

## Research Article

# The infralittoral zone on the south Aegean coast of Türkiye: A special emphasis on the fish fauna of Kazıklı Cove, Milas (Muğla)

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The survey conducted between 2019 and 2020, was aimed at collecting current data on the temporal and spatial changes of fish community structure in three distinct habitats of the infralittoral region of Kazıklı Bay in Milas, Türkiye. Using a fine beach seine, deployed seasonally at three different stations, the study identified 33 species from 14 families belonging to 5 orders. The most dominant species observed was the larvae of *Engraulis encrasicolus*. Other dominant species observed were the adults of *E. encrasicolus*, *Mullus surmuletus*, *Mullus barbatus*, and *Pagellus erythrinus*, which were documented only during three seasons viz. Spring, Summer and Autumn. Species that were observed only during one season include *Belone belone*, *Diplodus puntazzo*, *Epinephelus aeneus*, *Gobius cobitis*, *Oxyurichthys petersii*, *Siganus rivulatus* and *Gobius ophiocephalus* in spring; *Acantholabrus palloni*, *Atherina boyeri*, *Gobius niger*, *Salaria basilisca*, *Microlipophrys canevae*, *Sparus aurata*, *Sphyræna viridensis*, *Symphodus cinereus*, and *Syngnathus acus* in summer; *Labrus bergylta*, *Labrus merula*, *Symphodus ocellatus*, and *Symphodus tinca* in autumn; and *Spicara* sp., *Diplodus vulgaris*, and *Chelon auratus* in winter. Consequently, sampling stations II and III showed moderate species diversity, with station III having the highest number of observed fish species, reflecting differences in species composition and habitat preferences.

**[Keywords:** Aegean Sea, Fish fauna, Infralittoral zone, Kazıklı Cove, Shallow water]

## Introduction

Ecological diversity is the variety of ecosystems, species communities, and the number of species within these communities in a given region. The Earth's ecological diversity varies significantly across regions, primarily due to latitudinal variations. As the number of species in a community increases, so does species diversity and the amount of information contained in the community. A community with an equal number of members from each species is considered to have higher information content and species diversity than a community where only a few species are represented by many members while others are represented by very few members<sup>1</sup>. Coastal waters, especially river estuaries and lagoon systems, are highly productive areas that support diverse fish populations<sup>2</sup>. These populations experience spatial and temporal changes due to seasonal variations in climatic and hydrographic conditions within these complex systems. Estuaries and lagoon systems serve as both reproductive and feeding grounds for many adult fish, while also providing protection against predators<sup>3-8</sup>. Several studies<sup>7,9-13</sup> have reported that coastal areas are also ideal habitats for the growth and development of juvenile populations.

Numerous studies have been conducted by various researchers on both sides of the Aegean Sea to

determine the species diversity in bays and coves<sup>10,12,14-18</sup>. Infralittoral zones are essential for habitat conservation in marine environments. They host diverse array of marine fish species and provide feeding and sheltering areas to their eggs and larvae. Coastal habitats, river mouths, and lagoon systems harbour distinct fish communities in both space and time, and are where biological diversity is most strongly felt. The confluence of river mouths with the marine environment has distinct characteristics because the nutritious salts carried by the rivers facilitate the development of phytoplankton<sup>15</sup>. These areas exhibit a slightly different dynamic structure from other marine environments, as they serve the purposes of reproduction, feeding, and protection from predators for many adult fish species<sup>6,9</sup>. Coastal areas and shallow waters also serve as feeding and shelter areas, known as nurseries for many fish species, including commercial ones<sup>19-21</sup>. These habitats have been known as valuable commercial areas for many years<sup>22-23</sup>, but they are also the most affected by human-induced destruction, such as habitat loss<sup>24</sup>, chemical pollution<sup>25,26</sup>, artisanal and recreational fishing<sup>9,27</sup> and recently, anthropogenic noise pollution<sup>28</sup>.

On the other hand, littoral zones are shallow, well-lit ecosystems that play critical ecological roles in the life cycle of fish fauna. In these areas, high photosynthetic production enriches the food web, while macrophytes and rocky structures provide opportunities for spawning, juvenile rearing, and shelter from predators<sup>29</sup>. The abundance of insects and invertebrates offers feeding advantages, and species diversity is generally higher than in pelagic and deep-water zones<sup>30-33</sup>. However, as in Kazıklı Cove, anthropogenic pressures in the infralittoral zone, such as coastal construction, pollution, and water-level fluctuations, can disrupt the ecological integrity of these sensitive habitats and negatively affect fish stocks<sup>29,31</sup>.

The aim of this study is to gain fresh insights into the composition and diversity of fish species in Kazıklı Cove, Milas, Muğla. Specifically, the study aims to compile a quantitative checklist of fish species in shallow waters and monitor changes in species richness and abundance over time. The study also examines the distribution of fish fauna across three closely proximate infralittoral habitats, observing temporal and spatial changes. Given the area's ecological significance, with its surrounding vacation homes and numerous aquaculture facilities, these data play a vital role in sustainable management.

