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Year-round occurrence of crustacean holoplankton in Mae Klong River Mouth as indicators of natural food availability in the Gulf of Thailand

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ABSTRACT: Climate change has been a cause of significant global environmental variation, with rising temperatures observed in many regions. Temperature is a critical factor affecting organisms, including crustacean holoplanktons, a key food sources in aquatic ecosystem, particularly in nursery grounds for aquatic animals. Estuarine areas, such as river mouths, are especially important as they experience considerably physiochemical fluctuations. This study was conducted year-round at two sites: Don Hoi Lod (DH) and Mae Klong River (MK) in Samut Songkhram Province, Thailand. Water samples (approximately 30 m^3 each) were collected at a 30 cm depth by 200 µm sieve size of plankton net. The samples were preserved and identified in laboratory. The density of crustacean holoplankton was estimated and expressed by individuals per m^3. Field measurements were recorded. The relationship between crustacean holoplankton and environmental factors were analyzed using canonical correspondence analysis. The results indicated that salinity and temperature exhibited similar pattern between the DH and the MK sites which were high in the dry season and low in the southwest and northwest monsoons. However, these physical factors varied significantly across different seasons. Two main crustacean taxa were identified: class Copepoda and order Cladocera (class Branchiopoda). The copepod groups included order Calnoida Cycoida, Harpecticoida and the nauplius stage. Species richness was higher at the DH site than the MK. Seasonal change had a strong influence on holoplankton between the two sites. Additionally, the overall population of crustacean holoplankton decreased significantly with rising temperatures. These findings suggested that seasonal changes and increasing temperature could impact the biodiversity of crustacean holoplankton in estuarine area.

KEYWORDS: crustacean, holoplankton, mangrove, seasonal change, zooplankton

INTRODUCTION

Plankton, vital organisms within the ecosystem's food chain, are categorized into two main types: phytoplankton and zooplankton. Phytoplankton serve as primary producers in the food chain and are the main food source for zooplankton. Zooplankton, in turn, can be divided into two categories: meroplankton, which are temporary and exist during the larval stage, and holoplankton, which persist throughout their entire life cycle. These zooplankton provide an essential food source for various aquatic organisms, including fish that are significant for human consumption [1–3].

With the rapid increase in global population, there is an ever-growing demand for natural resources [3]. Human activities, such as pollution from industrial processes, agricultural runoff, and overfishing, have significantly contributed to environmental degradations [4, 5], leading to global warming and resulting in widespread environmental changes [6]. Fluctuations in environmental conditions, e.g., rising temperatures, extended dry seasons, and increased evaporation, have disrupted the water cycle [7]. Additionally, physicochemical factors such as salinity and pH levels in seawater have been altered [8]. These changes directly affect the life cycles, population densities, biodiversity, and population structures of both meroplankton and holoplankton of the zooplankton.

For example, the larvae of *Aratus pisonii* (a species of crab) require high salinity levels of 25–35 ppt during their early stages; whereas, during pre-adult stages, they thrive in lower salinity levels of 15–25 ppt [9]. Similarly, crustacean holoplankton such as *Apocyclops royi*, a dominant copepod species in the brackish waters of Southern Taiwan, exhibit optimal egg-laying rates at salinity levels of 10–20 ppt. When salinity deviates from this range, the egg-laying rate decreases [2].

The nauplius stage of *Tigriopus* sp. (harpacticoid copepod) exhibits a high survival rate at salinity levels of 5–45 ppt, with the most favorable salinity being around 30 ppt [10]. With regard to temperature change, some species within the Cyclopoid group can thrive at temperatures as high as 35 °C [11]. Temperature has also been found to influence the density of copepod species such as *Centropages chierchiae* and *Temora stylifera* [12]. Moreover, both salinity and temperature can significantly affect the morphological development of copepods, such as *Caligus* sp., a fish parasite whose larvae develop optimally at a salinity of 35 ppt, with mortality rates increasing at salinity levels below 20 ppt [13]. Thus, salinity is a crucial factor in determining the distribution of plankton populations [14–17] and also their population structure [18, 19].

