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RESEARCH ARTICLE

Evaluation of Water Quality in a Highly Impacted Urban Stream Using Water Quality Index (Ankara Stream, Türkiye)

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Abstract: Population growth along with other factors such as industrial, agricultural, and urban development, threaten freshwater resources in urban areas. Protecting urban water quality for ecological balance, water security, and energy production is crucial. The water quality index (WQI) provides an effective tool for assessing and managing water quality, and the Canadian Council of Ministers of the Environment Water Quality Index (CCME-WQI) is one of the extensively used method. In this study, the pollution status of the Ankara Stream which flows through the densely populated Ankara was examined using physico-chemical parameters collected from five stations (S1-S5), and the water quality status was estimated via CCME-WQI. The results revealed varying water quality across different points on the stream. S2, located in a protected area, exhibited the best quality; in contrast, S4 and S5, located downstream of a wastewater treatment plant, exhibited the poorest quality. The consistency of these findings with the literature and the historical records of Ankara Stream emphasize that the CCME-WQI can be used for the management of water resources with high levels of pollution. This study contributes to sustainable water management practices and highlights the need for advanced treatment techniques to control pollution in urban freshwater resources.

Anahtar kelimeler:

CCME-WQI
Ankara Çayı
Kentsel su kalitesi
Kirlilik değerlendirmesi

Su Kalite İndeksi Kullanılarak Yüksek Derecede Etkilenen Kentsel Bir Akarsuda Su Kalitesinin Değerlendirilmesi (Ankara Çayı, Türkiye)

Öz: Nüfus artışı ile sanayi, tarım ve kentsel bölgelerdeki gelişim gibi çeşitli nedenler, kentsel tatlı su kaynaklarını tehdit etmektedir. Ekolojik denge, su güvenliği ve enerji üretimi için kentsel su kalitesinin korunması yüksek öneme sahiptir. Su kalitesi indeksi (WQI), su kalitesinin değerlendirilmesi ve yönetimi için etkili bir yöntemdir ve Kanada Çevre Bakanlığı Konseyi Su Kalite İndeksi (CCME-WQI), bu yöntemlerin en yaygın kullanılanlarından birisidir. Bu çalışmada, yoğun nüfuslu Ankara şehrinin içinden akan Ankara Çayı'nın kirlilik durumu, beş istasyondan (S1-S5) elde edilen fiziko-kimyasal parametreler kullanılarak incelenmiş ve su kalitesi CCME-WQI ile tahmin edilmiştir. Sonuçlar, çayın farklı noktalarında değişen su kalitesini ortaya koymuştur. Korunan alanda bulunan S2, en iyi kalite değerine sahipken, atık su arıtma tesisinin mansabında bulunan S4 ve S5, en kötü kaliteyi sergilemiştir. Bu bulgular, Ankara Çayı'na ait geçmiş veriler ve literatür ile tutarlılık göstererek, CCME-WQI'in yüksek kirliliğe sahip su kaynaklarının yönetimi için kullanılabileceğini ortaya koymaktadır. Bu çalışma, sürdürülebilir su yönetimi uygulamalarına katkıda bulunmakta ve kentsel tatlı su kaynaklarındaki kirliliği kontrol etmek için ileri arıtma tekniklerine duyulan ihtiyacı vurgulamaktadır.

Introduction

Urban freshwater resources, an essential part of urban ecosystems, are exposed to pollution due to increasing population pressure. Apart from basic sectors such as industry and agriculture, traffic and urban building are also sources of water pollution. Urban water bodies are deteriorated by diverse pollutants such as metals, organic compounds and nutrients through rainfall and waste waters from various sectors (Saravanan et al., 2021). Accumulation of large quantities of pollutants in the waters, which exceeds the water's carrying capacity, disrupts the natural ecosystem of water and threatens all aquatic life and human health (Satterthwaite, 2011). For this reason, it is crucial to study and reduce water pollution, especially at the urban level. Protecting water quality and safety, especially in densely

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populated urban areas, requires strict planning and management in a broad framework (Hoekstra et al., 2018).

Good management of rivers plays a crucial role in supporting the natural infrastructure by providing ecological balance, as well as in issues related to drinking and irrigation water and energy production for large populations. However, simple and understandable data are needed due to the interdisciplinary nature of communication between stakeholders (Friberg, 2014). The usable water quality information, supported by scientific and standard methods, created using large-scale monitoring data and reflecting the actual situation can be reached using Water Quality Index (WQI) methods.

WQIs are optimized using specific statistical methods and provide a clear representation of a large amount of data. Therefore, they facilitate the use of data on water masses in the basins where monitoring studies are carried out and supply the knowledge for decision-makers to organize the management of that watershed (Liou et al., 2004). Additionally, they generally provide a rating for water quality, and the provided information can be used in managing water sources (Tyagi et al., 2013). CCME-WQI is a model used to demonstrate and document water quality in a more straightforward way (CCME, 2001). This model can provide a precise analysis of water quality parameters. CCME-WQI also tolerates missing data and provides many advantages in cases where some data cannot be produced due to setbacks in the field or laboratory. However, CCME-WQI usually does not give a detailed evaluation of water quality; instead, a broad overview of the ecological capability of water is obtained (Yan et al., 2016). CCME-WQI gives a single number for a location representing numerous variables assessed in different seasons. The index allows the user to select the parameters for more specific reasons, making it flexible. Besides the advantages, the information about individual variables and relationships between variables can be lost when reduced to a single number to determine the water class. Similarly, the index is unsuitable for biological parameters; all parameters have the same importance in the index, and CCME-WQI is ineffective in separating the importance of parameters (Terrado et al., 2010). Nevertheless, Canadian WQI is still one of the most frequently applied indices, as it is easy to use and gives inclusive and representative results.

CCME-WQI has also been used in European countries that apply Water Framework Directive (Zotou et al., 2020; Teodorof et al., 2021; Yotova et al., 2021). According to the comparative evaluation of CCME-WQI and Water Framework Directive (WFD) based quality estimation method for Greece, it is stated that CCME-WQI is a convenient tool for WFD implementation, especially because it allows the addition of toxic pollutants to the calculation procedure (Gikas et al., 2020).

Water quality estimation has been made for many years in Türkiye by applying water quality indices in lakes, streams, ground waters and wetlands. Among these works are the Universal WQI (UWQI), developed by Boyacıoğlu (2007) and first used in the Tahtalı Reservoir Basin, and the Lagoon WQI (LWQI), developed by Taner et al. (2011) and explicitly designed for the Lagoon ecosystem. In addition, international water quality indexes such as CCME, The National Sanitation Foundation Water Quality Index (NSF-WQI), Aquatic Toxicity Index, and Overall Index of Pollution were also used to determine the biological and chemical status of Kirmir Stream (Tunc Dede et al., 2013), Aksu and Acısu Creek (Tunc Dede and Sezer, 2017; Uslu et al., 2024), Karasu River (Alver and Baştürk, 2019), Melendiz River (Baştürk and Alver, 2019).

Türkiye's environmental problems and priorities evaluation report from 2020 states that 35% of surface water is Class 4 poorest quality, while only 26% of surface water sources are Class 1 quality (Ministry of Environment and Urbanization Report, 2020). Also, it is reported that domestic and industrial wastewater, municipal solid wastes, fertilizers and pesticides cause the most pollution. Ankara, the capital of Türkiye, is one of the cities with freshwater-related problems as its primary concern. High urbanization and population increase lead to pressure and additional load on Ankara's main water treatment center, (Tatlar Central Wastewater Treatment Plant, TWWTP) the intense stress on the wastewater treatment plant results in the poorest quality of water, Class 4. As a result, Ankara's urban greywater footprint exceeds the assimilation capacity for total nitrogen (TN), total phosphorus (TP) and ammonium, showing the need for urgent action for an increase in the scope and capacity of the plant (Kutlu, 2022).

The demand for freshwater is increasing in Ankara, primarily due to population growth and socio-economic development. In order to achieve a sustainable way of water usage, innovative tools and accurate estimations of current quality status should be used for water management systems. This study aims to examine the pollution status of Ankara Stream with various physico-chemical parameters and to estimate water quality with CCME-WQI using 26 water quality parameters.

Material and Methods

Study area and sampling

Ankara Stream is formed by the merging of Çubuk Stream and Hatip Stream in the Çubuk district. İncesu Stream which receives the waters of Mogan and Eymir Lakes, Ova Stream which passes through Mürted Plain, and Haymana Stream flow into Ankara Stream. Ankara Stream has a length of 140 km and 3153 km² of basin area (Figure 1). Ankara Stream merges with Sakarya River in Eskişehir. Sakarya River is the third biggest river in Türkiye, with a length of 720 km and a high flow rate with an annual value of 12 billion m³. It covers an area of 7% of Türkiye's land before being discharged into the Black Sea (TUBITAK MAM, 2013). Sakarya Basin, with 80 of 855 Urban Sensitive Areas and 91 of 844 Nitrate Sensitive Areas, is one of the most delicate areas in Türkiye regarding water quality (GDWM, 2021). The water is polluted due to excessive industrialization and agricultural activities in large cities such as Eskişehir and Ankara (Akbulut et al., 2022).

The locations of the stations are given in Figure 1 and Table 1. The samples from these stations were examined for water quality parameters in the General Directorate of State Hydraulic Works (SHW) chemistry laboratories. Water samples were taken from various locations representing potentially different pollution levels: S1 and S2 were far from residential areas and S3, S4 and S5 were from more polluted water bodies, close to residential and industrial regions and a water treatment plant (TWWTP).

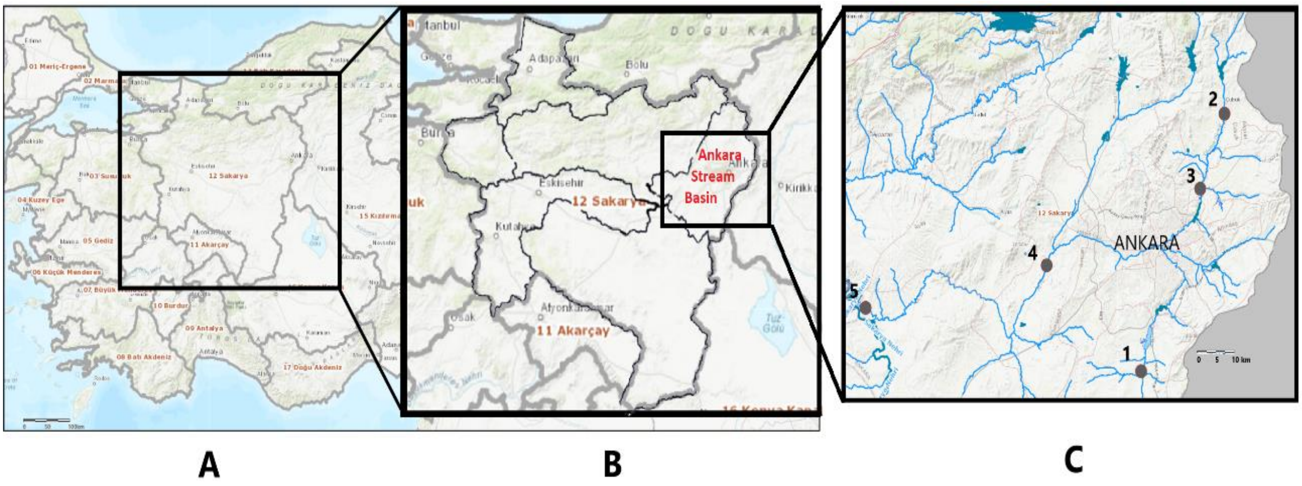

Figure 1. The location of the Sakarya River Basin (A), the Ankara Stream Basin and other subbasins of the Sakarya River Basin (B) and the locations of the stations in the Ankara Stream Basin-gray dots (C)

Table 1. The location and the coordinates of the sampling stations in Ankara Stream

Station number	Station 1	Station 2	Station 3	Station 4	Station 5
Code	S1	S2	S3	S4	S5
Latitude (N)	39° 41' 28.886"	40° 10' 55.688"	40° 3' 34.355"	39° 56' 18.000"	39° 48' 53.317"
Longitude (E)	32° 46' 35.559"	33° 1' 6.214"	32° 57' 16.321"	32° 29' 21.700"	31° 56' 8.581"

Sampling was performed in five periods: February, May, August, November 2019, and February 2020. Data covering one year was used for the index calculations. However, for Station 2, sampling could not be performed in August 2019 and November 2019 due to the drying of the stream bed. In the sampling process, the requirements of the TS ISO 5667-6 were complied with (ISO, 2014).

CCME-WQI calculation

The index value, which results from three factors called Scope, Frequency and Amplitude, provides a general assessment of water quality with a value on a scale of 0-100. Water quality status was determined according to a series of calculations according to CCME (2001):

The percentage of parameters exceeding the limit values relative to the total parameters:

$$\text{Scope} = \text{F1} = \frac{Number\ of\ failed\ variables}{Total\ number\ of\ variables} * 100 \text{ (Eq. 1)}$$

The percentage of failed tests to the number of tests performed in all times:

$$\text{Frequency} = \text{F2} = \frac{Number\ of\ failed\ tests}{Total\ number\ of\ tests} * 100 \text{ (Eq. 2)}$$

And the amount of deviation of failed tests exceeding the limit value was calculated in three steps:

a. Excursion is a value that shows the deviation of a parameter from the limit value and was calculated with one of the following equations, which was appropriate,

i. When the failed test value was over the limit value:

$$\text{excursion} = \frac{Failed\ test\ value}{Objective} - 1 \text{ (Eq. 3)}$$

ii. When the failed test value was below the limit value:

$$\text{excursion} = \frac{Objective}{Failed\ test\ value} - 1 \text{ (Eq. 4)}$$

iii. When test value was zero:

$$\text{excursion} = Failed\ test\ value \text{ (Eq. 5)}$$

b. The collective amount of the deviation values of each failed test was calculated as:

$$\text{nse} = \frac{\sum_{i=1}^{n} excursion i}{Total\ number\ of\ tests} \text{ (Eq. 6)}$$

c. F3 was calculated by scaling the normalized sum of the excursions from objectives (nse).

$$\text{Amplitude} = \text{F3} = \frac{nse}{0.01nse+0.01} \text{ (Eq. 7)}$$

With these factors CCME-WQI score was calculated as follows:

$$\textbf{CCME} - \textbf{WQI score} = 100 - \left[\frac{\sqrt{F_1^2+F_2^2+F_3^2}}{1.732}\right] \text{ (Eq. 8)}$$

Table 2. The parameters that are used for the CCME-WQI calculations with units, limit values and standards

Parameter	Unit	Limit Value	Limit Source	Analysis Method	Standard
pH		6<=pH<=9	EQS	pH Electrometric	TS EN ISO 10523
EC	µS/cm	400	EQS	Conductivity Electrode	TS 9748 EN 27888
DO	mg/L O_2	>8	EQS	Electrochemical Probe	TS EN ISO 5814
BOD	mg/L O_2	4	EQS	Electrochemical Probe	STMD 5210
COD	mg/L O_2	25	EQS	Open Reflux – Titrimetric	STMD 5220B
Total Nitrogen	mg/L N	3.5	EQS	UV Spectrophotometric	STMD 4500N
Ammonia Nitrogen	mg/L NH_4^+-N	0.2	EQS	Ion Chromatography	TS EN ISO 14911
Nitrite Nitrogen	mg/L NO_2	0.1	TS266	Ion Chromatography	TS EN ISO 10304-1
Nitrate Nitrogen	mg/L NO_3^--N	3	EQS	Ion Chromatography	TS EN ISO 10304-1
Total Kjeldahl Nitrogen	mg/L N	0.5	EQS	Distillation and Titration	STMD 4500NH_3
Total Phosphorus	mg/L P	0.08	EQS	Colorimetric	TS 7889
Sulphate	mg/L SO_4^{-2}	250	EQS	Ion Chromatography	TS EN ISO 10304-1
Fl	µg/L F^-	1000	EQS	Ion Chromatography	TS EN ISO 10304-1
Cl	mg/L Cl^-	250	TS266	Ion Chromatography	TS EN ISO 10304-1
Na	µg/L	200	TS266	Ion Chromatography	TS EN ISO 14911
K	mg/L	20	WHO2011	Ion Chromatography	TS EN ISO 14911
Se	µg/L	10	EQS	ICP-MS	EPA 200.8
Cd	µg/L	5	TS266	ICP-MS	EPA 200.8
Ni	µg/L	20	EQS	ICP-MS	EPA 200.8
Al	µg/L	300	EQS	ICP-MS	EPA 200.8
An	µg/L	5	TS266	ICP-MS	EPA 200.8
As	µg/L	20	EQS	ICP-MS	EPA 200.8
Cu	µg/L	20	EQS	ICP-MS	EPA 200.8
Ba	µg/L	1000	EQS	ICP-MS	EPA 200.8
Zn	µg/L	3000	WHO2011	ICP-MS	EPA 200.8
Co	µg/L	10	EQS	ICP-MS	EPA 200.8

EQS (RSWQM, 2012), TS266: Drinking water standard limits (TS 266, 2005), WHO 2011 (WHO, 2011)

The value obtained from the calculation was used to make a classification according to the CCME guideline (CCME, 2017; Khan et al., 2004). The five-level scale, as defined by the CCME, were color-coded to make them more coherent throughout the article. The following color codes were assigned to CCME WQI values: blue for 95-100 (excellent), green for 80-94 (good), yellow for 65-79 (fair), orange for 45-64 (marginal) and red for 0-44 (poor).

For the calculation of Ankara Stream CCME-WQI, SHW provided the data. The parameters used in index calculation were measured according to the standard methods in Table 2. Since the calculation employs the deviations of actual values from ecological quality standards, Ecological Quality Standards (EQS) were used as the primary source. Regulation on Surface Water Quality Management (RSWQM, 2012) and Turkish standard, water intended for human consumption (TS 266, 2005) were also used. WHO Guidelines for drinking-water quality (WHO, 2011) were used for the parameters for which the national guideline did not specify a standard value.

Results and Discussion

Chemical properties

The results of the 26 parameters tested in the water samples taken from five stations and in five periods covering one year were evaluated. The descriptive statistics for analysed physico-chemical parameters are listed in Table 3.

The pH values ranged between 7.5-8.75 throughout the sampling period for all the sampling stations, meeting the standard values given in the EQS. However, the concentrations of pollutants such as nitrogen compounds and heavy metals increased from stations S1 and S2 to S3 and eventually to S4 and S5. S1 and S2 were located upstream, S3 is in the populated area, and S4 and S5 were downstream of the Ankara Stream.

The DO concentrations were high at stations S1, S2 and S3, and were sufficient to support natural freshwater habitats. The annual mean values of DO from S1 to S5 were 9.51, 10.62, 8.37, 6.55 and 4.65 (mg O_2/L), respectively. It has been observed at all stations that DO concentrations decreased in the summer months when temperatures were high (Balls et al., 1996). Differences in upstream and downstream O_2 levels may be due to lower organic pollution in rural areas.

COD and BOD showed a similar trend. The mean BOD was 2.8 mg/L for S1, and it showed an increasing trend towards the downstream, reaching up to 128.8 mg/L in S5. The mean COD value for S5 was 164.5 mg/L, which indicated the increasing trend downstream due to organic pollution.

Nitrate (NO_3) levels were the most affected by fertilizer use. The nitrate concentrations were found as 6.48, 2.59, 3.09, 2.53 and 1.77 mg/L, from S1 to S5, respectively. Higher nitrate levels indicated agriculture induced pollution in S1 and S2.

TN and TP levels for all sampling stations were higher than those reported for the environmental quality standards. Except for S1, TP levels failed to reach the EQS value. According to the Sakarya River Basin Action Plan prepared by TUBITAK MAM, Ankara Stream Basin has severe pollution load due to the high population in the region. Ankara Stream Basin had 13% non-point and 87% point TP load (TUBITAK MAM, 2013). Elevated levels of TN are generally associated with sewage water coming from households. The highest values reached up to 34.54 mg/L downstream of the highly populated districts of Ankara.

Downstream of the treatment plant (S4 and S5), TP content showed a dramatic increase. This increase may be due to the industrial discharges and the treated municipal discharges, which are rich in detergents. These stations are located downstream of the densely populated area of the river. Results indicated high TP and TN levels at S4 and S5 with a higher risk for eutrophication, revealing that TWWTP is unable to reduce these pollutants. Therefore, there is an urgent need for increasing the wastewater treatment capacity and providing treatment in accordance with environmental standards.

In addition to organic pollution, inorganic pollutant concentrations at S4 and S5 are well above the standard levels. It has been determined that heavy metals Cd, Ni, Al, As and Cu increased significantly downstream of densely populated areas and industrial zones. Heavy metals can be poisonous to humans and other organisms, even in low amounts (Qu et al., 2018). The maximum value of As (60.7 μg/L) was found in S1, and the values in S3, S4 and S5 were also high. S1 is located at the inlet of Lake Mogan and high As concentration resulting from agricultural and industrial activities was identified as having the biggest contribution to metal pollution in the creeks which fed the lake (Pulatsü & Latifi, 2023a). Hence, it is essential to consider heavy metals while determining the water quality status. For example, excessive levels of Al (6054 μg/L) and Cd (669 μg/L) indicated the severity of impact. The elevated levels of heavy metals are mainly caused by discharges from industrial activities. Implementing and enforcing stringent environmental regulations for industries and promoting the adoption of cleaner technologies and sustainable practices reduces industrial pollution in industrial areas. It is also crucial to prevent industrial wastewater from being released into the Ankara Stream without adequate treatment before reaching the discharge points. Urban run off is also considered as a major cause for heavy metal pollution (Ghadiri et al., 2023).

CCME-WQI

The results of water quality index calculations are shown in Table 4 and Figure 2. According to the table, the water quality status of S1-S5 ranged between marginal, fair and poor.

Table 3. Descriptive statistics for the analysed physico-chemical parameters used in the CCME-WQI calculations (minimum, maximum, and mean values ±standard deviations)

			STATION 1			STATION 2			STATION 3			STATION 4			STATION 5		
#	Parameter	Unit	Min	Max	Mean ± SD	Min	Max	Mean. ± SD	Min	Max	Mean ± SD	Min	Max	Mean ± SD	Min	Max	Mean ± SD
1	pH		8.04	8.75	8.32±0.26	7.87	8.1	7.97±0.1	7.53	8	7.88±0.17	7.35	7.96	7.72±0.18	7.35	7.82	7.54±0.06
2	EC	µS/cm	235	2070	707±686	89	771	348±301	119	1395	908±430	119	1522	1000±587	91	1637	854±638
3	DO	mg/L	6.87	10.88	9.51±1.40	9.44	12.29	10.62±1.22	4.49	10.8	8.37±2.12	2.57	9.1	6.55±1.93	2.36	7.25	4.65±1.16
4	BOD	mg/L	1	7	2.8±2.1	1	6	3.7±2.1	2	13	7±4.2	5	130	42.8±35.28	18	280	128.8±26.9
5	COD	mg/L	8.12	14.09	10.56±2.28	10.21	10.6	10.41±0.2	11.36	23.65	14.94±5.05	11.36	240.39	110.56±92.81	28.98	331.37	164.50±44.27
6	Total N	mg/L	3.44	11.65	7.09±3.42	2.2	3.86	3.26±0.75	4.23	9.35	5.89±1.87	3.43	40.85	19.96±13.24	3.43	40.85	21.09±6.96
7	NH_4 N	mg/L	0.094	0.598	0.346±0.252	*	*	*	0.091	3.693	1.304±1.194	0.129	8.006	4.068±0.444	8.737	12.987	10.265±3.11
8	NO_2 N	mg/L	0.074	0.517	0.296±0.222	0.078	0.472	0.275±0.197	0.051	2.656	0.805±0.479	0.051	0.76	0.373±0.335	0.042	0.76	0.237±0.016
9	NO_3 N	mg/L	2.959	10.548	6.482±3.228	1.314	3.413	2.594±0.917	1.457	4.091	3.092±0.906	0.969	4.091	2.53±0.602	0.969	2.414	1.768±0.188
10	Total Kjeldahl N	mg/L	0.17	0.61	0.47±0.16	0.3	0.73	0.48±0.18	0.19	4.64	1.99±1.75	0.19	39.86	18.36±13.85	0.26	39.86	19.39±7.05
11	Total P	mg/L	0.014	0.115	0.054±0.034	0.166	0.287	0.222±0.05	0.172	0.802	0.355±0.232	0.172	1.254	0.593±0.563	0.193	1.703	1.24±0.254
12	SO_4	mg/L	435.42	1159.94	803.65±304.81	71.86	106.76	85.25±15.36	69.86	110.51	90.55±13.3	79.14	223.62	130.82±50.35	79.14	236.04	155.15±16.4
13	Fl	mg/L	0.48	2.16	1.03±0.58	0.15	0.36	0.23±0.09	0.17	0.38	0.28±0.09	0.17	0.58	0.33±0.09	0.36	0.58	0.44±0.06
14	Cl	mg/L	221.58	554.5	387.78±136.66	47.09	352.62	152.47±141.59	69.14	182.44	121.37±43.5	78.74	157.88	121.82±41.25	78.74	185.87	127.69±37.16
15	Na	mg/L	311.58	980.4	648.58±269.88	33.66	195.8	92.71±73.15	62.72	153.26	102.94±34.28	74.28	188.63	125.05±46.36	74.28	188.63	136.92±22.34
16	K	mg/L	2.65	9.44	6.34±2.40	5.51	11.04	8.65±2.32	8.21	15.69	12.48±3.46	10.72	15.69	13.26±8.39	9.74	32.02	16.12±7.34
17	Se	µg/L	3.95	4.1	4.03±0.08	*	*	*	**	**	**	**	**	**	2.53	12.87	7.7±0.53
18	Cd	µg/L	**	**	**	**	**	**	*	*	*	54.49	76.73	65.61±21.41	4.39	669.07	192.97±7.68
19	Ni	µg/L	3.53	54.09	18.61±11.89	3.19	3.9	3.55±0.36	3.19	16.55	7.78±5.30	3.19	22.25	12.6±6.22	19.41	35.04	26.59±23.99
20	Al	µg/L	115.9	538.83	346.58±171.83	105.3	147.1	130.7±18.2	213.1	481.96	328.27±96.99	308.9	5357	3412±2330.86	649	6054	3287±1648
21	An	µg/L	**	**	**	*	*	*	*	*	*	0.44	0.73	0.59±0.16	0.36	0.71	0.5±0.14
22	As	µg/L	8.53	60.74	26.94±23.93	4.69	6.12	5.6±0.65	3.28	46.28	14.35±10.64	3.81	54.71	18.94±12.93	11.65	59.48	39.73±12.68
23	Cu	µg/L	1.62	107.98	34.37±24.75	13.23	23.92	17.48±4.63	8.44	23.47	14.59±6.26	8.44	67.32	29.59±16.59	30.87	67.32	48.49±25.19
24	Ba	µg/L	72.48	160.27	115.17±33.88	117.2	170.8	143.1±21.92	72.05	116.7	95.79±18.62	72.05	121.58	97.18±25.72	97.13	176.28	128.55±34.54
25	Zn	µg/L	18.47	143.27	80.68±50.95	30.92	103.46	61.05±30.86	36.7	68.14	49.81±11.49	45.35	1360	455.39±338.42	323.7	2644.91	949.61±53.78
26	Co	µg/L	0.83	0.89	0.86±0.03	0.4	0.55	0.48±0.08	0.39	0.87	0.62±0.17	0.55	2.44	1.12±0.75	1.36	4.22	2.56±0.93

Minimum, maximum and standard deviation could not be calculated at points with * insufficient data ** results below the LOQ

Table 4. Factors and overall water quality values for the stations

Station	F1 Scope	F2 Frequency	F3 Amplitude	CCME-WQI	Status
S1	61.53846	31.66667	31.45197	56.10875	Marginal
S2	34.61538	17.80822	11.36856	76.58563	Fair
S3	42.30769	25.83333	29.94161	66.5635	Fair
S4	57.69231	42.5	86.1426	35.30601	Poor
S5	50	45.83333	87.44828	36.10265	Poor

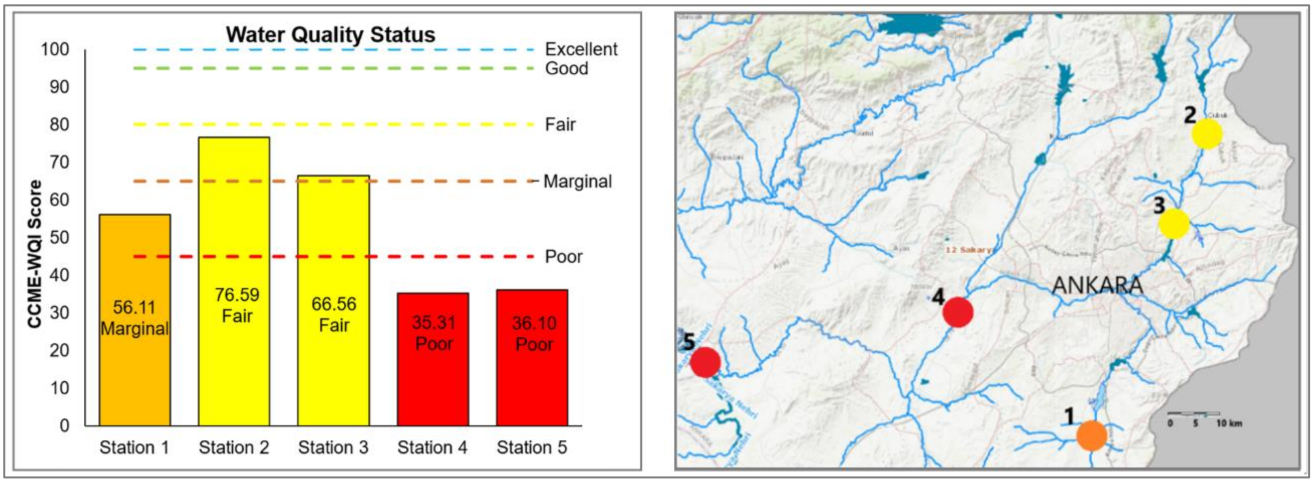

Figure 2. The color-coded water quality status for the sampling stations in accordance with the CCME-WQI scores

CCME-WQI values indicated “Marginal” quality in S1 which is located at the inlet of Lake Mogan. High values of EC, Total N, SO_4, Cl, Na, Al, As and Cu concentrations showed severe pollution. It was reported that polluted creeks flowing into Lake Mogan pose a risk to human health (Pulatsü & Latifi, 2023b). S2, located within a protected area, had a CCME-WQI score of 76.59, indicating a "Fair" quality status and representing the best quality among the sampling stations. Various measures were taken to safeguard the water and natural ecosystem in the region, which was designated as a protected area due to its importance as a drinking and utility water source. This region is a sensitive area where surface freshwater sources are vital for drinking water supply. Stringent precautions are taken to minimize anthropogenic impacts in sensitive areas, as high nitrate concentrations may occur if no preventive measures are in place (Bütünoğlu, 2018). S3 had a “Fair” water quality. This station is located at Çubuk Stream, close to a settlement where agricultural activities are also carried out. High TP and TN values can also be associated with these human-induced activities. S4 and S5 had “Poor” water quality. S4 is located downstream of TWWTP, Türkiye's largest wastewater treatment plant, which treats domestic and industrial wastewater from Ankara city center using activated sludge process and discharges it to Ankara Stream. It has a daily treatment capacity of 765,000 cubic meters (ASKİ, 2020) but currently can not effectively remove N and P (TUBITAK MAM, 2013). There is already an upgrade plan to increase the capacity of the plant to about 1,377,000 cubic meters per day to serve a population of approximately six million by 2025. S5 is located at Ankara Stream before it merges with the Sakarya River. The concentrations of EC, DO, BOD, COD, TP, TN, Cd, Ni, Al, As and Cu in S4 and S5 were higher than EQS limits. Consequently, organic and inorganic pollution continue to remain high at S4 and S5.

Pollution levels observed at points along Ankara Stream are in accordance with the historical data from earlier reports (Kazancı and Girgin, 1998; Atıcı and Ahıska, 2005). A recent study on Ankara Stream in 2018 estimates the quality of water by using NSF-WQI (Durmuş, 2021). According to this study, the water quality status in the upstream was determined to be Medium and Good in different seasons. However, it was stated that the water quality declined downstream and considered “poor” (Durmuş, 2021). While our findings agree with those of Durmuş (2021) in terms of consistency, it is important to note that flexibility in the type and number of variables chosen and allowance of the use of various quality standards that can be selected according to the research purpose to test water quality makes CCME-WQI a more reliable method (Chidiac et al., 2023). In addition, including heavy metals has proven to be advantageous while dealing with polluted waters. Interpreting pollution parameters with a single index value provides a useful tool in terms of water management.

Conclusion

In this study, CCME-WQI scores were determined for five stations on Ankara Stream to determine the water quality. The results showed that the water quality status of Ankara Stream was successfully estimated with WQI method and revealed a decrease in water quality from upstream to downstream, particularly in densely populated and industrialized areas.

The index shows that the quality of the water bodies highly varied depending on the location. S1 is located at the inlet of Lake Mogan and showed marginal quality status. Within a protected area, S2 has a higher score and maintains better water quality due to reduced human impact. S3 has also fair water quality but worse than S2 and this station is near to residential areas. The poor quality status of S4 and S5 stations, signals the need for urgent upgrades in the treatment plant, especially for N and P. The findings also align with previous research, emphasizing the ongoing pollution challenges Ankara Stream faces.

In conclusion, population growth and rapid urbanization increase the water demand, and therefore, a multidisciplinary approach and sustainable management practices have become essential. Protecting and improving urban water quality, especially in densely populated regions such as Ankara, becomes necessary for ecological balance and human welfare. Recent research trends in Türkiye focus on water quality indices, and this study shows that CCME-WQI can quickly and reliably estimate water quality status for regulatory purposes, thanks to the flexibility it provides in parameter selection and allowing the use of quality standards that can be selected according to the research purpose.

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Conflict of Interest

The authors have no competing interests to declare that are relevant to the content of this article. No funding was received for conducting this study. The authors declare they have no financial interests.

Author Contributions

The conception and design of the study were performed by both authors. The manuscript was written by the corresponding author and the second author read and commented on the previous versions. All authors read and approved the final manuscript.

Ethics Approval

No ethics committee approval is required for this study.

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RESEARCH ARTICLE

Determination of Heavy Metal Concentrations in Some Fish Species Consumed in Karaman Province, Türkiye

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Key words:

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ICP-OES.

Abstract: Heavy metals, with their ability to accumulate in the environment, can be transported to the aquatic ecosystem and to humans through fish consumption. Since they are not biodegradable, heavy metals have the potential to cause serious harm to human health. The insufficient aquaculture production of Karaman province has led to aquaculture products coming from different regions. No previous study has been conducted on the metal levels of fish species from different ecological regions in Karaman province. In 2023, the muscle metal bioaccumulations and the possible health effects of consumption of eight fish species (bogue *(Boops boops)*, European seabass (*Dicentrarchus labrax)*, European anchovy (*Engraulis encrasicolus)*, red mullet *(Mullus barbatus)*, rainbow trout (*Oncorhynchus mykiss)*, red porgy *(Pagrus pagrus)*, gilt-head seabream (*Sparus aurata)* and Mediterranean horse mackerel *(Trachurus mediterraneus*)) purchased from the local market were investigated in Karaman province. Metal concentrations (As, Cd, Cr, Cu, Fe, Mn, Ni and Zn) were determined by Inductively Coupled Plasma - Optical Emission spectroscopy (ICP-OES) and their levels were compared with the maximum permissible limits of national and international regulations. It was found that the mean concentrations of cadmium (Cd) in the Mediterranean horse mackerel (0.060 mg/kg), bogue (0.063 mg/kg) and red porgy (0.171 mg/kg), and the mean concentration of inorganic arsenic (iAs) in red porgy (0.233 mg/kg) exceeded the maximum permissible limits of the regulations. Health risk assessment methods (Estimated Daily Intake, Target Hazard Ratio, Hazard Index) have shown that the fish species examined are safe to consume.

Anahtar kelimeler:

Karaman
Ağır metal
Balık tüketim
Sağlık risk değerlendirme
ICP-OES.

Karaman İlinde Tüketilen Balıklarda Ağır Metal Birikimi ve İnsan Sağlığı Üzerindeki Etkileri

Öz: Ağır metaller, çevrede birikebilme yetenekleri ile su ekosistemine ve balık tüketimi yoluyla da insanlara taşınabilirler. Biyolojik olarak parçalanamadıkları için ağır metallerin insan sağlığına ciddi zarar verme potansiyeli bulunmaktadır. Karaman ilinin su ürünleri üretimi potansiyelinin yetersiz olması su ürünlerinin farklı bölgelerden gelmesine yol açmıştır. Farklı ekolojik bölgelerden gelen balık türlerinin metal seviyeleri ile ilgili Karaman ilinde daha önce bir çalışma yapılmamıştır. Karaman ilinde 2023 yılında yerel pazardan alınan halkın çok tükettiği sekiz balık türünün (gökkuşağı alabalığı (*Oncorhynchus mykiss*), barbun (*Mullus barbatus*), çipura (*Sparus aurata*), hamsi (*Engraulis encrasicolus*), istavrit (*Trachurus mediterraneus*), kupes (*Boops boops*), levrek (*Dicentrarchus labrax)* ve mercan (*Pagrus pagrus*)) kas metal biyobirikimleri ve tüketiminin insan sağlığı üzerindeki olası etkileri araştırılmıştır. Metal konsantrasyonları (As, Cd, Cr, Cu, Fe, Mn, Ni ve Zn) İndüktif Eşleşmiş Plazma - Optik Emisyon Spektrometresi (ICP-OES) cihazıyla belirlenmiştir. Tespit edilen metal konsantrasyonları ulusal ve uluslararası yönetmeliklerin maksimum izin verilebilir limitleri ile kıyaslanmıştır. İnorganik arsenik (iAs) ortalama konsantrasyonun mercan (0,233 mg/kg) balığında, kadmiyum (Cd) ortalama konsantrasyonlarının ise istavrit (0,060 mg/kg), kupes (0,063 mg/kg) ve mercan (0,171 mg/kg) balıklarında yönetmeliklerin maksimum izin verilebilir limitlerini aştığı bulunmuştur. Sağlık riski değerlendirme yöntemleri (Tahmini Günlük Alım, Hedef Tehlike Oranı, Tehlike İndeksi), incelenen balık türlerinin tüketiminin güvenli olduğunu göstermiştir.

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Giriş

Artan dünya nüfusunun ihtiyaçları endüstrileşmedeki büyüme ile karşılanmaya çalışılmakta, ancak aşırı endüstrileşmenin çevreye ciddi zararlar verdiği bilinmektedir (Tarley vd., 2001; Tokatlı ve Ustaoğlu, 2021). Sanayi devrimi boyunca kirlilik giderek artmış ve çevrenin kendini yenileme imkanı kalmamıştır (Gümüş ve Buluş, 2020). Evsel atıklar, endüstriyel ve tarım faaliyetleri sonucu çevrede birikime neden olan metaller inorganik kirleticilerdir (Durmaz vd., 2017). Akuatik ekosistemde bulunan metallar su, yem ve sedimentlerden balıklara geçebilmektedir (Bosch vd., 2016; Dadar vd., 2016; Tokatlı ve Ustaoğlu, 2021). Bu transfer süreci sebebiyle sucul besin zincirinin en tepesinde bulunan balık çevresel kirliliğin kontrolü amacıyla birçok çalışmada kullanılmıştır (Durmaz vd., 2017; Loghmani vd., 2022; Morgano vd., 2011; Zerizghi vd., 2020).