## Materials and Methods

### Study area

Milas Kazıklı village in the Muğla province is on the Akbük forest road, which connects Milas and Aydın. Kazıklı village is 40 km east of Milas and is bordered by Bozbük to the southwest and Gürçamlar village to the southeast. Furthermore, Kazıklı village is conveniently located just 7 kms west of the popular tourist destination of Akbük, Didim. To the south of Kazıklı village lies the Gulf of Güllük, which includes Akbük Cove, Kazıklı Cove, Güllük Cove, and the Güllük Lagoon, in the order from west to east. Figure 1 provides the location of the research area and the sampling stations within the cove.

Various factors, including depth, substrate characteristics, bottom vegetation status, freshwater input, proximity to the shore and road, and likely logistical support, were considered when choosing three different stations within the cove. Table 1 provides the substrate and vegetation status of Stations I, II, and III in Kazıklı Cove. Station I: The substrate at this sampling station is soft at depths of



Fig. 1 — Location of Kazıklı Cove within the borders of Milas district in Muğla, Turkey and sampling stations (I, II and III) in Kazıklı Cove.

Table 1 — Substrate and vegetation status at the sampling stations I, II, and III in Kazıklı Bay

Sampling stations	Coordinates of studied stations	Bottom structures and vegetation case
I	37°20'36.17" N; 27°28'39.73" E	Sandy and muddy substrate, covered with seagrass, <i>Zostera</i> sp. and <i>Cymodocea nodosa</i>
II	37°20'39.49" N; 27°28'19.16" E	Sandy and muddy bottom, covered partly with <i>Zostera marina</i>
III	37°20'09.94" N; 27°29'6.84" E	Predominantly clay and muddy, with a few small patches of sand and presence of <i>Zostera marina</i> , <i>Ulva lactuca</i> , <i>Caulerpa prolifera</i>

0 – 5 m and is covered with seagrass (*Zostera* sp.) in certain areas. It is also home to mollusc and *Callinectes sapidus* (Blue crab) species, in shallow areas with sandy and muddy bottoms. Station II: This station is located west of the first station, and the substrate is covered with *Zostera marina*. It is a relatively shallow area that contains a large number of *Penaeus* sp. Station III: This station is situated to the east of the first station and is a habitat with shallow waters and some reed beds surrounding it. In winter, a small freshwater inlet appears on the eastern side of the area. The ground is predominantly clay and muddy, with a few small patches of sand (Table 1).

### Sample collection and analysis

The project was planned for seasonal sampling at the three stations described above in Kazıklı Cove over the course of three years, from 2019 to 2021, and was evaluated accordingly. The study did not take into account how the equipment used in beach seining (mesh size, floats, weights, head rope, foot rope, cod-end, and distance between wings) affected the results. Each beach seining operation was conducted for 15 – 20 min and was treated as a straight line, with a 282-meter line at Station I, a 224-meter line at Station II, and a 190-meter line at Station III (Fig. 1).

The fish specimens were placed in containers with a mixture of formalin and seawater for preservation, and then transported to the laboratory. Using a 1 mm fish measuring ruler, the total length (in cm) of each identified species was measured, and their total weight (in g) was determined using a Sartorius scale with a precision of 0.01 g.

The studies conducted by Whitehead *et al.*<sup>34</sup> and Fisher *et al.*<sup>35</sup> were utilised to establish species within families. Additionally, Eshmeier<sup>36</sup> was used to determine systematic categories. Statistical analysis of species from three sampling stations included percentage distributions, minimum and maximum values, means, and standard deviations. The sex of the specimens caught in the study was not taken into account. All metrics were documented in the accompanying tables. The distribution of the species identified across sampling stations and seasons was evaluated using the Shannon-Weaver diversity index<sup>37</sup>.

$$H' = - \sum_{i=1}^f (pi \ln pi)$$

Here,  $H'$  represents the species diversity,  $pi$  represents the ratio of the number of  $i$ -th species to the total number of species, and  $f$  represents the total number of species.

The values obtained from the index were evaluated according to Washington<sup>38</sup>. Accordingly, values between 0 – 1 represent low diversity, values between 1 – 3 represent moderate diversity, and values between 3 – 5 represent high diversity.

The Biodiversity Pro (V.2) program was used for a Bray-Curtis similarity analysis to examine species similarities across sampling stations.

### Results

In Kazıklı Cove, beach seine net samplings identified a total of 33 fish species from 14 families, belonging to 5 orders (Table 2). Throughout all four

seasons, the most commonly observed species in the area were *Engraulis encrasicolus* larvae. Adult *E. encrasicolus*, *Mullus surmuletus*, *Mullus barbatus*, and *Pagellus erythrinus* were sampled during three seasons. The species caught only in a single season can be listed as follows: *Belone belone*, *Diplodus puntazzo*, *Epinephelus aeneus*, *Gobius cobitis*, *Oxyurichthys petersii*, *Siganus rivulatus*, and *Gobius ophiocephalus* in spring season; *Acantholabrus palloni*, *Atherina boyeri*, *Gobius niger*, *Salaria basilisca*, *Microlipophrys canevae*, *Sparus aurata*, *Sphyrnaena viridensis*, *Symphodus cinereus*, and *Syngnathus acus* in summer season; *Labrus bergylta*, *Labrus merula*, *Symphodus ocellatus*, and *Symphodus tinca* in autumn season; and *Diplodus vulgaris*, *Chelon auratus* and *Spicara* sp. in the winter season (Table 3). Upon analysing the specimens caught from Kazıklı Cove throughout the four seasons, encountered several different types of consumers. Zooplankton, small crustaceans, and larvae of larger animals mainly feed on the phytoplankton in the area. Tables 2 – 6 provide the average, minimum, and maximum lengths and weights, number of specimens caught, and overall occurrence percentages of fish species distributed in the three sampling stations in Kazıklı Bay. The most common species were *Engraulis encrasicolus* larvae (96.31 %), *E. encrasicolus* (0.96 %), *Atherina hepsetus* (0.55 %), *Diplodus sargus* (0.54 %), and *Atherina boyeri* (0.43 %). These five species accounted for 98.8 % of the total catch in Kazıklı Bay.

