

CONTEMPORARY METHODOLOGICAL APPROACHES IN AGRICULTURE, FORESTRY AND AQUACULTURE

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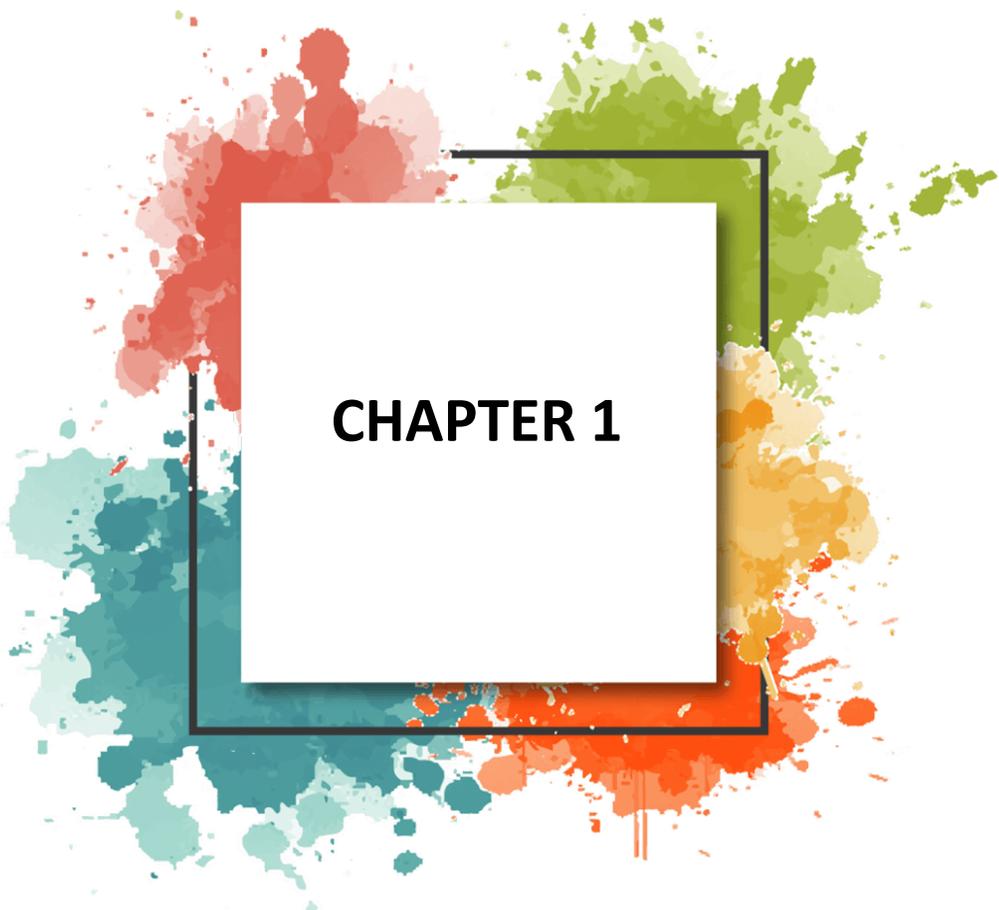
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CHAPTER 1

A Novel Spherical Fuzzy Critic-Edas Technique: A Conceptual Application to Sustainable Management of Urban Forests

Akın Menekşe¹ & Enis Küçük² & Abdurrahman Şahin³

Introduction

Sustainability thinking has become a significant topic in various research disciplines (Vaahteranoksa, 2023). One of those disciplines is urban planning, a significant element of urban life. The quick urbanization tendency is an obvious sign of this. In the 1900s, about 13% of the earth's population, approximately 1.6 billion people, lived in urban centers (Knapp, 2010). This percentage rose to 40% by 1980, 50% by 2000, and is expected to pass 60% by 2025 and further growth to 66% by 2060 (United Nations, 2014). Öner et al. (2007) stated that the conventional urban planning techniques were insufficient, considering the issues revealed by the urbanization process. Uncontrolled urbanization and rapid population growth lead to the deterioration of natural areas, a decline in biodiversity, and worsening living conditions (FAO, 2010). To that end, the strategic importance of city management stands out with rapid urbanization. Therefore, particular priority is required to be placed on improving metropolitan areas with rapidly increasing population densities (Botkin & Beveridge, 1997). When thinking about sustainability, one important area to improve is how urban forests are created and maintained, as they can significantly benefit the environment and public services. Forests naturally require long-term planning because ecological processes happen slowly and over time. Consequently, creating and maintaining urban forests and obtaining sustainability improvement

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represent permanent goals. Sustainability, in essence, makes an effort to ensure the sustained existence of something.

Urban forests are essential to human settlements, whether naturally occurring or intentionally planted. Urban forests are areas that are created intentionally or naturally (Uslu & Ayaşlıgil, 2007). These nature areas promote recreational opportunities to people who live in a city and improve their quality of life besides contributing to the functionality and aesthetics of cityscapes. Furthermore, these urban forests are easily reachable areas. Because of their closeness to residential areas, they provide easily accessible green spaces. In addition, According to Köse (2021), green spaces and forest recreation sites near or within the city should also be considered urban forests, as they serve similar ecological and social functions.

The sustainability of urban forests requires periodic attention and maintenance to obtain maximum benefit. In this case, Clark et al. (1997) stated that a sustainable urban forest comprises managing both natural and planted trees in urban areas to provide continuous economic, environmental, ecological, and social benefits to people living in urban areas. Clark et al. (1997) defined urban forests as containing the following main points: Firstly – urban communities need to recognize the various benefits of urban trees. Secondly—Human interference and management are required to regenerate urban forest spaces to maintain these benefits. Therefore, maintaining the life of urban forests is sustained by human action rather than nature. Thirdly - Sustainable urban forests are placed in specific geographical and political boundaries, comprising all trees in the area, without consideration of ownership. In other words, due to their multifaced functions, urban trees are important in providing urban ecosystem services. They benefit the community by delivering recreational opportunities, promoting mental and physical well-being, and protecting cultural values; help the environment by reducing air pollution, controlling the climate, and preserving biodiversity; last but not least help the economy by increasing property values and offering alternate income streams (Tyrväinen et al., 2005). The relevant literature indicates urban forest sustainability concept is broad and complex (Ordóñez & Duinker, 2010). It comprises principles, operational frameworks, and approaches relating to the urban forest areas in terms of achieving desired outcomes. Therefore, urban forest sustainability is a sophisticated issue requiring a comprehensive and inclusive interpretation. It seems obvious that a fixed mechanistic understanding of urban forest sustainability has limitations, and ambiguities occur. Evaluating the effectiveness of urban forest management requires establishing understandably defined criteria or objectives and performance indicators of success (Kenney et al., 2011). According to Clark et al. (1997), the key objectives for successfully managing urban forest resources include city-wide financing, a management plan, adequate staffing, conversation

of existing trees, species and location selection, assessment tools, citizen safety, standards for tree care, and recycling.

Researchers frequently implemented MCDM techniques to address sustainability-related issues. Relevant literature supports the applicability of MCDM methods in various research areas and shows their effectiveness in dealing with sustainability-related problems. To that end, Khulud et al. (2023) showed that MCDM techniques are applicable when selecting sustainable suppliers.

Considering the sustainability concept, the most frequently used MCDM technique appears to be the Analytical Hierarchy Process (AHP), as it supports various decision-making processes (Díaz-Balteiro et al., 2020; Kandakoğlu et al., 2019). Also, hybrid MCDM techniques have been widely implemented in this field. For instance, Štilić and Puška (2023) and Rane et al. (2023) emphasized integrating different MCDM methods to solve complex problems in the construction and renewable energy sectors. Rane et al. (2023) stated that hybrid MCDM (e.g., AHP-TOPSIS, AHP-Entropy, ELECTRE III - TOPSIS, AHP - TOPSIS - PROMETHEE II) methods promote more reliable and comprehensive sustainability evaluations. Also, in different research areas, Agustri et al. (2023) implemented an MCDM technique to evaluate industrial sustainability considering the herbal and medicine sector that supports the MCDM techniques' versatility to address complex sustainability issues.

Additionally, studies on sustainable tourism and energy projects revealed that MCDM frameworks are able to provide comprehensive analyses. In this case, studies on hydropower projects were conducted in India, and various sustainability factors, including economic viability and environmental impact, were evaluated using MCDM methods (Shaktawat & Vadhera, 2021). Also, in a similar direction, MCDM methods were used to effectively analyze environmental and sociocultural impact in evaluating sustainable tourism indicators (Janošik vd., 2023). These studies proved that MCDM techniques can effectively address sustainability issues in different sectors and serve as a valuable decision-making tool for complex evaluations.

For sustainable urban forest management, a multifaceted strategy is required; integrating environmental, economic, social, and governance elements in urban forest management is the aim of the multidisciplinary practice emphasized by Konijnendijk (2000). Also, Köse (2021) stated that geographic area studies, surveys with residents and professionals, expert opinions, SWOT analysis, environmental and recreational potential, regional plans, technical facilities and human resources, legal regulations, community opinions, and national and local action plans should all be gathered for sustainable urban forest management.

Regarding the above recommendations, *researchers' views* are considered within this study's parameters.

In 2003, Türkiye started the “Urban Forest Project” to create green spaces within densely populated cities. According to the General Directorate of Forestry (OGM), as of 2021, One hundred thirty-seven urban forests have been created (OGM, 2021). However, Köse (2020) raised concerns about the quick formation of these types of urban forests by the OGM due to insufficient legal and administrative infrastructure. The lack of comprehensive studies considering urban forests' management and planning caused various problems, as Bekiroğlu et al. (2015) and Atmiş et al. (2017) highlighted. These issues include arbitrary site selection, staffing difficulties, and insufficient funding, which hinder urban forestry objectives.

Some clarifications are needed as background information and to prevent any confusion. According to the OGM 2021 activity report, Türkiye had 137 urban (city) forests. However, with the publication of the ‘Forest Parks Regulation’ in the Resmi Gazete dated 28 May 2022 and numbered 31849, the areas previously known as urban forests have been officially renamed as forest parks, with or without accommodation (Resmi Gazete, 2022). In the same direction, 1,880 forest parks, 288 of which provided accommodation and 1,592 without accommodation, were created until the end of 2023. The term “forest park” includes structures of varying quality and quantity. Within the scope of this study, although it is referred to as a forest park, to avoid misunderstanding in terminology, the evaluation will be based on the “Urban Forest” areas as defined in OGM sources before 2022.

This study examines the sustainable management of urban forests, which is especially important for large and densely populated cities (like Istanbul). Through the literature review process and expert opinions, five hypothetical urban forests were examined according to eight different criteria. Given the limited resources in large cities, this evaluation framework can play a crucial role in optimizing urban forest management. To that end, the five hypothetical urban forests were evaluated for their sustainable management using the spherical fuzzy CRITIC-EDAS method (providing a robust framework for handling uncertainty and assessing multiple criteria).

Urban Forests and Sustainability

The United Nations estimated that the percentage of people living in urban areas is expected to surpass 60% by 2025, rising from 9% in the 1900s to 40% in the 1980s and almost 50% in the 2000s (McIntyre et al., 2008). In Türkiye, however, more than 90% of the population resides in urban areas (Köse, 2020). As rapid urbanization resulted in environmental and social problems, the

insufficiency of conventional urban planning techniques became more apparent (Öner et al., 2007). Natural areas are being destroyed, biodiversity is declining, and living conditions are deteriorating due to unchecked urban expansion and rapid population growth (FAO, 2010).

Because of their many uses, urban trees play a vital role in providing urban ecosystem services. They benefit society by offering recreational opportunities, fostering mental and physical well-being, and safeguarding cultural values; for the environment by lowering air pollution, controlling the climate, and preserving biodiversity; as well as benefiting the economy by raising property values and offering alternate revenue streams (Tyrväinen et al., 2005).

In addition to managing trees and forest areas, a sustainable urban forestry approach must take into account the sociocultural demands of the urban populace, environmental balance, and the overall quality of life in the city. Thus, an interdisciplinary, strategic, and participative strategy is needed for urban forest planning and management (Köse, 2021).

Decision-Making with MCDM Methods

The MCDM (Multi-Criteria Decision Making) approach effectively solves complex decision-making problems and is widely applied in various fields (Hwang & Masud, 1979). MCDM approaches can be applied across a wide range of research fields, including management, manufacturing, planning, education, transportation, construction, logistics, medicine, control, and agriculture (Singh & Malik, 2014). One of these MCDM methods is the CRITIC method, which helps obtain more objective results in decision-making processes.

The CRITIC method, a prominent multi-criteria decision-making approach presented by Diakoulaki et al. (1995), was designed to compute the relative importance of alternatives and attributes in decision-making (Dhumras & Bajaj, 2023). CRITIC is a technique that is used frequently to specify the objective weights of criteria and features simple computational steps (Siksnelyte-Butkiene et al., 2020). The CRITIC method also considers the criteria standard deviation and the correlation analyses between other criteria (Kumaran, 2022). As existing CRITIC methods fail to address the randomness and uncertainty of realistic decision-making problems, the integration of CRITIC into methods could be beneficial for practitioners and researchers (Keshavarz et al., 2015; Torkayesh et al., 2023). Therefore, it is evident that integrating CRITIC into different methods is important for obtaining more robust and reliable results.

Various studies have been executed on sustainable forest management using fuzzy methods in the literature. However, to our knowledge, no similar study has been found in the context of sustainable urban forest management. Existing research shows that the CRITIC-EDAS technique has been applied in various

fields. For example, Li & Li (2023) used this method to evaluate green building technologies. However, the Spherical Fuzzy CRITIC-EDAS method has been applied for the first time in this study within sustainable urban forest management. In this regard, our study represents the first fuzzy logic-based evaluation in this area. At the same time, it significantly contributes to the relatively limited number of fuzzy logic studies in forestry, offering a new perspective to the discipline.

EDAS is a recently developed alternative prioritization method in complex multi-criteria decision-making problems (Simić et al., 2023) in conventional distance-based practices, including VIKOR and TOPSIS, the most reasonable alternative is specified by using the distances to the Positive Ideal Solution (PIS) and Negative Ideal Solution (NIS). In many MCDM problems, being closer to the PIS and distant from the NIS does not assure the optimal solution (Qin et al., 2011). Accordingly, EDAS utilizes two distance measures: one is “positive distance to the average value,” and the other is “negative distance to the average value” to reveal the ranking order (Li & Sun 2024).

However, conventional distance-based methods may not adequately address the uncertainties in complex decision-making problems. The term “sustainability” is inherently ambiguous. For instance, frequently seen as the terms “sustainability” and “sustainable development” are often used interchangeably, and Parkin (2000) emphasized this ambiguity by noting that there are more than 200 definitions of “sustainable development.” The uncertainties inherent in sustainability and the frequent reliance on subjective data in multi-criteria decision-making processes make evaluation even more complex. At this point, one of the fundamental advantages of fuzzy logic is its ability to handle vague or imprecise concepts (Shabaia, 2014). In this case, fuzzy approaches make decision-making processes more flexible and reliable, promoting a helpful approach for modeling and analyzing scenarios based on incomplete, uncertain, or subjective data (Uma & Sharline, 2022). To that end, fuzzy logic-based methods are an ideal alternative in uncertain fields like sustainability.

In this regard, fuzzy MCDM methods allow for a more accurate and flexible evaluation of alternatives. Fuzzy MCDM is an effective tool for evaluating and selecting alternatives against different criteria, where the scores of the alternatives under different criteria and the importance weights of the criteria are typically evaluated using fuzzy numbers or linguistic values (Zadeh, 1975). The fuzzy MCDM model is used for evaluating alternatives based on specific criteria by an input from a group of decision-makers. In this approach, the suitability of the alternatives against the criteria and the importance weights of the criteria are

assessed by using linguistic values expressed by fuzzy numbers (Chen & Hwang, 1992).

In conclusion, the CRITIC method has several advantages. For example, it produces results similar to those obtained when applying PCA (Principal Component Analysis) to combine highly correlated criteria. However, CRITIC is a more straightforward approach that needs less computational effort and does not require subjective intervention (Diakoulaki et al., 1995). Similarly, the main advantages of EDAS are its simplicity of the application as well as the lower computational effort required for the calculations (Keshavarz et al., 2015) in contrast to methods like AHP, ANP, and DEMATEL. To that end, integrating fuzzy MCDM methods such as CRITIC and EDAS provides a more detailed and flexible approach to decision-making by addressing the uncertainties in complex urban forestry issues.

Fuzzy logic and multi-criteria decision-making (MCDM) methods effectively and successfully solve various problems by considering different criteria. In particular, the effectiveness of these methods in addressing uncertainty in decision-making processes and satisfying the requirements for multi-dimensional evaluation is significant. In this context, some studies related to the CRITIC-EDAS technique are presented in detail in Table 1.

Table 1. Outline of several of the relevant research on CRITIC-EDAS technique

Author/s	Aim	Technique	Criteria	Results
Menekşe & Camgoz Akdağ (2022)	Healthcare waste disposal method selection during covid-19	Sf Critic Topsis	<ul style="list-style-type: none"> • Annual operating cost • Reliability • Waste residuals • Infrastructure requirement • Treatment efficienc 	A simple and practical framework has been developed to solve healthcare facilities' waste disposal method selection problem.
Eşiyok, Ariş & Antmen, 2023	Ranking of G7 Countries and Türkiye on GGGI Indicators	Critic Entropy Edas	<ul style="list-style-type: none"> • Green economic opportunities • Social inclusion • Natural capital protection • Efficient an sustainable resource use 	The environmental performance of nations is found to be significantly impacted by the indicator of effective and sustainable resource utilization.
Li & Li, 2023	Green Building Technology	Edas Critic	<ul style="list-style-type: none"> • Outdoor environment 	It is concluded that market

	Schemes Evaluation		<ul style="list-style-type: none"> • Technology advancement • Annual operating cost • Owner acceptance 	environmental factors are pervasive and that future similar research should focus on other regulatory factors such as information technology turbulence, competitive pressure and government support.
Han et al. 2024	The evaluation of the tourism environment's sustainable potential bearing capacity	IFN (Ifss) (Intuitionistic Fuzzy Number/Sess) Edas Critic	<ul style="list-style-type: none"> • potential capacity of tourism industry development, • potential capacity for ecotourism development, • potential capacity of tourism economic development • potential capacity of tourism development 	When assessing the tourism environment's sustainable potential carrying capacity, IFNs can be used as a tool to describe unclear data. There might be some restrictions, though, which call for more research.

Previous studies on sustainability, or more specifically, sustainability in forest management, have employed fuzzy approaches, as shown in

Table 2. The application of CRITIC and EDAS techniques to forest sustainability has not been particularly popular. An opportunity to open a new window, such as “the use of CRITIC-EDAS method in the sustainability of forests,” is provided by this study.