Balık insanlar tarafından sıklıkla tüketilmekte ve yüksek kalitede protein, omega-3 yağ asidi, çeşitli vitamin ve mineraller içermesi sebebiyle beslenmede önemli bir rol üstlenmektedir (Bosch vd., 2016; Loghmani vd., 2022; Tuzen, 2009). Ancak endüstrileşmeyle birlikte artan çevre kirliliği, balık tüketiminin yararlarının yanında bazı sorunları da beraberinde getirmektedir. Balıkların bulundukları ekosistemdeki kirlilik sebebiyle taşıdıkları ağır metaller, tüketim ile insan vücuduna transfer olarak insan sağlığını olumsuz etkileyebilmektedir (Cui vd., 2011; Bosch vd., 2016; Türkmen vd., 2016). Bakır (Cu) ve çinko (Zn) gibi bazı ağır metaller canlıların varlığını sürdürebilmesi için esansiyel kabul edilse de belli bir konsantrasyonun üzerinde toksik etkiye sebep olabilirler. Arsenik (As), kadmiyum (Cd) ve kurşun (Pb) gibi ağır metallerin ise düşük dozları dahi insanlar için toksik etkiye sahiptir (Bosch vd., 2016; Varol ve Sünbül, 2017, Yin vd., 2020). Ağır metal zehirlenmesi insanlarda kanser, nörolojik bozukluklar, çeşitli hastalıklar ve hatta ölüme sebep olabilmektedir (Loghmani vd., 2022). Bu sebeple; balıkların içerdiği ağır metal konsantrasyonlarının bilinmesi insan sağlığına olumsuz etkilerinin ortaya konması açısından önemlidir (Qin vd., 2015; Tuzen, 2009; Yin vd., 2020).

Dünya genelinde, hem denizlerde hem de tatlı sularda ağır metal düzeyini belirleyebilmek için insanların en çok tükettiği canlılar tercih edilmektedir (Gümüş vd., 2024). Balıkların yenilebilir kısımlarındaki ağır metallerin konsantrasyonlarının belirlenmesi insan sağlığı açısından önemlidir, çünkü kirlenmiş balıkların tüketimi ağır metallerin insanlara aktarılmasının başlıca yoludur (Rajeshkumar ve Li, 2018). Yüksek ağır metal konsantrasyonları içeren balıkların insan sağlığı için ciddi riskler oluşturabileceği iyi bilinmektedir. Sağlık riskleri, insan sağlığı risk değerlendirme yöntemleri kullanılarak ölçülebilir ve değerlendirilebilir. Bu değerlendirmeler, ağır metal maruziyetinin potansiyel sağlık etkilerini belirlemek için balık tüketiminin miktarı ve sıklığı gibi faktörleri dikkate alır (USEPA, 2021). Bu nedenle, son yıllarda ağır metallere maruz kalan balıkların tüketiminden kaynaklanan potansiyel sağlık risklerini değerlendirmek için birçok çalışma yapılmıştır (Almafrachi vd., 2024; Prabakaran vd., 2024; Varol vd., 2022b; Varol ve Kaçar, 2023)

Beslenme ve gıda güvenliği açısından, gıdalarda bulunan eser elementler ve ağır metallerin tespit edilmesi büyük bir öneme sahiptir. Atomik absorpsiyon spektrometrisi (AAS), atomik floresans spektrometrisi (AFS) ve ICP-OES gibi analitik teknikler gıdalardaki elementlerin tayininde yaygın kullanılan yöntemlerdendir. AAS ve AFS'den farklı olarak aynı anda birçok elementin tayin edilebilmesi ve ölçümlerin yüksek doğruluğa sahip olması ICP-OES'in öne çıkan avantajlarındandır (Hongxing ve Yu-Kui, 2011).

Türkiye'de yapılan çalışmaların birçoğu birkaç balık türüne odaklanmıştır. Farklı balık türlerinde ağır metal birikimi kapsamlı bir şekilde araştırılmamıştır. Tüketimle ilgili risklerin daha iyi değerlendirilmesi için çeşitli balık türlerinin analiz edilmesi önemlidir. Hem sahil kentlerine yakın olması hem de il bazında önemli bir su ürünleri yetiştiriciliği faaliyetlerinin bulunması sebebiyle Karaman'da ciddi bir balık tüketimi olduğu bilinmektedir. Bu çalışmada, Karaman ilinde satışa sunulmuş halkın beslenme alışkanlıklarında en çok tercih ettiği çeşitli tatlı su, avcılık ve çiftlik balıklarından gökkuşağı alabalığı (*Oncorhynchus mykiss*), barbun (*Mullus barbatus*), çipura (*Sparus aurata*), mercan (*Pagrus pagrus*), kupes (*Boops boops*), levrek (*Dicentrarchus labrax*), hamsi (*Engraulis encrasicolus*) ve istavrit (*Trachurus mediterraneus*) türlerinin kas dokularında ağır metal (arsenik (As), bakır (Cu), çinko (Zn), demir (Fe), kadmiyum (Cd), krom (Cr), mangan (Mn) ve nikel (Ni)) içeriklerinin belirlenmesi hedeflenmiş ve insan sağlığı risk değerlendirilmesi yapılarak ilimizde tüketilen balıkların insan sağlığına olumsuz etkilerinin var olup olmadığının tespit edilmesi amaçlanmıştır (Akturfan ve Dağcı, 2024; Kavak ve Pekerşen, 2022; Orhan, 2023).

Materyal ve Yöntem

Örneklerin toplanması ve analizi

2023 yılında Karaman il merkezindeki balıkçılardan, belirlenmiş her türden 5 adet balık örneği satın alınmış ve buz aküleri içerisinde laboratuvara getirilmiştir. Araştırmada kullanılan her bir balığın toplam boyu ±1 mm hatalı ölçme tahtasında, ağırlıkları ise disekte edilmeden önce analitik terazide (GR 200, AND, Japonya) ölçülerek balık bilgi formuna kaydedilmiştir. Balıkların isimleri, ekolojik koşulları, boy ve ağırlık bilgileri Tablo 1'de verilmiştir. Yanal çizginin üst kısmında bulunan pullar temizlendikten sonra balıkların dorsal kısmından kas örneği alınmıştır. Balık örnekleri analize kadar +4°C'de buzdolabında saklanmıştır. Elemental analiz için, balık örneklerinden 50 ml'lik falcon tüplerine (ISOLAB, Almanya) yaklaşık 0,5 g tartılmıştır. Daha sonra tüpler üzerine % 65'lik 5 mL HNO_3 (Merck, Almanya), 2 mL H_2O_2 (Sigma-Aldrich, Almanya) ve 3 mL ultra saf su ilave edilmiş ve örnekler mikrodalga (Mars 6, CEM, ABD) ile çözündürme işlemine tabi tutulmuştur. Mikrodalgadan çıkan örnekler oda sıcaklığına soğutulduktan sonra, 110 mm mavi bant filtre kağıdından (ISOLAB, Almanya) süzülerek falcon tüplerine (ISOLAB, Almanya) aktarılmıştır. Süzüntü son hacmi ultra saf su ile 20 mL'ye tamamlanmıştır (Gümüş ve Akköz, 2021; UNEP, 1984).

Çözündürülmüş balık örneklerinin içerdiği element konsantrasyonları (As, Cd, Cr, Cu, Fe, Mn, Ni ve Zn) ICP-OES cihazı (Model 720, Agilent Technologies, ABD) ile ölçülmüştür. Analiz üç tekrarlı olacak şekilde gerçekleştirilmiştir (DIN EN ISO 11885, 2009). Cihazda elementler için sırasıyla As 228,812 nm, Cd 228,802 nm, Cr 205,560 nm, Cu 327,395 nm, Fe 239,563 nm, Mn 260,568 nm, Ni 216,555 nm ve Zn 213,857 nm dalgaboylarında ölçüm alınmıştır. ICP-OES cihazı; RF gücü 1,00 kW, dedektör CCD, nebulizer gaz akış hızı 0,75 L/dk, Auxiliary gaz akış hızı 1,5 L/dk, Plazma gaz akışı (Argon) 15 ml L/dk ve Nebulizer gaz akışı 0,75 L/dk koşullarında çalıştırılmıştır.

Tablo 1. Karaman ilinde incelenen balık türlerinin isimleri ve genel özellikleri

Balık İsmi	Menşei	Yaşam alanı	Yetişme Şekli	Çevre	Tam boy (cm)	Ağırlık (g)
Alabalık Gökkuşağı *(Oncorhynchus mykiss)*	Konya-Ereğli	Tatlı su	Kültür	Ağ kafesler	30,2-33,8	290-430
Barbun *(Mullus barbatus)*	Akdeniz	Deniz	Yabani	Demersal	13,5-15,0	29,1-37,2
Çipura *(Sparus aurata)*	Ege	Deniz	Kültür	Ağ kafesler	29,9-31,2	450-520
Hamsi *(Engraulis encrasicolus)*	Karadeniz	Deniz	Yabani	Pelajik-neritik	9,2-9,7	4,68-5,98
İstavrit *(Trachurus mediterraneus)*	Karadeniz	Deniz	Yabani	Pelajik-oseanik	11,7-14,2	11,9-26,3
Küpes *(Boops boops)*	Akdeniz	Deniz	Yabani	Yarı pelajik	17-20,3	47,8-75,3
Levrek *(Dicentrarchus labrax)*	Karadeniz	Deniz	Kültür	Ağ kafesler	33,1-34,7	470-550
Mercan *(Pagrus pagrus)*	Akdeniz	Deniz	Yabani	Bentopelajik	13,4-16	38,3-62,7

Analiz yapılan cihazın doğruluğunu kontrol etmek için balık referans maddesi olan TORT-2 (Kanada Ulusal Araştırma Konseyi referans materyali) ile test çalışmaları yapılmıştır. Her metal konsantrasyonundaki geri kazanım değerinin % 80-110 aralığında olması gerekir (AOAC, 2016). Analiz edilen referans madde değerleri, sertifika değeri ile yakın bulunmuştur. Hassasiyet dereceleri %95,1 ile %106,3 arasında farklılık göstermiştir. En yüksek hassasiyet derecesi Ni'de, en düşük hassasiyet derecesi Cu'da tespit edilmiştir.

Çalışmada balık numunelerinden elde edilen ölçüm sonuçları; Avrupa Komisyonu (EC, 2023), Avustralya ve Yeni Zelanda Gıda Standartları (FSANZ, 2024), Çin Halk Cumhuriyeti Sağlık Bakanlığı (MHPRC, 2022) ve Türk Gıda Kodeksi (TGK) Bulaşanlar Yönetmeliği (2023) tarafından belirlenen maksimum izin verilen değerlerle karşılaştırılmıştır.

İnsan sağlığı risk değerlendirmesi

Yetişkinler için balık tüketimi risk değerlendirmesi tahmini günlük alım (EDI) (Copat vd., 2013; Varol vd., 2019), hedef tehlike oranı (THQ) ve tehlike indeksi (HI) hesaplamaları (USEPA, 2019) aşağıdaki eşitlikler kullanılarak yapılmıştır.

EDI: Tahmini günlük alım (Estimated Daily Intake)

MC: Balık dokularındaki metal konsantrasyonu (mg/kg yaş ağırlık),

IR: Tüketicinin günlük balık tüketim oranı (g/gün),

BW: Yetişkin tüketicinin ortalama vücut ağırlığı (70 kg).

$$EDI = \frac{MC * IRd}{BW}$$

THQ: Hedef tehlike katsayısı (target hazard quotient)

EF: Maruz kalma sıklığı (350 gün/yıl) (USEPA, 1991),

ED: Maruz kalma süresi (26 yıl) (USEPA, 2011),

RfD: Metallerin oral referans dozu mg/kg/bw/day (iAs:0,3, Cu:40, Cd:1, Cr:1500, Fe:700, Mn:140, Ni:20, Zn:300) (USEPA, 2021), AT: Ortalama maruz kalma süresi (365 gün/yıl x 26) (USEPA, 1989),

IRd: Türkiye'de kişi başına düşen günlük balık tüketim miktarı (18,4 g/kişi/gün) (TOB, 2021)

$$THQ = \frac{EF*ED*IRd*MC}{RfD*BW*AT} * 10^{-3}$$

Toplam THQ ya da HI (tehlike indeksi) olarak ifade edilen değer çalışılmış metallerin HI değerleri ile hesaplanır.

$$HI = (THQ1 + THQ2 + \cdots \ldots .. + THQn)$$

Arsenik formları arasında, sadece inorganik arsenik formunun toksik olduğu ve toplam arseniğin %1-10'unu oluşturduğu belirtilmektedir (Kalantzi vd., 2019). Bu nedenle, arseniğin inorganik formu dikkate alınmış ve balık kasında belirlenen toplam As'nin %3'ünü inorganik As'i oluşturduğu varsayılmıştır (Copat vd., 2013; Varol vd., 2022a).

İstatistiksel analiz

Analize hazır olan tüm numuneler 3 kez okutulup ortalamaları alındıktan sonra metaller arasındaki ilişkileri tespit etmek için Spearman korelasyon analizi, varyanslar arasındaki farklılığın önem kontrolü için ise tek yönlü ANOVA kullanılmıştır. Spearman sıralama korelasyon katsayıları 0,3'ten küçük ise çok zayıf ilişki yada korelasyon yok; 0,3-0,5 arasında ise zayıf korelasyon; 0,5-0,7 arasında ise orta düzeyde korelasyon; 0,7-0,9 arasında ise güçlü korelasyon; 0,9'dan büyük ise çok yüksek korelasyon olduğu kabul edilmiştir (Mukaka, 2012). Varyans çözümleme sonuçları, Duncan çoklu karşılaştırma testi kullanılarak $p<0,05$ önemlilik düzeyinde değerlendirilmiştir. Bu testler, SPSS 22 paket programı kullanılarak yapılmıştır.

Bulgular ve Tartışma

Bu çalışmada en yüksek Arsenik (As) konsantrasyonu 9,366 mg/kg olarak mercan balığında en düşük As konsantrasyonu 0,001 mg/kg ile alabalıkta belirlenmiştir. Ortalama As konsantrasyonları 0,337-7,769 mg/kg arasında, ortalama inorganik arsenik değerleri ise 0,010-0,233 mg/kg arasında değişim göstermiştir. Ortalama inorganik As konsantrasyonları balık türlerine göre yüksekten düşüğe şu şekilde sıralanmıştır: mercan (0,233 mg/kg), kupes (0,074 mg/kg), hamsi (0,067 mg/kg), barbun (0,023 mg/kg), istavrit (0,016 mg/kg), çipura (0,011 mg/kg), levrek ve alabalıktır (0,010 mg/kg) (Tablo 2). İnorganik As içerikleri bakımından alabalık, barbun, çipura, istavrit ve levrek örnekleri arasında anlamlı farklılık bulunmamıştır ($p>0,05$). Hamsi ve kupes örneklerinin inorganik As konsantrasyonları da benzer bulunmuştur ($p>0,05$). Mercan balığının ortalama inorganik As konsantrasyonları istatistiksel olarak diğer balıklardan ayrılmış ve inorganik As miktarı MHPRC (2022) sınır değerinin (0,1 mg/kg) üzerinde bulunmuştur. Ancak mercan balığının inorganik As miktarı (0,233 mg/kg), FSANZ (2024) sınır değerinin (2,0 mg/kg) altındadır. Varol vd. (2019) barbun ve hamside ortalama inorganik arsenik değerlerini MHPRC (2013) sınır değerinin (0,1 mg/kg) üzerinde tespit ettiğini bildirmiştir.

Kadmiyum (Cd) suda çözünme yeteneği fazla olan Cd^{+2} iyonu halinde canlıların bünyesine girebilen bir elementtir. Cd canlılar için ihtiyaç duyulan bir element olmamakla beraber düşük konsantrasyonlarında bile toksik etki gösterebilmektedir (Aktop ve Çağatay, 2020). Çalışmada, ortalama Cd konsantrasyonları 0,024-0,171 mg/kg aralığında bulunmuştur (Tablo 2). Bu çalışmada en yüksek Cd konsantrasyonu 0,198 mg/kg olarak mercan balığında en düşük Cd konsantrasyonu 0,010 mg/kg ile barbun balığında tespit edilmiştir. Mercan balığında tespit edilen Cd miktarının istatistiksel olarak anlamlı derecede farklı olduğu belirlenmiştir ($p<0,05$). Zyadah ve Chouikhi (1999) mercan balığında ortalama Cd değerini 0,2 mg/kg bulmuştur. Gültürk (2021) barbunda Cd konsantrasyonunu 0,022 mg/kg bulmuştur. Varol vd. (2019) istavrit balığında Cd değerini 0,0093 mg/kg bulmuşlardır. Mercan balığında ortalama Cd konsantrasyonları EC (2023) sınır değeri (0,05 mg/kg), MHPRC (2022) sınır değeri (0,1 mg/kg) ve Türk Gıda Kodeksi (TGK) Bulaşanlar Yönetmeliği (2023) sınır değerinin (0,05 mg/kg) üzerinde bulunmuştur. İstavrit ve kupes balıklarının ortalama Cd miktarları ise EC (2023) sınır değeri (0,05 mg/kg) ve TGK (2023) sınır değerinin (0,05 mg/kg) üzerinde bulunmuş iken MHPRC (2022) sınır değerini (0,1 mg/kg) aşmamıştır.

Krom (Cr) toksik ağır metallerden biri olarak kabul edilmekte ve su girişinin çeşitli hastalık etkilerine neden olduğu bilinmektedir (Aşıkkutlu vd., 2021; Sai Bhavya vd., 2019). Ortalama Cr konsantrasyonları 0,163-0,860 mg/kg arasında değişim göstermiştir (Tablo 2). En yüksek ortalama Cr miktarı (0,860 mg/kg) istavrit balığında tespit edilmiş olup, bu değerin diğer balıklardaki Cr konsantrasyonundan anlamlı bir farklılık gösterdiği görülmüştür ($p<0,05$). Guérin vd. (2011), Fransa'daki marketlerden temin edilen 32 farklı balık türüyle yaptıkları çalışmada ortalama krom seviyesini 0,06-0,57 mg/kg arasında bulmuşlardır. Fallah vd., (2011) gökkuşağı alabalığında ortalama Cr değerini 0,14 mg/kg olarak tespit etmişlerdir. Varol vd. (2019) gökkuşağı alabalığında balığında Cr değerini 0,033 mg/kg olarak belirlemişlerdir. Türkmen vd. (2009) istavrit balığında Cr değerini 0,5 mg/kg bulmuşlardır. Çalışmada analiz edilen balıkların ortalama Cr konsantrasyonları MHPRC (2022) sınır değerinin (2,0 mg/kg) altında bulunmuştur.

Bakır (Cu) karasal ortamlarda ve yüzey sularında bulunabilmektedir. Belirli miktarlarda bulunan bakır zehirli değildir. Aşırı alınması durumunda sağlığa zararlı olabilmektedir (Güler ve Çobanoğlu, 1997). Balık örneklerinin ortalama Cu konsantrasyonları 0,115-0,959 mg/kg arasında değişim göstermiştir (Tablo 2). Hamsi ve istavrit örneklerinin ortalama Cu miktarlarında diğer türlerden anlamlı derecede farklılık tespit edilmiştir ($p<0,05$). Alabalık, barbun, çipura, levrek ve mercan balıkları düşük Cu içeren grupta (0,115 – 0,386 mg/kg) yer alırken, hamsi ve istavrit ise yüksek Cu içeren grupta (0,834-0,959 mg/kg) yer almıştır. Kalyoncu vd. (2012) Karacaören Baraj Gölü'nde ve Gümüş ve Akköz (2021) Eber Gölü'nde yaptıkları çalışmada Cu konsantrasyonlarını en yüksek 1 mg/kg bulmuşlardır. Korkmaz vd. (2019) Kuzeydoğu Akdeniz bölgesinde yaptıkları çalışmada balık türlerinde ortalama Cu konsantrasyonları 0,006–0,74 mg/kg arasında bulunmuştur.

Çoğunlukla hayvansal gıdalardan elde edilen demir (Fe) insan sağlığı için gerekli bir metaldir. Bazı durumlarda antropojenik etkilerden dolayı toksisiteye rastlanır (Çiftçi vd., 2021). Ortalama Fe konsantrasyonları 3,346-12,791 mg/kg arasında değişim göstermiştir (Tablo 2). Barbun ve hamsi örneklerinde Fe konsantrasyonları anlamlı derecede yüksek tespit edilmiştir ($p<0,05$). Çiftçi vd. (2021) Kırıkkale'de bazı balık türlerinde Fe konsantrasyonlarını 3,64-14,95 mg/kg arasında bulmuştur. Gültürk (2021) Bingöl'de bazı balık türlerinde Fe konsantrasyonlarını 2,75-21,43 mg/kg arasında bulmuştur. Varol vd. (2019) Kahramanmaraş'ta bazı balık türlerinde Fe konsantrasyonlarını 2,68-21,36 mg/kg arasında tespit edilmiştir.

Mangan (Mn) birçok enzim için kofaktör olarak gereklidir. Mangana aşırı maruz kalma nörotoksisiteye ve Alzheimer hastalığı ile Parkinson hastalığına neden olabilir (Aşıkkutlu vd., 2021; Martins vd., 2019). Ortalama Mn konsantrasyonları 0,475-0,102 mg/kg arasında değişim göstermiştir (Tablo 2). Hamsi balığı örneklerinde tespit edilen Mn konsantrasyonun anlamlı derecede yüksek olduğu görülmüştür ($p<0,05$). Çiftçi vd. (2021) Kırıkkale'de bazı balık türlerinde Mn konsantrasyonlarını 1,99-3,54 mg/kg arasında bulmuştur. Korkmaz vd. (2019) Akdeniz kıyılarında bazı balık türlerinde Mn konsantrasyonlarını 0,002-0,39 mg/kg arasında tespit etmiştir. Varol vd. (2019) Kahramanmaraş'ta bazı balık türlerinde Fe konsantrasyonlarını 0,093-2,023 mg/kg arasında belirlemiştir.

Çoğu sucul canlının gerekli bir eser element olarak nikel (Ni) ihtiyacı olmasına rağmen, yüksek miktarları balıklar, amfibiler ve omurgasızlar için tehlikeli olabilir (Brix vd., 2017; Naz vd., 2023). Ortalama Ni konsantrasyonları 0,121-0,445 mg/kg arasında değişim göstermiştir (Tablo 2). Varol vd. (2020) Dicle Nehri'ndeki balık türlerinde ortalama Ni konsantrasyonlarını 0,66-0,79 mg/kg arasında bulmuşlardır. Gültürk (2021), Bingöl'de bazı balık türlerinde Ni konsantrasyonlarını 0,018-0,256 mg/kg arasında bulmuştur. Varol vd. (2019) Kahramanmaraş'ta bazı balık türlerinde Ni konsantrasyonlarını 0,16-0,254 mg/kg arasında bulmuştur.

Çinkonun (Zn) suya ve toprağa aşırı deşarjı su kirliliğine yol açarak septisemi, menenjit, demir eksikliği anemisi gibi ciddi sağlık sorunlarına neden olur (Aşıkkutlu vd., 2021; Li vd., 2018). Ortalama Zn konsantrasyonları 2,272-18,011 mg/kg arasında değişim göstermiştir (Tablo 2). Hamsi balığı örneklerinde tespit edilen Zn miktarı anlamlı derecede yüksektir ($p<0,05$). Gültürk (2021) Bingöl'de bazı balık türlerinde Zn konsantrasyonlarını 2,52-39,56 mg/kg arasında bulmuştur. Çiftçi vd. (2021) Kırıkkale'de bazı balık türlerinde Mn konsantrasyonlarını 4,13-20,72 mg/kg arasında tespit etmiştir. Bat vd. (2019) balık kaslarında tespit edilen ortalama Zn konsantrasyonlarını 8,4-12,3 mg/kg arasında belirlemiştir.

Karaman ilinde balık tüketen yetişkin insanların maruz kaldığı sekiz metalin EDI, THQ ve HI değerleri Tablo 3'te gösterilmiştir. Alabalık, barbun ve istavrit örneklerinde Fe elementinin EDI değerleri diğer elementlerin EDI değerlerinden yüksekken; hamsi, mercan ve kupes örneklerinde Cr elementi, çipura örneğinde As, levrek örneğinde ise Zn elementlerinin EDI değerleri diğer elementlerin EDI değerlerinden yüksek bulunmuştur. İncelenen balık türlerinde her bir metalin EDI değerleri RfD değerlerinin çok altındadır, HI'nin 1'den büyük olması, tüketici bakımından kanserojen olmayan sağlık risklerinin olduğunun göstergesidir. Tüm balık türlerinde, bütün metallerin THQ'ları 1'in altında bulunmuştur (Tablo 3). Tüketicilerin balık türlerinin tüketimi yoluyla bireysel metallerin alımından dolayı, kanserojen olmayan sağlık etkileri yaşama ihtimalinin düşük olduğu görülmüştür. Balıklarda en yüksek tehlike indeksi değeri (HI) mercan balığında (0,2) tespit edilmiştir. Diğer balıklarda HI değeri yüksekten düşüğe doğru sırasıyla; hamsi (0,08), kupes (0,06), barbun (0,027), istavrit (0,02), alabalık (0,014), levrek (0,013) ve çipura (0,012) şeklindedir. Tüm balık türlerinin HI değerleri 1'in altında olması tüketiciler için balık türlerindeki birleşik metallerin alımından kaynaklanan kanserojen olmayan sağlık etkilerinin ortaya çıkmasının muhtemel olmadığını göstermektedir.

En yüksek THQ değerine sahip metaller tüm balıklarda inorganik As olmuştur. Balıkların yenilebilir dokularında analiz edilen metallerin tüketiciler için sağlık sorunlarına yol açmayacağı sonucuna varılabilir. Benzer sonuçlar birçok araştırmacı tarafından rapor edilmiştir (Loghmani vd., 2022; Gültürk, 2021; Tokatlı ve Ustaoğlu, 2021; Varol vd., 2022a)

Karaman ilinde toplanan balık örneklerinin ağır metal parametreleri arasındaki ilişkisi Spearman korelasyon analizi ile belirlenmiş ve Tablo 4'te belirtilmiştir. Balık örneklerinde ağır metaller arasında 0,01 anlam seviyesinde ($p<0,01$) Cu metali ile Ni metali arasında güçlü pozitif korelasyon görülmüştür. Ayrıca, 0,01 anlam seviyesinde ($p<0,01$) As metali ile Cd ve Ni metalleri arasında, Cr metali ile Ni metali arasında, Cu metali ile Fe ve Zn metali arasında ve Fe metali ile Mn metali arasında orta düzeyde pozitif korelasyon belirlenmiştir.

Tablo 2. Balıklarda bulunmasına izin verilen maksimum metal konsantrasyonları ile bu çalışmada belirlenen metallerin ortalama değerleri (mg/kg yaş ağırlık)

	iAs*	**Cd**	**Cr**	**Cu**	**Fe**	**Mn**	**Ni**	**Zn**
	ort±ss	**ort±ss**	**ort±ss**	**ort±ss**	**ort±ss**	**ort±ss**	**ort±ss**	**ort±ss**
Alabalık	0,010±0,007^{a}	0,035±0,025^{ab}	0,165±0,027^{a}	0,154±0,032^{a}	3,706±0,625^{a}	0,109±0,038^{a}	0,124±0,026^{a}	3,361±0,182^{abc}
Barbun	0,023±0,012^{a}	0,035±0,024^{ab}	0,292±0,159^{a}	0,234±0,131^{a}	12,458±8,816^{bc}	0,176±0,107^{a}	0,156±0,032^{a}	4,177±1,471^{bc}
Çipura	0,011±0,006^{a}	0,040±0,019^{ab}	0,163±0,021^{a}	0,115±0,055^{a}	3,564±1,804^{a}	0,105±0,049^{a}	0,121±0,035^{a}	3,115±0,226^{ab}
Hamsi	0,067±0,006^{b}	0,061±0,019^{b}	0,230±0,063^{a}	0,959±0,243^{c}	12,791±2,246^{c}	0,475±0,268^{b}	0,249±0,052^{ab}	18,011±2,387^{d}
İstavrit	0,016±0,010^{a}	0,060±0,031^{ab}	0,860±0,574^{b}	0,834±0,959^{bc}	7,912±2,608^{ab}	0,152±0,016^{a}	0,316±0,183^{ab}	4,997±1,150^{c}
Kupes	0,074±0,023^{b}	0,063±0,018^{b}	0,476±0,313^{a}	0,386±0,177^{ab}	6,306±1,522^{a}	0,102±0,080^{a}	0,445±0,334^{b}	3,310±1,172^{abc}
Levrek	0,010±0,004^{a}	0,024±0,016^{a}	0,220±0,077^{a}	0,175±0,063^{a}	3,346±0,785^{a}	0,156±0,032^{a}	0,204±0,109^{a}	4,607±0,809^{bc}
Mercan	0,233±0,065^{c}	0,171±0,041^{c}	0,336±0,078^{a}	0,205±0,036^{a}	6,220±2,018^{a}	0,162±0,063^{a}	0,279±0,063^{ab}	2,272±0,358^{a}
	Maksimum izin verilen değerler							
TGK (2023)		0,05-0,25**						
EC (2023)		0,05-0,25**						
MHPRC (2022)	0,1	0,1	2,0					
FSANZ (2024)	2,0							

*iAs: İnorganik arsenik.

**Hamsi (*Engraulis* türleri) için 0,25 mg/kg yaş ağırlık, diğer türler için ise 0,05 mg/kg yaş ağırlık. Türk Gıda Kodeksi (TGK) Bulaşanlar Yönetmeliği’nde hamsi için bu değer 31/12/2024 tarihinden itibaren uygulanmaya başlanacaktır.

Farklı üst simge harflere sahip aynı sütundaki ortalamalar önemli ölçüde farklıdır ($p<0,05$).

Tablo 3. Karaman İlinde balık tüketimi yoluyla tahmini günlük alım (EDI), tolere edilebilir günlük alım(TDI), hedef tehlike katsayıları (THQ'lar) ve tehlike indeksi (HI)

	iAs*	**Cd**	**Cr**	**Cu**	**Fe**	**Mn**	**Ni**	**Zn**	
	THQ								**HI**
Alabalık	8,47E-03	8,57E-06	2,77E-08	9,70E-07	3,56E-03	1,96E-07	1,56E-06	2,82E-03	1,49E-02
Hamsi	5,63E-02	1,54E-05	3,86E-08	6,04E-06	4,61E-03	8,55E-07	3,14E-06	1,51E-02	7,60E-02
Barbun	1,93E-02	8,82E-06	4,91E-08	1,47E-06	4,48E-03	3,17E-07	1,97E-06	3,51E-03	2,73E-02
Çipura	8,85E-03	1,01E-05	2,74E-08	7,25E-07	1,28E-03	1,89E-07	1,52E-06	2,62E-03	1,28E-02
İstavrit	1,34E-02	1,51E-05	1,45E-07	5,26E-06	2,85E-03	2,74E-07	3,98E-06	4,20E-03	2,05E-02
Levrek	8,52E-03	6,05E-06	3,70E-08	1,10E-06	1,20E-03	2,81E-07	2,57E-06	3,87E-03	1,36E-02
Kupes	6,19E-02	1,59E-05	8,00E-08	2,43E-06	2,27E-03	1,84E-07	5,61E-06	2,78E-03	6,70E-02
Mercan	1,96E-01	4,28E-05	5,65E-08	1,29E-06	2,24E-03	2,92E-07	3,52E-06	1,91E-03	2,00E-01
	EDI								
Alabalık	8,83E-02	8,94E-03	4,00E-01	4,05E-02	9,74E-01	2,87E-02	3,26E-02	8,83E-01	
Hamsi	5,87E-01	1,60E-02	9,23E+00	2,52E-01	3,36E+00	1,25E-01	6,55E-02	4,73E+00	
Barbun	2,01E-01	9,20E-03	1,35E+00	6,15E-02	3,27E+00	4,63E-02	4,10E-02	1,10E+00	
Çipura	9,23E-02	1,05E-02	2,65E-01	3,02E-02	9,37E-01	2,76E-02	3,18E-02	8,19E-01	
İstavrit	1,40E-01	1,58E-02	1,94E+00	2,19E-01	2,08E+00	4,00E-02	8,31E-02	1,31E+00	
Levrek	8,88E-02	6,31E-03	6,48E-01	4,60E-02	8,80E-01	4,10E-02	5,36E-02	1,21E+00	
Kupes	6,46E-01	1,66E-02	3,96E+00	1,01E-01	1,66E+00	2,68E-02	1,17E-01	8,70E-01	
Mercan	2,04E+00	4,47E-02	2,46E+00	5,39E-02	1,63E+00	4,26E-02	7,33E-02	5,97E-01	
RfD	0,3	1	1500	40	700	140	20	300	

*iAs: İnorganik arsenik

Tablo 4. Karaman'da toplanan balık örneklerinde tespit edilen ağır metallerin birbirleri arasındaki ilişkiler ve Spearman sıralama korelasyon katsayıları

	iAs†	Cd	Cr	Cu	Fe	Mn	Ni	Zn
iAs	1							
Cd	,594**	1						
Cr	,369*	,401*	1					
Cu	,451**	,260	,473**	1				
Fe	,390*	,218	,444**	,569**	1			
Mn	,276	,085	,195	,389*	,501**	1		
Ni	,645**	,356*	,564**	**,710****	,402*	,301	1	
Zn	-,162	-,192	,083	,519**	,384*	,467**	,075	1

*korelasyon 0,05 seviyesinde önemli (p<0,05); **korelasyon 0,01 seviyesinde önemli (p<0,01). iAs: İnorganik arsenik

Sonuç

Sağlık riski değerlendirme yöntemleri, balık tüketicileri için kanserojen olmayan sağlık etkilerinin beklenmediğini ortaya koymuştur. Mercan balığında ortalama inorganik As konsantrasyonu MHPRC (2022) sınır değerinin (0,1 mg/kg) üzerinde, ortalama Cd konsantrasyonu EC (2023) sınır değeri (0,05 mg/kg), MHPRC (2022) sınır değeri (0,1 mg/kg) ve TGK (2023) sınır değerinin (0,05 mg/kg) üzerinde; istavrit ve kupes balıklarında ise ortalama Cd konsantrasyonları EC (2023) sınır değeri (0,05 mg/kg) ve TGK (2023) sınır değerinin (0,05 mg/kg) üzerinde bulunmuştur. İzin verilen limit değerlerin üzerinde metal içeriği tespit edilen istavrit, kupes ve mercan balıkları yabani deniz türleridir. Tüm balıkların ortalama Cr konsantrasyonları MHPRC (2022) sınır değerine (2,0 mg/kg) göre uygun bulunmuştur. İnsan vücudunda birikerek sağlık riski oluşturma ihtimali bulunan ağır metalleri içeren besin öğeleri, yetkili otoriterlerce denetlenmeli ve bu besinlerin düzenli bir şekilde takibi yapılmalıdır.

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RESEARCH ARTICLE

Repeatability of Nest Site Selection of Green Turtles on Samandağ Beach

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Abstract: Nest site selection is a maternal effect on hatchling survival in species without parental care. Sea turtles depend on sandy beaches for nesting, and females perform nest site selection on the beach for the successful development of their embryos. This study investigated the repeatability of nest site selection on Samandağ beach, a major green turtle nesting beach in the Mediterranean. During the 2013 nesting season, the distance to the sea, distance to vegetation, horizontal distance, and nest depth of the first and second nests of females were recorded using a tagging method. Repeatability analysis was performed using the rtpR package in R. A total of 91 turtles were tagged, of which 36 were observed during their first and second nests. The highest repeatability was found for horizontal distance, followed by distance to vegetation and distance to the sea. In contrast, nest depth showed insignificant repeatability. This suggests that green turtles select nesting sites that are close to the vegetation line but far from the sea and sites that are very close in horizontal distance. The results of this study include the results of a single year nesting season. It is recommended that future studies be conducted in consecutive years to see the results of repeatability of nest site selection from year to year.

Anahtar kelimeler:

Chelonia mydas
Yeşil kaplumbağa
Yuva yeri seçimi
Tekrarlanabilirlik
Samandağ

Samandağ Kumsalında Yeşil Kaplumbağaların Yuva Yeri Seçiminin Tekrarlanabilirliği

Öz: Yuva yeri seçimi, ebeveyn bakımı olmayan türlerde yavruların hayatta kalması üzerinde maternal bir etkidir. Deniz kaplumbağaları yuva yapmak için kumsallara bağımlıdır ve dişiler embriyolarının başarılı bir şekilde gelişmesi için kumsalda yuva yeri seçimi yaparlar. Bu çalışmada, Akdeniz'de yeşil kaplumbağalar için önemli bir yuvalama kumsalı olan Samandağ kumsalında yuva yeri seçiminin tekrarlanabilirliği araştırılmıştır. 2013 yuvalama sezonu boyunca, dişilerin ilk ve ikinci yuvalarının denize uzaklığı, bitki örtüsüne uzaklığı, yatay mesafesi ve yuva derinliği etiketleme yöntemiyle kaydedilmiştir. Tekrarlanabilirlik analizi R programında rtpR paketi kullanılarak gerçekleştirilmiştir. Toplam 91 kaplumbağa etiketlenmiştir; bu kaplumbağaların 36'sı ilk ve ikinci yuvaları sırasında gözlemlenmiştir. En yüksek tekrarlanabilirlik yatay mesafede bulunmuş, bunu bitki örtüsüne olan mesafe ve denize olan mesafe izlemiştir. Buna karşılık, yuva derinliği önemsiz bir tekrarlanabilirlik göstermiştir. Bu da yeşil kaplumbağaların yuvalama alanı olarak bitki örtüsüne yakın ancak denizden uzak alanları ve yatay mesafe olarak birbirine çok yakın alanları seçtiğini göstermektedir. Bu çalışmanın sonuçları tek bir yıllık yuvalama sezonunun sonuçlarını içermektedir. Yuva yeri seçiminin yıldan yıla tekrarlanabilirliğinin sonuçlarını görmek için gelecekteki çalışmaların birbirini takip eden yıllarda yapılması tavsiye edilir.

Introduction

Nest site selection is a form of maternal influence that enhances the survival and variety of hatchlings' characteristics, which are subject to natural selection (Kamel and Mrosovsky, 2004). Sea turtles are a good example of these species and depend on sandy beaches for nesting. Most sea turtle species do not nest every year but typically lay two to four clutches every 2 to 4 years (Ehrhart, 1982). The female's nest site selection is critical to the successful incubation of eggs, as egg survival depends on the interaction of several factors, including temperature, moisture, salinity, tidal inundation, erosion, and predation. (Fowler, 1979; Yntema and Mrosovsky, 1980; McGehee, 1990; Sönmez and Yalçın Özdilek, 2013; Sönmez, 2018).

Nests close to the sea are more vulnerable to the risk of flooding and erosion (Sönmez and Yalçın Özdilek, 2013), while nests near or in vegetated areas may have roots that can affect the embryonic development (Kamel and Mrosovsky, 2004). Also, vegetated areas might increase

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the likelihood of predation (Sönmez, 2018). Furthermore, because sea turtles have temperature-dependent sex determination (Yntema and Mrosovsky, 1980), nest site selection may affect hatchling sex via incubation temperature (Heredero Saura et al., 2022). In addition to sex, incubation temperature can also affect the size and locomotor performance of sea turtle hatchlings (Booth, 2017). Consequently, nest site selection can affect hatchlings' health that may vary with changes in the external environment (Patricio et al., 2018). In the face of changing environmental conditions, the nest site selected by the mother can affect the successful incubation of eggs as well as the hatchlings' sex, fitness, and survivability.

