiced for centuries, especially during summer months, to preserve fruits such as apples, plums, and pears for off-season consumption. However, traditional methods like sun drying have notable drawbacks, including losses in shape, color, and overall product quality. Incomplete drying can also lead to microbial growth, resulting in spoilage or mold formation (Calín-Sánchez et al., 2020; Bachir Bey et al., 2017). Modern drying techniques have evolved to address these limitations, incorporating specialized equipment to enhance efficiency and product quality (Kovacı and Dikmen, 2018). Freeze-drying, or lyophilization, is one of the most advanced modern drying techniques. This method involves freezing the moisture in the material and subsequently removing it via sublimation at low temperatures and pressures. Freeze-drying produces high-quality products, preserving the color, texture, and nutritional content of the food (Li et al., 2023).

Seafoods, such as mussels, squid, crabs, and various fish species, are nutritionally valuable due to their high protein content and essential nutrients. Blue mussels (*Mytilus edulis*), also known as European mussels, are an excellent source of omega-3 fatty acids, zinc, folate, and other essential vitamins such as C and A. Mussels are highly sustainable to cultivate and have minimal environmental impact, making them an important and eco-friendly food source. They provide 26% of daily protein and 22% of daily iron requirements while being sugar-free (Murphy et al., 2019).

Like many marine organisms with high moisture content, drying is essential to stabilize the biochemical properties of mussels. Many sea creatures such as squid, crab, shrimp, sea cucumber, and fish species have been widely studied in the literature. Seafood can be dried naturally in coastal areas in a cost-effective traditional way. However, this method is highly dependent on weather conditions such as temperature and humidity, which can significantly affect the drying rate and the

final product quality (Azmi et al., 2024). Apart from natural methods, many studies have aimed to improve drying processes with different pretreatments and dryer types. For example, microwave, infrared, oven, and vacuum oven drying of squid with ultrasonication pretreatment (Ozyalcin and Kipcak, 2021, 2022), oven and vacuum oven of brown crab meat with blanching pretreatment (Özyalçın and Kıpçak, 2023a), and vacuum microwave drying of tilapia fish with osmosis dehydration pretreatment (Wang et al., 2019) have been studied. There are also some studies conducted on the drying of blue mussels using microwaves (Kipcak, 2017), oven and vacuum oven (Özyalçın and Kıpçak, 2023b), cabinet-type dryer (Kıpcak et al., 2021), and black mussels using an ultrasound-assisted vacuum oven (Kocabay, 2021).

Dried seafood can be enjoyed as a standalone snack or incorporated into various dishes. Among the drying processes, freeze drying, which provides the highest preservation of the nutritional value of the food, is among the preferred methods. Mussels, a popular choice among these seafood products, are generally consumed by seasoning with salt or umami flavors. To address the lack of information in the literature, this study was designed to investigate the effect of ultrasonication, blanching, and osmotic dehydration effects on the freeze-drying of blue mussels and the compatibility of the drying data with well-known mathematical models. In the design of pretreatments, the methods preferred in the literature for similar products were enhanced with the salt addition meeting the final consumption habits.

MATERIALS AND METHODS

Sample preparation

Blue mussels were bought frozen from a local market in Istanbul, Türkiye in May 2023. The supplied products were kept in the FLV-1003 model (Flavel, Eskisehir, Türkiye) deep freezer at -20°C ± 2 °C until the experiments started and were allowed to thaw in the +4°C refrigerator for 2 hours before the experiments. Mussels were weighed approximately 10 ± 0.1 g for every drying step using a Radwag AS 220.R2 digital balance (Radwag, Radom, Poland). The moisture content was determined using a KH-45 hot air-drying oven (Kenton, Guangzhou, China) at 105°C for 4 hours (AOAC, 2005). Ultrasonic pretreatment was carried out with the Isolab Water Bath with 1°C sensitivity and 120 W ultrasonic power (Isolab, Germany) and the freeze-drying was completed in a Labart LFD-10N standard-type freeze dryer with a cold trap temperature of -56/-80 °C (ART Laborteknik, Istanbul, Türkiye). Refined iodized table salt (Billur Tuz, Izmir, Turkey) was used as salt addition in pretreatments (salt content: E536, potassium iodate 3.5/100g).

Drying experiment

Blue mussel samples weighed 10.0 ± 0.1 g for 11 experiment sets including control, ultrasonication, blanching, and osmotic dehydration pretreatments. Ultrasonication (US) pretreatments were applied for 1 min (1 min US) and 5 min (5 min US) with 1:10 (w:v) deionized water. Blanching (BW) pretreatments were applied for 30 seconds (30 sec BW) and 60 seconds (60 sec BW) with 1:10 (w:v) deionized water at 90 °C. Blanching in salt water (BSW) pretreatments were applied for 30 seconds (30 sec BSW 10%) and 60 seconds (60 sec BSW 10%) with 1:10 (w:v) deionized water with 10% salt at 90 °C. Osmotic dehydration (OD) pretreatments were applied for 1 min (1 min OD 10%) and 5 min (5 min OD 10%) with 1:10 (w:v) deionized water with 10% salt, and 1 min (1 min OD 20%) and 5 min (5 min OD 20%) with 1:10 (w:v) deionized water with 20% salt. After pre-treatment, the samples were gently drained of excess water and immediately transferred to the freeze-dryer. During freeze-drying, the vacuum of the dryer was switched off at 60-minute intervals and the samples were weighed in less than 2 min, placed back into the dryer, and the vacuum was switched on. The absence of thermal exposure during the freeze-drying process ensures that the pores of the samples are more open and absorb moisture faster than in heat-treated samples. To allow for longer storage of the dried samples, the target final moisture content was reduced from 10% to 7%, taking into account the moisture uptake after drying until packaging under vacuum. When the final moisture content of the samples reached 7%, the drying process was terminated, and the samples were packed under vacuum.

Mathematical modeling and regression analysis

Predicting drying kinetics, mathematical models facilitate the analysis of transport phenomena during drying processes. These phenomena include internal and external heat transfer, as well as mass transfer, which are critical for understanding the dynamics of moisture removal (da Conceição Silva et al., 2012).

The moisture content (M) and moisture ratio (MR) contained in the blue mussel are calculated using Equations (1) and (2). M, given in equation (1), refers to the amount of moisture (kg water/kg dry matter), m_w refers to the amount of water in the sample (kg), and m_d refers to the amount of dry matter (kg) (Kipcak et al., 2019).

$$M = \frac{m_w}{m_d} \quad (1)$$

Moisture ratio (MR), a dimensionless number calculated by equation (2) using M_t, M_e, and M_0 (Kipcak et al., 2019):

$$MR = \frac{M_t - M_e}{M_0 - M_e} \quad (2)$$

Where M_t is the moisture content at any drying time, M_e is the equilibrium moisture content and M_0 is the initial moisture content (kg water/kg dry matter), respectively. The M_e value is usually very small, which is neglected in calculations. The non-linear regression studies were done using the Levenberg-Marquardt algorithm to analyze experimentally acquired drying data using Statistica 8.0 (StatSoft Inc., Tulsa, USA) software package. To test which mathematical model fits the data better, Aghbashlo et al., Alibas, Jena & Das, Lewis, Logarithmic, Midilli & Kucuk, Page, Parabolic, Wang & Singh, Two Term Exponential models whose formulae are given in Table 1 were

evaluated were evaluated (Ozyalcin et al., 2023). The best fitting model for the data sets was evaluated using the coefficient of determination (R^2), root mean square error (*RMSE*), and reduced chi-square (χ^2) values, selecting the higher R^2 values and lower values for χ^2 and *RMSE*. Equations for these parameters can be seen in following Equation (3), (4) and (5) (Kipcak et al., 2019).

$$R^2 \equiv 1 - \frac{\sum_{i=1}^{N}\left(MR_{exp,i} - MR_{pre,i}\right)^2}{\sum_{i=1}^{N}\left(MR_{exp,i} - \left(\frac{1}{n}\right)\sum_{i=1}^{N} MR_{exp,i}\right)} \quad (3)$$

$$\chi^2 = \frac{\sum_{i=1}^{N}\left(MR_{exp,i} - MR_{pre,i}\right)^2}{N - z} \quad (4)$$

$$RMSE = \left(\frac{1}{N}\sum_{i=1}^{N}\left(MR_{exp,i} - MR_{pre,i}\right)^2\right)^{\frac{1}{2}} \quad (5)$$

where N represents the number of the total experiments, MR_{exp} and MR_{pre} represent experimental and predicted values for moisture ratios respectively and z is the number of constants in the model used for evaluation.

Table 1. Mathematical Model Equations (Ozyalcin and Kipcak, 2022; Kipcak and İsmail, 2021)

Name	Model equation
Aghbaslo et al.	$MR = exp(-k_1t/(1 + k_2t))$
Alibas	$MR = a.exp((-kt^n) + bt) + g$
Jena and Das	$MR = a.exp(-kt + b\sqrt{t}) + c$
Lewis	$MR = exp(-kt)$
Logarithmic	$MR = a.exp(-kt) + c$
Midilli and Kucuk	$MR = a.exp(-kt^n) + bt$
Page	$MR = exp(-kt^n)$
Parabolic	$MR = a + bt + ct^2$
Wang and Singh	$MR = 1 + at + b\,t^2$
Two-Term Exponential	$MR = a.\ exp(-kt) + (1-a).\ exp(-kat)$

*a, b, c, g, coefficients; and n, drying exponent specific to each equation; k, k_0, k_1, k_2, drying coefficient specific to each equation; t, time (min).

Effective moisture diffusivity (D_{eff}) is a critical parameter in the drying process, influencing the rate at which moisture is removed from materials. It characterizes the intrinsic mass transport properties of moisture, including various mechanisms such as molecular diffusion, liquid diffusion, vapor diffusion, and hydrodynamic flow. D_{eff} value varies with several factors, including temperature, moisture content, and the physical properties of the material being dried. As moisture is removed, the diffusion rate tends to decrease, particularly in the later drying when the moisture content is lower. This phenomenon has been observed in studies on various agricultural products, where the drying rate is initially high but slows down significantly as the moisture approaches equilibrium (Bakal et al., 2012). D_{eff} in foodstuffs can be calculated based on Fick's second law of diffusion as given in equation (6) (Sacilik et al., 2006). The slope of the time versus the ln (MR) can also be used to calculate D_{eff} (Kipcak and Doymaz, 2020).

$$\ln(MR) = \ln\left(\frac{6}{\pi^2}\right) - \left(\pi^2 \frac{D_{eff} \times t}{R^2}\right) \quad (6)$$

RESULTS

As a result of the moisture analysis, the moisture content of the raw blue mussel was 71.89% wet basis and 2.5577 kg water / kg dry matter (kg W/kg DM). Moisture analysis was also carried out after each pretreatment to determine how much moisture the samples gained or lost during the pretreatments. Moisture analysis results are given in Table 2.

Table 2. Moisture analysis results of blue mussels

Sample	Moisture (% wet basis)	Moisture intake (% wet basis)	Moisture (kg W/kg DM)	Moisture intake (kg W/kg DM)
Control	71.89	-	2.5577	-
1 min US	74.44	2.55	2.9122	0.3545
5 min US	74.27	2.38	2.8871	0.3294
30 sec BW	69.41	-2.48	2.2692	-0.2885
60 sec BW	69.89	-2.00	2.3209	-0.2368
30 sec BSW 10%	66.26	-5.63	1.9643	-0.5934
60 sec BSW 10%	66.34	-5.55	1.9710	-0.5867
1 min OD 10%	71.09	-0.80	2.4589	-0.0988
5 min OD 10%	71.17	-0.72	2.4687	-0.0890
1 min OD 20%	68.30	-3.59	2.1543	-0.4034
5 min OD 20%	67.94	-3.95	2.1195	-0.4382

Figure 1 shows the samples before and after drying. The freeze-drying process was completed in 420 minutes for control, 1 min US, 5 min US, 30 sec BW, and 60 sec BW samples, and the final moisture contents for these samples were obtained as 0.1700, 0.1956, 0.2069, 0.1075, and 0.1620 kg water/kg dry matter, respectively. The drying time was shortened by 120 minutes with BSW treatment and completed in 300 minutes and the final moisture contents were 0.1956 and 0.2069 kg water/kg dry matter for 1 min BSW 10% and 5 min BSW 10%, respectively. Drying time increased to 480 minutes with the OD 10% pretreatment and the final moisture content was 0.1224 and 0.1092 kg water/kg dry matter for 1 min OD 10% and 5 min OD 10%, respectively. Drying took 360 minutes with the 1 min OD 20% process and 420 minutes with the 5 min OD 20% and the final moisture content was 0.1056 and 0.0763 kg water/kg dry matter, respectively.

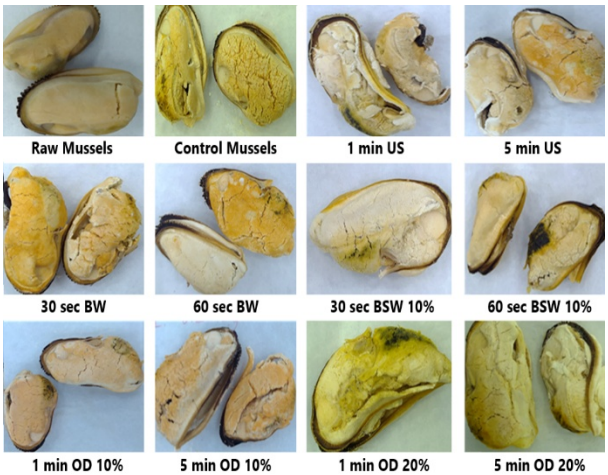

Figure 1. Raw and freeze-dried blue mussels

The drying curves of mussel samples are given in Figures 2 and 3. Among the pretreatments used, the initial moisture content of only US samples increased, as indicated in Table 2 and Figure 3. The US samples had the highest initial drying rate because of this increase. Although the drying profile of the 5 min US sample was faster than the 1 min US, the drying time remained the same. Aside from the US samples the initial moisture content of all pretreated samples have decreased. The samples that had the highest initial drying rate following the control sample were 1 min OD 10%, 5 min OD 10%, 30 sec BW, 60 sec BSW 10%, 1 min OD 20%, 60 sec BW, 5 min OD 20%, 30 sec BSW 10%, respectively.

The D_{eff} values calculated from equation (6), based on Fick's second law of diffusion, are 9.48×10^{-9}, 9.30×10^{-9}, 9.30×10^{-9}, 1.03×10^{-8}, 9.21×10^{-9}, 1.31×10^{-8}, 1.35×10^{-8}, 8.85×10^{-9}, 9.48×10^{-9}, 1.20×10^{-8}, and 1.14×10^{-8} for control, 1 min US, 5 min US, 30 sec BW, 60 sec BW, 1 min BSW 10%, 5 min BSW 10%, 1 min OD 10%, 5 min OD 10%, 1 min OD 20% and 5 min OD 20%, respectively.

Mathematical modeling and regression analysis results

The weight change data of blue mussels against time were used in the mathematical modeling of the drying process. Among the models tested to find the best-fitted model, the models with the highest R^2 and the lowest χ^2 and RMSE values were determined as Alibas, Midilli & Kucuk, and Two-Term Exponential, respectively.

The Alibas model was the best fitting model with an R^2 value of > 0.9998 in all models except 1 min OD 10%. However, the drying data of the 1 min OD 10% sample showed the highest agreement with Midilli & Kucuk with an R^2 value of 0.999965. The model coefficients for these three models are given in Table 3 for control, US, and BW samples and Table 4 for BSW and OD samples.

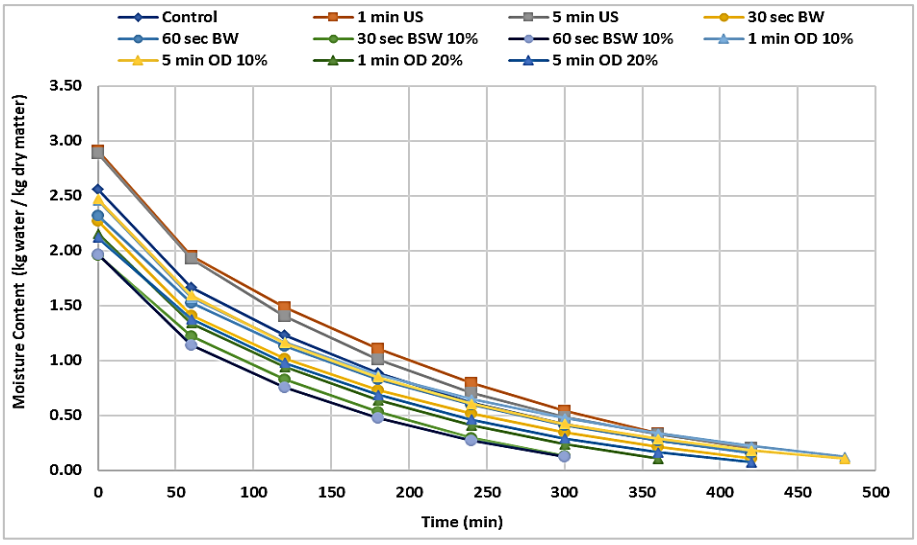

Figure 2. Moisture content versus time curves of freeze-drying blue mussels

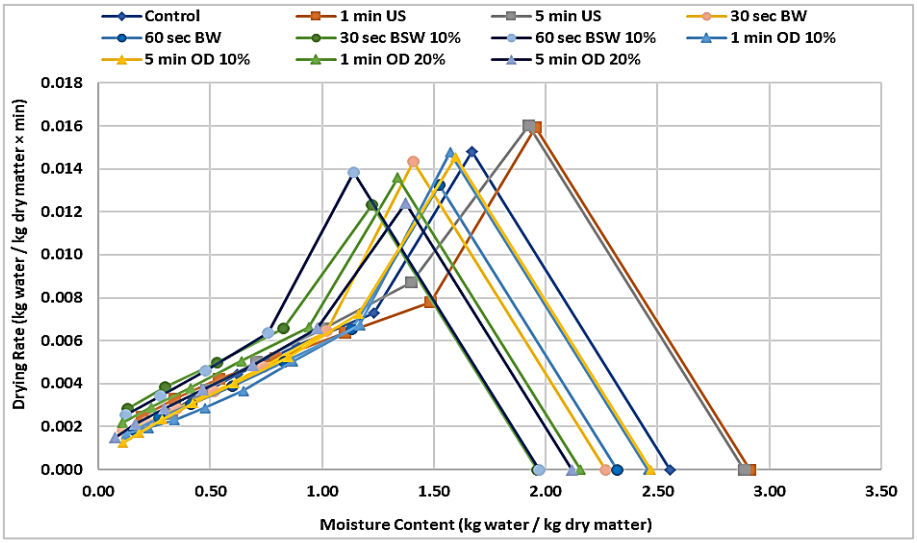

Figure 3. Drying rate versus moisture content curves of freeze-drying blue mussels

Table 3. Best-fitted model coefficients and statistical data for control, US, and BW

Model	Parameter	Control	1 min US	5 min US	30 sec BW	60 sec BW
Alibas	a	3.248950	2.098930	3.163730	1.645268	2.855050
	k	0.006080	0.009090	0.005300	0.016681	0.007480
	n	0.763900	0.729580	0.805320	0.681940	0.729720
	b	0.001320	0.000400	0.001530	0.000243	0.000900
	g	-2.249550	-1.099570	-2.164030	-0.645442	-1.855320
	R^2	0.999868	0.999802	0.999967	0.999975	0.999962
	χ^2	0.000031	0.000046	0.000008	0.000006	0.000009
	RMSE	0.003421	0.004164	0.001704	0.001485	0.001815
Midilli & Kucuk	a	0.999239	0.999331	0.999379	0.999743	0.999588
	k	0.014529	0.016187	0.011430	0.023216	0.016761
	n	0.808480	0.756242	0.859007	0.721842	0.768525
	b	-0.000204	-0.000355	-0.000145	-0.000280	-0.000260
	R^2	0.999704	0.999712	0.999849	0.999936	0.999890
	χ^2	0.000052	0.000050	0.000027	0.000011	0.000019
	RMSE	0.999852	0.005017	0.003656	0.002385	0.003085
Two Term Exponential	a	0.063696	12.478400	10.428560	0.899064	0.071323
	b	0.301166	0.006400	0.005970	0.005909	0.301865
	k_0	0.936304	-11.491900	-9.439310	0.100936	0.928677
	k_1	0.005730	0.006500	0.005970	0.309619	0.005489
	R^2	0.998730	0.995947	0.998587	0.998073	0.998438
	χ^2	0.000225	0.000708	0.000250	0.000344	0.000271
	RMSE	0.010602	0.018820	0.011185	0.013121	0.011633

Table 4. Best-fitted model coefficients and statistical data for BSW and OD samples

Model	Parameter	30 sec BSW 10%	60 sec BSW 10%	1 min OD 10%	5 min OD 10%	1 min OD 20%	5 min OD 20%
Alibas	a	1.370804	2.368910	0.362200	2.388490	3.058140	3.007880
	k	0.013105	0.012840	476.896100	0.008940	0.007840	0.006310
	n	0.776947	0.690390	0.010000	0.741240	0.729290	0.778970
	b	-0.000065	0.000680	-0.001300	0.000900	0.001060	0.001300
	g	-0.370936	-1.368960	0.637800	-1.388740	-2.058350	-2.008130
	R^2	0.999961	0.999989	0.977765	0.999979	0.999959	0.999981
	χ^2	0.000023	0.000007	0.004206	0.000004	0.000014	0.000005
	RMSE	0.001969	0.001055	0.043234	0.001355	0.001973	0.001346
Midilli & Kucuk	a	0.999856	0.999916	0.999801	0.999375	0.999716	0.999489
	k	0.016078	0.024789	0.021834	0.015491	0.018615	0.013348
	n	0.797847	0.733766	0.724848	0.803518	0.770503	0.833712
	b	-0.000512	-0.000452	-0.000204	-0.000147	-0.000362	-0.000230
	R^2	0.999946	0.999969	0.999966	0.999851	0.999899	0.999876
	χ^2	0.000016	0.000009	0.000005	0.000024	0.000023	0.000023
	RMSE	0.002324	0.001770	0.001692	0.003617	0.003116	0.003423
Two Term Exponential	a	-0.008500	0.060858	0.118894	0.916592	0.956947	0.027875
	b	1.000000	0.291881	0.388369	0.005627	0.006846	0.591097
	k_0	1.008500	0.939142	0.881106	0.083408	0.043053	0.972125
	k_1	0.007673	0.007805	0.005180	0.395296	0.282363	0.006409
	R^2	0.996468	0.997743	0.998848	0.999043	0.997052	0.997408
	χ^2	0.001053	0.000675	0.000174	0.000108	0.000659	0.000491
	RMSE	0.018734	0.015000	0.009841	0.009172	0.016809	0.015668

DISCUSSION

The results obtained in this study are intended to provide a detailed understanding of moisture dynamics, drying efficiency, and mathematical modeling of the drying process in the freeze-drying of blue mussels. Raw blue mussels with high moisture content were subjected to US, BW, BWS, and OD pretreatments, which resulted in changes in their initial and final moisture content and drying behavior. US increased the initial moisture content due to water absorption during pretreatment and although it accelerated the initial moisture removal, it did not significantly affect the overall drying time. While drying times remained the same with BW, BSW shortened the drying time. This is probably due to the osmotic effects of brine, which increases water transit through the tissue. BSW samples also exhibited lower final moisture content compared to the control, reflecting the effectiveness of BSW. OD caused different effects on drying times but resulted

in the lowest final moisture content of the samples. The drying studies of blue mussels in the literature were examined, and the microwave, infrared, cabinet dryer, oven, and vacuum oven results are summarized in Table 5 along with the results obtained with a freeze-dryer. The D_{eff} values obtained in freeze-drying mussels are in accordance with the literature, and the range of 10^{-12} to 10^{-8} was obtained in the literature for the drying of foodstuffs (Doymaz, 2012).