Table 2. Some Applications of Fuzzy Logic in Sustainability and/or Forestry

Author(s)	Aim	Technique
Mendoza & Prabhu (2004)	Assessing criteria and indicators of sustainable forest management	General fuzzy methodology
Şafak et al. (2013)	Determination of the efficiency of forest sub-district directorates in Izmir Forestry Regional Directorate	Fuzzy Data Envelopment Analysis
Taseh et al. 2020	To investigate, weigh, and prioritize criteria, indicators, and options aiming to protect Zagros forests in Kermanshah province	FTOPSIS
Bayram (2021)	Evaluation of sustainable forest management criteria and indicators	Fuzzy Analytic Hierarchy Process (AHP)

In conclusion, using hybrid MCDM methods (such as integration of CRITIC, EDAS, and fuzzy approaches) provides a comprehensive and flexible framework to address complex decision-making problems, provide more reliable and accurate solutions, and be applicable to different disciplines.

The flow of the study is structured as follows: 1. Introduction: An introductory section describing the subject matter. 2. Materials and Methods: This section of the study will provide the necessary information and definitions for the criteria used in the method, including an explanation of the SF SCRITIC-EDAS approach. 3. Results and Discussion: This part will present and discuss the findings acquired during the implementing method's stages. 4. Conclusion: A conclusive section contains the study's outcomes and insights.

Methods

This study benefits from the spherical fuzzy number - CRITIC EDAS method, and the workflow of the study is illustrated in **Hata! Başvuru kaynağı bulunamadı.**, providing a detailed outline of the methodological procedure academicians provided the initial data required for the method's application by evaluating five alternatives across eight criteria. Eight criteria for the sustainable management of urban forests have been identified based on relevant literature and reserchers insights. The criteria presented in the studies by Clark et al. (1997) and Urban Forest Innovations (UFI) Inc., and Kenny (2008) are shown in Table 3.

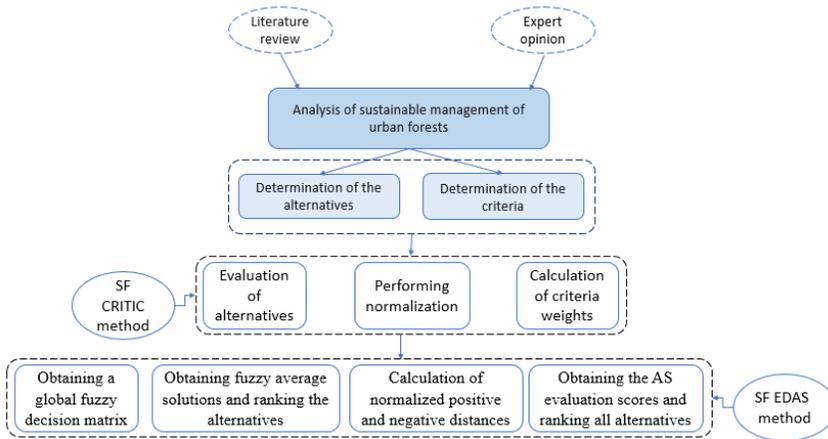


Figure 1. Flowchart of the proposed methodology

Table 3. The benefited criteria in the study

C1	Canopy Cover Inventory	Considering the existing and potential canopy cover; high-resolution assessments for the entire community.
C2	Tree Inventory	Complete inventory of the tree resource to direct its management. This includes tree condition, age distribution, species mix, and risk assessment.
C3	Hazard tree management	All publicly owned-trees are safe.
C4	Pruning of publicly-owned, intensively managed trees	All publicly-owned trees are pruned to maximize present and forthcoming benefits. Tree condition and health secure maximum longevity.
C5	City staffing	Within the urban forestry unit having a multidisciplinary team
C6	City-wide management plan	A comprehensive plan for all elements of the urban forest (public and/or private assets) was accepted and executed.
C7	Municipality wide funding	Municipality wide funding: Sufficient public and private funding to maintain the highest urban forest benefits.
C8	Tree establishment planning and implementation	Tree establishment is directed by necessities arising from a tree inventory and is adequate to satisfy canopy cover objectives.

The steps of the spherical fuzzy (SF) CRITIC EDAS

The proposed spherical fuzzy CRITIC EDAS methodology is described as follows: A multi-criteria decision making (MCDM) problem is defined with a set of specified alternatives and the relevant criteria. In this setting,

$A_i = (A_1, A_2, \dots, A_m)$ and $C_j = (C_1, C_2, \dots, C_n)$ are the alternatives and criteria of the MCDM problem.

On the other hand, a spherical fuzzy set is defined as in Eq. 1

$$\tilde{A} = \{\langle u, \mu_{\tilde{A}}(u), \nu_{\tilde{A}}(u), \pi_{\tilde{A}}(x) \mid u \in U \rangle\} \quad (1)$$

where

$$\mu_{\tilde{A}}(u): U \rightarrow [0,1], \nu_{\tilde{A}}(u): U \rightarrow [0,1], \pi_{\tilde{A}}(u): U \rightarrow [0,1],$$

and

$$0 \leq (\mu_{\tilde{A}}(x))^2 + (\nu_{\tilde{A}}(x))^2 + (\pi_{\tilde{A}}(x))^2 \leq 1, \forall u \in U \quad (2)$$

$\mu_{\tilde{A}}(u)$ is the membership value, $\nu_{\tilde{A}}(u)$ is the non-membership value, and $\pi_{\tilde{A}}(u)$ is the hesitancy of u to \tilde{A} .

The suggested spherical fuzzy CRITIC EDAS methodology is composed of two stages, as presented below:

Stage 1. Criteria weights are calculated with the spherical fuzzy CRITIC method.

Step 1.1. The alternatives are evaluated by the decision-makers regarding the criteria. The linguistic terms that are listed in Table 4 are used in the evaluation process.

Step 1.2. Linguistic evaluations obtained in Step 1 are transferred to spherical fuzzy atmosphere with the help of Table 4. After that, all spherical fuzzy matrices obtained are collected to reach one single collective matrix i.e. spherical fuzzy alternative evaluation matrix \tilde{E} . For collecting the aforementioned matrices, spherical weighted geometric mean SWGM operator (Eq. 3) is used.

Spherical Weighted Geometric Mean *SWGM* with respect to, $w = (w_1, w_2, \dots, w_n)$; $w_i \in [0,1]$; $\sum_{i=1}^n w_i = 1$, SWGM is defined as:

$$SWGM_w = (\tilde{A}_1, \dots, \tilde{A}_n) = \tilde{A}_1^{w_1} + \tilde{A}_2^{w_2} + \dots + \tilde{A}_n^{w_n} \quad (3)$$

$$= \left\{ \begin{array}{l} \left[\prod_{i=1}^n \mu_{\tilde{A}_i}^{wi}, \left[1 - \prod_{i=1}^n (1 - \nu_{\tilde{A}_i}^2)^{wi} \right]^{1/2} \right. \\ \left. \left[\prod_{i=1}^n (1 - \nu_{\tilde{A}_i}^2)^{wi} - \prod_{i=1}^n (1 - \nu_{\tilde{A}_i}^2 - \pi_{\tilde{A}_i}^2)^{wi} \right]^{1/2} \right\}$$

The \tilde{E} has a structure as in Eq. 4.

$$\tilde{E} = C_j(A_i)_{m \times n} = \begin{pmatrix} (\mu_{11}, \nu_{11}, \pi_{11}) & (\mu_{12}, \nu_{12}, \pi_{12}) & \cdots & (\mu_{1n}, \nu_{1n}, \pi_{1n}) \\ (\mu_{21}, \nu_{21}, \pi_{21}) & (\mu_{22}, \nu_{22}, \pi_{22}) & \cdots & (\mu_{2n}, \nu_{2n}, \pi_{2n}) \\ \vdots & \vdots & \cdots & \vdots \\ (\mu_{m1}, \nu_{m1}, \pi_{m1}) & (\mu_{m2}, \nu_{m2}, \pi_{m2}) & \cdots & (\mu_{mn}, \nu_{mn}, \pi_{mn}) \end{pmatrix} \quad (4)$$

Step 1.3. The normalization of the \tilde{E} is conducted as in Eq. 5.

$$x_{ij} = \frac{\sqrt{\frac{1}{2} \left((\mu_{ij} - \mu_-)^2 + (\nu_{ij} - \nu_-)^2 + (\pi_{ij} - \pi_-)^2 \right)}}{\sqrt{\frac{1}{2} \left((\mu_+ - \mu_-)^2 + (\nu_+ - \nu_-)^2 + (\pi_+ - \pi_-)^2 \right)}} \quad (5)$$

where μ_+, ν_+, π_+ and μ_-, ν_-, π_- are the maximum and minimum solutions parameters of, respectively. Since, score values of a fuzzy number can be used for ranking purpose, one can obtain maximum and minimum solutions based on the defuzzified values of the attributes in \tilde{E} . Eq. 6 is used to calculate score values.

$$Score(\tilde{A}) = (\mu_{\tilde{A}} - \pi_{\tilde{A}})^2 - (\nu_{\tilde{A}} - \pi_{\tilde{A}})^2 \quad (6)$$

Step 1.4. The correlation coefficients ρ_{jk} are calculated as in Eq. 7.

$$\rho_{jk} = \frac{\sum_{i=1}^m (x_{ij} - \bar{x}_j)(x_{ik} - \bar{x}_k)}{\sqrt{\sum_{i=1}^m (x_{ij} - \bar{x}_j)^2 \sum_{i=1}^m (x_{ik} - \bar{x}_k)^2}} \quad (7)$$

where \bar{x}_j and \bar{x}_k are the average values of j th and k th attributes can be calculated by utilizing Eq. 8.

$$\bar{x}_j = \frac{1}{n} \sum_{j=1}^n x_{ij}; i = 1, 2, \dots, m \quad (8)$$

Step 1.5. The standard deviation σ_j of j th criterion is calculated as in Eq. 9.

$$\sigma_j = \sqrt{\frac{1}{n-1} \sum_{j=1}^n (x_{ij} - \bar{x}_j)^2}; i = 1, 2, \dots, m \quad (9)$$

Step 1.6. The C indices of the criteria are calculated as in Eq. 10.

$$C_j = \sigma_j \sum_{k=1}^n (1 - \rho_{ik}); j = 1, 2, \dots, n \quad (10)$$

Step 1.7. The weight of j th criterion w_j is obtained as in Eq. 11.

$$w_j = \frac{C_j}{\sum_{j=1}^n C_j} \quad (11)$$

Stage 1 ends here. The criterion weights obtained in this stage are used in Stage 2.

Stage 2. Alternatives are ranked with spherical fuzzy EDAS.

Step 2.1. Spherical fuzzy decision matrix \tilde{F} is obtained by multiplying \tilde{E} by the criterion weights. Criterion weights are already obtained in the first stage. Eq. 12 is used in this step.

Multiplication by a scalar: $\lambda > 0$

$$\lambda. \tilde{A} = \left\{ \left(1 - (1 - \mu_{\tilde{A}}^2)^\lambda \right)^{1/2}, v_{\tilde{A}}^\lambda, \left((1 - \mu_{\tilde{A}}^2)^\lambda - (1 - \mu_{\tilde{A}}^2 - \pi_{\tilde{A}}^2)^\lambda \right)^{1/2} \right\} \quad (12)$$

Step 2.2. The EDAS method ranks the alternatives according to average solution. In this context, spherical fuzzy average solution $\tilde{A}_{av.}$ is obtained by using Eq. 3.

Step 2.3. Positive and negative distances D^+ and D^- of alternatives to spherical fuzzy average solution $\tilde{A}_{av.}$ as given in Eqs. 13 and 14.

$$D_i^+(\tilde{A}_{av.}, \tilde{A}_i) = \sqrt{\frac{1}{2n} \sum_{i=1}^n \left((\mu_{x_{av.}} - \mu_{x_i})^2 + (v_{x_{av.}} - v_{x_i})^2 + (\pi_{x_{av.}} - \pi_{x_i})^2 \right)} \quad (13)$$

$$D_i^-(\tilde{A}_i, \tilde{A}_{av.}) = \sqrt{\frac{1}{2n} \sum_{i=1}^n \left((\mu_{x_i} - \mu_{x_{av.}})^2 + (v_{x_i} - v_{x_{av.}})^2 + (\pi_{x_i} - \pi_{x_{av.}})^2 \right)} \quad (14)$$

Step 2.4. Calculate the normalized positive distance $NormD^+$ and normalized negative distance $NormD^-$ as in Eqs. 15 and 16.

$$NormD_i^+ = \frac{D_i^+}{\max(D_i^+)} \quad (15)$$

$$NormD_i^- = 1 - \frac{D_i^-}{\max(D_i^-)} \quad (16)$$

Step 2.5. Obtain the appraisal score AS of each alternative as in Eq. 16, and rank all alternatives accordingly. The highest score is the most satisfactory.

$$AS_i = \frac{1}{2}(NormD_i^+ + NormD_i^-) \quad (17)$$

Results

The research process pursues evaluating alternatives based on pre-determined criteria and specified linguistic terms (

Table 4). The obtained results are presented in Table 5. Next, a spherical fuzzy alternative evaluation matrix is created based on the data in Table 5 and shown in Table 6.

Correlation coefficients between the criteria are then formed and provided and displayed in Table 7.

The standard deviation σ_j , C index, and criterion weights w_j are obtained as in Table 8.

The spherical fuzzy final decision matrix \tilde{F} is constructed and shown in Table 9. Additionally, the spherical fuzzy positive A^+ and negative ideal A^- solutions are calculated and presented in Table 10. Finally, the appraisal scores and the final rankings of the alternatives are presented in Table 11.

Numerical Solution

The proposed methodology is demonstrated through a numerical example. Let A_1, A_2, \dots, A_5 represent the alternatives, while C_1, C_2, \dots, C_8 denote the criteria associated with the multi-criteria decision-making (MCDM) problem. The decision-makers, labeled as DE_1, DE_2 , and DE_3 , are assigned equal weights of $\frac{1}{3}$ each.

Table 4. Linguistic (verbal) terms and corresponding spherical fuzzy numbers

Linguistic Term	Spherical fuzzy number (μ, ν, π)		
AMI (Absolutely More Important)	0.90	0.10	0.10
VHI (Very High Important)	0.80	0.20	0.20
HI (High Important)	0.70	0.30	0.30
SMI (Slightly More Important)	0.60	0.40	0.40
EI (Equally Important)	0.50	0.40	0.50
SLI (Slightly Low Important)	0.40	0.60	0.40
LI (Low Important)	0.30	0.70	0.30
VLI (Very Low Important)	0.20	0.80	0.20
ALI (Absolutely Low Important)	0.10	0.90	0.10

Step 1.1. Three decision-makers evaluate five alternatives with respect to eight criteria as presented in Table 5.

Table 5. Linguistic (verbal) evaluations of alternatives

	C1	C2	C3	C4	C5	C6	C7	C8
A1	VHI	EI	VLI	HI	LI	LI	VLI	VHI
A2	AMI	SMI	EI	VLI	EI	ALI	ALI	VLI
A3	SLI	LI	SMI	ALI	SLI	VLI	VLI	LI
A4	EI	VHI	HI	EI	LI	EI	HI	VHI
A5	VHI	HI	AMI	SMI	HI	SMI	LI	HI
	C1	C2	C3	C4	C5	C6	C7	C8
A1	EI	HI	ALI	EI	LI	LI	LI	HI
A2	SMI	AMI	HI	SLI	SLI	SMI	VLI	EI
A3	LI	EI	EI	LI	VLI	SLI	EI	VLI
A4	SMI	HI	EI	SMI	ALI	HI	EI	SMI
A5	EI	EI	HI	HI	SLI	AMI	SLI	EI
	C1	C2	C3	C4	C5	C6	C7	C8
A1	SMI	HI	SLI	HI	LI	SMI	SMI	AMI
A2	HI	EI	HI	VLI	VLI	VLI	SMI	SLI
A3	EI	LI	SLI	ALI	VLI	ALI	ALI	ALI
A4	HI	HI	EI	AMI	ALI	HI	EI	EI
A5	SMI	SLI	SMI	EI	SLI	EI	SLI	SMI

Step 1.2. \tilde{E} is evaluated as in Table 6.

Table 6. Spherical fuzzy alternative evaluation matrix \tilde{E}

	C1		C2		C3		C4					
A1	0.62	0.35	0.40	0.63	0.34	0.39	0.20	0.80	0.22	0.63	0.34	0.39
A2	0.72	0.30	0.31	0.65	0.34	0.39	0.63	0.34	0.39	0.25	0.75	0.26
A3	0.39	0.59	0.40	0.36	0.63	0.36	0.49	0.48	0.44	0.14	0.86	0.16
A4	0.59	0.37	0.42	0.73	0.27	0.27	0.56	0.37	0.45	0.65	0.34	0.39
A5	0.62	0.35	0.40	0.52	0.46	0.42	0.72	0.30	0.31	0.59	0.37	0.42
	C5		C6		C7		C8					
A1	0.30	0.70	0.30	0.38	0.63	0.33	0.33	0.68	0.29	0.80	0.22	0.22

A2	0.34	0.65	0.36	0.23	0.78	0.22	0.23	0.78	0.22	0.34	0.65	0.36
A3	0.25	0.75	0.26	0.20	0.80	0.22	0.22	0.78	0.25	0.18	0.82	0.19
A4	0.14	0.86	0.16	0.63	0.34	0.39	0.56	0.37	0.45	0.62	0.35	0.40
A5	0.48	0.53	0.38	0.65	0.34	0.39	0.36	0.64	0.37	0.59	0.37	0.42

Steps 1.3 and 1.4. Correlation coefficients ρ_{jk} are calculated as in Table 7.

Table 7. Correlation coefficients ρ_{jk}

	C1	C2	C3	C4	C5	C6	C7	C8
C1	1.000	0.799	0.094	0.477	0.348	0.292	0.229	0.576
C2	0.799	1.000	-0.067	0.634	-0.262	0.430	0.642	0.684
C3	0.094	-0.067	1.000	-0.205	0.206	0.275	0.178	-0.376
C4	0.477	0.634	-0.205	1.000	-0.009	0.855	0.750	0.967
C5	0.348	-0.262	0.206	-0.009	1.000	0.011	-0.491	0.047
C6	0.292	0.430	0.275	0.855	0.011	1.000	0.846	0.701
C7	0.229	0.642	0.178	0.750	-0.491	0.846	1.000	0.607
C8	0.576	0.684	-0.376	0.967	0.047	0.701	0.607	1.000

Steps 1.5-1.7. Standard deviation σ_j , C index and criterion weights w_j are obtained as in Table 8.

