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RECEIVED 27 August 2025

ACCEPTED 30 October 2025

PUBLISHED 18 November 2025

CITATION

Wang X, Zhao D, Liu Q, Lu T, Zhong J,
Chen W, Xie S and Chen S (2025) Larval and
juvenile fish assemblages in the sandy beach
surf zones of Nanji Island, China.
Front. Mar. Sci. 12:1693531.
doi: 10.3389/fmars.2025.1693531

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Larval and juvenile fish assemblages in the sandy beach surf zones of Nanji Island, China

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The Nanji Islands, a nationally protected marine reserve in China, support high biodiversity but face significant fishery resource depletion. This study aims to describe the community structure of larval and juvenile fishes in the surf zone, a critical nursery habitat, to provide baseline data for conservation and management. Monthly surf zone sampling was conducted at five stations around Nanji Island from March 2023 to February 2024. Samples were collected during daytime (8:00–17:00) using a seine net (1×4m, 1mm mesh) with three replicates per station. A total of 8,568 fish were collected, representing 35 species from 21 families. The community was dominated by postflexion larvae (89.41%). Engraulidae was the most abundant family, with *Engraulis japonicus* constituting 91.30% of all specimens. Species number and catch per unit of effort (CPUE) peaked in August (16 species) and May, respectively, with minimal abundances from December to March. All diversity indices were highest in August and lowest in January. Cluster analysis of the data from 12 months indicated a strong, though not statistically significant, ecological pattern of community separation. The five stations were divided into western and eastern clusters. The species number, Margalef's richness index, and Shannon–Wiener's diversity index showed a positive correlation with temperature, but salinity showed a negative correlation with species number, CPUE and Shannon–Wiener's diversity index. Niche partitioning observed between surf zone and open sea species in the Nanji Islands indicates that the surf zone acts as a specialized nursery for a subset of species (e.g., *Engraulis japonicus* and *Lateolabrax maculatus*), as opposed to a general habitat for all larval and juvenile fishes. The research contributes essential data necessary for the conservation and sustainable management of Nanji Island's fisheries.

KEYWORDS

community structure, diversity pattern, early stages of fish, littoral zone, Nanji Islands National Marine Nature Reserve, spatial-temporal variations

1 Introduction

The Nanji Islands are located southeast of Pingyang County, Zhejiang Province in the East China Sea and were designated as one of China's first five national marine nature reserves in 1990. They were later accepted by United Nations Educational, Scientific and Cultural Organization (UNESCO) as a member of the World Network of Biosphere Reserves. The islands are 45 km away from the mainland, with a total protected area of 201.06 km² and a land area of 11.13 km², comprising 85 islands, including Nanji Island (Cai, 2021). This area is part of the Wen-Tai fishing grounds and is influenced by the Taiwan Warm Current and the Jiangzhe Coastal Current (Li et al., 2024). The specific geographic location and unique natural environment have created a rich and diverse marine ecosystem, making it one of the richest fishery resources areas in the East China Sea. However, the marine fishery resources in the Pingyang County have declined in recent years (Figure 1) (Wenzhou Municipal Bureau of statistics, and Survey Office of the National Bureau of Statistics in Wenzhou, 2012–2023). Lin (2011) reported that the economically important fish species, such as *Larimichthys crocea* and *Larimichthys polyactis*, declined sharply, while there is an increase in the occurrence of low-value fish, like *Harpadon nehereus* and *Benthoosema pterotum*. Current research on fish resources in the Nanji Islands mainly involved species composition (Sarr et al., 2024), the relationship between fish distribution and environmental factors (Sarr et al., 2023), and aquaculture (Yin et al., 2025).

The early life stages of fish, such as eggs and larvae, are highly vulnerable, with mortality rates reaching up to 99%. This extreme mortality is largely attributed to the larvae's limited swimming capabilities, which hinder their ability to escape unfavorable environmental conditions, avoid predators, or locate sufficient prey (Arevalo et al., 2023). The survival of fish larvae directly affects the fish community. It is important to investigate the early

life stages of fish assemblages to assess the fish resources, and these investigations could be used for the conservation and management of fisheries. However, there has been limited research regarding on the early life stages of fishes in the Nanji Islands. Wang et al. (2024) conducted a monthly collection at 12 stations around the Nanji Islands by using horizontal tow at the surface layer throughout one year. The fish larvae and juveniles were collected by a larval net (1.3 m mouth diameter, 0.5 mm mesh aperture). A total of 59 species in 31 families were collected. It's interesting that the larval density was the highest in winter than other seasons due to huge number of *Sebastiscus marmoratus* preflexion larvae.

Surf zones, the area of breaking waves abutting ocean beaches, serve as nurseries, refuges, foraging areas, and dispersal corridors for organisms, especially fishes, in their early life stages (Olds et al., 2018; Xia et al., 2023). A large number of studies have been conducted in the surf zone of South Africa (McGregor et al., 2021; Muller et al., 2023), Brazil (Esmaeili et al., 2021; Contente et al., 2023), United States (Marraffini et al., 2024), Australia (Henderson et al., 2022), and Japan (Iida et al., 2021; Shimizu et al., 2022), mainly focus on species composition and community structure, distribution, sampling methods and food habits, among others. The surf zone was easily overlooked, and the survey of larval and juvenile fish in the surf zone started late in China, and the relevant studies were primarily focused on the Yangtze River estuary (Jiang et al., 2008; 2009) and adjacent water (Chen et al., 2011; Mao et al., 2013; Wang et al., 2018), as well as the Hainan Island (Xia et al., 2023; 2024) and the Jiulong River (Lin et al., 2009). These surf zones serve as essential nursery habitats for numerous commercially valuable species.

