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Short communication

Effect of global warming on the distribution of *Lucifer intermedius* and *L. hanseni* (Decapoda) in the Changjiang estuary

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Abstract

We conducted an oceanographic census in 1959, 2002, and 2005 to evaluate changes in the temporo-spatial distribution and abundance of *Lucifer intermedius* and *L. hanseni* in the Changjiang estuary. In general, the abundance and frequency of occurrence (OF) for these two species were highest during the summer. We measured a significant change in the abundance and OF between years. The abundance and OF of *L. intermedius* increased from 3.7 individuals m^{-3} and 66.67%, respectively, in 1959, to 8.93 individuals m^{-3} and 85.19%, in 2002. In 1959, *L. hanseni* was only found during the summer (abundance: 0.01 individuals m^{-3}, OF: 3.70%). However, in 2002, this species was collected during all seasons except the winter. Furthermore, abundance (0.47 individuals m^{-3}) and OF (25.93%) were higher in 2002 than in 1959. Further increases in abundance and OF were measured during cruises during the spring of 2005. We hypothesize that global warming is responsible for the increase in abundance of *L. intermedius* and *L. hanseni* and the northward expansion of *L. hanseni* in the Changjiang estuary. Given our results, monitoring of both species may be useful to evaluate the effects of climate change.

Keywords: Zooplankton; *Lucifer intermedius*; *Lucifer hanseni*; Global warming; Changjiang estuary

1. Introduction

The genus *Lucifer* is a member of the zooplankton family Luciferidae (order Decapoda) [1] and is widely distributed in both tropical and subtropical waters [2,3]. *Lucifer intermedius* and *L. hanseni* are pelagic warm-water species [4]. Studies on the distribution [5], diversity [6], and species composition [7] of Decapod species in the East China Sea (ECS) suggest that *L. intermedius* and *L. hanseni* are dominant in this region. Furthermore, aggregations of *L. intermedius* have a significant effect on the community structure and diversity of other *Lucifer* species [6]. Many commercial fish species prey on individuals of the Luciferidae family [8,9]. Given this, members of the Luciferidae family are likely to play an important role in maintaining fishing opportunity in the Changjiang estuary.

A number of researchers have studied *Lucifer* during the past few decades. However, the majority of studies have focused on taxonomy [10,11] and ecology [9,12,13]. In the Changjiang estuary, the majority of studies involving zooplankton have focused on species composition and community characteristics [7,14]. Few studies have evaluated changes in species dominance. Similarly, there has been little attention given to the changes in the abundance and frequency of occurrence (OF) that has occurred as a result of long-term climate change. The phenomenon known as global warming is now widely acknowledged [15–17], and further increases in temperature are expected within the next century [18]. Climate change has undoubtedly had a significant impact on aquatic ecosystems [19–22]. To predict how aquatic ecosystems will respond to global warming, it is

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essential to understand how zooplankton populations have responded to changes in temperature historically. Global warming has changed both species diversity [23,24] and the abundance of zooplankton [25–28]. Shifts in zooplankton assemblages are a particularly sensitive indicator of climate change [29]. For example, warm-water assemblages of calanoid copepods have expanded 1000 km further north in the Northeast Atlantic over the past 40 years, with a concomitant retraction in the range of cold-water assemblages [29,30].

To improve our understanding about the effects of global warming on estuarine zooplankton ecology, we investigated the change in the abundance and temporo-spatial distribution of *L. intermedius* and *L. hanseni* in the Changjiang estuary.

2. Materials and methods

2.1. Location of sampling stations

To account for seasonal changes in community structure, we collected zooplankton samples during spring (May), summer (August), autumn (November), and winter (February) in 1959 and 2002, and during the spring of 2005. In 1959 and 2005, we sampled between 29°00′–32°00′N and 122°00′–123°30′E (Fig. 1). In 2002, we sampled between 28°00′–32°00′N and 122°00′–123°30′E. When comparing data between years, we only considered the data collected in the overlapping areas.

2.2. Sampling and analysis

Zooplankton was collected using vertical hauls (bottom to surface) of the standard, large plankton net (diameter: 80 cm, mesh aperture: 0.505 mm). A flowmeter was mounted in the center of the mouth of the net to measure the volume of filtered water. All samples were removed from the net and immediately preserved in 5% buffered seawater formalin. The abundance (individuals m^{-3}) of *L. intermedius* and *L. hanseni* was calculated by counting the number of individuals under a stereomicroscope. All enumeration and determination were performed following the Specifications of Oceanographic Surveys [31]. Vertical profiles of temperature were measured with a CTD system. The frequency of occurrence (OF) was calculated as the percentage of sites where the species was found.