The number of specimens for each species varied among the stations. Sampling station III had the highest number of specimens, and contained sandy-muddy and *Zostera marina* habitats with occasional freshwater entrance. The second-ranked station was Station I, with sandy-muddy habitats including *Zostera marina* and *Cymodocea nodosa*, and Station II was at last with sandy-muddy and *Zostera marina* habitats.

Fish species diversity was evaluated across the sampling stations using the Shannon–Wiener diversity index ( $H'$ ), which revealed notable spatial differences in diversity patterns. At Station I, the  $H'$  value was calculated as 3.18, while Station II exhibited a slightly higher value of 3.25. Both values fall within the moderate diversity range (typically 1.5 – 3.5), indicating a relatively balanced species composition and equitable distribution of individuals among species at these two locations. In contrast, Station III showed a substantially lower  $H'$  value of 0.23,

Table 2 — General composition of fish species in Kazıklı Cove

Sr No	Orders	Families	Species	Common names
1	Beloniformes	Belonidae	<i>Belone belone</i> (Linnaeus, 1761)	Garfish
2	Syngnathiformes	Syngnathidae	<i>Syngnathus acus</i> Linnaeus, 1758	Greater pipefish
3	Clupeiformes	Engraulidae	<i>Engraulis encrasicolus</i> (Linnaeus, 1758)	European anchovy
4	Mulliformes	Mullidae	<i>Mullus barbatus</i> Linnaeus, 1758	Red mullet
5	Mulliformes	Mullidae	<i>Mullus surmuletus</i> Linnaeus, 1758	Sur mullet
6	Perciformes	Sparidae	<i>Diplodus annularis</i> (Linnaeus, 1758)	Annular seabream
7	Perciformes	Sparidae	<i>Diplodus sargus</i> (Linnaeus, 1758)	White seabream
8	Perciformes	Sparidae	<i>Diplodus vulgaris</i> (Geoffroy Saint-Hilaire, 1817)	Common two-banded seabream
9	Perciformes	Sparidae	<i>Diplodus puntazzo</i> (Walbaum, 1792)	Sharpsnout seabream
10	Perciformes	Sparidae	<i>Sparus aurata</i> Linnaeus, 1758	Gilthead seabream
11	Perciformes	Sparidae	<i>Pagellus erythrinus</i> (Linnaeus, 1758)	Common pandora
12	Perciformes	Sparidae	<i>Pagellus bogaraveo</i> (Brünnich, 1768)	Blackspot seabream
13	Perciformes	Sparidae	<i>Spicara</i> sp.	Picarel
14	Perciformes	Labridae	<i>Symphodus cinereus</i> (Bonnaterre, 1788)	Grey wrasse
15	Perciformes	Labridae	<i>Symphodus ocellatus</i> (Linnaeus, 1758)	-
16	Perciformes	Labridae	<i>Symphodus tinca</i> (Linnaeus, 1758)	East Atlantic peacock wrasse
17	Perciformes	Labridae	<i>Acantholabrus palloni</i> (Risso, 1810)	Scale-rayed wrasse
18	Perciformes	Labridae	<i>Labrus bergylta</i> Ascanius, 1767	Ballan wrasse
19	Perciformes	Labridae	<i>Labrus merula</i> Linnaeus, 1758	Brown wrasse
20	Gobiiformes	Gobiidae	<i>Gobius niger</i> Linnaeus, 1758	Black goby
21	Gobiiformes	Gobiidae	<i>Gobius cobitis</i> Pallas, 1814	Giant goby
22	Gobiiformes	Gobiidae	<i>Oxyurichthys petersii</i> (Klunzinger, 1871)	Peter's goby
23	Gobiiformes	Gobiidae	<i>Gobius ophiocephalus</i> Pallas, 1814	Grass goby
24	Blenniiformes	Blenniidae	<i>Salaria basilisca</i> (Valenciennes, 1836)	Blennie-basilic
25	Blenniiformes	Blenniidae	<i>Microlipophrys canevas</i> (Vinciguerra, 1880)	Caneva's blenny
26	Mugiliformes	Mugilidae	<i>Chelon labrosus</i> (Risso, 1827)	Thicklip grey mullet
27	Mugiliformes	Mugilidae	<i>Chelon auratus</i> (Risso, 1810)	Golden grey mullet
28	Perciformes	Epinephelidae	<i>Epinephelus aeneus</i> (Geoffroy Saint-Hilaire, 1817)	White grouper
29	Scombriformes	Pomatomidae	<i>Pomatomus saltatrix</i> (Linnaeus, 1766)	Bluefish
30	Istiophoriformes	Sphyrnaenidae	<i>Sphyrna viridensis</i> Cuvier, 1829	Yellow mouth barracuda
31	Acanthuriformes	Siganidae	<i>Siganus rivulatus</i> Forsskål & Niebuhr, 1775	Marbled spinefoot
32	Atheriniformes	Atherinidae	<i>Atherina boyeri</i> Risso, 1810	Big-scale sandmelt
33	Atheriniformes	Atherinidae	<i>Atherina hepsetus</i> Linnaeus, 1758	Mediterranean sandmelt

