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Larval Spatiotemporal Distribution of Six Fish Species: Implications for Sustainable Fisheries Management in the East China Sea

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Abstract: The larval distributions of the small-sized fishes Omobranchus elegans, Erisphex pottii, Benthosema pterotum, Acropoma japonicum, Upeneus bensasi, and Apogonichthys lineatus in the East China Sea ecosystem are important due to their ecological and economic benefits. To date, however, there have been few studies describing their population distributions and dynamics. In the current study, ichthyoplankton surveys were carried out from April to July 2018 to analyze variations in the larval abundance, distribution, and development stages of these species. In addition, the spatiotemporal larval distribution was investigated in terms of measured environmental variables. It was found that larvae were mainly distributed at depths of 5.00–66.00 m, in areas with sea surface temperature of 4.40–29.60 °C, sea surface salinity of 16.54–34.60 psu, pH of 7.00–9.00, and dissolved oxygen concentration of 2.54–8.70 mg/L. Benthosema pterotum and A. lineatus migrated from 30.00–31.00 °N 123.17–123.50 °E in June to 30.00–32.50 °N 122.22–123.50 °E in July. The results of this study can help to preserve spawning and nursery grounds and contribute to sustainable coastal fisheries management.

Keywords: fish larvae; spatiotemporal distribution; fishery management; East China Sea

1. Introduction

The East China Sea is one of the most productive and warming marginal seas in the world, which has also been over-exploited since the late 1980s by large fisheries [1]. The area is connected to terrestrial water, the Pacific Ocean, the Sea of Japan, and the Yellow Sea by a very complex ocean system, including both deep and shallow sea features [2]. Several water masses in this area are described as Changjiang river diluted water (CRDW), with low temperature and salinity, Taiwan Warm Current (TWC), with high temperature and salinity, Yellow Sea cold water mass, with low temperature and high salinity, and Subei coastal current, with high temperature and low salinity. Kuroshio current flows from eastern Taiwan, enters into the East China Sea region, and then flows along the continental shelf. The Taiwan warm current extends northward and outward from the central Zhejiang coast to the southern Changjiang estuary. The distribution characteristics of the ichthyoplankton assemblages in this area are very complex. Many factors, such as type of water mass, might influence the larval distribution in shelf waters.

Understanding the larval distributions of the fishes Omobranchus elegans, Erisphex pottii, Benthosema pterotum, Acropoma japonicum, Upeneus bensasi, and Apogonichthys lineatus is crucial for the maintenance and sustainable development of the East China Sea.
ecosystem. They are the most abundant fish groups in the East China Sea, which is one of the largest marginal seas in the western Pacific [3,4]. These fish are prey for larger economically important fishes such as *Collichthys lucidus* [5], *Trichiurus japonicus* [6], *Aluterus monoceros* [7], *Larimichthys polyactis* [8], *Lophius litulon* [8], *Harpadon nehereus* [9], *Pennahia argentata* [10], and *Euthynnus affinis* [11]. In recent years, the biomass of *E. pottii*, *B. pterotum*, *A. lineatus*, and *A. japonicum* has gradually increased from year to year, representing a major component of the trawl bycatch in the East China Sea [11,12]. Ecologically these six species play an important role, occupying intermediate trophic levels that link secondary production to the upper trophic levels of marine food webs in this region.

Globally, they are widely distributed in the continental shelf regions from the West Pacific to the Indian Ocean. Generally, they have a long spawning period, a short lifecycle of one year or less, and fast generation time [3,13–21]. The spawning period of *A. japonicum*, *U. bensasi*, and *A. lineatus* is reported to be June to September with a peak in August [14], and January to September with a peak from June to September [13], and summer to autumn [15], respectively. The larvae of *O. elegans* are found from March to October with a peak in August [16]. The species *U. bensasi* and *A. lineatus* prefer to stay at depths of 30.00–120.00 m in areas with sandy substrates [13]. The trophic levels of *B. pterotum*, *A. japonicum*, and *Apogonichthys lineatus* are estimated to be 3.41, 3.48, and 3.39, respectively [17]. The biomass of *B. pterotum*, *U. bensasi*, and *A. lineatus* is estimated to be 2.30 million tonnes (MT) (carried out by acoustic surveys and trial fishing using pelagic trawls in 1992 to 1998 in the Oman Sea) [18], 880.82 tonnes (carried out by bottom trawls in 2003 in southwestern continental shelf of Nansha Islands) [19], and 0.14 MT (carried out by bottom trawls in 1997 to 2000 in the East China Sea) [8], respectively [20,21]. *Benthosema pterotum* is a recently introduced potential fisheries resource that can be utilized for the commercial production of fishmeal and oil [17,18,20].

