

Effect of Flood Disaster and Long Term Changes during 2011 to 2018 on Community Structure of Zooplankton in the Inner Gulf of Thailand

Porntep Punnarak, Pramot Sojisuporn, Hattaya Jitrapat, and Ajcharaporn Piumsomboon

Abstract—This study of community structure of zooplankton in the Inner Gulf of Thailand was initiated in late 2011 in response to a major flood disaster event and continued intermittently to 2018. Six cruises with 13-20 replicate stations/cruise, provided data for contour maps of zooplankton, nutrients, water hydrography, pigments and algae; this manuscript utilized this diverse data set to focus on mesozooplankton. Immediately after the flood, November 2011, mesozooplankton communities were dominated by calanoid copepods with contributions of about 78% of the total. This changed in 2012 to 2018 which the proportion of calanoid copepods was decreased while the other zooplankton such as hydromedusae, polychaete larvae, barnacle nauplii, pelagic shrimp (*Lucifer* sp. and protozoa) and chaetognaths were increased. The density of mesozooplankton varied between 1.70×10^4 to 1.26×10^6 ind./100 m³ with noticeably high densities near the four river mouths that flow into Inner Gulf. Distribution patterns of mesozooplankton emerged that are likely similar to the long-term patterns of this region which effected by water circulation in the Inner Gulf of Thailand. However, high density of zooplankton in November 2012 and October 2017 appeared along the north-eastern coast and may be related to the availability of food (i.g., algae). Zooplankton abundances in the Inner Gulf of Thailand were significantly correlated with environmental parameters mainly temperature, salinity and food supplies as represented by chlorophyll *a* concentrations.

Index Terms—Copepods, flood disaster, Inner Gulf of Thailand, zooplankton.

I. INTRODUCTION

The Inner Gulf of Thailand is the most important coastal ecosystem in Thailand receiving freshwater, nutrients and pollutants from four major rivers namely Bangpakong River, Chao Phraya River, Tha Chin River and Mae Klong River. At present, increases in water temperature and changes in the longevity and period of the rainy season as a result of global climate change are important issues in the Gulf and are

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caused by, or result in, varying loads of river runoff into the sea. In 2011, Thailand faced a flooding disaster, the worst within 50 years, affecting over 13 million people, causing the inundation of 11.2 million rai (18,000 km²) of land in 66 provinces [1]; flooding also resulted in decreased salinity in coastal areas of the Inner Gulf of Thailand due in large part to approximately 16 billion cubic meters of discharge from Chao Phraya River [2]. Furthermore, the counter-clockwise current direction during North-east monsoon period of flooding [3], [4] drove the low-salinity water mass toward the western part of the Inner Gulf and affected the biological production and biodiversity of marine living resources in the area particularly at the lower trophic levels of the marine food web. It is likely that this disturbance affected the community structure of zooplankton, a consumer of phytoplankton or microalgae in the water column, which play a major role as a linkage between producers and higher consumers [5]. Change in diversity and abundance of meroplankton such as shrimp larvae, crab larvae and fish larvae, generally can be used as an indicator for productivity of marine ecosystems [6]. For instance, earlier studies in the Gulf of Thailand found that spatial and temporal variations in community structure of zooplankton are usually under the influence of environmental factors e.g. river runoff delivers freshwater and nutrients into the coastal sea, which affect not only the variability of phytoplankton but also zooplankton abundance and population structure [7]. Knowledge based on the diversity and productivity of zooplankton is very important for understanding the effects of flood disaster as well as the proper management plan to recover the coastal ecosystem once flood waters recede. Thus, it is important to study variations in community structure of zooplankton during and/or immediately after a flood disaster and the long-term changes, if any, in the Inner Gulf of Thailand.