indicating very low species diversity. This suggests that the fish community at Station III is dominated by one or very few species, with minimal species richness and evenness. To further examine community structure, Bray–Curtis similarity analysis was conducted based on species abundance data. The results demonstrated the highest similarity in the number of individuals between Station I and Station II, with a similarity coefficient of 67.10 %. This finding supports the close resemblance in community composition between these two stations. Conversely, the lowest similarity was observed between Station II and Station III (0.24 %), highlighting a marked dissimilarity in fish community structure. These results are presented graphically in Figure 2.

When examining the seasonal dynamics of fish species richness in Kazıklı Bay, a total of 17 species

were recorded in spring, 19 species in summer, 11 species in autumn, and only 7 species in winter. This pattern indicates a clear seasonal fluctuation in species occurrence. The Shannon–Wiener index was also applied to assess seasonal changes in species diversity. The highest  $H'$  value was observed in summer (4.32), followed by spring (4.09), autumn (3.59), and winter (2.81). According to the conventional interpretation of  $H'$ , values exceeding 4.0 are considered indicative of very high diversity. Thus, summer and spring were characterized by very high species diversity, autumn showed moderately high diversity, and winter exhibited the lowest diversity level among the four seasons. In terms of the number of individuals, Bray–Curtis similarity analysis was performed to compare seasonal fish assemblages. The highest similarity was found between spring and

Table 3 — Seasonal occurrence of species caught from sampling stations

Species Captured	Seasons											
	Spring			Summer			Autumn			Winter		
	St. I	St. II	St. III	St. I	St. II	St. III	St. I	St. II	St. III	St. I	St. II	St. III
1 <i>Acantholabrus palloni</i>				X								
2 <i>Atherina boyeri</i>				X	X							
2 <i>Atherina boyeri</i> larva			X									
3 <i>Atherina hepsetus</i>	X	X	X	X	X		X					
4 <i>Belone belone</i>	X											
5 <i>Chelon auratus</i>												X
6 <i>Chelon labrosus</i>				X								X
7 <i>Diplodus annularis</i>				X	X	X				X	X	X
8 <i>Diplodus puntazzo</i>		X										
9 <i>Diplodus sargus</i>	X	X	X	X	X	X	X	X	X			
10 <i>Diplodus vulgaris</i>											X	X
11 <i>Engraulis encrasicolus</i>	X	X	X	X	X		X					
11 <i>E. encrasicolus</i> larva	X	X	X	X	X		X	X		X		X
12 <i>Epinephelus aeneus</i>	X											
13 <i>Gobius cobitis</i>			X									
14 <i>Gobius niger</i>	X	X		X	X							
15 <i>Gobius ophiocephalus</i>	X											
16 <i>Labrus bergylta</i>							X	X				
17 <i>Labrus merula</i>							X					
18 <i>Microlipophrys caneavae</i>				X	X							
19 <i>Mullus barbatus</i>	X	X	X	X	X	X	X	X	X			
20 <i>Mullus surmuletus</i>	X	X	X	X	X	X	X	X	X			
21 <i>Oxyurichthys petersii</i>	X											
22 <i>Pagellus bogavere</i>				X	X	X		X				
23 <i>Pagellus erythrinus</i>	X	X	X	X	X	X	X	X	X			
24 <i>Pomatomus saltatrix</i>	X	X	X	X	X	X						
25 <i>Salaria basilisca</i>				X								
26 <i>Siganus rivulatus</i>		X	X									
27 <i>Sparus aurata</i>				X	X					X	X	
28 <i>Sphyræna viridensis</i>				X								
29 <i>Spicara</i> sp.										X		
30 <i>Symphodus cinereus</i>					X							
31 <i>Symphodus ocellatus</i>							X					
32 <i>Symphodus tinca</i>							X					
33 <i>Syngnathus acus</i>				X	X							

autumn (93.13 %), suggesting a high degree of overlap in species composition and relative abundances between these two seasons. The lowest similarity was recorded between summer and winter (21.14 %), reflecting a pronounced seasonal shift in community structure (Fig. 3).

During fieldwork, small cryptic species belonging to families Blennidae, Syngnathidae, and Gobiidae, as well as anchovy post-larvae were observed frequently. This was due to the sandy, muddy, and sometimes vegetated habitats in the study areas along the shoreline.

## Discussion

Coastal regions are at risk of ecological harm due to industrialisation, tourism, secondary residences, and pollution caused by these activities. Furthermore, the depletion of natural fish populations, particularly juvenile fish and other organisms, as well as the presence of fish farming cages in these areas for the past 20 – 30 years, have contributed to this damage. Lagoons, estuaries, swamps, deltas, and river mouths are particularly vulnerable ecosystems that provide nourishment, shelter, and protection to juvenile fish and other species. Even minor alterations in one or more physical factors or human-induced adverse effects can have a rapid and harmful impact on these shallow waters, potentially leading to their complete collapse. Given the delicate ecological balance of shallow waters, it is crucial to conduct regular monitoring and remediation efforts as needed to ensure their sustainability.