Thus, it is necessary to understand the spatiotemporal variations in the early life history stages of these species in the East China Sea due to their importance in the ecological and economic aspects of sustainable ecosystem development. However, currently very few studies describe the spatiotemporal distributions and dynamics of the early life history of these species. In particular, there is a lack of in situ sampling over a large spatial region at a high resolution with a sampling grid of 0.50° N latitude and 0.167° E longitude. Information on the habitats of the larvae of these species remains unclear, especially in areas where trawl fishing is prohibited in the East China Sea. However, this information is essential to understand the structure and dynamics of the ecosystem, determining spawning and nursery grounds, and assessing population sizes. In this study, larvae of *O. elegans*, *E. pottii*, *B. pterotum*, *A. japonicum*, *U. bensasi*, and *A. lineatus* were collected in situ, on a monthly basis, as part of cruises over the continental shelf area (24.26–33.00° N 118.55–123.50° E; 133 sampling stations) from April to July 2018. The aims of this study were to describe the variations of occurrence of sampling stations, larval number, and development stages of these species, and to identify spatiotemporal distributions of larvae according to measured environmental variables (depth, water temperature, salinity, pH, and dissolved oxygen (DO)) from April to July 2018. The results will contribute to maintain ocean biodiversity and sustainable coastal fisheries management.

2. Materials and Methods

The study area covered the southern Yellow Sea and the northern East China Sea. The average depth of the southern Yellow Sea is 45.00 m. The study area included the Yellow Sea warm current and the Yellow Sea cold water mass [22]. As one of the largest marginal semi-enclosed sea areas in the western Pacific Ocean, the northern East China Sea is characterized by oceanic water with high salinity and diluted coastal water with low salinity [23]. Kuroshio current flows from eastern Taiwan, enters into the East China Sea region, and then flows along the continental shelf [24]. The Taiwan warm current extends northward and outward from the central Zhejiang coast to the southern Changjiang estuary.
Larvae of *O. elegans*, *E. pottii*, *B. pterotum*, *A. japonicum*, *U. bensasi*, and *A. lineatus* were collected in situ, on a monthly basis, as part of cruises over the continental shelf area (24.26–33.00° N 118.55–123.50° E; 133 sampling stations) from April to July 2018. The cruises were within the closed area for marine trawl fisheries in the southern Yellow Sea and the northern East China Sea and were carried out on fishing vessels (#Lanhai 201 and #Zhongkeyu 211) (Figure 1). The survey transects were perpendicular to the coastline of China, with a sampling grid of approximately 0.50° N latitude (0.25° latitude in a range of 30.50–31.50° N) and separated by a distance of 0.167° E longitude, moving progressively from west to east.

For sample collection, the engine of the survey vessel was stopped, and cone-shaped ichthyoplankton nets (130 cm diameter, 600 cm length, and 0.50 mm mesh size) were cast into the sea, equipped with a calibrated flowmeter mounted in the center of net mouth to measure flow rate. Near-surface discrete sampling was carried out with the top of the net ring just below the air–water interface for 10 min (“horizontal haul”). Near-bottom discrete sampling was carried out by towing the net from the near bottom to the near surface for 10 min, using a buoy line to adjust the desired depth (“oblique haul”). We used a SeaBird SBE–19 CTD at each site to record hydrographic parameters such as depth, water temperature, salinity, pH, and dissolved oxygen concentration. After the hauls, ichthyoplankton samples containing *O. elegans*, *E. pottii*, *B. pterotum*, *A. japonicum*, *U. bensasi*, and *A. lineatus* larvae were immediately washed into a stainless end collection cup with flowing seawater. The samples were preserved in situ in 5% buffered formaldehyde prepared in seawater for further analysis. Larvae from the samples were identified using morphological classification and enumerated in the laboratory using a stereomicroscope (ZEISS, Stemi 2000, Oberkochen, Germany). The developmental stages were divided into yolk-sac, preflexion, flexion, postflexion, and juvenile stages. The density of larvae in
the ichthyoplankton samples was quantitatively converted to number per 100 m$^3$ filtered seawater volume (unit: ind/100 m$^3$).