Table 5. Comparison of literature on mussel drying

Dryer Type	Drying Condition	Duration (min)	D_{eff} (m^2/s)	Mathematical Model	Reference
Microwave	90 W	16	2.74×10^{-8}	Weibull ($R^2 > 0.998135$)	Kipcak, 2017
	180 W	5	1.00×10^{-7}		
	360 W	2	2.32×10^{-7}		
	600 W	1.33	3.75×10^{-7}		
	800 W	1	4.79×10^{-7}		
	140 W	13	1.22×10^{-7}	Alibas ($R^2 > 0.999732$)	Sevim et al., 2023
	210 W	7.5	2.33×10^{-7}		
	350 W	4.5	3.91×10^{-7}		
Infrared	88 W	110	4.24×10^{-9}	Midilli and Kucuk ($R^2 > 0.999150$)	Kipcak et al., 2019
	104 W	80	6.29×10^{-9}		
	125 W	55	9.50×10^{-9}		
	146 W	45	1.10×10^{-8}		
	60 °C	405	4.23×10^{-9}	Alibas ($R^2 > 0.999886$)	Sevim et al., 2019
	70 °C	255	7.00×10^{-9}		
	80 °C	165	1.17×10^{-8}		
Cabinet Dryer	60 °C	270	1.89×10^{-9}	Midilli and Kucuk ($R^2 > 0.9984$)	Kipcak et al., 2021
	70 °C	180	3.05×10^{-9}		
	80 °C	120	4.94×10^{-9}		
Oven	60 °C	570	0.89×10^{-9}		
	70 °C	390	1.25×10^{-9}		
	80 °C	300	1.63×10^{-9}		
Vacuum Oven	60 °C	390	1.17×10^{-9}		
	70 °C	270	1.68×10^{-9}		
	80 °C	210	2.28×10^{-9}		
Freeze Dryer	Control	420	9.48×10^{-9}	Alibas ($R^2 > 0.9998$)	This study
	1 min US	420	9.30×10^{-9}		
	5 min US	420	9.30×10^{-9}		
	30 sec BW	420	1.03×10^{-8}		
	60 sec BW	420	9.21×10^{-9}		
	1 min BSW 10%	300	1.31×10^{-8}		
	5 min BSW 10%	300	1.35×10^{-8}		
	1 min OD 10%	480	8.85×10^{-9}	Midilli & Kucuk ($R^2 = 0.999966$)	
	5 min OD 10%	480	9.48×10^{-9}	Alibas ($R^2 > 0.9999$)	
	1 min OD 20%	360	1.20×10^{-8}		
	5 min OD 20%	420	1.14×10^{-8}		

According to the literature, D_{eff} values in freeze drying are consistent with the other methods that reported for dried seafood. In the compatibility of freeze-drying data with mathematical models, it was determined that the Alibas model was the best model which explains almost all the drying processes according to the statistical parameters examined. According to Table 5, which summarizes the drying of mussels with various dryers, the mathematical models of Alibas and Midilli & Kucuk are the models with the highest agreement for microwave, infrared, cabinet dryer, oven, and vacuum oven drying. This shows that the mathematical models developed by Alibas and Midilli & Kucuk are the first models to be evaluated for blue mussel drying.

CONCLUSION

The drying kinetics and mathematical modeling of freeze-dried blue mussels that underwent osmotic dehydration, blanching, and ultrasonication pretreatments were examined in this study. The drying findings showed that blanching in 10% salt water shortened the drying time by 120 minutes, but osmotic dehydration in 10% salt water prolonged it by 60 minutes. According to this result, the use of salt in pre-treatment can shorten the drying time when supported by heat, while it can prolong the drying time when heat is not supplied. At 20% salt concentration, the drying time decreased at 1-min pretreatment and increased at 5-min. The underlying condition may be that the salt molecules migrated into the pores of the sample with the prolongation of the treatment time, causing blockages and slowing down the drying. The final moisture contents for the pretreatments and control samples were found to be relatively close to one another. With R^2 values ranging from 0.999868 to 0.999981, Alibas was found to be the ideal

mathematical model in the test of fitting the drying data with mathematical models. The calculated D_{eff} values ranged from 1.35×10^{-8} m²⁄s – 8.85×10^{-9} m²⁄s. After drying, no visible degradation was seen in any of the samples. The results showed that blanching the sample with salt water was a more efficient way to accelerate the drying process than alternative pretreatments. How drying kinetics are affected by variations in pretreatment temperatures and durations should be investigated in the future.

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AUTHORSHIP CONTRIBUTIONS

All authors contributed to the idea and design of the study. Material preparation and investigation were performed by Nurgül Alp and Azmi Seyhun Kipcak. The writing/editing was carried out by Nurgül Alp and Zehra Ozden Ozyalcin, and all authors have read and approved the article.

CONFLICTS OF INTEREST

The authors declare that there are no conflicts of interest or competing interests.

ETHICS APPROVAL

No specific ethical approval was necessary for the study.

DATA AVAILABILITY

For any questions, the corresponding author should be contacted.

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RESEARCH ARTICLE ARAŞTIRMA MAKALESİ

Fuel efficiency of trawlers per kilogram of landed catch: Insights for decarbonizing fisheries in Türkiye

Trol teknelerinin karaya çıkarılan bir kilogram av başına akaryakıt verimliliği: Türkiye'de balıkçılığın karbonsuzlaştırılmasına yönelik çıkarımlar

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Abstract: Demersal trawling is among the most energy-intensive fishing practices worldwide, primarily due to the drag and frictional force caused by their heavy components. This study aimed to estimate fuel use intensity (litres of fuel per kilogram of landed catch) and associated carbon dioxide emissions of Turkish trawl vessels, most of which still operate using traditional trawl nets equipped with heavy otter boards and lead ground gear, increasing towing resistance and consequently fuel consumption. Data from 129 commercial fishing trips conducted by 13 trawl vessels between 2021 and 2022 were analysed using Generalized Linear Models (GLMs). Overall, to catch one kg of landed marine product, the trawl vessels consumed approximately a median value of 1.22 litres of fuel and emitted 3.21 kg of CO_2 for the given period. Vessel length, engine power and the target species group were the main factors affecting the fuel use intensity. The results obtained from the study provide critical insights for implementing effective management measures to decarbonize fisheries, offering practical recommendations for decision makers. Expanding the dataset to encompass a broad range of vessels, regions, and fishing seasons would further enhance the generalizability and applicability across different fisheries.

Keywords: Energy use, low-impact-fuel-efficient fishery, carbon footprint

Öz: Dip trolleri, ağır bileşenlerinden kaynaklanan sürükleme direnci ve sürtünme kuvveti nedeniyle dünyanın en yoğun enerji tüketen balıkçılık yöntemlerinden biridir. Bu çalışma, çoğu hala çekme direncini ve yakıt tüketimini artıran ağır kapılar ve kurşun yakalarla donatılmış geleneksel trol ağlarıyla çalışan Türk trol teknelerinin yakıt kullanım yoğunluğunu (karaya çıkarılan bir kilogram av başına kullanılan yakıt) ve ilgili karbondioksit emisyonlarını tahmin etmeyi amaçlamıştır. 2021-2022 yıllarında 13 trol teknesiyle gerçekleştirilen 129 ticari balıkçılık seferinden elde edilen veriler Genelleştirilmiş Doğrusal Modeller kullanılarak analiz edilmiştir. Genel olarak, bir kilogram deniz ürünü avlamak için medyan değeri yaklaşık 1,22 litre yakıt tüketilmiş ve söz konusu dönemde 3,21 kg CO_2 salınmıştır. Tekne boyu, motor gücü ve hedeflenen tür grubu, yakıt kullanım yoğunluğunu etkileyen başlıca faktörler olarak belirlenmiştir. Mevcut çalışma, balıkçılık sektörünün karbonsuzlaştırılması için etkili yönetim önlemlerinin uygulanmasına yönelik kritik bilgiler sağlayarak karar alıcılar için pratik öneriler sunmaktadır. Daha geniş filo, farklı bölgeler ve balıkçılık sezonlarını kapsayacak şekilde veri setinin genişletilmesi, elde edilen sonuçların genellenebilirliğini ve farklı balıkçılıklarda uygulanabilirliğini daha da geliştirecektir.

Anahtar kelimeler: Enerji kullanımı, düşük-etkili-yakıt-tasarruflu balıkçılık, karbon ayak izi

INTRODUCTION

The environmental impact of fuel consumption in the fishing industry has become a critical concern due to increasing consumer awareness and efforts to combat climate change. Bottom trawling, a widely used fishing method, is particularly scrutinized for its high fuel use, greenhouse gas (GHG) emissions, and potential disturbance of seabed sediments, which may release additional carbon into the ocean (Sala et al., 2021; Hilborn et al., 2023). While bottom trawls contribute to approximately 26% of global marine catches and support millions of livelihoods (Steadman et al., 2021), they are also recognized as one of the most fuel-intensive fishing methods due to the drag and friction caused by heavy gear components (Tyedmers, 2001; Suuronen et al., 2012; Sala et al., 2022). Such fishing practices naturally result in remarkably higher GHG emission (Winther et al., 2020; Ziegler et al., 2021).

Previous research on fuel consumption per kilogram of landed marine product has been instrumental in assessing the carbon footprint of the fisheries sector and providing insights into energy efficiency and sustainability (Ziegler and Hansson, 2003; Thrane, 2004; Campos et al., 2011; Parker et al., 2017; Bastardie et al., 2022). According to those studies, fuel consumption in fisheries varies based on several factors, including vessel length, engine power, fishing gear type, target species, catch per unit effort, and operational characteristics such as distance travelled and towing speed (Davie et al., 2014; Parker et al., 2017; Kristofersson et al., 2021). Using different methods, global studies have found that the amount of fuel used in fisheries ranges from 0.44 to 1.7 $tFuel \cdot tCatch^{-1}$ (Tyedmers et al., 2005; Parker et al., 2018; Greer et al., 2019). Despite technological advancements aimed at improving energy efficiency—such as modifications to gear design and vessel operations—fuel consumption trends in some regions have increased over time(Hornborg et al., 2018).

In Türkiye, bottom otter trawling is a key component of the

multispecies fishery, targeting high-value demersal species such as red mullet (*Mullus barbatus*), whiting (*Merlangius merlangus*), hake (*Merluccius merluccius*), and deep-water shrimps (*Parapenaeus longirostris, Aristaeomorpha foliacea, Aristeus antennatus*). However, studies on fuel consumption in the Turkish fishing fleet remain limited, despite the fleet's diverse fishing grounds and gear configurations. Most Turkish trawl vessels still operate using traditional Mediterranean trawl nets with heavy otter boards and lead ground gear, increasing towing resistance and fuel intensity. The impact of towing resistance created by such equipment during a fishing operation has significant implications for fuel use intensity, highlighting a significant knowledge gap. While some research has examined fuel use in purse seine and bottom trawl fisheries in specific regions (Demirci and Karaguzel, 2018; Sarica and Demir, 2021), a comprehensive assessment of fuel consumption and its determinants in Turkish bottom trawl fisheries is lacking. Nevertheless, recent studies have begun to shed light on different fishing gears, emphasizing their efficacy, such as utilizing artificial intelligence based models to predict the power of the main engine and the pollutants emitted by fishing vessels (Ozsari, 2023) or modifying beam trawls to improve fuel efficiency in the southern Black Sea sea snail (*Rapana venosa*) fishery (Kaykaç et al., 2017).

This study investigates the key determinants of fuel use intensity in Turkish trawl vessels, focusing on vessel length, engine power, and target species. By providing estimates of fuel consumption and associated CO_2 emissions, this research aims to contribute to the optimization of fishing operations and support a more sustainable and energy-efficient trawl fishery. Specifically, the research questions addressed are as follows:

- What are the key factors influencing fuel use intensity in Turkish bottom trawl fisheries?
- How do vessel characteristics, such as length and engine power, impact fuel consumption?
- What is the relationship between target species composition and fuel use efficiency in Turkish trawl fisheries?

MATERIALS AND METHODS

Collection of landed catch and fuel consumption data

The landed catch and fuel use (litre per hour) data during the fishing operations were obtained from otter trawl vessel owners and/or captains who record their catch data systematically and precisely. To ensure accuracy, the catch and fuel consumption values were cross-checked against available fuel logs and, when possible, compared with the standardized questionnaires conducted by fisheries observers under the discards monitoring program. This study was based on 13 trawl vessels that were regularly monitored through phone call interviews during 2021 and 2022. The sample size was determined by data availability, operational constraints, and the willingness of vessel owners to participate. While this sample provides valuable insights into fuel use intensity in Turkish trawl fisheries, a larger dataset would enhance the generalizability of the findings. The commercial fishing trips were conducted in three different sub-geographical areas (GSAs); GSA 22 (Aegean Sea), GSA 24 (Levant Sea) and GSA 29 (Black Sea).

Data analysis

Each fishing trip was classified as fish or shrimp targeted depending on the main target species that were composed of mainly shrimp or fish. The amount of fuel consumed per kg of landed catch (FUI) was estimated in two steps. First the average fuel consumption per hour data was multiplied by total tow duration in each fishing trip by using Eq. (1):

$$\mathrm{fTRIP} = hFUEL\ [\mathrm{l}] \times TD_j\ [\mathrm{h}] \quad (1)$$

where *hFUEL* is the fuel use (litre) per hour, which was obtained from fishers and *TD* represents the total tow duration in a single fishing trip *j*.

Subsequently, the amount of fuel consumed for each fishing trip (*fTRIP*) that was obtained from Eq. (1) was divided by the total landed catch in each fishing trip by using Eq. (2):

$$\mathrm{FUI} = fTRIP_j\ [kg] \,/\, TW_j\ [\mathrm{h}] \quad (2)$$

where TW_j is the total weight of landed catch in a single fishing trip *j*.

To calculate the carbon dioxide emission, the method applied by Sala et al. (2022) was employed, assuming that the total amount of CO_2 released when burning one litre of diesel was reported as 2640 g. However, in this study, only the fuel consumption during active fishing (tow time) was considered, excluding time spent before and after capture. Using the fuel consumed per one kg of marine product, which was calculated by Eq. (2), the catch related CO_2 emission was estimated by Eq. (3):

$$\mathrm{cGHG}\left[kg_{ghg}/kg_c\right] = \mathrm{FUI} \times 2640\ g/l \times 10^{-3} \quad (3)$$

Generalized linear model

A GLM was performed using the MASS package (Venables and Ripley, 2002). The goal of this analysis was to build a model that could explain the relationship between the fuel consumption per one kg of landed catch (response variable) and vessel length (explanatory variable), engine power (explanatory variable) and targeted group of species (explanatory variable), either fish or shrimp. Since there was no shrimp fishery in the Black Sea, the data obtained from GSA 29 was not included in the model. To assess multicollinearity among the explanatory variables, a Variance Inflation Factor (VIF) test was performed. Any explanatory variable with a VIF value exceeding a threshold would indicate problematic collinearity. In such cases, the variable was excluded from the model to ensure that the relationships between the remaining

variables were not confounded. For the logistic regression model, family = Gamma distribution was employed as this distribution was suitable for variables having highly skewed positive values. The model with the lowest Akaike's information criterion (AICc) was chosen (Akaike, 1974). DHARMa package containing quantile–quantile plot, residual investigation, and dispersion test was performed to assess whether the chosen model fits (Hartig, 2020; Araya-Schmidt et al., 2022). All statistical analyses and visualizations were performed in R (R Core Team, 2018).

RESULTS

Engine power and size of the trawl vessels investigated in the study were 316.2 kw and 17.0 m in length on average (Table 1). According to data provided by the trawlers, the average fuel consumed during a fishing operation provided by vessel owners was 30.3 l h^{-1} on average (Table 1). No correlation was detected between vessel lengths and engine powers (0.13, Figure 1).

Table 1. Technical specifications and fuel consumption per hour of the investigated trawl vessels (Values in parentheses are the 95% CI)

No. Trawl Vessels	LOA (m) 17.0 [14.7-19.4]	Engine Power (kW) 316.2 [272.5-359.8]	Fuel Consumption (l h^{-1}) 30.3 [24.87-35.75]
1	16.8	320.8	45.0
2	14.9	447.8	40.0
3	17.3	368.9	40.0
4	19.7	373.1	38.0
5	20.8	335.8	35.0
6	19.9	313.3	35.0
7	14.9	298.5	25.0
8	14.0	212.7	25.0
9	12.2	186.5	22.0
10	14.3	335.8	20.0
11	18.2	335.8	20.0
12	12.6	223.9	19.0
13	26.2	358.1	30.0

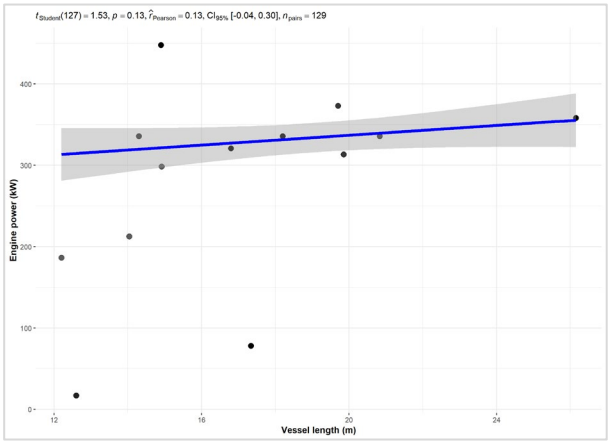

Figure 1. The relationship between vessel length and engine power

The number of commercial fishing trips analyzed was broken down as 28 for GSA 22 (22 %), 57 for GSA 24 (44 %) and 44 for GSA 29 (34 %) across the sub-geographic areas, totaling 129 (Table 2). The average catch per hour was 19.11, 24.12 and 45.77 kg for GSA 22, 24 and 29, respectively.

Table 2. Characteristics of fishing trips, median value of FUI and associated CO_2 emissions across the GSAs

Parameters	GSAs			
	22	24	29	Overall
No. of fishing trips	28	57	44	129
Avg. trip duration (h)*	9.36	8.04	7.65	8.19
FGSAFuel per trip (l)	374.29	205.05	282.31	268.14
FUI (l)	2.28	1.15	0.82	1.22
CO_2/kg of landed (kg)	6.01	3.03	2.16	3.21

*The average trip duration encompasses only the total time (hour) spent during the trawl operations.