In this study, we aimed to determine the main changes in the fish community structure in the sandy beach surf zones of Nanji Island throughout one year, identify the dominant species, clarify the relationships between larval and juvenile fishes and environmental factors, and discuss the differences in larval and

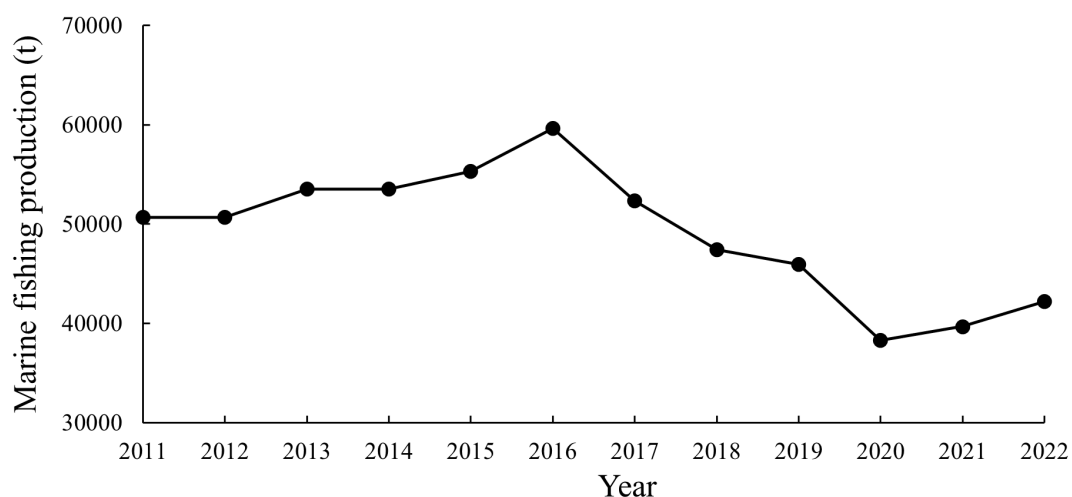


FIGURE 1
Marine fishing production in the Pingyang County from 2011 to 2022 (Wenzhou Municipal Bureau of statistics, and Survey Office of the National Bureau of Statistics in Wenzhou, 2012–2023).

TABLE 1 Situation of sampling stations in the sandy beach surf zone of Nanji Island.

Station	Artificial facility nearby
St.1	village, ferry port, aquaculture cages
St.2	village, aquaculture cages
St.3	tourist spot
St.4	village
St.5	biggest village, fishing port

All sampling stations substrate are sandy.

juvenile fish assemblages between the surf zone and the open sea. This information can provide valuable support to the local fisheries industry.

2 Materials and methods

Larval and juvenile fishes were collected monthly from March 2023 to February 2024 at five sampling stations (St.1-St.5, Table 1, Figure 2) in the sandy beach surf zones along the coast of Nanji Island during daytime. A small seine net (1 × 4 m, 1 mm mesh aperture) was used to collect the fish. The net was actively towed by two wading researchers along a path parallel to the shoreline. Each haul covered a distance of approximately 50 m at a constant walking speed and a water depth of 0.2 to 1.0 m. Sampling was repeated three times at each sampling station. Water temperature (°C) and salinity (ppt) were measured on site with a thermometer and a digital salinometer during the sampling period. This study was conducted under a fishing permit authorized and granted by the Nanji Islands National Marine Nature Reserve Administration.

All samples were fixed in a 5% seawater formalin solution and subsequently preserved in 75% ethanol. Fish were counted and identified to the lowest possible taxonomic level based on the number of myomere, fin composition, the shape and location of head spine and melanophore, etc., identified using morphological characteristics described in (Okiyama, 2014; Wu and Zhong, 2021). Unlabeled lengths refer to body length (BL) (notochord length for preflexion and flexion larvae, and standard length for postflexion larvae, juveniles, and young individuals). A maximum of 100 specimens of each species were measured in each haul.

The catch per unit of effort (CPUE, individual/hauls) was calculated using the following equation

CPUE = \frac{n}{E}

where *n* is the number of collected individual, *E* is the number of hauls.

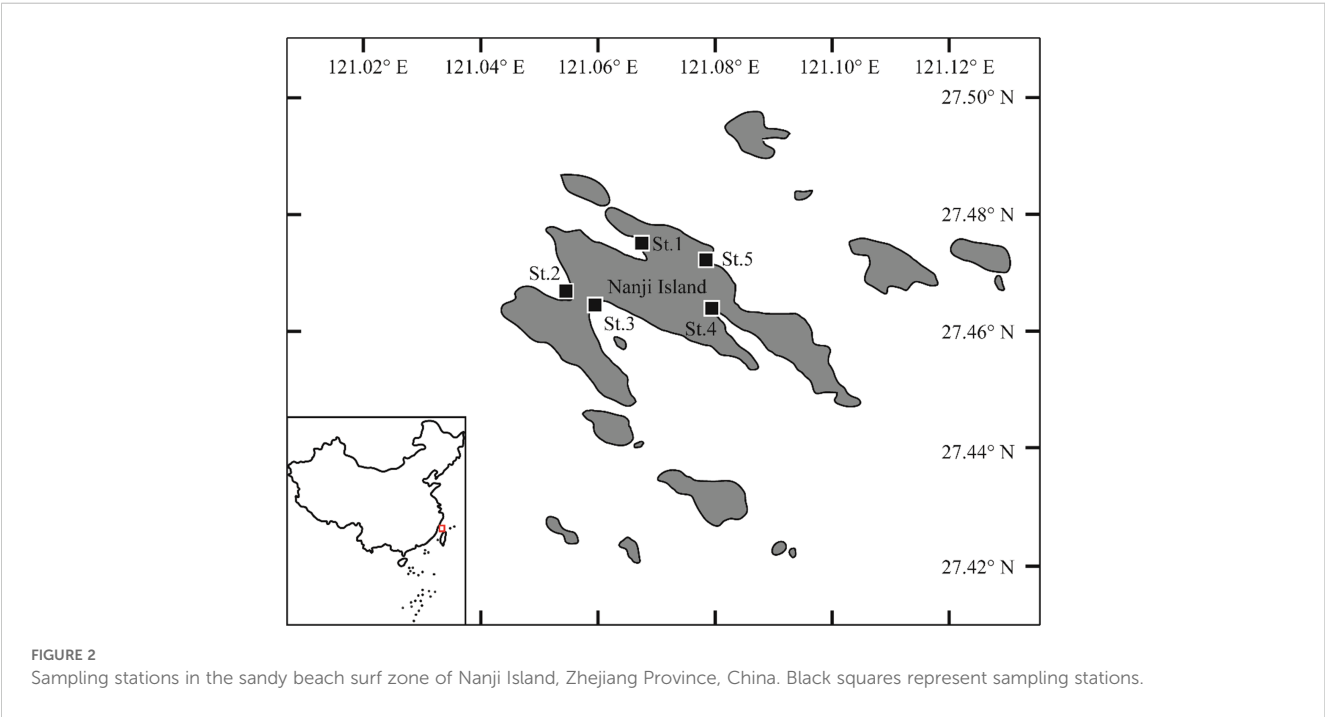
The index of relative importance (IRI) was calculated for each species using the formula

IRI = N \% \times F \% \times 10000

where *N%* is the percentage of the number of each species among the total number of fish species and *F%* is the species frequency per species sampled in percentage. Accordingly, each species was defined as dominant (*IRI* ≥ 100), common (100 > *IRI* ≥ 10), or rare (*IRI* < 10).