II. MATERIALS AND METHODS

The study was conducted in 2011 - 2018 in the Inner Gulf of Thailand from the coast of Chonburi Province to the coastal area of Hua-Hin, Prachuap Khiri Khan Province. Shipboard samples were taken from the R/V Chula vijai 1 and Kasetsart 1 at 13 to 20 stations/cruise from 2011 to 2018 (Fig. 1).

Duplicate zooplankton samples were collected using a 330 micrometers-meshed conical net towed vertically from 2 meters above the sea floor to the surface. Samples were preserved in neutralized formalin-seawater solution to a final concentration of 4-6%. Before sampling zooplankton, physico-chemical parameters including temperature, salinity,

dissolved oxygen and pH were measured in situ using a multi-parameters probe (YSI 650 MDS with SONDE 600 XLM, Xylem, USA and AAQ 177, Advantech, Japan). Zooplankton were identified and counted under stereo-microscope and reported as individuals per 100 m³ of

seawater. Contour plots of environmental parameters and zooplankton distribution were constructed using Ocean Data View (ODV, freeware computer program). Correlation analysis between zooplankton densities and environmental parameters were also conducted using SPSS (Ver. 22).

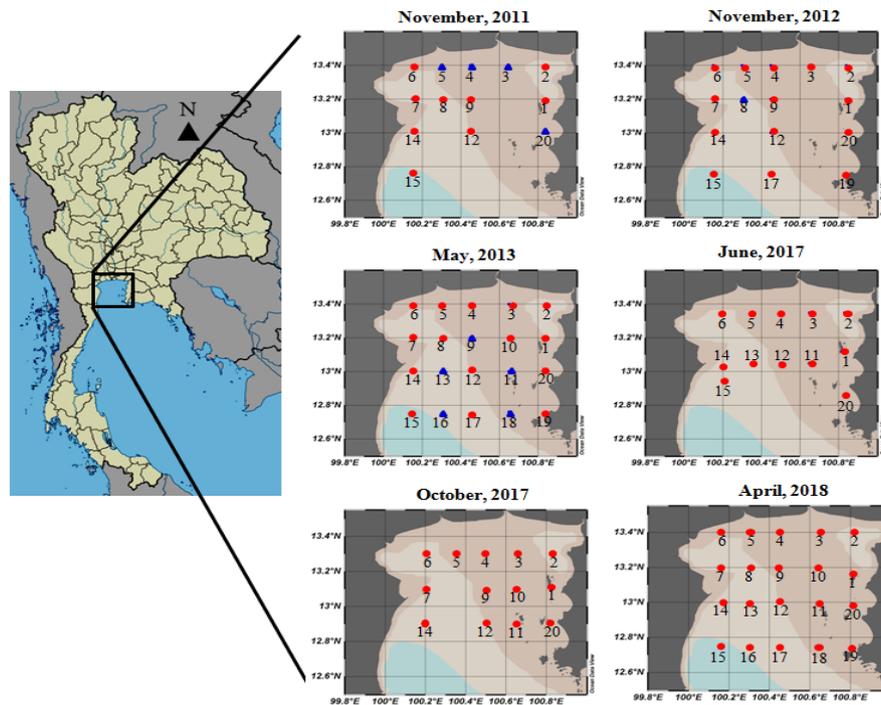


Fig. 1. Sampling stations in the Inner Gulf of Thailand 2011 to 2018. The triangle symbols are for stations that only environmental parameters were measured, and circle symbols are for stations that both zooplankton and environmental parameters were collected.