Samut Songkhram Province is located along the Inner Gulf of Thailand, an area characterized by significant fishing activities, with Mae Klong River flowing across the area into the Gulf of Thailand. It encompasses estuarine environments that serve as natural nursery grounds for aquatic species, particularly commercial species like mackerel. The sediments from the Mae Klong River together with the sediments from the sea form a system of expansive mudflats that support rich biodiversity. Given the importance of Samut Songkhram Province for Thailand's seafood industry, it is crucial to understand how changes in environmental factors, particularly salinity and temperature, affect zooplankton diversity in this area. Therefore, this study investigated the population dynamics of crustacean holoplankton at two sites in Samut Songkhram Province: Don Hoi Lod (DH), an estuarine area with high salinity, and the Mae Klong River (MK), a freshwater-dominated river system with lower salinity. The investigation spanned across seasons, aiming to assess how variations in salinity and temperature influencing the biodiversity and population density of holoplankton in these two distinct environments.

MATERIALS AND METHODS

Study sites

The study was conducted at two sampling sites located at river mouths connected to the Gulf of Thailand (Fig. S1). The first site, Don Hoi Lod (DH; 13°21′53.3″ N, 100°01′08.0″ E), is a mudflat area surrounded by mangrove forests. The second site, Mae Klong River (MK; 13°22′21.7″ N, 99°59′47.9″ E), is a community area along the coastline with high levels of utilization, including industrial factories and piers. Sampling was conducted year-round, from March 2019 to January 2020, during three distinct seasons: the dry season (DS) in March and May, the southwest monsoon season (SW) in July and September, and the northeast monsoon season (NE) in November and January.

Specimen sampling and identification

Water samples (approximately 30 m^3 each) were collected at a depth of approximately 30 cm below the water surface. The samples were filtered through a 200 µm plankton net. Three replicates were collected from each of the two sites. Due to strong winds at the open DH site, direct use of the plankton net was not feasible. Instead, a bucket was used to perform a back-and-forth dragging motion for 30 m^3 of water samples. The collected specimens were preserved in seawater with a final concentration of 6% formalin. Identification of specimens followed the plankton identification key from the handbook [20]. Hemocytometer was used as slide under the microscope in the identification process. Wet mount was prepared by gently stirring the sample to evenly suspend the plankton. Using a pipette, a drop of the sample was placed on a clean glass slide, and then a coverslip was carefully added without trapping any air bubbles.

Spatial comparison on density and distribution of crustacean holoplankton

The density of crustacean holoplankton was estimated by counting all number of individuals per unit volume of water, i.e., individuals per m^3. The average of the density was calculated by total individual found divided by six months. Species diversity and distribution were performed by the Shannon diversity index (H′) and Shannon Evenness (J′) which used for comparing diversity between various habitats [21].

Environmental data collection

Field measurements of environmental factors included water and air temperatures, pH, and salinity. For each parameter, three replications were recorded from the 15–30 cm depth of sampling water. Water and air temperatures were recorded using a handheld automatic measuring device (GONDO 7021). The pH was measured using a pH meter (INDEX ID1000), and salinity was measured using a refractometer (ATAGO Hand Refractometer).

Statistics analysis

Cluster analysis (CA) was performed on crustacean holoplankton to examine similarities between study sites and seasons. The analysis considered all recorded taxa, including taxa composition, the total number of taxa, and the abundance (the number of individuals recorded for each taxon). The grouping of similarities among sites and seasons was conducted using the UPGMA (Unweighted Pair Group Method with Arithmetic Mean), clustering data based on the arithmetic mean of pairwise similarities. The relationship between crustacean holoplankton and environmental factors were analyzed by canonical correspondence analysis (CCA) through the program MVSP (Multivariate Statistical Package Version 3.22). Data was converted to $\log(x+1)$ using Microsoft Excel before going through statistical analysis. All data were represented by mean±standard diviation in results.

RESULTS

Seasonal changes of temperature, salinity and pH throughout the year

The patterns of salinity and temperature were similar between the DH and the MK sites. However,