Table 8. Standard deviation σ_j , C index and criterion weights w_j

	C1	C2	C3	C4	C5	C6	C7	C8
Standard deviation	0.283	0.293	0.300	0.358	0.281	0.365	0.302	0.304
C index	1.182	1.211	2.072	1.265	2.146	2.814	2.343	1.153
Criterion weight	0.083	0.085	0.146	0.089	0.151	0.198	0.165	0.081

Step 2.1. \tilde{F} is obtained as Table 9 .

Table 9. Spherical fuzzy final decision matrix \tilde{F}

	C1		C2		C3		C4					
A1	0.20	0.92	0.15	0.20	0.91	0.15	0.08	0.97	0.09	0.21	0.91	0.16
A2	0.24	0.90	0.13	0.21	0.91	0.16	0.26	0.85	0.19	0.08	0.97	0.08
A3	0.12	0.96	0.13	0.11	0.96	0.12	0.20	0.90	0.20	0.04	0.99	0.05
A4	0.19	0.92	0.16	0.25	0.89	0.12	0.23	0.87	0.22	0.22	0.91	0.16
A5	0.20	0.92	0.15	0.16	0.94	0.15	0.32	0.84	0.17	0.20	0.92	0.16
	C5		C6		C7		C8					
A1	0.12	0.95	0.12	0.17	0.91	0.16	0.14	0.94	0.13	0.28	0.88	0.10
A2	0.14	0.94	0.15	0.10	0.95	0.10	0.09	0.96	0.09	0.10	0.97	0.11
A3	0.10	0.96	0.11	0.09	0.96	0.10	0.09	0.96	0.10	0.05	0.98	0.06
A4	0.06	0.98	0.06	0.31	0.81	0.22	0.25	0.85	0.23	0.20	0.92	0.15
A5	0.20	0.91	0.17	0.32	0.81	0.23	0.15	0.93	0.16	0.19	0.92	0.15

Step 2.2. Spherical fuzzy average solution \tilde{A}_{av} is calculated as in Table 10.

Table 10. Spherical fuzzy average solution \tilde{A}_{av} .

	C1		C2		C3		C4					
A_{av}	0.18	0.86	0.15	0.25	0.86	0.14	0.80	0.81	0.17	0.12	0.91	0.11
	C5		C6		C7		C8					
A_{av}	0.11	0.90	0.12	0.17	0.83	0.15	0.13	0.88	0.14	0.14	0.90	0.12

Steps 2.3-2.5. Positive distance to average solution D^+ , negative distance to average solution D^- , normalized positive distance to average solution Norm D^+ , normalized negative distance to average solution Norm D^- , appraisal scores AS_i and final rankings of alternatives are given in Table 11.

Table 11. Appraisal scores AS_i and final rankings of alternatives

	D⁺	D⁻	Norm D⁺	Norm D⁻	AS_i	Rank
A1	0.043	0.064	0.646	0.241	0.444	3
A2	0.000	0.065	0.000	0.232	0.116	4
A3	0.000	0.085	0.000	0.000	0.000	5
A4	0.066	0.036	1.000	0.573	0.786	2
A5	0.066	0.025	0.999	0.706	0.853	1

The A5 urban forest achieved the highest score (0.853) among five hypothetical alternative urban forests (Table 11). Therefore, it is understood that the most prominent alternative for the sustainable management of urban forests was the A5 urban forest. Additionally, appraisal scores illustrated in Table 11 show that the fourth alternative forest (A4) ranked in the second position (0.786), the first alternative (A1) ranked third (0.444), the second alternative forest (A2) (0.116), and the third alternative (A3) ranked in fifth position (0.000). Thus, the resulting order was $A5 > A4 > A1 > A2 > A3$.

Comparative Analysis

Table 12. Comparative analysis results with spherical fuzzy (SF) CRITIC TOPSIS

	SF CRITIC EDAS	Final ranking	SF CRITIC TOPSIS	Final ranking
A1	0.444	3	0.491	3
A2	0.116	4	0.422	4
A3	0.000	5	0.248	5
A4	0.786	2	0.688	2
A5	0.853	1	0.720	1

A comparative analysis is also conducted to test the validity of the study. In this context, the same problem is handled with spherical fuzzy (SF) CRITIC TOPSIS (Menekse, A., & Camgoz Akdag, 2022) methodology, and the alternatives are prioritized accordingly. Comparative analysis results are given in Table 12. Although SF CRITIC TOPSIS generates different appraisal scores, the ranking of alternatives remains the same.

Sensitivity Analysis

Table 13. Sensitivity analysis results for varying decision expert (DE) weight distribution scenarios

DE										
1;										
DE										
2;	0.33;	0.20;	0.20;	0.60;	0.30;	0.30;	0.40;	0.40;	0.40;	0.20;
DE	0.33;	0.20;	0.60;	0.20;	0.30;	0.40;	0.30;	0.40;	0.20;	0.40;
3	0.33	0.60	0.20	0.20	0.40	0.30	0.30	0.20	0.40	0.40
A1	0.49	0.49	0.33	0.44	0.46	0.41	0.44	0.39	0.48	0.42
A2	0.42	0.16	0.11	0.07	0.13	0.11	0.10	0.09	0.12	0.13
A3	0.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A4	0.68	0.82	0.75	0.66	0.79	0.77	0.77	0.66	0.78	0.81
A	0	0	0	0	0	0	0	0	0	0
5	.720	.782	.812	.856	.836	.845	.856	.851	.829	.823

A sensitivity analysis is conducted to investigate the impact of changing DE weights on results. In this regard, several weight settings are assigned to the DE weights that are equally distributed (0.33;0.33;0.33) in the base scenario. Table 13 provides DE weight distributions and appraisal score values obtained. In all scenarios, the ranking of alternatives remains the

same, and it is concluded that our approach gives stable results across varying DE weight distribution scenarios.

Discussion

In this study, benefiting from the spherical fuzzy CRITIC-EDAS method, the sustainability of urban forests was evaluated by considering a set of eight criteria and five hypothetical urban forests. The findings emphasize that the A5 urban forest scored the highest, showing its prominence in sustainable management among the alternatives. Based on the ranking scores, A5 was the best alternative, followed by A4, A1, A2, and A3. This order remained constant even after conducting a comparative analysis with the SF CRITIC-TOPSIS method, which, although resulting in slightly different appraisal scores, verified the robustness of the rankings. This consistency across two different methods indicates the reliability and validity of the spherical fuzzy CRITIC-EDAS approach in evaluating urban forest sustainability.

Identified criteria weights were ranked as $C6 > C7 > C5 > C3 > C4 > C2 > C1 > C8$ in this study. Based on this ranking, the criteria “City-wide management plan,” “Municipality-wide funding,” and “City staffing” stand out as the most prominent. Although this study presents a theoretical approach, the results align well with real-life applications.

As commonly expressed, the saying emphasizes the importance of a “City-wide” management plan,” the criterion with the highest weight in the study. “Failing to plan is planning to fail.” Planning is one of the fundamental elements of success, as it defines the steps to be taken in order to achieve the specified goals. Plans are significant tools that provide holistic views. To that end, they include the status of urban forest resources, stakeholder involvement, management policies, and the resources required for effective administration and present structured approaches (Chisika & Yeom, 2023; Clark et al., 1997). These approaches are especially beneficial for organizations like municipalities as addressing the multifaceted nature of urban forests such as biodiversity, social functions, and environmental benefits. In the context of city-wide inclusiveness, Fernández-Álvarez and Fernández-Nava (2020) indicated that public contribution is an important part of making significant contributions to plans.

The second most important criterion is the “Municipality-wide funding” criterion. Davies et al. (2017) stated that presenting proactive approaches to managing urban forests is difficult without sufficient funds and political support. Similarly, Wirtz et al. (2021) funding can limit the various planning and implementation stages.

“City staffing” was identified as the third important criterion. An effective staffing structure enables the successful implementation of the developed plans. In this case, Vogt (2020) indicated that untrained personnel for tree maintenance activities in municipalities are not recommended; instead, it is emphasized that highly skilled, certified professionals with training in tree care should be chosen.

In conclusion, relevant literature supported that setting effective city-wide management plans, providing adequate financial resources, and employing qualified personnel are important to sustainably managing urban forests. Also, the relevant literature supports the validity and real-world applicability of the findings presented in this study. Therefore, it can be concluded that these criteria should be prioritized when developing sustainable urban forest policies.

The results underline the importance of adopting a multifaceted approach to managing urban forests. Urban forests are important for cities’ environmental, social, and economic well-being. Their role in improving air quality, promoting mental and physical health, enhancing biodiversity, and providing recreational spaces cannot be overstated.

Also, the sensitivity analysis supported the robustness of the applied methodology. To that end, the reliability of the evaluation process was verified. Even though the distribution of decision expert (DE) weights displayed some variations, the overall ranking of alternatives stayed in the same order, which confirmed the stability of the model’s results. This condition supported the confidence in applying the spherical fuzzy CRITIC-EDAS method for urban forest sustainability assessments.

Conclusions

MCDM methods, including EDAS and CRITIC, are commonly used by researchers to determine the relative importance of criteria and select among alternatives. This study integrated fuzzy logic theory into MCDM methods—specifically the fuzzy CRITIC-EDAS method with spherical set extension—to address uncertainty and limited data challenges, which are common in sustainability-related decisions. This approach is supported by the study

conducted by Kaya and Kahraman (2011), who demonstrated that fuzzy MCDM methods can contribute meaningfully to complex decision-making contexts such as urban afforestation.

In our work, the evaluation employed specific criteria derived from relevant literature and expert opinions from the academic field to assess sustainable urban forest management. The fuzzy CRITIC-EDAS model proved suitable for handling uncertainty and helped identify the most appropriate management approach among five hypothetical alternatives. The results highlight the importance of city-wide management plans, sufficient funding, and qualified staffing, all of which are emphasized in the literature. Policymakers and forest managers can benefit from these insights. Furthermore, the evaluation model presented in this study can be used to analyze and compare the sustainability levels of urban forests, supporting practitioners in prioritizing their decisions.

This study evaluated five hypothetical urban forest alternatives using academic expert input. Considering the hypothetical nature of the alternatives and few academic views (which condition is sufficient for implementing fuzzy logic) represent key limitations. Additionally, the generalizability of the findings may be restricted by the absence of empirical data from real-world urban forests. The relatively narrow academic perspective may also have limited the diversity of viewpoints included in the evaluation.

In future studies, these limitations can be addressed by conducting similar research using empirical data from real-world urban forest examples. A case study approach could support the practical applicability of the proposed methodology. The reliability of the proposed model can be supported by participation from various fields (e.g., urban planners, environmental engineers, and local community voices). Additionally, the application of MCDM or hybrid MCMD can enable comparison and improve the recommended methodology's validity while revealing different perspectives.

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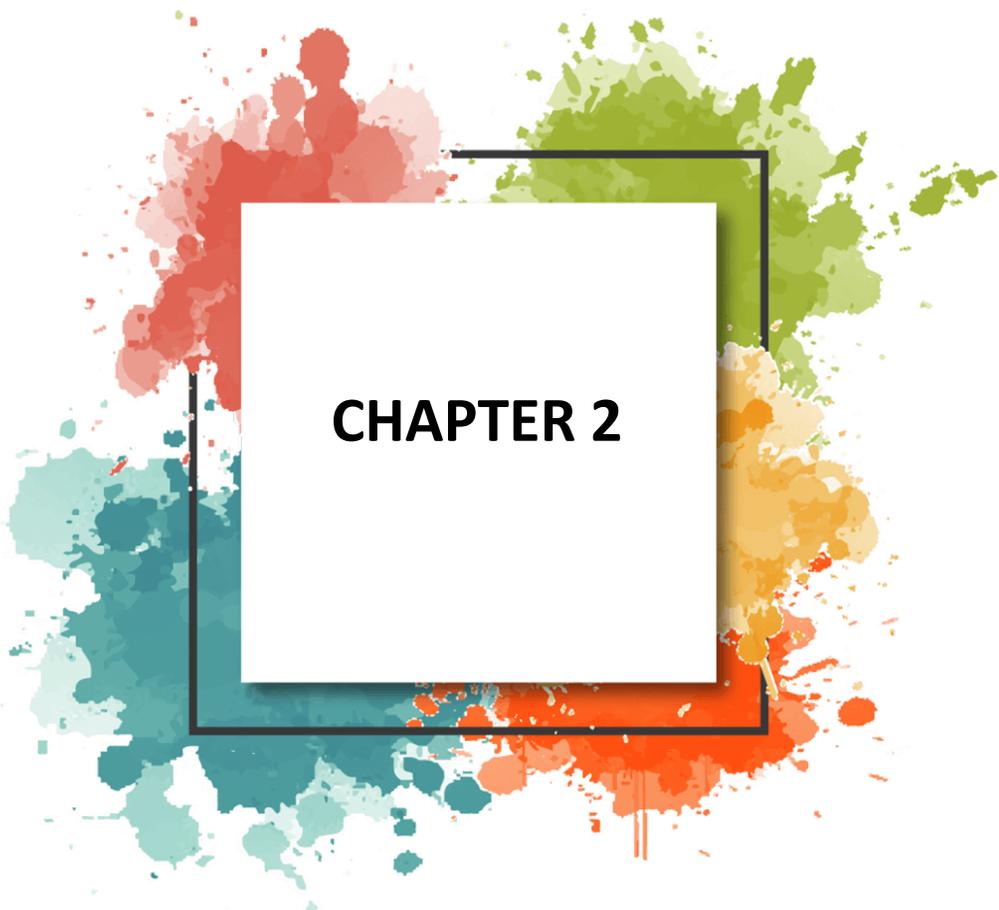
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CHAPTER 2

Nonlinear Climate Threats and Agricultural Productivity: A Paradigm Shift from Traditional Econometrics to Machine Learning Assoc.

Ayca Nur Sahin Demirel¹

1. Introduction

Agricultural productivity, one of the most fundamental determinants of global food security, has historically been extremely sensitive to variable climate conditions. However, human-induced climate change is transforming the scale and intensity of this variability, creating unprecedented pressure on plant physiology and agricultural systems (IPCC, 2022). Not only the increase in average temperatures, but also multidimensional changes such as the frequency of extreme heat waves, irregularities in precipitation patterns, seasonal shifts, and increases in atmospheric CO₂ concentrations are plunging the future of agricultural production into uncertainty.

Agricultural economists have been using various modeling tools for decades to quantify the potential impacts of climate change on the agricultural sector and provide information to policymakers. The traditional approach relies on econometric models derived from economic theory, which typically assume linear or log-linear relationships (). Foremost among these are Ricardian models (Mendelsohn, Nordhaus, & Shaw, 1994), which analyze climate variables through their effects on land rent, and production function approaches that incorporate climate as a production factor into Cobb-Douglas or translog production functions (Schlenker & Roberts, 2009). These models have provided valuable services in deriving meaningful relationships from historical data and estimating average effects.

However, these traditional methodologies suffer from serious limitations. The first is their constraints in variable selection. Many studies tend to focus only on average temperature and total precipitation, neglecting other critical meteorological factors that directly affect plant growth. Yet, plant physiology is determined by solar radiation, which influences photosynthesis and water use efficiency; relative humidity, which shapes the evapotranspiration rate and plant

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disease pressure; wind speed, which affects pollination, soil erosion, and plant structural integrity; the diurnal temperature range (the difference between night and day temperatures) (diurnal temperature range) on plant respiration and development; and finally, atmospheric CO₂ concentration, the raw material for photosynthesis. These five to seven fundamental variables, when considered together, produce a compound effect (Lobell & Gourdji, 2012; Hatfield & Prueger, 2015). Most of these variables are either not available in traditional datasets or have not been included in models.

The second and more fundamental limitation is the parametric assumptions on which these models are based. The assumptions of linearity and stationarity often conflict with the true nature of the climate-yield relationship. For example, the effect of temperature on yield can increase catastrophically in a negative direction once it exceeds a species-specific threshold; this is a distinctly non-linear response that cannot be represented by a linear model (Schlenker & Roberts, 2009). Similarly, the damage caused by high temperatures to yield may be relatively mitigated if soil moisture is sufficient, but it can increase exponentially under dry conditions (Lobell, Schlenker, & Costa-Roberts, 2011). Such **variable** interactions must be predefined by the researcher in traditional models, whereas real-world interactions are much more complex and cannot be known in advance. Finally, traditional models often treat extreme weather events as model-external **"exogenous shocks"** or statistical **"error terms,"** even though the most destructive effects of climate change stem precisely from these events (Lesk, Rowhani, & Ramankutty, 2016).

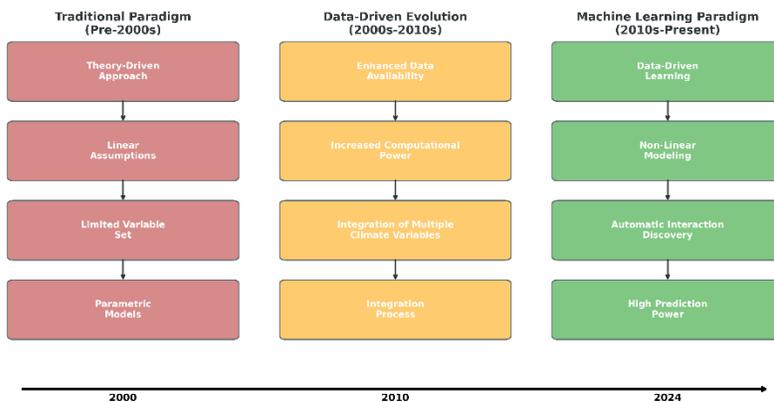


Figure 1. Transition from traditional to machine learning

Machine Learning (ML) algorithms offer revolutionary potential in closing this methodological gap. ML has the capacity to learn complex, non-linear patterns and interactions in data in a data-driven manner, without imposing a rigid theoretical formulation beforehand (as seen in Figure-1) (Hastie, Tibshirani, &

Friedman, 2009). The main objective of this section is to systematically synthesize the empirical literature from the last twenty years to reveal why and to what extent ML models using multiple climate variables outperform traditional econometric methods in agricultural yield forecasting. Our argument is that, in the face of the complexity of climate threats, a paradigm shift towards data-driven analytics in the discipline of agricultural economics is both inevitable and necessary.