The amount of fuel consumed for each fishing trip was estimated at 268.14 l (95% CI: 247.23, 289.04) (Table 2). Based on that calculation, for the investigated demersal trawl vessels, the FUI and the associated CO_2 emissions were estimated at a median amount of fuel of 1.22 l and 3.21 kg CO_2/kg landed, respectively (Table 2). Figure 2 illustrates the variation in estimated FUI across the 13 trawl vessels included in the study, which ranged between 0.42 and 2.49 l/kg landed catch. The results show considerable differences in fuel consumption between vessels, of which, some (Vessel 2 and 13) exhibits the highest variability and occasional extreme values. This suggests that operational factors such as engine power, vessel size, and fishing effort may significantly influence fuel consumption. Conversely, some of them (Vessel 4, 10 and 12) show relatively low and stable fuel consumption patterns, likely due to more consistent operational efficiency.

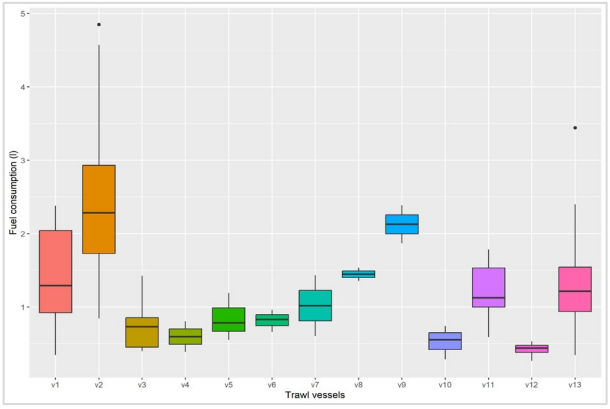

Figure 2. Box plot showing the fuel use intensity of each trawl vessel investigated

The Figure 3 presents the distribution of FUI across the three geographical sub-areas (GSAs): GSA 22 (Aegean Sea), GSA 24 (Levant Sea), and GSA 29 (Black Sea). The highest median FUI was observed in GSA 22, followed by GSA 24. In contrast, GSA 29 exhibited the lowest FUI, likely due to differences in target species and fishing practices in the Black Sea, where the shrimp fishery is absent, and fish-targeted trips typically use less fuel. (Table 2, Figure 3).Trawl vessels consumed a median amount of fuel of 1.69 l to catch one kg of landed catch during shrimp targeted fishing trips whereas fuel consumption was calculated 1.38 l for the fish targeted fishing trips (Figure 4, Table 3). According to the GLM results, the difference between these two types of fishing trips was also significant (Figure 4, Table 4).

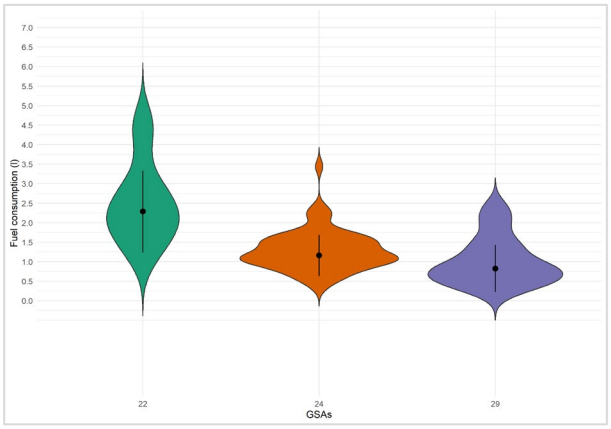

Figure 3. FUI across the GSAs

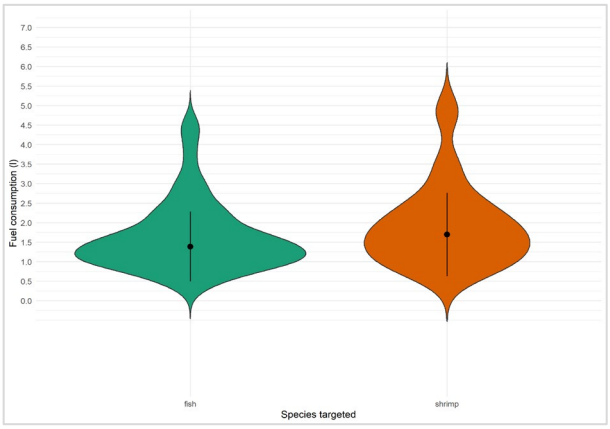

Figure 4. Violin plot showing the FUI for fish (green) and shrimp (orange) targeted fishing trips (GSA 29 region excluded)

Table 3. Comparison of published studies investigating FUI in different regions around the world

FUI (l/kg)	Differences in %	Fishery type	Region	References
3-5	77 %, 195 %	Shrimp	Skagerrak	(Ziegler et al., 2016)
2.6	88 %	Patagonian Toothfish (*Dissostichus eleginoides*)	Australia	(Hornborg et al., 2018)
0.2	-85 %	Demersal fish	Baltic and North Sea	(Thrane, 2004)
1.4	1 %	Atlantic cod (*Gadus morhua*)	Sweden	(Ziegler & Hansson, 2003)
4.2	185 %	Mixed demersal species	Strait of Sicily	(Sala et al., 2022)
11.4	568 %	Shrimp	Strait of Sicily	(Sala et al., 2022)
3.8	211 %	Mixed demersal species	Levant Sea	(Demirci & Karaguzel, 2018)
1.16	-31 %	Nephrops	Northern Ireland	(Cappell et al., 2022)
1.39	13 %	Mixed demersal species	Levant Sea	(Sarica & Demir, 2021)
1.22	-	Mixed demersal species	Turkish waters	The present study
1.69	-	Shrimp targeted	Turkish waters	The present study
1.38	-	Fish targeted	Turkish waters	The present study

GLM results indicated a significant relationship between fuel consumption, engine power, vessel length and the targeted group of species (Table 4). Table 4 shows the numerical output of the model that corresponds to the log-odds. The model with the lowest AIC included vessel length, engine power and targeted species as explanatory variables (Table 4). The GSA was removed from the predicters as there was no shrimp targeted fishery. Besides, its inclusion emerged higher AIC and caused multicollinearity during the analysis.

Table 4. Estimated regression parameters

Predictors	Estimate	SE	t-value	*p*(>t)
Intercept	-0.987	0.617	-1.600	0.113
Vessel length (m)	-0.028	0.011	-2.415	<0.05*
Engine power (kw)	0.005	0.001	4.458	<0.001*
Shrimp targeted fishing trips	0.412	0.117	3.519	<0.001*

Standard errors (SE), t-values and *p*-values for the GLM with the lowest AIC (Akaike's Information Criterion) model. *Statistically significant

The GLM results suggest that engine power is the strongest predictor of fuel consumption intensity, with each 1 kW increase in engine power resulting in a 0.5% increase in fuel use intensity, holding other variables constant. The coefficient of the engine power variable indicates that the log-odds of fuel consumption to catch one kg of landed catch increases by a constant 0.005. This means for every kW increase in engine power the odds ratio of fuel consumption to catch one kg of landed catch increases on average by a constant factor of 1.005, assuming that fishing trip type and vessel length are held constant.

Vessel length had a negative relationship with fuel consumption, where each meter increase in vessel length was associated with a 3% decrease in fuel use intensity. The coefficient of the vessel length variable has a numerical value of -0.028, which indicates that for every unit increase in vessel length, the log-odds of fuel consumption to catch one kg of landed catch decrease by -0.028. When exponentiated, for every meter increase in vessel length, the odds ratio of fuel consumption to catch one kg of landed catch decreases on average by a constant factor of 0.971 (or -3 %).

Finally, shrimp-targeted fishing trips had significantly higher fuel consumption compared to fish-targeted fishing trips, with shrimp-targeted trips having approximately 1.5 times the fuel consumption odds of fish-targeted trips. The difference in the log-odds of fuel consumption between shrimp and fish targeted fishing trips was 0.412, indicating that the fuel consumption in shrimp targeted fishing trips is significantly higher than that of the fish targeted fishing trips.

DISCUSSION

The results obtained from this study provides important insights into the fuel use intensity of Turkish bottom trawl vessels. However, it is acknowledged that the data collection is based on data from 13 vessels. Although these vessels

represent a range of operational characteristics, a larger sample size would enhance the ability to generalize findings across the entire Turkish trawl fleet. Similar studies in other fisheries have also stressed the limited sample sizes (Parker et al., 2017), highlighting the challenge of obtaining comprehensive fuel consumption data.

When converting the FUI value of 1.22, to catch one ton landed, demersal trawl vessels consume roughly between 1 000 and 1 037 t fuel, considering that the diesel weighs between 0.82 and 0.85 kg per litre. The findings in this paper were comparable with an earlier study in which the average FUI for bottom trawlers were estimated at 1.39 (Sarica & Demir, 2021). Fisheries that are mainly characterized by active fishing gears such as demersal trawls have been known to consume remarkable quantities of fuel (Park et al., 2015; Bastardie et al., 2022). Tyedmers et al. (2005) quantified the global average fuel use intensity for all types of fishing practices by applying an average diesel fuel intensity of 0.85, which was 1.7 times lower than the results for the demersal trawls under investigation in this study.

A comparison of Fuel Use Intensity (FUI) across different fisheries worldwide (Table 3) reveals substantial variation, ranging from -85% to 568%, depending on the fishery type. Variability in reported FUI values may arise from differences in data collection methods (Coello et al., 2015) and whether estimates include fuel use associated with illegal, unreported, and unregulated (IUU) fishing (FAO, 2014; Dağtekin et al., 2022). Additionally, factors such as catch per unit effort (CPUE), vessel characteristics (engine power and vessel length) (Parker et al., 2017) and post-fishing processing and transport activities (Sala et al., 2022) can result in regional variations in fuel use intensity (Parker et al., 2015). Compared to other regions, the FUI in Turkish trawl fisheries falls within the mid-range of reported values. The shrimp-targeted trawl fishery in Türkiye (1.69 l/kg) shows more energy efficiency than some other shrimp fisheries (e.g., Strait of Sicily, 11.4 l/kg), likely due lower towing speed and hourly fuel consumption of the main engine measured or reported by skippers. Additionally, estimation of Sala et al. (2022) was higher than what is found in this study due to the energy audit applied to calculate FUI as well as inclusion of post-fishing processing.

The present study is based on self-reported fuel consumption data from fishers, which may introduce reporting biases. However, despite having shortcomings, questionnaires and surveys are one of the most used methodologies in data collection on fuel consumption (Ziegler et al., 2016; Parker et al., 2017; Cappell et al., 2022). The reason for variations in individual vessel fuel use could be explained by operational and technological factors as some of them continue to operate decades old engines, which may adversely affect the engine efficiency over time (Greer et al., 2019). It must be noted that future research should incorporate direct fuel monitoring for validation.

Using real-world emission data from fishing vessels, CO_2 emission for the year 2000 was calculated as approximately 134 million t with an average rate of 1.7 t of CO_2 per ton of live weight landed marine product (Tyedmers et al., 2005). Based on that and the other two global GHG estimations reported by Parker et al. (2018) (179 million tons of CO_2) and Greer et al. (2019) (207 million tons), the average CO_2 amount generated by the Turkish demersal trawl fleet represented about 0.04 % (see Conclusion). Sala et al. (2022) demonstrated how GHG emissions might differ even between the typical Mediterranean trawl fisheries. The authors remarked that the Italian bottom otter trawls were substantially more fuel-intensive than most fisheries around the world, with an emission of 10.7 kg CO_2/kg, which was more than twice what was found in this paper (3.21 kg CO_2/kg).

The results also indicated that the fishery occurring in GSA 29 was the most efficient one in terms of FUI. The main target species of the Black Sea bottom trawling is whiting, which is the most abundantly landed demersal fish in Turkish waters (TURKSTAT, 2022). Another reason for this variation could be due to the lower discard ratio in the region (G. Gökçe, personal communication, March 15, 2024), leading to a cleaner catch composition (Emecan et al., 2023) and yielding a higher profit margin relative to fuel utilized. In other words, as catch increases, emissions per unit decrease, which was also demonstrated for the Icelandic demersal fishery by Kristofersson et al. (2021). Besides, overall trawl designs based on what Black Sea trawlers target could make remarkable differences in terms of frictional force and associated fuel consumption in comparison with the trawl fisheries performed in other regions (McHugh et al., 2015; Grimaldo et al., 2015). The highest median fuel consumption was recorded in GSA 22, exhibiting a broader range of values than the other regions. This variation is likely influenced by differences in vessel size and fishing operations within the Aegean Sea. In contrast, GSA 24 displayed a more consistent fuel consumption pattern, suggesting greater standardization in deep-water shrimp-targeted fishing activities, which generally require higher fuel use due to extended towing durations.

Higher fuel consumption in shrimp targeted fishing trips compared to the fish targeted fishing trips is also worth discussing from operational point of view. The deep-water rose shrimp, giant red shrimp, and blue and red shrimp are the main three component of the shrimp targeted fisheries in GSA 22 and GSA 24 where the depth ranged between 400 and 700 m (Deval, 2020). One possible explanation could be that the fish targeted fishery occurs in shallower waters while shrimp targeted mostly takes place in deep waters, which requires relatively better equipped larger vessels, much more effort and considerable time during the steel warp releasing, hauling and settlement of the trawl net. Another possible reason could be that such species with relatively lower abundance encourages trawlers to tow longer periods and use heavier gear components to catch (Ziegler and Hansson, 2003). In the northeast Atlantic demersal trawl fishery, fishing trips targeting

shrimps were shown to be significantly more fuel intensive than those targeting fish (Groen et al., 2013). Our results were also consistent with the findings of Ziegler and Hornborg, (2014), Parker et al. (2015) and Bastardie et al. (2022) but not with of Thrane (2004). Fuel consumption was also quantified and categorized as high for the northern shrimp (*Pandalus borealis* L.) stock shared by Sweden, Norway, and Denmark in the Skagerrak (Ziegler et al., 2016).

The GLM output indicated that the trawl vessels with lower power engines were more fuel efficient which confirmed earlier studies (Davie et al., 2014). However, fuel use intensity was negatively correlated with the vessel size. Ziegler et al. (2016) found the same tendency in Denmark fisheries, with larger vessels being more fuel efficient than smaller ones, unlike Sweden and Norway fisheries. This could be attributable to what earlier studies (Ziegler and Hornborg, 2014; Parker et al., 2017) have pointed out; rather than technical capacity of the vessels, target species and gear type might have influenced much more fuel consumption. Indeed, the larger vessels could be more efficient due to the fact that they are capable of utilizing on their greater dimensions, thereby obtaining higher catch rates from a wider variety of locations over extended durations.

With the present study, engine power was identified as the strongest predictor of fuel consumption, with higher engine power leading to increased fuel use intensity. Additionally, vessel length and the type of targeted species (shrimp vs. fish) were significant factors. These results have direct implications for fisheries management and policy, suggesting the following practical recommendations:

- Given the significant impact of engine power on fuel consumption, modifying vessels with more efficient engines or implementing engine efficiency upgrades could substantially reduce fuel use and associated greenhouse gas emissions.
- The inverse correlation between vessel length and fuel consumption suggests that design alterations—such as optimizing vessel dimensions and enhancing gear configurations to minimize towing resistance—may improve fuel efficiency.
- The adoption of gear with reduced drag characteristics may decrease the overall energy required during fishing operations, particularly in shrimp-targeted fisheries where fuel consumption is higher.
- Targeted policies and incentives aimed at promoting technological improvements and operational modifications can encourage the adoption of fuel-efficient practices and innovative gear designs, thereby supporting sustainable fisheries management and reducing the sector's environmental footprint.

CONCLUSION

For the years 2021 and 2022, Turkish demersal trawl fisheries achieved a total landing of approximately 17 667 tons (G. Gökçe, personal communication, March 15, 2024). Based on product-specific calculations, the entire trawl fleet's fuel use was estimated at around 18 million tons, resulting in roughly 56 711 tons of CO_2 emissions. Notably, these capture-related CO_2 emissions accounted for only 0.08 % of the total emissions from Turkey's agriculture sector in 2021 (TURKSTAT, 2022). Although this study examines fuel use and emissions from 129 fishing trips conducted by 13 trawl vessels, these estimates provide valuable insights into the environmental impact of the Mediterranean trawl fleet.

However, future research should expand the dataset to include a broader range of vessels across different regions and fishing seasons to improve the robustness and generalizability of the findings. Additionally, incorporating emissions from the entire fishing process—including post-landing activities, cruising time, and transportation—would better guide fisheries managers in transitioning toward more fuel-efficient and environmentally sustainable fishing practices. Furthermore, considering climate change is a fundamental concern in the General Fisheries Commission for the Mediterranean (GFCM) 2030 Strategy, fisheries policymakers must take a proactive approach by prioritizing fuel-saving technologies and lowering emissions associated with fishing operations in alignment with the goals outlined in the Paris Agreement.

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AUTHORSHIP CONTRIBUTIONS

Yunus Emre Fakıoğlu: Conceptualization, Methodology, Formal analysis, Data curation, Writing – original draft, Writing – review & editing, Visualization.

CONFLICT OF INTEREST

The author declares no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

ETHICS APPROVAL

No specific ethical approval was necessary for this study.

DATA AVAILABILITY

Data will be made available on request.

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RESEARCH ARTICLE ARAŞTIRMA MAKALESİ

Changes in the import dynamics of Atlantic mackerel and its economic implications for Türkiye in two last decades

Son yirmi yılda Atlantik uskumrusu'nun ithalat dinamiklerindeki değişimler ve Türkiye için ekonomik etkileri

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Abstract: The dynamics of Atlantic mackerel imports in Türkiye have undergone significant changes over the years. Initially, imports were predominantly sourced from high-cost suppliers such as Norway. However, rising costs prompted a shift toward more affordable alternative sources, including Morocco and Iceland. This diversification strategy reduced import costs, enabling lower consumer prices and decreased operational expenses for the aquaculture sector. Between 2005 and 2009, Türkiye's annual average fresh mackerel imports were approximately 0.3 tons, dropping dramatically to just 0.1 tons annually between 2020 and 2024. In contrast, frozen mackerel imports increased significantly, with annual averages rising from 14,209 tons in 2005-2009 to 27,032 tons in 2020-2024. This shift reflects a transition in import preferences toward frozen products due to logistical and storage advantages, as well as the availability of lower-cost alternatives. Although the reduction in import prices has provided notable economic benefits for both consumers and the aquaculture industry, it has also raised concerns about quality and labeling. For instance, products imported from Morocco are often marketed as "Atlantic mackerel," and different species, such as chub mackerel, are sometimes mislabeled as mackerel. These practices pose a risk of misleading consumers and highlight the need for stricter quality control and accurate labeling. The diversification of import sources and the accompanying price reductions have created significant economic advantages for Türkiye. However, sustaining these benefits requires the implementation of robust quality standards, proper labeling practices, and consumer protection measures. Such actions will enhance market confidence and ensure the long-term sustainability of these economic gains.

Keywords: Atlantic mackerel, import dynamics, price reduction, structural breakpoint

Öz: Türkiye'de Atlantik uskumrusu ithalat dinamikleri yıllar içinde önemli değişiklikler geçirmiştir. Başlangıçta ithalat, ağırlıklı olarak yüksek fiyatlı Norveçli tedarikçilerden yapılırken, artan maliyetler daha uygun fiyatlı alternatif kaynaklara, özellikle Fas ve İzlanda'ya yönelimi teşvik etmiştir. Bu çeşitlendirme stratejisi, ithalat maliyetlerini düşürerek tüketici fiyatlarının azalmasına ve su ürünleri yetiştiriciliği sektörünün operasyonel giderlerinin azalmasına imkân tanımıştır. 2005-2009 yılları arasında Türkiye'nin yıllık ortalama taze uskumru ithalatı yaklaşık 0,3 ton iken, 2020-2024 döneminde bu miktar yıllık ortalama sadece 0,1 tona kadar düşmüştür. Buna karşılık, dondurulmuş uskumru ithalatı önemli ölçüde artış göstermiş; yıllık ortalama ithalat miktarı 2005-2009 döneminde 14.209 ton iken, 2020-2024 yılları arasında 27.032 tona ulaşmıştır. Bu değişim, ithalat tercihlerinin, lojistik ve depolama avantajları ile daha düşük maliyetli alternatiflerin bulunabilirliği nedeniyle dondurulmuş ürünlere kaydığını göstermektedir. Her ne kadar ithalat fiyatlarındaki düşüş hem son tüketiciler hem de su ürünleri yetiştiriciliği sektörü için önemli ekonomik faydalar sağlamış olsa da kalite ve etiketleme konularında bazı endişeleri de beraberinde getirmiştir. Örneğin, İzlanda ve Fas'tan ithal edilen ürünler sıklıkla "Norveç Uskumrusu" hatta bazen farklı türler yanlış etiketlenerek sunulmaktadır. Bu tür uygulamalar, son tüketicilerin yanıltılma riskini artırmakta ve daha sıkı kalite kontrolü ile doğru etiketleme ihtiyacını ortaya koymaktadır. Sonuç olarak, ithalat kaynaklarının çeşitlendirilmesi ve beraberinde gelen fiyat düşüşleri Türkiye için önemli ekonomik avantajlar yaratmıştır. Ancak, bu kazanımların sürdürülebilirliğini sağlamak için sağlam kalite standartlarının uygulanması, doğru etiketleme uygulamalarının benimsenmesi ve tüketici koruma önlemlerinin hayata geçirilmesi gerekmektedir. Bu tür önlemler, piyasa güvenini artıracak ve söz konusu ekonomik kazanımların uzun vadede sürdürülebilirliğini sağlayacaktır.