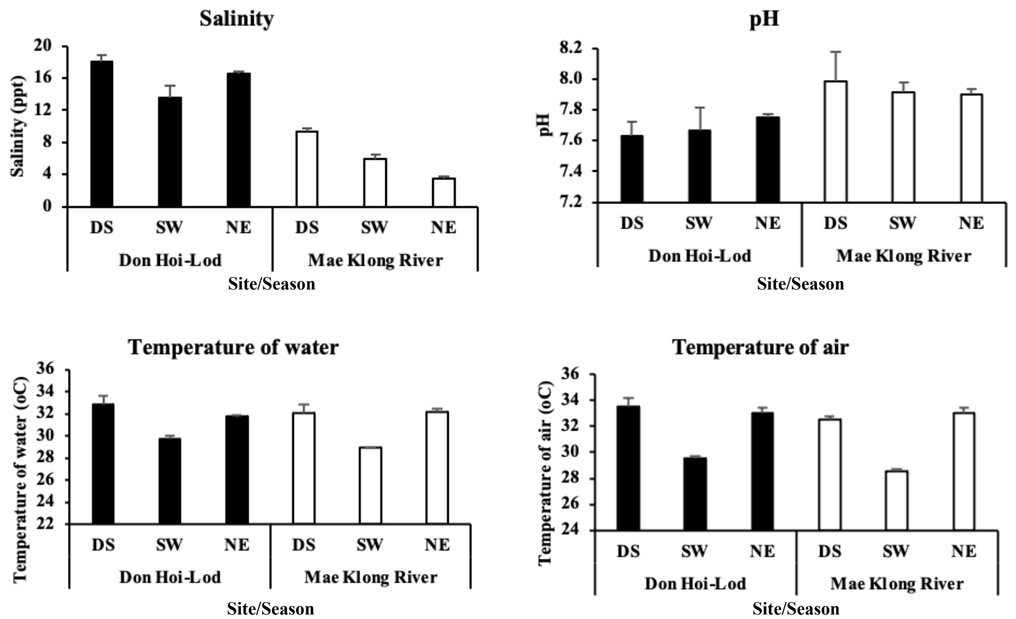

Fig. 1 Comparison of changes in physical factors (salinity, pH, water temperature, and air temperatures) across the DS, SW and NE at the DH and the MK sites.

these physical factors varied significantly across seasons (Fig. 1). The highest salinity was recorded during the dry season (DS), with values of 18±0.9 ppt at the DH site and 9.33±0.42 ppt at the MK site. During the northeast and southwest monsoon seasons, salinity values were 16.50±0.34 ppt and 13.50±1.57 ppt at the DH site, and 3.50±0.22 ppt and 6±0.45 ppt at the MK site, respectively. The highest water and air temperatures were also recorded during the DS. At the DH site, water temperature reached 32.82±0.80 °C, and air temperature was 33.50±0.67 °C. During the northeast monsoon season (NE), water and air temperatures were 31.80±0.1 °C and 33±0.45 °C, respectively. The lowest temperatures were observed during the southwest monsoon season (SW), with water temperature at 29.70±0.36 °C and air temperature at 29.50±0.22 °C. The pH values did not vary significantly across seasons within sites, with average pH values at the DH and the MK sites of 7.68±0.06 and 7.93±0.05, respectively.

Dominance of zooplankton groups between the DH and the MK sites

Two main taxa of crustacean holoplankton were identified at both the DH and the MK sites: class Copepoda and order Cladocera (class Branchiopoda) (Fig. 2). Among the copepods, three orders were present, including Calanoida, Cyclopoida, Harpacticoida, and the nauplius stage. Harpacticoids (Fig. 3A) was the most dominant group at the DH site, with an abundance of 13,739±13,380.75 individuals/m^3, followed by copepod nauplii (Fig. 3B) at 10,842±5,322.45 individuals/m^3. At the MK site, copepod nauplii and calanoid (Fig. 3C) were the dominant groups, with densities of 13,483±7,928.07 individuals/m^3 and 8,188±7,059.26 individuals/m^3, respectively. The abundance of cyclopoid and cladoceran was similar between the two sites: 1,744±1,629.38 individuals/m^3 and 9,089±5,361.15 individuals/m^3 at the DH site, and 1,784±1,733.25 individuals/m^3 and 5,982±5,634.25 individuals/m^3 at the MK site, respectively.