2. Theoretical Framework: Two Different Worlds in Climate-Yield Modeling

2.1. Traditional Approach: Theory-Driven and Parametric Models

Traditional economic modeling relies on a structural framework derived from theory and proposing testable hypotheses. In climate-yield analysis, this manifests in two main forms:

- **Ricardian Approach:** This methodology attempts to indirectly estimate the long-term economic costs of climate change by measuring the marginal effect of climate variables on land values (Mendelsohn et al., 1994). The assumption is that land markets reflect all climate-induced productivity differences in prices. The model is typically set up in a linear or quadratic form as $\text{Land Value} = f(\text{Average Temperature, Total Precipitation, Socioeconomic Controls})$. This model is important because it incorporates long-term adaptation, but it is vulnerable to short-term extreme events, and it is difficult to isolate the impact of non-climate factors (policy, technology) on land prices (Deschênes & Greenstone, 2007).
- **Production Function Approach:** This method claims to model climate as a direct production factor alongside other inputs such as labor, capital, and land. For example, a Cobb-Douglas function can be extended as follows: $\text{Yield} = A * (\text{Temperature}^{\beta_1}) * (\text{Precipitation}^{\beta_2}) * (\text{Other Inputs}^{\beta_{\dots}}) * e^{\varepsilon}$. More sophisticated versions represent temperature and precipitation with monthly or daily distributions throughout the growing season (Schlenker & Roberts, 2009). These models have the advantage of directly estimating marginal physical output.

The fundamental limitations of these approaches are as follows:

Linearity and Functional Form: The relationship is assumed to be linear, quadratic, or log-linear. However, plant responses often involve threshold values, optimum points, and saturation points (Lobell et al., 2011).

Ceteris Paribus and Interactions: The analysis attempts to isolate the effect of one variable "all other things being equal." However, in climate, all conditions change simultaneously. The modeler must decide which interaction terms (e.g., Temperature x Humidity) to include in the model, and this is arbitrary.

Inability to Model Extreme Events: These models, based on a standard normal distribution assumption, are weak at modeling extreme events at the "tails" of the distribution (e.g., 500-year droughts, record heat waves). These events are often seen as noise that reduces predictive power (Ciais et al., 2005).

Multiple Variable Integration: Adding multiple correlated variables (e.g., radiation, temperature, humidity) to the model simultaneously can lead to multicollinearity, rendering parameter estimates unstable and meaningless (Graham, 2003).

2.2. New Paradigm: Data-Driven and Non-Parametric Machine Learning

1. Machine Learning is an artificial intelligence subfield focused on enabling computers to learn from data and make decisions without explicit programming. In the context of climate-yield modeling, the philosophy of ML **is to learn** an optimal prediction function from the data's own structure and patterns, rather than imposing a theoretical functional form.
 - **Data-Driven Learning:** ML algorithms create a complex mapping function ($f(X)$) that best represents the correspondence between the input variables (climate data) and the target variable (yield) from a large amount of observations. This process minimizes the researcher's biases (Jordan & Mitchell, 2015).
 - **Nonparametric Structure:** In traditional econometrics, the shape of the model (number of parameters) is fixed. In ML, especially in "tree"-based methods, the complexity of the model (e.g., tree depth, number of nodes) can grow to match the complexity of the data. This provides the capacity to capture nonlinear relationships and complex interactions (Breiman, 2001).
 - **Automatic Interaction and Feature Discovery:** A Random Forest model automatically discovers and utilizes interactions between variables while creating thousands of decision trees. For example, rules such as "If temperature > 30°C and soil moisture < 20%, yield drops sharply" are learned by the model without human intervention.

- **Handling High-Dimensional Data:** Thanks to regularization and dimension reduction techniques, ML models can process dozens or even hundreds of interrelated variables (climate, soil, satellite images) simultaneously and select the most informative ones (Hastie et al., 2009).

The fundamental difference between these two paradigms is similar to the difference between induction (from data to theory) and deduction (from theory to data). With its inductive power, ML provides a powerful tool for discovering the complex and not yet fully understood effects of climate on agricultural systems.

3. Methodology

The arguments and syntheses presented in this section are based on the findings of a systematic literature review conducted by the author. This methodological framework included the following steps, in accordance with the systematic review guidelines proposed by Kitchenham and Charters (2007):

1. **Scope and Sources:** The analysis focused on studies comparing or combining machine learning and econometric methods in climate variable and agricultural yield forecasting. The review was conducted through the Web of Science Core Collection and Scopus, the main academic databases, covering articles published between January 2004 and March 2025.
2. **Keywords:** The search strategy used the following keyword combinations:
 - Theme 1: ("crop yield" OR "agricultural productivity" OR "yield prediction")
 - Theme 2: ("climate" OR "weather" OR "precipitation" OR "temperature")
 - Theme 3: ("machine learning" OR "random forest" OR "neural network" OR "LSTM" OR "XGBoost")
 - Theme 4: ("econometric" OR "regression" OR "production function" OR "Ricardian").
3. **Screening Criteria:** The hundreds of studies initially found were screened according to the following criteria:
 - **Inclusion Criteria:** (a) Published in peer-reviewed academic journals, (b) Compare at least one ML algorithm with at least one traditional econometric model (linear regression, panel regression, Ricardian model) on the same dataset, (c) Report

performance using at least one quantitative metric (R^2 , RMSE, MAE), (d) Use at least 4 different climate variables in the analysis.

- **Exclusion Criteria:** (a) Theoretical articles only, (b) Studies using only one methodology and not performing comparisons, (c) Studies focused solely on non-climate factors, such as pesticide/disease prediction.

4. **Final Sample:** After the exclusion process, some key studies were identified that were highlighted to support the arguments in this section and referenced in the text. These studies focus on staple crops such as corn, wheat, soybeans, and rice at global, regional, and national scales.

This systematic review aims to establish a reliable general view of the relative performance of different algorithms in different contexts.

4. Results and Discussion

4.1. Integration of Multiple Climate Variables and Their Impact on Predictive Power

As seen in the Figure 2 and 3, the literature shows that as the number of variables used in traditional models increases, model performance (R^2) increases marginally, but this increase is limited due to multicollinearity issues. In contrast, ML models, especially tree-based ones, can efficiently handle a large number of related variables.

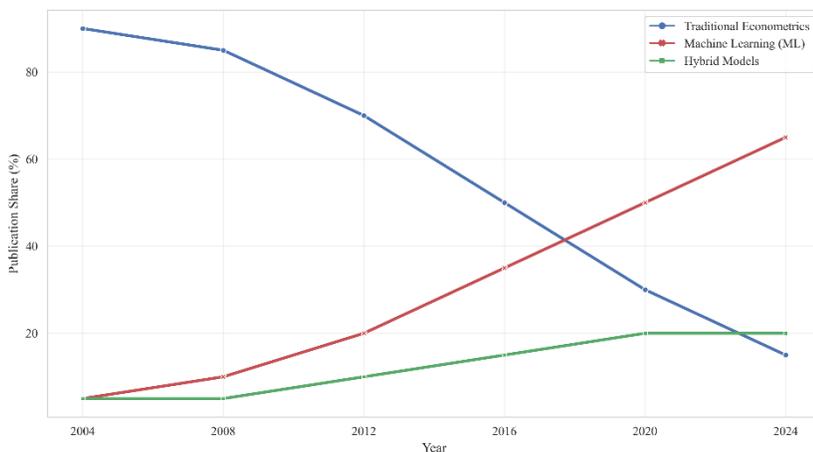


Figure 2. Methodological distribution in climate-yield (2004-2024)

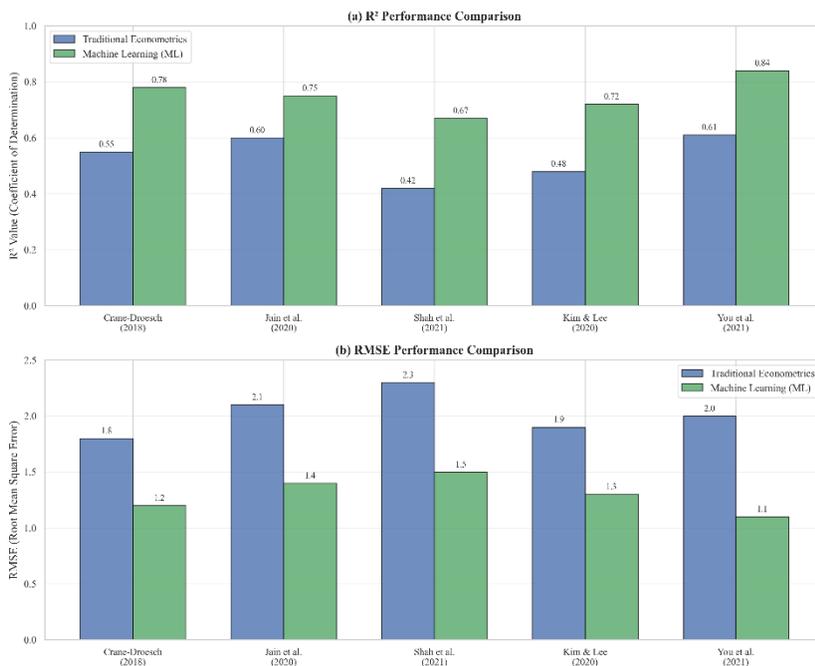


Figure 3. Performance comparison in selected studies

A significant study compared a panel regression model based solely on temperature and precipitation with a Random Forest model that included solar radiation, wind speed, and relative humidity in addition to the same variables, using daily meteorological data for the US corn belt (Crane-Droesch, 2018). The findings are striking: while the explanatory power (R^2) of the traditional model remained at ~ 0.55 , the Random Forest model increased the R^2 value to ~ 0.78 . More importantly, the root mean square error (RMSE) of the model decreased by more than 30% in Random Forest. Similarly, a study on rice yield in India showed that a Support Vector Machine (SVM) model incorporating 7 variables, such as minimum and maximum temperature, precipitation, humidity, cloud cover, and sunshine duration, increased R^2 from 0.42 to 0.67 compared to a standard quadratic

The reason behind this performance difference is ML's ability to **capture the compound effects** between these variables. For example, high radiation yield generally has a positive effect, but if there is insufficient soil moisture, this effect can be reversed. An algorithm such as Random Forest can automatically model this conditional relationship across thousands of trees. In a traditional model, the researcher would have had to pre-specify the Radiation x Soil Moisture interaction term and perhaps even guess its functional form (linear, quadratic).

4.2. Comparison of Algorithms: Strengths and Application Areas

Different ML algorithms exhibit different strengths in climate-yield modeling.

- **Random Forest (RF):** One of the most widely used and reliable methods in the literature. One of RF's greatest advantages is its ensemble learning structure, which reduces overfitting and improves generalization performance (Breiman, 2001). It also naturally provides variable importance levels (feature importance). This makes it possible to determine which climate factor is most critical in explaining yield variation. For example, many studies have revealed through RF importance rankings that, for corn and wheat in the US and Europe, maximum temperature is the variable of highest importance rather than average temperature; while in the Brazilian soybean belt, rainfall timing (flowering period rainfall) is the most decisive factor (Feng et al., 2019; Kim & Lee, 2020). This insight can shape policy priorities.
- **Artificial Neural Networks (ANN) and Deep Learning:** ANNs can demonstrate superior performance, especially when the relationship between input (climate) and output (yield) is extremely complex and non-linear. Thanks to their multi-layered structure, they can learn abstract features in the data (LeCun, Bengio, & Hinton, 2015). However, they generally require much more data than RF and their models tend to be a "black box" (their interpretability is low). Therefore, they are more frequently used in large-scale studies that combine high-resolution satellite data with climate data (You, Dong, Huang, et al., 2021).
- **Long Short-Term Memory (LSTM):** This is a special type of RNN (Recurrent Neural Network) and is revolutionary for time series data. Agricultural yield is deeply influenced not only by the climate of the current season but also by the conditions of previous weeks and months (phenological development stages). LSTM is unmatched in modeling these temporal dependencies and delayed effects (Hochreiter & Schmidhuber, 1997). For example, a heat stress during the flowering period can significantly impact yield at harvest. While traditional models struggle to model such delays, LSTM directly learns this relationship thanks to its "memory." One study showed that LSTM reduced RMSE by 15% more than a static RF model in predicting wheat yield in China (Wang, Li, Feng, & Zhao, 2022). This is consistent with studies emphasizing the importance of phenological timing (Sakamoto, 2020).

4.3. Machine Learning vs. Traditional Regression Head-to-Head

Landmark studies in the climate-yield literature have directly compared the two paradigms and clearly demonstrated the superiority of ML.

Crane-Droesch (2018) presents one of the most compelling comparisons in this field. The author compares a flexible nonlinear panel data model (a sophisticated example of traditional econometrics) using daily climate data with a Random Forest model to predict corn yield at the county level in the US. The results show that both models perform similarly in normal years, but in years with extreme weather events (drought or heatwaves), the RF model performs significantly better. While the traditional model fails to predict these extreme events, the RF model, thanks to its nonlinear structure, has the potential to capture the effects of these "tail events" much more effectively. This finding implies that as the frequency of extreme events increases with climate change, ML models offer more reliable early warning tools for policymakers. This is also consistent with the literature on the significant impact of extreme events on food systems (Lesk et al., 2016).

Similarly, Jain et al. (2020) tested multiple linear regression (MLR), RF, and Gradient Boosting Machine (GBM) models when predicting regional wheat yields in India. The study reported that RF and GBM provided improvements of 25% and 30%, respectively, in R^2 values compared to MLR and successfully modeled nonlinear threshold effects in climate variables. Similar results have been replicated in studies on maize yield in Africa (Chlingaryan, Sukkarieh, & Whelan, 2018) and soybean yield in South America (Feng et al., 2019).

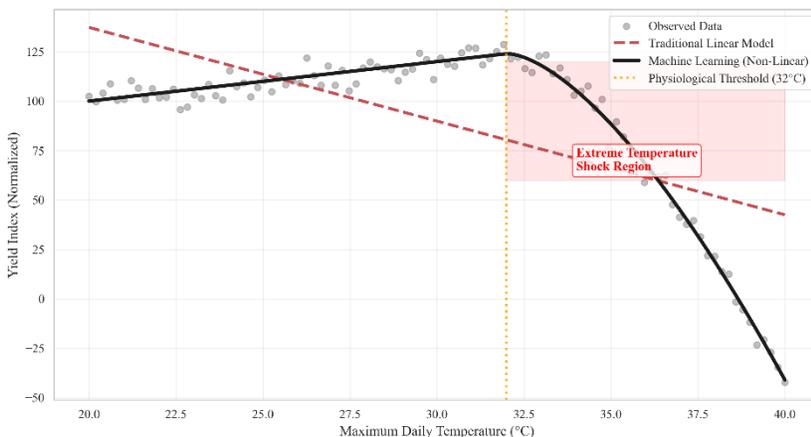


Figure 4. Impact of extreme temperature events on agricultural yield

As seen in the Figure 4 and the literature reviews the common conclusion of these comparisons is this: When the climate-yield relationship is non-linear and

complex (which is the case in most situations), traditional parametric models are inadequate, while ML algorithms transform this complexity in the data into interpretable predictions.

5. Conclusion and Future Perspective

This section has revealed that a methodological paradigm shift is occurring in efforts to understand and predict the effects of climate change on agricultural productivity. While traditional econometric models retain their value due to their theoretical rigor and interpretability, they have reached their limits in the face of the chaos, non-linearity, and multiple interactions inherent in the climate system and plant physiology (Lobell & Asseng, 2017). A systematic literature review shows that machine learning algorithms such as **Random Forest, Artificial Neural Networks, and LSTM** demonstrate a consistent superiority over traditional methods in terms of integrating multiple climate variables, automatically discovering nonlinear relationships and complex interactions, and providing higher accuracy, particularly in predicting extreme weather events.

In light of these findings, several critical recommendations for agricultural economists can be made for the future:

1. **Hybrid Modeling (Theory-Guided ML):** The future should not be a choice between entirely data-driven ML and entirely theory-driven econometrics, but rather a synthesis of the two. Theory-Guided Machine Learning aims to develop models that preserve physical meaningfulness and generalize better with less data by incorporating physical or biological constraints (e.g., yield cannot be negative, a specific light response curve for photosynthesis) into ML models (Karpatne et al., 2017; Reichstein et al., 2019). For example, the fundamental equations of a plant growth model (e.g., DSSAT) can be added as constraints to the structure of a neural network. This mitigates the "black box" criticism while preserving the predictive power of ML.
2. **Enriching the Data Infrastructure:** Fully realizing the potential of ML depends on high-quality and comprehensive data. This is an urgent call for policymakers: Meteorological observation networks must be expanded and strengthened to regularly measure critical variables such as solar radiation, soil moisture, relative humidity, and wind, not just temperature and precipitation (). Open data policies should facilitate researchers' access to this data (National Academies of Sciences, Engineering, and Medicine, 2019).

- 3. Shedding Light on the Black Box with Explainable Artificial Intelligence (XAI):** The criticism that ML models are a "black box" is valid. However, Explainable AI techniques such as SHAP (SHapley Additive exPlanations) and LIME (Local Interpretable Model-agnostic Explanations) address this issue (Lundberg & Lee, 2017; Molnar, 2022). These tools can explain, at the individual observation level, why an RF or ANN model made a particular prediction and which variable contributed in what direction. For agricultural policy decision-makers, an explainable insight such as "yield will decrease by X% due to expected extreme heat and low soil moisture next month" is far more valuable than simply predicting "yield will decrease."

Consequently, as climate change continues to threaten agriculture, our tools for understanding and predicting it must also evolve. Machine learning offers the methodological flexibility, scalability, and predictive power necessary to overcome this challenge. It is vital for the discipline of agricultural economics to develop innovative models that blend theoretical depth with data-driven power by embracing this new paradigm for the future of global food security (Lobell & Azzari, 2022). The paradigm shift has already begun; our task is to steer it efficiently and responsibly.