Anahtar kelimeler: Atlantik uskumrusu, ithalat dinamikleri, fiyat düşüşü, yapısal kırılma analizi

INTRODUCTION

Global mackerel production is highlighted by the significance of the Northeast Atlantic Mackerel (NEA) stocks. NEA mackerel is widely harvested within the economic zones of countries such as Norway and Iceland, where it is recognized as one of the most valuable pelagic species (Bertheussen et al., 2020). Approximately 300,000 tons of mackerel are exported annually from Norway, positioning it as a leading exporter. Over the past decade, Iceland has exported an average of 100,000 tons of mackerel per year. On average, Norwegian exports achieve prices that are 0.23 USD/kg higher than those from Iceland, attributed to the superior fat content and muscle firmness of Norwegian mackerel (Bertheussen et al., 2020).

Export markets for Norwegian mackerel focus primarily on high-value Asian countries such as Japan, China, and South Korea, whereas Iceland's exports are directed toward Eastern European markets, particularly Lithuania and Poland. The quality requirements in Asian markets provide Norway with a significant competitive advantage (Bertheussen et al., 2020). By contrast, Icelandic exports are channeled toward markets preferring lower-quality products, which explains the price differences (Kristófersson et al., 2016). However, the sustainable management of NEA mackerel stocks has faced challenges due to disputes among coastal states, hindering the attainment of Marine Stewardship Council (MSC) certifications

(Totland, 2020). Additionally, it has been suggested that climate change could alter stock distributions, potentially impacting existing biological and economic dynamics (Astthorsson et al., 2012).

Mackerel production in Morocco holds significant importance, particularly with Atlantic mackerel (*Scomber colias*). This species ranks as the second most harvested small pelagic fish, following sardines. In 2019, approximately 281,000 tons of mackerel were caught along Morocco's coasts, representing 20% of the total small pelagic fish landings, while sardines accounted for 75% (Techetach et al., 2024).

Mackerel is harvested along both the Atlantic and Mediterranean coasts, with the Larache region and M'diq Bay being the most productive areas. In addition to local consumption, mackerel is regarded as an essential export commodity. Exports are directed to European and Asian markets, where demand remains high. However, stock assessments have indicated overfishing of mackerel along Morocco's Atlantic coast, underscoring the need for sustainable management strategies (Derhy et al., 2024). Indian mackerel is widely harvested across South and Southeast Asia, where it plays a critical role in both local food security and export markets. In India, 249,000 tons of Indian mackerel were caught in 2016. Production is concentrated in the coastal states of Karnataka, Kerala, Goa, Maharashtra, Andhra Pradesh, and Tamil Nadu. The average price of Indian mackerel in local markets was 1.50 USD/kg, while processed and frozen products fetched higher prices in international markets (Aswathy et al., 2020).

Approximately 26% of Indian mackerel production in India is exported, with major markets including Southeast Asia, the Middle East, and Europe. However, increasing export demand has led to price increases in domestic markets, making the species less accessible to local consumers (Aswathy et al., 2020).

Beyond India, the harvesting of Indian mackerel is also significant in other countries. Indonesia is among the largest producers, where mackerel is an essential economic resource for small-scale fisheries. In Sri Lanka, the species is heavily consumed domestically, while Thailand and Malaysia play prominent roles in mackerel harvesting and exportation. Additionally, Oman and Yemen focus on catching Indian mackerel along the Red Sea and the Indian Ocean coasts (Jayabalan et al., 2014; Al-Mahdawi & Mehanna, 2010).

The growing economic importance of Indian mackerel has been accompanied by concerns over overfishing, which poses risks to stock sustainability. This situation necessitates the development of effective management strategies in India and other producing countries (Al-Mahdawi & Mehanna, 2010).

Studies on fish consumption habits in Turkey indicate that large pelagic species such as mackerel are among the most preferred types, especially in coastal regions. Mackerel, anchovy, and sardine stand out as the most consumed fish species in these areas (Sagun & Saygı, 2021). In offshore tuna farms in Turkey, mackerel is prominently used as feed to increase the fat content of tuna over a 6-8-month period. This practice plays a crucial role in meeting the demands of high-value markets such as Japan, where specific fat levels are highly desired (Koçak, 2018). Turkey has long relied on the importation of mackerel, both as a fresh fish feed and as a food source for human consumption. The dynamics of trade in this segment have been analyzed to better understand the economic and sustainability aspects of the market.

MATERIALS AND METHODS

This study investigates the effects of changes in countries of origin on the price per ton of mackerel imports using mathematical and statistical methods. The analysis covers data from 2005 to 2024. Data were obtained from the Turkish Statistical Institute (TUIK Obtained from the Biruni foreign trade statistics page by chapter and country) and international trade databases. Missing or outlier values were addressed using multiple imputation and statistical outlier detection methods (Tukey, 1977; Wickham, 2016). Initially, descriptive statistics were applied to understand the overall distribution of prices over time, and average prices were compared across countries. To better understand price changes during the transition from high-cost sources like Norway to other countries such as Iceland, Morocco, and Asian nations, structural breakpoint analysis, local regression (LOESS), and multiple regression analysis were conducted.

Structural breakpoint analysis

Structural breakpoint analysis was employed to examine whether trends, levels, or variances in the time series changed at specific points. The time series: y_t, where t = 1, 2, t, is expressed as:

$$y_t = \{\beta_1 + \varepsilon_t \, if \; t \leq \tau; \; \beta_2 + \varepsilon_t \, if \; t > \tau\}$$

Here:

β_1: The average or trend coefficient before the breakpoint.

β_2: The average or trend coefficient after the breakpoint.

ε_t: The error term (normally distributed and independent).

Breakpoints were identified using the Bai-Perron multiple breakpoint algorithm, which tests for multiple structural changes in time series data (Bai & Perron, 2003).

Local regression (LOESS)

Local regression (LOESS) was used to flexibly model the price data. Instead of a global trend, LOESS analyzes local trends around data points. Mathematically:

$$f(x_i) = \sum w_i(x_i) \, y_i$$

Where:

f(x): The predicted value (local trend).

$w_j(x_i)$: The weight function, typically using the tricube function:

$$w_j(x_i) = [1 - (|x_i - x_j| / d)^3]^3, if\ |x_i - x_j| < d$$

d: The bandwidth (window size).

This method was used to visualize and interpret price changes over time.

RESULTS

Table 1 provides the five-year averages and standard errors of mackerel import and export data in Türkiye, categorized by product type, over the last two decades. The data covers the periods 2005–2009, 2010–2014, 2015–2019, and 2020–2024. Quantities are reported in tons, and values are expressed in millions of dollars. For canned mackerel, export quantities decreased from 5.5 ± 5.5 tons in 2005–2009 to 3.9 ± 1.3 tons in 2020–2024. Imports followed a similar declining trend, reducing from 3.7 ± 3.4 tons to 1.229 ± 1.2 tons. Export values fluctuated slightly, stabilizing at 0.028 ± 0.010 million dollars in the most recent period.

Table 1. Five-year averages and standard errors of mackerel import and export data in Türkiye by product type over the last two decades

Period	Product type	Amount (tons)		Value (million of dollars)	
		Export	Import	Export	Import
2005-2009	Canned	5.5 ± 5.4	3.7 ± 3.4	0.062 ± 0.061	0.008 ± 0.007
	Fresh	0.3 ± 0.1	47.7 ± 25.6	0.001 ± 0.000	0.053 ± 0.019
	Frozen	9.8 ± 6.3	14209.2 ± 2402.4	0.034 ± 0.018	18.725 ± 3.147
2010-2014	Canned	4.1 ± 2.0	-	0.035 ± 0.016	-
	Fresh	8.6 ± 4.4	8.8 ± 3.262	0.022 ± 0.010	0.033 ± 0.012
	Frozen	26.9 ± 12.4	24921.1 ± 1791.0	0.093 ± 0.040	40.893 ± 1.908
2015-2019	Canned	6.3 ± 2.1	1.9 ± 1.0	0.044 ± 0.015	0.013 ± 0.007
	Fresh	41.9 ± 26.1	1.2 ± 0.8	0.127 ± 0.078	0.004 ± 0.003
	Frozen	51.5 ± 5.3	31939.1 ± 3816.6	0.138 ± 0.015	44.272 ± 6.464
	Indian M.	875.7 ± 70.3	581.4 ± 285.2	1.875 ± 0.242	0.792 ± 0.419
2020-2024	Canned	3.9 ± 1.3	1.229 ± 1.2	0.028 ± 0.010	0.005 ± 0.005
	Fresh	13.5 ± 4.8	0.1 ± 0.1	0.053 ± 0.015	0.000 ± 0.000
	Frozen	85.4 ± 9.2	27032.1± 3416.3	0.244 ± 0.022	35.725 ± 4.255
	Indian M.	1082 ± 120.4	1364.5 ± 286.4	1.884 ± 0.200	2.136 ± 0.426

Fresh mackerel exports showed an upward trend initially, increasing from 0.3 ± 0.1 tons in 2005–2009 to a peak of 41.9 ± 26.1 tons in 2015–2019, before decreasing to 13.5 ± 4.8 tons in 2020–2024. In contrast, import quantities dropped significantly from 47.7 ± 25.6 tons to 0.1 ± 0.1 tons over the same period. Export values exhibited gradual growth, while import values nearly disappeared by the latest period.

Frozen mackerel exports experienced steady growth, starting at 9.8 ± 6.3 tons in 2005–2009 and reaching 85.4 ± 9.2 tons in 2020–2024. Imports, already substantial, increased from 14,209.2 ± 2402.4 tons to 27,032.1 ± 3416.3 tons. Export values rose from 0.034 ± 0.018 million dollars to 0.244 ± 0.022 million dollars, while import values saw a slight decline from 18.725 ± 3.147 million dollars to 35.725 ± 4.255 million dollars.

For Indian mackerel, a product type recorded in the later periods, export quantities increased from 875.7 ± 70.3 tons in 2015–2019 to 1,082 ± 120.4 tons in 2020–2024. Similarly, imports grew from 581.4 ± 285.2 tons to 1,364.555 ± 286.4 tons. Export values rose from 1.875 ± 0.242 million dollars to 1.884 ± 0.200 million dollars, while import values increased from 0.792 ± 0.419 million dollars to 2.136 ± 0.426 million dollars.

Figure 1 identifies key structural breakpoints in the trends of mackerel import quantities, values, and unit prices in Türkiye, focusing on imports from Norway, Morocco, and Iceland. The structural breakpoints highlight periods of significant shifts in the data across the studied years (2005–2024). For Türkiye's total imports, breakpoints are observed around 2010 and 2015, with a marked shift in the rate of change for both import quantities and values. Unit prices also exhibit variations during these periods, with notable fluctuations aligning with the identified breakpoints. In imports from Norway, breakpoints are detected around 2013 and 2018. These points correspond to significant changes in import quantities and values, with a steady increase in unit prices over the years. For Morocco, the analysis indicates breakpoints around 2011 and 2016. These points reveal a steep rise in import quantities and values, particularly around 2011, followed by a stabilization in later years. Unit prices show variability, particularly during the identified breakpoints. Iceland exhibits structural breakpoints around 2012 and 2017. These points correspond to sharp increases in import quantities and values, followed by declines or stabilization. Unit prices display substantial fluctuations, particularly around these breakpoints.

Figure 2 presents the LOESS evaluation results of mackerel imports in Türkiye over the years, including a general overview as well as data specific to Norway, Iceland, and Morocco. The evaluations illustrate the trends in both quantity (tons) and value (million USD) of mackerel imports from 2005 to 2024. In the total panel, a consistent upward trend is observed in both the quantity and value of imports, with a noticeable stabilization in recent years. The LOESS curves smooth out annual fluctuations, revealing long-term patterns in Türkiye's overall mackerel import dynamics. The Norway panel indicates a rapid increase in both quantity and value of imports

until around 2014, followed by a decline and stabilization in subsequent years. The trends suggest a shift in import dynamics after a period of substantial growth. The Iceland panel shows a steady and continuous increase in both quantity and value of imports over the observed years. The LOESS curves suggest a consistent upward trajectory without significant disruptions, indicating growing trade between Türkiye and Iceland in mackerel. In the Morocco panel, a gradual rise in both quantity and value is observed, with a more pronounced increase beginning in the mid-2010s. The LOESS curves highlight the steady growth in Türkiye's mackerel imports from Morocco.

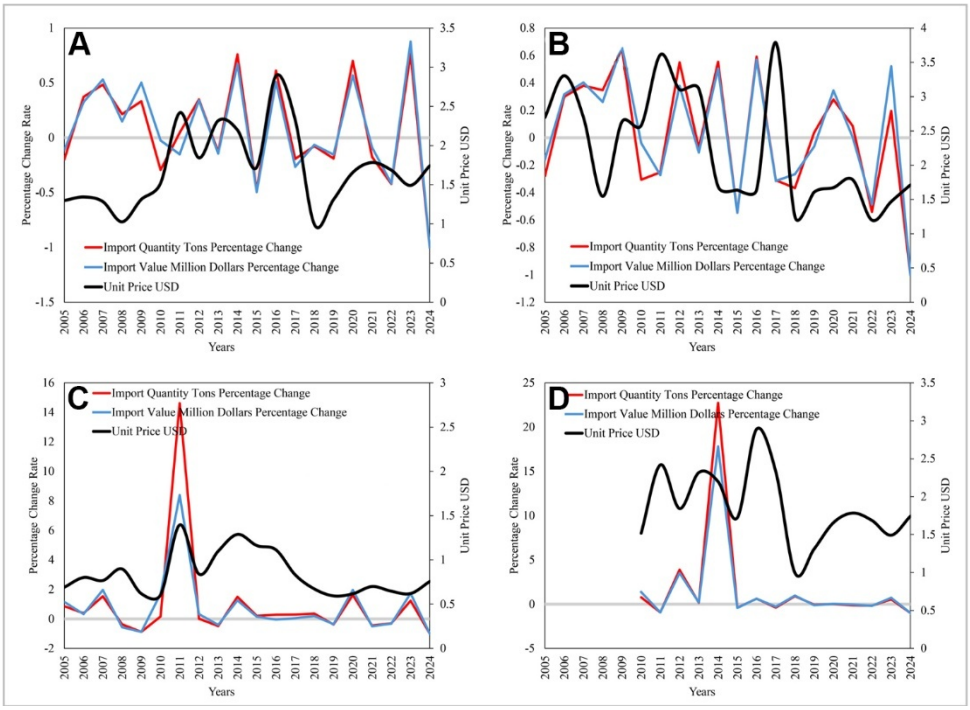

Figure 1. Annual variation rates of quantity and value, and unit prices of mackerel imports in Türkiye (A: Total, B: Norway, C: Morocco, D: Iceland)

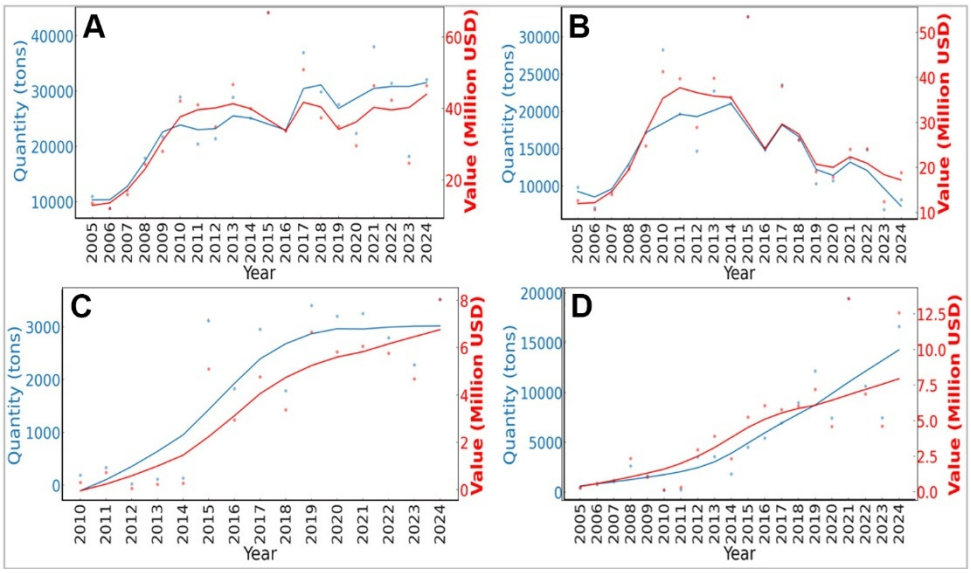

Figure 2. LOESs evaluation results of mackerel imports in Türkiye over the years (A: Total, B: Norway, C: Morocco, D: Iceland)

DISCUSSION

The structural breakpoint analysis and the LOESS curves provide a detailed understanding of the significant shifts in import dynamics across these countries, emphasizing changes in both quantity and value trends. It can be observed that Türkiye's mackerel imports have shown continuity over time (Pekmezci et al., 2023). This decline was influenced by the

search for alternative markets other than Norway, starting from 2013. The involvement of new markets, particularly Morocco and Iceland, has contributed to a significant decrease in the unit price of mackerel imported from Norway, which has been favorable for Türkiye. However, this favorable situation should not come at the expense of product quality. Therefore, necessary precautions must be taken. For instance, mackerel imported from Morocco is a different species, and there are opinions suggesting that the mackerel produced in Iceland is of lower quality compared to the Norwegian mackerel product (Bertheussen et al., 2020; Gottschalk, 2022).

The import of mackerel to Türkiye is likely to continue supporting the aquaculture industry (Koçak, 2018; Hougaard, et al., 2020), both in terms of fresh feed and fish meal production. Mackerel, like other small pelagic species, is a necessity for aquaculture in Türkiye, especially mackerel imported from North African countries. However, mackerel is also widely consumed as human food in the country, which poses a potential risk of misleading the end consumer. It is a common practice in Türkiye to sell chub mackerel under the name "mackerel." Additionally, products often imported from Morocco under the name "Atlantic mackerel" may potentially be offered to consumers. Similarly, Indian mackerel is also considered to have such potential. Necessary measures should be taken into account to protect end consumers.

Mackerel is a globally popular fish due to its high protein content and healthy fats (Bae et al., 2011). However, improper storage and handling can lead to serious public health issues, such as histamine poisoning. This is especially problematic when proper storage conditions and supply chain management are not maintained (Visciano et al., 2014). Histamine poisoning occurs when histidine in the fish is converted to histamine by bacteria. Bacteria such as *Pseudomonas spp.*, *Proteus spp.*, *Escherichia coli*, and *Morganella morganii* are commonly responsible for this process (Kovacova-Hanuskova et al., 2015; Schirone et al., 2017). High temperatures above 15°C accelerate bacterial growth and histamine production (Abuhlega & Ali, 2022). Symptoms of poisoning include rashes, itching, nausea, vomiting, low blood pressure, and headaches (Anusha et al., 2021). Proper cold chain management is essential throughout the supply chain to ensure the safety of mackerel and similar fish. Adherence to hygiene standards during processing, storage, and transportation is critical (Bedane et al., 2022). Storing fish at low temperatures, either frozen or chilled, minimizes bacterial activity and reduces toxin production (Shamsan et al., 2019). Preventing histamine poisoning requires strict monitoring and control at all stages of the supply chain. Compliance with national and international food safety standards must be enforced (ICMSF, 2018). Additionally, consumers should be educated on proper storage and cooking practices to further reduce risks (Madejska et al., 2022).

CONCLUSION

Mackerel imports in Türkiye hold critical importance for both aquaculture and human consumption. The diversification of import sources has led to a decrease in mackerel prices over time, creating a positive economic impact. By shifting from high-cost suppliers like Norway to more cost-effective sources such as Morocco and Iceland, the unit prices of mackerel imported into Türkiye have been reduced, enabling consumers to access products at more affordable prices. The reduction in prices has provided significant advantages, including lowering costs in aquaculture and allowing consumers to access quality products at more reasonable prices. However, maintaining quality standards and ensuring accurate labeling of different species should not be overlooked in this process. For instance, the importation of different species under the name "Atlantic mackerel" or the sale of chub mackerel under the name "mackerel" poses a risk of misleading consumers.

In this context, while the economic benefits of low-cost imports are preserved, increasing inspections and regulations to protect consumers is of great importance. Moreover, strengthening national and international cooperation for the sustainable management of mackerel stocks will ensure the long-term continuity of these benefits.

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AUTHOR CONTRIBUTIONS

Sevil Demirci: Conceptualization, methodology, investigation, data collection, writing-reviewing and editing.

CONFLICT OF INTEREST

The author declares that there is no conflict of interest.

ETHICS APPROVAL

No specific ethical approval was necessary for the study.