III. RESULTS AND DISCUSSION

A. Diversity of Zooplankton in the Inner Gulf of Thailand

Mesozooplankton communities in the Inner Gulf of Thailand were composed of 42 taxa groups from 12 phyla. The zooplankton communities were comprised of 29, 30, 37, 33, 29 and 26 taxa of mesozooplankton in November 2011, November 2012, May 2013, June 2017, October 2017 and April 2018, respectively. Holoplankton composed 24 taxa of mesozooplankton including foraminiferans, radiolarians, hydromedusae, siphonophores, jelly fish, ctenophores, planktonic polychaetes, cladocerans, ostracods, copepods (including calanoid copepods, cyclopoid copepods, harpacticoid copepods and their nauplius larvae), cumaceans, isopods, amphipods, pelagic shrimps (e.g. *Lucifer* sp. and protozoa larvae of *Lucifer* sp., mysids and acetes), chaetognaths, pteropods, larvaceans and salps (with doliolids). Eighteen groups of meroplankton were recorded including cnidaria larvae, pilidium larvae, actinotroch larvae, polychaete larvae, barnacle larvae (nauplius larvae), shrimp larvae, zoea larvae of crabs (including porcellanid and brachyuran larvae), megalopa of crabs, alima larvae, gastropod larvae, bivalve larvae, pluteus larvae (composed of ophiopluteus, echinopluteus, and auricularia larvae), fish larvae and fish eggs. All the zooplankton taxa found in this study have been reported as members of the general zooplankton found in coastal areas of the Inner Gulf of Thailand [4], [8].

Calanoid copepods were the dominant zooplankton in all

areas of the Inner Gulf during the surveys, similar to previous studies which reported that copepods were the dominant zooplankton in the river mouths, coastal areas and the Gulf of Thailand [9]-[12]. Calanoid copepods (mainly from the family Acartiidae, Eucalanidae and Centropagidae) had the greatest contribution of 60 to 87% (average 78%) to total zooplankton density in November 2011; the proportion of calanoid copepods declined from November 2012 to April 2018 with the average percentage of about 24% to 46% (Fig. 2). The dominance of these copepods has been reported in the Gulf of Thailand previously [13], [14]. Chaetognaths, salps, larvaceans and hydromedusae, - the true marine zooplankton -, showed higher contributions to mesozooplankton communities during November 2012 to April 2018 than in November 2011; the low abundance of these true marine zooplankton is likely due to the low salinities in November 2011, especially at stations 5 and 6 located near the Mae Klong River mouth where salinities were lower than 25 psu (22.82 to 24.58 psu). Chaetognaths and gelatinous zooplankton (including hydromedusae, ctenophores, siphonophores, salps and larvaceans) were usually found in high salinity regions but were also found in river mouths, estuaries and coastal areas due to tidal effects and normal seasonal variations [15]-[18]. Moreover, the merozooplankton, e.g. polychaete larvae, shrimp larvae, bivalve larvae, fish eggs and larvae together with the holoplanktonic zooplankton, e.g. pelagic shrimps (*Lucifer* sp. and protozoa larvae) were found in higher proportions in coastal areas, which are the nursing grounds for these taxa [4].