Acknowledgement

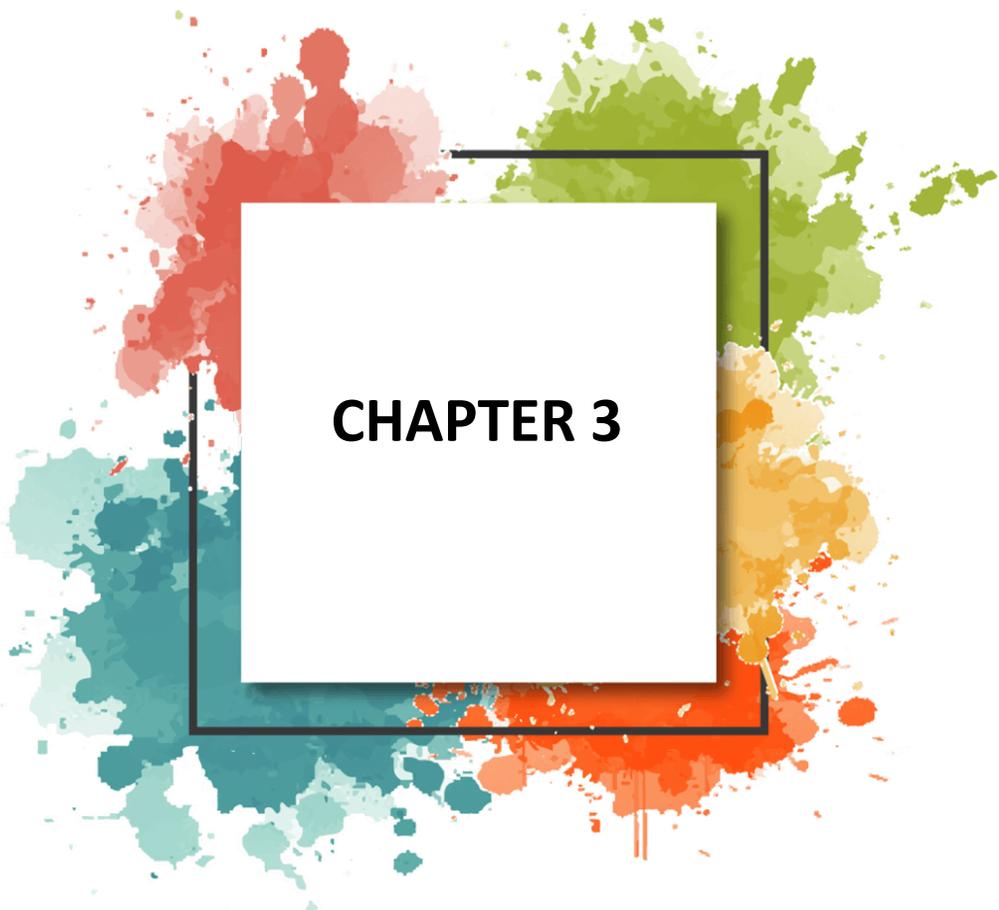
This study is derived from the project titled "Machine Learning Modeling of Agricultural Productivity in Türkiye Under the Impact of Climate Change and Productivity Predictions for 2025-2030 (Türkiye'de Tarım Ürünleri Verimliliğinin İklim Değişikliği Etkisi Altında Makine Öğrenmesi ile Modellenmesi ve 2025-2030 Verimlilik Tahminleri)" supported by Iğdır University Scientific Research Projects.

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CHAPTER 3

Evaluation of Tatvan (Bitlis, Türkiye) Fisheries for Occupational Health and Safety

Necati Önal¹ & Özgür Cengiz²

Introduction

The multidisciplinary field of occupational health and safety is concerned with the safety, health, and welfare of those who work. Promoting a safe and healthy working environment is the goal of an occupational health and safety program (Zakari et al., 2022). One of the oldest (Udolisa et al., 2012) and most adventurous jobs is fishing, which carries a high risk of occupational hazards, including acute injury (El-Saadawy et al., 2014) and endemic infections (Frantzeskou et al., 2012). Compared to other occupations, fishing has the highest rate of work-related injuries (Chauvin et al., 2007).

Individuals who work as traditional fishermen use boats and basic fishing equipment for capturing fish (Retnowati, 2011). These traditional fishermen, who typically follow in their family's footsteps, capture fish to support themselves (Purwanti, 2010). Multi-species coastal fisheries are dominated by small-scale fisheries (SSF) that employ low-tech fishing equipment such as nets, traps, and hooks and line (Halim et al., 2019). The target fish population dictates the level of intensity of any gear utilized (Rana et al., 2018). The majority of people don't realize how crucial small-scale fishing is to national income, food security, and livelihood. 90% of the 15 million individuals who engage in coastal and ocean fishing are small-scale fishermen, who employ modest fishing boats with little financial outlay (Zakari et al., 2022)

In Tatvan district, there is a dearth of accurate and readily available information regarding the safety concerns and occupational health management of SSF. The goal of the current study was to assess and pinpoint the occupational health risks that SSF face.

Materials and Methods

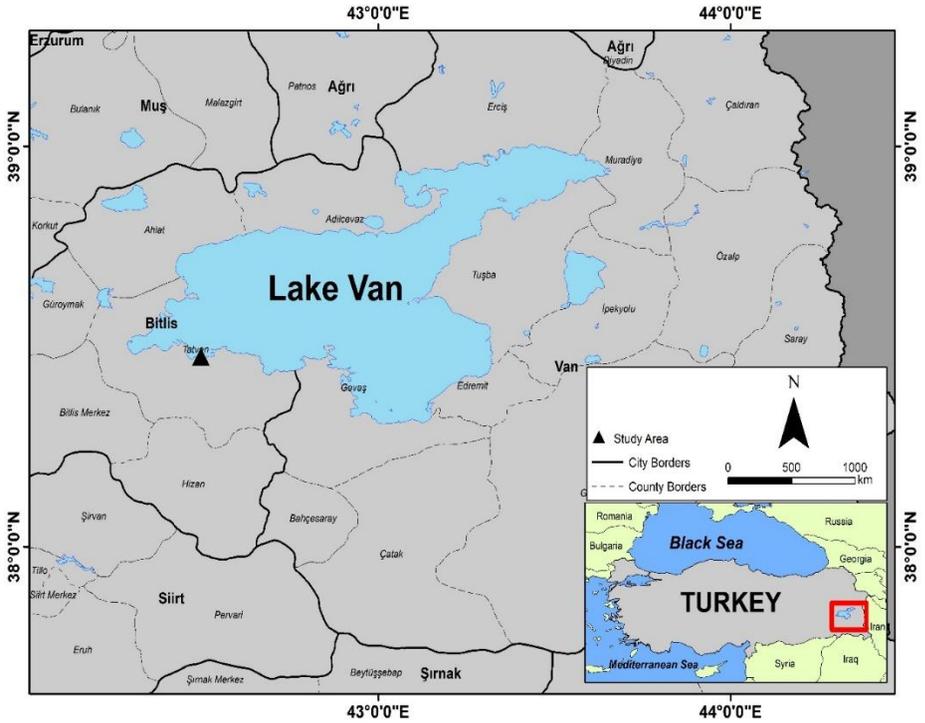
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Tatvan District is one of the six districts in Bitlis Province. The distance between Bitlis Province and Tatvan District is almost 25 kilometers and the district at issue is one of the areas within the Van Lake basin where intensive fishing operations are being done (Figure 1). Surveys were performed in-person from July to November 2022, asking 20 questions of commercial fishermen in the Tatvan district.

Figure 1. Tatvan (Bitlis, Türkiye)



Since the "L Type Matrix" approach is straightforward to apply to all sectors and practical in the field, it was chosen to analyze the risk elements of fishing activities in Tatvan district. When analyzing the cause-and-effect relationship, one technique is the "L-Type Matrix" method. This method use numerical values ranging from one to five to represent the probability of a risk/dangerous event occurring (Table 1) and the severity of that risk/dangerous event, in the event that it does occur (Table 2). After that, the likelihood that the risk/dangerous event will occur and the severity of that likelihood are multiplied to determine the risk score (Table 3). As a result, decisions are made about the needed activities (control measures).

Table 1. The likelihood of the risk becoming realized

Possibility		Risk Realization Frequency
Too small	(1)	Hardly ever
Small	(2)	Very little (once a year)
Medium	(3)	Few (several times a year)
High	(4)	Frequently (once in a month)
Very high	(5)	Very often (once a week / every day)

Table 2. Risk severity, if actualized

Severity	Possible Outcome
Very light (1)	No loss of working hours, needing first aid
Light (2)	No loss of working hours, no lasting effect and requiring outpatient treatment
Medium (3)	Condition that causes minor injury and requires inpatient treatment
Serious (4)	Condition that causes serious injury and requires long-term treatment, occupational disease
Very serious (5)	Condition causing death or permanent incapacity for work

Table 3. Deciding what should be done based on the risk score.

Risk Score	Meaning	Action
1	Minor risks	There is no need to take measures to eliminate the identified risks.
2-3-4-5-6	Low risks	There is no need for additional measures to eliminate the identified risks. Existing measures need to be maintained and their sustainability monitored.
8-9-10-12	Medium risks	Although not urgent, measures should be taken to reduce the identified risks.
15-16-20	High risk	Work should not be started until the risk has been reduced. Considerable resource allocation may be required to mitigate risk. If business is to continue despite this risk, urgent measures must be taken.
25	Intolerable risks	Work is not started until the identified risk is reduced to an acceptable level. Ongoing activities are stopped.

For those who fish, commercially, in Tatvan district, a risk analysis table was made utilizing the "L Type Matrix" approach. Based on Tantoğlu's (2016) and Soykan's (2018) firsthand observations and experiences, the example table was

created. In Table 4, twenty major risks have been identified along with potential outcomes. During the study, the fisherman were questioned:

- a) What the current safety measures are against risks at issue, and what are the conceivably consequences of these risks,
- b) The likelihood that these risks will materialize and how severity they would be if they did,
- c) By calculating a risk score, whether the safety precautions in place are adequate,
- d) The decision has been made to implement extra safety precautions, even if it is adequate.

Results and Discussion

Table 4 displays the responses from twenty two commercial fishermen in the Tatvan district who took part in in-person interviews. The likelihood and severity of the risk are represented by the average of the fishermen's numerical figures.

Table 4. Findings from the Tatvan district's risk analysis of fishing operations.

Risk/Dangerous Event	Possible Outcome	Current Safety Measure	Risk Level			Additional Safety Measure
			Likelihood of Risk	Severity of Risk	Risk Score	
1) Not checking the weather before sailing	Boat sinking, loss of life	Weather is checked, regularly	2	1	2	Current safety measure are sufficient
2) The occurrence of unpredictable weather conditions	Boat sinking, loss of life	Boats return to fishing coastal structure	1	2	2	Current safety measure are sufficient
3) Not using the pier during boarding and disembarking.	Falling overboard, injury	The scaffold is in continuous use	1	2	2	Current safety measure are sufficient
4) Boats are not equipped with fenders	Damage/material loss caused by boats rubbing against each other	There are fenders, but not enough	1	4	4	The number of fenders should be increased
5) Unevenness of the working area on the deck	Injuries resulting from falls, loss of life	Working area is kept tidy	1	3	3	Current safety measure are sufficient
6) Working hanging from the deck	Falling overboard, loss of life	Not working by hanging	2	1	2	Current safety measure are sufficient
7) Fishermen's inexperience	Injuries, decreased in work efficiency	Newly hired fisherman is being informed	3	3	9	This information should be provided by specialized institutions

8) Working in wet and cold conditions	Employee cold, decrease in work efficiency	Fishermen wear underwear and overalls	1	1	1	Current safety measure are sufficient
9) Falling overboard	Death by drowning	All fishermen can swim	1	1	1	Current safety measure are sufficient
10) Noise	Not hearing instructions	Sign language is used when necessary	1	2	2	Current safety measure are sufficient
11) Transport of catch/fishing gear	Injuries to the hands, back and lumbar	Fishermen help each other	2	4	8	Current safety measure are sufficient
12) Fatigue from irregular and long working hours	Injuries, decreased in work efficiency	No current safety measures	5	3	15	Fishermen must work in shifts
13) Fire	Boat sinking, loss of life	Such a situation has never happened	1	1	1	Fire extinguishers should be available on the boats.
14) Fishermen do not know how to swim	Death by drowning	All fishermen can swim	1	1	1	Current safety measure are sufficient
15) Problems with freshwater requirement	Infectious disease risk, hygienic problems	There is no problem with the freshwater requirement.	1	1	1	Current safety measure are sufficient
16) Lack of first aid cabinet on the boat	Injury	There is a first aid cabinet according to the first aid regulations	1	1	1	Current safety measure are sufficient
17) Lack of first aid training	Injury	Fishermen have the information they need	3	2	6	Current safety measure are sufficient
18) Having no training in occupational health and safety (OHS)	Injury, loss of life, occupational disease, material damage	No informing about OHS	4	4	16	Fishermen should be given training in OHS as soon as possible
19) Trying to land before the boat docks fully at the pier	Falling overboard, injury	No current safety measures	2	4	8	Do not go ashore before the boat is moored to the port and the engines are turned off.
20) Electric leakage	Injuries due to electric shock, loss of life, fire	It is stated that the sockets are solid	2	4	8	Plugs should be checked periodically.

Based on the fishermen's feedbacks, six of the 20 risks were classified as trivial (30%), eight as low risk (40.0%), four as medium risk (20.0%), and two as high risk (10%). "Fatigue due to irregular and long working hours" and "Having no training in occupational health and safety" are among the high-risk groups, according to this research. The studies at Çitören (Atay and Cengiz, 2022), Lake Erçek (Cengiz, 2022), and Gevaş (Cengiz et al., 2023) in the Van Lake Basin revealed the same observations.

Conclusion

The duty of all stakeholders is to create awareness among the relevant personnel regarding OHS and to create a safe working environment by detecting work accidents and taking the necessary precautions. The responsibility of employees is to comply with the precautions that can prevent work accidents and to increase their level of knowledge on the subject. As a result of these efforts, work accidents and occupational diseases can be prevented to a large extent.

Acknowledgments

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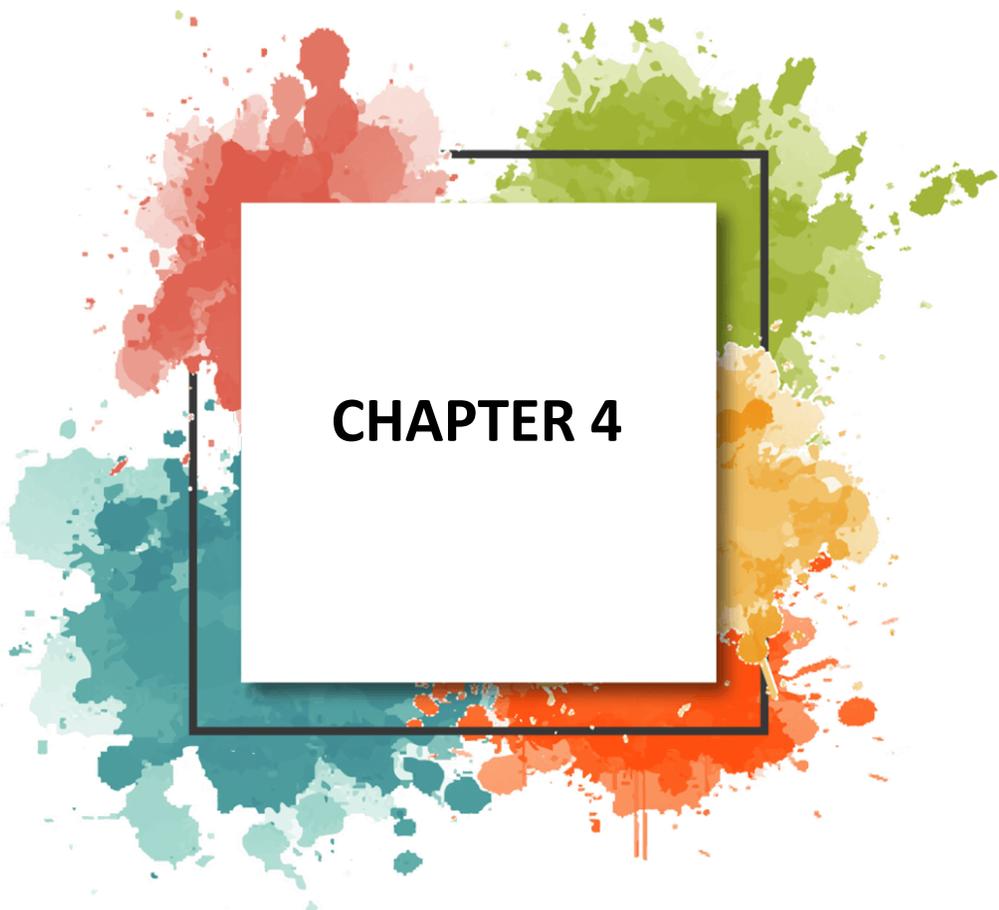
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CHAPTER 4

Agriculture and Energy: Sustainable Approaches

Ali Kahraman¹ & Neslihan Doruk Kahraman²

Introduction

Since the dawn of human being to the present day, main needs have included food, shelter and the survive of the various species. Today, around the world, the concept of energy has a huge importance. The misuse of the energy resources causes to undesirable and big environmental problems. By the rapid progress of technology, consumption of energy in the agricultural sectors is increasing quite faster than the national economy. Sustainable agriculture is an agricultural model that built on the principles of environmental protection, social justice and economic gain. This perspective aims to minimize the environmental impacts which is based on agricultural activities while take care about agricultural production by the goal of conservation of natural resources and releasing a healthy environment for future generations. In the present day, rise in the energy costs, climate based changes, and environmental sustainability concerns have made energy efficiency and the use of renewable based energy sources a strategic necessity in all the agricultural based sectors.

Dissimilar to the traditional based agricultural applications, sustainable farming methods may include many techniques likewise the usage of organic based fertilizers, rotation of crops, and agro-ecological based approaches. That kind of situation increases productivity of agriculture and also decreases the environmental impacts. For the agricultural sector, utilizing of alternative energy sources in place of the fossil fuels is a precedence to conservation of current energy resources and prevention of environmental pollution. The relations amongst the agricultural activities and the environment history back to the Neolithic era. Agriculture is a vital activity in the economic life of countries due to its contributions to production and consumption, industry, trade, and employment.

Although efforts have been made to achieve the goal of ending hunger and all forms of malnutrition worldwide by 2030, statistical data provides serious warnings that this will not happen. Due to global warming, natural disasters such as wildfires and floods have increased globally. For these reasons, countries need to enable and regulate their domestic companies to operate in a sustainable and

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environmentally friendly manner (Green Bank Design Platform, 2020). It has been argued that cleaner agricultural practices, such as sustainable farming techniques, have the capacity to mitigate climatic change (Paustian et al., 2020).

Water-saving techniques enhance water usage in agriculture besides providing a safeguard against water scarcity. Sustainability of agricultural activities and efficiency of energy enable more efficient administration of water resources. Usage of renewable typed resources is gaining importance as an alternative to traditional based oil and coal-based electricity generation techniques, owing to limited resources and environmental welded troubles. Similarly, since the 1990s, the EBRD has been a leading institution that is based on sustainable type of economy in Europe countries. So, its contribution is quite significant not only through the economic assistant but also through its academic research (Shields, 2020).

Interdisciplinary researches focused on the sustainable, efficient, and environmentally aware usage of energy resources in agricultural activities and processes are essential. Smart farming based practices, equipped by technologies likewise sensors and data analysis, support the aims of Sustainable Agriculture and Energy Efficiency with enable to more efficient usage of resources. Against the global climate change, the environmental awareness of countries and sectors has increased. Main objectives have been set within the framework of various policies established by several organizations for carbon emissions. Present paper focuses on reducing of agricultural dependence on energy, integrating of renewable type of energy sources into agricultural activities, and optimization of energy management. Sustainable agriculture and energy trends aim to increase food security worldwide by offering sustainable solutions from both environmental and economic perspectives. This study provides information on energy use and sustainability in agriculture. It explains the benefits of using renewable energy sources in the agricultural sector and offers suggestions on how to adapt agricultural activities at all stages to meet the demands of the era and to sustainable development.