We calculated the habitat suitability index (HSI) to investigate fish larval number distribution patterns of *B. pterotum* and *A. lineatus* in relation to selected measured hydrographic parameters, including depth (m), sea surface temperature (°C), sea bottom temperature (°C), sea surface salinity (psu), and sea bottom salinity (psu) in June and July 2018. HSI was obtained by comprehensive calculations of many number-based suitability index (SI) values [25]. Each SI was estimated as a value between 0.0 and 1.0. The SIs were estimated as follows:

$$SI = \frac{Y - Y_{\text{min}}}{Y_{\text{max}} - Y_{\text{min}}}$$

where $Y$ is larvae number after smoothed regression and $Y_{\text{max}}$ and $Y_{\text{min}}$ are maximum and minimum predicted values. A SI value closer to 1.0 means a higher suitability index, and a SI value closer to 0.0 means a lower suitability index. SI values between 0.7 and 1.0 correspond to environmental factors that are regarded as the most suitable environment range [26].

We calculated HSI values using the equation given below:

$$HSI = \frac{1}{\sum_{i=1}^{n} w_i} \sum_{i=1}^{n} S_i w_i$$

where $HSI$ is habitat suitability index, $S_i$ is the SI value of the environmental variable, $i$ and $w_i$ are the weight of the environmental variable, and $i$, and $n$ are the number of environmental factors [27].

Finally, a hydrodynamic numerical model was applied to simulate salinity and sea temperature structures. Based on the original estuarine, coastal and ocean models [28], the State Key Laboratory of Estuarine and Coastal Research, East China Normal University developed and improved the model [29]. A third-order HSIMT advection scheme was used to solve the tracer advection terms [29]. The model domain covered the entire Yellow Sea, East China Sea, and Bohai Sea, as well as part of the Pacific Ocean and the Japan Sea. The mesh grid with a resolution of ~1 km or higher was refined to 367 × 319 based on previous studies inside the Changjiang River Estuary and 2–4 km east and south of the Changjiang River mouth [30]. The model previously was validated comprehensively and performed in reproducing multi-scale salinity, temperature, and current distribution structures reasonably [31–36].

3. Results

3.1. Positive Sampling Stations and Larval Number

The positive sampling stations number range of *O. elegans*, *E. pottii*, *B. pterotum*, *A. japonicum*, *U. bensasi*, and *A. lineatus* were 2–24, 1–11, 1–51, and 11 only in July, and 3–6 and 1–40 thereafter. The stations of *O. elegans*, *E. pottii*, and *A. lineatus* were recorded at 24, 11, and 30 in June, respectively, making June the month with the highest number of records. In the other sampling months, *E. pottii* was only recorded at 1–2 sampling stations. *Omobranchus elegans* and *A. lineatus* were recorded at the second highest number of sampling stations in July, being present at 15 and 29 stations, respectively. *Apogonichthys japonicum* was recorded at 11 sampling stations in July, and *U. bensasi* was recorded at 3–6 sampling stations from April to July. *Benthosema pterotum* was recorded at the highest number of sampling stations (51) in July, followed by 32 sampling stations in June, with the lowest number of records (1 and 3 sampling stations) from April to May (Table 1).
Table 1. Positive station number (sn), total larvae number (tn), mean larval density (mld, inds/100 m$^3$), and the number in each developmental stage (yolk-sac: yolk; preflexion: pre; flexion: flex; postflexion: post; juvenile: j) of *Omobranchus elegans*, *Erisphex pottii*, *Benthosema pterotum*, *Acropoma japonicum*, *Upeneus bensasi*, and *Apogonichthys lineatus* in horizontal and oblique hauls conducted from April to July 2018.