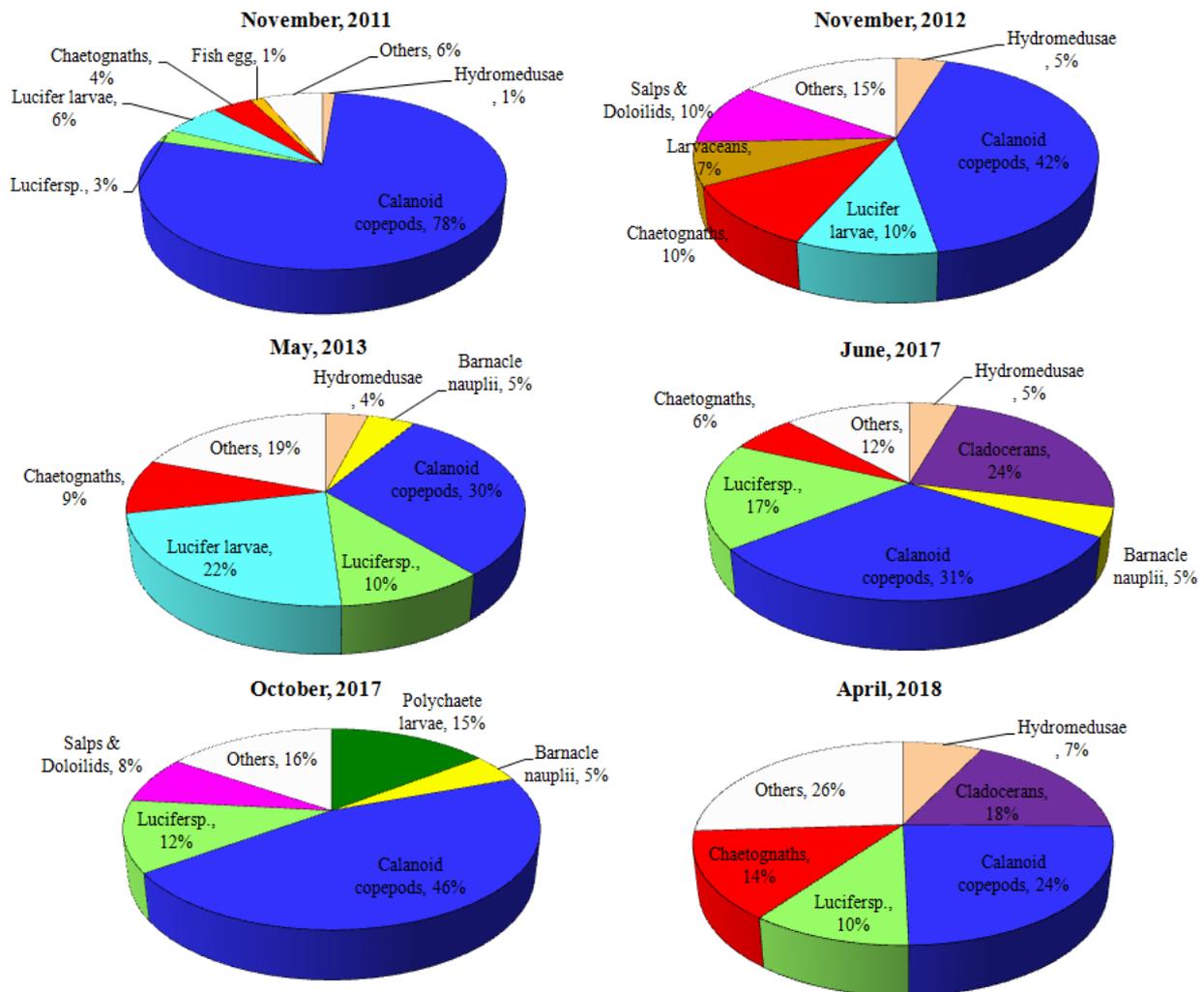


Fig. 2. Composition of dominant mesozooplankton taxa in the Inner Gulf of Thailand during 2011 to 2018.

B. Abundance and Distribution of Mesozooplankton in the Inner Gulf of Thailand

Total densities of mesozooplankton during 2011 to 2018 were in the range of 1.70×10^4 to 1.26×10^6 ind./100 m³. These values were similar to previous reports in the Inner Gulf of Thailand, which reported the total density of mesozooplankton from 1.4×10^4 to 4.0×10^6 ind./100 m³ [8]-[10], [19]. High densities were observed in stations near the major four river mouths, especially in stations near the Chao Phraya river mouth (e.g., station 3) which showed the highest zooplankton density in May 2013 (Fig. 3). This may be due to high nutrient loads from land to the coastal areas of Inner Gulf of Thailand [20] which enhanced growth of micro-phytoplankton, important food sources for the dominant zooplankton, e.g. calanoid copepods. In contrast, the lowest density was observed in November 2011 in station near the Mae Klong River mouth (station 5).