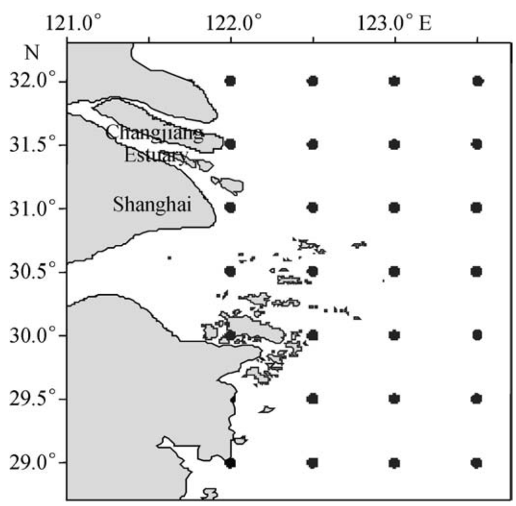

Fig. 1. Sampling locations.

3. Results

3.1. Seasonal variation of L. intermedius and L. hanseni between 1959 and 2002

The average abundance and OF of *L. intermedius and L. hanseni* were highest in summer and lowest in winter (Table 1), with intermediate values during spring and autumn, in both 1959 and 2002. The abundance and OF of *L. intermedius* were much higher than *L. hanseni*. Furthermore, we found *L. intermedius* individuals during all the sampling periods. The abundance and OF of *L. intermedius* were higher in 2002 (3.7 individuals m^{-3} and 66.67%, respectively) than in 1959 (8.93 individuals m^{-3} and 85.19%, respectively). In contrast, *L. hanseni* was only found during the summer of 1959 (abundance: 0.01 individuals m^{-3}, OF: 3.70%) and in all seasons except the winter of 2002. During the summer of 2002, the abundance and OF of *L. hanseni* were 0.47 individuals m^{-3} and 25.93%, respectively.

3.2. Spatial distribution of L. intermedius in 1959 and 2002

We observed a significant difference between years in the abundance and distribution of *L. intermedius* during spring and summer (Fig. 2). The distribution of *L. intermedius* expanded northward and their abundance increased significantly in 2002 compared with that in 1959. During the spring of 1959, the distribution of *L. intermedius* was limited to south of latitude 30.5°N (Fig. 2(a)). However, during the spring of 2002, the distribution had expanded to

Table 1
Seasonal abundance and frequency of occurrence (OF) of *L. intermedius* and *L. hanseni* in the Changjiang estuary in 1959 and 2002.

Season	Year	SST (°C)	Abundance (individuals m^{-3})		OF (%)	
			L. intermedius	*L. hanseni*	*L. intermedius*	*L. hanseni*
Spring	1959	17.2	0.10	0	22.22	0
	2002	17.53	0.28	0.06	40.74	7.41
Summer	1959	27.77	3.70	0.01	66.67	3.70
	2002	27.26	8.93	0.47	85.19	25.93
Autumn	1959	19.11	0.18	0	34.48	0
	2002	18.84	0.14	0.02	31.03	13.79
Winter	1959	9.07	0.04	0	6.90	0
	2002	10.36	0.01	0	6.90	0

SST denotes the sea surface temperature.