DATA AVAILABILITY

All relevant data is in the article. Even so, for any questions, the author should be contacted.

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DERLEME **REVİEW**

Türkiye'de Karadeniz somonu (*Salmo labrax* Pallas, 1814) balıkçılığının dönüşüm seyri

The course of alteration of Black Sea salmon (*Salmo labrax* Pallas, 1814) fishery and culture

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Öz: Karadeniz somonu, Karadeniz'e has endemik türlerden biridir. Doğal dağılım alanı Karadeniz ve Karadeniz ile Azak Denizi'ni besleyen birçok akarsudur. Göçmen olmayan formları Karadeniz'e dökülen küçük dereler ve nehir kollarında bulunurken anadrom formları ise Karadeniz'e dökülen büyük akarsular ve nehirlerde bulunmaktadır. Son yıllarda antropolojik etkiler neticesinde türün dağılım gösterdiği akarsularda özellikle anadrom formların nesli tükenme tehlikesiyle karşı karşıyadır. Doğal popülasyonun azalmasında etkili olan avcılığın av yasakları listesinde yer almasında önemli olan isimlendirilmesine yönelik karmaşa günümüzde de devam etmektedir. Ancak Karadeniz somonu, *Salmo labrax*, Black Sea salmon isimleri güncelliğini korumaktadır. Türkiye'de sinonim olarak Karadeniz somonu, deniz alabalığı, denizalası ve kırmızı benekli alabalık isimleri yaygın olarak kullanılmaktadır. Türün, kültür şartlarında üretimine yönelik bilinen ilk çalışma, 1920'li yıllarda Abazya bölgesinde kurulan bir kuluçkahanede balıklandırma amacıyla başlatılmıştır. Türkiye'de 1988 yılında FAO desteğinde başlatılan çalışma ile deniz alabalıklarının stok durumu araştırılmış olup kültür üretimi için tesis yerlerinin ön etüt çalışmaları yapılmıştır. Bu çalışmaya müteakip 1998 yılından itibaren doğal ortamdan toplanan bireylerle damızlık stok oluşturulmuş, birçok kültür özelliği belirlenmiş, kültüre alınmış, balıklandırma amacıyla kullanılmış ve özel sektöre kazandırılmıştır. Günümüzde, Karadeniz'e komşu ülkeler arasında sadece Türkiye'de ticari yetiştiricilik üretimi devam etmektedir. Bu çalışma doğal dağılım alanındaki topluluklar tarafından sevilerek tüketilen Karadeniz somonunu daha iyi tanımak, tür için değişen ekosistemi anlamak ve ticari üretiminin yaygınlaşmasına katkı sağlamak amacıyla hazırlanmıştır.

Anahtar Kelimeler: *Salmo labrax*, deniz alası, yetiştiricilik, balıklandırma, koruma, ticari üretim

Abstract: The Black Sea salmon is one of the endemic species of the Black Sea. Its natural distribution area is the Black Sea and many rivers that feed the Black Sea and the Sea of Azov. While its non-migratory forms are found in small streams and river branches that flow into the Black Sea, its anadromous forms are found in large streams and rivers that flow into the Black Sea. In recent years, as a result of anthropological effects, the anadromous forms in particular are facing the danger of extinction in the streams where the species is distributed. The confusion regarding its naming, which is important in the hunting ban list, which is effective in the decrease of the natural population, continues today. However, the names Black Sea salmon, Salmo labrax, Black Sea salmon are still current. In Turkey, the synonyms Black Sea salmon, sea trout, sea trout and red spotted trout are widely used. The first known study on the production of the species under culture conditions was initiated in the 1920s in a hatchery established in the Abkhazia region for the purpose of fish breeding. In Turkey, the stock status of sea trout was investigated with the study initiated with FAO support in 1988, and preliminary studies were conducted for facility locations for culture production. Following this study, breeding stock was created with individuals collected from the natural environment starting in 1998, many culture characteristics were determined, they were cultured, used for fish breeding purposes and introduced to the private sector. Today, commercial aquaculture production continues only in Turkey among the countries neighboring the Black Sea. This study was prepared to better understand the Black Sea salmon, which is consumed with pleasure by the communities in its natural distribution area, to understand the changing ecosystem for the species and to contribute to the spread of its commercial production.

Keywords: *Salmo labrax*, denizalası, Black Sea trout, aquaculture, stocking, conservation, commercial production

GİRİŞ

İnsanların besin ihtiyaçlarının karşılanmasında en sağlıklı protein kaynaklarından biri olan su ürünleri, sürdürülebilir yetiştiriciliği ile gelecek nesillerin tercih edebileceği iyi özelliklere sahiptir. Yetiştiricilik sektöründe yüksek sosyo-ekonomik ve ekolojik değere sahip alabalıkgiller küresel ölçekte sürdürülebilir yetiştiricilik için en çok tercih edilen türler arasındadır. Alabalıkgillerden doğal dağılım alanı Karadeniz olan ve diğer somon türleri gibi anadrom özellik gösteren Karadeniz somonu (*Salmo labrax*) yüksek yetiştiricilik potansiyeli ile sektöre göz kırpmaktadır.

Birleşmiş Milletler, dünya nüfusunun yılda ortalama 78 milyon artışla 2050 yılında yaklaşık 12 milyara ulaşacağı öngörmektedir. Dünya nüfusunun artışı ile birlikte gıda artışında yaşanan darboğaz ve yükselen hammadde fiyatları gıda güvencesi olmayan özellikle geri kalmış ve gelişmekte olan toplumlar için önemli sorunlar yaratmaktadır. Bu sorunları iyi analiz etmek, günümüz koşullarına göre yorumlamak ve sorunların yerinde çözümüne yönelik planlamalar yapmak oldukça önemlidir (FAO, 2020). Tamda burada yerel hastalık suşlarına bağışık, yerel çevresel

koşullara uyumlu endemik türlerin yetiştiriciliği ön plana çıkmaktadır. Dünya nüfusunun sağlıklı beslenmesinde en önemli üretim sektörlerinden biri de su ürünleridir. Deniz ve tatlı su ekosistemlerinden elde edilen balık, kabuklu, eklem bacaklı, bitkiler ve algler olarak tanımlanan mavi gıdalar, dünya çapında geçim kaynaklarını, ekonomileri ve kültürleri desteklerken milyarlarca insanın gıda ve beslenme güvenliğinde de önemli bir rol oynamaktadır (Costello vd., 2020; FAO, 2020; Golden vd., 2021; Short vd., 2021; Teh ve Sumaila, 2013). Küresel ölçekte su ürünleri tüketimi sürekli artma eğilimindedir (De Silva vd., 2009; Subasinghe vd., 2009; Swartz vd., 2010). Tarihsel olarak, dünyada tüketilen balıkların %80'inden fazlası deniz balıkçılığından elde edilmiştir (Tidwell ve Allan, 2001). Bununla birlikte, 1950 ile 1980 yılları arasında toplam avcılık ile karaya çıkarılan ürün beş kat artmış, fakat 1980 yılından sonra düşmüştür (Watson ve Pauly, 2001). Artık, dünyadaki balık stoklarının %80'inin tamamen veya aşırı sömürüldüğü kabul edilmektedir (FAO 2009). Bu nedenle, gelecekte balıkçılık çabaları artmaya devam etse de, balıkçılığın bugün olduğundan daha fazla su ürünleri tedarik edebilmesi pek olası değildir (Myers ve Worm, 2003; Morato vd., 2006). Sürdürülebilir üretim sağlamak ve biyolojik çeşitliliği korumak için balıkçılık kapasitesinin dünya çapında önemli ölçüde azaltılması gerekmektedir (Pauly vd., 2003; Worm vd., 2009). Bu durumda su ürünlerinin insan protein tüketimine olan katkısını korumanın veya arttırmanın yolu balık yetiştiriciliği olarak görülmektedir (De Silva vd., 2009; Subasinghe vd., 2009). En hızlı büyüyen küresel endüstrilerden biri olarak kabul edilen su ürünleri yetiştiriciliği, ilk kez dünya çapında insan toplumları tarafından tüketilen balığın yarısını üretmektedir (FAO 2009). Kültür balıkçılığı, birçok Avrupa ülkesinde 19. yüzyılın ortalarında yaygınlaşmıştır ancak dünya çapındaki en büyük yayılımı 1960'lardan bu yana gerçekleşmiştir. Günümüzde yaklaşık 250 sucul türün yetiştiriciliği yapılmaktadır (De Silva vd., 2009; Bostock vd., 2010). Bu nedenle su ürünleri yetiştiriciliği çok eski bir gelenek olmasına rağmen esas olarak 20. yüzyılın son çeyreğinde küreselleşmiş ve giderek daha fazla türün evcilleştirilmesini hedefleyen bir endüstri haline gelmiştir (Harache, 2002; Duarte vd., 2007; De Silva vd., 2009). Küresel ölçekte yaşanan bu gelişmelere Türkiye ilgisiz kalmamış, Prof. Dr. Curt Kosswig öncülüğünde yapılan ilk denemeler ile Abant gölünde 1954 yılında *Salmo trutta abanticus* üretimi başarılmıştır (Korkut vd., 2023). Sonraki yıllarda birçok farklı balık türlerinin yetiştiriciliğe kazandırılması için çalışmalar yapılmış fakat az sayıda tür için başarı sağlanmıştır. 1998 yılında, Trabzon Su Ürünleri Merkez Araştırma Enstitüsünün (SUMAE) Karadeniz kalkan balığı, mersin balığı türleri ve Karadeniz somonunun kültür koşullarında üretimini başarmıştır. Bu türler arasında ise sadece Karadeniz somonu ıslah çalışmaları başarılı olmuş ve türün üretimi yaygınlaştırılmıştır.

Bu çalışma, Karadeniz somonu ticari ve sportif amaçlı avcılığının bölge halkı üzerinde kültürel, sosyal ve ekonomik etkisini saha çalışmaları, bilimsel veriler ve röportajlarla ortaya koymaktadır. Ayrıca, Karadeniz somonunun doğal dağılım alanı dışındaki toplumlar tarafından da tanınması ve bilinirliğinin artırılmasını hedeflemektedir.

TANINIRLIK HİKÂYESİ

Karadeniz somonu, beslenmek için akarsudan Karadeniz'e, üremek için denizden akarsulara geri dönüş göçleriyle tanınırlar (Tabak vd., 2001). Karadeniz somonu, Prusyalı bir zoolog, botanikçi, etnograf, kâşif, coğrafyacı, jeolog, doğa tarihçisi ve taksonomistti olan Peter Simon Pallas tarafından bulunmuş ve isimlendirilmiştir. İlk bulunuş yeri Sivastopol-Ukrayna'dır (Anonim, 2024a). Türkiye'de; Karadeniz somonu, alabalık, denizalası, Karadeniz alabalığı, kırmızı benekli alabalık gibi yerel isimleri vardır. Ayrıca, türün avcılığını yapan İlyas Tabak, Salim Biber, Nizamettin Çavuşoğlu ve Muharrem Hamza ile kişisel görüşmelerde (2024), Karadeniz Somonuna yerel olarak alabalık, kırmızı benekli alabalık, küçük olanlara "ala" büyük olanlara ise "ponço" denildiği, Fırtına deresine kurulan çitlerle avlanan büyük balıklara ise "Uneh" ve "ineği" denildiği beyan edilmiştir.

Karadeniz havzasındaki nehirlerde bulunan Karadeniz somonunun sistematik durumu ihtiyologlar arasında tartışma konusudur. Bazı bilim adamları endemik bir tür olarak, bazıları da Atlantik somonunun (*Salmo salar*) alt türü olarak kabul etmişlerdir (Dorofeeva, 1965). Karyolojik verileri Karadeniz somonunun, Atlantik somonunun bir alt türü olamayacağını göstermiş, osteolojik çalışmalar sonunda Karadeniz somonunun kahverengi alabalığın (*Salmo trutta*) bir alt türü olduğu tespit edilmiştir (Dorofeeva, 1967).

Kahverengi alabalıklar, çevre koşullarına büyük ölçüde uyum sağlama ve göç etme yeteneğine sahip bir somon türüdür (Okumuş vd., 2007). 42° Kuzey Enleminin kuzeyinde göç eden kahverengi alabalık popülasyonları bulunmaktadır (Elliot, 1994). Bu tür popülasyonlara Karadeniz'in Kuzeydoğu kıyılarında ve buradan akan derelerde de rastlanmaktadır. Göçmen bireyler Deniz alabalığı olarak isimlendirilir. Üreme için geri geldiklerinde göç etmeyen alabalıkların iki, üç katı veya daha fazla büyüklükte olurlar. Göçmen karakterli Doğu Karadeniz popülasyonları ise diğer bir alt tür olan *Salmo trutta labrax* olarak tanımlanmaktadır (Slastenenko, 1956; Geldiay ve Balık, 1996). Davranış farklılıkları, fenotipik, morfolojik ve ekolojik özellikler, kahverengi alabalık popülasyonlarının tür veya alt türlerinin tanımlanmasında temel faktörlerdir. Bu kriterlere göre Türkiye'de yapılan çalışmalarda *Salmo trutta labrax*'ın üç farklı ekotipi bulunmuştur (Slastenenko, 1956; Tabak vd., 2001; Okumuş vd., 2007). Çelikkale vd. (1988), kahverengi alabalıkların Türkiye sularındaki ihtiyofauna üyesi olduğuna inanmaktadır. Uyum sağladıkları ortama ve coğrafi bölgeye göre dere, deniz ve göl ekotipleri bulunmaktadır. Karadeniz'de, boyları 100 cm'ye ve ağırlıkları 26 kg'a ulaşan deniz ekotipi bireyler bulunmakta, hayatlarının büyük kısmını denizde geçirmekte ve üreme dönemlerinde ise Karadeniz'e akan nehirlere girerek kış aylarında çakıllı ve taşlık alanlarda yumurtlarlar (Şekil 1). Göl ekotipi bireyler, gölde kapalı olarak kalmış olup, hayatlarının tümünü orada geçirmekte, aynı sucul alanda beslenme ve üreme göçü yapmaktadır (Şekil 2).

Dere ekotipi bireyler ise bir akarsuya bağlanmış durumda olup, bütün yaşamlarını orada sürdürmektedir, deniz ve akarsular arasında göç etmedikleri halde, akarsu ortamında, kaynak, yan kollar ve dere ağzı arasında kısa mesafeli beslenme ve üreme göçü yaparlar (Şekil 3), (Slastenenko, 1956; Svetovidov, 1984; Geldiay ve Balık, 1996).

Şekil 1. Karadeniz somonu deniz (marina) ekotipi (Fırtına Deresi-Rize; Çakmak vd., 2011)

Şekil 2. Karadeniz somonu göl (lacustris) ekotipi (Büyük Deniz Gölü-Rize; Tabak vd., 2001)

Şekil 3. Karadeniz somonu dere (stream) ekotipi (Solaklı Deresi-Trabzon; Çakmak vd., 2011))

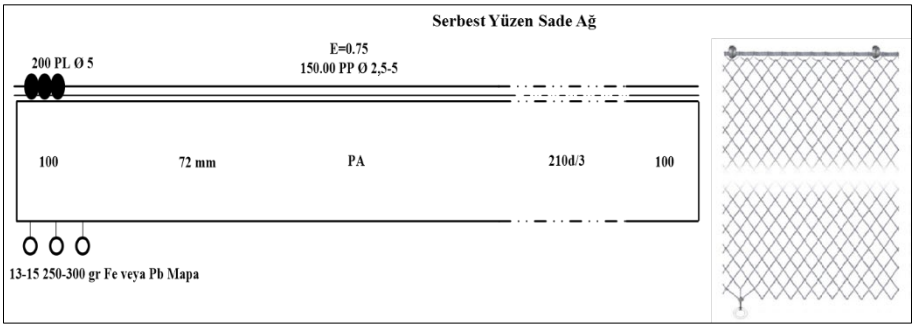
Dünya'da kahverengi alabalık adıyla anılan *Salmo trutta* popülasyonları arasında bazı fenotipik farklılıklar vardır (Froese ve Pauly, 2018). Bu sebeple farklı görünümdeki bu türler taksonomik pek çok tür ya da alt tür adıyla tanımlanmıştır. Ancak son çalışmalar bu türlerin genetik olarak benzerlik gösterdiğini ortaya koymaktadır (Altinok vd., 2020). Günümüze değin olan çalışmalarda Doğu Karadeniz'in güney kıyılarında yayılım gösteren ve kahverengi alabalıkların bir üyesi olan Karadeniz somonu da farklı isimlerle anılmıştır. Çiftçi vd. (2007)'ye göre Karadeniz somonunu tür, alt tür veya lokal popülasyon olarak kabul etmek mümkündür. Tür ile ilgili yapılan daha eski çalışmalarda; tür adı *Salmo trutta labrax* olarak kabul edilse de, bu isimlendirme artık sinonim olarak kabul edilmektedir. Latiu (2020), Romanya sularında yapmış olduğu çalışmada türün ismini Karadeniz somonu *(Salmo labrax)* olarak kabul etmiştir. Fishbase (Froese ve Pauly, 2018) ve World Register of Marine Species (WORMS, 2017) veri tabanları ise bu türün adını Karadeniz somonu *(Salmo labrax)* olarak kabul etmiştir. Karadeniz somonu için kullanılan *Salmo rizehensis* ve *Salmo coruhensis* adlandırmalarını ise Rize alabalığı ve Çoruh alabalığı olarak ayrı kayıtlar olarak vermiştir. Bu sebeple, güncel literatür ve dünyaca kabul görmüş veri tabanları göz önünde tutulduğunda, tür için *Salmo labrax* kullanımı doğru olacaktır.

İLK BİLİNEN AVCILIĞI VE AV ARAÇLARI

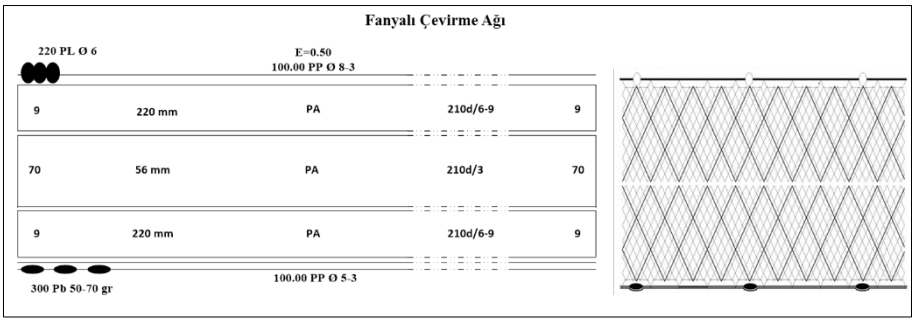
Diğer birçok göçmen hayvanda olduğu gibi somon balığı da önemli ticari, rekreasyonel ve geleneksel balıkçılığı destekler ve besin maddelerini denizden tatlı su ortamlarına aktarır (Kline vd., 1990). Göç zamanlaması, somon balıkçılığının yönetiminde önemlidir (Adkison vd., 2015; Mundy ve Evenson, 2011). Somon balıkçılığı ile benzer olan Karadeniz somonu balıkçılığında da göç dönemi önemli olmuştur. Özellikle deniz ekotipinin zamansal ve mekânsal avcılığını üreme ve beslenme göçü belirler. Diğer ekotipler ise bulundukları akarsu veya göl sınırları içinde üreme ve beslenme göçü yaptığından yılın her döneminde av verme olasılıkları yüksektir. Yine de su sıcaklığına bağlı olarak özellikle yaz aylarında akarsuyun memba tarafına göçleri söz konusudur. Karadeniz somonu avcılık zamanı, kullanılan av aracı ve avlak sahası (av mekânı) üzerinde ekotip belirleyici etkenlerin ön sırasındadır.