Wilson (1998) describes nest site selection as the process of nesting in non-randomly selected locations, and sea turtles exhibit diverse patterns of nest site selection that may vary between species or locations. For instance, Kamel and Mrosovsky (2004) reported significant repeatability and individual consistency in leatherback sea turtle nest site selection on the French Guiana nesting beach. Researchers have also reported that green turtles in Costa Rica exhibit nest site repeatability and prefer areas close to vegetation, particularly under trees (Heredero Saura et al., 2022). Similarly, green turtles showed high repeatability in microhabitat types such as open sand, forest border, and forest in Guinea-Bissau, West Africa (Patricio et al., 2018). Kamel and Mrosovsky (2005) reported that repeatability behavior in nest site selection in hawksbill sea turtles is inherited and may show potential for further evolution. In loggerhead sea turtles, females showed high variability in nest site selection, but larger females (>93 cm curved carapace length) showed higher repeatability in distance from vegetation on Boa Vista Island, Cabo Verde (Martins et al., 2022). In addition, Nordmoe et al. (2004) stated that it is more consistent to hypothesize that leatherback sea turtles nest close to the location of the previous nest rather than being fidelity based on a specific location on the beach.

Repeatability, which measures the proportion of total variation that is due to differences between individuals, is important for selection (Falconer and Mackay, 1996). Moreover, Boake (1989) asserts that it also reveals individual consistency. High and statistically significant repeatability in a behavioral trait indicates the potential for a genetic basis (Dohm, 2002). This highlights the importance of understanding behavioral repeatability in sea turtle nest site selection. In this case, repeatability can provide insight into whether factors such as distance to the sea and vegetation, temperature, and nest depth are important. These factors, which may affect the population's future and have a significant impact on nest site selection, are either genetically determined or random. As a result, this situation can provide guidance for future conservation and monitoring programs for the sea turtle population. Studies on the Samandağ green turtle population have reported that nests are exposed to flooding (Sönmez and Yalçın Özdilek, 2013; Sönmez et al., 2024), nests close to vegetation are at high risk of predation (Sönmez 2018), and female biased hatchlings are produced (Yalçın Özdilek et al., 2016). Nest site repeatability is known to exist in green turtles (Patricio et al., 2018; Heredero Saura et al., 2022). However, this has not been confirmed for the Mediterranean green turtle population. The aim of this study was to investigate the repeatability of nest site preference in terms of spatial distribution (distance to sea and vegetation, horizontal distance, and nest depth) in Samandağ green turtles.

Material and Methods

The study was conducted at Samandağ beach (36°07'N, 35°55'E) in the eastern Mediterranean during the 2013 nesting season. The beach was divided into 3 sections: Çevlik (5.5 km), Şeyh-hızır (4.1 km), and Meydan (4.4 km) sub-sections (Figure 1). Çevlik Harbor in the north was defined as the reference (zero) point for determining the horizontal distribution of nests. The study was conducted only in the Şeyh-Hızır sub-section due to very high nest density (Sönmez et al., 2024).

The data were collected within the framework of the collaboration protocol signed between Hatay Directorate of Nature Protection and National Parks of the Ministry of Agriculture and Forestry and Samandağ Environmental Protection and Tourism Association under the title "Research and conservation of sea turtle (*Chelonia mydas* and *Caretta caretta*) populations on Samandağ beach in Hatay " during the nesting season of 2013. Five people monitored the beach at night to observe the nesting female turtles. After nest camouflage was completed, turtles were tagged with metal tags. The tags were placed on the posterior margin of the left anterior flipper, as suggested by Balazs (1999). After the turtles returned to the sea safely, the distance from the sea and vegetation of the nest were measured (the vertical distance from the egg chamber to the tide line and vegetation). Also, the distance to the reference point of the nest was recorded with GPS (± 5 m, GARMIN). During night patrols throughout the nesting season, when a previously tagged female was found nesting (another nest belonging to the same female), the same measurements as above were recorded.

All nests were monitored during incubation and protected against predators with cages. A week after the first hatchling emerged, the nests were excavated and the remains were examined. During nest excavation, the number of eggshells, dead embryos, and nest depth were recorded. Of these records, only nest depth was used for repeatability analysis. The vertical distance from the sand surface to the bottom of each nest was measured using a flexible tape measure to determine the nest depth.

Nonparametric Wilcoxon Signed Rank Test was used to compare the distance to the sea and vegetation, nest depth, and horizontal distance of nests belonging to the same female (Salleh et al., 2021). The repeatability measure in Gaussian data with the linear mixed-effects model (LMM) was used to assess whether there were within-individual preferences in nest site selection (Nakagawa and Schielzeth, 2010; Patricio et al., 2018). Linear mixed models directly estimate the variances, which are both necessary and sufficient for calculating repeatability. The predominant method for estimating unbiased variance components in linear mixed models is restricted maximum likelihood (Nakagawa and Schielzeth, 2010). Therefore, repeatability analysis for Gaussian data, i.e., distance to sea and vegetation, distance to reference point (horizontal distance), and nest depth rtpR package in R, was performed using the Linear Mixing Model (Nakagawa and Schielzeth, 2010; Patricio et al., 2018). The results of the repeatability analysis are presented along with the R value, standard error (SE), and 95% confidence interval (CI) values.

The statistical analyses were performed with rptR (Stoffel et al., 2017), ggplot2 (Wickham, 2016), and ggstatsplot (Patil, 2021) packages in R (R Core Team 2020 and R Studio Team 2020).

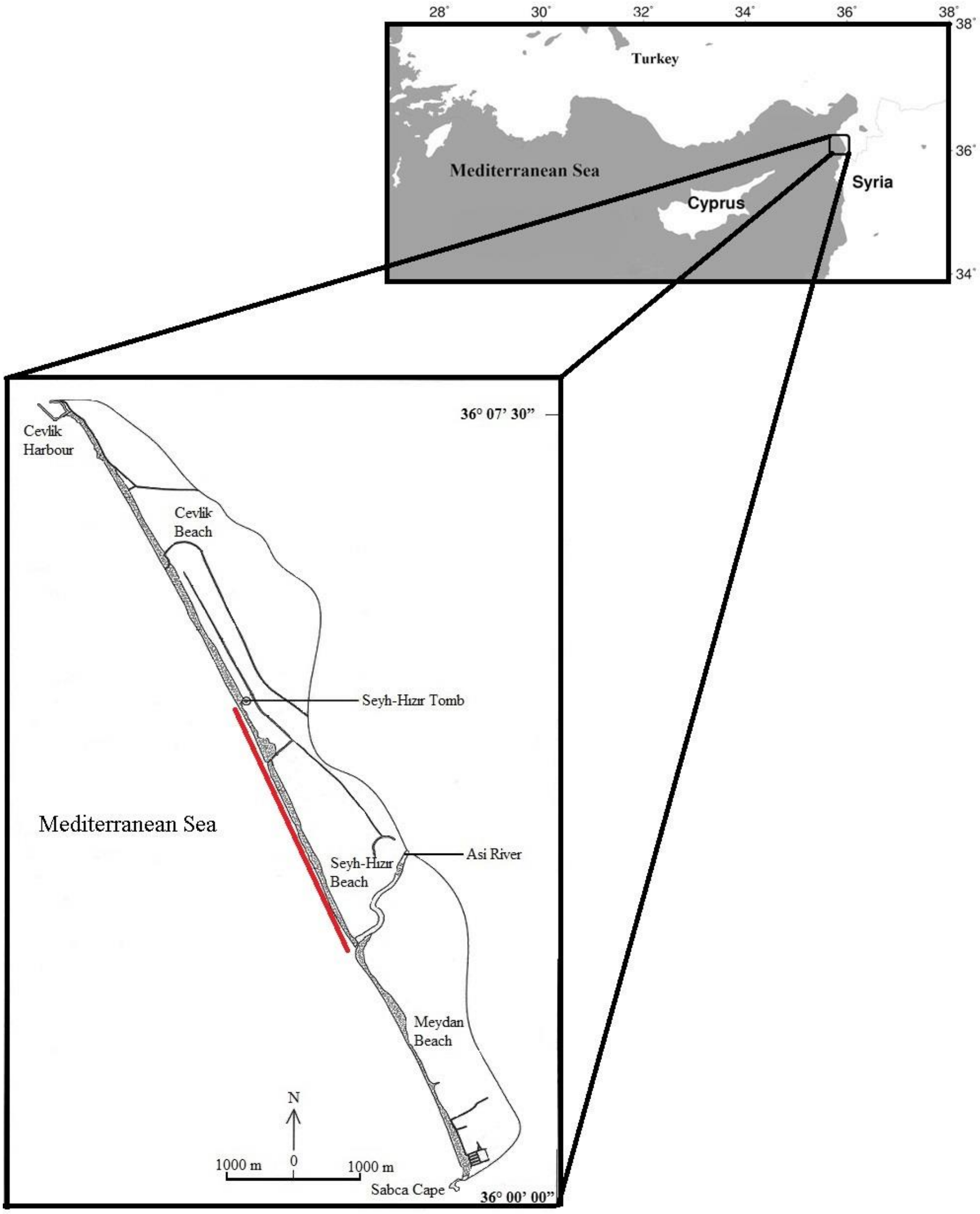

Figure 1. General view of Samandağ beach (red line shows the Şeyh-Hızır sub-section where tagging was done for repeatability analysis)

Results

A total of 1175 green turtle nests were recorded during the 2013 nesting season. 91 turtles were tagged; 36 of these turtles were observed during their second and third nests, and 55 turtles were observed only during their first nest. Since only two turtles were observed during their third nest, all data from the third nest of these two turtles were excluded from all statistical analyses. Thus, 72 nests (first and second nests) of 36 turtles were analyzed for repeatability. The median box plots of the distance to the sea and vegetation, horizontal distance, and nest depth for the first and second nests are shown in Figure 2. There was no significant difference between the distance to the sea and vegetation, the horizontal distance, and the nest depth of the first and second nests of the tagged females (see Table 1 for details).

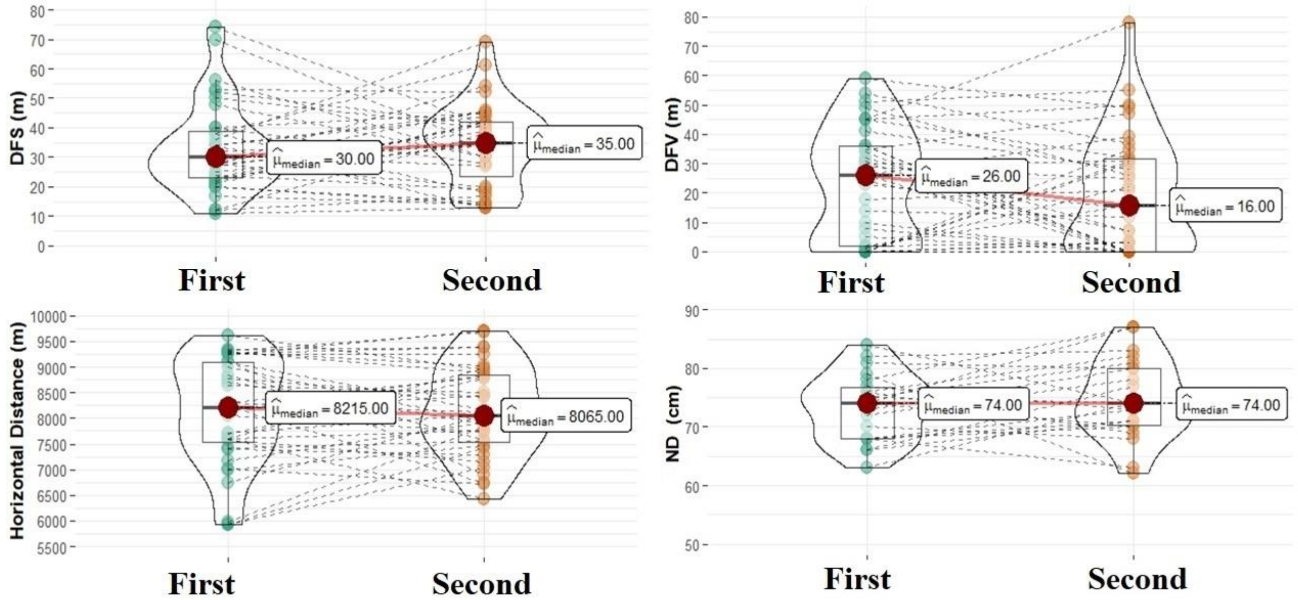

Figure 2. Box plots and medians of the first and second nests in terms of distance to sea, distance to vegetation, horizontal distance and nests depth (DFS: distance from sea, DFV: distance from vegetation and ND: nest depth)

Table 1. The Wilcoxon signed-rank test and repeatability measure of the two consecutive nests of green turtle females (DFS: distance from sea, DFV: distance from vegetation and ND: nest depth)

	Wilcoxon Signed Rank Test			Repeatability Measure			
	n	Wilcoxon	p	R	SE	p	95% CI
DFS	35	280	0.57	0.323	0.147	0.0301*	0.002 – 0.592
DFV	35	339	0.30	0.515	0.129	0.0006*	0.223 - 0.720
Horizontal	36	324	0.89	0.584	0.113	0.000723*	0.327 – 0.758
ND	22	89	0.23	0.304	0.176	0.0875	0 – 0.627

Individuals at their nest site had the highest repeatability for horizontal distance (see Table 1 and Figure 3a), followed by distance to vegetation (see Table 1 and Figure 3b), and distance to the sea (see Table 1 and Figure 3c). In contrast, nest depth showed no significant repeatability between individuals (see Table 1 and Figure 3d). In the multiple assessment (distance to sea + distance to vegetation + horizontal distance), when nest depth was excluded (due to no significant repeatability), the analyses showed a high repeatability within individuals at the nest location (R: 0.547, SE: 0.13, $p<0.001$, and CI: 0.238–0.758).

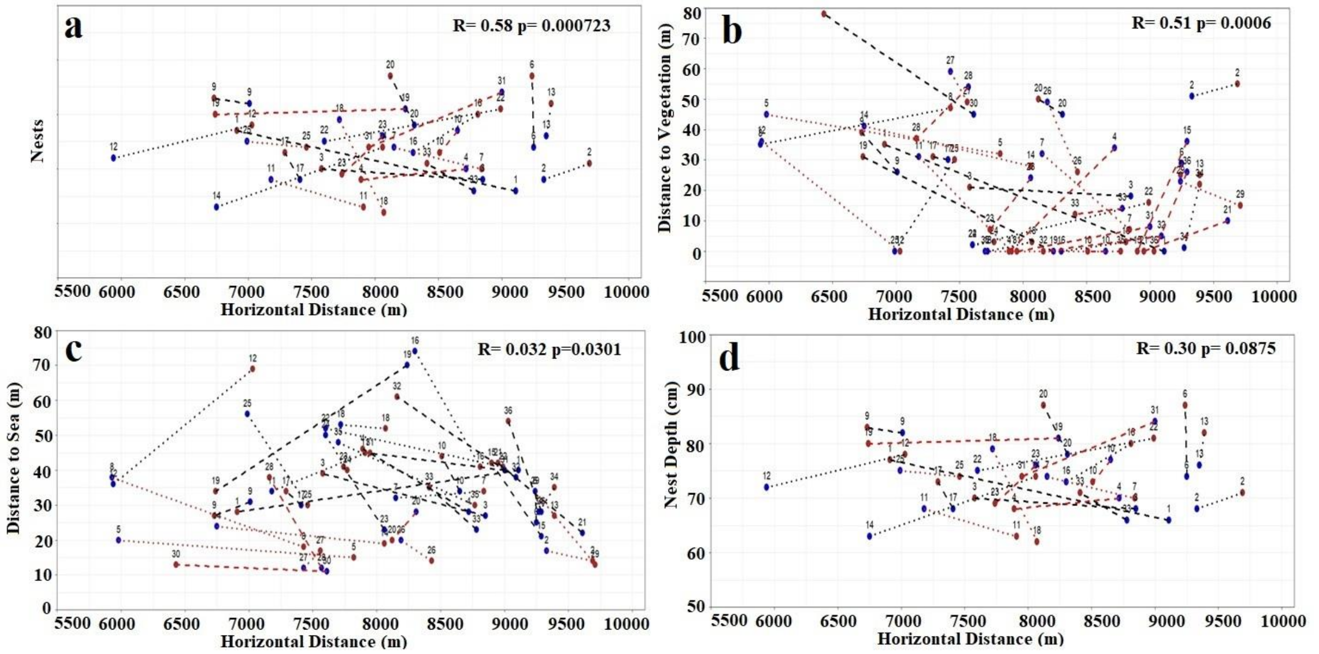

Figure 3. Graphical representation of individual locations between two consecutive nests of green turtle females and repeatability for horizontal distance (a), distance to vegetation (b), distance to sea (c), and nest depth (d) (blue dot indicates the first nest and red dot indicates the second nest; dotted line indicates positive change; and dashed line indicates negative change).

Discussion

Nest site selection, defined as the placement of nests in areas that differ from random sites (Wilson, 1998), has been proposed to provide developing embryos with a higher probability of survival at selected sites than at unselected sites (Schwarzkopf and Brooks, 1987). While all species of sea turtles follow a similar nesting procedure, there is considerable variation in the selection of nesting sites among different species and populations. For example, loggerhead turtles in Cabo Verde preferred to nest in the middle of the beach and avoided nesting close to both the shoreline and the vegetation line (Martins et al., 2022). Furthermore, it was reported that leatherback turtles lay predominantly in open sand and green turtles in vegetated areas in Suriname (Whitmore and Dutton, 1985). Additionally, Hart et al. (2014) reported that olive ridley turtles in Mexico prefer to nest on open beaches from the berm to the vegetation line. Green turtles nest mostly in areas with vegetation, while loggerhead turtles nest mostly in areas without vegetation on Akyatan beach, Türkiye (Türkozan et al., 2011). Similarly, green turtle nests are often reported to be in vegetation at the back of the beach, where the risk of flooding is lowest in the Chagos Archipelago, Indian Ocean (Stokes et al., 2024).

The present study found that green turtles in Samandağ exhibit intra-individual consistency and high repeatability in their nest site selection. This suggests that green turtles selected areas close to the vegetation line (just in front of the vegetation rather than in the vegetation zone) but far from the sea as nesting sites. Previous studies have reported nest site repeatability for leatherback turtles in French Guiana (Kamel and Mrosovsky, 2004), hawksbill turtles in Guadaloupe (Kamel and Mrosovsky, 2005), green turtles in Guinea-Bissau (Patricio et al., 2018), and eastern Pacific green turtles in northwestern Costa Rica (Heredero Saura et al., 2022). The presence of a high degree of repeatability may represent a process constancy in the nest site selection among sea turtles (Heredero Saura et al., 2022). Although constancy may be advantageous for turtles that encounter ideal conditions for egg development, it can also be disadvantageous when conditions turn unsuitable (Bowen and Karl, 2007). Bowen and Karl (2007) proposed that there may be mixed strategies within a sea turtle population, with some individuals choosing to scatter their nests, while others prefer to nest in a restricted area. The green turtle population at Cabuyal beach in northwestern Costa Rica exhibits this mixed nesting strategy, with some individuals nesting at relatively large distances from each other (Heredero Saura et al., 2022). Thus, long-distance nests may benefit from changing unfavorable conditions due to the dynamic structure of the beach. In fact, poor nest site repeatability has sometimes been observed in some populations in response to local beach dynamics (Pfaller et al., 2022).

Studies have reported that green turtles mostly prefer vegetated areas for nest site selection (Whitmore and Dutton, 1985; Türkozan et al., 2011; Heredero Saura et al., 2022; Stokes et al., 2024). In contrast, Patricio et al. (2018) found high repeatability in green turtles and reported that 67% of nests were located in open sand, with the remainder in forests and forest edges. Nesting farther from the sea may reduce the risk of inundation (Sönmez and Yalçın Özdilek, 2013; Stokes et al., 2024) and thus tend to increase hatching success (Patricio et al., 2018; Martins et al., 2022). In addition to increasing hatching success by reducing the risk of flooding, nest site selection in vegetated areas (under trees rather than in grassy areas) with high repeatability may result in cooler temperatures and thus less female bias (Patricio et al., 2018; Heredero Saura et al., 2022). However, nests in forest edges and habitats had lower hatching success than those in open sand (Patricio et al., 2018). While the behavior of repeatability in terms of distance from the sea may be aimed at reducing the risk of flooding on Samandağ' beach, proximity to vegetation lines may increase the likelihood of predation. It has been reported that the probability of predation is higher in nests close to vegetation on Samandağ beach (Sönmez, 2018).

Samandağ green turtles showed high repeatability in horizontal distance in addition to distance to the sea and vegetation. The median of the horizontal distances between the first and second nest of females show that there is only a 150 m difference between two consecutive nests (see Figure 2). This shows that females tend to nest in the same area of the beach with high repeatability.

The most obvious limitation of the study is its single year nature, which limits the generalizability of the results to more than one year, and the sample size limitation with only 36 turtles observed for their second nest. The repeatability of nest sites between years has been demonstrated for hawksbill sea turtles in Guadeloupe (Kamel and Mrosovsky, 2006). Furthermore, the fact that the study was conducted on only one section of the beach (i.e., Şeyh Hızır) is an important limitation. If similar studies had been conducted on the entire beach or even on nearby beaches, different results might have been obtained. This is because a green turtle nested in both Snoubar (Syria) (about 100 km from Samandağ beach) and Samandağ beach during the same nesting season (Sönmez et al., 2017).

Another limiting factor is that the study did not consider external factors that may influence nest site selection, such as predation pressure or human activities. In fact, the entire Şeyh-Hızır subsection where the study was conducted has a low anthropization frequency (Sönmez et al., 2024). The low frequency of anthropization can be considered as an important factor in nest site selection. Similarly, Siqueira-Silva et al. (2020) reported a higher frequency of anthropization in areas with fewer nests in northeastern Brazil. Furthermore, on Kenyan beaches where human activity is intense, it has been associated with high organic matter content, which significantly affects the number of green turtle nests on the beach (Obare et al., 2019).

In conclusion, green turtles nesting on Samandağ beach showed high repeatability in nest site selection, especially in terms of distance to vegetation and horizontal distance. However, the results of the present study were conducted during a single nesting season and only in a sub-section of the beach. It may be recommended that future studies investigate the repeatability of nest site selection across years and across the entire nesting beach. This will test whether similar results occur in different nesting seasons and across the entire nesting beach.

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Conflict of Interest

The author has no relevant financial or non-financial interests to disclose.

Author Contributions

Bektaş Sönmez (BS) conceived the ideas and designed methodology and analysed the data, and wrote of the manuscript.

Ethics Approval

No ethics committee approval is required for this study.

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RESEARCH ARTICLE

Assessment of Bycatch and Lost Fishing Gear in Sea Bass (*Dicentrarchus labrax*) Fishing Using Vertical Setline in the Coastal Waters of Yumurtalık Bay

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Small scale fisheries
Northeastern Mediterranean
Bycatch
Fisheries management

Abstract: In this study, conducted in Yumurtalık Bay (Adana/Turkey) between October 2020 and February 2021, 40 commercial fishing operations were monitored. During the fieldwork, the length and weight of the species caught by commercial fishers were measured, and the number of deployed set lines and the lost set lines were recorded for each operation. The results showed that, aside from European seabass (*Dicentrarchus labrax*), only six species were caught, with bycatch species constituting 4.64% by weight. Of the 859 seabass individuals caught, only 88 were found to be below the minimum legal catch size (25 cm) specified in Turkish fisheries regulations. These findings suggest that the method demonstrates species and size selectivity, indicating an environmentally friendly fishing approach. A total of 4791 set lines were deployed during the monitored operations, of which 198 lines (4.13%) were lost. The total number of set lines lost by the entire fleet in a single season was estimated to be approximately 2800 lines. While the reasons for gear loss typically include gear conflicts, adverse weather conditions, operational errors, maritime traffic, and vandalism, this study did not specifically identify the causes of gear loss. However, inferences were made regarding possible causes based on previous studies.

Anahtar kelimeler:

Dicentrarchus labrax
Küçük ölçekli balıkçılık
Kuzeydoğu akdeniz
Hedef dışı av
Balıkçılık yönetimi

Yumurtalık Koyu (Adana/Türkiye) Kıyısal Bölgesinde Levrek (*Dicentrarchus labrax*) Avında Kullanılan Bırakma Olta Takımının Hedef Dışı Av ve Kayıp Av Aracı Bakımından İncelenmesi

Öz: Yumurtalık koyunda (Adana/Türkiye), Ekim 2020 ile Şubat 2021 tarihleri arasında gerçekleştirilen bu çalışmada, 40 ticari balıkçılık operasyonu takip edilmiştir. Bu saha çalışmalarında, ticari balıkçılar tarafından yakalanan türlerin boy ve ağırlıkları ölçülmüş, ayrıca her bir operasyonda denize atılan bırakma oltası sayısı ile kaybolan olta sayısı kaydedilmiştir. Elde edilen sonuçlar, levrek dışında sadece 6 tür yakalandığını, hedef dışı türlerin ağırlıkça oranın %4,64 olduğunu göstermiştir. Yakalanan 859 levrek bireyinin sadece 88 tanesinin, ülkemiz balıkçılık mevzuatında belirtilen avlanabilir asgari boydan (25cm) küçük olduğu belirlenmiştir. Bu sonuçlar, yöntemin tür ve boy seçiciliği açısında çevre dostu olduğu fikrini vermektedir. Takip edilen operasyonlarda toplam 4791 adet bırakma olta denize atılırken, bu oltalardan 198 tanesi (%4.13) kaybolmuştur. Tüm filonun bir sezonda kaybettiği bırakma olta sayısı yaklaşık 2800 adet olarak tahmin edilmiştir. Av araçlarının kaybolma nedenleri olarak; av araçları arasında çatışma, kötü hava koşulları, operasyonel hatalar, deniz trafiği ve vandalizm gibi nedenler görülmekte ise de bu çalışmada kayıp nedenleri konusunda herhangi bir tespit yapılmamıştır. Bununla birlikte, daha önce yapılan çalışmalar dikkate alınarak olası kayıp nedenleri hakkında çıkarımda bulunulmuştur.

Giriş

Küçük ölçekli balıkçılık, 12m'den küçük teknelerle yürütülen ve sürütme ağlarının kullanılmadığı balıkçılık olarak tanımlanmaktadır (Natale vd., 2015). Bu tip balıkçılık, birçok açıdan çevre dostu olarak kabul edilmektedir. Örneğin küçük ölçekli balıkçılığın deniz tabanındaki habitata zarar verilmesi ve hedef dışı av miktarı oldukça düşüktür (Jennings vd., 2001; Chuenpagdee vd., 2003). Küçük ölçekli balıkçılıkta genellikle; tuzak, paraketa ve uzatma ağı gibi pasif av araçları kullanılmaktadır. Bu av araçları ya tabana hiç temas etmemekte (pelajik paraketa ve pelajik uzatma ağı gibi) ya da operasyon sırasında tabanda sabit (sepet tuzak, dip uzatma ağı, dip pareketası gibi) durmaktadır. Dolayısıyla da bentik tahribata yol açmamaktadır. Buna ek

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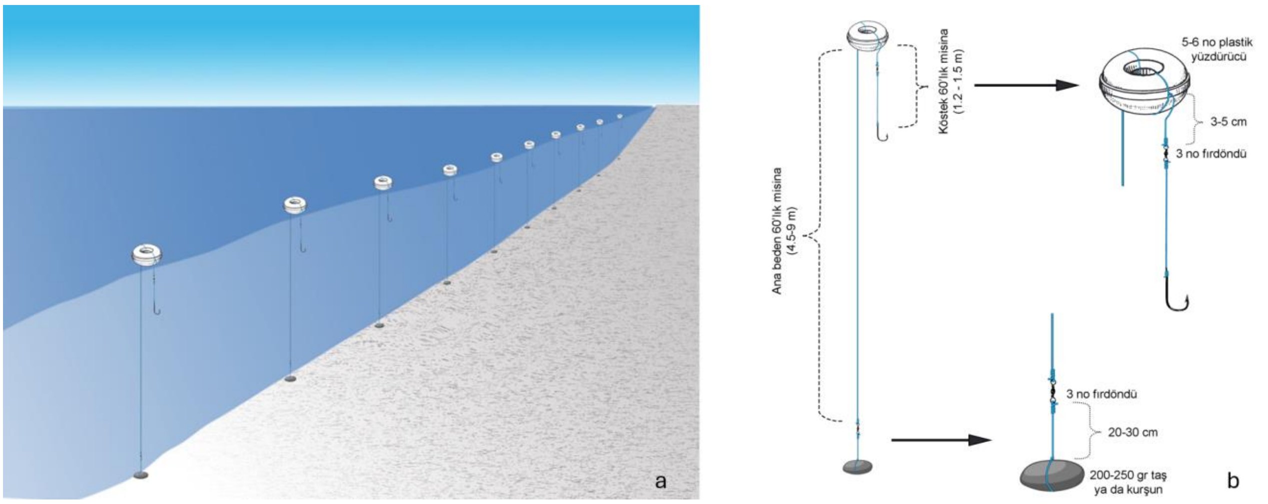
olarak, küçük ölçekli balıkçılıkta kullanılan pasif av araçlarının boy ve tür seçiciliği yüksek olduğundan (Jennings vd., 2001) trol gibi aktif av araçlarına göre hedef dışı av ve ıskarta oranının daha düşük olmaktadır. Ancak yukarıda açıklanan tüm önemli özelliklerine karşın küçük ölçekli balıkçılığım görünürlüğü düşüktür (Staples vd., 2004). Son dönemde bu konuyla ilgili olarak çalışmalarda artış olmasına rağmen bazı bölgelerde yürütülen küçük ölçekli balıkçılık ile ilgili veriler (hedef türler, olası tehditler vb) sınırlıdır.

Yumurtalık Koyu İskenderun Körfezi'nin (Kuzeydoğu Akdeniz) güney batısında yer almaktadır. Koyun toplam alanı yaklaşık 46 km^2'dir ve çok sayıda kıyısal lagün bulunmaktadır. Bölgenin hem ekonomik (çipura, levrek, lüfer, kefal vb.) hem de bazı kritik türlere (orfoz, yeşil deniz kaplumbağası, kum köpekbalığı vb.) ev sahipliği yaptığı bilinmektedir (Akamca vd., 2010; Basusta vd., 2021; Özyurt vd., 2017; Özyurt vd., 2019). Koydaki ana balıkçılık faaliyetleri; uzatma ağı, bırakma olta ve paraketa avcılığıdır (Özyurt ve Kiyağa, 2016). Bu alanda kullanılan bırakma olta takımı, temel olarak dikey bırakma oltasıdır (He vd., 2021). Bu dikey oltalardan 100-150 kadarı bir araya getirilerek bir takım oluşturulmaktadır. Operasyonda bu oltalar düz bir hat üzerinde belirli aralıklarla (35-40 m) atılmaktadır (Şekil 1a). Oltaların arasında herhangi bir bağlantı yoktur. Bu yöntemde hedef türler levrek ve lüferdir. Özellikle kış aylarında levrek avcılığı diğer aylarda ise dönem dönem lüfer avcılığı yapılmaktadır. Balıkçılar yem olarak kefal türlerini kullanmaktadır (Özyurt vd., 2023). Dikey olta takımının teknik özellikleri ve operasyon şekli Özyurt vd., (2019) tarafından yapılan çalışmada açıklanmıştır. Levrek avcılığında operasyon öncesi çevirme ağları ile kefal bireyleri yakalanmakta (Özyurt ve Köylü, 2024) ve yaşatma tanklarında canlı olarak tutulmaktadır.

Bölgede uygulanan dikey bırakma olta takımının; av verimi (CPUE), tür dağılımı, boy dağılımı ve olası çevresel etkileri ile ilgili herhangi bir çalışma bulunmamaktadır. Yürütülen bu çalışmada; Yumurtalık Koyu'nda balıkçılık sezonu boyunca (yaz dönemi lüfer avcılığı izlenmemiştir) 40 Ticari balıkçılık operasyon gözlemlenerek, uygulanan levrek avcılığı takip edilmiştir. Bu kapsamda; av sezonu, birim çabada elde edilen ürün (CPUE) değerinin zamana göre değişimi, tür dağılımı, boy dağılımı, kayıp av aracı miktarı belirlenmiştir.

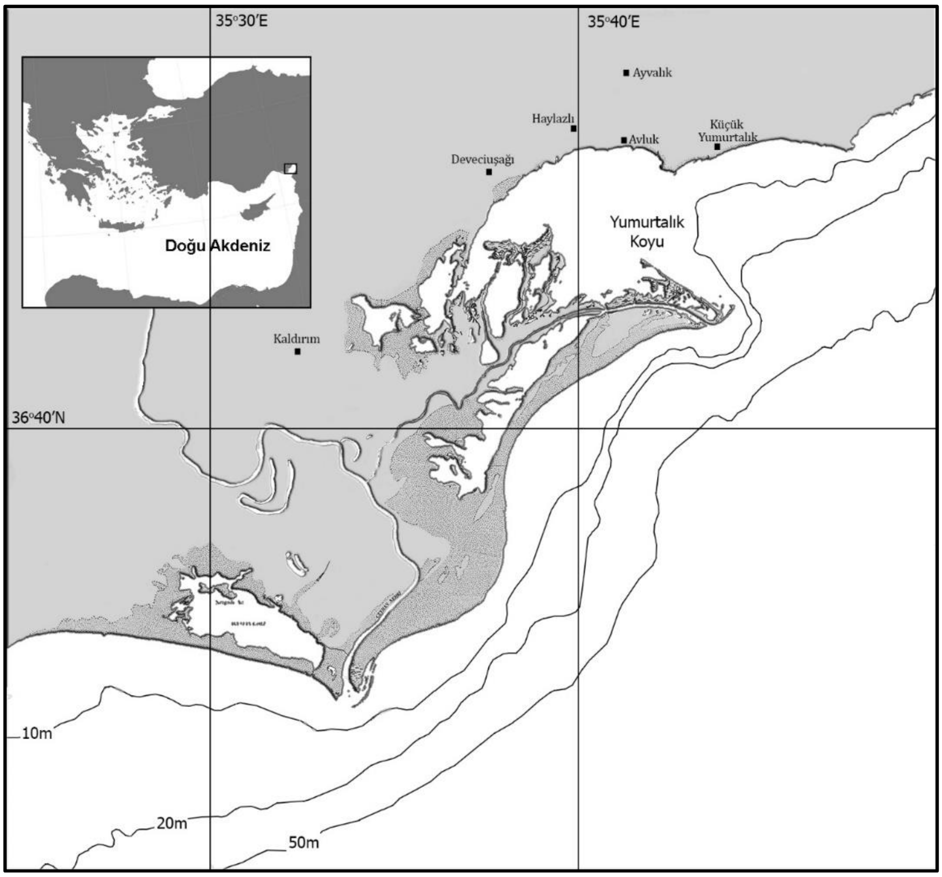
Materyal ve Yöntem

Saha çalışmalarına, balıkçıların dikey bırakma olta takımları ile levrek avladıkları sezon boyunca (Ekim 2020 ile Şubat 2021) devam edilmiştir. Bu süreçte, 11 farklı balıkçı teknesi tarafından yapılan 40 farklı ticari balıkçılık operasyonuna eşlik edilmiştir. Balıkçılar tarafından kullanılan dikey bırakma oltanın teknik özellikleri Şekil 1b'de gösterilmiştir. Operasyonlara Yumurtalık koyunda bulunan Avluk Balıkçı Barınağından çıkılmıştır (Şekil 2).



Şekil 1. Bırakma olta takımının şematik görünümü (a: sudaki genel görünüm, b: bir vertikal bırakma oltanın teknik özellikleri)

Tüm operasyonlar 5 m'den sığ alanlarda yapılmıştır, dikey bırakma oltalar gün batımından sonra atılmış, gün doğumundan sonra toplanmıştır. Yakalanan tüm bireylerin ölçümleri karaya çıkarıldıktan sonra barınakta yapılmıştır. Total boylar "mm", total ağırlıklar ise "g" olarak ölçülmüştür. Buna ek alarak; balıkçının operasyonda attığı toplam bırakma olta sayısı, kesik köstek sayısı ile kayıp bırakma olta sayısı kaydedilmiştir. Kesik köstek, sadece olta iğnesinin olmadığı, bırakma oltanın geri kalan kısmının (yüzdürücü, batırıcı, ana beden ve kösteğin bir kısmı) balıkçı tarafından geri toplandığı durumu ifade etmektedir. Genellikle, yakalanan bireyin köstek kısmını oluşturan misinayı dişleri ile keserek kurtulmasından kaynaklanmaktadır. Kayıp ise, bırakma oltanın tamamının geri alınamadığı durumu ifade etmektedir.



Şekil 2. Yumurtalık Koyu

Balıkçılıkta CPUE değeri "ürünün" "çabaya" bölünmesi ile elde edilebilir. Oltalarda "iğne sayısı" ve "operasyon gün sayısının" toplam çabayı temsil edebileceği belirtilmiştir (Sparre ve Venema, 1998). Benzer şekilde; paraketalar için efektif balıkçılık çabasının belirli bir alanda, belirli bir zaman diliminde kullanılan iğne sayısı olduğu da ifade edilmiştir (Bigelow vd., 2002). Bu çalışmada, çaba bir operasyonda kullanılan bırakma olta sayısı (iğne sayısı) olarak kabul edilmiştir. CPUE değerlerinin belirlenmesi için, gözlem yapılan her bir operasyonda yakalanan bireylerin ağırlığı, iğne sayısına oranlanarak CPUE (gr/iğne) değeri hesaplanmıştır. Bunun için; $CPUE = \frac{w}{h}$ eşitliği kullanılmıştır. Bu eşitlikte; $w =$ gözlem yapılan operasyonlarda yakalanan bireylerin toplam ağırlığını, $h =$ gözlem yapılan operasyonlarda kullanılan toplam iğne (bırakma olta) sayısını göstermektedir. Her ay ilk 15 gün ve ikinci 15 gün olarak ikiye ayrılmış ve CPUE değerleri bu 15 günlük periyotlar için hesaplanmıştır. Bu periyotlarda yapılan örnekleme sayıları Tablo 1'de verilmiştir. Sezon boyunca her 15 gün için ortalama CPUE değerleri belirlenmiş ve arasındaki farkın istatistiksel olarak önemli olup olmadığı Kruskal Wallis Test İstatistiği ile test edilmiştir. Kruskal Wallis Test İstatistiği R programı içindeki onewaytest paketi kullanılarak yapılmıştır (Dag vd., 2018).

Tablo 1. Örnekleme dönemleri kodları ve yapılan örnekleme sayısı

Örnekleme Dönemi			Kodu	Operasyon Sayısı
15.10.2020	-	31.10.2020	Ekim 2 (İkinci periyot)	1
01.11.2020	-	15.11.2020	Kasım 1	5
16.11.2020	-	30.11.2020	Kasım 2	5
01.12.2020	-	15.12.2020	Aralık 1	7
16.12.2020	-	31.12.2020	Aralık 2	7
01.01.2021	-	15.01.2021	Ocak 1	7
16.01.2021	-	31.01.2021	Ocak 2	6
01.02.2021	-	15.02.2021	Şubat 1 (İlk periyot)	2

Hedef dışı av oranının hesaplanması için $\%Hd = \frac{(Ts+Is)}{Ta}$ eşitliğinden faydalanılmıştır. Bu eşitlikte; $\%Hd =$ Hedef Dışı Av Oranını, $Ts =$ Tesadüfi Av Miktarını (gr), $Is =$ Iskarta Av Miktarını ifade etmektedir (Alverson vd., 1994).