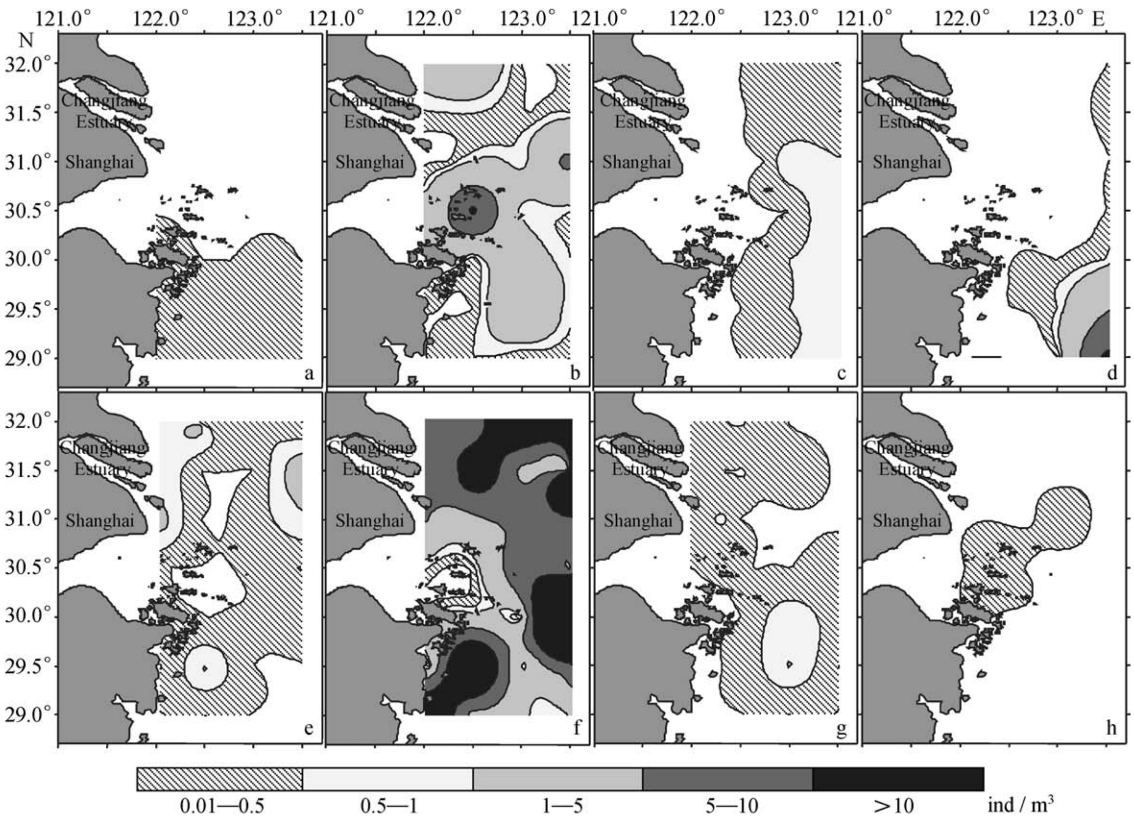

Fig. 2. Spatial distribution of the change in average abundance of *L. intermedius* in the Changjiang estuary in 1959 and 2002. Panels (a)–(d) denote the seasons (spring, summer, autumn, and winter, respectively) in 1959. Panels (e)–(i) denote the corresponding seasons in 2002.

most areas of the Changjiang estuary (Fig. 2(e)). The changes in abundance and distribution of *L. intermedius* between 1959 and 2002 were most obvious during the summer (Fig. 2(f)): *L. intermedius* was distributed throughout both sides of the Changjiang estuary, although abundance was higher on the south side than the north side. There was also a zone of low abundance in the area influenced by Changjiang diluted water (CDW) (Fig. 2(b)) in 1959 but not in 2002. Furthermore, in 2002, the number of *L. intermedius* increased significantly (Fig. 2(f)). Conversely, the abundance and distribution of *L. intermedius* during the autumn and winter of 1959 (Fig. 2(c) and (d)) and 2002 (Fig. 2(h) and (i)) were similar.

3.3. Spatial distribution of L. intermedius during the spring

The spatial distribution of *L. intermedius* during the spring differed significantly between 1959 and 2005 (Fig. 3). *L. intermedius* was distributed to the south of latitude 30.5°N in April and May of 1959 (Fig. 3(a) and (b)). In 2005, the range of this species was somewhat contracted (Fig. 3(d)), although we did find *L. intermedius* in the Changjiang estuary in May (Fig. 3(e)). Both the abundance and OF increased in June of 1959 (Fig. 3(c)) and 2005 (Fig. 3(f)). Furthermore, the aggregation intensity and abundance of *L. intermedius* increased significantly in the Changjiang estuary in 2005 compared with that in 1959.