2001 yıllına kadar türün avcılığını yapan İlyas Tabak, Salim Biber, Nizamettin Çavuşoğlu ve Muharrem Hamza ile 2024 yılında yapılan kişisel görüşmelerde "Balıkların denizden dereye girmesinin genelde Mart, Nisan ve Mayıs aylarında olduğu ve bu aylarda yukarıya çıkmaya başladıkları, yumurtladıktan sonra da Ekim Kasım aylarında aşağıya inmeye başlıdıkları, avcılıkta akarsuyun denizle bağlantılı kısımlarında uzatma ağları, voli ağları ve serpme ile akarsuda ise tuzak, olta, dinamit, elektrik, zehirli ot ve sönmemiş kireç yöntemlerinin kullanıldığı, az miktarda olsa da derin göllere dalarak elleriyle taşların altından ve mağaradan balıkların çıkarıldığı, bazen derenin ikiye ayrıldığı yerde bir tarafı taş ve çimlerle kurutup avcılığın yapıldığı ve en fazla kullanılan av aracının voli ağları olduğu beyan edilmiştir." Karadeniz somonu deniz (marina) ekotipi bireylerin avcılığı, popülasyonun üremek için denizden akarsuya ve üremesini tamamlayan bireylerin tekrar denize göçü esnasında yapılmaktadır. Diğer ekotiplere nazaran büyük olan deniz ekotipi bireylerin avcılığında kullanılan av araçları serbest yüzen uzatma ağları, çevirme ağları (voli), kıyı sürütme ağları (ığrıp, manyat), serpme ağlar ve alabalık tuzakları (çit) şeklinde sıralanabilir. Küçük ölçekli balıkçılar deniz ve akarsuyun deniz ile birleştiği alanda yapmış oldukları av operasyonlarında serbest yüzen uzatma ağları, çevirme ağları ve kıyı sürütme ağları kullanırken akarsuda avlanan yöre halkı ise serpme ağ, olta takımı ve tuzakları kullanmaktadır. Serbest yüzen uzatma ağları (alabalık uzatması), akarsu mansabına yakın denizel alanda küçük balıkçı teknesi yardımıyla kıyıya dik su yüzeyinde kalacak şekilde genellikle gece yapılan av operasyonlarında kullanılmıştır. Balıkları solungaç kapaklarından yakaladıkları için bu ağlara galsama ağları da denilmektedir. Tek kat ve ince materyalden yapılan göz açıklığı balığın başının geçip vücudunun geçemeyeceği genişlikte Karadeniz somonu için özel olarak donatılırlar (Şekil 4). Çevirme (voli) ağları, akarsu mansabına yakın denizel

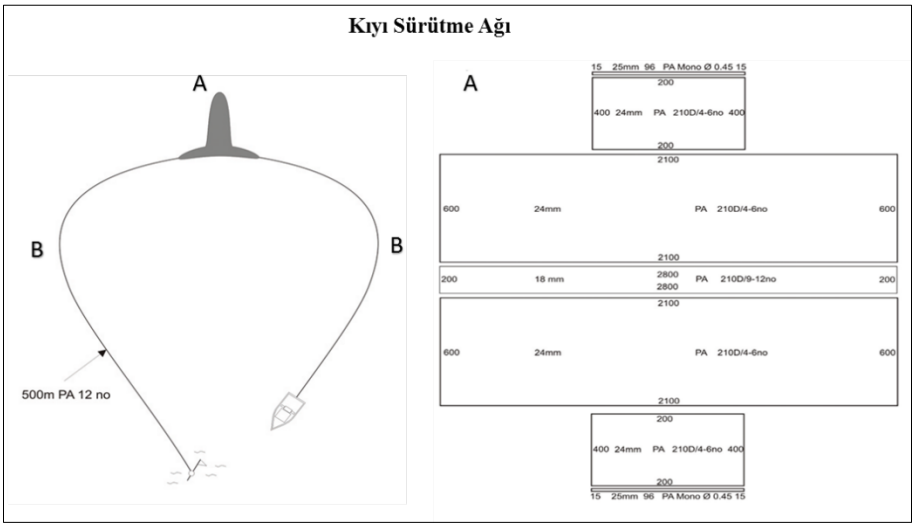
alanda balık sürüsünün tespit edildiği alanın küçük balıkçı teknesi yardımı ile gece/gündüz ağ daire şeklinde dökülerek av operasyonu yapılmaktadır. Balıkların etrafını çevrilerek ağ içerisinde hapsedilmesi sağlanır. Karadeniz somonu avcılığında kullanılanlar özel olarak fanyalı donatılmıştır (Şekil 5). Kıyı sürütme ağları (ığrıp, manyat) ise genel olarak akarsuyun denizle birleştiği, balıkların tatlısuya uyum sağladığı acısu alanındaki av operasyonlarında kullanılmaktadır. Bu ağ, kıyıda belirli bir bölgenin önce çevrilmesi daha sonra halatlar aracılığıyla çekilerek taranması şeklinde kullanılmaktadır. Ağın derinliği yaklaşık 1.5-2 m olup, uzunluğu 50-150 m'ler arasında değişmektedir. Ağlar fanyalı ve fanyasız olarak donatılmaktadır (Şekil 6). Serpme ağlar, akarsuda ve göllerde yıl boyu türün avcılığında en çok kullanılan av araçlarındandır. Yerel halk ve amatör balıkçıların kullandığı bu ağ su yüzeyinden dairesel şekilde atılır, balık ağ ile kapatılıp ağ içinde kalması sağlanır (Şekil 7). Alabalık tuzakları (çit), anadrom balıkların üreme dönemi sonunda denize göçleri zamanında yöreye özgü kullanılan bir av aracıdır. Akarsuyun akış yönünde hareket eden damızlık bireylerin göç yollarına ağaç malzemeden inşa edilmektedir. Alabalık tuzakları akarsu mansabından itibaren yaklaşık 20 km mesafeye kadar yerel halk tarafından kullanılmaktadır (Şekil 8).



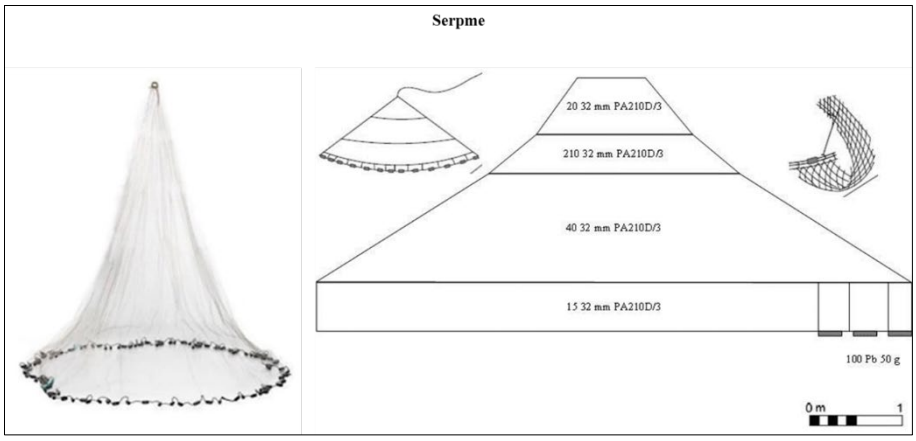
Şekil 4. Fanyasız serbest yüzen uzatma ağı (alabalık uzatması) (Mısır vd., 2020)



Şekil 5. Fanyalı çevirme ağı (voli) (Mısır vd., 2020)



Şekil 6. Kıyı sürütme ağı (Tokaç vd., 2010)



Şekil 7. Serpme ağı

Şekil 8. Tuzak (çit) ve serpme ağ uygulaması (Tabak vd., 2001)

Göl (lacustris) ekotipi bireylerin avcılığı, üreme dönemi hariç yıl boyu yerel halk ve amatör avcılar tarafından yıl boyu yapılmaktadır. Göllerdeki avcılıkta genel olarak olta takımları kullanılmakta olup göl zemininin uygun olduğu durumda da serpme ağları da kullanılmaktadır.

Dere (stream) ekotipi bireylerin avcılığında, akarsu ve akarsu kollarındaki üreme ve beslenme göçü belirleyicidir. Çevresel özelliklerin alabalıklar için uygun olduğu kış aylarında tüm akarsu boyunca av veren dere ekotipi, akarsu mansabına yakın mesafelerde su sıcaklığının yükselmesi ile memba tarafında av verir. Akarsu balıkçılığında genel olarak olta takımları ve serpme ağları kullanılmaktadır. Akarsularda avcılık yerel halk, amatör balıkçılar ve yerli turistler tarafından yapılmaktadır. Tüm bu av araçları haricinde yerel halkın mahareti olarak kabul edilen akarsu ve kollarında yapılan avcılıkta gece vakti fener yardımıyla taşların altından elle avcılık da söz konusudur.

Karadeniz somonunu nesli tükenmekte olan ve korunan (kaybolan) olarak Ukrayna Kırmızı Kitabı'na 1994 yılında kaydedilmiştir (Akimov ve Radchenko, 2009). Rusya Federasyonu, 10 yılda bir yenilenen ve son baskısı 2020 yılında yayınlanan Kırmızı Kitabı'nda türü nadirlik kategorisinde tehlike altında olarak kategorilendirmiştir (Anonim, 2024b) Gürcistan, Kırmızı Listesinde 2006 yılında yer almıştır (Goradze, 2009). Türkiye'de, Karadeniz somonu avcılık yasakları 1977-1978 av döneminde zamansal ve mekânsal olarak uygulanmaya başlanmış olup 2006-2008 av dönemine Denizalası (*Salmo trutta labrax*) adı ile ilk kez avlanması tamamen yasak olan cins ve türler sınıfına dâhil edilmiştir.

İLK BİLİMSEL ÇALIŞMALAR

Balıklar; gelişimsel biyoloji, genetik, biyoteknoloji, evrimsel biyoloji, fizyoloji, nörobiyoloji, karşılaştırmalı biyoloji, hastalık araştırmaları, toksikoloji, ekoloji, su ürünleri yetiştiriciliği ve eğitimi gibi birçok farklı alan ve amaç için bilimsel çalışmalarda kullanılmaktadır (Korkmaz, 2023). Balık araştırmaları hem laboratuvarlarda hem de saha ortamlarında gerçekleştirilebilir ve kullanılan yöntemler, müdahalesiz gözlemlerden, işleme ve deneysel manipülasyona kadar bir sürekliliği temsil eder (Sloman vd., 2019). Her bir balık türünün diğer balıklara göre kendine özgü avantajları bulunmaktadır ve farklı amaçlar için uygun farklı balık türlerinin de yeni model organizmalar olarak kullanılmasına devam edilmektedir (Korkmaz, 2023). Karadeniz'in endemik

türlerinden olan Karadeniz somonu anadrom özellik göstermesi, emsallerine göre daha büyük olması, beğenilen vücut formuna ve renklere sahip olması, etinin lezzetli olması ve ekonomik değerinin yüksek olması gibi özelliklerinden dolayı birçok bilimsel araştırmada model organizma olmuştur. Doğal dağılım alanı, biyolojisi, ekolojisi, korunma durumu ve kültür şartlarında üretimine yönelik birçok bilimsel çalışma yapılmıştır. Karadeniz'e kıyısı olan ülkelerden Türkiye, Rusya, Gürcistan, Ukrayna, Romanya ve Bulgaristan türün doğal dağılım alanı, biyoekolojik özellikleri, genetik özellikleri, doğal stokların korunması ve balıklandırmaya yönelik çok sayıda çalışma yürütmüştür. Bu ülkeler arasında Türkiye, türün biyoekolojisi, kültür özelliklerinin belirlenmesi ve kültür hattını oluşturmak amaçlı yürüttüğü selektif ıslah çalışmaları ile ön plana çıkmıştır.

Karadeniz somonunun doğal dağılım alanı, Karadeniz ve Azak Denizi kıyıları ile bu denizlere dökülen nehirlerdir. Bazı bilim adamları Karadeniz somonunu endemik bir tür olarak, bazıları da Atlantik salmonunun (*Salmo salar*) alt türü olarak kabul etmektedir (Bănărescu, 1964; Dorofeeva, 1965; Jonsson, 1982; Barachi, 1962; Oțel, 2007). Genel olarak anadrom bir tür olarak anılır ancak izole edilmiş potamodrom popülasyonları da vardır. Türün Karadeniz ve Azak Denizi havzası için endemik olması nedeniyle yalnızca Romanya, Türkiye, Gürcistan, Rusya, Bulgaristan ve Ukrayna'da mevcut olduğu varsayılmaktadır (Cărăuşu, 1952; Svetovidov, 1984; Vasilieva, 2003; Kottelat & Freyhof, 2007). Türün morfolojik yapısına yönelik çok sayıda çalışma yapılmıştır. Anadrom formunun rengi daha gümüşi olup, vücuttaki kırmızı beneklerin sayısı azdır (bazen eksiktir) ve siyah benekler diğer ekotiplerdeki kırmızı yuvarlak beneklere kıyasla x şeklindedir. Kuyruk yüzgeci hafifçe çıkıntılıdır vda kenarı daha koyudur. Yağ yüzgeci diğer alabalık türlerine göre daha az gelişmiştir (Bănărescu, 1964; Popescu-Gorj ve Dimitriu, 1956; Oțel, 2007). *Salmo labrax*'ın diş yapısı *Salmo trutta* ile benzerdir (her iki türün de üst çenesinde, alt çenesinde, dilinde ve vomer kemiğinde dişleri vardır). Ancak Salmonidae ailesinden *Salvelinus alpinus* ve *Hucho hucho* gibi diğer türlerle karşılaştırıldığında ana dişlerin farkı vomer diş yapısının eksik olmasıdır (Constantinescu vd., 2015; Ihuț vd., 2017). Pilor keselerinin sayısı 40 ile 62 arasında, genellikle 46 ile 47 arasında değişmektedir (PopescuGorj ve Dimitriu, 1956). Karadeniz somunu, kahverengi alabalıklardan meristik karakterlerle ayırt edilebilir. *Salmo labrax*'ın sırt yüzgeci (D) ışın sayıları, bazen *Salmo trutta*'nın (S. trutta = III-V'ye karşı S. labrax = III-IV) ışın sayılarıyla örtüşmektedir. Dallanmış ışınlar için de aynı durum sözkonusudur (S. trutta = 9-10 (11) ve S. labrax = 9-10). Sırt yüzgecindeki 11 dallı ışın *Salmo trutta*'yı gösterebilir. *Salmo labrax*'ın anal yüzgeci (A) dallanmamış ışın sayısı, *Salmo trutta* ile örtüşmektedir (*S. trutta* = II-IV'e karşı *S. labrax* = III-IV). Ventral yüzgeç (V) Dallanmamış ışın sayısı her iki tür için de eşittir. *Salmo labrax*'ın karın yüzgecinin dallanmış ışınları her zaman 8'e eşitken, *Salmo trutta'*da bu sayı 7 ila 9 arasında değişir (Bănărescu, 1964; Kottelat ve Freyhof, 2007; Cărăuşu, 1952; Svetovidov, 1984; Holčík ve Stefanov, 2008; Bușniță ve Alexandrescu, 1963; Page ve Burr, 1991; Oțel, 2007; Popescu-Gorj ve Dimitriu, 1956). Türkiye'nin Doğu Karadeniz Bölgesinden elde edilen doğal bireylerle yapılan karyolojik ve serolojik analizlerde tür veya alt tür düzeyinde bir farklılığın olmadığı ortaya konmuştur. Morfolojik farklılıkların ekolojik yaşama ortamlarından kaynaklandığı ve bu türün ekotiplerini oluşturduğu tespit edilmiştir (Tabak vd., 2001).

Karadeniz somonları, deniz ve akarsu arasında beslenme ve üreme göçü yapmaktadır (Barachi,1962). Karadeniz havzasında olduğu gibi anadrom populasyonların bulunduğu tüm nehirlerde ve iç bölgelerde yer alan birçok akarsuda alabalığın denize göç etmeyen populasyonları da bulunmaktadır (Jonsson, 1985; Chelkowski vd., 1994; Frosman vd., 1998; Baglinière ve Maisse, 1999). Karadeniz alabalığının anadrom formu yaklaşık 1-3 yıl süreyle denizde kalmakta ve yeterli büyüklüğe eriştikten sonra, üremek amacıyla derelere giriş yapmaktadır. Tatlısuda yumurtadan çıkan balıklar bir veya üç yıl akarsu ortamında kalmakta ve daha sonra dere ağızlarında ve kıyısal bölgede belirli bir sürede smoltifikasyon geçirerek denize göç etmektedir (Berg, 1962; Solomon, 2000).

Karadeniz somonunun bulunduğu doğal ortama bağlı olarak beslenmesi de değişmektedir. Tatlısuda kabuklu ve böceklerle beslenen bireyler, kıyı bölgelerinde smoltlaşma döneminde bu besinlerin yanında balık ve bentik organizmalarla beslenmektedir (Johnstone vd., 1995). Göl ortamındaki ana besin grubunu yumuşakçalar, akarsu ortamında sucul böcekler oluşturuken, denizel ortamda ise kabuklu ve balıklar baskın durumdadır (Tabak vd., 2001).

Diğer alabalık türlerine benzer olarak Karadeniz somonunun yumurtlama dönemi eylül-kasım aylarında başlamakta ve şubat ayının sonlarına kadar devam edebilmektedir (Berg, 1962; Çelikkale, 1988; Svetovidov, 1984; Kuru, 1975). Denizden dönen alabalıklar içgüdüsel olarak, yumurta bırakmak için uygun olan alanları seçmektedir. Anaç balıklar, genellikle kumsal olmayan, iri çakıllı ve taşlık alanlarda, temiz ve yeterli su akışına sahip, kuraklık, bulanıklık, taşkın ve buzlanma gibi faktörlerden etkilenmeyen alanlarda yumurta bırakmaktadır (Ölmez vd., 1998). Karadeniz somonu deniz ekotipine ait bireyler ağırlıklı olarak kasım ayında, nadiren de aralık ayı ortalarına kadar üremesini sürdürmektedir. İlk eşeysel olgunluk boyunun dere ekotipi dişileri için 15.54 cm, erkekler için 13.70 cm, deniz ekotipi bireylerin ise 44.76 cm olarak belirlenmiştir. İlk üreme yaşı dere ekotipinde 2+, deniz ekotipinde ise 3+ yaş olduğu tespit edilmiştir. Yumurta verimi dere ekotipinde 2428±162 adet/kg, deniz ekotipinde 2543±131 adet/kg hesaplanmıştır. Yumurta çaplarının dere ekotipinde 3,6-5,7 mm, deniz ekotipinde 4,6-7,2 mm arasında olduğu görülmüştür (Tabak vd., 2001).

Karadeniz havzasındaki kahverengi alabalık popülasyonlarının genetik özelliklerine yönelik çalışmalar oldukça azdır. Karadeniz, Hazar ve Aral Denizi havzalarında dağılım gösteren çok az sayıda kahverengi alabalık

popülasyonu araştırılmıştır (Bernatchez ve Osinov, 1995; Osinov ve Bernatchez, 1996; Bernatchez, 2001). Bu bölgede Tuna, Atlantik ve Adriyatik olmak üzere üç filocoğrafik grup tespit edilmiştir. Çalışılan Karadeniz popülasyonlarının büyük bir kısmının Tuna Soy Grubuna ait olduğu görülmüştür (Osinov ve Bernatchez, 1996; Bernatchez, 2001). Togan vd., (1995), Karadeniz ve Akdeniz havzalarındaki iki popülasyon arasında üç allozim lokusunda sabit farklılıklar olduğunu, Türkiye'nin Karadeniz kahverengi alabalığı popülasyonunun, Tuna ve Akdeniz grupları arasında yer alan, tanımlanamayan bir filogenetik gruba ait olduğunu belirlemiştir. Türk kahverengi alabalığı popülasyonuna özgü dört alel bulmuş, ancak Karadeniz alabalığı için spesifik bir alel veya morf bulamamışlardır. Çiftçi vd., (2007), Türkiye'nin değişik bölgelerinde bulunan anadrom ve anadrom olmayan kahverengi alabalık ve Anadolu alası (*Salmo platycephalus*) populasyonlarının genetik ve morfolojik yapıları mtDNA-RFLP analiz yöntemi ve Truss ağı sistemi kullanılarak çalışılmıştır. Morfometrik ve meristik karakterler için populasyonlara ait bireylerin kendi orjinal gruplarına doğru sınıflandırma oranının % 84,36 olduğu, S. *platycephalus* ve *S. t. abanticus*'un diğer taksonlardan açık bir şekilde ayrıldığı ve *S. t. labrax* ile *S. t. fario* ve *S. t. caspius* ile *S. t. macrostigma*'nın aynı alt grup içinde yer aldığı tespit edilmiştir. Bu türler arasındaki herhangi bir genetik farklılığın, mikrosatellit analizi gibi hassas bir yöntemle bile tespit edilemediğini göstermektedir (Susnik vd., 2006, 2007). Latiu vd. (2020) Türkiye'de Tuna soyuna ait olan *S. trutta*'nın *Salmo trutta* olarak anılmasını ve suşların Abant, Hazar, Karadeniz ve Anadolu gibi lokasyonlara göre isimlendirilmesini ayrıca balıklar üzerinde yapılan genetik çalışmalara morfolojik ve meristik verilerin, coğrafi koordinatların ve balık örnekleme periyodunun da eklenmesini önermiştir. Yeni nesil dizilemenin (NGS) ve ilgili analitik araçların geliştirilmesi ile Segherloo vd. (2021), 15.169 filtrelenmiş SNP ve mitokondriyal DNA (mtDNA) D-loop dizilerini dizileyerek Genotipleme (GBS) yöntemiyle 21 türü ve 84 bölgeden toplanan üç tanımlanmamış grubu temsil eden 166 kahverengi alabalık arasındaki filogenetik ilişkileri çalışmışlar ve Tuna drenajından *S. rizeensis* ve *S. coruhensis*'in *S. labrax* ile çok yakın akraba olduğunu belirlemişler ve tür ayrımının garanti edilemeyebileceğini öne sürmüşlerdir.