| The Species          | Month | sn   | tn   | mld  | Yolk | Pre | Flex | Post | j   | tn   | mld  | Yolk | Pre | Flex | Post | j   |
|----------------------|-------|------|------|------|------|-----|------|------|-----|------|------|------|-----|------|------|-----|
| *Omobranchus elegans* | April  | 2    | 1    | 0.11 | -    | -   | -    | -    | 1   | -    | 1    | 0.11 | -   | -   | -    | 1   |
|                      | May    | 8    | 120  | 2.39 | -    | 114 | 5    | 1    | 7   | 1.32 | 7    | 30  | 14  | 1    | 7   |
|                      | June   | 24   | 49   | 0.32 | -    | 42  | 1    | 1    | 45  | 0.81 | 30  | 14  | 1    | 1   |
|                      | July   | 15   | 101  | 0.89 | -    | 10  | 28   | 63   | 1.26 | 3    | 1    | 5   | -   | -    | -   |
| *Erisphex pottii*    | April  | 1    | -    | -    | -    | -   | -    | -    | 1   | 1.89 | -   | -   | -   | -    | -   |
|                      | May    | 1    | 1    | 0.12 | -    | 1   | -    | -    | -   | -    | -   | -   | -   | -    | -   |
|                      | June   | 11   | 20   | 0.89 | 4    | 12  | 4    | -    | 7   | 2.61 | 4   | 3   | -   | -    | -   |
|                      | July   | 2    | 1    | 0.03 | -    | -   | -    | -    | 1   | 0.19 | -   | -   | -   | -    | -   |
| *Benthosema pterotum*| April  | 1    | -    | -    | -    | -   | -    | -    | 1   | 1    | 0.10 | -   | -   | -    | -   |
|                      | May    | 3    | 1    | 0.09 | -    | -   | -    | 1    | 3   | 2.95 | -   | 1   | 1   | -    | -   |
|                      | June   | 32   | 820  | 8.54 | 2    | 43  | 570  | 205  | -   | 1973 | 8.83 | -   | 29  | 1168 | 756  |
|                      | July   | 51   | 5303 | 20.30 | 13 | 27  | 658  | 1476 | 3129 | 8327 | 395.20 | -   | 10  | 1147 | 5068  |
| *Acropoma japonicum* | April  | -    | -    | -    | -    | -   | -    | -    | -   | -    | -   | -   | -   | -    | -   |
|                      | May    | -    | -    | -    | -    | -   | -    | -    | -   | -    | -   | -   | -   | -    | -   |
|                      | June   | -    | -    | -    | -    | -   | -    | -    | -   | -    | -   | -   | -   | -    | -   |
|                      | July   | 11   | -    | -    | -    | -   | -    | -    | -   | 52   | 6.87 | 8   | 18  | 13   | 13  |
| *Upeneus bensasi*    | April  | 6    | 6    | 0.25 | -    | 2   | 3    | 1    | -   | 29   | 0.84 | 4   | 18  | 7    | -   |
|                      | May    | 3    | 3    | 0.17 | -    | -   | -    | 1    | 2   | 2    | 0.11 | -   | 1   | 1    | -   |
|                      | June   | 11   | 11   | 0.51 | 4    | 5   | 2    | -    | 15  | 0.76 | 3   | 10  | 1    | 1    | -   |
|                      | July   | 3    | 34   | 1.17 | -    | 1   | -    | 33   | -   | -    | -   | -   | -   | -    | -   |
| *Apogonichthys lineatus* | April | 2    | 3    | 0.15 | -    | -   | -    | 3    | -   | -    | -   | -   | -   | -    | -   |
|                      | May    | 1    | 1    | 0.10 | -    | -   | -    | -    | -   | -    | -   | -   | -   | -    | -   |
|                      | June   | 40   | 364  | 3.40 | 5    | 67  | 245  | 47   | 262  | 2.40 | -   | 93  | 86  | 82   | 1   |
|                      | July   | 29   | 174  | 1.73 | 4    | 14  | 69   | 87   | 344  | 12.17 | 32  | 9   | 79  | 192  | 32  |

In terms of larval number, only 52 *A. japonicum* individuals were collected in July during the oblique haul. For *B. pterotum*, 1 and 3 individuals were collected from April to May. However, 5303 and 8527 individuals were collected in the horizontal and oblique hauls in July, respectively. The number of *B. pterotum* larvae collected by oblique hauls in June and July was higher than the number collected in horizontal hauls. The number of *U. bensasi* larvae was recorded as 3–34 and 2–29 individuals (ind), respectively, in horizontal and oblique hauls. The abundance of *E. pottii* larvae was highest in June, and very few individuals were collected in the other months. The abundance of *O. elegans* larvae in the horizontal hauls was higher than the number in oblique hauls, particularly in May (120 versus 7 individuals) and July (101 versus 10 individuals). A low abundance (1–3 individuals) of *A. lineatus* was recorded in samples from April to May, with highest abundance (174–364 individuals) recorded from June to July (Table 1).

The larvae of *O. elegans* collected in horizontal hauls were predominantly in the preflexion stage from May (114 individuals) to June (42 individuals), while the postflexion stage was dominant in July (63 individuals). The larvae of *E. pottii* were predominantly in the preflexion stage in June. The majority of *B. pterotum* larvae were in the flexion stage in June and postflexion and juvenile stages in July. *Acropoma japonicum* larvae were recorded from the yolk-sac to the postflexion stage, with the preflexion stage being dominant in July. The larvae of *U. bensasi* ranged from the yolk-sac to the postflexion stage, with the preflexion stage being dominant in July. The larvae of *A. lineatus*, collected in horizontal hauls in June, were mainly in the flexion stage (245 individuals), while those collected in oblique hauls were in the preflexion to postflexion stages (Table 1).