Diversity studies were conducted using Margalef’s richness index (*D*), Shannon–Wiener’s diversity index (*H'*), and Pielou’s evenness index (*J*) (Xia et al., 2023).

D = \frac{S - 1}{\ln N}



$$H' = -\sum P_i \ln P_i$$

$$J = \frac{H'}{\ln S}$$

where S is the number of larval and juvenile fishes; N is the number of species; and P_i is the proportion of individuals in taxa i .

To evaluate the variation in the structure of the larval and juvenile fish assemblages, the CPUE data were $\log_{10}(x+1)$ transformed to mitigate the influence of extremum and then analyzed using non-metric multi-dimensional scaling (n-MDS) based on the Bray–Curtis's similarity index. For visualization, a two-dimensional n-MDS plot was generated with cluster points (CLUSTER) to illustrate the relationships among samples. Stress is a value between 0 and 1 and expresses a proportion between the distance in the original dissimilarity matrix and the fitted distance in ordination space. The lower the stress value, the better is the fit. The stress values <0.05 indicate excellent. The analysis of similarities (ANOSIM) was employed to assess differences between assemblages (by month or station), while the percentage similarity analysis (similarity of percentage analysis, SIMPER) was used to identify the contributions of individual species to the overall similarity within communities (Jiang et al., 2009). All these analyses were conducted using Primer 6.0.

Differences in the species number, CPUE, Margalef's richness index, Shannon–Wiener's diversity index, and Pielou's evenness index among all sampling months or stations were tested using the Kruskal–Wallis test. Furthermore, Spearman correlation coefficients were calculated using SPSS 19.0 to examine the relationships between environmental and biotic variables.

3 Results

3.1 Species composition

In the present study, a total of 8568 larval and juvenile fishes were collected, representing 35 species, 28 genera, and 21 families (Table 2). Among them, postflexion larvae constituted the majority (89.41%), followed by young (7.56%), juveniles (2.98%), and flexion larvae (0.05%). No earlier stage larvae were collected. Engraulidae was the most abundant family, with three species accounting for 91.33% of the total number of collected fish. Other families with multiple species included Mugilidae, Gerreidae, Terapontidae, Sparidae, and Lutjanidae (each with three species), followed by Kyphosidae and Sillaginidae (each with two species). The remaining families were represented by a single species each. According to the IRI results, the dominant species was *Engraulis japonicus*, accounting for 91.30% of the total number of samples collected. The common species was *Valamugil speigleri* (2.73%), while all other species were rare species.

3.2 Temporal variations

The CPUE increased from March to May 2023, then declined from June 2023 to February 2024 (Figure 3). The highest CPUE was

recorded in May, when 7554 postflexion larvae of *E. japonicus* were collected (Kruskal–Wallis test, $p = 0.015$). The highest species number was observed in August (16 species), followed by June and July (11 species each). In contrast, only one or two species with few individuals were collected during later autumn and winter (Kruskal–Wallis test, $p = 0.004$). Margalef's richness index ranged from 0 to 3.58, with a mean value of 1.21 ± 0.27 (Kruskal–Wallis test, $p = 0.023$). Pielou's evenness index ranged from 0 to 0.85 (mean 0.56 ± 0.08 , Kruskal–Wallis test, $p = 0.023$), and the Shannon–Wiener diversity index ranged from 0 to 2.36 (mean 0.95 ± 0.20 , Kruskal–Wallis test, $p = 0.023$). All three diversity indexes exhibited similar trends, with the highest values in August, followed by July and June, and the lowest in January (Figure 4).

The monthly cluster analysis revealed that the 12 months could be divided into four groups based on a similarity threshold of 10 (Figure 5). February, March, and December formed Group I (winter group), April–June formed Group II (spring group), July–November formed Group III (summer–autumn group), January was Group IV. The n-MDS analysis showed a stress value of 0.01. ANOSIM analysis revealed a strong, though not statistically significant, ecological pattern of community separation ($R = 0.958$, $P = 0.1$), potentially due to limited sample size. SIMPER analysis showed that the average similarity within Group I was 14.30%, with *Mugil cephalus* contributing 100.00%. The average similarity with Group II was 42.78%, with *V. speigleri* contributing 54.68% and *E. japonicus* contributing 26.65%. The average similarity within Group III was 32.02%, with *Terapon jarbua*, *Sillago sihama*, and *Planiliza haematocheilus* contributing 46.79%, 22.85%, and 15.04%, respectively.

3.3 Spatial variations

The highest CPUE was observed at St.3, followed by St.4, St.5, St.1, and St.2 (Kruskal–Wallis test, $p = 0.035$). Species number was highest at St.5 and lowest at St.3 (Figure 6, Kruskal–Wallis test, $p = 0.058$). Margalef's richness index ranged from 0.68 to 4.05, with a mean value of 2.67 ± 0.56 (Kruskal–Wallis test, $p = 0.076$). Pielou's evenness index ranged from 0.02 to 0.88 (mean 0.48 ± 0.13 , Kruskal–Wallis test, $p = 0.050$), and Shannon–Wiener diversity index ranged from 0.04 to 2.49 (mean 1.38 ± 0.38 , Kruskal–Wallis test, $p = 0.060$). All diversity indexes were highest at St.2 and lowest at St.3 (Figure 7).

The station cluster analysis revealed that the five stations could be divided into two groups based on a similarity threshold of 30 (Figure 8). Sts.1–2 was clustered as Group I, located on the west coast of the island, while Sts.3–5 formed Group II, located on the east coast. The n-MDS analysis showed a stress value of 0. ANOSIM analysis revealed a strong but not statistically significant ecological pattern between the two groups ($R = 0.833$, $P = 0.1$) due to limited sample size. SIMPER analysis showed that the average similarity within Group I was 36.78%, with *V. speigleri* contributing 27.47%, *Gerres erythrorus* contributing 12.97%, and *T. jarbua* contributing 12.97%. The average similarity within Group II was 51.06%, with *E. japonicus* contributing 71.22% and *V. speigleri* contributing 13.71%.

TABLE 2 Species composition, developmental stage (F: flexion larvae; Post: postflexion larvae; J: juveniles; Y: young), body length, index of relative importance (IRI) values, and occurring month of larval and juvenile fishes collected from the surf zone of Nanji Island from March 2023 to February 2024.