3.4. Distribution of L. hanseni in 1959, 2002, and 2005

During the seasonal cruises in 1959, *L. hanseni* was captured at only one site (30.5°N 122.5°E) during the summer. In contrast, we captured *L. hanseni* during all seasons in 2002, although the highest abundance (2.91 individuals m^{-3}) (Table 2) was still measured during the summer. The OF of *L. hanseni* was very low in 2002, especially during the spring and winter. However, it was significantly higher than in 1959. We found *L. hanseni* in the Changjiang estuary (Fig. 4(a)) in the summer. By the end of summer, the distribution of *L. hanseni* had retracted southward (Fig. 4(b)) and abundance had increased slightly. The spatial distribution of *L. hanseni* during the spring of 2005 was limited to south of latitude 29.5°N, and abundance was very low during this season (Fig. 5(a)). In May, the range expanded to the north although abundance was relatively unchanged (Fig. 5(b)). Both abundance and distribution increased significantly in June (Fig. 5(c)).

4. Discussion

The distribution of *L. intermedius* and *L. hanseni* expanded northward and abundance increased during the spring and summer of 2002 compared with that of 1959 in the Changjiang estuary (Table 1 and Fig. 2). Further increases were observed during the spring of 2005 (Figs. 3 and 5).

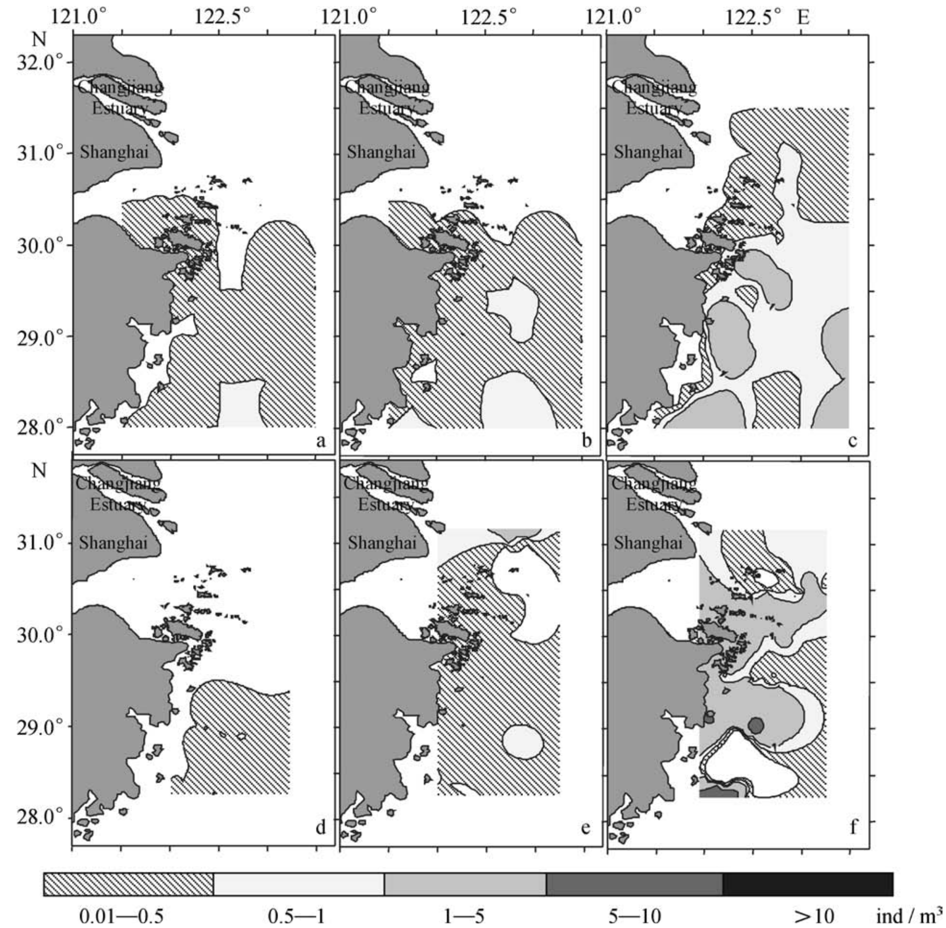

Fig. 3. Spatial distribution of the change in abundance of *L. intermedius* in the Changjiang estuary and adjacent waters during the spring of 1959 and 2005. Panels (a)–(c) represent surveys conducted in April, May, and June of 1959. Panels (d)–(f) represent surveys conducted in April, May, and June of 2005.

Table 2
Sampling locations and abundance of *L. hanseni* during oceanographic censuses of the ECS in 1959 and 2002.