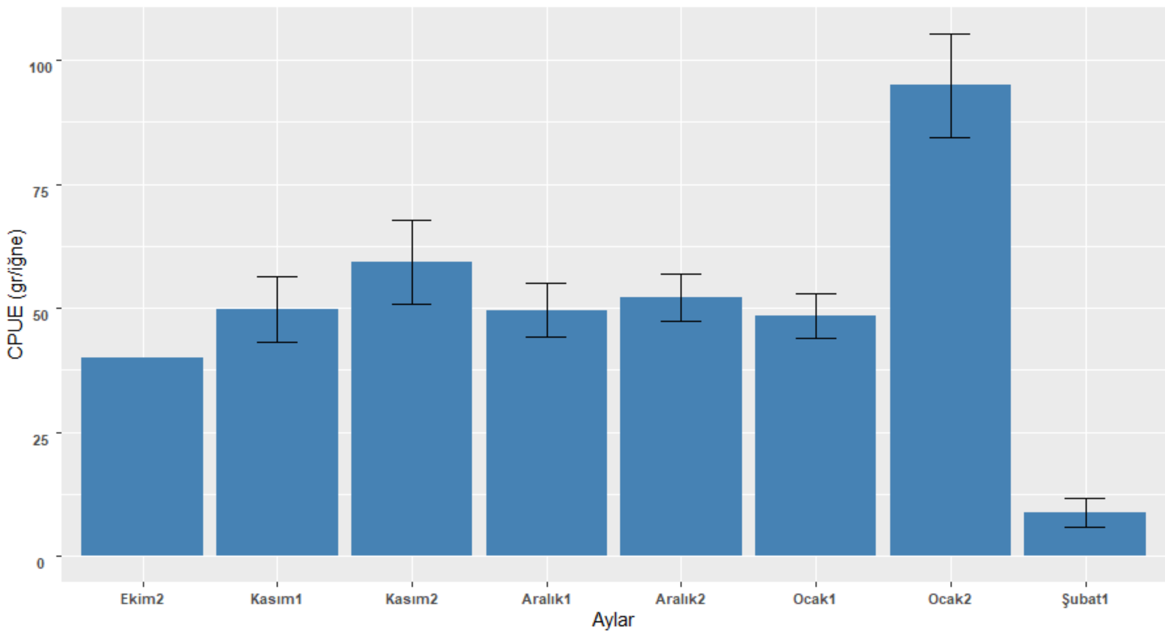
Verilerin görselleştirilmesi için R programı içerisindeki ggplopt2 paketi kullanılmıştır (Wickham, 2016).

Bulgular

Gözlem yapılan 40 operasyonda, toplam 890 adet birey yakalanmıştır. Hangi türden kaç birey yakalandığı ve bunların boy ve ağırlıkları ile ilgili tanımlayıcı istatistikler Tablo 2'de verilmiştir. Bu tablodan de görülebileceği gibi, yakalanan bireylerin %96.52'sini levrek oluşturmaktadır. Birim Çabada Elde Edilen Ürünün (gr/iğne) 15 günlük periyotlara göre değişimi Şekil 3'de verilmiştir. Ekimin ikinci yarısı ile Ocağın ilk yarsı arasında birbirine yakın olan CPUE değerlerinin Ocağın ikinci yarısında belirgin şekilde yükseldiği ve Şubat ayının ilk yarısında sert şekilde düştüğü görülmektedir. Yapılan Kruskal Wallis Testi, ortalama CPUE bakımında 15 günlük periyotlar arasındaki farkın istatistiksel olarak önemli olduğunu göstermiştir ($p<0.05$). Buna ek olarak, yapılan Post Hoc test sonuçları; Ocağın ikinci periyodu ile Şubatın ilk periyodunun tüm 15 günlük periyotlardan istatiksel olarak farklı olduğunu göstermiştir. Balıkçılar bu operasyonlarda yaklaşık ortalama 120 adet bırakma oltası kullanmaktadır. Dolayısıyla her bir operasyonda ortalama 6.8 kg levrek yakalamışlardır. Bu oran belirgin şekilde düştüğünde bu avcılık yöntemi ile levrek avcılığı bırakılmıştır. Dolayısıyla, bırakma olta ile levrek avcılığı sezonunun Kasım, Aralık ve Ocak ayları olduğu belirlenmiştir.

Tablo 2. Örneklemelerde yakalanan türler ve tanımlayıcı istatistikler

Tür	Adet (n)	Oran (%)	Boy (cm)		Ağırlık (g)	
			Ortalama	Std Sapma	Ortalama	Std Sapma
Sparus aurata	9	1,01	19,42	4,20	112,22	96,31
Umbrina cirrosa	2	0,22	37,50	1,56	560,00	56,57
Trichuris lepturus	11	1,24	55,29	2,99	149,09	36,10
Dicentrarchus labrax	859	96,52	30,20	5,97	316,46	258,82
Pomatomus saltatrix	5	0,56	36,04	6,77	463,60	220,97
Argyrosomus regius	2	0,22	33,10	2,69	379,00	134,35
Belone belone	2	0,22	77,50	4,53	697,00	108,89
Toplam	890	100,00	-	-	-	-

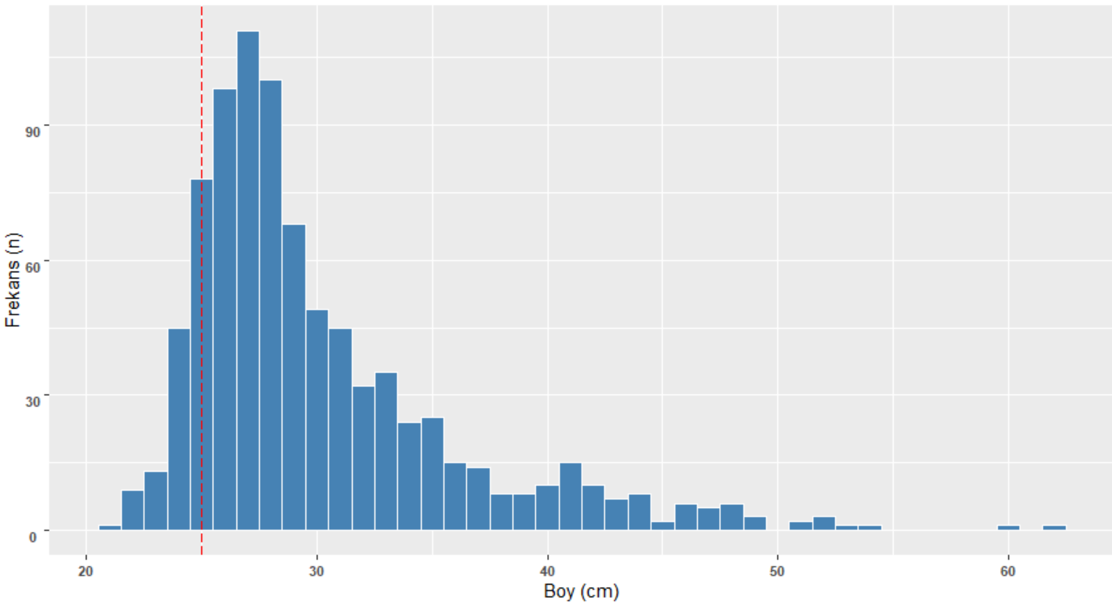


Şekil 3. 15 günlük periyotlar için CPUE değerlerinin değişimi

Çalışmada balıkçılar tarafından 7 tür avlandığı gözlenmiştir. Bu türlerden levrek hedef tür olduğundan, hedef dışı tür sayısının 6 olduğu anlaşılmaktadır. Bu 6 türünde ekonomik değeri olduğundan ıskarta edilmemektedir. Dolayısıyla sadece minimum av boyundan küçük bireyler ıskartayı oluşturmaktadır. Tablo 3'de avlanan türlerin mininim av boyundan küçük ve büyük olanlarının sayısı ve ağırlığı gösterilmiştir. Hedef dışı türlerden *Umbrina cirrosa* (karakulak), *Trichiurus lepturus* (kayış), *Argyrosomus regius* (muskar) ve *Belone belone* (zargana) türleri için belirlenmiş bir minimum av boyu yoktur. Ancak hedef dışı türlerden çipura için minimum av boyu 20 cm'dir. Yakalanan 9 çipura bireyinin 6'sı minimum av boyundan küçüktür ve ağırlıkça ıskarta oranı %40.59'dur. Bu oran yüksek gibi gözükse de çipuranın toplam av içerisindeki oranı yaklaşık %1'dir. Yine hedef dışı türlerden lüferin yakalanan 5 bireyinin de minimum av boyunda büyük olduğu görülmektedir. Bu avcılık yönteminin hedef türü olan levreğin boy frekans dağılımı Şekil 4'de gösterilmiştir. Grafikteki kırmızı vertikal çizgi yasal minimum av boyunu (25 cm) göstermektedir. Sonuçlar, 859 adet levrek bireyinin sadece 88 tanesinin minimum av boyundan küçük olduğunu göstermiştir. Ülkemiz balıkçılık mevzuatında "hamsi, sardalya ve istavrit'te ağırlıkça %15, diğer su ürünlerine ise ağırlıkça %5 oranında küçük boylara istisna tanınır" denilmiştir. Bu çalışmada, mesleki balıkçılar avlanan levrek bireylerinin toplam ağırlığı 271,84 kg, 25 cm küçük bireylerin ağırlığı ise 12,62 kg olarak belirlenmiştir. Dolayısıyla, minimum av boyundan küçük bireylerin ağırlık oranı %4,64 'dür. Bu sonuçlar, bırakma olta ile levrek avcılığının minimum av boyu açısından mevzuatla uyumlu olduğunu göstermektedir.

Tablo 3. Türlere göre, yakalanan bireylerin minimum av boyundan küçük ve büyük olanlarını sayıca ve ağırlıkça oranı (* Yasal olarak minimum av boyu bulunmayan türler)

	Tür	Yasal Boy	Adet		Ağırlık (kg)	
			n	% n	w	%w
Hedef	*Dicentrarchus labrax*	< 25 cm	88	10.24	12,62	4,64
		≥ 25 cm	771	89,76	259,22	95,36
Hedef Dışı	*Sparus aurata*	< 20 cm	6	66.67	0.41	40.59
		≥ 20 cm	3	33,33	0,60	59,41
	Pomatomus saltatrix	< 18 cm	-	-	-	-
		≥ 18cm	5	100	2.32	100
	*Umbrina cirrosa**	-	2	-	1,12	-
	*Trichiurus lepturus**	-	11	-	1,64	-
	*Argyrosomus regius**	-	2	-	0,76	-
	*Belone belone**	-	2	-	1,39	-



Şekil 4. Levrek bireylerinin boy frekans dağılımı

Takip edilen 40 operasyonda toplam 4791 adet bırakma olta takımı denize bırakılmıştır. Bunlarda 43 (%0.89) tanesinde kesik köstek olduğu belirlenmiştir. Buna ek olarak, toplam 198 adet (%4.13) bırakma olta kaybolmuştur. Bir operasyonda kullanılan bırakma olta, kesik ve kayıp sayısı sırasıyla; 119,76±7.28, 1.06±0.33 ve 4.95±0.87 adet olarak belirlenmiştir.

Tartışma

Bu çalışmada elde edilen bulgular; Ekim ikinci yarısı ile Ocağın ilk yarısı arasında 15 günlük periyotlarda CPUE değerinin birbirine yakın olduğunu ancak Ocağın ikinci yarısındaki CPUE değerinin belirgin şekilde yükseldiği ve Şubatın ilk yarısında hızla düştüğünü göstermiştir. Burada akla gelen soru; CPUE değerinin Ocağın ikinci yarısında belirgin şekilde yükseldikten sonra Şubat ayında neden bu kadar hızlı düştüğüdür? Avcılıkta; av aracı ile hedef türün aynı ortamda bulunma ve hedef türün av aracı ile karşılaşması olasılığı av verimini etkileyen önemli iki parametrelerdir (Holst vd., 1998; Parrish, 1963). Levreklerin su sıcaklığının belli bir seviyenin altına düşmesi sonrasında kıyısal bölgelerdeki beslenme alanını terk ederek daha derine üreme göçü yaptığı ve Akdeniz’de Aralık ile Mart aylarında ürediği belirtilmiştir (Pérez-Ruzafa ve Marcos, 2014). Bu durum, levreğin Kasım, Aralık ve Ocak aylarında kıyısal bölgede bulunduğu ancak Şubat ayında üreme göçü yaptığı fikrini vermektedir. Bölgede levreğin üreme biyolojisi ve göç ekolojisi üzerine yapılmış bir çalışma olmadığından bu teoriyi doğrulamak güçtür. Ancak, elde edelin boy frekans dağılımından (Şekil 4) görülebileceği gibi, minimum av boyundan küçük birey sayısının oldukça az olması bu teoriyi desteklemektedir. Ancak bu durum Ocak ayının ikinci periyodundaki CPUE değerinin artışını açıklamamaktadır. Birçok türde üreme dönemi öncesinde ve sonrasında besin talebinin arttığı bilinmektedir (Argillier vd., 2012; Jardas vd., 2004; Özyurt vd., 2012). Ocak ayının ikinci periyodundaki CPUE değerinin yükselişi üreme göçü öncesinde levrek bireylerinin daha yoğun beslenmesinden kaynaklı olabilir. Nitekim bu durumda Şubat ayının ilk yarısında üreme göçü olduğu teorisini desteklemektedir.

Av araçları; av araçları arasında çatışma, kötü hava koşulları, operasyonel hatalar, deniz trafiği ve vandalizim gibi nedenlerle kaybolabilmektedir (Brown vd., 2005). Kayıp av araçlarının etkileri ise; hedef türleri avlamaya devam etmesi; hedef olmayan balık ve kabuklu türlerini avlamaya devam etmesi; diğer deniz canlılarının (fok, kaplumbağa ve su kuşları) ölümüne neden olması; çürüme esnasında deniz fauna ve florasını etkilemesi, bentik çevreye fiziksel olarak zarar vermesi, denizel alandaki plastik kirliliğini arttırması olarak sıralanabilir (Macfadyen vd., 2009). Elbette bu etkiler av aracının türüne, kaybolduğu bölgeye göre değişiklik göstermektedir. Bu çalışmada elde edilen sonuçlar kaybolan bırakma olta oranının %4.13 olduğunu göstermektedir. Ancak bu av aracının hangi sebeplerle kaybolduğu ya da kaybolduktan sonra hangi etkilere neden olduğu ile ilgili bir saptama yapılmamıştır. Buna karşın, bölgede daha önce farklı amaçlarla yapılan saha çalışmalarında; yeşil deniz kaplumbağalarının bırakma oltanın üzerindeki yemle beslenmeye çalıştığı, hatta bir operasyonda 1-3 adet bireyin olta iğnesine yakalanabildiği belirtilmiştir (Özyurt vd., 2019). Yeşil deniz kaplumbağaları genellikle herbivor olarak bilinseler de özellikle erken yaşam evrelerinde ominivor ve pelajik beslenme özelliği göstermektedir (González Carman vd., 2014). Dolayısıyla, oltanın ucunda asılı duran ölü ya da kaçamayan bir kefal bireyi, yeşil deniz kaplumbağaları için cezbedici bir besin kaynağı oluşturuyor olabilir. Buna ek olarak, bırakma oltaya yakalanan yeşil deniz kaplumbağalarının oltayı sürükleyerek başka bir alana taşıyabildiği de ifade edilmiştir (Özyurt vd., 2019). Yeri değişmiş bir bırakma oltayı balıkçının bularak geri alması çok zordur. Bu durum, belirlenen kayıpların bir kısmının bırakma oltalara yakalanan yeşil deniz kaplumbağalarından kaynaklı olabileceğini göstermektedir. Bırakma oltaya yakalanmış bir yeşil deniz kaplumbağasının normal yaşamsal faaliyetlerini (beslenme, göç vb.) sürdürmesi mümkün değildir. Bu ise kayıp nedeninin (yeşil deniz kaplumbağasının bırakma oltaya yakalanarak başka bir alana taşıması), aynı zamanda hassas bir türün ölüm nedeni olabileceğini göstermektedir. Bu bölgede, bir balıkçılık sezonunda kullanılan bırakma olta sayısının 67553 adet olduğu belirtilmiştir (Özyurt ve Köylü, 2024). Kayıp oranı %4.13 olduğundan, bir sezondaki kayıp bırakma olta sayısının yaklaşık 2800 adet olduğunu anlaşılmaktadır. Bu kayıp miktarının ne kadarının yeşil deniz kaplumbağalarından kaynaklı olduğu bilinmediğinden, bu sorunun boyutu hakkında yorum yapmak zordur. Ancak yine bu çevresel riskin göz ardı edilmemesi gerekir.

Bu çalışmada elde edilen sonuçlar; bırakma olta takımı ile levrek avcılığının üreme dönemi öncesindeki üç ayda yapıldığını, hedef dışı tür sayısının, miktarının oldukça az olduğunu ve boy seçiciliğinin yüksek olduğunu göstermiştir. Bu anlamda çevre dostu bir avcılık yöntemi olarak gözükse de, kayıp olan bırakma oltaların yeşil deniz kaplumbağalarına zarar verme olasılığı olduğu anlaşılmaktadır. Bu nedenle bırakma olta takımları kayıplarının nedenleri, yeşil deniz kaplumbağalarının takımı sürükleyerek başka alanlara taşıdığına ve türün ölümüne neden olup olmadığına yönelik çalışmalar yapılmalıdır.

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Yazarlar çıkar çatışması olmadığını beyan etmektedir.

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RESEARCH ARTICLE

The Growth and Survival of the European Lobster (*Homarus gammarus* Linnaeus, 1758) Larvae and Juveniles in a Recirculating System

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Wet diets

Abstract: In this study, the growth and survival of *H. gammarus* larvae and juveniles were investigated in two different consecutive trials. In the first trial, newly hatched lobster larvae were raised in 100 liter cylindro-conical tanks in triplicate. Each tank was stocked with 150 lobster larvae (a total of 450 larvae) and the growth and survival of larvae at the end of stage IV were determined. In the second trial, the growth and survival of juvenile lobsters fed on three different diets were determined for a period of 102 days using an integrated recirculating system with 10% daily water renewal. For this purpose, a total of 3 different diets including a mollusk based (M), a crustacean based (C) and a commercial seabass diet (L) were prepared. A total of 135 juvenile lobsters, 45 for each treatment were used for the juvenile growth trial. At the end of the larval growth experiment, the mean carapace and total length of Stage IV larvae were 5.255±0.052 mm and 13.027±0.486 mm, respectively, with no significant differences within tanks (p>0.05) and the mean survival rate of lobsters was 13.11%. In the juvenile growth trial, the highest carapace length was 1.371±0.023 cm in treatment C, followed by 1.251±0.039 cm and 1.187±0.095 cm in treatment M and L, respectively. At the end of 102 days, the mean survival rates of juvenile lobsters were 98.7%, 80% and 53.3% in treatments C, M and L, respectively. The most successful diet for juvenile lobsters, with respect to growth and survival, was the crustacean based diet. The findings of this study provide information to help improve the growth and survival rates of larval and juvenile *H. gammarus* in captivity.

Anahtar kelimeler:

Homarid ıstakoz
Decapod
Kanibalizm
Zoea larvası
Yaş yemler

Avrupa Istakozu (*Homarus gammarus* Linnaeus, 1758) Larva ve Jüvenillerinin Kapalı Devre Sistemde Büyüme ve Hayatta Kalmaları

Öz: Bu çalışmada, *H. gammarus* larva ve jüvenillerinin büyüme ve hayatta kalma oranları 2 farklı çalışma ile araştırılmıştır. İlk denemede yumurtadan yeni çıkmış ıstakoz larvaları biyolojik filtrasyon içeren kapalı devre bir sisteme entegre 100 litre hacminde 3 adet silindir-konik tank kullanılmıştır. Her bir tanka 150 adet yumurtadan yeni çıkmış larvanın kullanıldığı bu çalışmada (toplam 450 larva) larvaların büyüme ve hayatta kalma oranları IV evre sonuna kadar tespit edilmiş ve deneme larvalar IV. evreye ulaşınca sona erdirilmiştir. İkinci denemede farklı yemlerin jüvenil ıstakoz büyümesi ve hayatta kalması üzerindeki etkileri incelenmiştir. Büyüme denemesine larvalar bentik aşamaya geçtikleri IV. evreden sonra başlanmıştır. Bu amaçla mollusk (M) veya crustacea (C) içeren 2 farklı yaş yem ile ticari levrek yemi (L) olmak üzere toplam 3 farklı yem kullanılmıştır. Her bir uygulama için 45 adet olmak üzere toplamda 135 adet ıstakoz kullanılmıştır. Larval yetiştiricilik denemesinde IV. evre larvalarının ortalama karapaks uzunluğu ve toplam uzunluğu sırasıyla 5,255±0,052 mm ve 13,027±0,486 mm olarak tespit edilmiş ve tanklar arasında karapaks boyu ve toplam boy bakımından istatistiksel açıdan önemli bir fark bulunmamıştır (p>0,05) ve ortalama hayatta kalma oranı %13,11 olarak bulunmuştur. Istakoz jüvenillerinin büyütme denemesinde en büyük karapaks boyu 1,371±0,023 cm ile C ile beslenen grupta bulunurken, M ve L ile beslenen gruplarda karapaks uzunluğu sırasıyla, 1,251±0,039 cm ve 1,187±0,095 cm arasında değişiklik göstermiştir. 102 gün süren besleme çalışması sonucunda jüvenil ıstakozların ortalama hayatta kalma oranları, C yemiyle beslenenlerde %98,7, M yemiyle beslenenlerde %80 ve L yemiyle beslenenlerde %53,3 olarak bulunmuştur. Bu çalışmada elde edilen bulgular, *H. gammarus* larva ve jüvenillerinin yetiştiricilik şartları altında hayatta kalma ve büyüme oranlarının arttırılmasına yönelik katkı sağlamaktadır.

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Introduction

In Turkey, wild harvests of the European lobster, *H. gammarus*, have dropped considerably during the last two decades and amounted to 1.8 tons in 2022, a substantial drop from 25 tons in 2003 and 15 tons in 2008 (TÜİK, 2023 www.tuik.gov.tr). However, it is believed that lobster landings are much higher as the commercial lobster fishery in Turkey is mostly by scuba-diving and trammel nets therefore, the majority of lobster catches remains unreported. On the other hand, the development of larval culture methods for *H. gammarus* and their subsequent release to suitable habitats have provided a substantial supply of lobsters to the diminishing wild populations. In the last three decades, restocking programs of *H. gammarus* in Europe through hatchery production has become a successful model (Bannister et al., 1994; Agnalt et al., 2004). For example, on the east coast of England, released lobsters survived in the wild for up to eight years and have been caught in traps by commercial fishermen, with survival estimates of 50-84% (Bannister et al., 1994). In 1998, in southwestern Norway, following a restocking program up to 50-60% of the landings belonged to released lobsters contributing to the reproduction of the natural stocks (Agnalt et al., 2004). A similar management plan for diminishing native stocks of this species can be adopted for the Turkish seas. The recent establishment of mussel farms in northwest Turkey, i.e. in the Sea of Marmara and the Çanakkale Strait, may also provide a refuge by providing a valuable food source for the released lobsters in a no-fishing zone. In addition, in the last decade, reports are promising both for the land-based and sea-based culture systems for the commercial aquaculture of the European lobster (Drengstig and Bergheim, 2013; Daniels et al., 2015). There is currently no commercial-scale hatchery production of *H. gammarus* in Türkiye and therefore, efforts are required for developing hatchery culture methods for restocking purposes and to investigate the aquaculture potential of *H. gammarus*. Land or sea-based lobster aquaculture in Turkish waters may be advantageous due to relatively higher temperature regime throughout the year compared to northern climates.

Although well defined in the literature (Beard et al., 1985; Nicosia and Lavalli, 1999; Fiore and Tlusty, 2005; Ellis et al., 2015; Powell et al., 2017; Hinchcliffe et al., 2022), larval and juvenile lobster culture is still problematic due mainly to low survival rates during zoea stages, lack of effective grow-out systems, high production costs and slow growth (Daniels et al., 2015; Powell et al., 2017). Typically, larvae are reared in 60-100 L cylindro-conical tanks with an upwelling flow pattern using enriched *Artemia* or other plankton types with a stocking density of 50 larvae/L (Hinchcliffe et al., 2022). Lower stocking densities did not improve survival rates (Hinchcliffe et al., 2022; Önal and Baki, 2021). Survival in commercial hatcheries range between 5-20% (Hinchcliffe et al., 2022). and therefore, there is still room to develop successful and standardized methods for larval rearing.

A successful diet development is a crucial part of lobster grow-out operations for economic production. However, information on the nutritional requirements of the European lobster is relatively limited compared to the American lobster, *H. americanus* and spiny lobsters (Goncalves et al., 2020; Hinchcliffe et al., 2020). Although formulated dry diets offer several advantages such as reduced feeding and labor costs, nutritional consistency and sustainable production (Powell et al., 2017), wet feeds (fresh or frozen) such as mussel, krill and squid are preferred over dry diets for *H. gammarus* grow-out (Hinchcliffe et al., 2022). Efforts toward developing dry diets for juvenile European lobsters have resulted in lower growth and/or survival compared to wet or moist diets. For example, growth and survival of *H. gammarus* post-larvae fed on wet shrimp feed were significantly higher than those fed on dried feed ingredients (Hinchcliffe et al., 2020). Similarly, growth of *H. gammarus* juveniles were inferior when they were fed dry, formulated feeds containing 38.5-49.7% protein, 8.5-23.3% lipid and 20.97-34.69% carbohydrate compared to a krill control diet (Goncalves et al., 2020). High protein requirements (50%), along with benefits of carotenoids and chitin supplementation for better growth, survival and wild-type coloration in *H. gammarus* juveniles have been reported (Goncalves et al., 2020; Goncalves et al., 2022; Hinchcliffe et al., 2022). Further studies are required to elucidate nutritional requirements and develop standard feeding protocols for better lobster grow-out practices. Despite the obvious advantages of a formulated pelleted food in lobster culture, a formulated wet diet that supports the growth and survival of all stages of lobsters is still relevant for shedding light on the nutritional requirements and successful grow-out of lobster juveniles.

This study aims to investigate the growth and survival of *H. gammarus* larvae and juveniles in two consecutive trials. In the first trial newly hatched larval lobsters were cultured in 100 L cylindro-conical tanks with low stocking densities. In the second trial, early juveniles (stage V-X) were cultured using locally available feed ingredients. Local supply of feed sources is important in terms of sustainable production of lobsters. For this purpose, the performance of a high protein commercial seabass feed was compared to that of two wet diets containing either crustaceans or mollusks which are locally available. An important objective of the present study is to develop a feeding protocol that will result in high growth and survival rates of juvenile lobsters which will be an important roadmap for future grow-out studies.

Material and Methods

Experimental animals

The experiments were carried out in the Marine Resources Research Laboratory, Faculty of Marine Sciences and Technology, Çanakkale Onsekiz Mart University. (Dardanos, Çanakkale, Türkiye). Larvae were obtained from a single wild-caught ovigerous female caught by commercial fishermen using trammel nets in February 2022. Two experiments were carried out to determine the growth and survival rates of lobster larvae and juveniles. Water quality parameters were measured daily and included dissolved oxygen, pH, salinity and ammonia (NH_3).

Larval growth and survival experiment

Larvae were reared in a recirculating system, containing 100 L cylindro-conical tanks and a biofilter. Aeration was supplied with air stones to prevent larval settlement on the bottom of tanks and water stratification. The experiment was carried out in triplicate and 150 larvae were added to each tank corresponding a stocking density of 1.5 larvae/L. Densities <20 larvae/L can be considered as low density compared to typical higher stocking densities (>50 larvae/L) used in commercial lobster culture (Hinchcliffe et al., 2022). Larvae were fed with *Artemia* nauplii enriched with RotiGrow OneStep (Reed Mariculture, USA) for a period of 24 h after hatching. *Artemia* nauplii were maintained at a density of 3-5 individuals/ml during the day and no feeding was given between 18:00-09:00. Lighting was ambient with no overhead illumination. Fresh seawater exchange rate was 10% daily. Growth was monitored for each stage by measuring total length (TL) and carapace length (CL). The experiment was terminated once all larvae reached stage IV.

Juvenile growth and survival experiment

In a second experiment, growth and survival of juveniles fed on 3 different diets were determined for a period of 102 days. For this purpose, a crustacean based diet (C), a mollusk based diet (M) and a commercial seabass pellet feed (L) were used. Diets C and M were wet diets (moisture content > %60). Diet M composed of 50% mussel meat, 30% seabass pellet feed and 20% gelatin (w:w). Diet C only composed of 80% crustaceans and 20% gelatin. All ingredients were mixed together in a blender to form a wet paste and bound with gelatin. Wet diets were preferred over dry diets as preliminary experiments indicated higher acceptance of wet diets by lobster juveniles. Only larvae that reached stage IV within 5 days were pooled and used. Juvenile lobsters were kept separately to prevent cannibalism. For the growth study, juveniles were transferred to plastic boxes with 15 individual 4x6 cm compartments. Treatments were randomly assigned to each box (15 lobsters per box) with three replicate per treatment corresponding to a total of 45 juvenile lobsters per treatment. Juvenile lobsters were randomly allocated to compartments and allowed to acclimate for 2 days. Growth was monitored periodically (day 1, 18, 31 and 102) by measuring TL and CL throughout the experimental period. Daily ration was added to each compartment and the juvenile lobsters were allowed to feed for 4 hours. Uneaten feed was then removed from each container. The proximate nutritional compositions of diets are given in Table 1.

Table 1. The proximate nutritional compositions (%) of diets used in the juvenile grow-out experiment. C: crustacean based diet, L: seabass pellet, M: mollusc based diet

Diet	Protein	Lipid	Ash	Moisture
C	36.94±0.60	20.26±0.16	31.15±0.17	76.78±0.60
L	44.86±5.63	19.92±0.88	7.36±0.03	7.56±0.33
M	48.81±0.54	16.48±0.36	7.30±0.03	73.39±1.44

Statistical analysis

Data were analyzed using the statistical software package IBM SPSS Statistics for Windows (Version 19, IBM, Corp., USA). The suitability of data for ANOVA was checked by Bartlett's test for homogeneity. The growth and survival rates of lobsters were analyzed by ANOVA. Differences in growth and survival among treatments were compared using Tukey's HSD multiple range test ($p<0.05$).

Results

Larval growth and survival

Water quality parameters during the experimental period were as follows: Temperature ranged between 17 - 19.2 ºC; dissolved oxygen 7.8-8.3 ppm and salinity 32±1 ppt. NH_3-N levels were below 0.1 ppm.

The carapace and total length of larvae are given in Table 2 and 3. The initial carapace and total length of larvae were 2.602±0.157 mm and 8.094 ±0.118 mm, respectively, with no significant differences between tanks ($p>0.05$). Stage II larvae had a carapace and total length of 3.404±0.116 mm and 9.746±0.252 mm, respectively. Stage III larvae had a carapace and total length of 3.404±0.116 mm and 9.746±0.252 mm, respectively. The mean carapace and total length of Stage IV larvae were 5.255±0.052 mm and 13.027±0.486 mm respectively, with no significant differences between tanks.

The highest growth rate in CL was observed when larvae transformed from stage I to stage II (Table 2). Subsequent stages had lower growth. Changes in carapace length of larvae between stages I-II, II-III and III-IV were %30.8; %16.8 and %32.2%, respectively. Changes in TL were lower than those for CL (Table 3).

The survival rates of larvae at the end of the experiment differed between the tanks with a mean survival of 13.11%. Survival rates were 16.0, 15.3 and 8.0% for tank 1, tank 2 and tank 3, respectively.

Table 2. Changes in carapace length of lobster larvae at different stages

Stage	Tank 1	Tank 2	Tank 3	Mean ± SE
I	2.667±0.22	2.716±0.14	2.423±0.18	2.602 ±0.157
II	3.358±0.17	3.536±0.12	3.319±0.25	3.404±0.116
III	3.744±0.10	3.883±0.11	4.299±0.24	3.975±0.288
IV	5.299±0.28	5.197±0.22	5.269±0.16	5.255±0.052

Table 3. Changes in total length of lobster larvae at different stages

Stage	Tank 1	Tank 2	Tank 3	Mean ± SE
I	8.082±0.26	8.218±0.14	7.983±0.10	8.094 ±0.118
II	9.614±0.32	10.037±0.25	9.587±0.60	9.746±0.252
III	10.332±0.36	10.401±0.33	11.102±0.28	10.612±0.426
IV	13.012±0.69	12.548±0.48	13.520±0.58	13.027±0.486

Juvenile Growth and Survival

Water quality parameters during the experimental period were as follows: Temperature ranged between 17.0 - 19.5 ºC; dissolved oxygen 6.0-6.9 ppm and salinity 32±1 ppt. NH_3-N levels were below 0.1 ppm.

The overall mean initial carapace and total length of larvae were 0.545±0.007 cm and 1.466±0.018 cm, respectively, with no significant differences between treatments. Changes in carapace and total length of juvenile lobsters are given in Table 4.

There were significant differences between treatments 18 days after the start of the experiment (ANOVA; p = 0.0065). The lowest carapace length was 0.775±0.008 cm in treatment L which was significantly lower than that of treatment C (Tukey HSD test; p<0.05). There was no significant difference between treatments M and C with CL of 0.818±0.018 cm and 0.856±0.028 cm, respectively (Tukey HSD test; p>0.05).

There were significant differences between treatments 31 days after the start of the experiment (ANOVA; p = 0.0004). The lowest carapace length was 0.972±0.004 cm in treatment L. Treatment C had the highest CL of 1.030±0.013 cm which was significantly higher than those of other treatments (Tukey HSD test; p<0.05).

There were significant differences between treatments 102 days after the start of the experiment (ANOVA; p = 0.048). The highest mean CL was 1.347±0.023 cm in treatment C, followed by 1.253±0.039 cm and 1.251±0.039 cm in treatment L and M. The CL of treatment C was significantly higher than that of treatment L (Tukey HSD test; p<0.05), but there was no significant difference between treatment C and M (Tukey HSD test; p>0.05).

Table 4. Changes in carapace (CL) and total length (TL) of lobster juveniles fed with 3 different diets. R: Replicate; C: crustacean based diet, L: seabass pellet, M: mollusc based diet. Letters denote significant differences (p<0.05)

Day	T	R1		R2		R3		Mean CL ± SE	Mean TL ± SE
		CL	TL	CL	TL	CL	TL		
1	C	0.517	1.472	0.524	1.481	0.589	1.493	0.543 ±0.040^{a}	1.482 ±0.011^{a}
	L	0.543	1.467	0.561	1.496	0.512	1.448	0.539±0.025^{a}	1.470±0.024^{a}
	M	0.576	1.461	0.547	1.454	0.533	1.423	0.552±0.022^{a}	1.446±0.020^{a}
18	C	0.878	1.863	0.825	1.854	0.866	1.848	0.856±0.028^{b}	1.855±0.008^{a}
	L	0.784	1.793	0.771	1.745	0.769	1.734	0.775±0.008^{a}	1.757±0.031^{b}
	M	0.798	1.769	0.831	1.818	0.825	1.789	0.818±0.018^{b}	1.792±0.025^{b}
31	C	1.040	2.289	1.015	2.303	1.034	2.375	1.030±0.013^{b}	2.322±0.046^{a}
	L	0.968	2.147	0.972	2.166	0.976	2.185	0.972±0.004^{a}	2.166±0.019^{b}
	M	0.983	2.119	0.987	2.123	0.992	2.136	0.987±0.005^{a}	2.126±0.009^{b}
102	C	1.325	2.809	1.344	2.822	1.371	2.836	1.347±0.023^{b}	2.822±0.014^{a}
	L	1.269	2.581	1.209	2.518	1.282	2.591	1.253±0.039^{a}	2.563±0.040^{b}
	M	1.210	2.511	1.256	2.568	1.288	2.608	1.251±0.039^{ab}	2.562±0.049^{b}

There were significant differences in the TL of juveniles between treatments after 18 days (ANOVA; P=0.0061). The highest TL was 1.855±0.008 cm in treatment C, followed by 1.792±0.025 cm and 1.757±0.031cm in treatment M and treatment L, respectively. Total length of larvae in treatment C was significantly higher than those of treatments M and L (Tukey HSD test; $p<0.05$).

There were significant differences in the TL of juveniles fed on three different diets 31 days after the start of the experiment. The highest TL was 2.322±0.046 cm in treatment C which was significantly higher than those of 2.166±0.019 cm and 2.126±0.009 in treatment M and L, respectively (Tukey HSD test; $p<0.05$).

There were significant differences between treatments 102 days after the start of the experiment (ANOVA; p=0.002). The highest TL was 2.822±0.014 cm in treatment C, followed by 2.563±0.040 cm and 2.562±0.049 cm in treatment L and M, respectively. The total length of treatment C was significantly higher than those of other treatments (Tukey HSD test; $p<0.05$) and there were no significant differences between treatment M and L (Tukey HSD test; $p>0.05$).

The survival rates of juvenile lobsters were significantly different among treatments by the end of the experimental period. Juveniles fed on diet C had highest survival rate with 99.78%, followed by lobsters fed on diet M with 80% and those fed on diet L with 53.33% (Tukey HSD test; $p<0.05$).

Discussion

In this study, *H. gammarus* larvae were cultured in 100 L cyclindro-conical tanks in a recirculating system achieving a mean survival rate of 13% by stage IV. This survival rate aligns with reported values of 10-15% by previous researchers (Jørstad et al., 2009; Ellis et al., 2015). Enriched *Artemia* nauplii supported the growth of zoea stages and the growth of larvae up to stage IV was consistent with findings from other studies (Agnalt et al., 2013; Middlemiss et al., 2015; Powell et al., 2017; Önal and Baki, 2021). In an earlier study, Önal and Baki (2021) reported a survival rate of 3% using 800 L tanks with a larval density of 1.25 larvae/L. Similarly, lower stocking densities in the present study did not support higher survival rates which is in accordance with Hinchcliffe et al., (2022). Although the feeding regimes and stocking densities were similar between the two studies, considerably higher rates of survival obtained in this study may be due to the smaller volume of the culture tanks. Smaller tank volumes allow a better control of the tank environment in terms of water quality, prey density and distribution, turbulence and flow patterns compared to larger volumes. However, despite similar growth rates, survival rates in tanks ranged between 8-16%. Variations in survival rates between replicates are common in the culture of larval stages of fish and crustaceans and specific reasons for this varying success levels are usually unknown but may indicate differences in tank specific conditions. Since, progeny, nutritional composition, size of live prey (*Artemia* nauplii), prey abundance, feeding regime, illumination, flow rates, water quality and other aspects of overall husbandry practices were similar across all tanks, factors that are difficult to control such as turbulence and conspecific aggression might have contributed to lower survival rates. In fish larvae culture, for example, turbulent water flow reduced the likelihood of cod (*Gadus morhua*) larvae to successfully chase and ingest prey items in larval tanks (MacKenzie and Kiørboe, 2000). However, the raptorial feeding behavior of zoea larvae of *H. gammarus* is in contrast to ambush predation by fish larvae and turbulence, may in fact, facilitate larval lobster feeding through pelagic stages I-III by increasing chance encounter. A larval culture tank design that will maximize encounter and capture rates of prey with respect to turbulence may result in higher survival rates. In addition, a potential improvement in lobster larvae culture may be to maintain a prey density of 3-5 nauplii/ml throughout a 24 h period, particularly during the night because pelagic larvae exhibit active feeding behavior at night (Juinio and Cobb, 1992). Increasing survival rates of larvae remains to be an important challenge for mass production of lobster larvae.

The growth rates of larvae through stages I-IV were similar to those reported in earlier studies (Agnalt et al., 2013; Middlemiss et al., 2015; Powell et al., 2017; Önal and Baki, 2021). Slight differences in growth rates observed with respect to the carapace length and total length is due to the curvature of the abdomen and flexion of abdominal segments which result in differences when taking measurements. Therefore, carapace measurements have inherently lower variations and is a better indicator of growth in early stages of lobster development. In this study, there were differences in growth rates of lobster larvae based on carapace length between consecutive stages (16.8-32.2% through stages I-II, II-III and III-IV). Similar differences in growth rates between stages were reported by other researchers (Agnalt et al., 2013; Önal and Baki, 2021). However, Middlemiss et al. (2015) reported similar rates of changes in carapace length through stages I-IV. Discrepancies between growth rates in succeeding stages may be a factor of prey quality and quantity and may and indicate suboptimal conditions in the culture tank.