Somon balıklarının eşsiz temsilcisi olan Karadeniz somonu, somon balıklarının en büyük türlerinden biridir (Nikandrov ve Shindavina, 2007). Kodori Nehri'nde 24 kg'a kadar, Batum'da 16 kg kadar, Türkiye'nin Doğu Karadeniz Bölgesindeki akarsularda 13 kg kadar bireyler yakalanmıştır (Berg, 1948; Solomon, 2000; Aksungur vd., 2011; Çakmak vd., 2022a, b). Geçen yüzyılın ilk yarısında *S. trutta labrax*'ın sayısını koruma ve iyileştirme girişimleri yapılmıştır. 1935'ten 1958'e kadar Abhazya'da Kodori nehirlerinde balıklandırma çalışmaları yapılmıştır (Barachi, 1962; Shevtsova, 1969). 1990'lı yıllardan 2000'e kadar serbest bırakılan yavruların sayısını artırmak, yumurtlama için gelen dişilerin nadir görülmesi nedeniyle mümkün olmamıştır (Kulyan, 1999). Kuluçkahane kökenli Karadeniz somonu yavruları (F3) kullanılan ilk balıklandırma çalışması Yanbolu Deresi'nde yapılmıştır. Bu çalışmada markalı kuluçkahane kökenli bireylerin akarsudaki dağılımı, adaptasyonu, büyüme ve beslenme özellikleri incelenmiştir (Çakmak vd., 2010). Karadeniz'in ve bölgesel biyolojik çeşitliliğin eşsiz ve değerli bir olgusu olan somon balığı, son iki yüzyıldır sürekli olarak antropojenik baskı altındadır (Goradze, 2009). Karadeniz somonu popülasyonunun, aşırı avlanma ve habitatlarının bozulması nedeniyle yok olma aşamasına gelen stokların toparlanması için yeni bir yönetim stratejisi uygulanmalıdır (Aksungur vd., 2011).

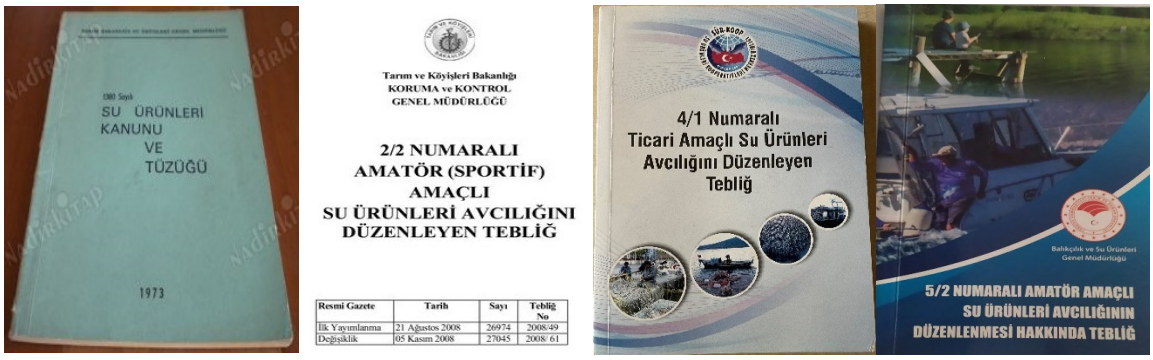
Karadeniz somonunun kültür şartlarında üretimi ilk olarak balıklandırma amacıyla Rusya'da yapılmıştır. Bu çalışmalarda türün üretim veriminin iyileştirilmesi ve yetiştiricilik sektörüne kazandırılması gibi hedefler gözetilmemiştir. Türkiye'de, FAO desteği ile 1988 yılında başlatılan ekonomik değeri yüksek türlerin dağılım alanı, stok durumları ve üretim alanlarının belirlenmesi çalışmalarına mersin balıkları (*Acipenser sp.*) ve kalkan (*Scophthalmus maximus*) ile beraber Karadeniz somonu da dâhil edilmiştir. 1998 yılından sonra her üç türün biyoekolojik ve kültür özelliklerini belirlemek amacıyla Su Ürünleri Merkez Araştırma Enstitüsü çalışmalar yürütmüştür. 1998-2001 yılları arasında yapılan çalışmalarla doğadan toplanan Karadeniz somonu bireyleri kültür şartlarına adapte edilerek ilk damızlık stok oluşturulmuş ve F1 bireyler elde edilmiştir. Bu çalışmada, türün kültür potansiyeli fark edilmiş ve tüketici tercihi yüksek yeni bir türün yetiştiriciliğe kazandırılması amacıyla seçim programı başlatılmıştır. 2002 yılında hazırlanan seçici ıslah programında; smolt boya erken ulaşma, doğal morfolojik karakterleri muhafaza, kültür şartlarına erken adaptasyon, geç cinsi olgunluğa ulaşma ve yüksek üreme verimi gösteren bireyler tercih edilmesi kararı alınmıştır (Çakmak vd., 2022a). Yürütülen seçici ıslah programında başarı sağlanmış olup kültür şartlarına adaptasyon kabiliyeti yüksek ve kültür özellikleri iyileştirilen F3 nesil kültür hattı damızlıkları 2009 yılında türün doğal dağılım alanında faaliyet gösteren özel sektöre verilmiştir. Sonraki yıllarda devam ettirilen seçici ıslah çalışmaları beraberinde türün besin ihtiyaçları belirlenmiş ve 2020 yılında F7 nesil bireyler elde edilmiştir. Günümüzde türün genetik yaklaşımlı ıslah çalışmaları devam etmektedir.

AVCILIĞIN MEVZUATLARDAKİ YERİ

Türkiye akarsularında yaşayan endemik (*Salmo platycephalus, Salmo trutta abanticus*, *Salmo labrax*) ve egzotik (*Oncorhynchus mykiss, Salvelinus alpinus, Salvelinus fontinalis* vb.) alabalık türlerinin Karadeniz somonu da dâhil olmak üzere avcılığı, yüzlerce yıldır yapılmaktadır. Türün popülasyonları da dâhil olmak üzere özellikle endemik alabalık türlerinin korunması ve sürdürülebilir kullanımı Türkiye için uzun süredir önemli bir hedef olmuş ve konuya yönelik birçok yasal mevzuat hazırlanmıştır.

Türkiye hem doğal stokları korumak hem de sürdürülebilir kullanımını sağlamak amacıyla su ürünleri avcılığını düzenleyen tebliğler ilk çıktığında yıllık, sonrasında iki yılda

bir ve günümüzde ise her dört yılda bir yayınlamaktadır (Şekil 9). Bunlardan biri, 5/1 Numaralı Ticari Amaçlı Su Ürünleri Avcılığını Düzenleyen Tebliğ; su ürünleri avcılığında uygulanmak üzere bilimsel, çevresel, ekonomik ve sosyal hususlar göz önüne alınarak su ürünleri kaynaklarının korunması, sürdürülebilir işletilmesinin sağlanması için su ürünleri avcılığına ilişkin yükümlülük, sınırlama ve yasakları düzenlemektedir. Diğeri ise amatör balıkçılığın belirli kurallar çerçevesinde yapılmasını sağlamak üzere kullanımına izin verilen avlanma araçları ile ticari amaç dışı su ürünleri avcılığı yapacak olanların avlanmalarına ilişkin usul ve esasları belirleyen 5/2 Numaralı Amatör Amaçlı Su Ürünleri Avcılığını Düzenleyen Tebliğdir. 5/1 numaralı tebliğ ile avlanmasına izin verilen alabalıkların boy, yer ve zaman aralıkları belirlenmiştir. 5/2 numaralı tebliğde ise içsularımızdaki ekolojik açıdan potansiyel sakıncalı balıkların kontrolsüz ve izinsiz olarak canlı nakledilmesi ve başka kaynaklara bırakılması, avlanabilir asgari boy ve alıkonulabilir miktar, zaman yasakları, av aracı sayı sınırlaması, avcılıkta kullanılacak yem cinsi ve avcılığın tamamen yasaklandığı sular ve türler belirlenmiştir (Anonim, 2024c). 1380 Sayılı Su Ürünleri Kanununun koruma ve kontrol konulu 33. Maddesi ile Tarım ve Orman Bakanlığı teşkilatında ve Bakanlığa bağlı su ürünleri ile ilgili teşekküllerde su ürünlerinin, deniz ve içsuların koruma ve kontrolü ile görevlendirilen personel ile emniyet, jandarma, sahil güvenlik, gümrük ve orman muhafaza teşkilatları mensupları, belediye zabıtası amir ve mensupları, kamu tüzel kişilerine bağlı muhafız, bekçi ve korucular ile emniyet ve jandarma teşkilatının bulunmadığı yerlerde köy muhtarı ve ihtiyar heyeti üyeleri bu Kanunla ve bu Kanuna istinaden konulan yasaklardan dolayı, bu Kanun kapsamına giren kabahatler ve suçlar hakkında zabıt varakası tutmak, kabahatin ve suçun işlenmesinde kullanılan istihsal vasıtalarına ve elde edilen su ürünlerine el koymak ve bu Kanunun ek 3 üncü maddesinde yer alan hükümler çerçevesinde idarî para cezalarını kesmekle vazifeli ve yetkilendirilmiştir (Anonim, 2024d). 5/1 ve 5/2 numaralı tebliğ ile Karadeniz somonunun avlanması tamamen yasaklanmıştır (Anonim, 2024e).



Şekil 9. 1380 Sayılı Su Ürünleri Kanunu ve Tüzüğü-1973 (Nadirkitap, 2024), 2/2 Numaralı Amatör (Sportif) Amaçlı Su Ürünleri Avcılığını Düzenleyen Tebliğ-2008, 4/1 Numaralı Ticari Amaçlı Su Ürünleri Avcılığını Düzenleyen Tebliğ-2016 ve 5/2 Numaralı Amatör Amaçlı Su Ürünleri Avcılığının Düzenlenmesi Tebliğ-2020

Tarım ve Orman Bakanlığı (TOB, 2024), Türkiye sularında dağılım gösteren alabalık türlerini ve stoklarını belirlemek amacıyla 1970'lı yıllarda çalışma başlatılmıştır. 1380 sayılı Kanuna ilişkin Su Ürünleri Tüzüğü 27 Temmuz 1973 tarih ve 14670 sayılı Resmî Gazete'de yayımlanarak yürürlüğe girmiştir. İlk Su Ürünleri Avcılığının Düzenlenmesine Dair 1 Numaralı Sirküler ise 28.08.1973 ve 14634 sayılı Resmi Gazete'de yayınlanarak yürürlüğe girmiştir. Bu sirkülerle bazı yerel alanlarda alabalıkların avlanmasına zaman yasağı getirilmiştir. Su Ürünleri Avcılığını Düzenleyen 1977-1978 Av Dönemine İlişkin 5 Numaralı Sirküler'de ise ilk defa Karadeniz somonunun dağılım gösterdiği Fırtına Deresi, İkizdere ve Meryemana Deresi'ndeki avcılığa mesafe ve zaman yasağı getirilmiştir. Su Ürünleri Avcılığını Düzenleyen 1978-1979 Av Dönemine İlişkin 6 Numaralı Sirküler'de mesafe ve zaman yasağı yanında ilk defa boy yasağı getirilmiştir. Su Ürünleri Avcılığını Düzenleyen 1985- 1986 Av Dönemine İlişkin 18 Numaralı Sirküler'de Karadeniz somonunun dağılım gösterdiği Artvin, Rize ve Trabzon İllerindeki tüm akarsuların bazı kesimlerinde avcılık yıl boyu yasaklanmıştır. Karadeniz somonu, Deniz alası (*Salmo trutta labrax*) adı ile ilk kez 2006-2008 Av Dönemine Ait 37/1 Numaralı Sirküler ile avlanması tamamen yasak olan cins ve türler sınıfına dahil edilmiştir.

Karadeniz somonu, doğal stokları üzerinde uzun yıllar devam eden antropolojik etkenler nedeniyle Avrupa Konseyinin 1952 yılında hazırlamış olduğu Bern Sözleşmesi uyarınca soyu tükenen ve koruma altına alınması gereken türler arasında sayılmıştır (Arançlı, 2001). Fakat yerel halk tarafından sevilerek tüketilen, albenisi ve ekonomik değeri yüksek olan türün doğal stokları üzerindeki av baskısı günümüzde de devam etmektedir. Türkiye iç sularında 2013 yılında 437,5 ton/yıl olan avcılıktan elde edilen alabalık miktarının %67,08 azalma ile 2023 yılında 144 ton/yıla (TÜİK, 2024) gerilemiştir.

İLK YETİŞTİRİCİLİK ÇALIŞMALARI, YAYGINLAŞMASI VE MEVCUT DURUM

Son yıllarda su ürünleri sektöründe yaşanan hızlı büyümede (FAO 2022) su ürünleri yetiştiriciliğinin ekonomik ve sosyal ilkeler ile uzlaşı içinde olması, gıda güvenliğine ve kıyı topluluklarının refahına katkıda bulunması etkili olmuştur (Carrasco vd., 2024). Küresel düzeyde yaşanan bu gelişmelere Türkiye kayıtsız kalmamış ve uluslararası pazarda önde gelen üretici ülkelerden biri olmuştur. FAO

(2022) verilerine göre Türkiye, Dünya su ürünleri üretiminde deniz avcılığında 43. sırada, içsu avcılığında 36. sırada, yetiştiricilikte ise 17. sırada yer almaktadır. AB ülkeleri arasında su ürünleri yetiştiricilik üretiminde ise 1. sırada olup bu üretimin %38,2 si alabalıktır. Türkiye'de alabalık üretimi için ticari yatırımlar 1970'li yıllarda başlamıştır (Korkut vd., 2023). Son yıllarda su ürünleri yetiştiriciliğinin ürettiği sosyo-ekolojik ve bilimsel literatür değişiklikleri diğer sektörlerle beraber akademisyenlerin de dikkati çekmiştir (Belton ve Bush, 2014; Ruff vd., 2022). Yerel tüketim için küçük ölçekli yetiştiricilikten küresel pazar için endüstriyel ölçekli yetiştiriciliğe geçişte üretim sistemlerinde yeni teknoloji kullanımı ile yetiştiriciliği yapılan türlerin çeşitlendirilmesi sürdürülebilirlik açısından önemli olmuştur (Naylor vd., 2021). Bu bağlamda Türkiye, 1990'lı yılların sonunda bilimsel kuruluşlarını yeni türlerin kültüre alınması için harekete geçirmiştir. Yeni türlerin kültür üretimine kazandırılması için yapılan ilk bilimsel çalışmalardan biri de Karadeniz somonuna yöneliktir.

Karadeniz somonunun doğal dağılım alanı olan Karadeniz havzasındaki ülkeler, genel olarak türün biyoekolojik ve genetik özellikleri ile balıklandırma amaçlı üretimine yönelik bilimsel çalışmalar yapmışlardır. Türün kültür özelliklerinin belirlenmesi ve kültür hattının oluşturulmasına yönelik çalışmalar ise ilk olarak Türkiye'de başlatılmıştır. Türkiye'de, Karadeniz somonunun biyo-ekolojik özelliklerinin belirlenmesi amacıyla SUMAE 1997 yılında başlatılan çalışma ile ilk doğal damızlık stoku oluşturulmuştur. Kuluçkahane kökenli ilk damızlık stok ise 2001 yılında oluşturulmuş olup bu tarihten itibaren türün kültür özelliklerini iyileştirilmesi amacıyla ıslah çalışmaları başlatılmıştır (Çakmak vd., 2022a). Yürütülen seçici ıslah çalışmaları ile kültür şartlarına adaptasyonu tamamlanmış, üreme ve büyüme özellikleri iyileştirmiş 3. nesil damızlık bireyler 2009 yılında türün yetiştiriciliğinin yaygınlaşması için özel sektöre kazandırılmıştır (Çakmak vd., 2011). Özel sektör tarafından ilk kültür üretimleri deneme üretimi şeklinde olmuştur. Takip eden yıllar içinde türün doğal dağılım alanı olan Doğu Karadeniz Bölgesinde faaliyet gösteren özel işletmeler ticari üretime başlamıştır.

Bilio (2007a), balıklarda hangi türlerinin evcilleştirildiğini belirlemek için kapsamlı bir analiz gerçekleştirdi. Seçici yetiştirme ile en az üç ardışık üreme döngüsünden (nesiller) sonra türlerin evcilleştirilmiş olduğu kabul edildi; bunun yabani türden değişiklikler elde etmek için yeterli süre olduğu varsayılmıştır (Bilio, 2007b). Teletchea ve Fontaine (2014) yüzgeçli balık türlerinin evcilleştirilmesi düzeylerini 5 basamakla farklı şekilde açıklamıştır. Buna göre; 0. doğal ortamdan temin, 1. kültür ortamına adaptasyon, 2. yaşamının bir bölümünü kültür şartlarında tamamlama, 3. tüm yaşam döngüsünü kültür şartlarında tamamlama, 4. seçici yetiştirme programı uygulanmadan tüm yaşam döngüsünü kültür şartlarında tamamlama ve 5. belirli hedeflere odaklanarak seçici ıslah programı uygulama ve yeni kültür hattı oluşturmadır. Bu çalışmalara göre, SUMEA'nın yürüttüğü seçicilik programı neticesinde Karadeniz somonu evcilleştirilmiş türler arasında kabul edilebilir.

Günümüzde ağırlıklı olarak Doğu Karadeniz Bölgesinde faaliyet gösteren 26 adet özel işletme Karadeniz somonunun ticari üretimini yapmaktadır (Tablo 1). Kuluçkahaneler, akarsu havuz işletmeleri, baraj gölü ağ kafes işletmeleri ve deniz ağ kafes işletmeleri sıralaması üretim zinciri halinde kullanılmaktadır. Damızlık yönetimi genel olarak akarsu havuz işletmelerinde doğal çevresel şartlarda yapılmaktadır. Birkaç özel işletme ve araştırma kurumu üretimde biyoteknolojik (fotoperiyot, kısır-dişi stok) uygulamalar yapmış fakat halen bu uygulamalar deneme üretimi şeklindedir. Kaynak suyu kullanılan kuluçkahanelerde 3-5 gr'a kadar büyütülen yavru balıklar porsiyonluk boya (200-250 g) büyütülecekleri havuzlara (akarsu ile beslenen) veya baraj gölü ağ kafeslerine nakledilmektedir. Deniz ağ kafes sistemleri ise smolt boydan (11,5 cm) sonra az sayıda porsiyonluk üretim için kullanılmakta olup daha çok filetoluk (≥ 3 kg) üretim için kullanılmaktadır.

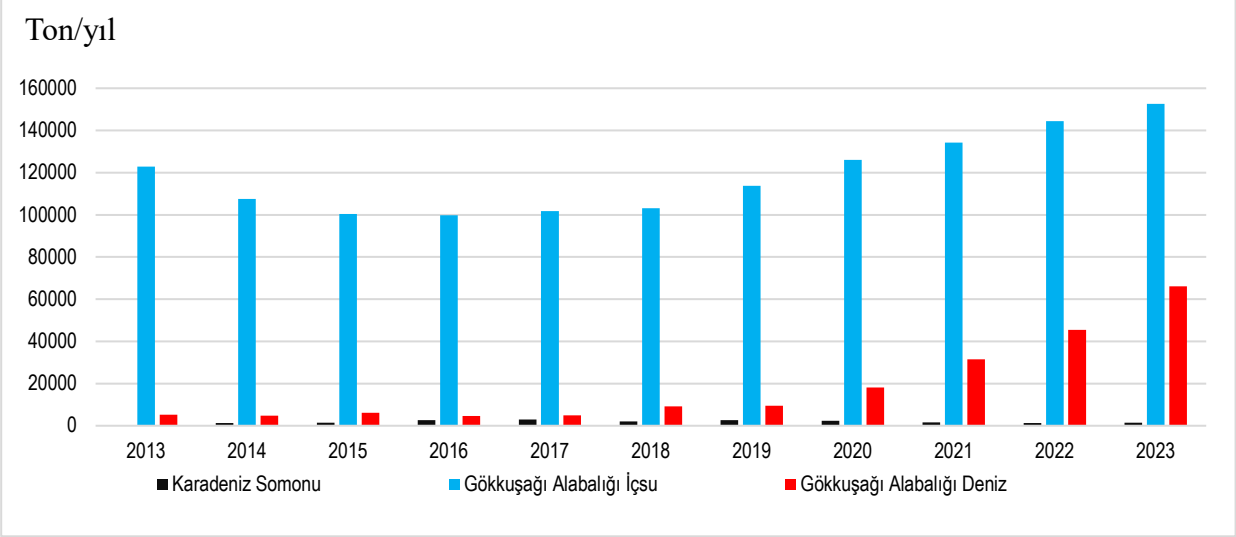
Bu üretim tesisleri aynı firmanın olduğu gibi sadece bir üretim tesisine sahip firmalar da mevcuttur. Damızlık yönetimi uygulayan 12 adet kuluçkahane işletmesinin Karadeniz somonu (deniz alası) toplam yavru üretim kapasiteleri 73.783.000 adet/yıl'dır. 16 adet akarsu havuz işletmesinin toplam porsiyonluk üretim kapasitesi 443 ton/yıl'dır. 6 adet baraj gölü ağ kafes işletmesinin porsiyonluk ve filetoluk toplam üretim kapasiteleri 1.405 ton/yıl, 4 adet deniz ağ kafes işletmesinin filetoluk (≥1500 g) üretim kapasiteleri ise 990 ton/yıl'dır (BSGM, 2023) (Tablo 1). Çevresel özelliklerinden dolayı özellikle yaz aylarında Karadeniz'den karşılanamayan filetoluk balık talebi çevresel özellikleri uygun olan ve yıl boyu üretim yapılan baraj gölü ağ kafes işletmelerinden karşılanmaktadır.