Species	Abundance %	Developmental stage	Body length (mm)	IRI	Occurring Month
Engraulidae					
<i>Engraulis japonicus</i> †	91.3	Post,Y	12.40-61.75	464.26	5, 6
<i>Stolephorus commersoni</i> †	0.01	Post	28.96	0.01	10
<i>Thryssa hamiltonii</i>	0.02	Post	16.13-16.37	0.01	9
Chanidae					
<i>Chanos chanos</i> †	0.34	Post	9.67-12.35	0.96	7, 9
Myctophidae					
<i>Benthosema pterotum</i> †	0.08	Y	27.72-32.91	0.14	11
Gobiidae					
<i>Tridentiger obscurus</i>	0.01	Post	7.65	0.01	8
Ambassidae					
<i>Ambassis gymnocephalus</i> †	0.64	Post-J	3.8-13.86	3.26	7, 9
Mugilidae					
<i>Planiliza haematocheilus</i> †	0.15	Y	13.67-42.45	0.6	7, 8, 10, 11
<i>Mugil cephalus</i> †	0.19	Y	15.01-29.69	0.74	3, 12, 2
<i>Valamugil speigleri</i>	2.73	Y	12.05-166.60	29.32	4, 6
Exocoetidae					
<i>Hirundichthys oxycephalus</i>	0.01	Post	4.40	0.01	6
Carangidae					
<i>Trachinotus ovatus</i>	0.02	Y	59.12-61.48	0.01	8
Sphyraenidae					
<i>Sphyraena pinguis</i>	0.02	Y	55.01-59.26	0.01	8
Gerreidae					
<i>Gerres erythrouus</i>	0.43	J	10.78-14.79	1.71	6, 8, 9
<i>Gerres filamentosus</i>	0.08	J	11.40-15.40	0.18	7, 8
<i>Gerres japonicus</i> †	0.18	Post-J	6.03-11.49	0.4	7, 8
Mullidae					
<i>Upeneus japonicus</i>	0.01	Y	64.94	0.01	7
Kyphosidae					
<i>Girella punctata</i>	0.13	Post-Y	14.23-38.41	0.29	4, 6
<i>Microcanthus strigatus</i>	0.01	J	15.17	0.01	4
Terapontidae					
<i>Pelates quadrilineatus</i> †	0.01	J	10.75	0.01	6
<i>Terapon jarbua</i> †	0.58	Post-J	10.70-40.36	6.59	6, 11
<i>Terapon theraps</i>	0.02	J	8.70-8.77	0.03	6, 7

(Continued)

TABLE 2 Continued

Species	Abundance %	Developmental stage	Body length (mm)	IRI	Occurring Month
Leiognathidae					
<i>Nuchequula nuchalis</i>	0.04	J	11.40-12.71	0.04	8
Lutjanidae					
<i>Lutjanus fulvivflamma</i>	0.01	Y	19.09	0.01	8
<i>Lutjanus</i> sp.1	0.01	Y	20.79	0.01	10
<i>Lutjanus</i> sp.2	0.01	Y	18.51	0.01	10
Scatophagidae					
<i>Scatophagus argus</i> †	0.02	J-Y	10.04-24.21	0.03	7, 9
Stichaeidae					
<i>Dictyosoma burgeri</i>	0.12	F-Post	6.00-13.46	0.26	4
Moronidae					
<i>Lateolabrax maculatus</i> †	0.36	Post-Y	11.18-74.8	2.66	3, 6
Sillaginidae					
<i>Sillago japonica</i>	0.09	Post-J	9.97-14.44	0.21	6, 8
<i>Sillago sihama</i> †	0.89	Post-J	9.87-17.58	7.02	7, 9
Sparidae					
<i>Acanthopagrus latust</i> †	0.21	J-Y	10.90-17.19	0.83	11, 1-2
<i>Acanthopagrus schlegelii</i> †	0.30	J-Y	11.72-28.01	1.71	4,5
<i>Pagrus major</i>	0.01	J	12.12	0.01	8
Tetraodontidae					
<i>Takifugu alboplumbeus</i>	0.92	Post-Y	6.04-24.60	7.81	4-6, 8, 10

†represents this species occurred in the open sea of the Nanji islands (Wang et al., 2024).

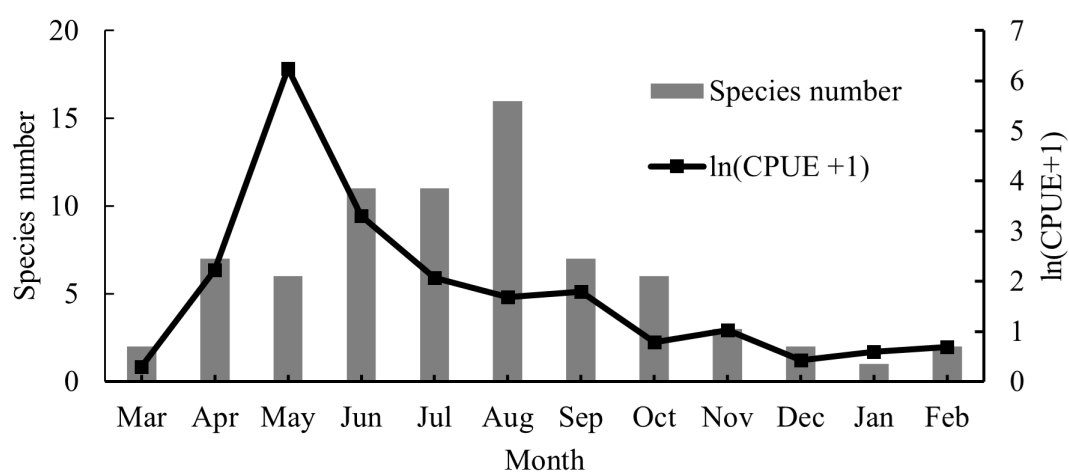


FIGURE 3
Temporal variations of species number and CPUE.