Larval density intervals at sampling stations were 0–1, 1–10, 10–50, 50–100, 100–500, and >500 ind./100 m$^3$ (Figure 2). At the majority of stations, *O. elegans* (1–16 stations) and *E. pottii* (1–7 stations) were recorded 0–1 ind./100 m$^3$ and were present in the surface samples in April to July. Most stations where *B. pterotum* were recorded were in the intervals of 0–1, 1–10, and 50–100 ind./100 m$^3$ from June to July. *Acropoma japonicum* larvae were found in the bottom in July 2018, ranging from 0–1 to 10–50 ind./100 m$^3$. Only 1–3 stations where *U. bensasi*...
were recorded were in the interval of 1–10 ind/100 m³. For A. lineatus, 0–1 ind/100 m³ were
recorded at 1–2 stations in April to May and 1–10 ind/100 m³ at 8–19 stations in June to July.

Figure 2. The station percentage of larval density interval (0–1, 1–10, 10–50, 50–100, 100–500, and
>500 ind/100 m³) of Omobranchus elegans, Erisphex pottii, Benthosema pterotum, Acropoma japonicum,
Upeneus bensasi, and Apogonichthys lineatus in horizontal and oblique hauls from April to July, 2018.
“S” denotes the horizontal haul and “B” denotes the oblique haul.

3.2. Spatiotemporal Abundance Distributions

The spatial distribution range of O. elegans in June mainly included the coastal area of
the Zhejiang coastline and outside the Yangtze Estuary, at latitudes ranging from 26.00° N
to 32.00° N. At 122.00° N 29.00° E in July, the total number of larvae reached 76 individuals
in preflexion to postflexion stages, ranging from 27.50° to 31.25° N (Figure 3).

In June, Erisphex pottii was mainly distributed in the area of outside the Yangtze Estuary
with the range of 31.00° to 31.50° N. Upeneus bensasi was distributed in the coastal area of
Fujian province, China with the range of 24.26–26.00° N in June. Benthosema pterotum and A. lineatus were mainly distributed in the water area (between the Yangtze River estuary
and the Zhoushan fishing ground) at the confluence of the Kuroshio branch current and the
Changjiang diluted water in June and July, migrating from 30.00–31.00° N 123.17–123.50° E
in June to 30.00–32.50° N 122.22–123.50° E in July (Figures 1 and 3 and Table 2). Compared
with the distribution range of B. pterotum, the spatial distribution of A. lineatus was closer
to the Yangtze River estuary in July (Figure 3). The habitat–area range of these two species
roughly overlapped.

3.3. Variations in Measured Environmental Variables

The six species were distributed from shallow waters (5.00 m deep) to deeper waters
(66.00 m deep). The sea surface temperature (SST) range of the six species was 4.40–29.60 °C.
*Omobranchus elegans* had the widest temperature range, from 4.40–28.73 °C. The lower SST limit of *E. pottii*, *U. bensasi*, and *A. lineatus* were similar (18.69 to 18.89 °C), and the upper range limits for these species were 25.20, 28.07, and 29.60 °C, respectively. The highest SST values for *B. pterotum* and *A. japonicum* were 29.60 °C, but the lower SST limit of *B. pterotum* was far lower than that of *A. japonicum* (16.26 versus 24.11 °C). The lower limits of sea bottom temperature for *E. pottii*, *A. japonicum*, *U. bensasi* and *A. lineatus* were ~18.00–19.00 °C. The highest upper limit was 30.03 °C for *A lineatus*, followed by 27.44 °C for *A. japonicum*, and the lowest values were 20.69 °C and 22.62 °C for *E. pottii* and *U. bensasi* respectively. The sea bottom temperature range for *O. elegans* and *B. pterotum* was 13.97–28.74 °C.