Keywords: Climate Change, CO₂ Emission, Energy, Sustainability.

Sustainability of Agriculture: Perspective on Agricultural Energy

Sustainable agricultural practices contribute to strengthening local economies. Supporting agricultural activities at the local level increases farmers' income levels and improves the well-being of communities. Focusing on energy analysis and planning in agricultural production, the use of renewable energy sources (solar, wind, biogas, biomass, hydrogen, etc.) in agricultural activities, energy efficiency, carbon footprint calculations, and the development of sustainable energy policies are of great importance for both the present and the future.

Renewable energy sources take various forms, including wind energy, solar energy, geothermal energy, hydropower, and more.

Agricultural production has played a significant role in the prosperity achieved by today's developed economies. However, the agricultural sector also makes a considerable contribution to greenhouse gas emissions through waste from livestock production, nitrogen fertilizers used in crop production, diesel fuel in tractors, heating fuels in homes, and electricity used in greenhouses and animal shelters. The use of sustainable methods in agricultural activities supports the goal of leaving a healthier and more balanced world for future generations. It is claimed that the agricultural sector is responsible for approximately 14% to 30% ratio over global quantity emissions of greenhouse gas yielded by its intensive fossil fuel energy consumption (Jebli and Youssef, 2017).

From a sustainability perspective, reducing energy costs without compromising the quality and yield of agricultural products can be achieved through the efficient use of energy and energy efficiency. Degradation of environment is the corruption of the environment with regards of consuming of natural based resources likewise water, air and soil welded by growth in population and industrialization; the ecosystems destruction and extinction over wildlife; and primary reason of environmental degradation is known as human intervention (Tyagi et al., 2014). Global energy demand is increasing by approximately 4–5% annually. In contrast, the fossil fuel reserves that meet this need are decreasing much more rapidly (Görez and Alkan, 2005). In their study investigating the relationship among the renewable and non-renewable production of electricity, economical growing, international trade, and emissions of CO₂ for Italy during the period 1960-2011, Bento and Moutinho (2016) concluded that renewable electricity production reduces CO₂ emissions and that the (EKC hypothesis: Environmental Kuznets curve) ECR is valid.

Energy conservation contributes to the conservation of natural resources, thereby providing future generations with a cleaner world. With advancing technology, energy-intensive practices are also being implemented in the agricultural sector. Coal dominates global emissions from fuel combustion (45%), followed by oil (33%) and natural gas (22%) (IEA, 2024). Due to climate change and rising energy costs, solar energy systems are being used in many agricultural production activities and processing units, from cold storage and greenhouses to livestock farming and agricultural irrigation. Advanced energy efficiency techniques help combat with climatic changes beside decreasing of

greenhouse based gas emissions. Studies show that the energy needed, especially in the agricultural sector, tends to increase as the trade deficit with CO₂ emissions grows (Dauda et al., 2021).

Energy systems in agriculture exactly address not only the technical aspects of agriculture but also its interaction and relation with energy economics and many types of sustainable development goals. Sustainable usage of energy in agricultural activities leads to healthier production of foods and improvement of nutritional standards for human being. Researchers (Paramati et al., 2017) analyzed the closeness over renewable energy consumption, the consumption of non-renewable typed energy, economical growing, population, and also the CO₂ emissions for G20 countries between 1991 and 2012, concluding that renewable energy consumption reduced emissions. Fossil based fuels continued uninterrupted to representation of 81% ratio of the totally global wide energy supplying, by the oil accounting for approximately 30% ratio, that is followed with coal (28% ratio) and after natural gas (23% ratio) respectively (IEA, 2024). CO₂ emission rates according to energy production type are given as follows: CO₂ emission rates according to energy production type are given as follows: Petroleum 760 g/kw, Coal 790 g/kw, Lignite 910 g/kw, Natural Gas 380 g/kw, Nuclear 25 g/kw, respectively (Anonymous, 2021).

The use of renewable energy not only provides environmental advantages but also creates new job opportunities and areas of economic development for the agricultural sector. Non-renewable energy types accounted for more quantity than about three-quarters of the totally greenhouse based gas emissions in global scale (IEA, 2024). Research reports (Dong et al., 2017) proved the effects over energy consumption by means of renewable type, besides natural gas typed consumption, GDP per capita, and the square of GDP per capita on CO₂ emissions for BRICS countries between 1985 and 2016 and concluded that renewable energy consumption reduces carbon emissions and that the “EKC” hypothesis is valid. Making elements such as water, land, and energy use more sustainable will help minimize the negative impacts of climate change. Nature conservation, conducting economic activities without harming the environment, and activities related to renewable energy sources for sustainability are among the EBRD's main activities today (Kilpatrick and Williamts, 2021). The contribution of agriculture to greenhouse gas emissions indicates that the "EKC" hypothesis still needs improvement (Rafiq et al., 2015).

Efficiency can be achieved not only through energy conservation but also through the efficient use of natural resources in agricultural enterprises. Given the importance of the relations among consumption of energy and economically growth, many past reports have emphasized close connections between the energy consumption and economical growth (Chandio et al., 2019). In their study,

Bhattacharya et al. (2017) tested the relationship between non-renewable typed and renewable typed energy consumption, institutional quality, growth in economy, and CO₂ emissions for a group of 85 in total including developed countries and also developing countries covering the periods between 1991-2012 years. The finding that renewable based energy consumption reduces carbon emissions was confirmed. The Food and Agriculture Organization (FAO) was established by the United Nations in 1945 after World War II. While in the past, measures were taken to address food crises through trade and production, the organization's work has shifted, and today, with climate change and its profound effects, its focus is on adapting to new conditions and leading states in taking the necessary steps (FAO, 2017). Paradoxically, increased agricultural based activities refers increased consumption of energy and so higher emission quantities (Zhang et al., 2019).

In particular, energy efficiency integrated with modern agricultural practices is supported by innovative solutions such as hydroponic systems, solar-powered irrigation systems, and energy-efficient equipment. To ensure the effective management of energy resources used in agriculture, engineering, environmental sciences, and energy technologies come together; therefore, a multidisciplinary approach is necessary. Emissions from activities such as stubble burning, deforestation, conversion of pastures into arable land, and planting contribute to the increase in greenhouse gas emissions (Raihan et al., 2024). The lower the input costs in agricultural production, the higher the profitability will be. Turning to environmentally friendly and more economical solutions such as solar and geothermal energy will significantly reduce the costs for producers and entrepreneurs, and consequently, product prices will decrease, allowing consumers to obtain products at more affordable prices. Sinha and Shahbaz (2018) investigated the pressure of renewable typed energy production over CO₂ emissions for India over 1971-2015 years using the “EKC” hypothesis model. They concluded that renewable energy production has a significant effect on reducing CO₂ emissions and that the reverse “U” shaped “EKC” hypothesis is valid. Data from 1990-2014 were examined to investigate the effects of renewable typed energy consumption, agricultural production, in addition to forestry on emissions of CO₂ in Pakistan (Waheed et al., 2018). Long-term emissions showed; agricultural based productions are significant carbon source at Pakistan. Another report (Chen et al., 2019) attempted to explain the consumption interactions of non-renewable type energy and renewable type energy, economically growth, and emissions of CO₂ for China between 1980-2014 years. According to the ARDL bounds test results, renewable based consumption of energy reduces emissions of CO₂, while the hypothesis of “EKC” is valid. On the other hand, the European Union has reinforced this region by providing of support in many kind of areas to assistance of agricultural sectors.

That kind of areas have helped to the achieve goals likewise establishing and management of supply chains and complying with the environmental standards in the national economy (Canton, 2021). In another former research (Ullah et al., 2018), they examined the consequential relations among the agricultural ecosystems and CO₂ emissions as an indicator of environmental pollution in Pakistan from 1972 to 2014 years. The findings revealed that a 1% ratio of increase in CO₂ equivalent to nitrous oxide (N₂O) emissions from agricultural based production in the long term would lead to rise in the emissions of CO₂ as well.

Integrating renewable based energy sources for achievement of sustainable agriculture and energy efficiency goals not only offers farmers a cleaner production method but also increases the sustainability of these methods. For these reasons, the agricultural sector and some other sectors are quite strictly encouraged by usage renewable based energy types (Qiao et al., 2019). In their study, researchers (Waheed et al., 2018) attempted to explain the relationship between renewable energy consumption, agricultural production, forested area, and CO₂ emissions for Pakistan during 1990-2014 periods. It revealed that renewable typed energy consumption and forested area could reduce emissions, while agricultural production had no statistically significant effect. Studies have shown that as trade increases, GDP also increases. The rise in income is directly linked to CO₂ emissions. This aspect highlights the excessive pollution levels in African countries (Dauda et al., 2021). Energy efficiency is considered a crucial resource for achieving many goals in countries, such as economic growth, energy supply security, climate change, and sustainability. Researchers (Jebli and Youssef, 2017), in their study testing the impact of the agricultural sector, consumption of renewable based energy, and economically growing in CO₂ gas emissions over countries in North African for the years of 1980-2011 period found that consumption over renewable typed energy sources and economically growing increased emissions of carbon, while agriculture reduced carbon emissions. The findings of another research realized in Croatia (Ahmad et al., 2017) revealed that there is an inverted U-shaped relations among CO₂ emissions and economic growth in the long term.

In the present day, the main goal in addressing about climatic changes is decrease gas emissions related with greenhouse. To succeed this goal might be possible through appropriate planning of energy requirements. Using of the renewable typed energy sources is critical for prevention of climatic changes and ensuring of a more livable world. Therefore, sustainable agriculture indicates one of the most essential needs of our time: it feeds human being while protecting the environment.

Conclusions

To succeed sustainable agricultural development requires decreasing of the usage of fossil based fuels, encouraging the usage of renewable typed energy sources, and increasing efficiency for energy. Numerous exciting trends are expected to emerge in the fields of sustainable agriculture and energy efficiency in the future. By the fast growth of population and limited water resources worldwide, agriculture has become and will continue to become increasingly important for providing the nutritional needs of societies as well.

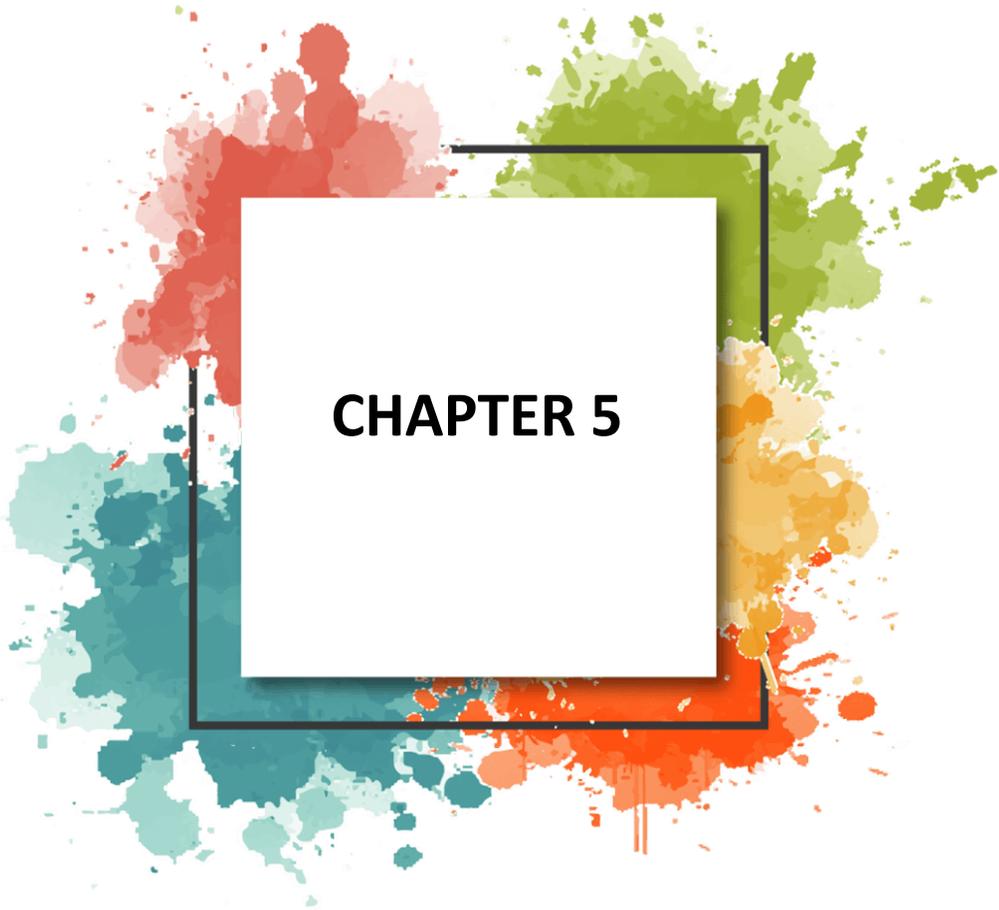
Based on feasibility researches in agricultural production, assistance should be provided for energy efficiency focused projects; the advantages of distributed energy systems should be utilized by providing the energy needed for sustainable agricultural production from local resources; and intensive efforts should be made to encourage the use of renewable energy sources (solar, wind, geothermal, biomass) in agricultural production processes to reduce energy costs and the environmental impact of agricultural production. It is essential to focalize on efforts targeted at increasing efficiency and environmental sensitivity in agricultural production by expanding the use of renewable type energy sources. Effectiveness of energy acts a critical role to overcome about sustainability goals and is key to success in agricultural activities.

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CHAPTER 5

Wrasses of the Aegean Sea

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1. INTRODUCTION

The family Labridae is represented by 504 species in the world's oceans (Parenti and Randall, 2010) and by 20 species in Turkish seas (Bilecenoğlu et al., 2014). Members of the Labridae family are generally referred to in Turkish as “lapin” and “çırçır” fishes.

All members of the family are marine species distributed throughout the Atlantic, Indian, and Pacific Oceans, including the Mediterranean Sea. Most species excavate burrows in the sediment and live within these burrows, generally exhibiting carnivorous (feeding on benthic invertebrates) and planktivorous feeding habits. Many species of the family change color and sex as they grow, and most species eventually transform into males. It has been reported that one male dominates multiple females. While the largest species of the family reaches 2.3 m, the smallest is 4.5 cm, and most species are smaller than 15 cm (Froese and Pauly, 2023).

Although members of the family are not consumed for nutritional purposes, they are highly sought after in the marine aquarium sector due to their bright colors and active behavior; therefore, they can be considered commercially important species. In addition, it is known that some large individuals caught in artisanal fisheries are consumed as food. Compared to other commercial families and species, there are relatively few scientific studies on this family both worldwide and in Türkiye.

Studies on Labrid species in Türkiye are quite limited, and there is no comprehensive study on individuals distributed in the Aegean Sea. The Aegean Sea is very rich in terms of biodiversity, and the presence of 20 species from the Labridae family has been reported in the region (Bilecenoğlu et al., 2014).

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However, there are no studies that interpret interpret reproductive biology, length–weight relationships, growth, condition factor, and gonad development indices of these species.

Through the data obtained in this study, scientific literature has been enriched both in Türkiye and in the Mediterranean basin, and up-to-date biological findings have been obtained for these species. The growth parameters and reproductive periods determined for the species identified in the present work also provide an important scientific basis regarding which species are more suitable for the aquarium sector.

Within the scope of this study, population dynamics of Labridae species obtained from commercial fishers in the region using various sampling methods were comprehensively investigated for the first time in Turkish seas.

2. GENERAL INFORMATION

Green (1996) investigated the spatial, temporal, and ontogenetic characteristics of habitat use by Labridae species distributed around Lizard Island. Green (1996) identified 64 Labrid species in the area and reported that 8 of them were permanently present in the region, while others occurred only occasionally. This study revealed that species of the same family exhibit different characteristics in habitat use.

Fulton et al. (2001) examined the relationship between swimming ability and habitat use of Labrid fishes in the Great Barrier Reef, Australia. However, the study did not include any findings on the population dynamics of the species.

Palloro and Jardas (2003), who studied *Symphodus tinca* along the Croatian coast, reported several biological parameters. They found the male-to-female ratio to be 1.43:1, maximum lifespan to be 12 years for males and 13 years for females, and estimated von Bertalanffy growth parameters as follows: asymptotic length (L_{∞}) = 28.14 cm, growth coefficient (k) = 0.294, and theoretical age at zero length (t_0) = -0.775 years.

Jones (2005) studied the habitat range of six Labrid species distributed in the Caribbean Sea (*Halichoeres bivittatus*, *H. garnoti*, *H. maculipinna*, *H. poeyi*, *H. radiatus*, and *Thalassoma bifasciatum*), but did not provide any results regarding basic population parameters such as reproduction and growth.

Sara et al. (2005) examined the courtship behavior and reproductive biology of *Thalassoma pavo* in the northwestern Mediterranean.

Benal et al. (2006), in their study titled “Determination of Fish Composition in Artificial Reefs Placed on Different Substrates along the Ürkmez Coast,” reported that the Labridae family was the dominant family, with 13 species in

seagrass beds, and the second dominant family, with 4 species in muddy substrates.

Aydın et al. (2008) identified four Labridae species (*Coris julis*, *Labrus bergylta*, *Symphodus mediterraneus*, and *Symphodus tinca*) in gillnet fisheries in İzmir Bay and reported that all of these species were considered discards. The researchers did not present any biological findings for these species.

Raposeiro and Azevedo (2009) studied the reproductive biology of *Symphodus mediterraneus* along the Portuguese coast and reported that the species exhibits gonochoristic characteristics. They found that reproduction occurs in spring and summer, and that the length at sexual maturity is 12.1 cm in males and 9.6 cm in females.

Kazancıoğlu and Alonzo (2010) investigated the effects of sex change on size and growth in the Labridae family.

Türkmen et al. (2011), in their study on adapting some bony fish species from Turkish seas to marine aquariums, stated that 70 species could be adapted to marine aquariums, and among these, the family with the highest potential was Labridae, with 13 species.

Skiftesvik et al. (2014) reported that species of the Labridae family are used as cleaner fish in salmon aquaculture. These fish feed on parasites known as sea lice, thereby increasing the survival rates of salmon. For this reason, *Symphodus melops* and *Labrus bergylta* have become commercially important species in Norway and surrounding areas.

İlkyaz et al. (2014), in their study titled “Potential Use of Net Traps in Supplying Live Fish for Marine Aquariums,” identified two Labrid species (*Symphodus cinereus* and *Symphodus rostratus*) in their samplings in İzmir Bay. However, they did not present any biological findings for these species.