The presence of anchovy larvae, which were extensively sampled throughout the year in Kazıklı Bay, creates a beautiful example of the food pyramid in the area. These fish gain energy by feeding on calanoid copepods, which are their main prey. The energy that anchovies obtain is used for growth, vital activities, or reproduction. As a result, anchovies fulfil their roles in the food pyramid either through natural deaths or by being consumed by tertiary consumers. Furthermore, anchovies can also travel from the cove to the open sea or return to the cove. Like many organisms, these fish are highly influenced by the temperature and salinity of the water in which they live. Small-sized species, such as members of Atherinidae, Clupeidae, and Gobiidae, that complete their entire life cycle in such environments are typical inhabitants of the sandy-muddy habitats found in shallow coastal regions. On the other hand, members of the Labridae, Syngnathidae, and Blennidae families are typically associated with fish fauna related to algal communities. These areas are considered ideal habitats for juvenile fish to grow, feed, and find protection from predators. Dulčić *et al.*<sup>39</sup> stated that various physical and chemical factors, such as water temperature, dissolved oxygen levels, salinity, depth, turbidity, and wave conditions, affect the distribution of juveniles. In addition, the natural structure of the substrate and the feeding habits of the species can also determine their prevalence<sup>40</sup>. The differences in the distribution of the species at three different stations sampled may also indicate differences in bottom structure and feeding behaviour.

Table 4 — Minimum, maximum, and mean (Mean±SD) lengths and weights, and overall occurrence percentages of species in fish composition of Station I

Species caught	Overall%	N	Station I			
			Length (cm)		Weight (g)	
			Min-Max.	Mean±SD	Min-Max.	Mean±SD
<i>Acantholabrus palloni</i>	0.00	-	-	-	-	-
<i>Atherina boyeri</i>	0.43	82	1.0-7.8	5.75±1.15	0.17-3.4	1.63±0.76
<i>Atherina boyeri larva</i>	0.01	-	-	-	-	-
<i>Atherina hepsetus</i>	0.55	116	4.5-8.2	6.04±0.79	0.73-4.42	1.78±0.75
<i>Belone belone</i>	0.01	2	10.5-12.3	11.4±1.27	1.13-1.52	1.33±0.28
<i>Chelon labrosus</i>	0.01	-	-	-	-	-
<i>Diplodus annularis</i>	0.13	16	2.1-11.1	4.51±2.87	0.1-22.38	3.64±6.41
<i>Diplodus sargus</i>	0.54	53	1.6-8.5	3.02±1.04	0.07-9.69	0.60±1.31
<i>Diplodus puntazzo</i>	0.01	-	-	-	-	-
<i>Diplodus vulgaris</i>	0.03	-	-	-	-	-
<i>Epinephelus aeneus</i>	0.01	1	9.00	-	9.85	-
<i>Engraulis encrasicolus</i>	0.96	14	1.5-2.6	2.01±0.32	-	-
<i>E. encrasicolus larva</i>	96.31	100	-	-	-	-
<i>Gobius cobitis</i>	0.01	-	-	-	-	-
<i>Gobius niger</i>	0.13	7	4.0-7.8	5.43±1.34	0.67-4.54	1.9±1.36
<i>Labrus bergylta</i>	0.09	-	-	-	-	-
<i>Labrus merula</i>	0.01	-	-	-	-	-
<i>Salaria basilisca</i>	0.01	1	10.6	-	9.5	-
<i>Chelon auratus</i>	0.02	-	-	-	-	-
<i>Microlipophrys caneavae</i>	0.06	11	2.8-3.5	3.23±0.64	0.21-1.54	0.43±0.38
<i>Mullus barbatus</i>	0.14	20	4.0-7.5	4.74±0.77	0.48-4.31	1.05±0.85
<i>Mullus surmuletus</i>	0.18	32	4.1-9.6	5.16±5.18	0.55-9.19	1.51±1.62
<i>Oxyurichthys petersii</i>	0.01	2	2.5-2.8	2.65±0.21	0.18-0.23	0.21±0.03
<i>Pagellus erythrinus</i>	0.07	5	4.6-10.2	7.12±2.06	0.89-14.46	5.59±5.23
<i>Pagellus bogaraveo</i>	0.05	2	2.3-2.5	2.4±0.14	0.13-0.14	0.14±0.01
<i>Pomatomus saltatrix</i>	0.03	1	4.1	-	0.52	-
<i>Siganus rivulatus</i>	0.05	-	-	-	-	-
<i>Sparus aurata</i>	0.01	-	-	-	-	-
<i>Spicara sp.</i>	0.08	17	2.0-3.0	2.49±0.26	0.1-0.28	0.15±0.05
<i>Sphyaena viridensis</i>	0.02	4	4.5-5.8	5.1±0.65	0.31-0.78	0.56±0.25
<i>Symphodus ocellatus</i>	0.01	-	-	-	-	-
<i>Symphodus tinca</i>	0.01	-	-	-	-	-
<i>Symphodus cinereus</i>	0.01	-	-	-	-	-
<i>Syngnathus acus</i>	0.01	1	13.5	-	1.29	-
<i>Gobius ophiocephalus</i>	0.01	-	-	-	-	-