Date	Longitude	Latitude	SST (°C)	Salinity (psu)	Abundance (individuals m^{-3})
1959-09-08	122.50°E	30.50°N	25.76	23.37	0.5
2002-04-27	123.01°E	30.00°N	17.92	32.70	0.68
2002-04-29	123.50°E	29.00°N	20.23	34.09	0.90
2002-08-27	123.52°E	31.01°N	28.63	22.89	2.91
2002-08-28	122.98°E	30.51°N	27.67	3.29	0.54
2002-08-28	123.50°E	30.50°N	28.09	18.08	0.57
2002-09-03	123.50°E	30.00°N	26.84	18.14	0.59
2002-09-03	122.49°E	29.50°N	26.86	19.43	2.86
2002-09-03	123.02°E	29.51°N	26.61	17.92	2.25
2002-09-02	122.05°E	29.00°N	27.64	18.83	2.91
2002-11-06	123.50°E	31.50°N	17.10	5.67	0.18
2002-11-10	123.00°E	30.00°N	18.43	9.14	0.04
2002-11-11	122.92°E	30.02°N	20.58	22.38	0.03
2002-11-10	122.50°E	29.00°N	20.14	23.28	0.32

SST denotes the sea surface temperature.

The temporo-spatial abundance and OF of *L. intermedius and L. hanseni* were primarily affected due to temperature. *L. intermedius* was found in both the ECS and South China Sea (SCS), whereas *L. hanseni* was found primarily in the SCS. The abundance of both species decreased with increasing latitude, which is characteristic of warm-water species. Typically, the abundance of warm-water species peaks during the summer or autumn [32]. *L. intermedius* was the most commonly found species in all years we sampled. *L. hanseni* became more abundant in the Changjiang

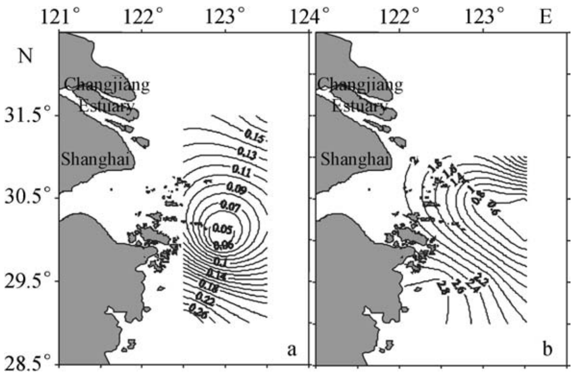

Fig. 4. Spatial distribution of the change in abundance of *L. hanseni* in the summer (a) and autumn (b) of 2002.

estuary during 2002 and 2005 (Table 2 and Figs. 4 and 5). The geographic distribution of both species confirmed that these were warm-water species that have expanded northward in the coastal waters of the ECS, coincident with warming of the ocean in this region (Table 1 and Figs. 2 and 3).

Water masses played an important role in determining the spatial distribution of *L. intermedius and L. hanseni* in the Changjiang estuary. The highest abundance of *L. intermedius* and *L. hanseni* occurred on the seaward side of the mixing zone between the CDW and the ECS. Conversely, abundance was much lower in waters influenced by the CDW. *L. intermedius* was primarily distributed on the southern side of the Changjiang estuary (Fig. 2(a)) during the spring of 1959. Furthermore, the abundance was much lower in the zone adjacent to the CDW current, which flowed in a northeast direction during summer (Fig. 2(b)).

Within the ocean, the distribution of *L. intermedius* was confined to waters with higher temperature and salinity in the autumn and winter of 1959. However, in 2002, the distribution of this species extended westward to the Changjiang estuary during the spring, summer, and autumn (Fig. 2(e), (f) and (h)). We hypothesize that this is related to the strengthening of the Taiwan Warm Current (TWC) due to global warming. The abundance of *L. intermedius* in the Changjiang estuary remained lower than in other areas during the summer (Fig. 2(f)). Similarly, *L. hanseni* was primarily found in waters influenced by TWC and was not found in areas influenced by the CDW during the spring of 2005 (Fig. 5(a) and (b)). The effect of the TWC on the spatial distribution of *L. intermedius* and *L. hanseni* was consistent with the patterns expected due to an increase in temperature. Thus, the location of the TWC plays a minor role in determining the spatial distribution of these two species. However, the major determinant of the spatial distribution of both *L. intermedius* and *L. hanseni* in the Changjiang estuary appears to be the CDW.