Seasonal variation in the abundance of crustacean holoplankton

Both the DH and the MK sites exhibited seasonal variations in the abundance of crustacean holoplankton (Fig. 4). At the DH site, the highest density of crustacean holoplankton was observed during the NE with 73,750 individuals/m^3; and the most abundant group (40,500 individuals/m3) was Harpacticoid, followed by copepod nauplii (7,250 individuals/m^3) and cladoceran (4,750 individuals/m^3). During the SW, the mean of crustacean density was 35,250 individuals/m^3, and the highest abundance was cladoceran (19,750 individuals/m^3), followed by copepod nauplius (15,000 individuals/m^3) and harpacticoid (500 cells/m^3). Unfortunately, there were no calanoid and cyclopoid found in this season. Among the three seasons, the lowest density was observed in the DS, with an average of 3,687 individuals/m^3; and the most abundance was cladoceran (2,767 individuals/m^3) followed by copepod nauplius (277 individuals/m^3) and

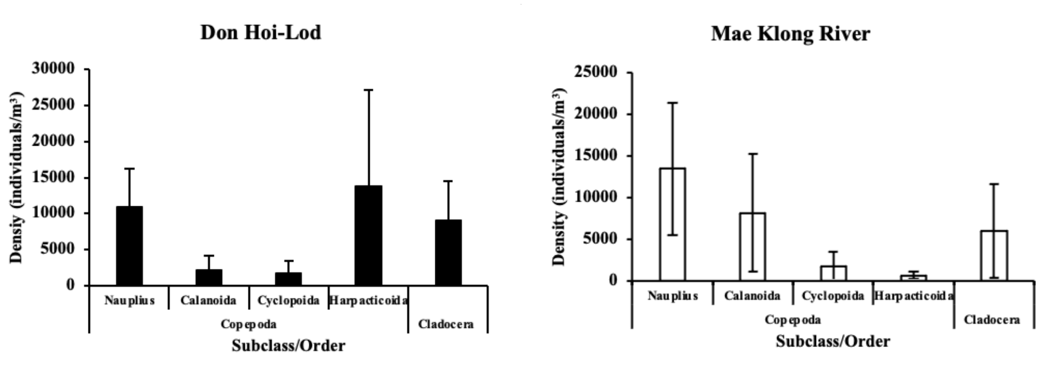

Fig. 2 Abundance of copepod and cladoceran at the DH and the MK sites.

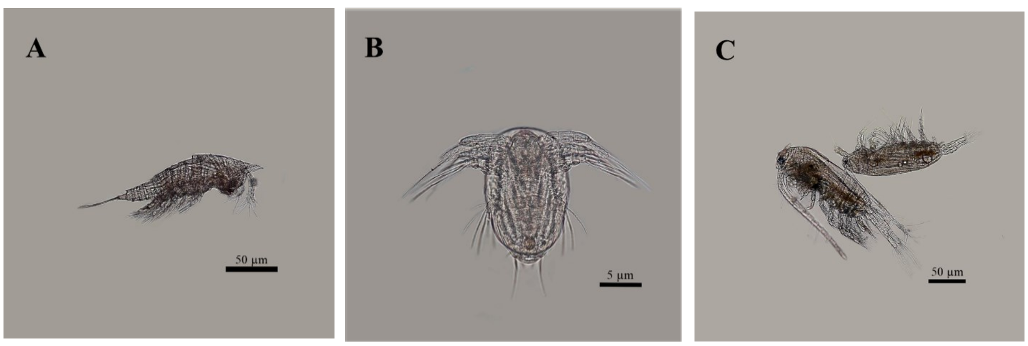

Fig. 3 Dominant taxa: (A), harpacticoid; (B), copepod nauplius; and (C), calanoid copepod.