Owing to its coastal morphology and the ecologically favourable conditions created by lagoon and bay systems, Muğla Province has emerged as a strategic hub for aquaculture in Türkiye. In particular, its production capacity for gilthead seabream (*Sparus aurata*) and European seabass (*Dicentrarchus labrax*) supports sectoral continuity by ensuring a stable supply to national and international markets<sup>17,18</sup>. Nevertheless, although intensive production accounts for a substantial proportion of Türkiye's marine finfish aquaculture output, it also poses challenges, including the risk of exceeding carrying capacity, concerns regarding environmental

sustainability, elevated disease pressure, and constraints in feed supply. Accordingly, the development of smart and sustainable aquaculture practices through interdisciplinary research is warranted. While aquaculture expansion generates economic opportunities, it also increases the risks of pollution, landscape alteration, and biodiversity loss<sup>17,18</sup>. Key contributors to environmental impacts include feed composition, fecal wastes, fertilizers, disinfectants, antibiotics, and probiotics<sup>25,29,41</sup>. In particular, in areas surrounding high-density cage farms in Güllük Bay and Kazıklı Bay, combined pressures from recreational fishing and the rapid

Table 5 — Minimum, maximum, and mean (Mean±SD) lengths and weights, and overall occurrence percentages of species in fish composition of Station II

Species caught	Overall%	N	Station II			
			Length (cm)		Weight (g)	
			Min-Max.	Mean±SD	Min-Max.	Mean±SD
<i>Acantholabrus palloni</i>	0.03	6	2.2-4.5	3.23±0.96	0.11-0.92	0.42±0.36
<i>Atherina boyeri</i>	0.43	-	-	-	-	-
<i>Atherina boyeri larva</i>	0.01	-	-	-	-	-
<i>Atherina hepsetus</i>	0.55	-	-	-	-	-
<i>Belone belone</i>	0.01	-	-	-	-	-
<i>Chelon labrosus</i>	0.01	2	12.5-18.0	15.25±3.89	20.82-54.89	37.86±24.09
<i>Diplodus annularis</i>	0.13	7	2.1-3.0	2.7±0.29	0.15-0.31	0.24±0.05
<i>Diplodus sargus</i>	0.54	60	1.5-11.0	4.43±2.75	0.04-23.65	3.04±4.55
<i>Diplodus puntazzo</i>	0.01	2	3.5-6.2	4.85±1.90	0.47-3.61	2.04±2.22
<i>Diplodus vulgaris</i>	0.03	5	4.3-6.3	5.14±0.76	1.04-3.53	1.90±0.99
<i>Epinephelus aeneus</i>	0.01	-	-	-	-	-
<i>Engraulis encrasicolus</i>	0.96	-	-	-	-	-
<i>E. encrasicolus larva</i>	96.31	-	-	-	-	-
<i>Gobius cobitis</i>	0.01	-	-	-	-	-
<i>Gobius niger</i>	0.13	20	4.0-8.0	6.61±1.06	0.51-5.6	3.18±1.35
<i>Labrus bergylta</i>	0.09	18	11.0-22.5	18.01±2.46	15.51-129.63	79.11±28.23
<i>Labrus merula</i>	0.01	2	3.9	3.9±0.0	0.58-1.03	0.81±0.32
<i>Salaria basilisca</i>	0.01	-	-	-	-	-
<i>Chelon auratus</i>	0.02	-	-	-	-	-
<i>Microlipophrys canevae</i>	0.06	-	-	-	-	-
<i>Mullus barbatus</i>	0.14	9	9.6-11.6	10.46±0.84	9.31-18.36	12.17±3.21
<i>Mullus surmuletus</i>	0.18	5	4.2-18.5	8.42±5.91	0.68-73.7	16.94±31.9
<i>Oxyurichthys petersii</i>	0.01	-	-	-	-	-
<i>Pagellus erythrinus</i>	0.07	4	4.7-5.7	5.28±0.43	1.16-2.28	1.68±0.41
<i>Pagellus bogaraveo</i>	0.05	-	-	-	-	-
<i>Pomatomus saltatrix</i>	0.03	2	10.7-15.7	13.2±3.54	8.82-17.25	18.04±13.03
<i>Siganus rivulatus</i>	0.05	5	17.5-20.6	19.2±1.39	67.75-120.93	91.23±24.33
<i>Sparus aurata</i>	0.01	2	15.0-18.0	16.5-2.12	41.07-70.51	55.79±20.82
<i>Spicara sp.</i>	0.08	-	-	-	-	-
<i>Sphyraena viridensis</i>	0.02	-	-	-	-	-
<i>Symphodus ocellatus</i>	0.01	1	4.0	-	0.68	-
<i>Symphodus tinca</i>	0.01	2	10.1-10.4	10.3±0.21	13.67-14.55	14.11±0.62
<i>Symphodus cinereus</i>	0.01	1	7.5	-	7.17	-
<i>Syngnathus acus</i>	0.01	1	14.5	-	1.6	-
<i>Gobius ophiocephalus</i>	0.01	1	7.3	-	3.19	-

growth of second-home development over the past two decades underscore the need for careful regional monitoring.