**Figure 3.** The larval distributions of each developmental stage collected in the study area in the surface (a–h) and bottom (i–p) trawls. (a,i) *Omobranchus elegans* in June; (b,j) *Benthosema pterotum* in June; (c,k) *Erisphex pottii* in June; (d,l) *Apogonichthys lineatus* in June; (e,m) *Omobranchus elegans* in July; (f,n) *Benthosema pterotum* in July; (g,o) *Upeneus bensasi* in June; and (h,p) *Apogonichthys lineatus* in July.
Table 2. Suitable measured habitat variable range calculated with the HSI of *Benthosema pterotum* and *Apogonichthys lineatus* from June to July 2018. D—depth (m), SST—sea surface temperature (°C), SBT—sea bottom temperature (°C), SSS—sea surface salinity (psu), SBS—sea bottom salinity (psu), and MSAR—most suitable area range.

|                  | D               | SST (°C) | SBT (°C) | SSS (psu) | SBS (psu) | MSAR                      |
|------------------|-----------------|----------|----------|-----------|-----------|---------------------------|
| *Benthosema pterotum* | June 59.00–61.00 | 18.40–19.20 | 18.62–20.79 | 32.37–34.30 | 30.31–34.53 | 30.00–31.00° N, 123.17–123.50° E |
|                  | July 26.00–51.95 | 23.89–26.02 | 19.71–22.27 | 17.77–22.26 | 32.22–33.80 | 30.00–32.50° N, 122.22–123.50° E |
| *Apogonichthys lineatus* | June 57.85–59.00 | 18.89–19.00 | 17.53–19.35 | 30.49–33.28 | 30.51–31.95 | 30.50–31.00° N, 123.17–123.33° E |
|                  | July 27.51–42.06 | 23.89–29.60 | 19.08–21.82 | 21.41–27.85 | 32.54–33.94 | 31.25–32.00° N, 122.50–123.50° E |

The sea surface salinity (SSS) range for these six species was 16.54–34.60 psu. The SSS range of *O. elegans*, *B. pterotum*, *A. lineatus*, *E. pottii*, and *A. japonicum* were very similar (16.54–34.60 psu versus 25.89–34.60 psu). The species with the narrowest SSS range was *U. bensasi* (29.30–34.50 psu). The sea bottom salinity ranges were 20.34–33.80 psu for *O. elegans* (the highest), 24.95–34.59 psu for *B. pterotum* and *A. japonicum*, 27.85–34.57 psu for *A. lineatus* (the second highest), and 31.19–34.59 psu for *E. pottii* and *U. bensasi* (the lowest). The pH value range of these six species was 7.00 to 9.00. The DO range of *O. elegans* was the widest (2.54–8.70 mg/L). The lower DO limit of other four species (*B. pterotum*, *A. japonicum*, *U. bensasi*, *A. lineatus*) was ~5.00 (4.80–5.05) mg/L, and the upper DO limit range of *A. japonicum* (5.89 mg/L), *U. bensasi* (6.21 mg/L), *A. lineatus* (7.58 mg/L), and *B. pterotum* (8.50 mg/L) ranged from 5.89 to 8.50 mg/L (Table 3).

Table 3. The range of measured environmental variables are presented for the species including *Omobranchus elegans*, *Erisphex pottii*, *Benthosema pterotum*, *Acropoma japonicum*, *Upeneus bensasi*, and *Apogonichthys lineatus* from April to July 2018 in the study area. Abbreviation: SST—sea surface temperature, SBT—sea bottom temperature, SSS—sea surface salinity, SBS—sea bottom salinity, and DO—dissolved oxygen.

| Species                   | Depth (m) | SST (°C) | SBT (°C) | SSS (psu) | SBS (psu) | pH     | DO (mg/L) |
|---------------------------|-----------|----------|----------|-----------|-----------|--------|-----------|
| *Omobranchus elegans*     | 5.00–61.30| 4.40–28.73| 15.07–28.74 | 16.54–34.60 | 20.34–33.80 | 6.98–8.98 | 2.54–8.70 |
| *Erisphex pottii*         | 15.00–60.00| 18.89–25.20 | 18.37–20.69 | 26.54–34.60 | 31.73–34.59 | -      | -         |
| *Benthosema pterotum*     | 8.10–61.00| 16.26–29.60 | 13.97–27.44 | 17.53–34.30 | 24.95–34.59 | 7.10–9.05 | 4.80–8.50 |
| *Acropoma japonicum*      | 32.00–61.00| 24.11–29.60 | 18.72–27.44 | 25.89–33.65 | 24.95–34.55 | 7.15–8.65 | 4.91–5.89 |
| *Upeneus bensasi*         | 13.00–66.00| 18.69–28.07 | 18.89–22.62 | 29.30–34.50 | 31.19–34.57 | 7.16–8.89 | 5.05–6.21 |
| *Apogonichthys lineatus*  | 8.10–59.00| 18.89–29.60 | 17.53–30.03 | 17.53–33.72 | 27.85–34.57 | 7.08–9.05 | 4.80–7.58 |

4. Discussion

*Benthosema pterotum* larvae were recorded almost all year round in the East China Sea, with the highest abundance from July to August [17]. In the Indian Ocean, *Benthosema pterotum* spawning takes place throughout the year with peaks from March to June and September to November, which corresponds to the transition period between monsoon seasons [37]. In the Oman Sea, the breeding season is from May to September [18]. In the current study, *B. pterotum* larvae were most abundant in July. This indicated that the spawning period in the East China Sea is much shorter than that in the Indian Ocean.