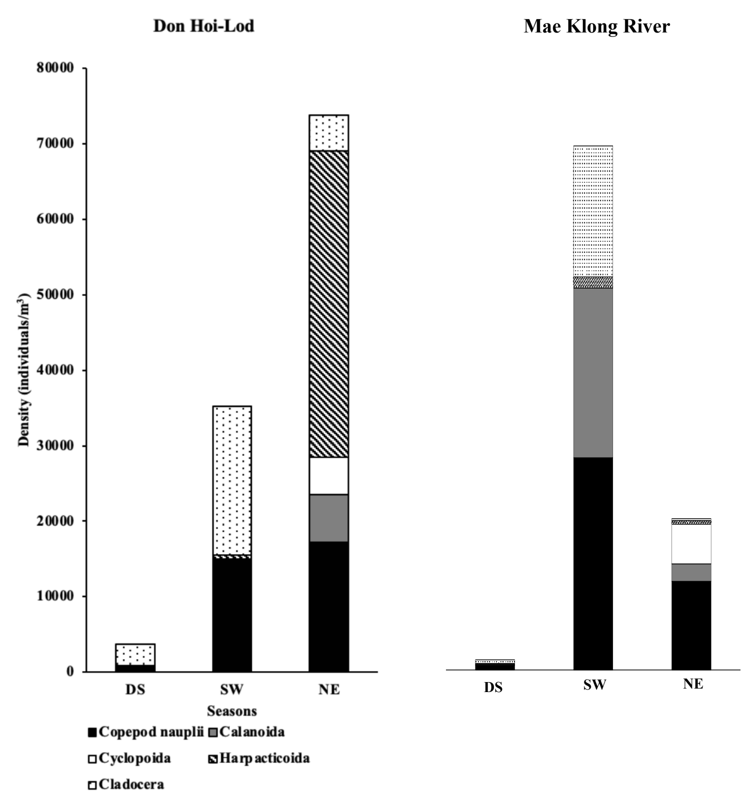

Fig. 4 Abundance of crustacean holoplankton at the DH and the MK sites during the DS, SW and NE.

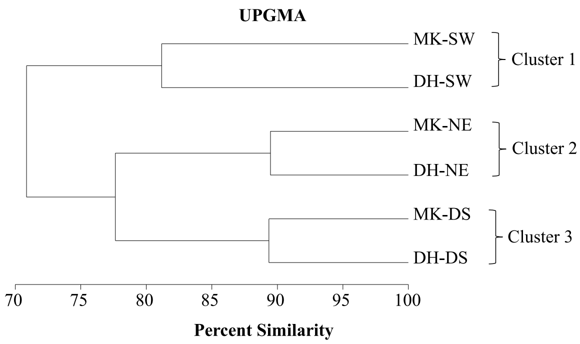

Fig. 5 Dendrogram showing the percentage of similarity of crustacean holoplankton across seasons (DS, SW and NE) and sites (DH and MK).

the lowest density calanoida (194 individuals/m^3).

Meanwhile, the MK site showed the highest abundance of crustacean holoplankton during the SW by 69,000 individuals/m^3. Copepod nauplius group was the highest abundance by 28,000 individuals/m^3, followed by calanoid group (22,250 individuals/m^3). Cyclopoid was not found in this season of sampling. The NE had a mean of crustacean amount by 20,000 individuals/m^3. The highest density of copepod nauplius was 11,750 individuals/m^3, followed by cyclopoid (5,250 individuals/m^3) and cladoceran (250 individuals/m^3). During the DS, there was the lowest abundance of crustacean holoplankton by 1,377 individuals/m^3. with the most abundance of copepod nauplius (701 individuals/m^3), followed by cladoceran (446 individuals/m^3) and the two groups of calanoid and harpacticoid (64 individuals/m^3).

The species distribution index showed that the DH site exhibited a higher diversity than the MK site of 1.376 and 1.289, respectively. The degree of evenness in species abundance of the DH site was 0.855, which was similar to the 0.801 value of the MK site. Moreover, the species diversity at the same site was highly different between seasons. At the DH site, the species diversities during the SW and the NE were 0.748 and 1.237, respectively; while the values were 0.796 and 1.056 at the MK site.

Similarity of crustacean holoplankton

Similarity of crustacean holoplankton among seasons and sites was analyzed and divided into three distinct clusters (Fig. 5). Holoplankton from the same season at both sites tended to group together: Cluster 1, representing the SW, the least similar to the other seasons; Cluster 2, representing the NE; and Cluster 3, representing the DS. The similarity between the NE and the DS was at 77.65%, which was higher the 70.86% of the SW. The pattern and proportion of crustacean holoplankton in the nauplius stage during the SW was the most different from other seasons. In addition, the NE and the DS were rather similar.

Relationship between physical factors and crustacean holoplankton

The abundance of crustacean holoplankton was correlated with specific physical factors (Fig. 6). Cyclopoids were more abundant in areas with higher water and air temperatures, while cladocerans and copepod nauplii were more abundant in areas with lower temperatures. Additionally, calanoids were more abundant in areas with higher pH but lower salinity. Canonical correspondence analysis (CCA) confirmed these relationships, with water temperature showing a strong negative correlation (biplot score = −0.888) and the highest percentage of eigenvalues along axis 1 (Table 1).