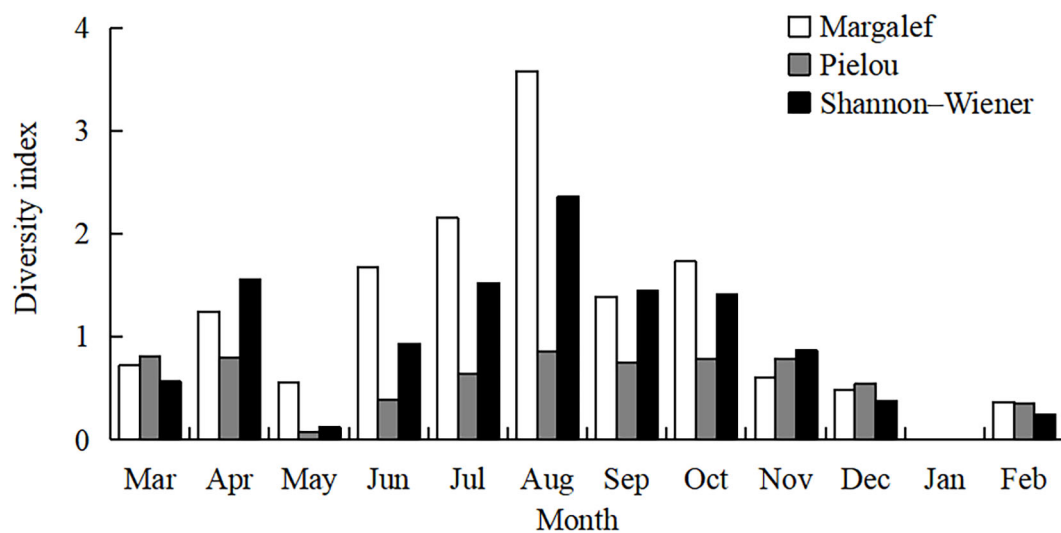


FIGURE 4
Temporal variations of three diversity indexes.

3.4 Environmental conditions

The water temperature in the sandy beach surf zones exhibited distinct seasonal variations. It gradually increased from March to September 2023 and then decreased steadily until February 2024. The temperature was notably lower in January and February 2024. Salinity showed highly variability throughout the study period. It remained around 24 ppt from March to July 2023. In August and September 2023, the salinity dropped to relatively low levels due to the influence of the typhoon season. From October 2023 to February 2024, salinity returned to approximately 30 ppt (Figure 9).

3.5 The relationships between environmental and biotic variables

The species number, Margalef's richness index, and Shannon–Wiener's diversity index exhibited positive correlation with

temperature ($p < 0.05$, Table 3). In contrast, salinity showed a negative correlation with species number, CPUE, and Shannon–Wiener's diversity index ($p < 0.05$). Other variables did not show significant correlations with either temperature or salinity ($p > 0.05$).

4 Discussion

4.1 The dominant species in the Chinese surf zone

The fish species diversity in the surf zone varies markedly across different regions. In Nanji Island a total of 35 species were collected (Table 2), with *Engraulis japonicus* being the dominant species and *Valamugil speigleri* as the common species. In Sijiao Island, 46 species were recorded, and the main dominant species were *Mugil*

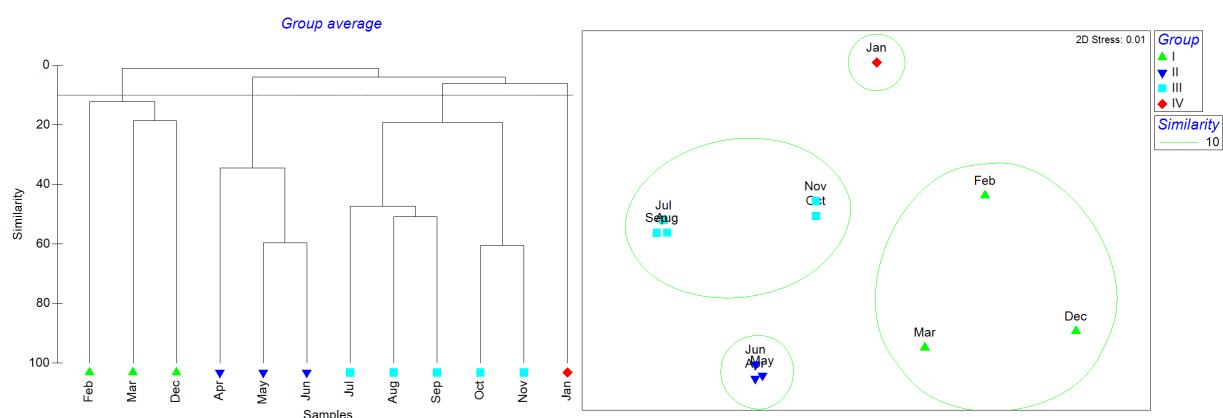


FIGURE 5
Cluster analysis of larval and juvenile fish community among 12 months.

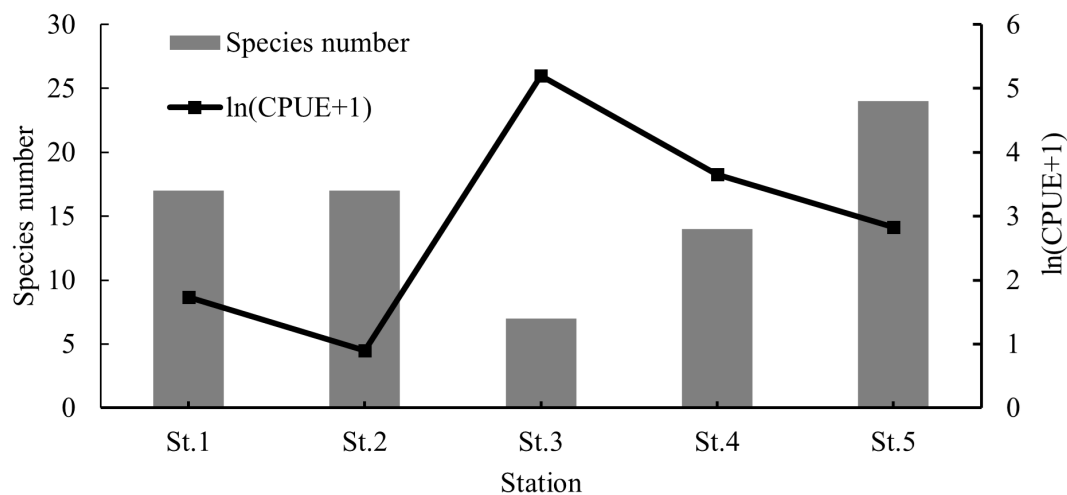


FIGURE 6
Spatial variations of species number and CPUE.

cephalus, *Lateolabrax maculatus*, and *E. japonicus* (Mao et al., 2013). In the sandy beaches of Zhoushan Islands, 37 species were collected, with *Chelon affinis* (Mugilidae) being the most dominant, followed by *Tridentiger trigonocephalus* (Gobiidae), *L. maculatus*, and *Stolephorus chinensis* (Clupeidae) (Wang et al., 2018). In Gaolong Bay, 83 species were collected, *Terapon jarbua* (Theraponidae), *Moolgarda seheli* (Mugilidae), *Ambassis urotaenia* and *Ambassis dussumieri* (Ambassidae) were the dominant species (Xia et al., 2024).