The health and sustainability of local adult fish populations depend heavily on the success of their larvae and juvenile stages. Therefore, it is crucial that juveniles have access to nurseries, which serve as shelters and feeding areas, to ensure the conservation of stocks and the sustainability of fisheries<sup>32,42-44</sup>. Settlement in these nursery areas can vary throughout the year depending on the species<sup>45,46</sup>, leading to changes in species composition at different times of the year. Additionally, the process of joining the

resident population usually follows similar patterns, although some alternatives may exist. During settlement, one or several groups of settlers may form a single or multi-peaked settlement event.

Beck *et al.*<sup>20</sup> and Heck *et al.*<sup>47</sup> provide a detailed description of the "nursery value" of a particular habitat. They explain that the "nursery value" of a particular habitat is the amount of new juvenile individuals produced per unit area and delivered to adult fish populations. This is determined by a combination of four components: the number of initial settlers provided to the shelter-nutrition-growth area per unit area (a), their growth (b),

Table 6 — Minimum, maximum, and mean (Mean±SD) lengths and weights, and overall occurrence percentages of species in fish composition of Station III

Species caught	Overall %	N	Station III			
			Length (cm)		Weight (g)	
			Min-Max.	Mean±SD	Min-Max.	Mean±SD
<i>Acantholabrus palloni</i>	0.03	-	-	-	-	-
<i>Atherina boyeri</i>	0.43	10	3.0-7.0	5.19±1.42	0.17-2.98	1.28±0.92
<i>Atherina boyeri larva</i>	0.01	1	1.0	-	-	-
<i>Atherina hepsetus</i>	0.55	1	5.1	-	0.9	-
<i>Belone belone</i>	0.01	-	-	-	-	-
<i>Chelon labrosus</i>	0.01	-	-	-	-	-
<i>Diplodus annularis</i>	0.13	4	7.5-12.1	9.3±1.97	5.79-27.93	14.46±9.45
<i>Diplodus sargus</i>	0.54	3	3.5-7.5	5.23±2.05	0.58-7.34	3.08±3.71
<i>Diplodus puntazzo</i>	0.01	-	-	-	-	-
<i>Diplodus vulgaris</i>	0.03	2	3.4-4.3	3.85±0.63	0.45-0.99	0.72±0.38
<i>Epinephelus aeneus</i>	0.01	-	-	-	-	-
<i>Engraulis encrasicolus</i>	0.96	192	2.0-7.0	4.36±1.18	0.15-1.7	0.69±0.27
<i>E. encrasicolus larva</i>	96.31	20500	-	-	-	-
<i>Gobius cobitis</i>	0.01	2	4.5-5.1	4.8±0.42	0.84-1.29	1.07±0.32
<i>Gobius niger</i>	0.13	-	-	-	-	-
<i>Labrus bergylta</i>	0.09	1	7.0	-	4.36	-
<i>Labrus merula</i>	0.01	-	-	-	-	-
<i>Salaria basilisca</i>	0.01	-	-	-	-	-
<i>Chelon auratus</i>	0.02	4	5.1-13.7	7.9±3.9	1.1-20.98	6.56±9.64
<i>Microlipophrys caneavae</i>	0.06	1	4.4	-	0.58	-
<i>Mullus barbatus</i>	0.14	1	4.7	-	0.8	-
<i>Mullus surmuletus</i>	0.18	2	5.0-5.8	5.4±0.57	1.15-2.06	1.61±0.65
<i>Oxyurichthys petersii</i>	0.01	-	-	-	-	-
<i>Pagellus erythrinus</i>	0.07	5	6.0-7.0	6.46±0.38	4.12-2.72	3.32±0.55
<i>Pagellus bogaraveo</i>	0.05	9	4.7-5.5	5.1±0.34	1.3-2.19	1.66±0.34
<i>Pomatomus saltatrix</i>	0.03	3	3.6-3.9	3.77±0.15	0.37-0.48	3.77±0.15
<i>Siganus rivulatus</i>	0.05	6	7.6-23.3	17.58±5.37	5.06-126.75	77.20±43.29
<i>Sparus aurata</i>	0.01	1	18.2	-	80.02	-
<i>Spicara sp.</i>	0.08	-	-	-	-	-
<i>Sphyaena viridensis</i>	0.02	-	-	-	-	-
<i>Symphodus ocellatus</i>	0.01	-	-	-	-	-
<i>Symphodus tinca</i>	0.01	-	-	-	-	-
<i>Symphodus cinereus</i>	0.01	-	-	-	-	-
<i>Syngnathus acus</i>	0.01	-	-	-	-	-
<i>Gobius ophiocephalus</i>	0.01	-	-	-	-	-

survival (c), and their capacity to join the adult population (d).

In the study of Güllük Lagoon<sup>48</sup>, a total of 1,960 fish specimens were caught, including *Mugil cephalus*, *Mugil capito*, *Solea solea*, *Dicentrarchus labrax*, *Chelon labrosus*, *Anguilla anguilla*, *Sparus aurata*, and *Liza saliens*. Meanwhile, Akyol & Ceyhan<sup>17</sup> identified 42 species from 24 families in their study of wild fish living under fish farms located in the North Aegean and Güllük Bay, including the southern Aegean Sea. The fish species collected under cages in the southern Aegean Sea were limited to 24

species. The identified fish species were Atherinidae: *Atherina boyeri*; Balistidae: *Balistes caprisicus*; Belonidae: *Belone belone*; Carangidae: *Caranx rhonchus*, *Seriola dumerili*, *Trachurus mediterraneus*; Centrarchidae: *Spicara smaris*; Clupeidae: *Sardina pilchardus*, *Sardinella aurita*; Engraulidae: *Engraulis encrasicolus*; Gymnuridae: *Gymnura altavela*; Labridae: *Symphodus tinca*; Moronidae: *Dicentrarchus labrax*, *Mugil cephalus*; Myliobatidae: *Aetomylaeus bovinus*; Scombridae: *Scomber colias*; Sparidae: *Boops boops*, *Diplodus puntazzo*, *Diplodus sargus*, *Diplodus vulgaris*, *Oblada melanura*, *Sarpa*