The lack of suitable artificial diets has been considered as a major bottleneck for lobster culture (Powell et al., 2017; Hinchcliffe et al., 2020; Goncalves et al., 2021). However, similar to fish larval culture, formulated dry diets inherently resulted in lower growth and survival rates in *H. gammarus* and *H. americanus* juvenile culture (Conklin et al., 1975; Ali and Wickins, 1994; Goncalves et al., 2020). In this study, a crustacean based wet diet (diet C) resulted in higher growth and survival rates in juvenile lobsters compared to those of other diets (diets L and M) containing non-crustacean ingredients. The higher growth of lobster juveniles fed on diet C was noticeable 18 days after the start of the trial and this trend was consistent throughout the experimental period. However, growth rate exhibited a decreasing trend in all treatments throughout the experimental period. A decreasing trend in growth rates may indicate sub-optimal feeding rate, compartment size limitations or undetected water quality problems. In the present study, juvenile lobsters fed on a commercial seabass pellet feed with a relatively higher protein and lipid contents (44.86%±5.63 and 19.92±0.88, respectively) had the lowest growth and survival rates and proved that this diet did not meet the nutritional requirements of juveniles when fed alone. The mollusk based diet, on the other hand, performed slightly better than the seabass pellet in terms of growth but performed considerably better in terms of survival rates. Both the crustacean based diet and the mollusk based diets performed well in terms of growth and survival for early juveniles. The crustacean based diet supported the growth and survival of juvenile lobsters and only 1 individual out of 45 died during the experimental period of 102 days. The lower protein content of the crustacean diet (36.94%±0.60) compared to those of other diets did not result in reduced growth rates and survival. Similarly, Conklin et al. (1975) suggested a protein requirement of 30% for the American lobster, *H. americanus*. given sufficient non-protein sources in their diet. In contrast, previous studies on dietary requirements of *H. gammarus* suggested higher protein requirement for juveniles (Goncalves et al., 2020; Hinchcliffe et al., 2020; Powell et al., 2017). In the present study, higher growth and survival of juveniles fed on diet C with lower protein level may also indicate that nutritional factors other than protein plays an important role for *H. gammarus* juveniles. For example, chitin along with calcium carbonate and protein was considered as an important component of crustacean shells (No and Meyers, 1995). Dietary supplementation of chitin and its derivatives such as glucosamine were shown to increase survival in crustaceans (Powell and Rowley, 2007; Niu et al., 2013) and *H. gammarus* juveniles (Hinchcliffe et al., 2020; Goncalves et al., 2022). Although chitin and astaxanthine levels were not measured in the experimental diets, both chitin and astaxanthine levels are expected to be much higher in the crustacean diet as indicated by the higher ash content. This finding supports those of earlier reports and indicates that dietary chitin is crucial for juvenile lobster growth and survival (Powell and Rowley, 2007; Niu et al., 2013; Goncalves et al., 2022).

Although, wet diets hold the promise of higher growth and maintaining the natural coloration of cultured lobsters, potential drawbacks such as presentation and delivery of wet or semi-moist feed particles and higher leaching rates should be investigated. The use of different binders may also offer effective solutions to develop better wet/moist diets for juvenile lobsters. Despite the higher growth of juvenile lobsters with wet diets in the present study, optimization of the nutritional contents and intrinsic properties of feed particles along with husbandry protocols and technical and economic aspects of maintaining larger size lobsters are the major obstacles that needs to be addressed in future studies for land-based lobster aquaculture.

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Conflict of Interest

The authors declare no conflict of interest

Author Contributions

Enes Osman carried out all experiments and measurements, analyzed the data and wrote the manuscript. Umur Önal conceived and planned all the experiments and contributed to statistical analyses and interpretation of the results and commented on the manuscript.

Ethics Approval

This research did not need ethical approval as it involved experimental procedures on a decapod crustacean.

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RESEARCH ARTICLE

Community Structure of Gurnards in Relation to Different Environmental Variables in Antalya Gulf

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Abstract: Fish assemblages have not been studied at the family level using comprehensive environmental variables. Ecological studies focusing on spatiotemporal density (abundance and biomass) and morphometry (size and inter-traits relationships) of fish species have been highly limited in the Mediterranean Sea, particularly in the Turkish Levant coast. Gurnards (Family: Triglidae) have received little attention in ecological research. In the present study, in order to outline the spatiotemporal dynamic of density and morphometry in space (region and bottom depth) and time (season) alongside environmental parameters, gurnards collected seasonally from a study conducted on shelf/shelf break of the Antalya Gulf in 2014-2015 (de Meo et al. 2018) were studied. A total of 79 stations were sampled in year period (22 stations in May, 17 in August, 21 in October and 19 in February). Of the total stations, occurrence of the gurnards in stations varied between 4 (*Trigla lyra*) and 34 (*Lepidotrigla cavillone*). The gurnards were represented by six species in Antalya Gulf. In general, the small-sized specimens (*L. cavillone* and *L. dieuzeidei* < 15 cm) outnumbered the larger specimens (*Chelidonichthys lucerna, C. cuculus, C. lastoviza* and *T. lyra*) in the gurnard population. The species were significantly differentiated by the bottom depth, followed by the depth-gradient environment. Shallow water, middle shelf and deeper water species were distinguished among the six species. The gurnards avoided the seagrass meadows. Only *Chelidonichthys lastoviza* was found close to the meadow beds. Small-sized species had more abundance than large-sized species on bare bottoms. Large-sized species exhibited greater sizes in eutrophic areas compared to those in oligotrophic areas, whereas small-sized species had similar sizes in both trophic states, leading to differences in their growth types. Overall, females outnumbered the males for all species and the species exhibited a size-dependent sexual dimorphism with the females being longer and heavier than the males. Assemblage of six gurnard species was correlated with depth, thus bottom type (coarse to fine material of sediment from coast to open water) and chl-*a* and fine bioseston. With respect to fish-epibenthic fauna relation, the gurnard community was correlated primarily with Decapoda and Holothuroidea and secondarily with Crinoidea, followed by Ophiuroidea. The gurnards were distributed specifically at different depths of the shelf/break, preferring bare bottoms in general with depth-graded environment in space and time.

Anahtar kelimeler:

Kırlangıç balıkları
Yoğunluk
Balık karakterleri
Mekansal-zamansal ekolojik dağılım
Levantin Denizi

Antalya Körfezi'ndeki Farklı Çevresel Değişkenlere Bağlı Olarak Kırlangıç Balıklarının Topluluk Yapısı

Öz: Balık toplulukları kapsamlı çevresel değişkenlerle familya düzeyinde incelenmemiştir. Balık türlerinin mekansal-zamansal yoğunluğunu (bolluk ve biyokütle) ve morfometrisini (boyut ve aralarındaki ilişkiler) belirlemek için ekolojik çalışma Akdeniz'de, özellikle Türk Levant kıyılarında oldukça sınırlı olmuştur. Ekolojik çalışma için göz ardı edilen balık familyalarından olan Triglidea'dır. Mekansal (bölge ve dip derinliği) ve zamansal (mevsim) yoğunluk ve morfometrinin mekansal-zamansal dinamiklerini çevresel parametrelerle özetlemek için, 2014-2015 yıllarında Antalya Körfezi'nin kıta sahanlığı/sahan kırığında yürütülen bir çalışmadan mevsimsel olarak toplanan kırlangıç balıkları değerlendirilmiş ve ardından istatistiksel analizler kullanılarak yorumlanmıştır (de Meo ve vd. 2018). Yıl içindetoplam 79 istasyon örneklendi (22 istasyon Mayıs'ta, 17 istasyon Ağustos'ta, 21 istasyon Ekim'de ve 19 istasyon Şubat'ta). Toplam istasyonlarda, gurnard balığının varlığı 4 (*Trigla lyra*) ile 34 istasyon (*Lepidotrigla cavillone*) arasında değişti. Kırlangıç balıkları Antalya Körfezi'nde altı türle temsil edilmiştir. Genel olarak, kırlangıç balık türü popülasyonunda küçük boyutlu türler (*L. cavillone* ve *L. dieuzeidei* < 15 cm) büyük türlerden (*Chelidonichthys lucerna, C. cuculus, C. lastoviza,* ve *T. lyra*) sayıca daha fazlaydı. Örnekler, dip derinliğine, ardından derinlik bağlı çevresel parametrelere göre önemli ölçüde farklılaşmıştır. Altı tür arasında sığ su, orta sahan ve daha derin su türleri ayırt edilmiştir. Kırlangıç balıkları çayırlık alandan uzak kaldı. Çayır yatağına yakın sadece *Chelidonichthys lastoviza* bulundu. Çayırların bulunmadığı çıplak dipte, küçük boylu türler büyük boylu türlerden daha fazla bolluğa sahipti. Daha büyük boylu türler ötrofik alana kıyasla oligotrofik alanda daha küçük boyuta sahipti, ancak küçük boyutlu türler karşılaştırmalı olarak benzer aralıklarda ölçüldü, bu da karşılaştırmada büyüme tipini değiştirdi. Genel olarak, tüm türlerde dişi bireyler erkeklerden daha fazlaydı ve türler boyut olarak eşeysel dimorfizme sahipti; dişi bireyler erkeklerden daha uzun ve daha ağırdı. Altı kırlangıç balığı türünün topluluğu dip derinliğiyle, dolayısıyla dip tipi (kıyıdan açık su tabanına kadar sedimanın kaba ila ince malzemesi) ve chl-*a* ve ince biyosestonla ilişkilendirildi. Balık-epibentik fauna ilişkisi açısından, kırlangıç balık topluluğu öncelikle Decapoda ve Holothuroidea ile ve ikincil olarak Crinoidea ile, ardından Ophiuroidea ile ilişkilendirildi. Kırlangıç balıkları, kıta sahanlığın/kırığın farklı derinliklerine tür bazında dağılmış olup, genel olarak mekansal ve zamansal dip derinliği bağlı çevre ile çıplak dipleri tercih etmektedir.

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Introduction

Besides their worldwide occurrence in temperate and tropical marine waters (about 114-125 triglid species belonging to 8 genera) (Colloca et al., 2019; Dobroslavić et al., 2021), the sea robins or gurnards are widely distributed in the Mediterranean Sea, represented by eight species. They are found on the shelf and shelf slope (Colloca et al., 2019). Gurnards have been valued commercially and also are considered by-catch and discard fish in some cases (Machias et al., 2001). Concerns on commercial gurnard fisheries are minimal, with only large specimens caught as by-catch being valued for food (Colloca et al., 2019). The gurnards inhabit sandy and muddy bottoms and feed mainly on epibenthic fauna (Platella and Potter, 1999). Therefore, from an ecology standpoint, studying gurnards' feeding behavior is important to study prey-predator interaction (Platella and Potter, 1999), spatiotemporal density and morphometry distribution in different locations. Recently, Colloca et al., (2019) highlighted the significance of gurnards with respect to their spatiotemporal distribution in the western Mediterranean Sea, noting that the abundance of coastal species has been declining compared to the deep-dwelling gurnards over the past 2 decades.

Understanding the life history patterns of fish species is crucial for effective fisheries management across different temporal and spatial scales. The main factor which affects the local distribution and abundance patterns of fish assemblages in space and time is the bottom depth inducing different bottom type and seasonal hydrography of the water column and food availability (e.g. Demestre et al., 2000; Kallianiotis et al., 2000; Araújo et al., 2002; Katsanevakis et al., 2009). All these factors are well known to influence the distribution of density and size traits of the gurnards (Colloca et al., 2003).

Levantine Basin, one of the largest Mediterranean basins under the influence of climate chance, is characterized by high temperature and the "tropicalization" of the subtropical climate, inducing high salinity and extreme oligotrophy (Sisma-Ventura et al., 2017). Climate related changes could reduce discharge rates of some rivers feeding the Levantine basin, located in the eastern Mediterranean Sea. Gulf of Antalya is one of the ultra-oligotrophic regions of the eastern Mediterranean Sea (Sisma-Ventura et al., 2017) and is impacted by the introduction of non-indigenous species primarily via Suez Canal, followed by the Atlantic rim current and ballast waters. The Turkish coastal area, Antalya, Mersin and Iskenderun harbors in particular, has economical and strategical importance and is under the pressure exerted by the inputs of organic material and chemical pollutants derived from intense urbanization, maritime, touristic and agricultural activities (Polat-Beken et al., 2009; de Meo et al., 2018).

In the Mediterranean Sea and its basins, gurnards have been studied in terms of their spatial or temporal or both spatial and temporal distribution of demersal catch values using specimens considered as by-catch or discard fish (e.g. Machias et al., 2001; Damalas et al., 2010; Ordines et al., 2014; Farriols et al., 2017; Colloca et al., 2019). Gurnards were also studied for their population growth dynamic parameters (e.g. Papaconstantinou, 1984, 1986; İşmen et al., 2004; İlhan and Toğulga, 2007; Ragonese and Bianchini, 2010; Türker et al., 2010; Mehanna, 2022; Şirin et al., 2024) and population structure (e.g. Tsimenides et al., 1992; Terrats et al., 2000; Merigot et al., 2007; Massuti and Renones, 2005; Ihsanoglu et al., 2016). Majority of the studies focused on a single species, overlooking the interaction among other gurnard species collectively. Some researchers studied diet (Caragitso and Papaconstantinou, 1994; Terrats et al., 2000; Boudaya et al., 2007; Stagioni et al., 2012; Montanini et al., 2017; İlhan 2019) and reproduction (e.g. Boudaya et al., 2008; Dobroslavić et al., 2021) of the gurnards. Numerous other studies have analyzed the distribution patterns of fish communities in the Levantine Sea, but their ecological interactions have barely been outlined regarding density and size of specimens in space and time. However, ecological studies on fishes are highly limited in the literature, and the studies were conducted in a wide range of the stratified bottom depths without considering certain specific environmental variables in relation to the fish community. Fishery biologists measured generally basic physical parameters (temperature and salinity of the water). With limited environmental variables such CTD (temperature and salinity), the first ecological study performed on gurnards was conducted in the Cretan waters (Tsimenides et al., 1992). In Turkey, only few studies on the ecology with comprehensive environmental parameters are available (de Meo et al., 2018). Ecological studies at the fish family level are important because they highlight the ecology of a specific family, unaffected by the species of other families. This approach reflects the ecological patterns of the most abundant and dominant fish species within the same study. (Mutlu et al., 2021, 2022b, e, f).

Regarding the density and morphometry, the objective of the present study was to investigate the spatial and temporal structure of gurnard assemblages found over the shelf of Antalya Bay and to determine their response to various environmental variables.

Material and Methods

Details of fish sampling and environmental parameters are given in a paper published by de Meo et al., (2018). Briefly, specimens of the family Triglidae were collected using an otter bottom trawl (mesh size 44 mm in diamond, head rope length: 35 m) from the continental shelf and shelf break of Gulf of Antalya, Türkiye. The temporal trawl samplings were conducted in May, August, October 2014 and February 2015 to study the density of the species in space and time. Spatial samplings were performed in three different transects (R1, R2 and R3) each having a bottom depth of 10, 25, 75, 125 and 200 m and one riverine coastal transect (R4) on the shelf and one of the transects was located in non-fishing zone (R3) (Fig. 1). Furthermore, there were two shelf break sampling stations located on a bottom depth of 300 m, one for R3 (non-fishing zone), and one for pooled region of R1-R2 (fishing zone). Trawl sampling duration was 30 minutes. After recovery of the trawl on board of R/V "Akdeniz" from each sampling, the fish and other materials were sorted, identified, and number of individuals and total weight were determined on board. For laboratory work, the significant parts of the total catch were frozen at -18 ^oC. but when in doubt, further detailed identification was performed in the laboratory (de Meo et al., 2018).

After each trawl operation, the environmental parameters were recorded and analyzed for ecological studies. The parameters were composed of physical (sea surface and near-bottom temperature, salinity, density, pH and dissolved oxygen), chemical (chlorophyll-*a*, suspended matter: seston, tripton and bioseston in three size fractions separated using sieves of 1, 0.5 and 0.063 mm), and optical (Photosynthetically Active Radiation and Secchi disk depth) measurements and materials. Furthermore, bottom types of sampling ground were determined using a scientific echo sounder by a software of Visual Bottom Typer, VBT (BioSonics inc.). Details of the environmental parameters measurements and analyses were given in a paper published by de Meo et al., (2018).

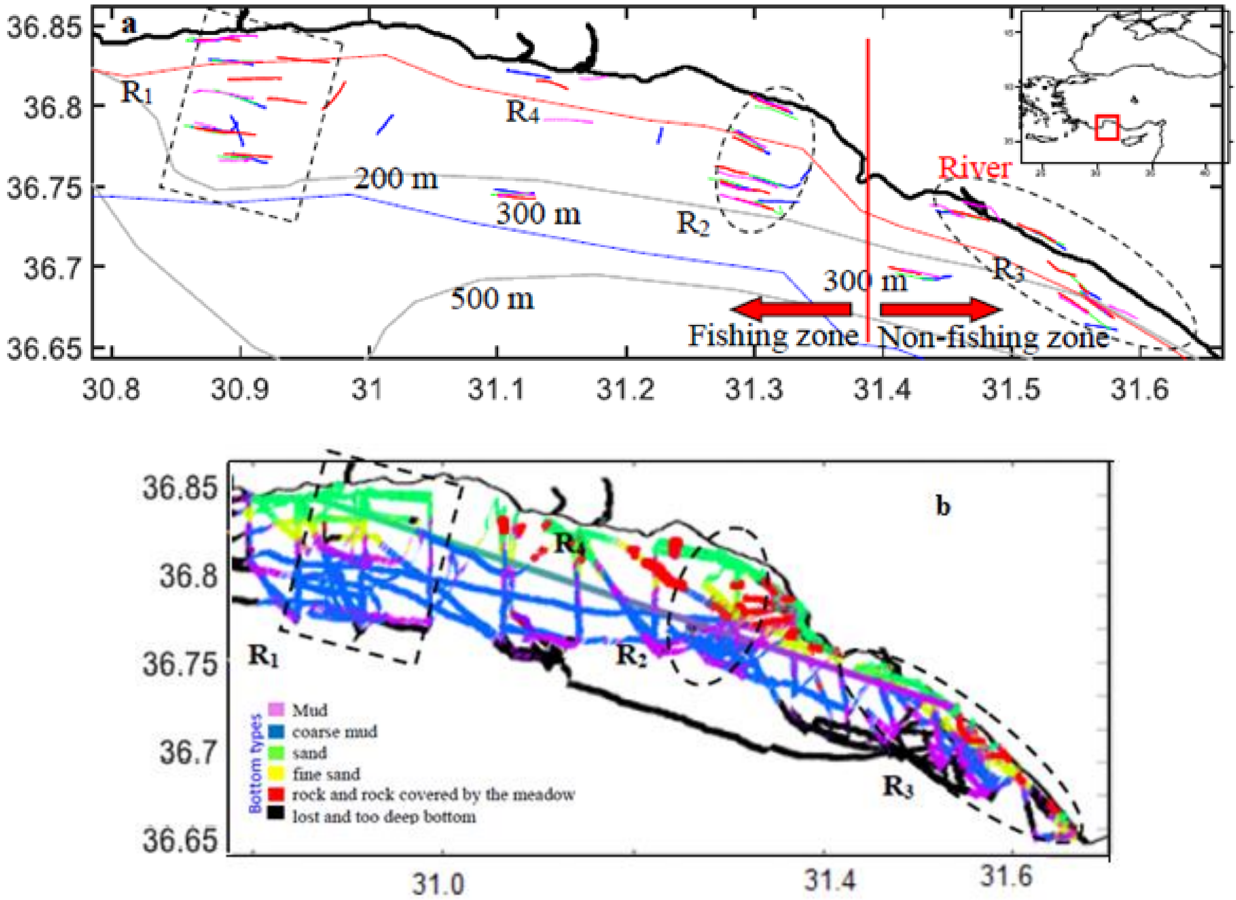

Figure 1. Seasonal trawl sampling track lines during 2014–2015 (blue; spring 2014, green; summer 2014; red; autumn 2014 and magenta; winter 2015), and two miles border for prohibition of the fishery, red line and 12 miles border, blue line, and fixed depths are in the order of the shallowest to the deepest bottom depths from the coast to open water seaward in each of regions (R1-R3) (a), and the study area showing different bottom types (BT) from the acoustical track lines by the echo sounder in 2014–2015 (b) (from Garuti and Mutlu 2021).

The catch data of each fish species were then converted to biomass (kg/km^2) and abundance (ind/km^2) taking the trawling distance converted from GPS data and trawl effective width (35 m * 0.5; 0.5 is a constant suggested by Pauly, (1980). In addition to weight and number of individuals, individual total length and weight of were recorded in a precision of mm and 0.0001 g, respectively. Sex was determined from gonads. Sex ratio was calculated using female (F)/Male (M).

For statistical analyses, univariate analyses and multivariate analyses were used to determine faunal assemblage and fauna-environment relation. Univariate analyses were used for assessing dominance (DO% equal to number of stations with occurrence of the species / total station number*100), frequency occurrence (FO%), numerical occurrence (NO%) (Holden and Raitt 1974), and Soyer index was used for the determination of constant DO%>50), common (25≤DO%≤50) and rare (DO%<25) species in the study area (Soyer, 1970). Univariate analyses were used also for estimating length distribution and histograms, length-weight relationship (power fit regression and Pearson correlation) and their sexual difference (Analysis of Covariance: ANOCOVA), significance (student t-test), difference in abundance, biomass, length weight and sex ratio among the transect, season and bottom depths (Three and One -way Analysis of Variance: ANOVA) and growth type (t-testing difference of estimated slope from an isometric growth, value 3). The post-hoc test (LSD, least significant difference) was then applied to each variable separately for each factor (way). The data was checked for random distribution, taking the mean-variance dependence into account for each factor (way) (FAO, 1991), and then, the data was log10-transformed before any statistical analyses. A COST function (Shimazaki and Shinomoto 2007) was applied to length data to estimate the optimal bin size (size class). Accordingly, the empirical methods for the bin size selection in a bar graph histogram in an order are as follows : i) estimation of the number of sequences required for the histogram, and ii) estimation of the scaling exponents of the optimal bin size were corroborated by theoretical analysis derived for a generic stochastic rate process by dividing the observation period T into N bins of width Δ from the measurement (iii), and counting the frequency (k_i) of ith bin size (iv), and then constructing the mean and variance of the number of k_i (v) before repeating that computing the cost function changing the bin size Δ to search for minimum $C\Delta*$ (vi) which is the optimum bin size for the measurement. Thereafter, Kernel Density Function (KDF) was applied to the length-frequency data to determine the length cohorts. The choice of interval width (bin width/band width) is one of the central problems in density estimation within discriminated growth cohorts. There are several ways to select an appropriate bin width for histograms; frequency polygons, or averaged shifted histograms and a bandwidth for the KDF. The KDF are superior at recovering interesting structure (Scott, 1979). All statistical analyses were performed using the statistical tool of MATLAB (R2021a, MathWorks, Inc.). The length frequency plot of three abundant gurnard species was formed using FISAT II software (vers. 1.2.2., Gayanilo and Pauly 2001).

A data matrix of the gurnard abundances was subjected to canonical correspondence analysis (CCA) to cluster the stations to estimate the gurnard species-environment relation and the gurnard species-mega benthic fauna (Garuti and Mutlu 2021; Patania and Mutlu 2021) relation using CANOCA (VER 4.5.). According to high explained variance in total, CCA1 and CCA2 elucidating best the relationships were taken into account of the cluster estimation. In the present study, all statistical tests were significantly accepted at $p < 0.05$.

Results

In the shelf and shelf break waters of Antalya Gulf, specimens of family Triglidae were represented with six species (Table 1). The most encountered species were *Lepidotrigla cavillone* and *Trigloporus lastoviza* (accepted valid name as *Chelidonichthys lastoviza*), and both species were assigned as common species according to Soyer index (Soyer, 1970). However, there was no constant gurnard species in the study area (DO%>50) (Table 1). The rest of the species were considered as rare (DO%<25) (Table 1).

Table 1. Annual percent dominance (DO%), frequency of occurrence (FO%) and numerical occurrence in abundance (NO%) and biomass (BO%) of gurnards and all species (165 species caught during the present study) and catch amount in average ± standard deviation (Avg±SD) and maximum abundance: Max (A in ind/trawl) and weight (B in kg/trawl). Tot denotes total number of individuals captured with trawl for each species.

Species		Triglidae species				All species			Catch in A			Catch in B	
	Abb.	DO%	FO%	NO%	BO%	FO%	NO%	BO%	Avg±SD	Max	Tot	Avg±SD	Max
Chelidonichthys cuculus (Linnaeus, 1758)	*Ccuc*	7.59	6.32	2.71	3.19	0.12	<0.01	0.08	27±202	1792	100	0.51±3.86	34.17
Chelidonichthys lucerna (Linnaeus, 1758)	*Cluc*	17.72	14.74	1.16	2.48	0.12	<0.01	0.07	11±35	211	44	0.39±1.29	9.96
Lepidotrigla cavillone (Lacepède, 1801)	*Lcav*	43.04	35.79	65.65	53.44	0.29	0.03	1.42	644±2485	16060	1752	8.45±32.48	217.03
Lepidotrigla dieuzeidei Blanc & Hureau, 1973	*Ldie*	16.46	13.68	17.59	19.74	0.29	0.01	0.52	173±657	4737	595	3.12±13.92	108.93
Trigla lyra Linnaeus, 1758	*Tlyr*	5.06	4.21	3.54	2.78	1.94	1.23	0.07	35±238	2064	83	0.44±2.97	25.80
Chelidonichthys lastoviza (Bonnaterre, 1788)	*Tlas*	30.38	25.26	9.35	18.37	1.94	3.25	0.49	92±251	1393	255	2.91±8.28	43.41

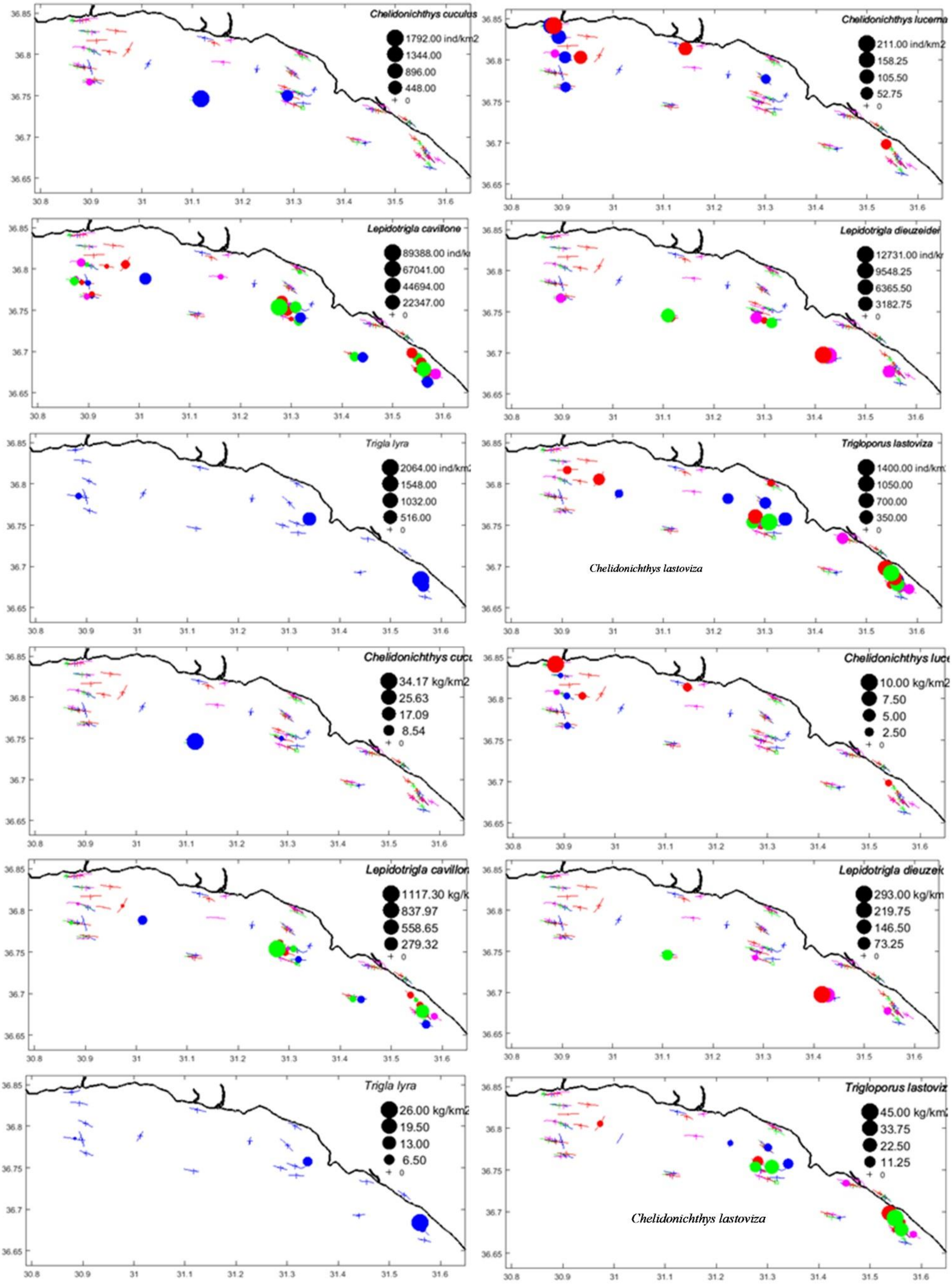

Figure 2. Spatiotemporal distribution of abundance (ind/km^2) (upper panel) and biomass (kg/m^2) (lower panel) of the gurnard species. Color of circle shows season (Blue denotes May, red August, green October and magenta February)

The species with the highest frequency of occurrence (FO%) was the same as the most commonly encountered species within the gurnard family. The abundance of gurnards was, in general, very low among all 165 species (Table 1).

The most abundant species (NO%) was *Lepidotrigla cavillone*, followed by *Lepidotrigla dieuzeidei*. Numerical occurrence of gurnards in abundance (NO%) and biomass (BO%) among all species was also very low (NO%<3.3%) (Table 1).

Temporal and spatial variations of CPUE

Bottom depth segmentation was observed for the distribution of the gurnard species on the shelf-shelf break zone (Fig. 2). There were species found at shallow and middle shelf water; *Chelidonichthys lucerna* was distributed at 10-75 m, ubiquitous shelf species; *C. lastoviza* at 10-200 m, deep shelf species: *T. lyra* at 100-125 m, and deep shelf/break species; *C. cuculus* at 125-300 m and *L. dieuzeidei* at 200-300 m, and ubiquitous shelf/shelf break species; *L. cavillone* at 10-300 m (Table 2, Fig. 2).

The maximum abundance among gurnards varied between 211 ind/km^2 (*C. lucerna*) and 89388 ind/km^2 (*L. cavillone*), followed by 12731 ind/km^2 (*L. dieuzeidei*) (Fig. 2). Catch amount was also similar to the abundance distribution. *C. cuculus* and *C. lucerna* dominated the R1, the rest of the species occurred abundantly in R2 and R3 (Table 2, Fig.2).

The regional significant difference in abundance was estimated only for *C. lucerna* which had higher abundance in R1 than R2 and R3 ($p < 0.05$; Tables 2-3, Fig. 2). However, there was no significant seasonal difference in the abundance of each gurnard species (Tables 2-3, Fig. 2). Seasonal mean abundance varied between 0.6 ind/km^2 (*C. lucerna*) and 640 ind/km^2 (*L. dieuzeidei*) (Table 2, Fig. 2). The maximum seasonal abundance of *C. cuculus* was estimated in May, *C. lucerna* in May and October, *L. cavillone* in August and October, *L. dieuzeidei* in October and February and *C. lastoviza* in August (Table 2, Fig. 2). Depth-wise difference in abundance was significantly assessed only for *L. dieuzeidei* and *C. lastoviza* ($p < 0.05$; Tables 2-3, Fig. 2). The maximum depth-wise abundance of *C. cuculus* was estimated at 300 m, *C. lucerna* at 10 m, *L. cavillone* at 100-125 m, followed by 75 m, *L. dieuzeidei* at 300 m and *C. lastoviza* at 50 m, followed by 75 m (Table 2, Fig. 2).

Maximum catch in weight was found for *L. cavillone* (53.4% of BO%) with a mean of 8.45±32.48 kg/trawl, followed by *L. dieuzeidei* (19.7% of BO%) with 3.12±13.92 kg/trawl (Table 1). Regional difference in biomass occurred only for *C. lastoviza*, and no seasonal difference was observed for any of the gurnard species. Depth-wise difference was observed for *L. dieuzeidei* and *C. lastoviza* at $p < 0.05$ (Table 3). Maximum biomass was estimated for *L. cavillone* and then *L. dieuzeidei* (Fig. 2). The lowest maximum biomass was estimated for *C. lucerna* and followed by *T. lyra* (Fig. 2). Regional, seasonal and depth-wise distributions of gurnard biomasses were similar to the corresponding distribution of the abundance.

Sex distribution in space and time

Overall, female specimens outnumbered the males (Table 2, Fig. 3). Female abundance was significantly different among the regions for *C. lucerna*, and depth-wise difference in female abundance was present for only *C. lastoviza* and *L. dieuzeidei* ($p < 0.05$; Tables 2-3, Fig. 3). However, there was no significant seasonal difference in the abundance of female specimens. Regarding to males, there was only depth-wise significant difference, and this difference was estimated for only three gurnard species ($p < 0.05$; Table 3).

Female/male abundance ratio showed that females predominated in the population and varied between 2.25 and 5.44 for *C. cuculus*, between 0.56 and 1.56 for *C. lucerna*, between 0.25 and 2.83 for *L. cavillone*, between 0.68 and 4.10 for *L. dieuzeidei*, and between 0.08 and 6.65 for *C. lastoviza* (Table 2, Fig. 3). However, all specimens of *T. lyra* were determined as females (Fig. 3).

Morphometry distribution in space and time

Length of the six gurnard species ranged from 4 cm to 24.9 cm (*Chelidonichthys cuculus*), followed by 24.7 cm (*Chelidonichthys lastoviza*), and weight from 0.78 g (*Chelidonichthys cuculus*) to 142.18 g (*Chelidonichthys lastoviza*). In general, the small-sized specimens (< 15 cm) outnumbered the larger specimens in the gurnard population (Figs. 4-6).

COST function and Kernel Density Function (KDF) estimated number of length cohorts as 4+ (*Chelidonichthys cuculus*), 1+ (*Chelidonichthys lucerna*), 4+ (*Lepidotrigla cavillone*), 4+ (*Lepidotrigla dieuzeidei*), and 3+ (*Chelidonichthys lastoviza*) for each species (Fig. 4). Notably, number of specimens induced precision in the estimation of cohort. For instance, Fig. 5 showed a clear separation in the estimation of length cohorts for three abundantly found species: 4+ for *L. cavillone* and 6+ for *C. lastoviza* (Fig. 5). However, there was no clear length cohort discrimination with and exception of samples in February for *L. dieuzeidei* (Fig. 5).