Bilecenöglü et al. (2014) reported that there are 20 Labridae species in Turkish seas but did not provide any biological evaluation of these species.

As seen from the literature review, the number of studies addressing the biological characteristics of this family is very limited both worldwide and in Türkiye. Therefore, the present work makes a significant contribution to the literature on the Labridae family.

3. MATERIAL AND METHODS

The sampling areas of the study, from north to south, were Urla, Çeşme, and Gökova Bay. Samples were obtained from small-scale fisheries operating in these regions using gillnets; additionally, passive fishing gears such as rods and traps were also used (Figure 1). Sampling was conducted at depths between 0 and 20

meters. The collected specimens were stored frozen at -22°C in the laboratory during the period between capture and measurement.

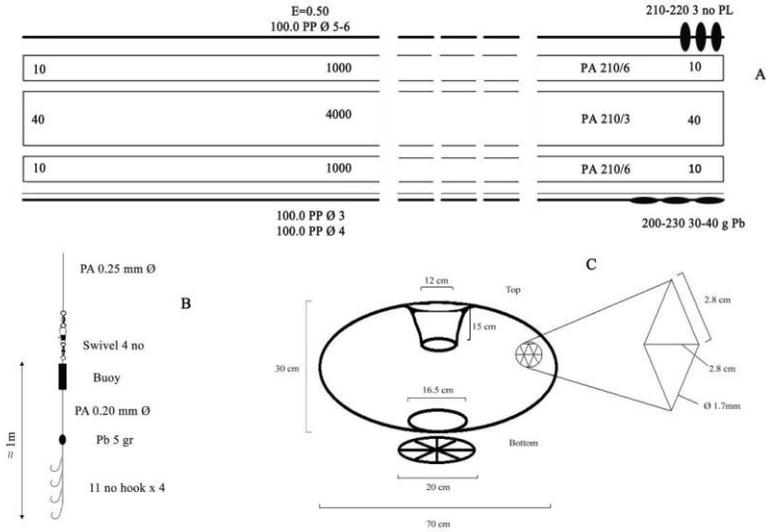


Figure 1. Fishing gears used in the study; A: Trammel net (Inner mesh size: 50 mm; Outer mesh size: 200 mm); B: Rod; C: Trap.

For each individual, measurements of total length (TL), body weight (W), sex (Sex), gonad stage (GS), and gonad weight (GW) were recorded, and otoliths were extracted. Total length measurements were taken using a fish measuring board with 1 mm precision. Total body and gonad weights were measured using an electronic balance with 0.01 g precision. Sex determination was performed by macroscopic observation, and gonad stages were classified according to Gunderson (1993). In this classification, gonad development stages were evaluated in five categories:

i. **Immature.** This stage is observed only in juvenile individuals of both sexes. The gonad occupies approximately one-third of the body cavity. In females, the ovary is thin, tubular, and transparent. In males, the gonads are white.

ii. **Developing.** Gonads occupy up to half of the body cavity. The ovary in females is pinkish and transparent. Male gonads are whitish.

iii. **Maturing.** Gonads occupy nearly two-thirds of the body cavity. The ovary is pinkish-yellow, and eggs can be distinguished with the naked eye. Male gonads are whitish-cream colored and soft.

iv. **Mature.** Gonads occupy more than two-thirds of the body cavity. The ovary is orange or pink and surrounded by blood vessels. Large, transparent eggs can be clearly distinguished. In males, gonads are whitish-cream colored and soft.

v. **Spent.** After spawning, gonads take on an appearance between stages two and four. Gonads shrink to approximately one-third of the body cavity. In females, it is possible to observe dark, adherent mature eggs. Female gonads appear dark or transparent, while male gonads appear bloody and flaccid.

For age determination, direct observation under a stereoscopic microscope was used. For this purpose, the right and left otoliths were removed separately and packaged. Otoliths were cleaned of fat and tissue residues in 96% ethanol, taking care not to break them. The cleaned otoliths were placed in a black dish with alcohol and examined under a stereomicroscope using top illumination for age reading. Age determination followed the method described by Soykan et al. (2015).

To determine the length–weight relationship, total length of each individual was considered as “x” and weight as “y”, and the natural logarithms of both values were calculated. A regression analysis was performed between Ln(TL) and Ln(W) using the least squares method. The length–weight relationship was expressed by the exponential equation $W=aL^b$ (Ricker, 1973; Ricker, 1975). The strength of the relationship between observed and predicted values was assessed using the square of the Pearson correlation coefficient.

Length–weight relationships were calculated separately for all individuals, females, and males. A *t*-test was used to determine whether the estimated *b* value significantly differed from the cubic growth value ($b = 3$). For this purpose, the standard error of *b* (*SEb*) was first calculated, and the confidence interval was evaluated using the *t*-distribution at the 95% confidence level.

Gonadosomatic index (GSI) was calculated using both female and male individuals for species with sufficient sample sizes. Monthly mean GSI values were calculated based on the proportional relationship between gonad weight and body weight using the equation proposed by Gibson and Ezzi (1980):

$GSI = [GW/(W-GW)] \times 100$, where GW is the gonad weight

(g) and W is the total weight (g) of the fish.

4. RESULTS

Members of the Labridae family generally inhabit rocky areas with *Posidonia* meadows. Sexual dimorphism is observed in this family during the breeding period. In general, males have striking colors, whereas females have dull, less conspicuous coloration. Some species have typical spots, the patterns of which

are species-specific. They are represented in Turkish seas by 8 genera and 19 species (Froese and Pauly, 2023). Members of the family distributed in the Atlantic, Indian, and Pacific Oceans are also found in Turkish seas.

The taxonomic classification of the family is as follows:

Phylum: Chordata

Subphylum: Vertebrata

Class: Osteichthyes

Order: Percomorphi (Perciformes)

Family: Labridae

The species distributed in Turkish seas, as reported by Bilecenoglu et al. (2014), are as follows:

- *Acantholabrus palloni* (Risso, 1810)
- *Coris julis* (Linnaeus, 1758)
- *Ctenolabrus rupestris* (Linnaeus, 1758)
- *Labrus bergylta* (Ascanius, 1767)
- *Labrus merula* (Linnaeus, 1758)
- *Labrus mixtus* (Linnaeus, 1758)
- *Labrus viridis* (Linnaeus, 1758)
- *Lappanella fasciata* (Cocco, 1833)
- *Pteragogus pelycus* (Randall, 1981)
- *Symphodus cinereus* (Bonnaterre, 1788)
- *Symphodus doderleini* (Jordan, 1890)
- *Symphodus mediterraneus* (Linnaeus, 1758)
- *Symphodus melanocercus* (Risso, 1810)
- *Symphodus melops* (Linnaeus, 1758)
- *Symphodus ocellatus* (Forsskål, 1775)

- *Symphodus roissali* (Risso, 1810)
- *Symphodus rostratus* (Bloch, 1791)
- *Symphodus tinca* (Linnaeus, 1758)
- *Thalassoma pavo* (Linnaeus, 1758)
- *Xyrichtys novacula* (Linnaeus, 1758)

In the present study, 12 species belonging to the Labridae family were identified, and the total number of sampled fish was 407. It was found that the genus *Symphodus* was the most dominant, with 6 species and 292 individuals, followed by the genus *Labrus* with 4 species and 18 individuals, while the genera *Coris* and *Thalassoma* were each represented by a single species.

The species obtained were:

- *Coris julis* (Linnaeus, 1758)
- *Symphodus tinca* (Linnaeus, 1758)
- *Symphodus mediterraneus* (Linnaeus, 1758)
- *Symphodus ocellatus* (Forsskål, 1775)
- *Symphodus roissali* (Risso, 1810)
- *Symphodus cinereus* (Bonnaterre, 1788)
- *Symphodus rostratus* (Bloch, 1797)
- *Labrus merula* (Linnaeus, 1758)
- *Labrus bergylta* (Ascanius, 1767)
- *Labrus viridis* (Linnaeus, 1758)
- *Labrus mixtus* (Linnaeus, 1758)
- *Thalassoma pavo* (Linnaeus, 1758).

***Coris julis* (Linnaeus, 1758)**

A total of 96 individuals were obtained during the study, with total lengths ranging from 13.5 to 19.5 cm and body weights between 23.3 and 78.2 g. The mean total length and weight of the sampled *C. julis* individuals were calculated as 16.4 ± 1.2 cm and 47.2 ± 12.0 g, respectively.



Figure 2. Underwater Picture of *Coris julis*
(<https://www.fishbase.se/photos/PicturesSummary.php?resultPage=7&ID=58&what=species>)

In the sampled population, 36 females and 43 males were identified, while the sex of 17 individuals could not be determined. Otolith examinations revealed that individuals ranged between 2 and 6 years of age, and the species exhibited positive allometric growth (t -test; $p < 0.05$). The length-frequency and length-weight relationship graphs for this species are presented in Figure 2 and 3. Spawning was found to occur between April and August. GSI values for males and females in months where data were available are presented in Table 1.

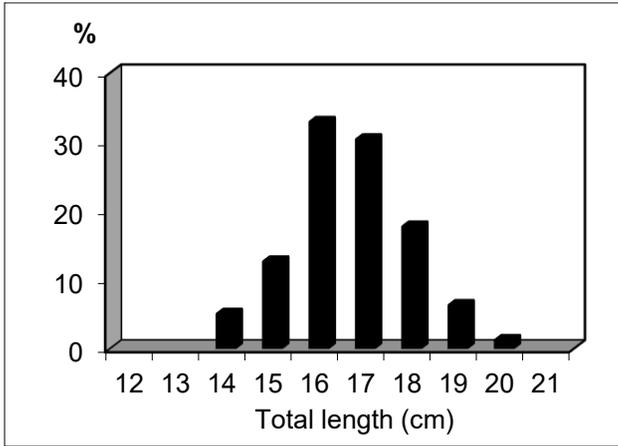


Figure 3. The length-frequency of sampled *C. julis*

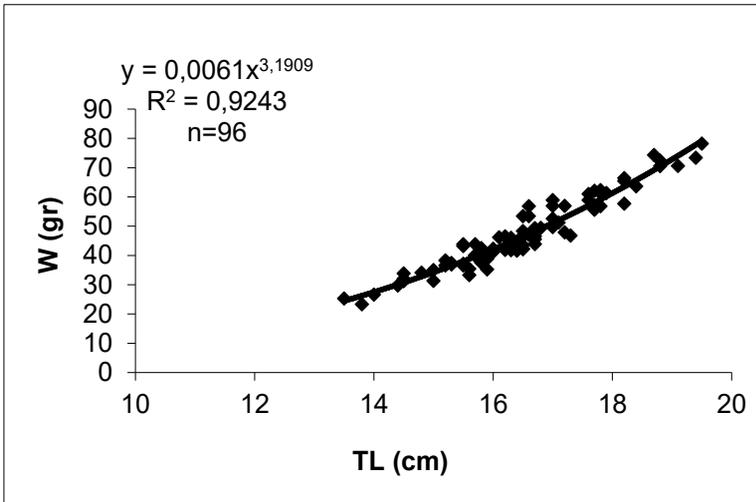


Figure 4. The length-weight relationship of *C. julis*

Table 1. GSI values for *C. julis*

	Jan	Feb	Mar	Apr	May	Jun	Jul	Agu	Spt	Oct	Nov	Dec
M	0.02	NA	NA	1.22	0.39	NA	NA	NA	NA	NA	NA	NA
F	0.43	NA	0.02	4.66	NA	1.98	1.63	3.62	NA	NA	NA	NA

***Symphodus tinca* (Linnaeus, 1758)**

A total of 110 individuals were obtained, with total lengths ranging from 10.6 to 19.1 cm and body weights between 16.0 and 102.8 g. The mean total length and weight were 13.9 ± 1.6 cm and 39.3 ± 15.6 g, respectively.



Figure 5. A specimen of *Symphodus tinca*
 (<https://fishbase.se/photos/UploadedBy.php?autoctr=155&win=uploaded>)

Among these, 68 females and 32 males were identified, while the sex of 10 individuals remained undetermined. Individuals ranged between 1 and 5 years of age, and 72% of them were between 3 and 6 years old. Length-frequency and length-weight relationship graphs are presented in Figures 5 and 6. Spawning was determined to occur between April and July. The species exhibited isometric growth. Monthly GSI values for males and females are given in Table 2.

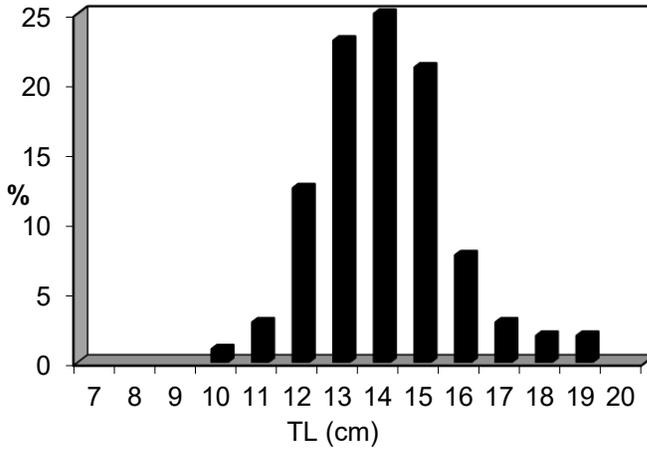


Figure 6. The length-frequency of sampled *S. tinca*

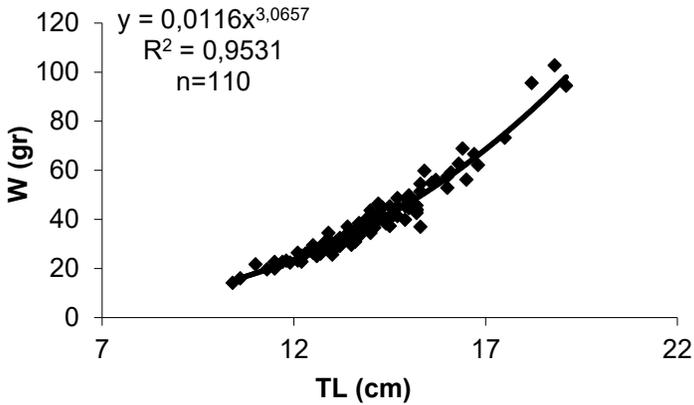


Figure 7. The length-weight relationship of *S. tinca*

Table 2. GSI values for *S. tinca*

	Jan	Feb	Mar	Apr	May	Jun	Jul	Agu	Spt	Oct	Nov	Dec
M	0.02	NA	3.14	3.75	1.32	0.16	NA	0.05	NA	NA	NA	NA
F	0.53	2.25	2.02	5.11	3.10	2.27	1.62	0.28	NA	NA	NA	NA

***Symphodus mediterraneus* (Linnaeus, 1758)**

A total of 64 individuals were collected, with total lengths between 10.7 and 16.3 cm and body weights ranging from 18.8 to 56.75 g. Mean total length and weight were 12.4 ± 0.9 cm and 29.4 ± 5.7 g, respectively.



Figure 8. Underwater Picture of a *Symphodus mediterraneus* individual (<https://fishbase.se/photos/PicturesSummary.php?resultPage=2&ID=4578&what=species>).

Of the sampled individuals, 4 were female, 54 were male, and 6 had undetermined sex. Individuals were found to be between 2 and 4 years of age. Length-frequency and length-weight relationship graphs are presented in Figures 9 and 10. Due to the insufficient female sample size, a definitive conclusion regarding the spawning period could not be reached; however, females collected in April and May exhibited gonads in stages 3 and 4, suggesting that spawning occurs during these months. The species showed negative allometric growth (t-test; $p < 0.05$). Because the number of individuals was insufficient for annual GSI estimation, female GSI was calculated as 7.84 for June and 0.26 for July, while male GSI in April was 0.17.

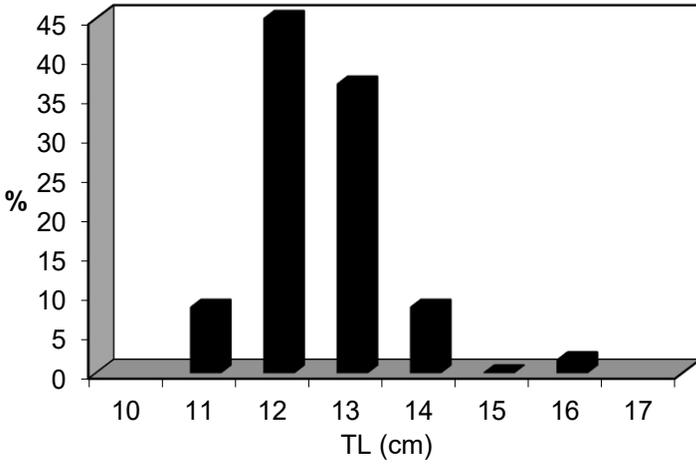


Figure 9. The length-frequency of sampled *S. mediterraneus*

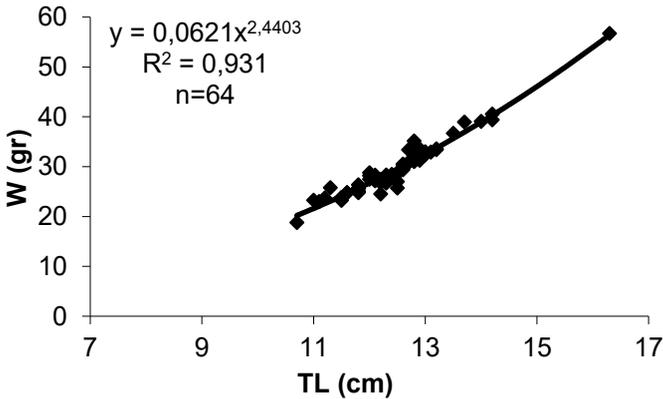


Figure 10. The length-weight relationship of *S. mediterraneus*

***Symphodus ocellatus* (Forsskål, 1775)**

A total of 39 individuals were obtained, with total lengths ranging from 7.2 to 22.0 cm and body weights between 5.8 and 148.7 g. Mean length and weight were 12.4 ± 3.4 cm and 33.0 ± 27.4 g, respectively.



Figure 11. Underwater Picture of *Symphodus ocellatus*
 (<https://fishbase.se/photos/UploadedBy.php?autoctr=6756&win=uploaded>)

The sampled population consisted of 4 females, 21 males, and 14 individuals of undetermined sex. Otolith analyses indicated that individuals ranged between 1 and 4 years of age. Length-frequency and length-weight graphs are shown in Figures 12 and 13. Based on mature gonads, spawning was considered to begin in April. Monthly GSI values are presented in Table 3.