DISCUSSION

The dominant crustacean holoplankton differed in both taxa and density between the two site, DH and MK; however, they were present year-round at both sites. High standard deviation was shown in this study due to the seasonal difference. The lowest densities were observed during the dry season, likely due to the negative correlation with high temperatures in this season. Temperature emerged as the primary factor affecting holoplankton abundance in this study. Air temperature directly influences water temperature in the same habitat, which subsequently impacts aquatic organisms [22]. Several studies have highlighted the correlation between temperature and zooplankton abundance [23, 24]. For instance, research on copepod species revealed that the densities of *Centropages chierchiae* and *Temora stylifera* varied with seasonal temperature fluctuations, *C. chierchiae* was mostly found in summer season, whereas *T. stylifera* showed high density in cold season [12]. Few of holoplankton taxa found in this study was noticed. The sampling limitation complied with the depth might affect the group of zooplankton. The common taxa were recorded exclusively from collections conducted in the coastal regions of Don Hoi Lod and the Mae Klong River.

With the current trend of rising global temperatures, various ecosystems are experiencing significant impacts, particularly in tropical regions [25], where plankton communities are affected in terms of both abundance and diversity [26, 27]. In this study, the DH site had a higher density of crustacean holoplankton compared with the MK site, except during the SW. At the MK site, copepod nauplii dominated the crustacean holoplankton population year-round, with the highest densities recorded during the SW. This might be attributed to the nauplius stage's higher survival rate in areas with lower temperatures [10]. In contrast, the DH site exhibited the highest density of crustacean holoplankton during the NE, with harpacticoid and

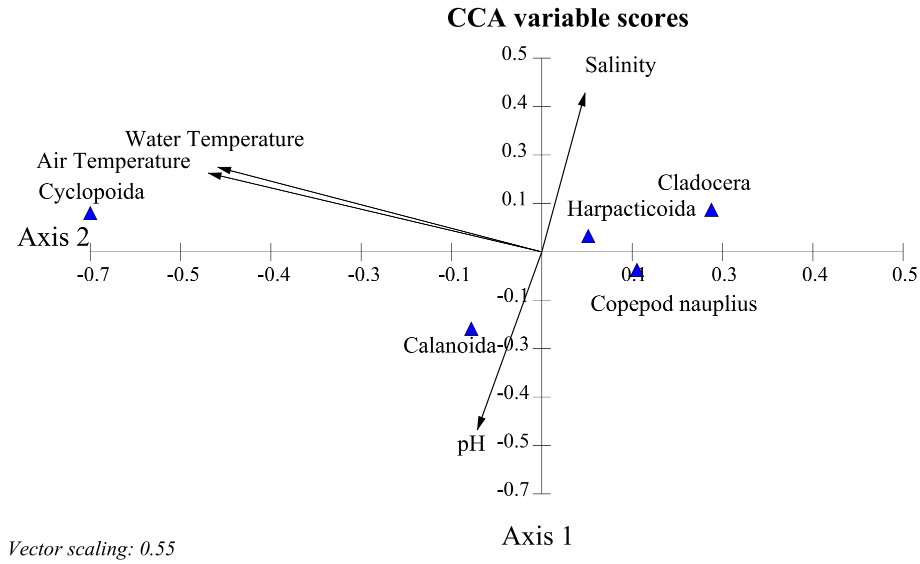

Fig. 6 Canonical correspondence analysis illustrating the relationship between physical factors and crustacean holoplankton. Triangles represent crustacean groups, and arrows represent physical factors.

Table 1 Biplot scores and eigenvalues from CCA analysis of the relationship between physical factors and crustacean holoplankton. Bold text indicates values mentioned in the results.

Biplot scores for environmental variables			Eigenvalues		
	Axis 1	Axis 2		Axis 1	Axis 2
pH	−0.177	−0.910	Eigenvalues	0.085	0.014
Water temperature	**−0.888**	0.432	Percentage	63.649	10.537
Air temperature	−0.194	0.402	Cumulative percentage	63.649	74.186
Salinity	0.118	0.813	Cumulative constrained percentage	81.862	95.414
			Species-environmental correlations	0.973	0.702

cyclopoid copepods being more abundant in areas with elevated water and air temperatures. Cyclopoid copepods were found at both sites during the DS and the NE, likely due to the higher air and water temperatures, as this group thrives at temperatures around 35 °C [11].