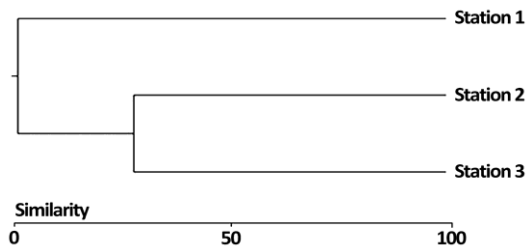


Fig. 2 — Similarity between stations based on the abundance

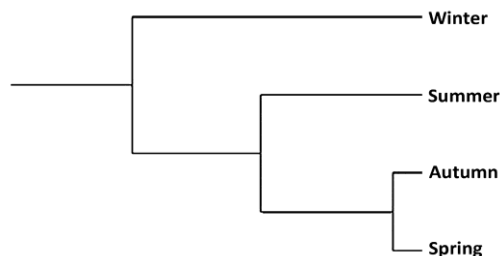


Fig. 3 — Similarity between seasons based on the abundance

*salpa*, *Sparus aurata*; and Xiphiidae: *Xiphias gladius*. Some of the species found in their study overlap with those identified in this research.

Further, Cerim & Ateş<sup>18</sup> examined the age, growth, and weight-length relationships of 1136 common sole (*Solea solea*) sampled from the Gulf of Güllük. However, the present study did not encounter any larvae or juveniles of the *S. solea*, indicating that the area may not be suitable for common sole juveniles. While comparing similarities among stations, differences were observed in the number of individuals caught. Stations I and II showed higher similarity, while station III differed from stations I & II due to differences in ground structure and weak freshwater input.

*Engraulis encrasicolus*, *Mullus barbatus*, *Sparus aurata*, *Diplodus sargus*, *Epinephelus aeneus*, *Pomatomus saltatrix*, and *Siganus rivulatus* are economically important species in the region. According to 2022 official data from the Turkish Statistical Institute (TurkStat; <https://www.tuik.gov.tr/>) and the General Directorate of Fisheries and Aquaculture of the Ministry of Agriculture and Forestry (<https://www.tarimorman.gov.tr/BSGM>), regional catch for these species were 22,342; 1,045; 1,872; 842; 78; 512; and 348 tonnes, respectively. For *Sparus aurata*, the 1,872 tonnes figure represents both wild-caught fish and aquaculture production. *Epinephelus aeneus*, a protected species, has restricted fishing. On the other hand, *Siganus rivulatus*, an invasive species, had a catch amount of 348 tonnes in 2022. Its

population has grown rapidly in recent years, making monitoring crucial for protecting native ichthyofauna.

The debate about the impact of fish farming on the marine environment has been ongoing since the start of the aquaculture industry. With an increase in the number of fish cages in coastal areas, it has become clear that water quality is deteriorating at a rapid pace. Unfortunately, local communities are sometimes quick to blame fish farms without scientific evidence, leading to conflicts. To prevent biased views and support, it's important to conduct scientific studies that identify and evaluate sources of pollution<sup>49</sup>. Coastal area management must focus on protecting sensitive habitats and ensuring the sustainability of water resources and natural ecosystems. Following these principles, scientific studies can help understand the effects of fish farms on the coastal environment and assist development of planning and management tools<sup>49</sup>.

## Conclusion

The results of this study highlight the critical role that shallow waters play in supporting abundant fish populations. It is evident that observing and safeguarding these areas is necessary for maintaining healthy marine ecosystems. Therefore, it is vital to conduct further research on the potential impacts of human activities on coastal environments. The effects of factors such as fish farms, secondary residences, tourism investments, artisanal, and recreational fishing must be thoroughly examined to develop comprehensive management strategies that aim to mitigate any negative impacts. The information obtained from future research can be used to create planning and management tools that ensure sustainable practices are implemented for the long-term preservation of these essential resources. It is crucial to consider the economic potential of biological diversity and take measures to protect endangered species. Failing to do so for the sake of short-term benefits could have negative consequences for future generations. We believe that approaching this topic with this understanding will not only benefit our country but also the Mediterranean and Aegean basins.

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### Conflict of Interest

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

### Ethical Statement

The study received approval from the Ethics Review Committee of Ege University, and the Ministry of Agriculture and Forestry's General Directorate of Fisheries and Aquaculture granted permission for shallow water fishing, issued December 12, 2019 (reference number E-12153681-325.04.02-9145126).

### IRB Approval

Approval was obtained from the Institutional Review Board of Ege University (Decision 2021/24 and Decision date 14.10.2021) for this study.

### Author Contributions

ET: Conceptualisation, administration, methodology, sample collection and processing, investigation, and writing; SG: Sample processing, methodology, formal analysis, and writing; and BT: Sample collection and processing.

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