The abundance of both species increased significantly in 2002, especially in the summer, compared with 1959 (Table 1). The abundance of *L. intermedius* increased from 3.70 individuals m^{-3} in 1959 to 8.93 individuals m^{-3} during the summer of 2002. Similarly, the abundance of *L. hanseni* increased from 0.01 individuals m^{-3} in 1959 to 0.47 individuals m^{-3} in 2002 (Table 1). Interestingly, the abundance of this species increased further in 2005 (Fig. 5(c)).

We hypothesize that the change in abundance and distribution of *L. intermedius* and *L. hanseni* is due to the effects of global warming on ocean temperatures. The mean sea surface temperatures (SST) during the spring and summer of 1959 were 17.86 °C and 26.82 °C, respectively. In 2002, the SST increased to 19.53 °C and 27.26 °C, respectively (unpublished data). Thus, warming of the ECS occurred during the same time period in which we measured an increase in the abundance of *L. intermedius* and *L. hanseni* in the Changjiang estuary. We also note that *L. hanseni* was

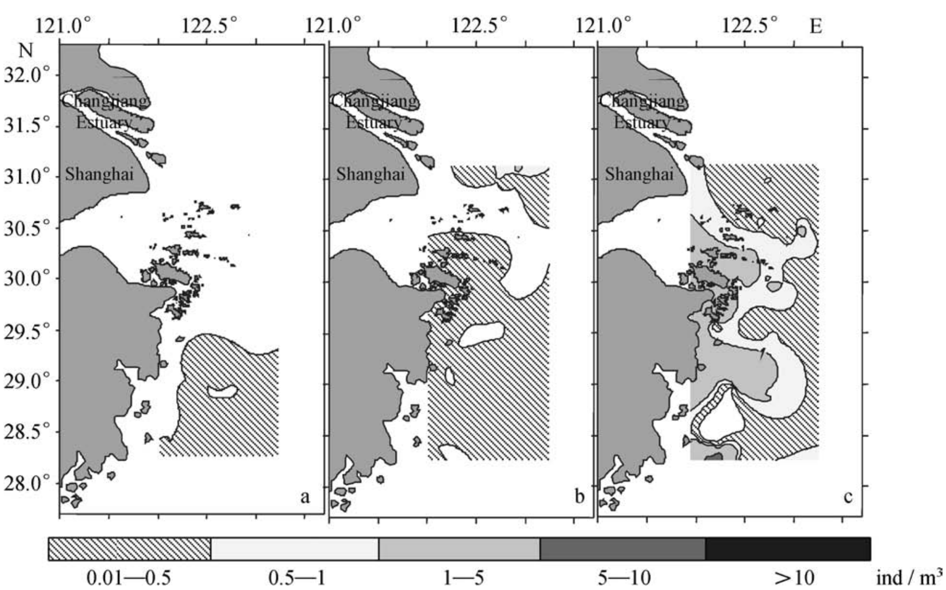

Fig. 5. Spatial distribution of the change in abundance of *L. hanseni* in the ECS during the spring of 2005. Panels (a)–(c) represent surveys conducted in April, May, and June, respectively.

found only once in 1959, but was collected in all cruises in 2002 (Table 2). Furthermore, the abundance increased significantly between years (Table 2, Fig. 5). Other factors, such as food availability, salinity, and predation pressure, are also likely to contribute to the abundance of zooplankton populations [33,34]. However, increases in temperature are likely to be the key factor controlling the increase in OF of *L. hanseni* (an oceanic warm-water species) in the Changjiang estuary. Increases in SST and a subsequent expansion of the range of warm-water species are generally thought to be driven by global warming [35,36].

The Changjiang estuary lies within the transition zone between a subtropical and warm-temperate zone in the ECS. The zoogeography in this region is characterized by warm-temperate species during the spring and winter and subtropical zooplankton in the summer and autumn [37]. Given this, it is an ideal region for studying the effects of global warming on marine and estuary ecosystems. We measured a significant change in the geographical distribution of copepod assemblages in the ECS. Specifically, the range of warm-water species expanded northward coincident with a regional increase in sea surface temperature. Furthermore, a decrease in the number of cold-water species has been observed over time [35,38–40]. Based on our observations, *L. intermedius* and *L. hanseni* appear to be useful indicators for the effects of long-term climate change on aquatic ecosystems.

Acknowledgments

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