Table 2. Mean± standard deviation (SD) of the biomass (B in kg/km^2), abundance (A in ind/km^2) of combined specimens, females (F) and males (M), female/male abundance ratio (F/M), length (L in cm) and weight (W in g) in space (region and bottom depth) and time (season) and sex only for L and W. ID: insufficient data for the statistical analyses of the species (see Fig. 2), and empty cells denote no occurrence of specimens at the factor (see Fig. 2)

Species	Factor	B	A	F	M	F/M	L	W
C. cuculus								
Region	R1	1.32±0.75	69.6±39.9	0.5±0.3	0.3±0.1	1.6± 0.2	12.8±0.6	25.7±3.5
	R2	0.08±0.80	7.7±42.4	0.1±0.3	0.1±0.1	1.0± 0.2	9.2±1.1	11.3±6.4
	R3						22.5±2.2	100.2±12.9
Season	M	1.63±0.82	88.8±43.0	0.7±0.3	0.3±0.1	3.84±1.59	11.3±0.5	19.5±3.6
	A			0.1±0.3	0.1±0.1	1.0± 0.2	19.8±1.3	71.6±8.6
	O	0.01±0.84	0.7±44.1	0.04±0.3			12.1±3.1	16.1±19.4
	F	0.02±0.88	1.0±46.3		0.1±0.1		13.3±3.1	19.1±19.4
Depth	10							
	25							
	75							
	125	0.15±1.05	13.6±55.4	0.2±0.4	0.1±0.1	2.25±0	8.8±1.4	10.6±9.5
	200	0.03±1.09	1.6±57.6	0.08±0.4	0.1±0.2	0.8± 0.3	12.7±2.7	17.6±17.9
	300	4.27±1.34	224.0±70.6	2.0±0.5	1.1±0.2	5.44±0	13.5±0.7	31.5±4.8
Sex	M						12.9±0.8	28.3±5.8
	F						13.6±1.0	29.9±7.5
C. lucerna								
Region	R1	0.73±0.23	23.6±6.3	0.6±0.1	0.6±0.1	1.20±0.48	14.4±0.6	32.7±4.0
	R2	0.01±0.24	0.8±6.7	0.08± 0.1	0.1±0.1	0.8± 0.1	16.8±1.4	41.4±9.7
	R3	0.06±0.23	1.0±6.5				19.7±3.6	62.6±23.8
Season	M	0.28±0.25	15.8±7.0	0.4±0.1	0.4±0.2	1.20±0.60	12.1±0.6	19.5±4.3
	A			0.1±0.2			17.3±1.0	44.0±7.0
	O	0.75±0.26	17.7±7.2	0.3±0.2	0.2±0.2	0.56±0.78	16.3±0.6	42.0±4.3
	F	0.06±0.27	0.6±7.6	0.05±0.2	0.3±0.2	1.00±1.36	21.8±2.8	101.1±18.5
Depth	10	0.95±0.31	30.4±8.6	0.7±0.2	0.7±0.2	1.56±0.77	14.0±0.6	30.4±4.4
	25	0.11±0.33	8.5±9.2		0.4±0.2	0±0.94	12.4±1.3	17.3±8.7
	75	0.33±0.32	8.5±8.9	0.5±0.2	0.1±0.2	1±0.77	16.4±1.0	44.2±6.8
	125			0.07±0.2	0.1±0.2	0.7± 0.2	16.3±2.3	34.6±15.2
	200	0.13±0.35	1.9±9.6	0.08±0.2	0.1±0.2	1±1.33	20.6±2.3	69.5±15.2
	300							
Sex	M						14.4±0.7	30.3±5.0
	F						14.8±0.8	35.7±5.2
L. cavillone								
Region	R1	0.11±0.11	0.7±0.2	1.1±2.1	1.1±2.2	1.19±0.35	9.1±0.1	9.5±0.5
	R2	0.43±0.12	1.2±0.2	8.1±2.2	7.3±2.4	1.25±0.32	8.8±0.1	9.2±0.1
	R3	0.53±0.11	1.4±0.2	7.5±2.1	7.6±2.3	1.54±0.29	9.9±0.1	12.7±0.2
Season	M	0.26±0.12	0.7±0.2	1.9±2.3	1.6±2.4	1.44±0.46	10.2±0.1	13.6±0.4
	A	0.63±0.14	1.6±0.3	9.3±2.6	9.9±2.7	1.13±0.34	9.3±0.1	10.9±0.2
	O	0.34±0.13	1.2±0.2	7.2±2.3	6.3±2.5	1.34±0.31	9.0±0.1	9.9±0.2
	F	0.22±0.13	0.9±0.3	3.2±2.4	3.5±2.6	1.36±0.39	9.4±0.1	10.4±0.3

Table 2. Continued

Depth	10	0.005±0.14	0.1±0.2	0.06±2.7		1.00±0.99	9.3±1.0	10.9±3.6
	25	0.007±0.15	0.1±0.3	0.07±2.9	0.1±3.1	0.25±0.99	8.4±0.6	7.1±2.1
	75	0.62±0.14	1.9±0.3	10.5±2.8	10±2.9	1.41±0.33	8.6±0.1	8.4±0.1
	125	0.79±0.15	2.1±0.3	10.3±2.9	12.1±3.1	0.83±0.33	9.6±0.1	11.5±0.2
	200	0.39±0.16	1.5±0.3	5.9±3.0	4.8±3.2	1.70±0.35	9.8±0.1	12.4±0.3
	300	0.31±0.19	0.7±0.4	2.8±3.7	2.7±3.9	1.01±0.70	11.8±0.1	20.6±0.5
Sex	M						9.4±0.14	11.2±0.2
	F						9.5±0.1	11.4±0.2
L. dieuzeidei								
Region	R1	2.04±7.08	121.7±324.3	2.9±1.6	2.3±1.5	4.10±2.01	11.0±0.1	16.7±0.4
	R2	0.31±7.52	49.3±344.8	0.5±1.7	0.8±1.6	0.68±3.18	8.8±0.2	9.1±0.8
	R3	18.42±7.22	891.3±330.7	3.7±1.6	4.2±1.5	0.96±2.01	11.1±0.1	17.5±0.3
Season	M							
	A	2.86±8.87	190.4±406.8	4.2±2.0	2.9±1.8	1.34±2.31	10.9±0.1	16.7±0.4
	O	14.49±7.98	640.4±366.0	2.2±1.8	2.6±1.6	0.89±2.67	11.2±0.1	19.1±0.5
	F	8.83±8.39	520.7±384.8	3.3±1.9	4.3±1.7	3.73±2.07	10.4±0.1	14.0±0.4
Depth	10							
	25							
	75							
	125							
	200	2.36±9.44	239.5±425.8	4.3±2.0	3.7±1.6	3.59±1.78	9.4±0.1	10.8±0.4
	300	61.57±11.56	2963.4±521.5	16.3±2.5	17.8±2.0	0.86±1.78	11.4±0.1	18.6±0.2
Sex	M						10.8±0.1	16.3±0.4
	F						11.0±0.1	16.9±0.4
T. lyra								
Region		ID	ID	ID	ID	ID	ID	ID
Season		ID	ID	ID	ID	ID	ID	ID
Depth		ID	ID	ID	ID	ID	ID	ID
Sex		ID	ID	ID	ID	ID	ID	ID
C. lastoviza								
Region	R1	0.11±1.35	5.2±46.0	0.1±0.5	0.1±0.8	4±5.46	12.0±0.9	21.3±6.5
	R2	2.64±1.44	125.4±48.9	1.8±0.6	2.2±0.9	1.06±1.82	11.8±0.2	19.9±1.4
	R3	5.73±1.38	151.0±46.9	2.0±0.5	2.8±0.8	2.57±1.57	14.6±0.2	36.3±1.3
Season	M	1.34±1.50	49.0±50.3	0.8±0.6	0.6±0.9	1.41±2.10	13.6±0.4	29.0±3.0
	A	5.76±1.71	191.1±57.3	2.2±0.7	3.6±1.0	0.37±2.57	13.1±0.2	27.7±1.5
	O	3.11±1.54	95±51.5	1.3±0.6	1.8±0.9	0.98±1.81	13.5±0.3	30.4±2.1
	F	0.75±1.62	26.7±54.2	0.6±0.7	0.4±1.0	6.65±2.57	12.7±0.5	25.5±3.7
Depth	10	0.04±1.70	1.3±55.4		0.1±1.0		14.5±2.5	31.0±16.5
	25	0.76±1.83	22.6±59.5	0.6±0.7	0.5±1.1	1.00±3.32	14.2±0.6	32.3±4.1
	75	8.33±1.76	317.7±57.3	4.1±0.7	5±1.0	1.31±2.03	12.4±0.2	23.2±1.3
	125	3.27±1.83	76.6±59.5	1.3±0.7	1.5±1.1	5.33±2.57	15.3±0.4	40.7±2.6
	200	0.13±1.90	1.9±61.9		0.1±1.1		16.3±1.8	48.5±11.6
	300							
Sex	M						13.4±0.2	28.8±1.5
	F						13.9±0.2	32.6±1.7

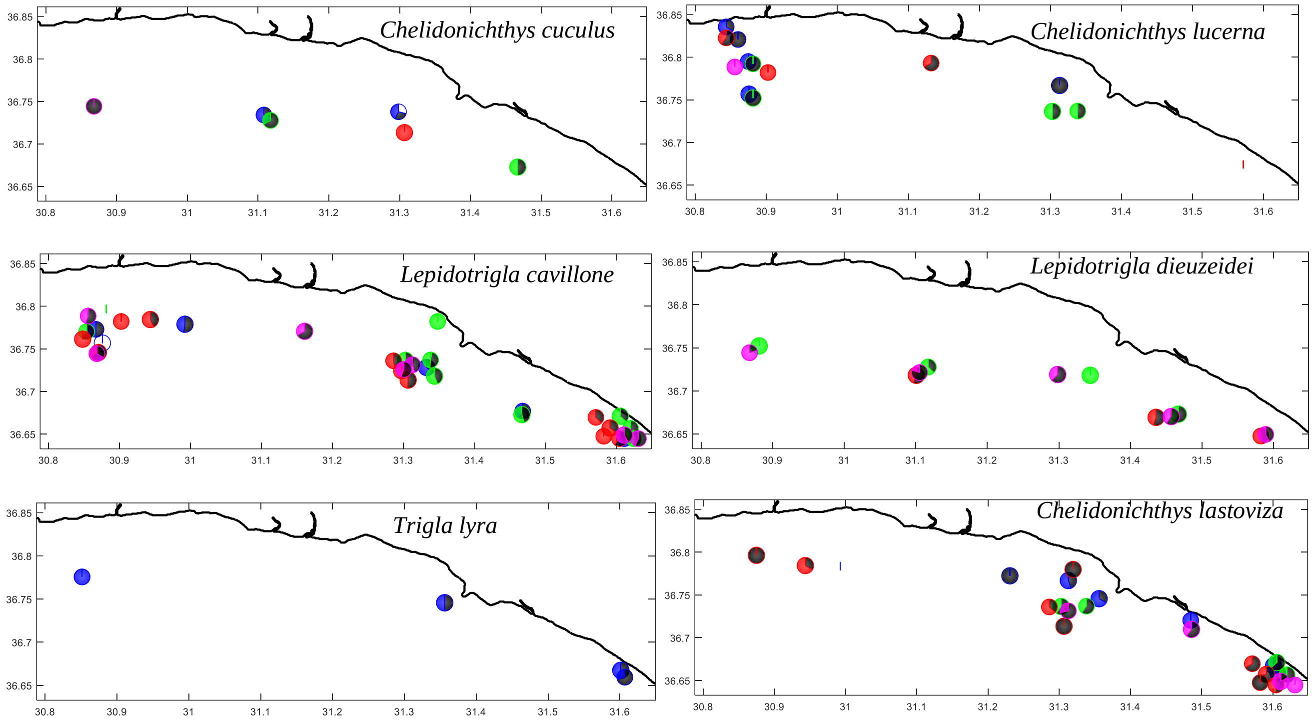

Figure 3. Spatiotemporal of percent sex composition within the circle. Color of circle edge shows season (Blue denotes May, red August, green October and magenta February) and color in circle denotes percent pie of male (black), female (seasonal color) and juvenile or identified sex (white)

Overall, there were significant differences in the length among each of the regions, seasons and bottom depths ($p < 0.05$; Table 3). However, there was no significant regional difference in the length for *C. lucerna* and seasonal difference for *C. lastoviza* (Table 3). Average length of all species increased with the bottom depths. In general, the length was significantly larger in R3 (unfished zone) than that in R1-R2 (Table 2). The larger specimens occurred in October for *C. cuculus*, in February for *C. lucerna*, in May for *L. cavillone*, in October for *L. dieuzeidei*, and in May for *C. lastoviza* (Table 3, Fig. 5).

Regarding to individual maximum weight, heavy species (W> 100 g) were *C. cuculus*, *C. lucerna* and *C. lastoviza*. The rest was lighter fish (W<50 g) (Fig. 6). Only *L. cavillone* and *L. dieudeidae* differed in individual weight significantly among all factors of regions, seasons and bottom depths (Table 3). Individual weight of *C. cuculus* was significantly differentiated by region and season, *C. lucerna* by season and depth, and *L. dieuzeidei* by region and depth (Table 3). Individual weight increased with bottom depths, and heavier specimens occurred in R3 (non-fishing zone, Fig. 1). Specifically, seasonally, species which had heavier specimens in the summer was *C. cuculus*, *L. cavillone*, in the autumn was *L. dieuzeidei* and *C. lastoviza*, and in the winter was *C. lucerna*. Secondary peak in the weight occurred in the winter for *L. cavillone* and spring for *C. lastoviza* (Table 2).

There was no significant sexual dimorphism in size (length and weight) for *C. lucerna*. Only the length of *C. cuculus* was significantly longer in females than males. The rest of the species had sexual dimorphism in sizes, females being longer and heavier than the males (Tables 2, 3, Fig. 6).

Regarding to statistical rejection (t-test) of the null hypothesis (H_0) for Pearson correlation (H_0: r=0), intercept (H_0: a=0) and slope (H_0: b=0) of regression, the length-weight relationships were significantly established using a power fit model of the regression (Fig. 6). ANOCOVA analysis showed that the LWR was significantly different among the sexes for only *L. dieuzeidei* at $p < 0.05$ (Table 3). Regional differences in the LWR occurred for *C. cuculus*, seasonal difference for *L. cavillone* and *L. dieuzeidei*, and depth-wise difference for *L. dieuzeidei* (Table 3).

Table 3. ANOVA results of the biomass (B), abundance (A) of combined specimens, females (F) and males (M), female/male abundance ratio (F/M), length (L), weight (W) and length-weight relationship (LWR) in space (region and bottom depth) and time (season) and sex only for L, W and LWR with the growth type; I: isometric growth, P: positive allometry and N: negative allometry. LWR was tested using ANOCOVA test. ID: insufficient data for the species, and empty cells denote no occurrence of species at the factor

Species	B	A	F	M	F/M	L	W	LWR
C. cuculus								
Region	0.5861	0.6022	0.6533	0.4541	0.9365	**0.0000**	**0.0000**	**0.0395**
Season	0.4272	0.3944	0.3655	0.4063	0.3969	**0.0001**	**0.0001**	0.4813
Depth	0.2723	0.2796	0.1483	**0.0243**	ID	**0.0246**	0.1486	
Sex						**0.0221**	0.4900	0.181 (N)
C. lucerna								
Region	0.1259	**0.0462**	**0.0489**	0.1202	0.6012	0.2754	0.5497	0.8424
Season	0.1985	0.1957	0.5112	0.5362	0.8203	**0.0000**	**0.0001**	
Depth	0.5204	0.3206	0.3368	0.5472	0.6693	**0.0177**	**0.0334**	
Sex						0.2264	0.2162	0.078 (I)
L. cavillone								
Region	0.5642	0.5317	0.0824	0.1579	0.5888	**0.0000**	**0.0000**	0.0982
Season	0.1583	0.1584	0.1294	0.1427	0.9445	**0.0000**	**0.0000**	**0.0045**
Depth	0.4035	0.4205	0.0574	0.0702	0.4175	**0.0000**	**0.0000**	**0.0009**
Sex						**0.0000**	**0.0000**	0.639 (P)
L. dieudeidae								
Region	0.2739	0.2542	0.5381	0.4310	0.5002	**0.0000**	**0.0000**	0.1601
Season	0.5867	0.5890	0.4249	0.3324	0.6432	**0.0000**	**0.0000**	**0.0024**
Depth	**0.0022**	**0.0008**	**0.0000**	**0.0000**	0.3052	**0.0000**	**0.0000**	0.4284
Sex						**0.0000**	**0.0087**	**0.014** (P)
T. lyra								
Region	ID	ID	ID	ID	ID	ID	ID	ID
Season	ID	ID	ID	ID	ID	ID	ID	ID
Depth	ID	ID	ID	ID	ID	ID	ID	ID
Sex	ID	ID	ID	ID	ID	ID	ID	0.992 (N)
C. lastoviza								
Region	**0.0333**	0.1110	0.0817	0.1044	0.7701	**0.0000**	**0.0000**	0.9307
Season	0.1492	0.1723	0.3970	0.1240	0.2887	0.5292	0.6333	
Depth	**0.0066**	**0.0017**	**0.0016**	**0.0065**	0.8482	**0.0000**	**0.0000**	
Sex						**0.0000**	**0.0000**	0.680 (I)

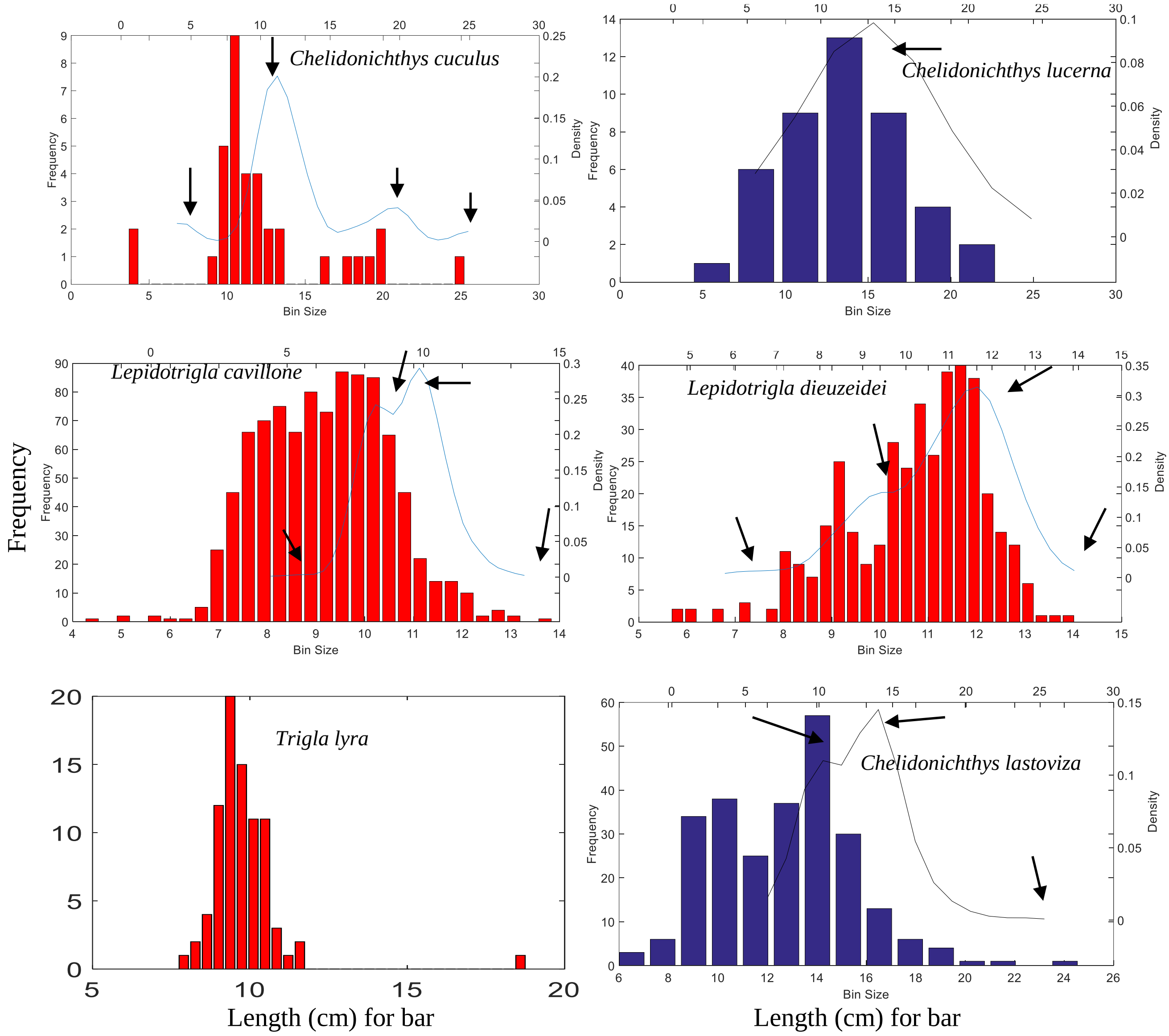

Figure 4. Annual length frequency histograms of the gurnard species. Bin size means length class in cm. Curves shows modal length classes derived from the kernel density function. Arrow showed cohort in mode of the size

Species which had isometric growth was *C. lucerna* and *C. lastoviza*, negative allometry was found for *C. cuculus* and *T. lyra*, and positive allometry for *L. cavillone* and *L. dieuzeidei*; females showed positive allometry, and males had isometric growth (Table 3, Fig. 6).

Ecological distribution in space and time

Regarding to species-abiotic environment relation, six gurnard species was assembled and positively correlated with the bottom depth and negatively correlated with the bottom type (coarse to fine material of sediment from coast to open water bottom) on CCA1 axis (Table 4, Fig. 7a). There was a shelf species community (bottom depth < 200 m) and a deep water community (bottom depth ≥ 200 m): *C. cuculus* and *L. dieuzeidei*, respectively. Shelf species community was separated with two depth segmentations: shallow water (bottom depth < 75 m) but abundantly found at the shallowest depth: *C. lucerna* and ubiquitous shelf species but abundantly found at middle depth (bottom depth >75 m till 125 m): *L. cavillone* and *C. lastoviza* (Table 2, Fig. 7a). On CCA1, there were slight negative correlations between fish species-limited environment relation (chl-*a* and fine bioseston) (Table 4, Fig. 7a). However, season and region did not dictate the gurnard community (Fig. 7b, c). The CCA1 was statistically proved with Monte Carlo test (F: 8.639, p: 0.0020). This co-linearity and correlation on CCA1 was elucidated with a percent variance of 34.0 (Table 4).

On CCA2, the species community was governed with positive effect of constitutes of total suspended matter (all fractions of seston and fine materials of tripton) and negative effect of concentrations of sea surface and subsurface chl-*a* (Table 4, Fig. 7a). However, physical environments were not correlated with co-linearity by the species. All CCA axes were statistically proved with Monte Carlo test (F: 2.175, p: 0.0020). The species-environment relation on CCA2 was discriminated with an explained percent variance of 23.5 of the total variance (Table 4).

Regarding to species-biotic environment relation with the mega-benthic fauna, the species community was positively correlated with specimens of decapoda and holothuroidea on CCA1 (Table 5, Fig. 7d). The CCA1 was not significantly validated with Monte Carlo test (F: 7.659, p: 0.0640). This co-linearity and correlation on CCA1 was elucidated with a percent variance of 43.0 of the total variance (Table 5). On CCA2, there was positive correlation between the gurnard species and Crinoidea, followed by Ophiuridea (Table 5, Fig. 7d). The species-environment relation on CCA2 was discriminated with an explained percent cumulative variance of 72.5 of the total variance (Table 5). All CCA axes were statistically proved with Monte Carlo test (F: 1.643, p: 0.0340).

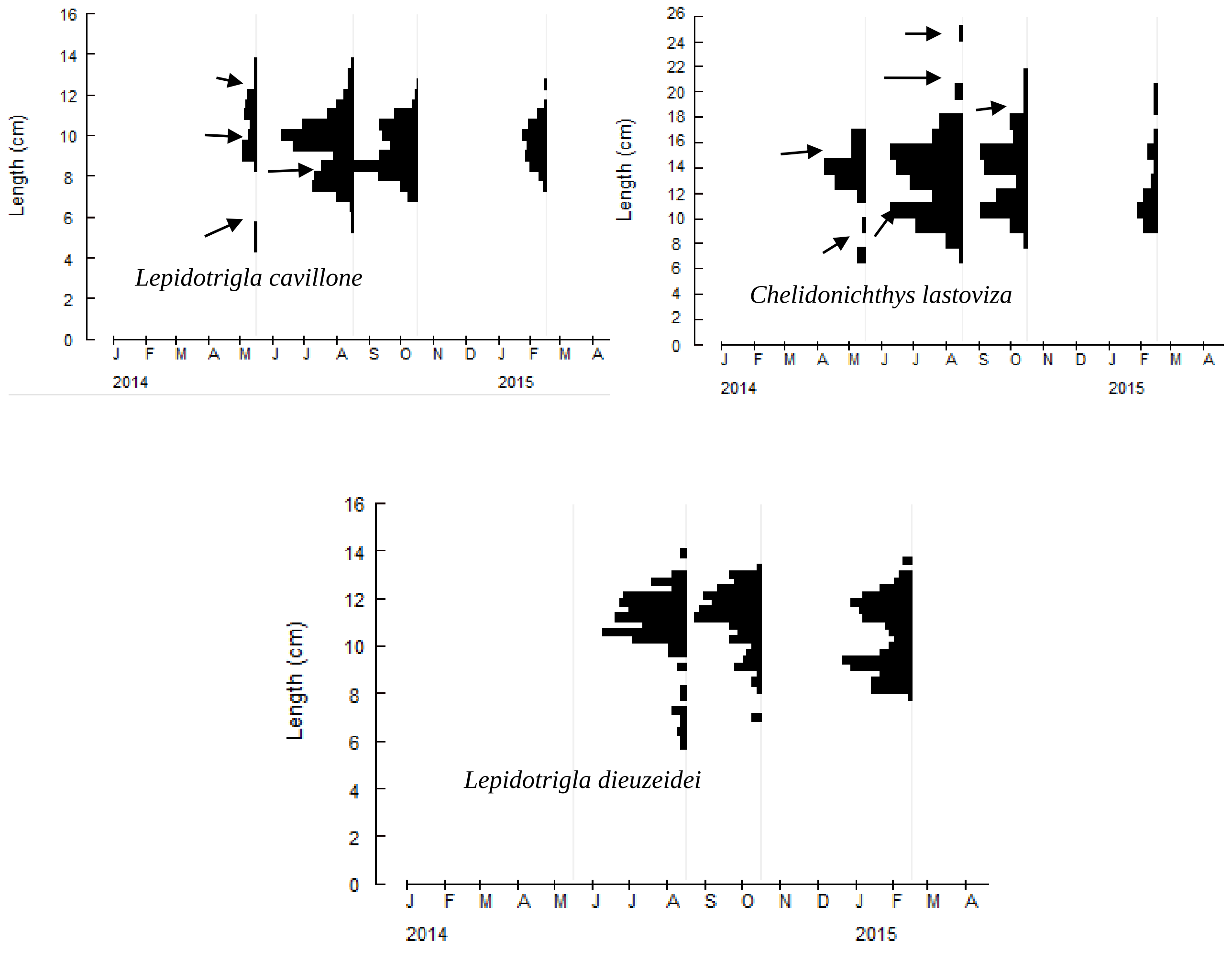

Figure 5. Temporal distribution of total length-frequency data of three abundant gurnard species caught in the present study area. Arrow shows size cohort mode

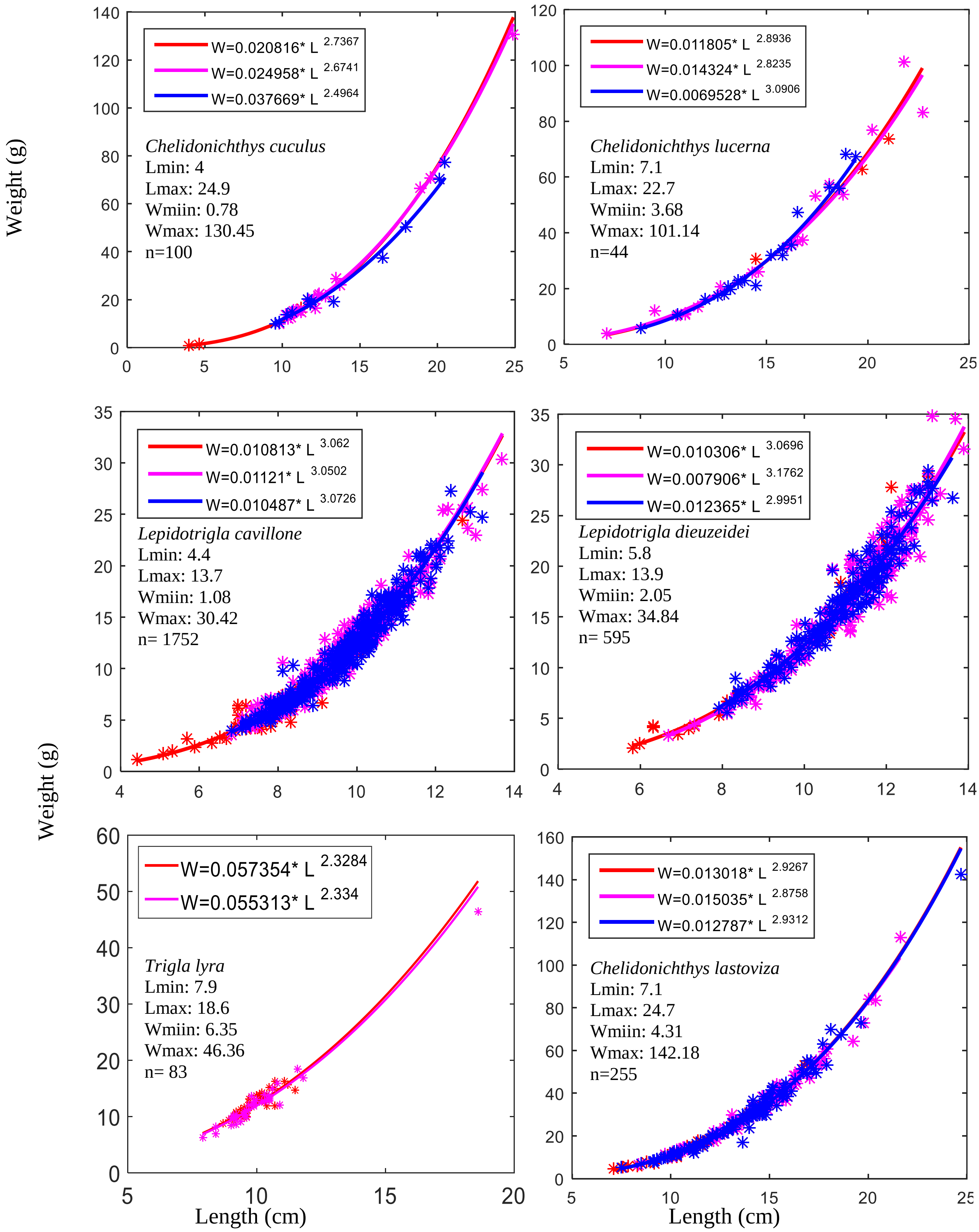

Figure 6. Length-weight relationships of the gurnard species. Females in pink, males in blue, combined specimens including unsexed individuals also in red. n is number of individuals

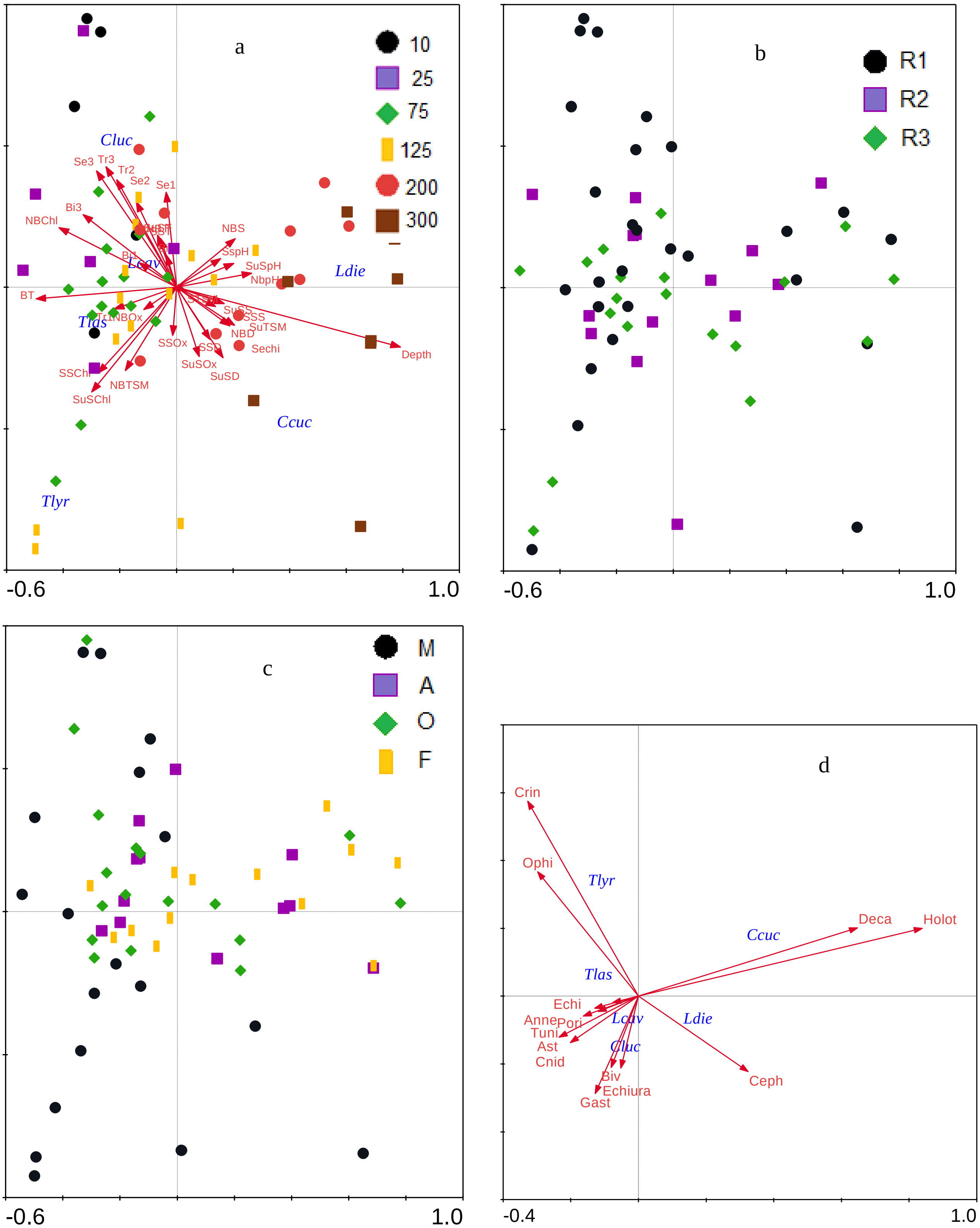

Figure 7. Triplot of Canonical Correspondence Analyses (CCA) of the gurnard fishes' log10-transfomed abundance in trawls classified by the bottom depth (a), region (b) and season (c) with the environmental parameters and megafaunal abundance (d) (see Table 1 for the abbreviations of the fish species and Table 4 for environmental parameters, and Table 5 for the megafaunal species abbreviations)

Table 4. Summary of statistical measures of the characteristics of gurnard abundance in relation to the environmental variables for the CCA. Environmental parameters with the abbreviations used in statistical analyses (prefixes for the abbreviations: SS, sea surface, Su; subsurface and NB; near-bottom water)

Variables	Abb	CCA1	CCA2
Bottom depth (m)	Depth	**0.7481**	-0.1842
Total Suspended Matter (g/m^3)	STSM	0.0323	-0.0121
Total Suspended Matter (g/m^3)	SuTSM	0.1311	-0.0592
Total Suspended Matter (g/m^3)	NBTSM	-0.1703	-0.2572
Secchi disk depth (m)	Sechi	0.1941	-0.1178
Oxygen (mg/l)	SSOx	-0.0125	-0.1483
Oxygen (mg/l)	SuSOx	0.0759	-0.2138
Oxygen (mg/l)	NBOx	-0.1086	-0.0689
Temperature (°C)	SST	-0.0518	0.1502
Temperature (°C)	SuST	-0.0631	0.1608
Temperature (°C)	NBT	-0.0621	0.1591
Salinity (PSU)	SSS	0.1594	-0.0507
Salinity (PSU)	SuSS	0.1530	-0.0460
Salinity (PSU)	NBS	0.1959	0.1504
pH	SspH	0.1478	0.0886
pH	SuSpH	0.1914	0.0740
pH	NbpH	0.2513	0.0438
Density, σ_t	SSD	0.1125	-0.1613
Density, σ_t	SuSD	0.1556	-0.2174
Density, σ_t	NBD	0.1782	-0.1190
Chl-*a* (mg/l)	SSChl	-0.2610	**-0.2648**
Chl-*a* (mg/l)	SuSChl	-0.2824	**-0.3233**
Chl-*a* (mg/l)	NBChl	**-0.3922**	0.1841
Seston - 1 mm (g/m^3)	Se1	-0.0342	**0.2934**
Seston – 0.5 mm (g/m^3)	Se2	-0.1337	**0.2639**
Seston – 0.063 mm (g/m^3)	Se3	-0.2670	**0.3594**
Bioseston - 1 mm (g/m^3)	Bi1	-0.1237	0.0754
Bioseston – 0.5 mm (g/m^3)	Bi2	-0.0334	0.0985
Bioseston – 0.063 mm (g/m^3)	Bi3	**-0.3113**	0.2244
Tripton – 1 mm (g/m^3)	Tr1	-0.2072	-0.0671
Tripton – 0.5 mm (g/m^3)	Tr2	-0.1993	**0.3318**
Tripton – 0.063 mm (g/m^3)	Tr3	-0.2357	**0.3723**
Bottom types (see Fig. 1b)	BT	**-0.4693**	-0.0355
Eigenvalues :		0.703	0.487
Species-environment correlations :		0.945	0.873
Cumulative percentage variance			
of species data :		24.9	42.2
of species-environment relation:		34.0	57.5

Table 5. Summary of statistical measures of the characteristics of gurnard species abundance in relation to the mega-benthic fauna abundances for the CCA

Taxa	Abb	CCA1	CCA2
Decapoda	Deca	**0.4870**	0.1331
Annelida	Anne	-0.0895	-0.0301
Cnidaria	Cnid	-0.1514	-0.0903
Echinodermata,Asteroidea	Ast	-0.1766	-0.0801
Echinodermata,Crinoidea	Crin	-0.2463	**0.3802**
Echinodermata,Echinoidea	Echi	-0.0571	-0.0127
Echinodermata,Holoturidea	Holot	**0.6311**	0.1324
Echinodermata,Ophiuridea	Ophi	-0.2241	**0.2424**
Echiura	Echiura	-0.0393	-0.1402
Mollusca,Bivalvia	Biv	-0.0609	-0.1389
Mollusca,Cephalopoda	Ceph	0.2437	-0.1469
Mollusca,Gastropoda	Gast	-0.0961	-0.1899
Porifera	Pori	-0.0975	-0.0237
Tunicata	Tuni	-0.1226	-0.0387
Eigenvalues :		0.410	0.281
Species-environment correlations :		0.753	0.661
Cumulative percentage variance			
of species data :		4.5	24.5
of species-environment relation:		43.0	72.5

Discussion

Biomass estimation is of paramount importance in the stock assessment of aquatic organisms, particularly fish, as it allows extrapolation or interpolation of biomass to both non-stratified and stratified areas under investigation. Gurnards are particularly suitable for stock assessment and biomass estimation as they are true demersal fish, not semi-demersal. This makes them ideal for efficient sampling with bottom trawls. However, the species could be highly influenced by trawl fisheries. For instance, *L. cavillone* highly contributed to fishing effort levels in the trawl fishery in the western Mediterranean Sea (Farriols et al., 2017). Gurnards were considered discard fishes before. In Greek waters (Ionian Sea and Aegean Sea), about 39%-49% (with a mean of 44%) of the total catch (vertebrates and invertebrates) by bottom trawls was discarded including only *L. dieuzeidei* (Machias et al., 2001). *L. cavillone* (3.14% of the total catch) and *T. lyra* (0.17%) were discarded in the Aegean Sea (Damalas et al., 2010). After gurnards became the target species in demersal fisheries, their abundance was studied. *C. cuculus* and *T. lastoviza* are important species as by-catch in the western Mediterranean (Ordines et al., 2014). *C. cuculus* had a relative dominance of 26.3% in the Croatian waters, Adriatic Sea, at depths extending to 500 m (Vallisneri et al., 2014) which was deeper than the maximum sampling depth (300 m) in the present study.

Of the total number of 8 gurnard species belonging to 4 genera reported from the Mediterranean Sea (Colloca et al., 2019) and 6-8 species in the eastern Mediterranean Sea with 6 species in Greek waters (Terrats et al., 2019) and 8 species in the Turkish seas (Bilecenoğlu and Taşkavak, 1999) and Levant waters (Bilecenoğlu et al., 2014), 6 species were detected on the bottom of shelf (10-200 m) /shelf break (300 m) zone in the Antalya Gulf. In the sea of Marmara, five gurnard species were updated to 7 species recently (Daban et al., 2021; Bilecenoğlu 2024), eight species in the Turkish Aegean Sea and three species in the southern Black Sea were reported (Bilecenoğlu, 2024). The same species reported in the present study were also found in Cretan waters (Tsimenides et al., 1992). Common species distributed over the study area were dominant species such as *L. cavillone* and *C. lastoviza* occurred in the Antalya Gulf whereas *C. cuculus* and *L. dieuzeidei* preferred substantially greater depths (> 125 m). *L. cavillone*, which was found at 30 m - 330 m, was the most common species in the Mediterranean Sea (Collaco et al., 1997). However, *T. lyra* was encountered once in the spring (May). This could be due to the rare occurrence of the species or seasonal ontogenic migration toward deeper waters than our sampling depths. In the Aegean Sea and the Sea of Marmara, abundance of *T. lyra* increased at depths down to 200 m (Damalas et al., 2010 and Daban et al., 2021), followed by a decrease at greater depths (Damalas et al., 2010). *L. cavillone* was found as the third dominant species among demersal fish on the continental shelf of the Gulf of Lions (north-western Mediterranean Sea) (Merigot et al., 2007). *C. cuculus* was distributed at depths of 70-235 m (DO%: 29-36%), *L. cavillone* at 41-167 m (30-49%), *C. lucerna* at 70-74 m (2%), and *T. lyra* at 103-416 m (17-30%) around Balearic Islands (Massuti and Renones 2005). In Greek waters, *C. cuculus* (5-30 cm in length) were distributed at depths of 97-298 m, *T. lastoviza* (5-25 cm; two size classes) at 32 -191 m, and *L. cavillone* (4-14 cm) at 54-216 m (Terrats et al., 2000). In Saros Gulf, five gurnard species were reported, four of which were the same species reported in the present study with the exception of *C. cuculus*, and they accounted for 3.4% of the total catch (Ihsanoglu et al., 2016). All five species were abundantly found at depths of 50-100 m, and followed a decreasing trend as a factor of depth down to 500 m (Ihsanoglu et al., 2016). *T. lyra* was mostly found between 100 - 200 m in the Sea of Marmara (Şirin et al., 2024).

Regardless of species' preference of depth, small-sized gurnard (*L. cavillone* and *L. dieuzeidei*) specimens (L<15 cm, Mutlu et al., 2022a) were numerically abundant and dominant in the gurnard population while larger specimens were less abundant relative to their corresponding biomass. With high abundance in coastal waters, Vallisneri et al., (2011) estimated three size classes (5-15 cm, 15-32 cm, and >32 cm in range of 6.3-41.5 cm with a mean of 20.8 cm) of *C. lucerna* in the Adriatic Sea, which included more size classes than our estimate (5-23 cm). This could be due to the habitat preference of *C. lucerna* for sand bottoms (Tunesi et al., 2006); R2-R3 were covered by *P. oceanica*, and R1 was bare bottom in the present study area (Levantine Sea). Differences in size classes between the two studies could also be attributed to variations in the trophic levels of the two seas. Similar to our estimates, *L. cavillone* had four modal size classes in Sicilian waters (Ragonese and Bianchini, 2010).