In the estuarine environments, larval and juvenile fishes are often dominated by migratory, brackish or freshwater species. For example, in the Jiulong River estuary, China, 91 species were collected, with *Ambassis gymnocephalus* (Ambassidae) being the most dominant, followed by *Sillago sihama* (Sillaginidae), *Acentrogobius pflaumii* (Gobiidae), and *Konosirus punctatus*

(Clupeidae) (Lin et al., 2009). In the Yangtze River estuary, *Coilia nasus* (Engraulidae) was the main dominant species, followed by *Hemiculter* sp. (Cyprinidae) and *Pseudolaubuca* sp. (Cyprinidae) (Jiang et al., 2008).

In summary, Engraulidae, Cyprinidae and Ambassidae tend to dominate in estuarine surf zones, while Mugilidae, Theraponidae, Ambassidae, Engraulidae and Clupeidae are more prevalent in oceanic surf zone.

4.2 Spatial and temporal distribution

This study demonstrates that larval and juvenile fishes in the sandy beach surf zones of Nanji Island were not randomly distributed but exhibited significant seasonal variability. Species

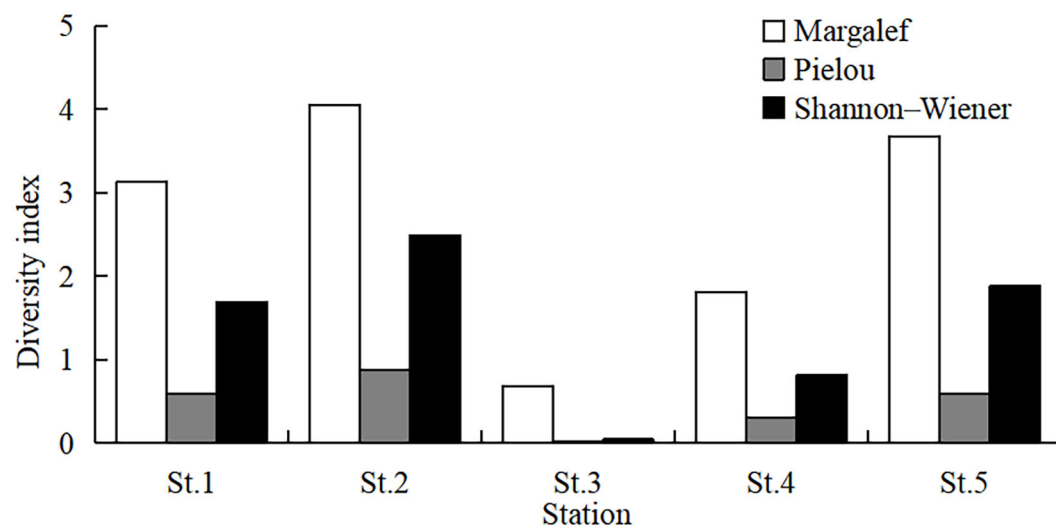


FIGURE 7
Spatial variations of three diversity indexes.

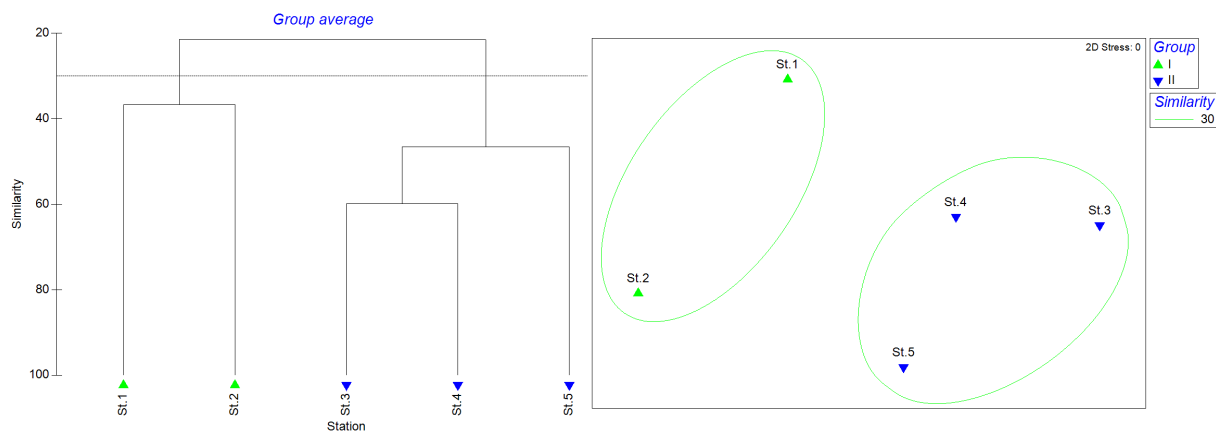


FIGURE 8
Cluster analysis of larval and juvenile fish community among 5 stations.

number shows a positive correlation with temperature, peaking in August during the summer months. In contrast, CPUE does not show a correlation with temperature. The highest CPUE values occurred in May due to the present of large schools of *E. japonicus* postflexion larvae (more than 1000 and 5000 ind. by the second and third hauls, respectively, at St.3).

Engraulis japonicus, the most abundant species, was predominantly in the postflexion stage in May and transitioned to the young stage in June. These larvae were also dominant in the open sea of the Nanji Islands from May to June (Wang et al., 2024). Based on developmental stage and body length (Figure 10), the size of the larvae collected by larval net in the open sea is extremely smaller than those collected by seine net in the sandy beach surf zones, it appears that *E. japonicus* may utilize the surf zones as nursery ground, a phenomenon also observed in Sijiao Island (Mao et al., 2013). The local names for the larvae and juveniles of this

species are Dingxiangyu and Xiangyan, respectively, both of which are important commercial fish in the Nanji Islands (Cai, 2021). Their sustainable utilization and management require greater attention.