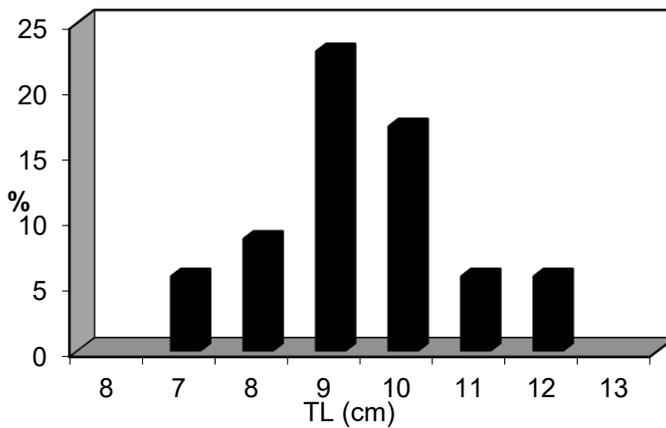


Figure 12. The length-frequency of sampled *S. ocellatus*

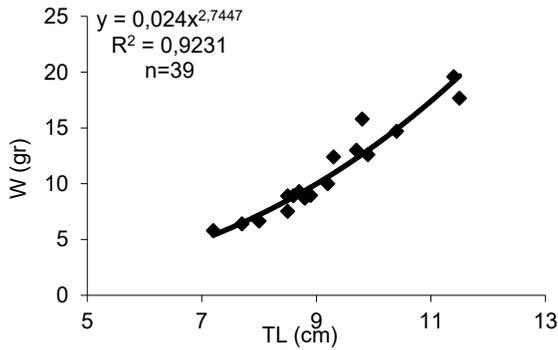


Figure 13. The length-weight relationship of *S. ocellatus*

Table 3. GSI values for *Symphodus ocellatus* according to data available months

	Jan	Feb	Mar	Apr	May	Jun	Jul	Agu	Spt	Oct	Nov	Dec
E	0.30	NA	0.17	0.84	NA	NA	0.99	NA	NA	NA	NA	NA
D	0.46	NA	0.60	4.20	NA	NA	NA	NA	NA	NA	NA	NA

Symphodus roissali (Risso, 1810)

A total of 44 individuals were collected, with total lengths between 9.8 and 17.7 cm and body weights ranging from 17.5 to 66.2 g. Mean length and weight were 12.7 ± 4.4 cm and 33.3 ± 16.3 g, respectively.



Figure 14. Underwater Picture of *Symphodus roissali*
(<https://fishbase.se/photos/UploadedBy.php?autoctr=7548&win=uploaded>)

Among the sampled individuals, 28 were female, 12 were male, and 4 had undetermined sex. Individuals ranged between 2 and 4 years of age. Length-frequency and length-weight graphs are presented in Figures 15 and 16. Spawning was evaluated to occur between April and June based on the months for which data were available.

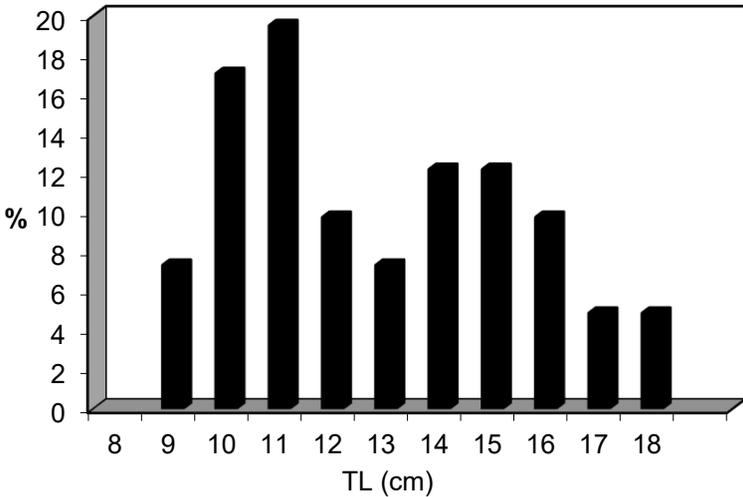


Figure 15. The length-frequency of *S. roissali*

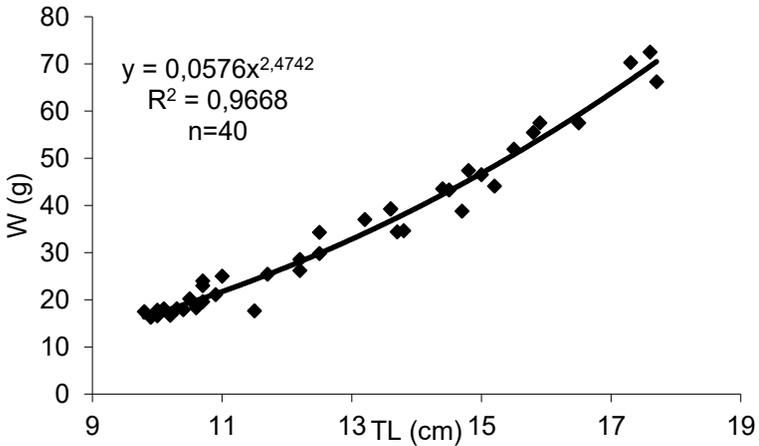


Figure 16. The length-weight relationship of *S. roissali*

***Symphodus cinereus* (Bonnaterre, 1788)**

A total of 17 individuals were collected, with lengths between 6.8 and 10.6 cm and weights ranging from 4.0 to 16.6 g. Mean length and weight were 8.6 ± 1.0 cm and 9.3 ± 3.6 g, respectively.



Figure 17. Underwater Picture of *Symphodus cinereus* (<https://fishbase.se/photos/PicturesSummary.php?resultPage=1&ID=1791&what=species>)

Of these individuals, 8 were female, 4 were male, and 5 had undetermined sex. Length-frequency and length-weight graphs are shown in Figures 18 and 19. Due to the insufficient female sample size, a definitive spawning period could not be determined; however, females collected in March and April had gonads in stages 3 and 4, suggesting that spawning likely occurs during these months.

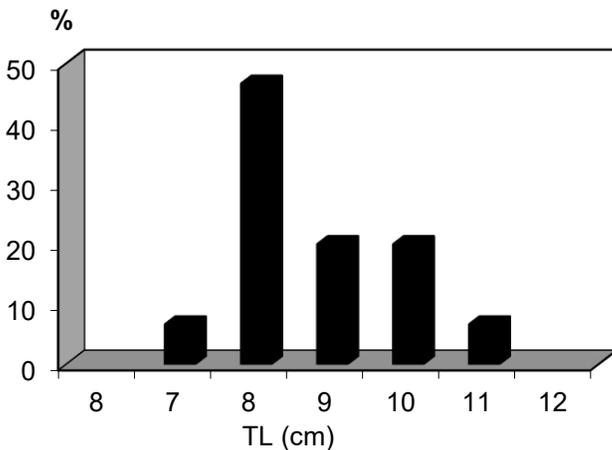


Figure 18. The length-frequency of *S. cinereus*

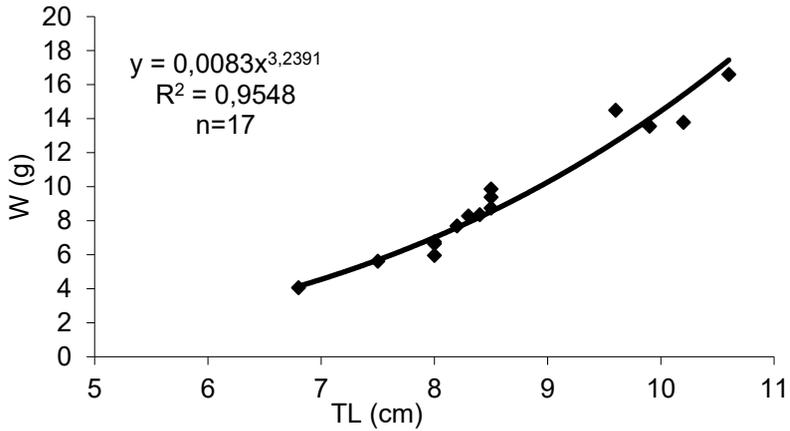


Figure 19. The length-weight relationship of *S. cinereus*

***Symphodus rostratus* (Bloch, 1797)**

A total of 18 individuals were collected, with total lengths between 9.9 and 12.0 cm and body weights from 12.7 to 22.7 g. Mean length and weight were 10.5 ± 0.5 cm and 15.4 ± 2.3 g, respectively.



Figure 20. Underwater Picture of *Symphodus rostratus* (<https://fishbase.se/photos/PicturesSummary.php?resultPage=1&ID=4580&what=species>)

Twelve individuals were female, 2 were male, and 4 had undetermined sex. Individuals were found to be between 3 and 4 years old. Length-frequency and length-weight graphs are presented in Figures 21 and 22. Due to the limited

sample size, a definitive spawning period could not be determined; however, spawning likely occurs in April.

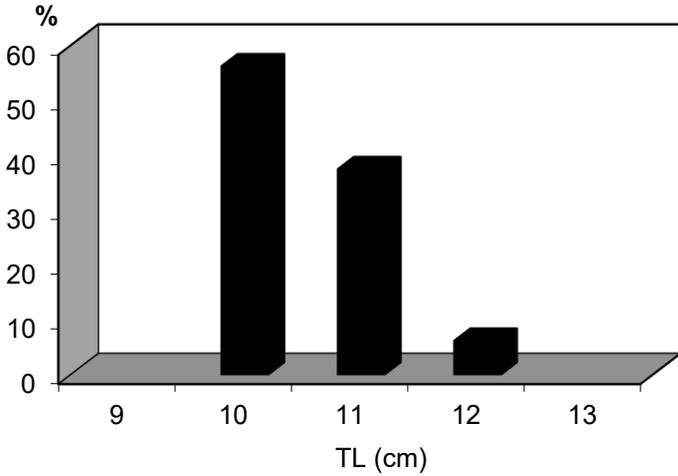


Figure 21. The length-frequency of *S. rostratus*

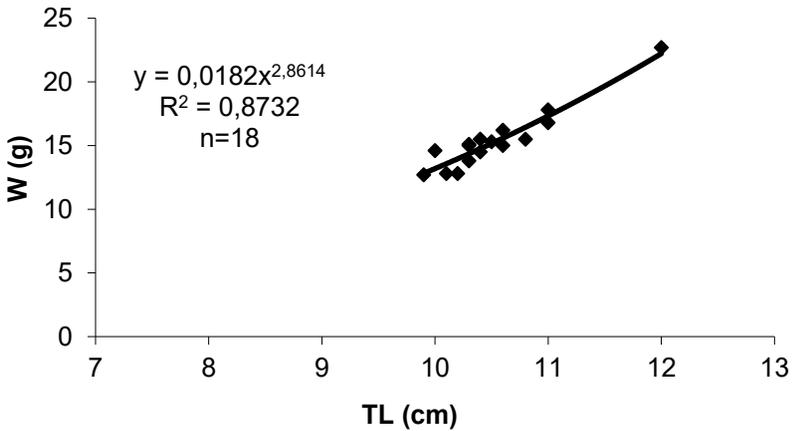


Figure 22. The length-weight relationship of *S. Rostratus*

***Labrus merula* (Linnaeus, 1758)**

A total of 6 individuals were obtained. Their total lengths ranged from 17.0 to 30.6 cm, with a mean of 18.1 cm. Body weights ranged from 71.0 to 392.8 g, with a mean of 111 g. Two individuals were identified as female, while the sex of the

remaining individuals could not be determined. Ages ranged from 2 to 4 years. Due to the limited number of specimens, further analyses could not be conducted.



Figure 23. Underwater Picture of *Labrus merula*
(<https://www.fishbase.se/photos/PicturesSummary.php?resultPage=1&ID=4582&what=species>)

***Labrus mixtus* (Linnaeus, 1758)**

Only one individual was sampled, with a length of 24.3 cm and a weight of 167.2 g. Dissection revealed that the individual was male, with a gonad weight of 0.71 g. The individual was 4 years old. No further conclusions could be drawn due to the insufficient sample size.



Figure 24. Underwater Picture of *Labrus mixtus*
(<https://www.fishbase.se/photos/PicturesSummary.php?resultPage=1&ID=1375&what=species>).

***Labrus bergylta* (Ascanius, 1767)**

A total of 7 individuals were collected, with total lengths ranging from 17.8 to 33.2 cm (mean: 22.1 cm) and body weights between 77.3 and 485.2 g (mean: 173.7 g). Five individuals were female, while the sex of the remaining individuals was undetermined. Ages were determined as 1 and 3 years. One female sampled in March exhibited stage 4 gonads, suggesting that spawning includes March. Further analyses could not be conducted due to the limited sample size.



Figure 25. Underwater Picture of *Labrus bergylta*

(<https://www.fishbase.se/photos/PicturesSummary.php?resultPage=2&ID=572&what=species>)

***Labrus viridis* (Linnaeus, 1758)**

A total of 4 individuals were obtained, with lengths between 19.8 and 26.9 cm (mean: 23 cm) and weights from 119.6 to 246.1 g (mean: 165.3 g). Three individuals were female, and one had undetermined sex. Similar to *L. bergylta*, gonads in stages 3 and 4 were observed in March samples, indicating that spawning likely occurs in March. Two otoliths were successfully extracted, revealing ages of 2 and 3 years. Further analyses were not possible due to the low sample size.



Figure 26. Underwater Picture of *Labrus viridis*
(<https://fishbase.se/photos/PicturesSummary.php?resultPage=1&ID=51659&what=species>)

***Thalassoma pavo* (Linnaeus, 1758)**

Only one individual was sampled, with a length of 14.3 cm and a weight of 56.2 g. Sex could not be determined due to very small gonads. No further conclusions could be drawn due to the insufficient sample size.



Figure 27. Underwater Picture of *Thalassoma pavo*
(<https://www.fishbase.se/photos/PicturesSummary.php?resultPage=4&ID=2500&what=species>)

5. DISCUSSION AND CONCLUSION

In this study, a total of 407 Labrid fish were collected and found to belong to four genera. Among these genera, the highest number of individuals belonged to *Symphodus* (n = 292), while the lowest number belonged to *Thalassoma* (n = 1). Considering the total lengths of the individuals obtained, the smallest individuals belonged to the genus *Symphodus*, whereas the largest species belonged to the genus *Labrus*. Although the species of this family are not commercially exploited, it was observed that some large individuals belonging to the genera *Labrus* and *Symphodus* were retained by fishers for consumption.

Aydın et al. (2008) reported four species of the Labridae family (*Coris julis*, *Labrus bergylta*, *Symphodus mediterraneus*, and *Symphodus tinca*) in gillnet fisheries in İzmir Bay and stated that all of these species were considered discard. In contrast, Gürel et al. (2011) indicated that the species has potential for commercial utilization. In their study on adapting some bony fish species from Turkish seas to marine aquariums, the authors stated that 70 species could be adapted to marine aquariums, and that the family with the highest potential was Labridae, represented by 13 species. Given the rapidly growing marine aquarium sector, it is highly likely that Labridae species, which are considered attractive for this industry, will be increasingly harvested and adapted for this sector in the coming years.

The most limiting factor in biological studies on the Labridae family or its species is the difficulty in obtaining sufficient sample sizes for population dynamics analyses. The main reason for this difficulty is that these species are generally distributed in shallow infralittoral zones and, in some cases, even in mediolittoral areas. Since these areas are mainly exploited by small-scale or recreational fisheries, obtaining adequate samples for scientific studies is challenging. In addition, because Labridae species are generally not consumed as food, most individuals caught are discarded back into the sea. For these reasons, there is no specialized fishing method or gear targeting these species. Consequently, in this study, the number of individuals obtained for many species was insufficient to draw detailed and robust conclusions. As seen in the literature review provided in the “General Information” section, the number of studies focusing on the biological characteristics of this family is very limited both worldwide and in Türkiye. This limitation mainly stems from the difficulties in obtaining specimens, as discussed above.

Regarding studies on the distribution of family members along Turkish coasts, Benal et al. (2006) reported 13 species along the Ürkmez coast. Aydın et al. (2008) identified four species in İzmir Bay. In contrast, Bilecenoğlu et al. (2014) reported 20 Labridae species in Turkish seas. In the present study, 12 species were obtained, and no new records for Turkish seas were identified.

In this study, the length–weight relationships of the species were found to be consistent with previous studies. Bilge et al. (2014) reported the parameters a and b for *C. julis* as 0.0068 and 3.19, respectively, which are similar to the values obtained in the present study. Similarly, the a and b values reported by the same authors for *S. tinca*, *S. mediterraneus*, *S. ocellatus*, *S. cinereus*, and *S. rostratus* were in agreement with our findings. Although Bilge et al. (2014) reported b values of 2.968 and 2.813 for *L. merula* and *L. viridis*, respectively, the insufficient sample size in our study did not allow for the estimation of these parameters; therefore, no comparison could be made.

Although it was not possible to obtain very precise results regarding the reproductive periods of most species due to sampling limitations, spawning periods for *C. julis*, *S. tinca*, *S. mediterraneus*, *S. ocellatus*, and *S. roissali* were determined to occur in spring and early summer. Quignard et al. (1986) reported that the spawning period of these species occurs between April and August, which supports the findings of this study. In addition, Raposeiro and Azevedo (2009) found that *Symphodus mediterraneus* reproduces in spring and summer and that the length at sexual maturity is 12.1 cm for males and 9.6 cm for females. Due to the insufficient sample size, no conclusions regarding length at sexual maturity could be drawn in the present study.

There is very limited literature on the age and growth of Labridae species. Although difficulties in sample collection have been emphasized, extracting otoliths for age determination is also challenging due to their small size and morphology, requiring expertise. Quignard et al. (1986) reported maximum ages of 8 years for *S. mediterraneus*, 5 years for *S. ocellatus*, 8 years for *S. roissali*, 6 years for *S. cinereus*, and 4 years for *S. rostratus*. In the present study, maximum ages for *S. tinca*, *S. mediterraneus*, and *S. ocellatus* were found to be 4 years. The maximum age of *C. julis* was determined as 4 years, whereas Macpherson et al. (2000) reported a maximum age of 8 years for this species. Differences among studies are likely due to variations in age determination methods, sampling areas, and sample sizes.

In conclusion, 407 individuals belonging to 12 Labrid species were collected along the Aegean coast of Türkiye. The difficulty in obtaining Labrid species was the most important limiting factor of the present study. Nevertheless, the data obtained undoubtedly contribute to both the scientific literature and the marine aquarium sector. Considering the increasing number of non-native and invasive species in Turkish seas, it is highly likely that Labridae species not yet recorded in Türkiye will be detected in the near future. Therefore, future marine biological studies should give greater consideration to members of the Labridae family.

6. ACKNOWLEDGEMENT

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