The population structure of both study sites did not exhibit a clear pattern. This indicated that other factors beyond temperature, such as other environmental parameters-salinity, DO, turbidity and nutrient, could be involved. Phytoplankton survival rates and availability of food for zooplankton might also play a role. For example, when ambient temperatures rise above 32 °C, certain phytoplankton species experience significant declines, impacting the zooplankton that depend on them for food [28, 29]. Moreover, higher temperatures can reduce dissolved oxygen levels, leading to hypoxia and adversely affecting both phytoplankton photosynthesis and zooplankton respiration [30]. Additionally, nutrient availability and environmental conditions in different seasons, along with the life cycles of plankton, are likely to influence reproduction and growth rates, further contributing to the observed population changes [28]. There was a study on economically red snapper (*Lutjanus argentimaculatus*) juvenile showing salinity change not affecting metabolism and digestion but influencing food rejection; and the animals died in three weeks after taking low salinity treatments (0 and 7.5 ppt) [31].

The results from this study suggested that increased temperatures led to reduced crustacean holoplankton densities in both sites. Temperature not only influences growth and abundance but also affects the life cycle, behavior, and population structure of zooplankton [23, 28, 32]. In addition, species with low mobility can be more sensitive to environmental changes and water properties compared with mobile species. Temperature tolerance also affects spatial distribution and causes community changes [33]. These changes could have far-reaching impacts on the ecosystem, potentially altering biodiversity and disrupting trophic levels [9, 14, 15, 34]. Since zooplankton serve as a critical food source for aquatic animals, including economically important species, any disruption to zooplankton populations could also affect fisheries and food security [29]. Ultimately, the findings of this study underscored the need for appropriate conservation and management strategies to protect biodiversity and maintain ecological balance in these areas [9].

CONCLUSION

Crustacean holoplankton in the Gulf of Thailand play a crucial role as a natural food source, and their populations are significantly affected by seasonal temperature fluctuations. Zooplankton populations tend to decline as temperatures increase, which could pose serious challenges to food security during periods of temperature extremes.

Appendix A. Supplementary data

Supplementary data associated with this article can be found at https://dx.doi.org/10.2306/scienceasia1513-1874.2025.037.

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Appendix A. Supplementary data

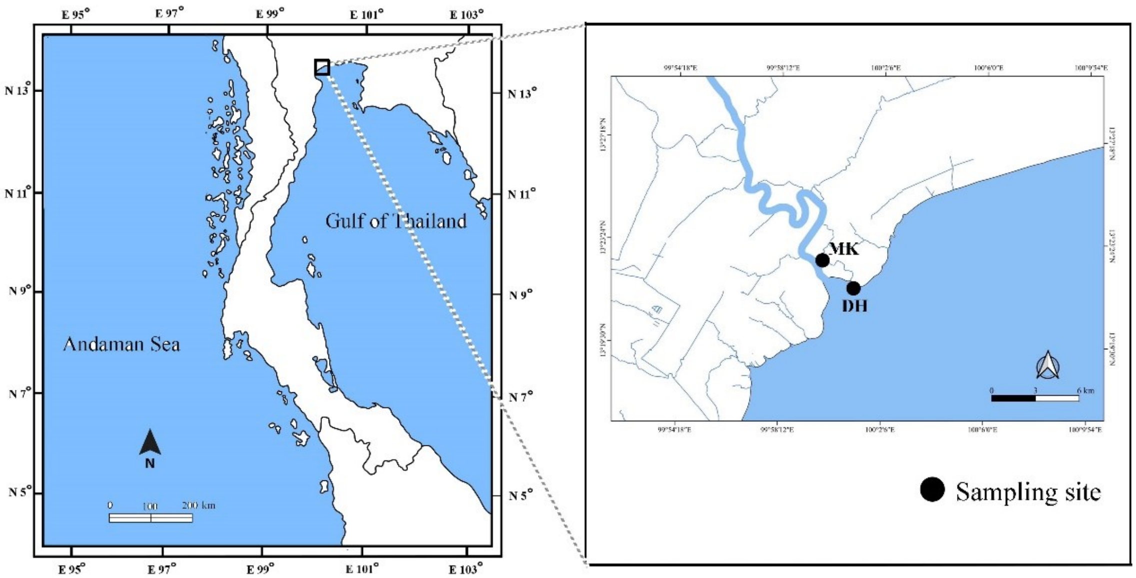

Fig. S1 Study area showing sampling sites at DH and MK.