Some of the gurnards exhibited transect-wise difference in density within the study area. R3 had higher mean abundance and biomass than the species dominant in R1-R2. R3 is a non-fishing zone closed to the trawl fishery. Such marine protected areas sustain the stock of the species such as *C. lucerna* and *C. lastoviza*. *T. lyra* and *C. lucerna* had CPUE higher in the Sea of Marmara than our estimates whereas the rest of the species had similar CPUE in comparison (Daban et al., 2021). In Türkiye, the 2-nautical mile (nm) area from the coast is closed to fishery, but open to artisanal fishery, the 12 nm border is the open fishery area seaward, accessible year-around. Notably, the 2 nm area has been updated to 3 nm, recently (Deval and Mutlu, 2024). Antalya Gulf is one of the oligotrophic basins of the Mediterranean Sea (Sisma-Ventura et al., 2017). Therefore, Coll et al (2010 classified Antalya as a low-diversity area in terms of cartilaginous fishes. Recently, Deval and Mutlu (2024) have upgraded the number of cartilaginous species for the Antalya Gulf. de Meo et al., (2018) detected 147 fishes, Patania and Mutlu (2021) 59 megabenthic crustaceans and Garuti and Mutlu (2021) 90 non-crustacean megabenthic species in the present study. The Gulf of Antalya is fished by 16 trawlers that operate in the study area annually during the fishing season. The fishing fleet concentrates in the area between the two-mile limit and the 200-meter isobaths, mainly in the R1-R2 region. The specific fishing effort is 2.6 hours per day per boat (9310 hours in total) during the fishing season (Mutlu et al., 2022b). This fishing pressure suggested that unprotected area (R1-R2) could be affected by the artisanal fishery during ontogenic distribution of the reproduction period and biological cycle of the gurnards (e.g. Colloca et al., 1997; Boudaya et al., 2008; Dobroslavić et al., 2021). Similarly, *L. cavillone* dominating the middle shelf had higher abundance in the summer than the spring in the central Tyrrhenian Sea (Collaco et al., 1997).

For many taxa of the nektonic or benthic organisms, bottom depth segmentation is valid for restricting their spatial distribution and the bottom depth, followed by season, is a primary factor influencing their distribution. The shelf is generally segmented with classification of lower (depth ≤ 25 m) shelf, middle shelf (25-125 m) and upper shelf (> 125 m) for fish (de Meo et al., 2018), megabenthic fauna (Patania and Mutlu 2021; Garuti and Mutlu 2021) and macro benthic fauna (Mutlu and Ergev 2008, 2012, 2013; Mutlu et al., 2010; Mutlu, 2015) in the Levantine Sea. Besides, the ubiquitous species can peak at certain depth intervals with their density distribution varying during different seasons of the year. In Cretan shelf/slope bottoms, *C. lastoviza* was the contributor species to fish assemblage at 50 m, and *L. cavillone* at 100 m with 5% of the density (Kallianiotis et al., 2000). *L. cavillone* was one of the abundant species in the middle shelf of the central Mediterranean Sea (Collaco et al., 2003). This resulted in depth-wise differences in the density of a species both on the shelf, and along the shelf slope. A study conducted at the shallower waters (<10 m) of the Gulf of Fos, France in 1983-1985 by Letourneur et al., (2001) showed similar mean abundance and biomass of *L. cavillone* and *C. lucerna* to those observed at corresponding depths in our study.

In the present study, the morphometry of the gurnards was overall differentiated by the bottom depth, season and sex of the specimens. Additionally, regional differences were observed, with larger and heavier specimens found in the protected area (R3) compared to the unprotected area (R1-R2). Morphometry can be influenced by several factors and stressors in the marine environment, i.e. bottom depth geographical coordinate, physical variables, and sex of specimens of fish etc on a broad scale, and season, physicochemical variables, food availability, habitat types, trophic level, occurrence of non-indigenous and indigenous species, and Levantine nanism, depending on biology and reproduction demands of the species (Mutlu et al., 2023) etc on a fine scale in loci such as the present study area. Coastal waters of R2 and R3 featured a habitat type with seagrass meadow (Mutlu et al., 2022c) and R1 and R2 had two dominant seaweeds (Mutlu et al., 2022d). For instance, *C. lucerna* preferred sandy bottoms among four different bottom types including *P. oceanica* (Tunesi et al., 2006) and similarly, we found the species to be abundant at R1, an unvegetated bottom with *P. oceanica*. Farre et al., (2016) concluded that morphospaces exhibited lower richness of body forms for demersal fish assemblages, including gurnards having negative morphospace values (elongated shapes) with increasing depth in the western Mediterranean Sea. Larger specimens (L>7.5 cm) of *L. cavillone* was dominant in the spring when maturity decreased with depth and peaked at the middle shelf. In contrast, smaller specimens ($L \leq 7.5$ cm) were more abundant in the summer in the central Tyrrhenian Sea, with length decreasing with depth (Collaco et al., 1997). Despite difference in size classes between the Adriatic Sea (Vallisneri et al., 2011) and Levantine Sea (the present study), *C. lucerna* had similar length-weight relationships for sexed and unsexed specimens. In İzmir Gulf (Aegean Sea), all morphometry and their relationship were overestimated compared to our estimates (İlhan and Toğulga 2007). However, *L. dieuzeidei* had similar size structure and relationship between the Adriatic Sea (Dobroslavić et al., 2021) and Antalya Gulf. *C. lastoviza* had similar length range in both Antalya Gulf and Egyptian Mediteraanean waters with slightly higher slope in LWR in comparison, and both populations showed isometric growth (Mehanna, 2022), but had higher size structure in the Saronikos Gulf in 1980s (Papaconstantinou, 1986). In Iskenderun Gulf, characterized by high fishing pressure and eutrophic region, *C. lucerna* had similar size range and growth type (İşmen et al., 2004) to our estimates which had lower size structure values compared to the Tunisian waters (Boudaya et al., 2008), but had higher size structure values in the Thermaikos Gulf in 1980s (Papaconstantinou, 1984) and in the Sea of Marmara (Eryilmaz and Meriç, 2005). Even if there were similar size ranges of *C. cuculus* between the Croatian and Antalya Gulf, slopes (positive allometry) of the LWR was rather higher than our estimates (negative allometry), resulting in different growth types with high abundance in the Adriatic Sea (Vallisneri et al., 2014). All four common species excluding *C. cuculus*, had longer body size in Saros Gulf, Aegean Sea compared to the the present study area, with nearly higher slopes in the LWR (Ihsanoglu et al., 2016). Asimilar comparison was observed with gurnards in Edremit Gulf, Aegean Sea (Uçkun, 2005).

Ecological studies on fishes are highly limited in the literature, and existing studies cover a wide range of the stratified bottom depths as fishery biologists have not considered measuring certain specific environmental variables. In general, only basic physical parameters (temperature and salinity) were reported. With limited environmental variables such CTD (temperature and salinity), the first ecological study performed on gurnards was conducted in the Cretan waters (Tsimenides et al., 1992). In Türkiye, there are few studies on ecology that include comprehensive environmental parameters. (de Meo et al., 2018; Daban et al., 2021). Ecological studies at the family level are important to elucidate the patterns of the most abundant and dominant species within the same family (Mutlu et al., 2021, 2022b, e, f). Specimens of *L. cavillone* in Izmir Gulf showed similar size structure to our estimates (Türker et al., 2010).

Regarding to diet of the gurnards for the species-megabenthic fauna relation, *C. lucerna* fed mostly on Brachyura, *C. lastoviza* on Mysidacea, followed by Brachyura, *L cavillone* on Mysidacea, followed by Amphipoda, and *T. lyra* on Gastropoda, followed by Brachyura in the Edremit Gulf, Aegean Sea (İlhan 2019). In the Greek waters, *C. cuculus* fed mainly on Mysidacea and Euphausiacea, *T. lastoviza* and *L. cavillone* mainly on Mysidacea (Terrats et al.,, 2000) and *T. lyra* on Mysidacea (Caragitso and Papaconstantinou. 1994). *C. lastoviza* fed on crustaceans, mostly mysids and decapods in the Tunisian watres (Boudaya et al., 2007). Both, *C. cuculus* and *C. lucerna* feed mostly on crustaceans in the Adriatic Sea (Montanini et al., 2017) and *C. lucerna* on crustaceans (Decapoda: Brachyura) in the Italian Adriatic waters (Stagioni et al., 2012). In the present study, deep-water gurnard species (*C. cuculus* and *L. dieuzeidei*) were correlated with decapods and specimens of Holothuroidea which increased with depth.

In conclusion, of the 8 gurnard species reported in the Turkish marine waters, 6 species were found on the shelf/shelf break in the present study. The most dominant species were *L. cavillone* and *C. lastoviza* and there were no consistently present gurnard species in the study area. The abundantly found species were *L. cavillone* and *L. dieuzeidei*. Gurnards were very low in number and biomass as compared to other 165 species found in the present study. Shallow and middle shelf water gurnard species was *C. lucerna* distributed at 10-75 m, ubiquitous shelf species *C. lastoviza* at 10-200 m, deep shelf species *T. lyra* at 100-125 m, deep shelf/break species *C. cuculus* at 125-300 m and *L. dieuzeidei* at 200-300 m, and ubiquitous shelf/shelf break species was *L. cavillone* at 10-300 m. The maximum abundance among gurnards varied between 211 ind/km^2 (*C. lucerna*) and 89388 ind/km^2 (*L. cavillone*), followed by

12731 ind/km^2 (*L. dieuzeidei*). Maximum catch in weight was found for *L. cavillone* (53.4%) with 8.45±32.48 kg/trawl on average, followed by *L. dieuzeidei* (19.7%). Overall, female specimens outnumbered the males. Female/male abundance ratio showed that females predominated in the population and varied between 2.25 and 5.44 for *C. cuculus*, between 0.56 and 1.56 for *C. lucerna*, between 0.25 and 2.83 for *L. cavillone*, between 0.68 and 4.10 for *L. dieuzeidei*, and between 0.08 and 6.65 for *C. lastoviza*. Lengths of six gurnard species ranged from 4 cm to 24.9 cm (*C. cuculus*), followed by 24.7 cm (*C. lastoviza*), and weights from 0.78 g (*C. cuculus*) to 142.18 g (*C. lastoviza*). In general, the small-sized specimens (< 15 cm) outnumbered the larger specimens. In terms of individual maximum weight, the heavier fish species (W > 100 g) were *C. cuculus, C. lucerna, and C. lastoviza*, while the rest were lighter fish species (W < 50 g). The species exhibiting isometric growth were *C. lucerna* and *C. lastoviza*, while negative allometry was observed in *C. cuculus* and *T. lyra*, and positive allometry was observed in *L. cavillone* and *L. dieuzeidei*; females showed positive allometry, and males isometric growth. Regarding the species-abiotic environment relationship, six gurnard species were grouped and positively correlated with bottom depth, while negatively correlated with bottom type. This was followed by a positive effect of total suspended matter (including all fractions of seston and fine materials of tripton) and a negative effect of sea surface and subsurface chl-*a*.

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Conflict of Interest

On behalf of all authors, the corresponding author states that there is no conflict of interest.

Author Contributions

Erhan Mutlu: Onboard works, Project administration, Supervision, Software, Data analyzes, Writing, Funding acquisition. Ilaria de Meo: Onboard works, Laboratorial works, Measurements, Data entry. Claudia Miglietta: Onboard works, Laboratorial works, Measurements, Data entry. Mehmet Cengiz Deval: Onboard works, Laboratorial works, Measurements, Data entry.

Ethics Approval

The authors declare that all applicable guidelines for sampling, care and experimental use of animals in the study have been followed in compliance with ethical standards approved by the Akdeniz University (Protocol no: 2013.12.03).

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RESEARCH ARTICLE

Changes on the Temporal Patterns of Ichthyoplankton Assemblages in the Çanakkale Strait, Türkiye

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Abstract: Monitoring studies in a particular area after a long period of time can provide opportunities to understand environmental, physical and biological events that have occurred over time. From this point of view, we aimed to reveal ichthyoplankton assemblages in the Çanakkale Strait after 10 year period. Our findings indicated a 3 ºC difference in sea surface termperature in the late spring and early winter compared to earlier studies. As expected, the highest mean abundance and biodiversity of ichthyoplankton were found in the late spring-early summer period but they showed rapid fluctuations even in consecutive weeks. Coastal resident species such as *Diplodus annularis*, *Gobius niger*, and *Spicara maena* were found to be abundant. In Çanakale Strait, larvae of mesopelagic species were sampled for the first time in this study. The occurrence of mesopelagic species far from their natal habitat in the northern Aegean deep sea trench may indicate a change in the region's hydrodynamics.

Anahtar kelimeler:

Balık yumurtaları
Balık larvaları
Bolluk
Biyoçeşitlilik

Çanakkale Boğazı'nda İhtiyoplankton Topluluklarının Zamansal Değişimi

Öz: Belirli bir bölgede uzun süre aradan sonra yapılan izleme çalışmaları zamanla gerçekleşen çevresel, fiziksel ve biyolojik olayları anlama fırsatı sunar. Bu amaçla, 10 yıl aradan sonra Çanakkale Boğazı ihtiyoplankton topluluğunun ortaya konması amaçlanmıştır. Deniz suyunun beklenenden yaklaşık 3 derece geç ısındığı ve geç soğuduğu belirlenmiş, ancak bu durumun ihtiyoplankton kompozisyonuna etki etmediği tespit edilmiştir. Beklendiği gibi en yüksek ihtiyoplankton bolluk ve biyoçeşitliliği ilkbahar sonu-yaz başı döneminde görülmüş ancak birbirini takip eden haftalarda bile önemli dalgalanmalar tespit edilmiştir. *Diplodus annularis, Gobius niger* ve *Spicara maena* gibi kıyısal yerleşik türlerin daha baskın hale geldiği belirlenmiştir. Mezopelajik Derinsu larvaları ilk kez bu çalışmada Çanakkale Boğzı'nda örneklenmiştir. Bu türlerin varoluş alanı olan Kuzey Ege derin deniz çukurundan bu kadar sürüklenmiş olmaları, bölge hidrdinamiğinin değiştiğini göstermektedir.

Introduction

Icthyoplankton surveys provide essential data for stock assessment, understanding ecosystem functions, and investigating spawning strategies, behavior, and biology. They also play a key role in determining closed areas, closed seasons, and marine protected areas. In addition, icthyoplankton surveys provide a cost-effective and simpler fishery-independent research tool (Doyle et al., 2002). Understanding variabilities and success in fish recruitment is one of the most critical issues for stock management (Hjort, 1926). Sudden changes, influenced by environmental conditions, chemical pollutants, and human-induced factors, lead to high mortality rates in early life stages. In addition, predation and challenges during early feeding contribute to very high losses due to limited morphological and physiological development (Rodriguez et al., 2009; Cuttitta et al., 2016). Thus, ichthyoplankton studies are crucial for understanding species biology and interpreting effects of sudden or long-term variables.

Continuous and uninterrupted data collection can undoubtedly yield more reliable results for monitoring. Some successful examples have been realised in the Gulf of Alaska (McClatchie et al., 2014) and the Gulf of California (Smith and Moser, 2003). However, due to the high costs of continuous monitoring, obtaining such data in every region of the world has not been feasible. Nevertheless, ichthyoplankton studies conducted in the same geographic area at regular time intervals, could provide valuable insights for monitoring.

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Ichthyoplankton studies in Türkiye started approximately 70 years ago, with the study of Arım (1957). To date, several important studies have been carried out in the North Aegean Sea and in the Marmara Sea (Somarakis et al., 2002; Demirel, 2004; Türker Çakır, 2004; Isari et al., 2008, Somarakis et al., 2011; Kara, 2015; Daban and Işmen, 2020). However, there have been no ichthyoplankton studies conducted in the Çanakkale Strait. Daban (2013) presented the first ichthyoplankton results of the Çanakkale Strait.

This study aims to investigate the ichthyoplankton composition and compare abundance and biodiversity of ichthyoplankton in the Çanakkale Strait, over a 10-year period.

Material and Methods

In the late spring and summer, ichthyoplankton abundance and biodiversity reach the highest level throughout the Mediterranean Sea (Sabates and Olivar, 1996; Somarakis et al., 2002). Therefore, sampling design of the present study was structured to account for these seasonal conditions. Samplings were performed weekly between May 18th to December 7th, 2023, for a period of 27 weeks. Stations were located at the end of the European side of the Çanakkale Strait (Fig. 1) at the specified coordinates (P1: 40° 02' 35.7972" N lat. 26° 11' 36.8586" E long. P2: 40° 02' 54.1356" N lat. 26° 12' 35.4924" E long.).

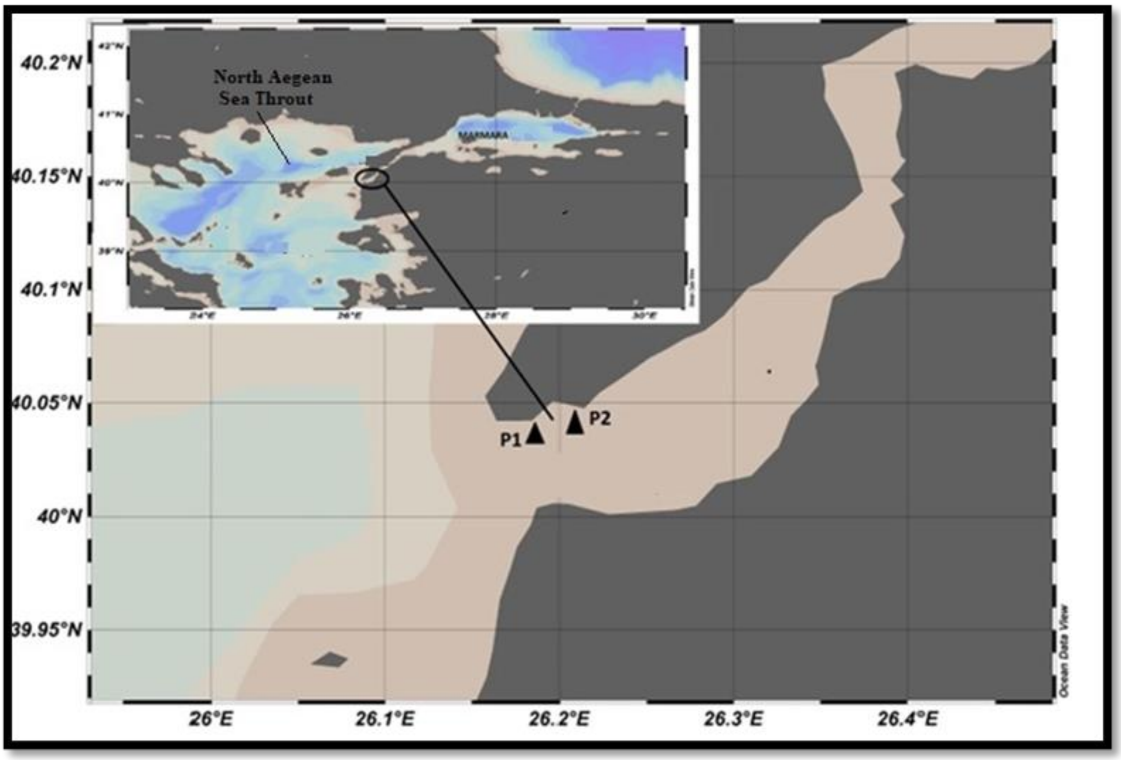

Figure 1. Study area and locations of sampling stations in the Çanakkale Strait, Türkiye

Ichthyoplankton tows were conducted using a WP-2 type plankton net (3 m length, 57 cm frame diameter, 350 µm mesh size) with vertical tows performed from above the thermocline layer to the surface.

Ichthyoplankton samples were fixed with 4% formaldehyde solution. Before species identification, all fish eggs and larvae were seperated from other plankton samples. Species identification were based on Dekhnik (1973), Russell (1976), and Rodríguez et al. (2017).

The embryonic development of fish eggs were staged according to Dekhnik (1973). Fish egg and larval abundance in a unit area (n/10 m^2) was calculated according to FAO Fisheries Technical Paper No: 175. PAST Version 2.17. was used for calculating biodiversity indices Shannon Wiener (*H'*) and dominance (*D*) (Hammer et al. 2001). *H'* index ranges between 0 and 5, with higher values indicating greater diversity of species in a particular community. D represents the dominance of certain groups within a community, with values ranging from 0 to 1, where higher values indicate greater dominance.

Sea surface temperature, salinity and dissolved oxygen values were recorded with a YSI 6600 Model Multiple Water Analysis Probe. Mean values were presented as mean ±standard error. Temporal variations of the physico-chemical variations and mean abundance were analyzed with ANOVA. The statistical differences between groups were tested with Tukey's pairwise comparisons. PCA analyses was used for determining the relationship between mean abundance/biodiversity and temporal variations of ichthyoplankton (Jolliffe, 2002).

Results

Physico-chemical parameters

SST ranged between 15.5 Cº and 24.4 Cº. The lowest and the highest SST values were measured on May 17th and August 5th, respectively. SST on December 7th (17.6 Cº) was higher than that in May. Similarly, the mean SST in November (19.2 Cº) was higher than that in May and similar to that in June (19.6 Cº).

The mean dissolved oxygen (DO) was 7.66±0.15 mg/lt. The lowest DO levels were measured in July and August, when the SST was highest. The relatively high dissolved oxygen (DO) values may be due to the study area's distance from industrial facilities and the high surface flow in the Çanakkale Strait. The surface salinity (S) values ranged between 23.2 - 29.5 ppt, with a mean of 25.5±0.23 ppt. The lowest salinity levels were measured in July and August, whereas the highest salinity was detected on October 30th with 29.5 ppt. The highest monthly mean salinity was in November with 27.9±0.09 ppt.

The temporal variations of monthly mean SST (df:8, F: 37.219; P<0.05), DO (df:8; F:2.640; P<0,05) and S (df:8; F:4.763; P<0,05) values were significantly different. The highest variations were observed for SST. According to Tukey Pairwise comparisons, it was detected that the mean SST of May was significantly different from the SST of all months. Mean SST in June was significantly different from that in July, August and September. Also, mean SST in August and September were significantly different from those in November and December SST values in July, August and September reflect the typical summer conditions. The mean salinity levels in November and December were significantly different from those in other months. Mean DO in July and August were significantly different from those in the remaining months.

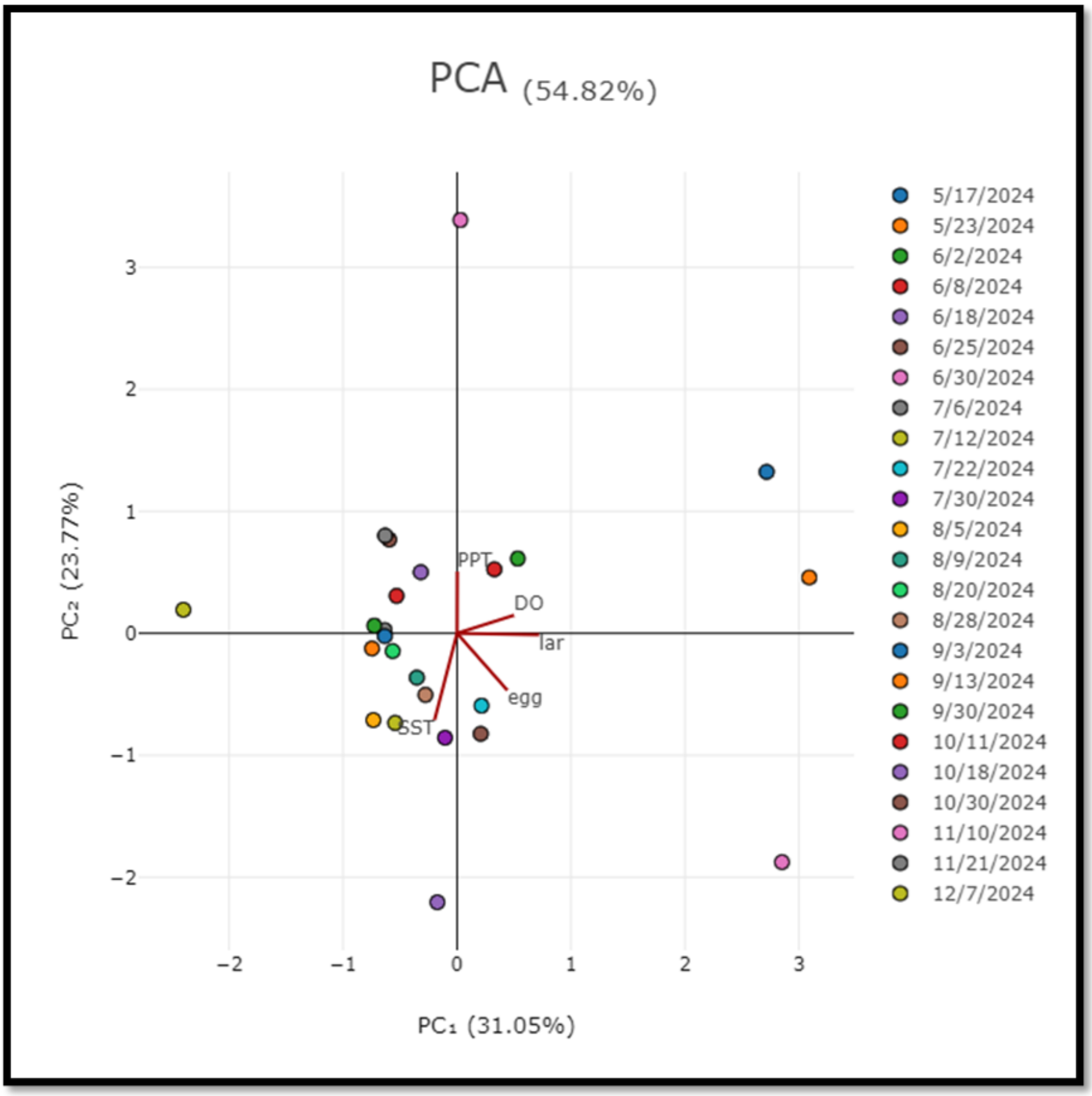

Fig. 8. PCA plot for relationship with biological and physico-chemical parameters.

PCA was performed to determine the relationship between environmental variables and the number of ichthyoplankton species and abundance. PCA1 axis explained 31.05% of the total variance in the study, and PCA2 axis explained 23.77% of the total variance. Both dimensions explained 54.82% of the total variance. SST was detected as the most important variable for fish egg abundance and the salinity negatively effected the larval biomass.

Table 1. Ichthyoplankton assemblages in the Çanakkale Strait, Türkiye

Order:	Clupeiformes		Stage
	Family:	Engraulidae	
		Engraulis encrasicolus (Linnaeus, 1758)	E - Pre - Post
	Family:	Clupeidae	
		Sardina pilchardus (Walbaum, 1792)	E
Order:	Syngnathiformes		
	Family:	Syngnathidae	
		Hippocampus hippocampus (Linnaeus, 1758)	Post
Order:	Perciformes		
	Family:	Serranidae	
		Serranus cabrilla (Linnaeus, 1758)	E - Pre - Post
Order:	Carangiformes		
	Family:	Carangidae	
		Trachurus trachurus (Linnaeus, 1758)	E - Pre - Post
		Trachurus mediterraneus (Steindachner, 1868)	E - Pre
Order:	Eupercaria		
	Family:	Sparidae	
		Diplodus annularis (Linnaeus, 1758)	E - Pre - Post
		Diplodus puntazzo (Linnaeus, 1758)	E
		Pagellus erythrinus (Linnaeus, 1758)	E
		Boops boops (Linnaeus, 1758)	E - Post
		Pagrus pagrus (Linnaeus, 1758)	E - Pre - Post
		Spicara maena (Linnaeus, 1758)	E - Pre - Post
	Family:	Sciaenidae	
		Sciaena umbra Linnaeus, 1758	Post
	Family:	Labridae	
		Thalassoma pavo (Linnaeus, 1758)	Post
		Symphodus ocellatus	E - Pre - Post
Order:	Blenniiformes		
	Family:	Blenniidae	
		Blennius ocellaris Linnaeus, 1758	Post
Order:	Mulliformes		
	Family:	Mullidae	
		Mullus barbatus Linnaeus, 1758	E - Pre - Post
		Mullus surmuletus Linnaeus, 1758	E - Pre - Post

Table 1. Continued

Order:	Callionymiformes		
	Family:	Callionymidae	
		Callionymus lyra Linnaeus, 1758	E - Post
Order:	Gobiiformes		
	Family:	Gobiidae	
		Gobius niger Linnaeus, 1758	Pre - Post
		Gobius paganellus Linnaeus, 1758	Post
		Gobius sp.	Pre - Post
Order:	Carangaria		
	Family:	Sphyraenidae	
		Sphyraena sphyraena (Linnaeus, 1758)	Pre - Post
Order:	Pleuronectiformes		
	Family:	Bothidae	
		Arnoglossus thori Kyle, 1913	Post
		Arnoglossus kessleri Schmidt, 1915	E- Post
	Family:	Soleidae	
		Microchirus variegatus (Donovan, 1808)	E
		Solea solea (Linnaeus, 1758)	E
		Buglossidium luteum (Risso, 1810)	E
Order:	Myctophiformes		
	Family:	Myctophidae	
		Electrona risso (Coco, 1829)	Post
		Myctophum punctatum Rafinesque, 1810	Post
		Ceratoscopelus maderensis (Lowe, 1839)	Post
		Hygophum benoiti (Cocco, 1838)	Post

*Abbreviations: E: Fish egg; Pre: Prelarvae; Post: Postlarvae

Fish eggs

In the present study, sampled eggs were assigned to 19 different fish species belonging to 7 orders and 10 families (Table 1). Sparidae and Soleidae families were the most represented families with 6 and 3 species, respectively. Of the sampled eggs, 62.9% belonged to *Engraulis encrasicolus* and the abundance of all other 18 species was <10%. (Fig. 2).

Eggs belonging to *D. annularis*, *Spicara maena* and *Trachurus trachurus* were represented with higher abundances compared to other species. The total mean fish egg abundance was calculated as 3607.9 eggs/10 m^2. Mean fish egg abundances were found as 4221.8 egg/10 m^2 and 2865.5 eggs/10 m^2 at P1 and P2, respectively. Of the 4786 fish eggs sampled, 2391 eggs were dead corresponding to a mortality rate of 49.96%.

In terms of development, the majority of eggs were at stage 3 and 4 (Fig. 3). Eggs at stages 1, 5 and 6 had frequencies <10% (Fig. 3).

With respect to temporal variations in species richness, eggs sampled in in May and June had higher richness and were represented by 13 and 9 fish species, respectively. The lowest richness was detected in November with only 2 species. The highest *H'* index was observed in May (1.13) and June (1.19). Similarly, the lowest *D* index was detected in May (0.456) and June (0.468).

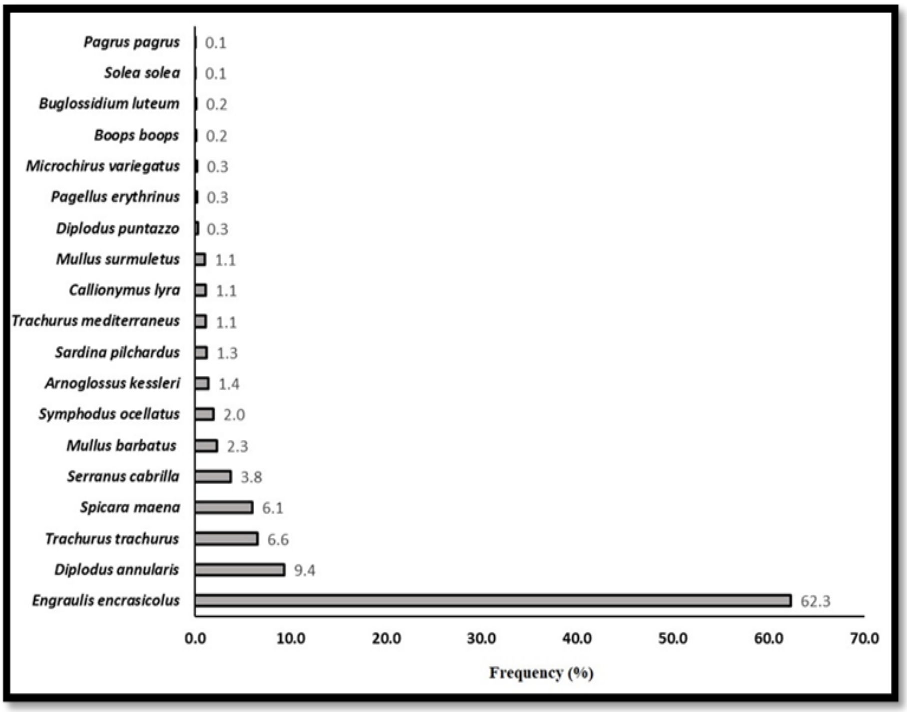

Figure 2. Numerical dominancy of the fish egg species distributed in the Çanakkale Strait

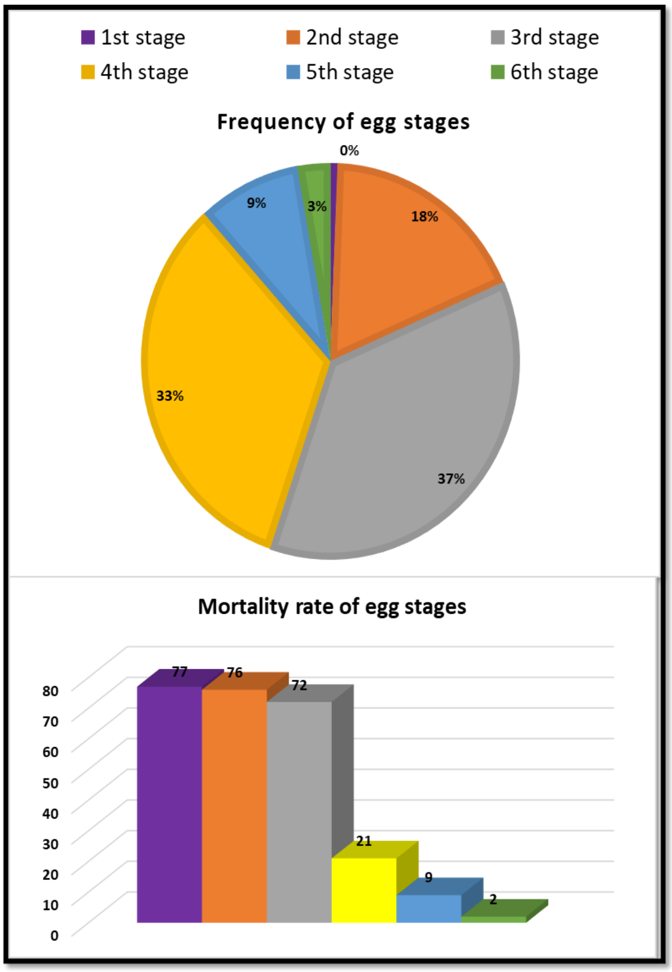

Figure 3. Fish egg development stages and associated mortality rates.

Fish larvae

Sampled larvae were assigned to 27 fish species belonging to 12 ordo and 15 families (Table 1). In terms of the development phase, prelarvae of 13 species and postlarvae of 25 species were identified. Of the total larvae sampled, 71.7% belonged to three species: *E. encrasicolus, D. annularis* and *G. niger* (Fig. 4).

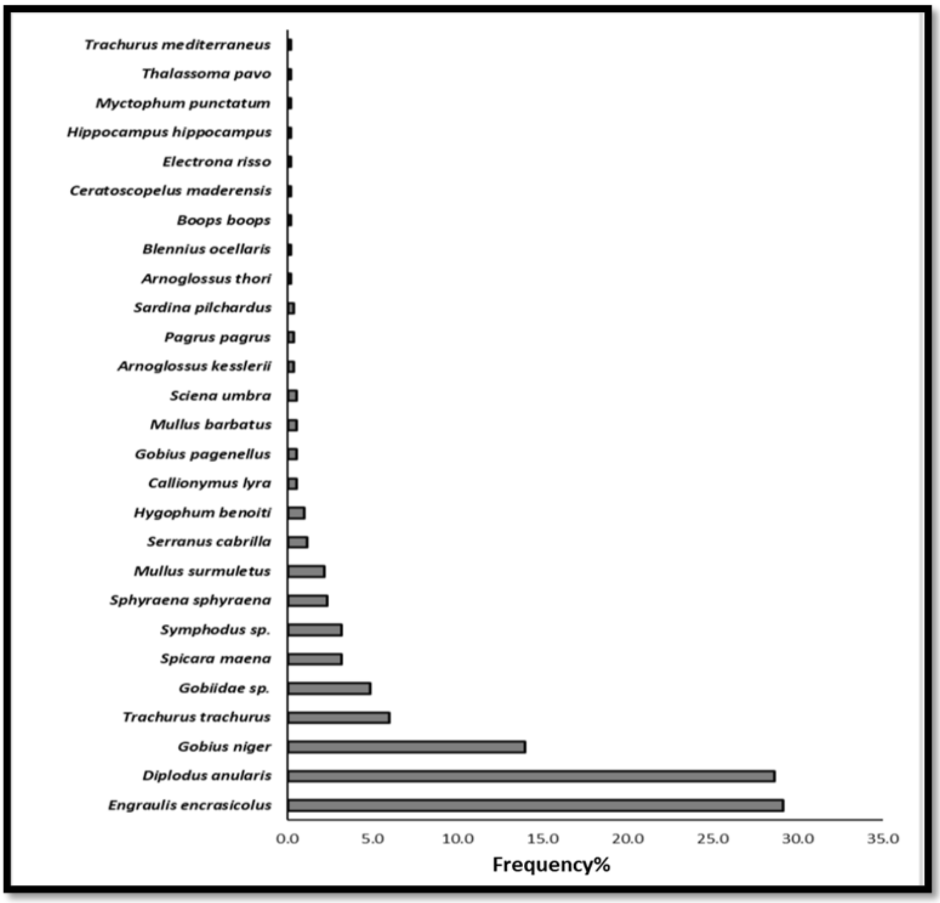

Figure 4. Frequency of occurrence of the fish larvae species distributed in the Çanakkale Strait.

Mean prelarvae, postlarvae and total larvae abundance were found as 33.3 larvae/10 m^2, 419.8 larvae/10 m^2 and 453.2 larvae/10 m^2, respectively (Fig 5). The mean fish larvae abundance found in P1 was slightly higher than that in P2.

The families with the highest percentages were Sparidae and Myctophidae, each represented by four species. The highest number of species, 15, was recorded in June. Species richness was also high in May and July, with 12 and 11 species, respectively. In terms of weekly temporal variations, the highest number of fish larvae was found on May 23rd with 114 specimens, whereas highest taxa number was found on May 23rd and June 25th, with 10 species. Weekly temporal variations of biodiversity indices are given in Figure 5. Between May 17th and December 7th, mean *H'* index and *D* index were found as 1.08 and 0.45, respectively. The highest mean biodiversity was detected between June 2nd and August 28th, corresponding to the *H'* index value of 1.22. The highest biodiversity was detected on August 28th, with 18 fish larvae belonging to 6 different species Larvae biodiversity was also higher on July 22nd and June 2nd with *H'* index values of 1.642 and 1.635, respectively. Larval biodiversity exhibited high weekly variations and the larvae biodiversity indice could not calculated after November 10th, due to the presence of only single species. The lowest larvae biodiversity was 0.198 on September 13th, corresponding to a total of 20 larvae belonging two species.

The dominancy of fish larvae showed strong variations across the sampling period (Fig. 6). Gobiidae members were important representatives until September. *D.annularis* was the major representative larval species in May. *S. maena* was mostly found in June. The other 20 species were poorly distributed until October. *E.encrasicolus* dominated the study area in September and October. By November, abundant species leave the area, the winter spawners begin to appear and abundance decreases.