In terms of habitat, adult *B. pterotum* are reported to be distributed in the area of north of 30.00° N [38]. They migrate a short distance in the northern East China Sea, from the southwest in winter to the northeast in spring, and then from the northeast in summer to the southwest in autumn. The population distribution in spring and summer is a little more east than that in autumn and winter [38]. Li et al. (2006) suggested that adults are mainly distributed in...
30.50–32.50° N 124.00–126.50° E [38]. In the current study, *Benthosema pterotum* larvae migrated from 30.00–31.00° N 123.17–123.50° E in June to 30.00–32.50° N 122.22–123.50° E in July. Sassa et al. (2015) also observed that the high abundance of the larvae occurred in the area of 30.00–30.50° N 124.50–126.00° E [39]. That is to say, the spawning grounds might be in the intersecting waters between the Changjiang diluted water and Kuroshio branch current. The shelf-break salinity front might act as a barrier restricting the offshore dispersion of the larvae, enabling them to recruit into the area of adult habitat. In addition, cold water in Northern Taiwan resulting from the impingement of the Kuroshio Current onto the continental shelf causes upwelling, creating good spawning and nursery grounds for *B. pterotum* [40].

The current study also identified the larvae of *B. pterotum* migrating to the nearshore. The density of the adult population was reported to be higher in the nearshore waters than offshore areas [38], suggesting that larger individuals of this species preferred to inhabit coastal waters. Some juveniles moved to the south of the Changjiang River estuary. We suggest that the reason they migrate to the inshore area is due to high productivity and low transparency. High concentrations of *B. pterotum* were observed in the highly productive areas [41]. It has been reported that increases in primary production occur with greater river discharge from nearshore waters to offshore waters in the East China Sea [42]. Regarding the low transparency, highly turbid waters in the bottom layer are found at 30.00–32.00° N over the mud shelf region [43]. Suspended particulate matter discharged into the ocean along with river water produced highly turbid waters. The dim light conditions enable the mesopelagic *B. pterotum* to live in such a shallow area. In addition, the larvae are less likely to be preyed upon when water turbidity increases and light decreases [44].

In the current study, the larvae of *B. pterotum* were mainly in the flexion stage in June and the postflexion stage in July. Owing to a very short egg hatching period (12 h at 21 °C) [45], the distribution of larvae at the preflexion to flexion stages represented the approximate location of the spawning grounds. After complete formation of the caudal fin base, postflexion larvae have sufficient swimming ability. It was reported that the preflexion and flexion larvae were mainly observed in the waters of the south and central shelf region, and postflexion larvae and juveniles were abundant in the waters of the north and peripheral shelf region of the East China Sea [46]. In terms of larval abundance, the mean abundance of the larvae in this study was 0.06–5993.68 ind/100 m³, changing from 0.09–4.88 ind/100 m³ in April–May to 8.54–395.19 ind/100 m³ in June to July (8.54–8.83 ind/100 m³ in June, 20.30–395.20 ind/100 m³ in July). It was previously reported that the median abundance varied from 8.80 to 24,881.90 ind/100 m³, with the highest in June 2009 and lowest in July 2010 (656.80 against 57.80 ind/100 m³) [46].