In the open sea of the Nanji Islands, there were 59 species collected by a larval net. The developmental stages, most of them preflexion larvae, were earlier than those in the surf zones. The density was higher in autumn and winter and lower in spring and summer, and species number was higher in summer and lower in winter (Wang et al., 2024). While seasonal trend in species number aligns with prior findings, CPUE patterns in the present study were inversely related. In winter, *Sebastes marmoratus* and *Lateolabrax maculatus* was the dominant species in the open sea (Wang et al., 2024). *L. maculatus* was also present in the surf zone from March to June, whereas *S. marmoratus* was absent. Compared to *L. maculatus* larvae in the open sea, those in the surf zone

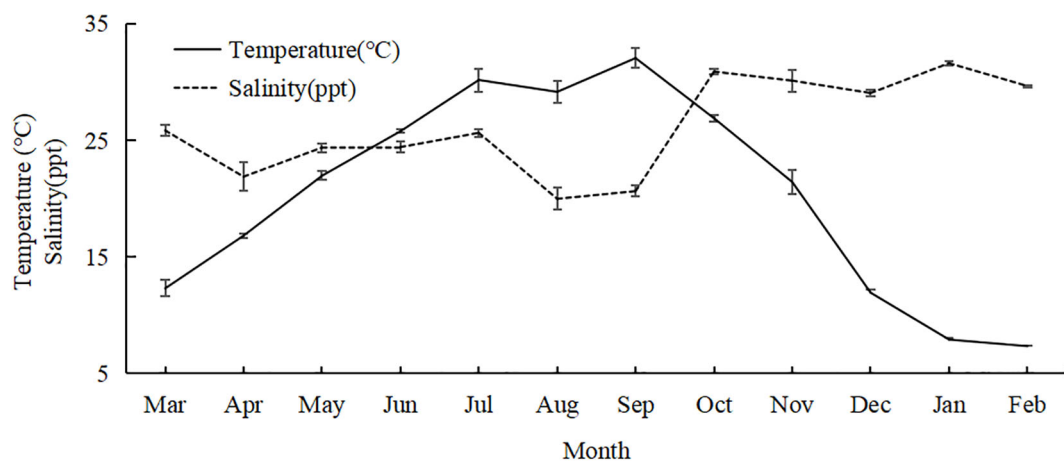


FIGURE 9
Water temperature and salinity from March 2023 to February 2024.

TABLE 3 Matrix showing the Spearman correlation coefficients for environmental and biotic variables.

Environmental Biotic					
	Species number	CPUE	Margalef	Pielou	Shannon–Wiener
Temperature	0.828**	0.566	0.853**	0.343	0.706*
Salinity	-0.747**	-0.608*	-0.524	-0.371	-0.608*

* $p < 0.05$, ** $p < 0.01$.

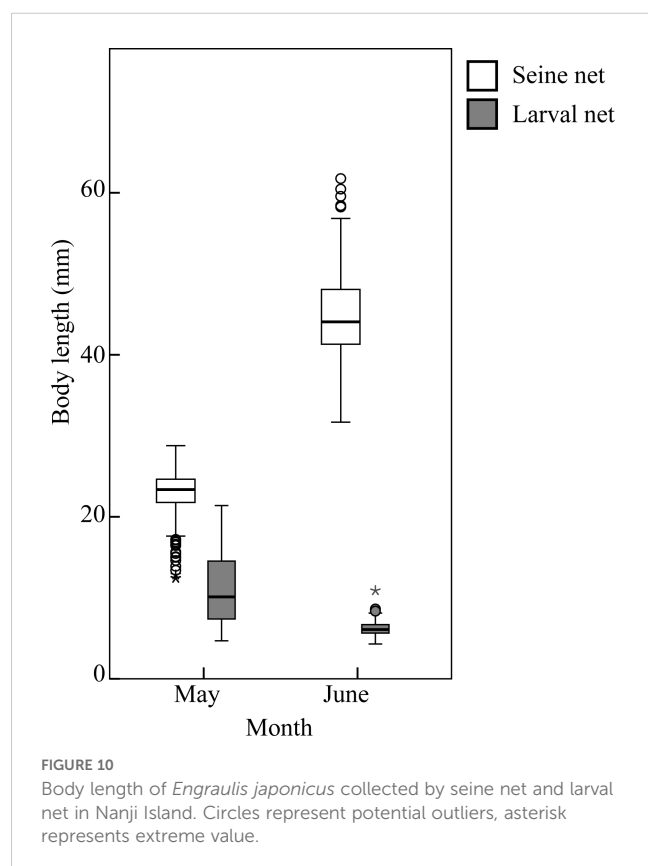
exhibited substantially greater body lengths (Figure 11). This finding aligns with previous studies by Chen et al. (2011) and Mao et al. (2013), who also reported a significant growth in body length of *L. maculatus* from March to June in the surf zones of Hangzhou Bay and Sijiao Island. This size discrepancy is not merely a descriptive pattern but likely reflects a substantial survival advantage. Larger body size in early life stages is a key trait linked to higher survival rates; it confers a refuge from a wider range of gape-limited predators and enhances swimming ability for efficient foraging and predator avoidance (Robert et al., 2023). These results further support the role of surf zones as nursery habitats for *E. japonicus* and *L. maculatus*.

The low species overlap (only 15 shared species) underscores the distinct ecological functions of the surf zone and the open sea (Wang et al., 2024). The surf zone species are likely benthic-

oriented or require shallow, structured nurseries, like *E. japonicus* and *L. maculatus* (Mao et al., 2013). Conversely, the open sea species are presumably planktonic forms that depend on stable, pelagic conditions during larval stages. *S. marmoratus*, an ovoviviparous, reef-associated species with limited mobility and no long-distance migratory behavior (Jin, 2006), appears to avoid littoral zone. Instead, its larvae likely settle in the deeper layer after they grow up, explaining the absence of high CPUE values for this species in surf zones during winter. This clear niche partitioning highlights the surf zone's role as a critical nursery for a specific subset of species rather than a universal habitat for all larval and juvenile fishes. The main contributing species in the sandy beach surf zone also show distinct differences in occurrence and duration, likely due to variations in spawning seasons and migration routes. *Valamugil speigleri*, *E. japonicus*, *Gerres erythrouirus*, and *Terapon jarbua* first appear in the surf zone in April, May and June, respectively, with durations ranging from 2 to 6 months (Table 2). Notably, *E. japonicus* is only found on the east coast of the island, while *V. speigleri*, *G. erythrouirus*, and *T. jarbua* occur on both coasts. This suggests that differences in physicochemical or biological factors, such as turbidity, light, flow velocity and direction, prey organisms, and predators, may influence species distribution even in sandy beaches with similar geomorphology and substrate (Pessanha et al., 2021). To explore the reasons behind these differences in species distribution across similar sandy beach habitats, it is necessary to supplement the study with surveys of plankton communities and additional physicochemical parameters.