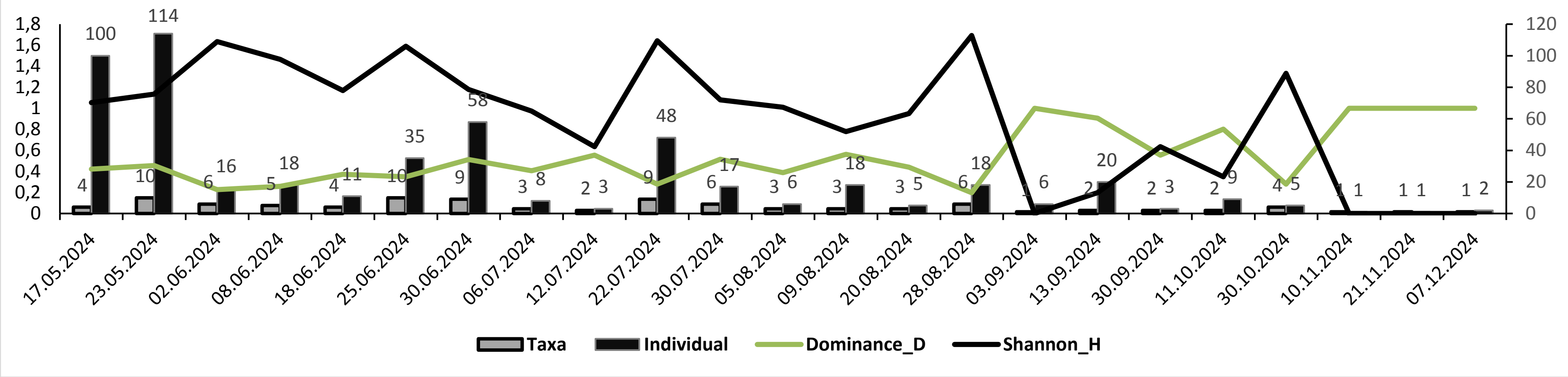

Figure 5. Temporal variation of fish larvae taxa number, abundance, dominance index and Shannon biodiversity index

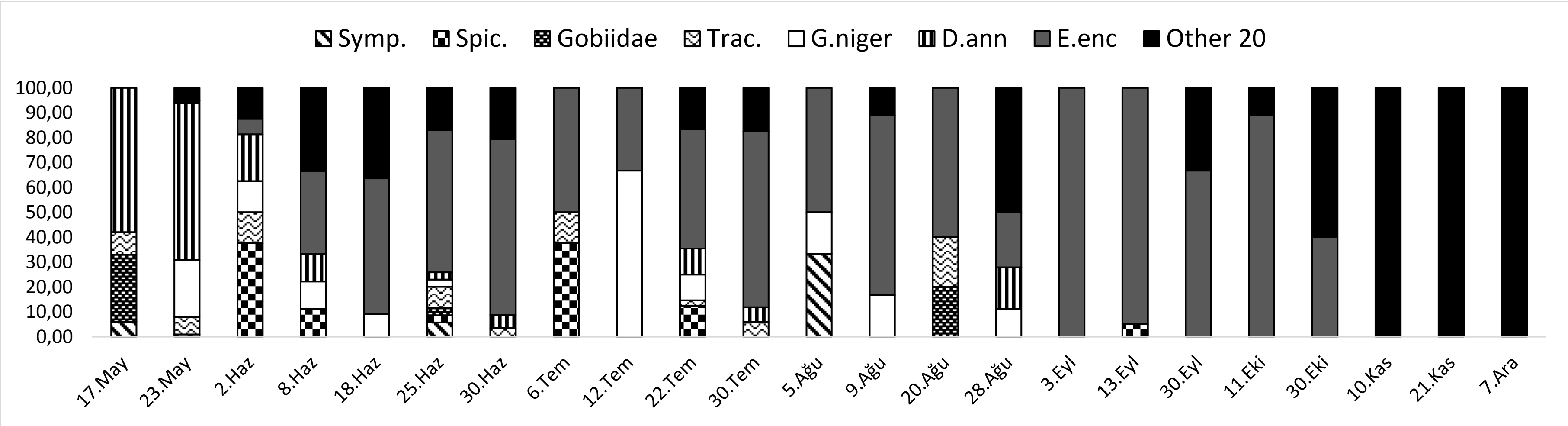

Figure 6. Weekly variation in the dominancy of fish larvae (Symp: *Symphodus ocellatus*; Spic: *Spicara maena*; Trac: *Trachurus trachurus*; D.ann: *Diplodus annularis*; E.enc: *Engraulis encrasicolus*)

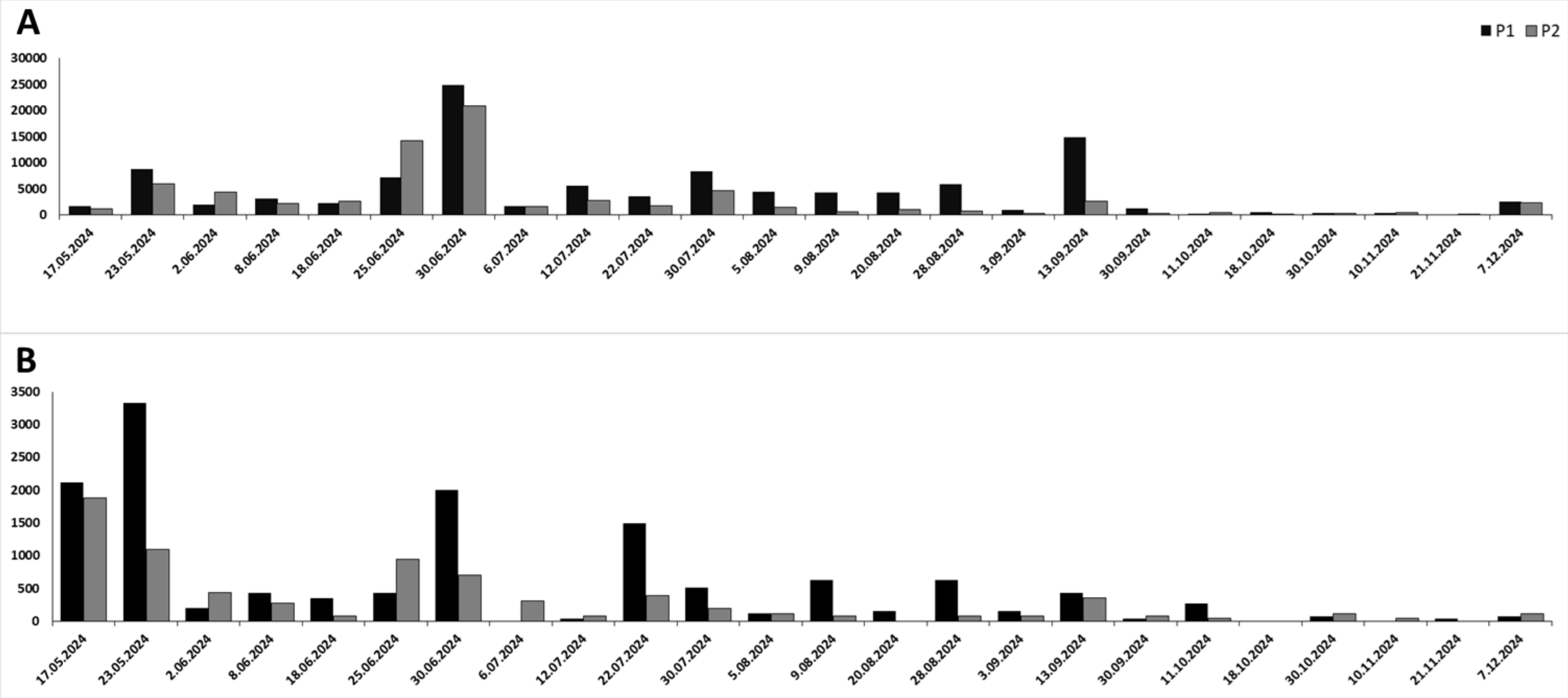

Figure 7. Weekly temporal variation in mean abundance of fish eggs (A) and larvae (B)

Discussion

The onset of spawning in fish species distributed throughout the Mediterranean is primarily attributed to late-spring and early-summer spawners (Tsikliras et al., 2010). Spring-summer ichthyoplankton abundance and biodiversity also were detected as highest around NW Mediterranean by various researchers (Palomera and Olivar, 1996; Sabatés et al., 2003; de Puelles et al., 2007). In the present study, we aimed to assess ichthyoplankton abundance and biodiversity under summer conditions in an area known for its low biodiversity. The data obtained from weekly sampling intervals allowed us to observe rapid fluctuations. According to SST data from the study area, a potential seasonal shift in the temperature regime was observed in comparison to previous studies. Surprisingly, the SST in November (20 °C) and December (17.6 °C) were higher than that in May (15.8 °C). Türkoğlu (2010) reported that SST was 18-19 °C in May and around 14 °C on December 7th, in the Çanakkale Strait. Similarly, Daban ve Yüksek (2017) reported a SST of 18 °C in May and 14 °C in December in the Çanakkale Strait. Differences in SST between the present study and earlier studies may suggest a seasonal shift but more data are needed. The delayed warming up of water temperature did not lead to a decrease in the diversity and abundance of spawning species. In contrast mean fish egg abundance peaked in the May (Fig 7) and species richness of fish larvae remained relatively high in May. Seasonal variations of species richness and ichthyoplankton abundance were similar to those reported in previous studies (Demirel, 2004; Kara, 2015; Daban and Yüksek, 2017). For instance, the highest number of ichthyoplankton taxa was found in May, and it rapidly decreased by the beginning of November. In addition, with the onset of November, autumn-winter spawners such as *Pagrus pagrus* and *Sardina pilchardus* began spawning, as expected. The spring-summer spawners completed their spawning activity although SST remained high. Also, ichthyoplankton abundance was highest in May and started to decrease by September. Alvarez et al. (2012) stated that high spawning activity in early June associated with high metobolism rate, high larval growth rate and low dispersal rate related summer physico-chemical conditions and demersal productivity peak. Thus, the results of this study showed that spawning strategies of Mediterranean teleost species depends on complex and varied biological and abiotic variables and cannot be explained with temporal shift of a several parameters such as SST, salinity or dissolved oxygen. The results of PCA analyses also confirmed this pattern and did not give clear relationship with ichthyoplankton abundance/biodiversity and physical-chemical parameters (SST, salinity and DO%).

In terms of the ichthyoplankton biodiversity, one of the most surprising result was the occurrence of mesopelagic fish species such as *Electrona risso, Myctophum punctatum, Ceratoscopelus maderensis* and *Hygophum benoiti*, which has not been sampled in the ichthyoplankton studies conducted in the Marmara Sea before. Of the species mentioned above, three (excluding *C. maderensis*) and three (excluding *E. risso*) were previously found around Gökçeada Island in the northern Aegean Sea (Daban and İşmen, 2020) and Sığacık Bay in the central Aegean Sea (Uygun and Hoşsucu, 2024), respectively. In addition, all these species were identified in the Greek part of the north Aegean Sea (Isari et al., 2008). Mesopelagic fish species are already well-known in the central and southern part of the Aegean Sea but little is known about their presence in the Sea of Marmara and the Black Sea. The results of this study provide evidence that the distribution areas of these species are expanding. The occurrance of the larvae of the mesopelagic fish species around the northern exist of the Çanakkale Strait may be due to the drifting patterns associated with the cyclonic gyre around Gökçeada and Samothraki. This dispersal pattern may pose challenges to their survival as they move away from their natal habitats into unfamiliar environments, such as the shallower waters of the Çanakkale Strait.

The remaining ichthyoplankton species richness and the mean abundance were similar to those found in previous studies carried out in the adjacent areas. Daban and Yüksek (2017) found 28 ichthyoplankton species in the late spring and summer seasons. When these two studies are compared, the mean abundance of Gobiidae (*G. niger*, *G. pagenellus* and Gobiidae sp.) showed an increase and reached 25% of total larvae abundance. In addition, *D. annularis* (Family: Sparidae) larvae was more abundant after 10 years and the occurrence of relatively high *Mullus barbatus* and *Mullus surmuletus* larvae was noticable. The occurrence of *Hippocampus hippocampus* larvae in both studies is also encouraging in terms of marine biodiversity which may be attributed to to bans on demersal and beam trawling. *H. hippocampus*, is listed as as “Data Deficient” and “Near Threatened” in the Mediterranean as it is subject to high fishing pressure, habitat degredation and limited offspring number according to IUCN (IUCN, 2024). Furthermore, larvae of *Sphyraena sphyraena*, *P. pagrus* and *Sciaena umbra*, which are highly economic species, were reported for the first time in the study area. Among these species, the occurrence of *S.umbra* is promising as it is listed as “Near Threatened” and is considered at risk of extinction in the near future by IUCN (Chao, 2020). When compared with previous studies in which fish eggs and larvae were identified by Kara (2015), Demirel, (2004), Daban and Yüksek, (2017) in the Sea of Marmara Sea, no Scombridae larvae (*Scomber colias*, *Scomber scombrus*, and Thunnus sp.) were found in the present study. This may be due to the increased fishing pressure from seine net fisheries on these species.

The development stages fish eggs reveals information about the spatial proximity of the spawning areas. The vast majority of fish eggs (70%) were found at stages 3rd and 4th of their development. Due to the stratified conditions in the study area, water currents flow from north to south in the upper layer. First-stage eggs suggest that spawning occurs in a nearby area, as the time interval between developmental stages is relatively short. (Pauly and Pullin, 1988). Considering the surface current direction, since the study area is located downstream, it is likely that pelagic eggs are tranported from the Sea of Marmara to the Aegean Sea. Higher mortality rate of early development stages of fish eggs found in the present study aligns well with previous reports of high mortality during the early egg development stages, specifically during cleavage (Thompson, 1981) and gastrulation (Rombough, 1996). It has been stated that as the embyonic development advances, mortality rate decreases (Bunn et al., 2000). Thus, lower occurence of eggs with late development stages in the present study may indicate high mortality rates and can be considered negatively in terms of sustainability.

In summary, it was found that the ichthyoplankton biodiversity of the Çanakkale Strait was mostly derived from coastal resident species. Members of Gobiidae and Labridae and *S. maena*, appears to be successful in competing with the coastal species with increasing abundance over time. Previous studies over the past 10 years showed that ichthyoplankton biodiversity has mostly remained similar. The recent occurrences of some larvae species such as *P. pagrus*, *S. umbra* etc. may be related to the weekly sampling interval, which increased the likelihood of encountering low-abundance species. In addition, abundance and biodiversity values exhibited constant changes on a weekly basis. Therefore, in order to detect species with short developmental periods, frequent sampling intervals are required.

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Conflict of Interest

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

Author Contributions

Ismail Burak DABAN: Designing of the study, identification of species, data analysis, writing original draft preparation. Oğuzhan AYAZ: Sample collections, Ali İŞMEN: Data analysis, checking-original draft preparation.

Ethics Approval

Ethics committee approval is not necessary for this study.

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SHORT COMMUNICATION

A Report on Penaeid Prawn Diversity in Digha Coast, Bay of Bengal, India

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Key words:

Diversity
Digha coast
Penaeid prawn
Report
West Bengal

Abstract: Prawn community in the coastal habitat of Digha is predominantly composed of the family Penaeidae. The present study evaluates the diversity of Penaeidae species in the Digha coast. Penaeidae species were obtained from the Digha Coast between January 2022 and January 2024. A total of 26 species from 8 genera were documented from the Digha Coast and five species represent the first observation from the study area. The Penaeid prawn diversity in Digha Coast, West Bengal of India is substantial. This study will provide valuable insights for prawn fisheries managers and researchers in the study region.

Anahtar kelimeler:

Çeşitlilik
Digha sahili
Penaeid karides
Rapor
Batı Bengal

Digha Kıyısı'ndaki (Bengal Körfezi, Hindistan) Penaeid Karides Çeşitliliği Üzerine Bir Rapor

Öz: Digha kıyı habitatındaki karides topluluğu, ağırlıklı olarak Penaeidae familyasından oluşmaktadır. Bu çalışma, Digha kıyısında Penaeidae türlerinin çeşitliliğini değerlendirmektedir. Penaeidae türleri, Ocak 2022 ile Ocak 2024 arasında Digha Kıyısı'ndan toplanmıştır. Toplamda, Digha Kıyısı'ndan 8 cinsten 26 tür belgelenmiştir ve bunlardan 5 tür, çalışma alanından ilk kez gözlemlenmiştir. Batı Bengal, Hindistan'da Digha Sahili'ndeki Penaeid karides çeşitliliği oldukça zengindir. Bu çalışma, bölgedeki karides balıkçılığı yöneticileri ve araştırmacıları için değerli bilgiler sunacaktır.

Introduction

India's marine and coastal habitats harbours significant natural resources that support the livelihoods of millions of people living in coastal areas. Among a myriad of aquatic organisms, crustaceans have a significant impact on the structure and function of tropical ecosystems in benthic communities, as stated by Hendrickx (1995). Decapod crustaceans, in particular, are a significant source of shellfish and play a crucial role in connecting benthic microorganisms with higher vertebrates in the coastal food chain and food web (Trayer et al., 1984, Huh and An, 1997). Penaeid prawns constitute about 70% of the global prawn catch, and their nutritional value contributes significantly to a thriving commerce and export industry in India (FAO, 2008). Penaeid prawns have rapid growth and have a relatively short lifespan (Rao et al., 2013). Their life cycle typically lasts one year (Rao et al., 2013). The majority of aquaculture is primarily focused on Penaeid prawns, particularly those belonging to the genus Penaeus (Rath et al., 2016). This is due to their ease of cultivation from eggs, rapid growth rate, and high population numbers (Chanda 2016). The fishing industry generates the highest amount of foreign currency, serving as the primary source of income for millions of individuals engaged in direct or indirect fishing-related activities (Rashed-Un-Nabi & Ullah, 2012). The Penaeid prawns that are crucial for industrial fishing along the Indian coast are also present along the Digha Coast, as documented by Chanda (2002, 2014). Digha coast in West Bengal is widely recognized for its extensive beaches that sustain a wide range of aquatic animals. It is located in the Purba Medinipur district, situated at the northernmost point of the Bay of Bengal (21º38'18"N and 87º30'35"E). In the Digha Coast, Penaeidae consists of 8 genera and 26 species (Chanda, 2014). Chanda and Bhattacharya (2002) identified and documented three previously unknown species of prawn from the waters of India. Siva Rama Krishnan (2012) has provided a description of the survey conducted on trawl fishing of Penaeid prawns at the Northern Mandapam

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Coast of Palk Bay. Radhakrishnan (2012) published a comprehensive list with explanatory notes of the Penaeoid, Sergestoid, Tenopoid, and Caridean prawn species found in India. In addition to these, numerous taxonomic studies have been conducted on the group, including those by Fischer and Bianchi (1984), Paulinose (1986), Achuthankutty and Parulekar (1986), Reddy (1995), Pathan and Jalihal (1997), Chanda and Bhattacharya (2002, 2003, 2004, 2009, 2014), Chanda and Roy (2004, 2005), Chanda (2015), Kunju (1967), and Kurian and Sebastean (1993). The aim of this study is to report the diversity of penaeid species found along the Digha Coast between January 2022 to January 2024.

Material and Methods

Study area

The Digha Coast is situated in the Purba Medinipur district of West Bengal. The route extends from Udaipur to Shankarpur. The study was undertaken at four separate study sites: Udaipur (87º 29' 5.751" 21º37'0.994"N), Old Digha (87º31'24.95″E, 21º37'25.621"N), Digha Mohana (87º32'35.898"E, 21º37'48.21"N), and Shankarpur (87º34'17.149"E, 21º38'29.327"). These locations are depicted in Figure 1.

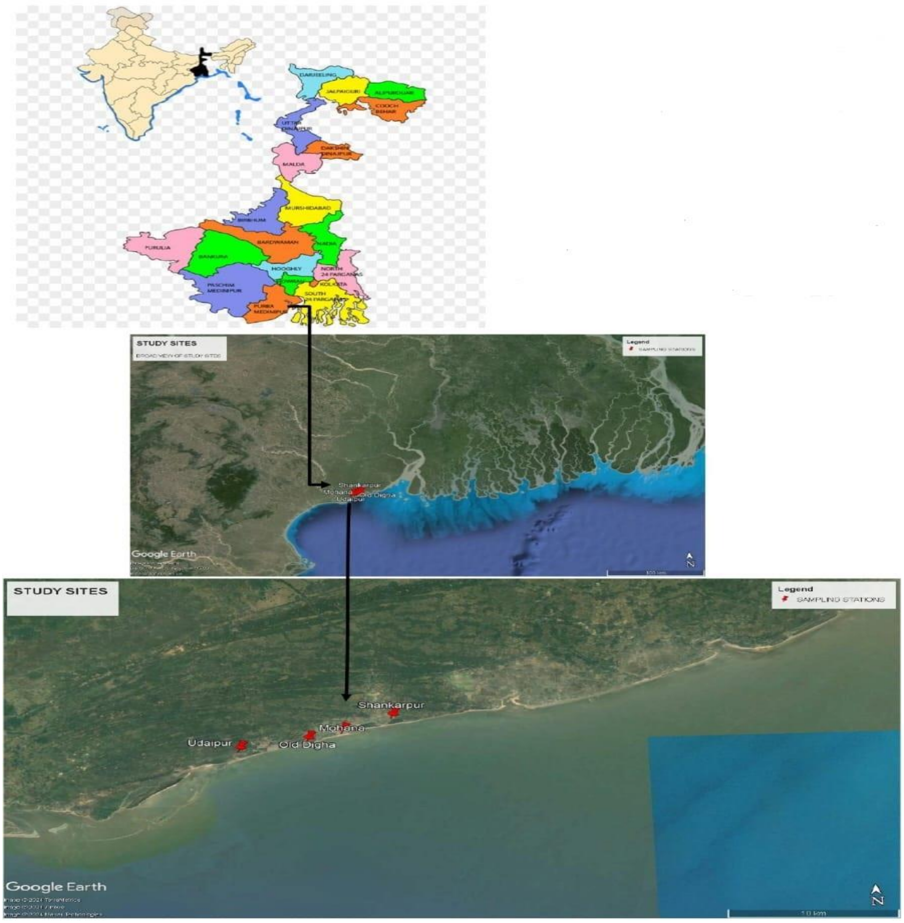

Figure 1. Study area and sampling stations.

Specimens Collection

The samples were collected on a monthly basis during the pre-monsoon, monsoon, and post-monsoon periods in the early morning throughout the study period from January 2022 to January 2024. Prawn samples were obtained from each site through shore fishing (gillnet), trawl fishing, and fish landing centers.

Preservation

The collected samples were kept in a formalin solution with a concentration of 2-4% and were properly catalogued in the laboratory of Raja N.L. Khan Women's College (Autonomous) to ensure accurate identification.

Identification

The specimens in the laboratory were identified, classified by sex, and different taxonomical parameters were measured for easy identification. The overall length was determined by measuring from the tip of the rostrum to the end of the telson, the carapace length was measured from the posterior margin of the orbit to the posterior-median margin of the carapace, and the total weight was measured as wet weight. The identification and categorization of all species were based on Alcock's (1901, 1905 and 1906), FAO species identification sheet (1984), Farfante & Kensley (1997), Fllgel (2002 & 2008), and Ma et al., (2011). The WoRMS Register has been used to verify the valid genus and species name.

Results

In the present study twenty-six penaeid prawn species from eight genera were identified, with *Parapenaeopsis coromandolica* (Alock,1906), *Metapenaeus lysianassa* (De Man,1888), *Helleropenaeopsis sculptilis* (Heller,1862), *Parapenaeopsis stylifera* (H. Milne Edwards, 1837), and *Metapenaeus brevicornis* (H. Milne Edwards,1837) being the most abundant species. Other species present includes *Helleropenaeopsis hardwickii* (Miers,1878), *Kishinouyepenaeopsis maxillipedo* (Alock,1905), *Megokris granulosus* (Haswell,1879), *Metapenaeopsis toloensis* Hall,1962, *Metapenaeus dobsoni* (Miers,1878), *Metapenaeus elegans* De Man,1907, *Metapenaeus ensis* (De Haan,1844), *Metapenaeus stebbingi* Nobili,1904, *Penaeus monodon* Fabricius,1798, *Penaeus japonicus* Spence Bate,1888, *Penaeus semisulcatus* De Haan,1844, *Penaeus latisulcatus* Kishinouye,1896, *Penaeus indicus* H.Milne Edwards,1837, *Penaeus merguiensis* De Man,1888, *Alockpenaeopsis uncta* Alcock,1905, *Metapenaeus monoceros* (Fabricius,1798), *Metapenaeus affinis* (H. Milne Edwards,1837), *Metapenaeus stridulans* (Alock,1905), *Kishinouyepenaeopsis cornuta* (Kishinouye,1900), *Penaeus penicillatus* Alock,1905, *Penaeus canaliculatus* (Olivier,1811). The information regarding various species of the Penaeidae family, observed from January 2022 to January 2024 along the Digha Coast, is presented in Figure 2 and Table 1. In this study, several prawn species that had not been previously reported and observed in Digha, such as *Metapenaeopsis toloensis* Hall, 1962, *Metapenaeus elegans* De Man, 1907, *Metapenaeus stebbingi* Nobili, 1904, *Penaeus latisulcatus* Kishinouye, 1896, and *Kishinouyepenaeopsis cornuta* (Kishinouye, 1900) are reported for the first time. The distinctive morphological characteristics of the newly reported species collected from Digha coast are outlined in Table 2.

Table 1. List of prawn species of Digha Coast collected during January 2022 – January 2024

Genus	Species	Common Name
1. *Helleropenaeopsis*	1. *Helleropenaeopsis sculptilis* (Heller,1862)	Rainbow shrimp
	2. *Helleropenaeopsis hardwickii* (Miers,1878)	Spear shrimp
2. *Parapenaeopsis*	3. *Parapenaeopsis coromandolica* (Alock,1906)	Coromandel shrimp
	4. *Parapenaeopsis stylifera* (H.Milne Edwards, 1837)	Karikkadi shrimp
3. *Kishinouyepenaeopsis*	5. *Kishinouyepenaeopsis maxillipedo* (Alock,1905)	Torpedo shrimp
	6. *Kishinouyepenaeopsis cornuta* (Kishinouye,1900)	Coral shrimp
4. *Megokris*	7. *Megokris granulosus* (Haswell,1879)	Coarse shrimp
5. *Metapenaeopsis*	8. *Metapenaeopsis toloensis* Hall,1962	Tolo velvet shrimp
6. *Metapenaeus*	9. *Metapenaeus lysianassa* (De Man,1888)	Bird shrimp
	10. *Metapenaeus brevicornis* (H.Milne Edwards,1837)	Yellow shrimp
	11. *Metapenaeus dobsoni* (Miers,1878)	Kadal shrimp
	12. *Metapenaeus elegans* De Man,1907	Fine shrimp
	13. *Metapenaeus ensis* (De Haan,1844)	Greasyback shrimp
	14. *Metapenaeus stebbingi* Nobili,1904	Peregrine shrimp
	15. *Metapenaeus stridulans* (Alock,1905)	Fiddler shrimp
	16. *Metapenaeus monoceros* (Fabricius,1798)	Speckled shrimp
	17. *Metapenaeus affinis* (H. Milne Edwards,1837)	Jinga prawn
7. *Alcockpenaeopsis*	18. *Alockpenaeopsis uncta* Alcock ,1905	Uncta shrimp
8. *Penaeus*	19. *Penaeus merguiensis* De Man,1888	Banana prawn
	20. *Penaeus japonicus* Spence Bate,1888	Kuruma prawn
	21. *Penaeus semisulcatus* De Haan,1844	Green tiger prawn
	22. *Penaeus latisulcatus* Kishinouye,1896	Western king prawn
	23. *Penaeus indicus* H.Milne Edwards,1837	Indian prawn
	24. *Penaeus penicillatus* Alock,1905	Redtail prawn
	25. *Penaeus canaliculatus* (Olivier,1811)	Witch prawn
	26. *Penaeus monodon* Fabricius,1798	Giant tiger prawn

Penaeus monodon

Alcockpenaeopsis unta

Penaeus indicus

Penaeus semisulcatus

Metapenaeus lysianassa

Metapenaeopsis toloensis

Penaeus latisulcatus

Metapenaeus stebbingi

Penaeus merguiensis

Helleropenaeopsis sculptilis

Parapenaeopsis coromandolica

Metapenaeus brevicornis

Penaeus penicillatus

Metapenaeus stridulans

Kishinouyepenaeopsis cornuta

Metapenaeus monoceros

Metapenaeus affinis

Figure 2. Photographs of Penaeidae species collected during January 2022 – January 2024 from Digha Coast

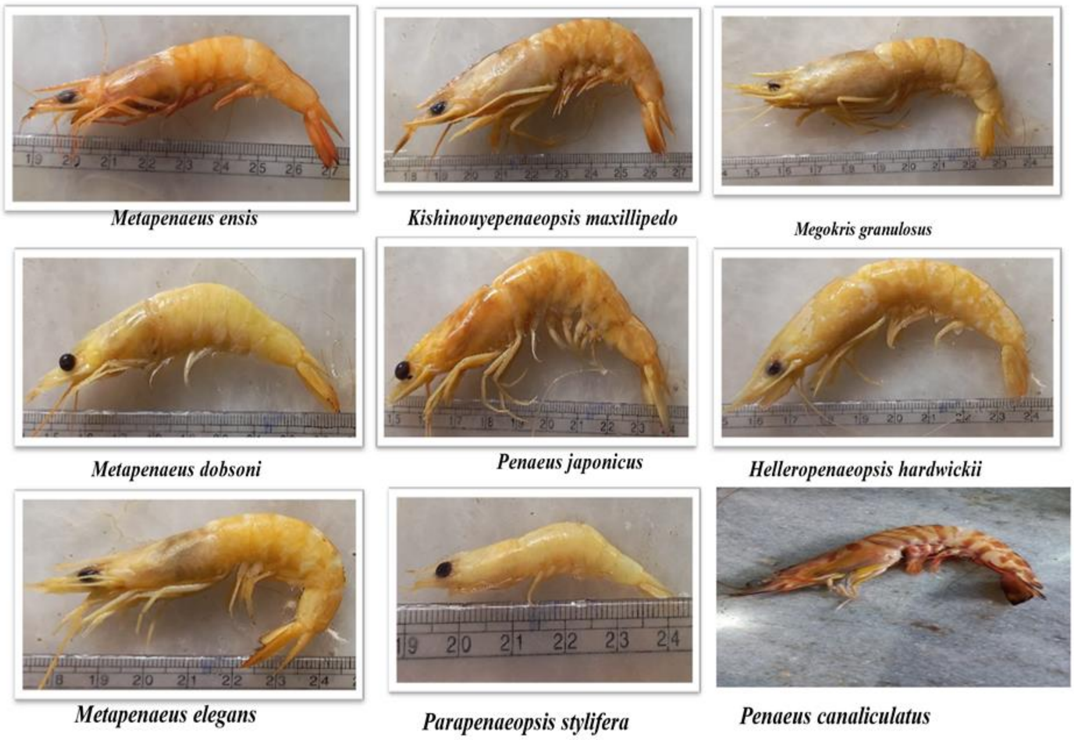

Figure 2 continued. Photographs of Penaeidae species collected during January 2022 – January 2024 from Digha Coast

Table 2. Diagnosis of newly reported prawn species obtained from Digha Coast during January 2022 - January 2024

Sl.	Penaeidae species	Diagnosis
1	*Metapenaeopsis toloensis*	Rostrum straight, dorsal teeth 9, stridulating organ with 14 small ridges in a curved at ¼ of carapace, body densely sexual maturity, asymmetrical petasma, right distoventral projection shorter with small apical processes, left distovental projection broadly swollen, outer intermediate strip lightly shorter and subdivided distally, distomedian libule longer, thelycum subquadrate with circled.
2	*Metapenaeus elegans*	Number of dorsal teeth 9, telson arm consists of spinules and has a distomedian projection of the petasma that is directed anterolaterally. The petasma is leaf-like in shape and has a longitudinal groove.
3	*Metapenaeus stebbingi*	Number of dorsal teeth 8, telson arm consists of a row of tiny, moveable spines. The distomedian projection of the petasma has a stiff, styliform appendix that is directed forward and ventrally indented.
4	*Penaeus latisulcatus*	Number of upper rostral teeth is 12, while the number of ventral teeth is 1. The ischial spine on the first pereopod is not present. In the petasma, the distomedian projection reaches to or slightly intended the distal margins of the costae. The thelycum has an anterior process with raised anterolateral edges, forming two ringlike projections. The posterior process is triangular.
5	*Kishinouyepenaeopsis cornuta*	The rostrum is slightly sigmoidal or straight, with eight dorsal teeth. There is a basial spine on both the first and second pereopods. The petasma has long and slender horn-like distolateral projections that diverge proximally and curve inward distally. Each projection has a small dorsal spiniform process. The anterior plate of the thelycum is oval and hollow, and it is fused posteromedially with the posterior plate. The posterior plate has a pair of lateral depressions. Behind the thelycum, there is a median tuft of long setae.

Table 3. Comparative checklist of Penaeid prawn found in Digha Coast

Sl.No.	Species Name	Goswami (1992)	Chanda and Bhattacharya (2002)	Sarkar and Talukdar (2003)	Present Study (2024)
1	*Helleropenaeopsis sculptilis* (Heller,1862)	+	+	+	+
2	*Helleropenaeopsis hardwickii* (Miers,1878)	-	+	+	+
3	*Parapenaeopsis coromandolica* (Alock,1906)	+	+	+	+
4	*Parapenaeopsis stylifera* (H.Milne Edwards, 1837)	-	-	+	+
5	*Kishinouyepenaeopsis maxillipedo* (Alock,1905)	+	-	+	+
6	*Megokris granulosus* (Haswell,1879)	-	+	-	+
7	**Metapenaeopsis toloensis* Hall,1962	-	-	-	+
8	*Metapenaeus lysianassa* (De Man,1888)	+	-	+	+
9	*Metapenaeus brevicornis* (H.Milne Edwards,1837)	+	+	+	+
10	*Metapenaeus dobsoni* (Miers,1878)	+	-	+	+
11	**Metapenaeus elegans* De Man,1907	-	-	-	+
12	*Metapenaeus ensis* (De Haan,1844)	-	+	-	+
13	**Metapenaeus stebbingi* Nobili,1904	-	-	-	+
14	*Penaeus monodon* Fabricius,1798	+	+	+	+
15	*Penaeus japonicus* Spence Bate,1888	-	-	+	+
16	*Penaeus semisulcatus* De Haan,1844	+	-	+	+
17	**Penaeus latisulcatus* Kishinouye,1896	-	-	-	+
18	*Penaeus indicus* H.Milne Edwards,1837	+	+	+	+
19	*Alockpenaeopsis uncta* Alcock ,1905	+	+	+	+
20	*Penaeus merguiensis* De Man,1888	-	-	+	+
21	*Penaeus penicillatus* Alock,1905	-	-	+	+
22	*Metapenaeus monoceros* (Fabricius,1798)	+	-	+	+
23	*Metapenaeus stridulans* (Alock,1905)	-	+	-	+
24	**Kishinouyepenaeopsis cornuta* (Kishinouye,1900)	-	-	-	+
25	*Metapenaeus affinis* (H. Milne Edwards,1837)	+	+	+	+
26	*Penaeus canaliculatus* (Olivier,1811)	+	-	+	+
27	*Trachysalambria curvirostris* (Stimpson,1860)	+	-	+	-
28	*Atypopenaeus stenodactylus* (Stimpson,1860)	+	-	+	-
29	*Parapenaeopsis longipes* Alcock,1905	+	-	+	-
30	*Parapenaeopsis acclivirostris* (Alock,1905)	+	-	+	-
Total		17	11	22	26

*New report from the region

Discussion

In the present study twenty-six penaeid prawn species belonging to eight genera under Penaeidae were identified, with *Parapenaeopsis coromandolica* (Alock,1906), *Metapenaeus lysianassa* (De Man,1888), *Helleropenaeopsis sculptilis* (Heller,1862), *Parapenaeopsis stylifera* (H. Milne Edwards, 1837), and *Metapenaeus brevicornis* (H.Milne Edwards,1837) being the most abundant species (Table 1 and Figure 2). Among the 26 reported species, five species, namely *Metapenaeopsis toloensis, Metapenaeus elegans, Metapenaeus stebbingi, Penaeus latisulcatus, and Kishinouyepenaeopsis cornuta* are reported for the first time from Digha coast (Table 3). Previously, *M. toloensis*, *M. elegans* and *K. cornuta* were reported from Andaman and Andhra Pradesh coasts and *P. latisulcatus* and *M. stebbingi* were reported from the Gulf of Kutch and Maharastra coasts of India (Chanda, 2017). The distinct morphological traits exhibited by these species are given in Table 2.

The initial investigation of marine biodiversity along the Digha coast was conducted by Bharati Goswami between 1975 and 1987 (Bharati Goswami, 1992). A total of 17 species belonging to 8 different genera of the Penaeidae family have been documented in the Digha region and its nearby coastlines (Bharati Goswami, 1992). From Digha and its nearby coasts, 11 species belonging to 6 genera of the Penaeidae family have been identified by Chanda and Bhattacharya (2002). Digha and its neighbouring coast have 22 species belonging to 8 genera of the Penaeidae family were reported by Sarkar and Talukdar (2003). Farfante and Kensley (1997) provided a comprehensive list of 26 genera that belong to the Penaeidae. Later, Flegel (2007, 2008) expressed significant doubts regarding the categorization of the genus Penaeus into six genera and finally Ma et al. (2011), refuted the six-genus classification of Penaeus and strongly suggested to retain the old Penaeus genus which is still the valid classification and as such, family Penaeidae has 21 valid genera. Indian waters are represented by 17 genera (Chanda, 2017) and Digha waters are represented by 26 species under 6 genera.

Conclusion

Penaeid prawns are one of the most economically significant taxa in estuaries and coastal waters, and they play an important role in regulating the structure and function of tropical ecosystems. The prawn fishery makes a considerable contribution to the national fishing sector in terms of gross output, gross revenue profits, and exports. The uncontrolled harvesting of juveniles in inshore and deep sea areas, as well as the disposal of numerous species, are diminishing Penaeidae diversity. The present study found 26 Penaeidae species from eight genera and five species represent the first observation from the study area. Fishing is a major economic component for the region investigated in the present study and is one of the most important sources of income for residents of the Digha coastal belt and the adjacent area. As a result, conservation efforts are often adopted for Penaeidae species of the Digha coast to protect the existing Penaeidae diversity in West Bengal of India.

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Conflict of interest

The authors declare that there are no conflicts of interest.

Author Contributions

Angsuman Chanda & Arun Jana Designing, Monitoring, Communication, Reviewing; Sanchita Nayak Tripathi & Godhuli Sit- Specimen collection, Identification, Data analysis, Manuscript preparation and finally all authors discussed the results and contributed to the final manuscript.

Ethics Approval

Ethical clearance from Institutional Animal Ethics Committee (IAEC), Approval no. 16/IAEC (1)/RNLKWC/2023, dated-15/06/2023

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Abstract

Briefly give the objectives, methods, results and conclusions and it should not exceed 300 words.

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Should indicate the subject of the article which is generally based on a brief interpretation of the related literature. The novelty and the aim of the study should be clearly stated. The introduction should be general enough to attract a reader's attention from a broad range of scientific disciplines.

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- D. Nak, E. Kuruoglu and Y. Nak, planned and designed the research. Z. M. Ekıcı, D. Koca, T. Avcılar, M. E. Sahın and A. H. Shahzad provided help in the clinic process. M. O. Ozyıgıt and Z. Avcı Kupelı made histopathological examinations. All authors discussed the results and contributed to the final manuscript.
- D. Çayan and E. Unur conceived the ideas of the study and writing manuscript; D. Çayan, M. Nisari, D. Patat and E. Dağlı performed data collection and analysis; H. Akalın performed gene expression stages.

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Journal article

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