In terms of measured hydrographic characteristics (such as DO, water temperature, and salinity) affecting the distribution of the larvae, the largest DO range in the current study was recorded for *B. pterotum* (4.80 to 8.50 mg/L). CCA ordination analysis showed that the larvae were most influenced by high DO concentrations [47]. High DO concentrations in the coastal waters, caused by upwelling, attracted larvae to move inshore [48]. In the Indian Ocean, spawning is expected to occur in waters of ~21.00–28.00 °C [45]. The optimal water temperature for the larvae in the current study was 18.00–20.00 °C with a range of 13.97–29.60 °C, suggesting an optimum temperature >24.00 °C for larvae [49]. Larvae in the preflexion and flexion stages inhabit optimum temperatures ranging from 28.20 to 28.80 °C at 25.00–29.00° N 121.00–125.00° E [46]. The sea surface temperature isotherm produced by the Kuroshio front might be a key oceanographic structure defining larval distribution dynamics. Sassa et al. (2014) suggested that salinity affected the distribution of the larvae [50]. In the Arabian Sea, the salinity of the larvae ranged from 35.00 to 37.00 psu [51]. On the shelf of the East China Sea, the salinity was much lower than that of the Arabian Sea with a range of 33.50–33.90 psu [52]. Sassa et al. (2014) suggested two distinct distribution patterns of larvae: the area of <33.70 psu and near the 33.70 psu isohaline [50]. Our study suggested the bottom salinity isohaline of 32.00–34.00 psu for larvae distribution.
Comparing \textit{A. lineatus} with \textit{B. pterotum}, both species migrated from birth places $58.00–61.00$ m deep to the coastal shallow waters with depths of $26.00–51.95$ m. However, the depth range of \textit{A. lineatus} was lower than \textit{B. pterotum} ($27.51–42.06$ m versus $26.00–51.95$ m). Suitable SST and bottom sea temperature for these species changed from $18.40–19.20$ °C to $23.89–29.60$ °C and from $17.53–20.79$ °C to $19.08–22.27$ °C from June to July, respectively. The SSS of \textit{B. pterotum} and \textit{A. lineatus} changed from $30.49–34.30$ psu to $17.77–22.26$ psu and $21.41–27.85$ psu, respectively. The sea bottom salinity of \textit{B. pterotum} and \textit{A. lineatus} changed from $30.51$ to $31.95$ psu, which was lower than the range for \textit{B. pterotum} in June, which was basically along the isolines of $30.00–32.00$ psu, and $32.54$ to $33.94$ psu in July, along the isolines of $32.00–34.00$ psu (Table 2).

To date, there have been very few studies identifying the larval distributions of \textit{O. elegans}, \textit{E. pottii}, \textit{A. japonicum}, \textit{U. bensasi}, and \textit{A. lineatus} in the East China Sea. \textit{Acropoma japonicum}, \textit{A. lineatus}, and \textit{E. pottii} are seasonally dominant species in the Zhoushan fishing ground [53]. We reported that these species are distributed from $5.00$ m to $66.00$ m. The temperature and salinity of \textit{O. elegans} habitat were previously reported to be $12.00–30.00$ °C and $27.40–32.50$ psu [16], lower than those recorded in the current study (SST: $4.40–28.73$ °C; SBS: $20.34–33.80$ psu). The habitat temperature (SST) of the \textit{A. lineatus} larvae was estimated to be $18.89–19.00$ °C in June and $23.89–29.60$ °C in July. Compared with \textit{B. pterotum}, \textit{Apogonichthys lineatus} prefers to remain in water with large variations of SSS ($21.41–27.85$ psu) and is closer to the offshore area (Table 2). Larval distribution corresponded closely with the adult habitat of small-sized fishes in the East China Sea.

Conclusively, the East China Sea is one of the most rapidly warming large marine ecosystems, and its SST increased by $1.22$ °C between 1982 and 2006 [54]. SST showed a significant warming trend in the waters of China, and its increasing rate is far higher than the global average [55,56]. Wang et al. (2020) reported that the SST in the waters of northeastern Taiwan in winter increased between 1985 and 2015 [45]. In July and August 2017, extreme warm SST anomalies (SSTAs) were observed in the northern Yellow Sea, which lasted for 60 days with a maximum daily SST of $2.93$ °C on the date of the peak. High water temperature was considered as one of the most important factors leading to the mass emaciation and mortality of scallops on Zhangzi Island [57,58]. Larval assemblies are more easily to be affected by extra climate and increasing water temperature. Thus, it is important to perform continuous large-scale ichthyoplankton surveys in the East China Sea to understand the spatiotemporal variations of eggs and larvae of important fish species in the context of increasing temperatures.

5. Summary

The descriptions on the larval distribution of the small-sized fishes \textit{Omobranchus elegans}, \textit{Erisphex pottii}, \textit{Benthosema pterotum}, \textit{Acropoma japonicum}, \textit{Upeneus bensasi}, and \textit{Apogonichthys lineatus} in the East China Sea ecosystem remain scant. The current study contributed to the knowledge of the spatiotemporal distributions and dynamics of the early life history of these species. Especially, we found \textit{B. pterotum} and \textit{A. lineatus} migrated from $30.00–31.00^\circ$ N $123.17–123.50^\circ$ E in June to $30.00–32.50^\circ$ N $122.22–123.50^\circ$ E in July. Our findings contribute to the maintenance of ocean biodiversity and promote sustainable fisheries managements.

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