4.3 The relationships between larval fish and environmental factors

The species number and diversity indexes in the sandy beach surf zones of Nanji Island exhibited significantly positive and negative correlation with temperature and salinity, respectively. This finding aligns with broader observations that water temperature has a substantial impact on fish species diversity and abundance, often following a clear seasonal pattern in many marine ecosystems (Olds et al., 2018). Specifically, water temperature is positively correlated with fish abundance and diversity (Rodrigues and Vieira, 2013). Jiang et al. (2008) reported that the monthly trends of species number and abundance of larval and juvenile fishes in the surf zone of the Yangtze River estuary were consistent



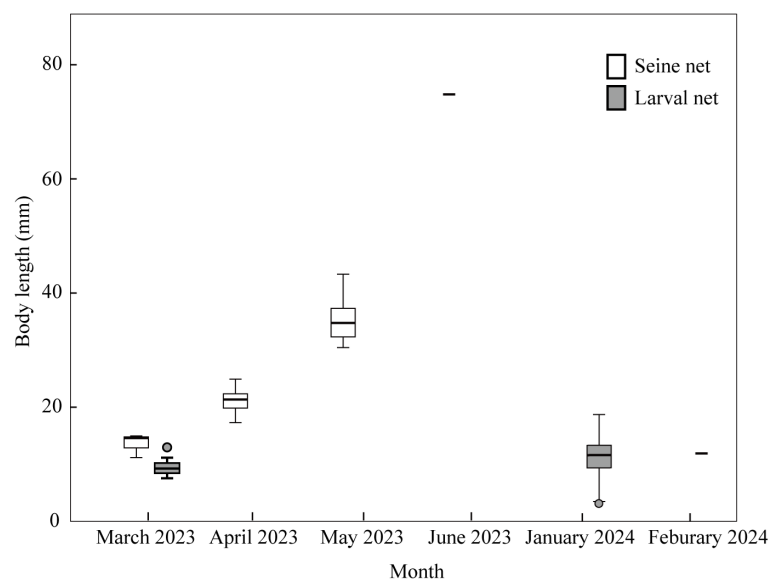


FIGURE 11

Body length of *Lateolabrax maculatus* collected by seine net and larval net in Nanji Island. Circles represent potential outliers.

with water temperature. Seasonal changes in community structure were relatively pronounced, with higher larval and juvenile fish diversity and abundance when the average water temperature exceeded 23 °C. Water temperature not only directly influences fish reproduction and proliferation of bait organisms but also indirectly affects the spatial and temporal distribution of larval and juvenile fishes by influencing individual growth and development (Jiao et al., 2016).

Salinity also plays a crucial role in shaping the composition of larval and juvenile fish species. The observed negative correlation between salinity and species number, CPUE and Shannon–Wiener’s diversity index may be attributed to episodic freshwater input, particularly since recorded salinities generally remained within marine conditions (Figure 9). For instance, during summer, typhoon-induced heavy rainfall may attract more euryhaline fishes, such as *Trachinotus ovatus* and *Gerres* spp. (Wu and Zhong, 2021), thereby enhancing overall diversity. Furthermore, freshwater inflow, especially from the village near St. 5 (Table 1), may deliver terrestrial nutrients that stimulate localized primary productivity and subsequently enrich the prey resources for certain fish species. Chen et al. (2011) compared the southern branch of the Yangtze River estuary and the northern shore of Hangzhou Bay, two geographically closely connected areas but differently influenced by freshwater discharge from the Yangtze River. The study found significant differences in species composition between these areas. In the southern branch of the Yangtze River estuary, where salinity remained low throughout the year, larval and juvenile fishes were predominantly migratory and freshwater fishes. In contrast, on the northern shore of Hangzhou Bay, larval and juvenile fishes were mainly estuarine and marine

fishes, and a higher diversity were found in this area due to the salinity variations. Similar patterns have been observed in other regions, such as within and outside Tokyo Bay (Arayama et al., 2002), the estuary of the Lima River (Ramos et al., 2006), and adjacent coastal waters (Azeiteiro et al., 2006).

5 Conclusion

A total of 8568 larval and juvenile fishes were collected from the sandy beach surf zones of Nanji Island, representing 35 species and 21 families. The highest abundance of larval and juvenile fishes was recorded in May, primarily dominated by postflexion larvae of *Engraulis japonicus*, which were only found on the east coast of the island. The highest species diversity was observed in August. Temperature showed a positive correlation with species number, Margalef’s richness index, and Shannon–Wiener’s diversity index, while salinity showed negative correlations with species number, CPUE, and Shannon–Wiener’s diversity index. Additional physicochemical parameters should be examined in the future study.

The fish composition differed significantly between the surf zones and the open sea, with only 15 species shared between the two habitats, suggested significant niche partitioning. *Engraulis japonicus*, the most dominant species in the surf zone, and *Lateolabrax maculatus* were also present in the open sea. However, individuals of both species exhibited larger body sizes in the surf zones compared to those collected in open waters, suggesting that these species utilize sandy beach surf zones as nursery grounds for growth and development.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

Ethical approval was not required for the study involving animals in accordance with the local legislation and institutional requirements. This study complies with the Specifications for oceanographic survey—Part 6: Marine biological survey and laws of China. Larval and juvenile fish samples were collected with a seine net, as this sampling method results in the mortality of the sampled fishes; they were not reared or maintained in the laboratory. According to the above guidelines, ethical approval was not needed for this study.

Author contributions

XW: Investigation, Writing – original draft, Writing – review & editing. DZ: Formal Analysis, Investigation, Writing – original draft. QL: Data curation, Investigation, Validation, Visualization, Writing – original draft. TL: Data curation, Formal Analysis, Investigation, Software, Writing – original draft. JZ: Funding acquisition, Methodology, Supervision, Writing – review & editing. WC: Investigation, Resources, Writing – original draft. SX: Project administration, Resources, Writing – original draft. SC: Conceptualization, Supervision, Writing – review & editing.

Funding

The author(s) declare financial support was received for the research and/or publication of this article. This study was supported by the Nanji Islands National Marine Nature Reserve Administration.

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Acknowledgments

We extend our sincere gratitude to the staff from Nanji Islands National Marine Nature Reserve Administration for their generous assistance with sample collection. We also wish to thank to Roland Passmore for improving the English of this manuscript.

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