Türkiye su ürünleri yetiştiricilik istatistiklerine ticari Karadeniz somonu üretimi ilk defa 2014 yılında Alabalık [(*Salmo* sp.) Trout (*Salmo* sp.)] ismi ile dâhil edilmiştir. 2014 yılında toplam 1248 ton/yıl olan ticari yetiştiricilik üretimi, 2017 yılında 2924 ton/yıl ile giderek yükselen ivme kazanmıştır. 2017 yılından sonra azalma eğilimine görülen üretim miktarı 2023 yılında 1440 ton/yıl seviyelerine gerilemiştir. Karadeniz somonu üretimindeki azalma eğilimi, Türkiye'de ihracata yönelik Türk Somonu (*Oncorhynchus mykiss*) üretiminin başladığı tarih ile örtüşmektedir (Şekil 10). Özellikle Türkiye'nin Doğu Karadeniz Bölgesinde yoğunlaşan Türk Somonu üretimi, Karadeniz somonunun baraj gölü ve deniz ağ kafes sistemlerinde üretimini geri plana itmiş olup üretimin akarsu havuz işletmelerine sıkışmasına neden olmuştur.

Yeni bir türün kültüre alınması ve yetiştiricilik sektörüne kazandırılması oldukça uzun soluklu uğraşlar gerektirmektedir. Çakmak vd. (2011) ilk çalışmadan (1998) sonra yaklaşık 11. yılda 3. nesil bireylerle özel sektörün desteklenmesini sağlamış olup ıslah çalışmaları günümüzde de devam etmektedir. Bu başarıda doğal koşulların elverişliliği ve araştırmacıların özverili gayreti yanında bilimsel çalışmaların devamlılığı, artan tüketici talebi, teknolojik gelişmeler ve özel sektörün istikrarlı yatırım isteği önemli olmuştur. Benzer şekilde, Naeve vd. (2022), Norveç'te kültür üretimine kazandırılan ve önemli bir endüstri haline gelen Atlantik somonunun ıslah çalışmalarının 11. nesil ile devam ettiği bildirilmektedir.

Tablo 1. Türkiye'de Karadeniz somonu üreten işletmeler ve üretim miktarları (BSGM, 2023)

Firma Adı	Yavru Üretimi (adet/yıl)	Havuz Porsiyonluk Üretimi (kg)	Baraj Gölü Porsiyonluk Üretimi (kg)	Deniz Filetoluk Üretimi (kg)
Biberoğlu Alb.	-	-	250000	-
Kuzuoğlu A.Ş.	-	-	600000	-
Kuzuoğlu A.Ş.	-	-	500000	-
Y. Bilir	-	-	5000	-
S. Yılmaz	1.500.000	2000	-	-
Tuna A.Ş.	-	-	50000	-
Abu Ltd. Şti.	55000000	75000	-	-
S. Kuru	1350000	9000	-	-
Nombane Ltd. Şti.	1450000	11000	-	-
Arde-Som A.Ş.	400000	10000	-	-
Arde-Som A.Ş.	775000	150000	-	-
Ofis A.Ş.	-	14000	-	-
F. Demirkıran	56000	14000	-	-
M. A. Akyaz	-	-	-	350000
Turk Salmon Ltd. Şti.	-	-	-	350000
İ. Güner	-	5000	-	-
İ. Kayacı	20000	5000	-	-
İ. Sarı	-	10000	-	-
M. Önder	-	10000	-	-
İstanbul Ü.	3200000	20000	-	-
D. Altıntaş	-	-	-	-
D. Karadeniz A. Ş.	-	-	-	290000
F. Kibar	24000	6000	-	-
Sümela Ltd. Şti.	10000000	100000	-	-
C. Murutoğlu	-	-	-	-
S. Bahram	8000	2000	-	-
Toplam	**73783000**	**443000**	**1405000**	**990000**



Şekil 10. Türkiye'de yıllar itibarıyla alabalık üretim miktarları (TÜİK, 2024)

TÜRÜN BÖLGE HALKININ SOSYO-EKONOMİK HAYATINA ETKİLERİ

Ekolojik sürdürülebilir kalkınma ve ekosistem temelli balıkçılık yönetimi ilkeleri, balıkçılığın sosyal, çevresel ve ekonomik hedefler doğrultusunda yönetilmesini gerektirir. Ancak balıkçılığın bu üç hedefe ulaşma başarısını kapsamlı değerlendiren çalışmalar nadirdir (Voyer vd., 2017). Bu üç hedef, aynı zamanda dünyanın birçok balıkçılık politikası ve düzenleyici çerçevesinin merkezinde yer almakla beraber ekolojik olarak sürdürülebilir kalkınma ilkelerinin de merkezinde yer almaktadır (Brundtland, 1990). Karadeniz somonunun doğal dağılım alanının benzer türlere göre daha dar olması ve Karadeniz'e komşu ülkeler arasındaki balıkçılık iş birliğinin oldukça iyi düzeyde olması türe yönelik sosyo-ekonomik çalışmalara bütüncül yaklaşım için fırsat sunmaktadır.

Dünyanın birçok ülkesinde olduğu gibi Türkiye'de de deniz ve içsularında ticari ve rekreasyonel balıkçılık, yerel halk için yasal haktır ve geçmişi uzun yıllara dayanan bir gelenektir. Genel olarak bakıldığında, belgeli veya belgesiz

rekreasyonel balıkçılığa katılanlar avın tamamına yakınını taze olarak tüketilmektedir. Avcılığı yapılan bu türler yerel halk için önemli sosyal, kültürel ve ekonomik değere sahiptir. Avcılar ve av araçları dikkate alındığında Türkiye'de kıyı (küçük ölçekli) ve rekreasyonel balıkçılık diğer ülkelerdekine benzer şekilde yapılmaktadır. Rekreasyonel balıkçılık, doğadan keyif alan ve balık tutmayı önemli bir boş zaman etkinliği olarak görenler tarafından tercih edilmektedir. Daha fazla erkeklerin tercih ettiği ve motivasyon kaynağı olarak kabul edilen bu tür faaliyetlere çocukların eşlik ettiği ve az da olsa bir kısım kadınların ilgi gösterdiği görülmektedir.

Karadeniz somonunun dağılım alanı olan Giresun, Trabzon, Rize ve Artvin İllerinin toplam nüfusu 1.782.304 kişidir (TÜİK, 2023). Bu illerde, 16.234 kişinin su ürünleri ticari avcılık ve amatör avcılık ruhsatı vardır (BSGM, 2023). Bu oran Türkiye ortalamasının yaklaşık 4 katıdır. Türkiye'de eğlence, gezme-görme, ruhsal rahatlık amacıyla yapılan amatör avcılığa katılan topluluklar geniş ve çeşitli mesleklere sahiptir. Tarım ve Orman Bakanlığının 2022 tarihli verilerine göre Türkiye'de farklı isimlere ve faaliyet alanına sahip 59 adet amatör balık avcılığı derneği bulunmaktadır. Amatör avcıların çok azı bu derneklere üyedir. Amatör avcılar, genel olarak bir olta ve yem kullanarak çoğunlukla akarsularda nadiren de denizlerde balık avlamaktadır.

Kıyı ve rekreasyonel balıkçılığın; ekonomik gelir ve istihdam, geleneklerin ve kültürün korunması gibi sosyal motivasyonları yanında turizmle ilgili ekonomik boyutu, insan refahına katkısı, kültürel hizmeti (eğlence ve ekoturizm, estetik anlayışın gelişimi, ilham verici, eğitici, aidiyet duygusu, kültürel mirasın korunması) önemlidir (Raymond vd., 2009; Jax vd., 2013). Rekreasyonel balıkçılıkta, denizel türler (*Trachurus* sp., *Pomatomus* sp., *Sarda sarda* vb.) yanında tatlısu türleri olan alabalıklar (*Salmo sp.*), sazanlar (*Cyprinus sp.*), sudak (*Sander lucioperca*), turna (*Esox lucius*) ve benzeri türler tercih edilmekle beraber Karadeniz somonu gibi anadrom türler özellikle önemli olmuştur. Yerel halk için bu türün önemi; yararlı bir besin, omega-3 açısından zengin bir kaynak olması yanında halk arasında parmak ve daha küçük yutulabilir boydaki yavru balıkların mide rahatsızlıklarına ve yetişkin balıkların ise bel ağrılarına şifa kaynağı olduğu inancıdır.

Karadeniz somonu, doğal dağılım alanı olan Türkiye'nin Doğu Karadeniz Bölgesi denizel alanında, göllerinde ve akarsularında doğal stoklarının azaldığı gerekçesiyle avcılığının yasaklandığı 1982 yılına kadar avlanmıştır. Doğal stokların azalmasında en önemli etkenlerden biri olan aşırı avcılığın nedeni Karadeniz somonunun emsallerine göre ticari değerinin yüksek olması ve eğlence amaçlı balıkçılıkta en değerli olarak görülmesidir. Bu konu ile alakalı olarak yapılan proje çalışmasında, türün doğal dağılım gösterdiği akarsularda ve bu akarsuların denizel alanında avcılığın genel olarak smolt bireyler ve dere formları üzerinde yoğunlaştığı, sadece serpme ağları ile bir yılda 1036 kg balığın avlandığı, avın en fazla yoğunlaştığı mart ve nisan aylarında birim güçteki av miktarının (CPUE) 0.76 kg/gün/ağ olduğunu fakat yıl içindeki av miktarının tam olarak tespit edilemediği, yıl içindeki avın tahmin edilenin 4-5 katı olabileceği bildirilmiştir (Tabak vd., 2001). Ayrıca, av baskısının deniz ekotipi üzerinde yoğunlaştığını, üreme göçü yapan damızlık bireylerin Ekim-Haziran ayları arasındaki dönemde kıyı boyunca kurulan uzatma ağları ile yumurtlama sonrasında Ekim, Kasım ve Aralık aylarında tuzaklar ile yoğun olarak avlandığı, bu yöntemle bir yıl içindeki toplam avın 11099 kg olduğunu bildirmişlerdir. Aynı çalışmada Artvin, Rize, Trabzon, Giresun ve Ordu İlleri denizel alanında avlanan küçük ölçekli balıkçılar uzatma ağları ile bir üreme dönemi içinde 2416 kg damızlık balığın avlandığını bildirmişlerdir (Tabak vd., 2001). Yörede avcılığı yasaklanmadan önce türün avcılığını yapan Salim Biber, Nizamettin Çavuşoğlu ve Muharrem Hamza ile Eylül 2024'te yapılan yüz yüze görüşmemizde; küçük ölçekli ticari balıkçıların denizel alanda ve akarsu mansaplarında avlamış oldukları 3 kg'dan büyük Karadeniz somonlarını yaklaşık 200 ₺/kg (130 USD) fiyatla büyük şehirlerdeki lüks otel ve lokantalara, 3 kg'dan küçük olanların ise bölgede 130-150 ₺/kg (80-100 USD) karşılığında pazarlandığını beyan edilmiştir. Ayrıca akarsuda avcılık yapan amatör balıkçıların avladıkları 150 gr'dan büyük Karadeniz somonlarını bölgede faaliyet gösteren ve genelde turistlerin uğrak yeri olan restoranlara 400-500 ₺/kg karşılığında, yavru balıkları ise tedavi amaçlı 100 ₺/adet (65 USD) karşılığında pazarladıkları beyan edilmiştir. Av yasağından önce Karadeniz somonunun bölge halkı için çay, fındık ve ticari balıkçılık gelirinden sonra en önemli yan gelir kaynağı olduğu görülmektedir.

Bölge halkının sosyo-kültürel yaşamında çok özel bir önemi olan Karadeniz somonunun avcılığının 1982 yılında yıl boyu yasaklanmasına rağmen halen illegal avcılığı devam etmektedir. Çok eski yıllardan beri Anadolu'da bazı halk hekimliği uygulamalarında yaygın olarak alabalık etinden yararlanılmıştır (Akçiçek ve Canyurt, 1993). Halen bu tür uygulamalara halk arasında inanılmakta ve yaygın olarak kullanılmaktadır. İstanbul, İzmir ve Ankara benzeri büyük şehirlerdeki bazı sağlık merkezlerinde adale ağrıları, romatizma ve kemik hastalıkları gibi rahatsızlıkların tedavisinde büyük ölçüde doğal alabalıklardan yararlanılmaktadır. Tedavide kullanılmak üzere Doğu Karadeniz Bölgesi'ndeki akarsulardan avlanan balıklar yüksek fiyatlarla satın alınmaktadır (Hürriyet Gazetesi, 2000). Doğal alabalığın yararlı bir besin, bağışıklık sisteminin güçlenmesinde önemli olduğu bilinmekle beraber çeşitli hastalıklara iyi geldiğine yönelik bilimsel bir çalışmaya ulaşılamamıştır.

MEVCUT DURUM VE ÖNERİLER

Karadeniz'in ve bölgesel biyolojik çeşitliliğin eşsiz ve değerli bir olgusu olan somon balığı, son iki yüzyıldır sürekli olarak antropojenik baskı altındadır. Her ne kadar son yıllarda doğal yaşam ortamları değiştirilmiş olsa da, öncelikle Karadeniz'de meydana gelen ötrofikasyon ve ekosistemlerin bozulması gibi süreçlerle sonucunda türün nesli tükenme tehlikesiyle karşı karşıyadır (Goradze, 2009). Karadeniz

alabalığı, Avrupa deniz alabalığı ile benzer bir yaşam döngüsüne ve biyolojiye sahiptir. Tatlı su ve denizdeki çevresel bozulmanın bir araya gelmesi, özellikle de hidroelektrik barajlar ve enerji santrallerinin inşası nedeniyle doğal stoklarda ciddi düşüşler meydana gelmiştir (Okumuş vd. 2006). Son yıllarda Karadeniz somonu popülasyonları aşırı avlanma ve habitatlarının bozulması nedeniyle tükenme aşamasına gelmiştir (Aksungur vd., 2011). Araştırma sonuçları ile beraber çevresel şartlardaki bozulmayı ve türün popülasyonu üzerindeki baskıyı gören Türkiye 2006 yılında avcılığını tamamen yasaklamış ve koruma altına almıştır. Gürcistan hükümeti de 2006 yılında doğal stoklarının endişe verici boyutta olması nedeniyle türü Kırmızı Listeye eklemiştir. Ayrıca Freyhof (2024)'e göre Karadeniz somonu kırmızı liste de düşük riskli olarak değerlendirmiş ve neslinde azalmanın olduğu belirtilmiştir.

Karadeniz ülkelerinde yönetime entegre ve stratejik bir yaklaşıma acil ihtiyaç vardır (Okumuş vd., 2007). Somon balığının korunması, muhafazası, rehabilitasyonu ve yönetimi büyük ölçüde Karadeniz ülkelerinin yakın gelecekte elde edeceği ekonomik, sosyal ve eko-eğitimsel başarılara bağlı olacaktır (Goradze, 2009). Karadeniz somonu doğal stokların toparlanması için yeni bir yönetim stratejisi ve koruma programları hayati önem taşımaktadır (Aksungur vd., 2011). Karadeniz somonu doğal popülasyonunun korunması ve sürdürülebilir kullanımı için daha birçok araştırıcı yukarıda yazılı fikirlerle örtüşen fikirleri paylaşmaktadır. Tüm bu görüşler ışığında, daha çok Karadeniz ülkeleri için biyoçeşitlilik, sosyoekonomik, kültürel ve eğlencelik önemi olan Karadeniz somonunun gelecek nesillere aktarılması için;

1) Karadeniz somonunun halen var olduğu habitatlar korunmalı, ekolojik koşulları iyileştirilmeli, göç yollarındaki engeller kaldırılmalı ve yumurtlama alanlarına kolay erişim sağlanmalı, legal veya illegal avcılık tamamen engellenmeli ve kati olarak doğal üreme öncelikler arasına alınmalıdır.

2) Karadeniz somonunun doğal dağılım alanında bulunan özel işletmelerde ticari yetiştiriciliğinin yaygınlaşması için yasal prosedür kolaylaştırılmalıdır.

3) Kültür özelliklerinin ve çevresel performansının iyileştirilmesi için genetik yaklaşımlı ıslah çalışmaları devam ettirilmeli, farklı ekotiplere için elde edilen morfometrik ve genetik özellikleri uygun yeni kültür hatları tescil edilmelidir.

4) Kültür üretimi morfometrik ve genetik incelemelerle takip edilerek türün saf ırk olarak kalması sağlanmalıdır.

5) Karadeniz ülkeleri (Türkiye, Bulgaristan, Romanya, Rusya, Ukrayna ve Gürcistan) konu uzmanı araştırıcıları ve bürokratların katılımı ile Karadeniz somonu uluslararası komisyonu oluşturulmalı, bu komisyon marifetiyele:

a) Karadeniz somonunun korunması ve sürdürülebilir kullanımını sağlayacak iş ve işlemler için yöntembilim birlikteliği sağlanmalı,

b) Türün varlığını devam ettirdiği sucul alanlar ve stok durumu belirlenmeli,

c) Literatürde varlığı bilinen sucul alanlardan elde edilecek bireylerin morfometrik ve genetik analizleri yapılmalı, anadrom ve potamodrom (Limnodrom) popülasyonları belirlenmeli,

d) Türün doğal dağılım alanındaki akarsuların ve akarsu etkisi altında kalan denizel alanın faunası, çevresel özellikleri ve antropolojik etkiler belirlenmeli,

e) Türün doğal dağılım alanında kültürü yapılan egzotik türlerle etkileşimi (predator-prey ilişkisi) ve genel sağlık durumu belirlenmeli,

f) Türün popülasyonunun tamamen tükendiği veya tükenme aşamasında olduğu uygun sucul alanlara yeniden kazandırılması için uygun bölgelerde balıklandırma amaçlı üretim tesisleri kurulmalı, Türün kültür şartlarında üretimine yönelik el kitabı hazırlanmalı,

g) Kurulacak balıklandırma tesislerinde görevlendirilecek personele kültür şartlarına adaptasyon, damızlık yönetimi, kuluçkahane yönetimi ve farklı yetiştiricilik sistemlerinde (havuz, kafes) büyütme konularında yerinde yapılacak eğitim çalışmaları bilgi ve tecrübe kazanmaları sağlanmalı,

h) Doğal popülasyonun durumu ve balıklandırmanın etkisi belli dönemlerde takip edilmeli ve veri paylaşım ağı kurulmalı,

i) Ticari üretim yapmak isteyen özel sektör üyelerine, yerinde eğitim planlamaları yaparak türün yetiştiriciliği konusunda bilgi ve tecrübe kazanmaları sağlanmalıdır,

j) Doğal stokların sürdürülebilir kullanımına yönelik kısa-orta-uzun vadeli eylem planları oluşturulmalı, türün doğal stoklarının korunması için kanun koyuculara önerilerde bulunulmalı,

k) Türün korunması ve sürdürülebilir kullanımına yönelik yerel halkın da katılacağı bilgilendirme organizasyonları yapılmalıdır.

SONUÇ

Tüm koruma önlemleri ve av yasaklarına rağmen, Karadeniz somonunun doğal dağılım alanındaki antropolojik etkiler ve çevresel bozulmaya bağlı balık popülasyonlarındaki azalma, türün rekreasyonel aktivite aracı olarak kullanılmasını gün geçtikçe artırmaktadır. Bu durum, nesli tükenme aşamasında olan türün yok olmasını hızlandırmaktadır. Günümüze kadar stok durumu, biyolojisisi, genetik özellikleri ve kültür özellikleri konularında yapılan çalışmalar türün sürdürülebilirliği için yeterince bilgi birikimi sağlamıştır. Karadeniz ve Karadeniz'e dökülen akarsuların biyolojik çeşitliliğinde oldukça kıymetli olan Karadeniz somonu neslinin idamesi için bir an önce bu bilgi birikimi ve tecrübe saha çalışmalarıyla uygulanmalıdır.

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ETİK ONAY

Bu çalışma için etik onay gerekli değildir.

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Yazarlar hernagi bir çıkar çatışması ve rekabet eden çıkarlar olmadığını beyan eder.

VERİ KULLANILABİLİRLİĞİ

Çalışmaya konu olan veriler ile ilgili sorumlu yazar ile iletişime geçilebilir.

YAZARLIK KATKILARI

Çalışma kurgusu: Eyüp Çakmak, Mülakat: Eyüp Çakmak, Osman Tolga Özel, Gözden geçirme: Eyüp Çakmak, Osman Tolga Özel, Zehra Duygu Düzgüneş, Devrim Selim Mısır, Volkan Örnek, Makale yazımı: Eyüp Çakmak, Osman Tolga Özel, Zehra Duygu Düzgüneş, Devrim Selim Mısır, Volkan Örnek, Literatür taraması: Eyüp Çakmak, Osman Tolga Özel, Zehra Duygu Düzgüneş, Volkan Örnek.

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