The distribution pattern of mesozooplankton was affected by the distribution pattern of the dominant mesozooplankton especially calanoid copepods and chaetognaths (Fig. 4). The distribution of mesozooplankton in November 2011 was different from the later years. Particularly in November 2011 which represented for the north-east monsoon, high densities of zooplankton were recorded in the coastal areas near the 4 major river mouths and the western coast of the Inner Gulf of

Thailand while the distribution pattern of zooplankton during south-west monsoon including May 2013 and June 2017, and inter-monsoon period (October 2017 and April 2018), other sampling periods that showed high abundances of mesozooplankton in the north-eastern coast (Fig. 3) [13], [14]. The distribution and abundance of mesozooplankton is likely impacted by the counter-clockwise direction of water circulation in the Inner Gulf of Thailand during the north-east monsoon (November 2011) and by the clockwise direction during the south-west monsoon periods (May 2013, June 2017 and April 2018) [3]. However, the distribution of mesozooplankton in November 2012 (one year after the flood), which the high abundance was observed in north-eastern coast, was different from November 2011 (immediately after the flood). These differences in November (2011 vs 2012) may relate to the availability of zooplankton food, especially microplankton, availability rather than the effect of water current. In November 2012, micro-phytoplankton, as indicated from chlorophyll *a* data, tended to accumulate in coastal areas of the north and east part of the Inner Gulf of Thailand [21], corresponding to high nutrient fluxes supported by river discharge during the rainy season (July to October) and the residence time of water from Bangpakong river mouth during the transition period (November to December) [22], [23].

C. Physico-Chemical Parameters and Factors Affect to Mesozooplankton Community Structure

No significant differences of the average salinities were observed at the cruise stations during 2011 to 2018, with average salinities in the range of 22.82-33.56, 27.38-31.38, 25.80-30.98, 24.77-32.34, 27.93-31.63 and 28.53-32.33 psu in November 2011, November 2012, May 2013, June 2017, October 2017 and April 2018, respectively. In contrast to the cruise-wide averages, salinities were significantly different between sampling stations ($p < 0.05$), with lower salinities in the coastal areas near the river mouths. Turning now to water temperature, pH and dissolved oxygen (DO), these parameters were significantly different between sampling times ($p < 0.05$) but not significant different between sampling stations in the same cruise ($p > 0.05$). In brief, water temperatures were in the range of 27.66-31.94 °C over the entire seven year period, with the lowest temperature in November 2011 while the highest temperature was recorded May 2013. In addition, pH of seawater varied from 7.55-8.51, with the highest and lowest pH recorded in November 2011 and 2012, respectively. Likewise, the highest dissolved oxygen of about 7.78 mg/L was observed in November 2011, immediately after the flood, while the lowest dissolved oxygen of about 1.06 mg/L was noted in October 2017. In addition, a high concentration of chlorophyll *a* in all size categories (pico-, nano-, micro- and total) was usually collected from the northern coast stations [21]. This was similar to distribution patterns of zooplankton during 2011 to 2018 (Fig. 3); these patterns are caused by well-described water currents in this region [3].

Pearson's correlation coefficient indicated that total mesozooplankton abundance/distribution was correlated to water temperature and salinity ($p < 0.05$). In particular, salinity was the main factor that effected distribution and abundance in the present study since the salinity has been reported as one of the most important factors affecting zooplankton distribution [7]. In detail, the flooding disaster in November 2011 resulted in low salinity waters along the coastal areas of the western part of the Inner Gulf of Thailand due to the counter clockwise direction of currents, which induce large amounts of freshwater discharge from Chao Phraya River [2]; coincident with these conditions, calanoid copepods can be found as the dominant zooplankton with the proportion more than 78% (Fig. 2). The high abundance of calanoid copepods is likely due to their ability to tolerate a wide range of salinity fluctuations compared to other zooplankton. For instance, the salinity tolerance of a calanoid copepod, *Acartia tonsa*, from tropical Amazon estuary, where salinity varied from 7.2 to 39.2 psu [24]; in addition, this species readily adjusts in laboratory conditions with salinities from 3.6 to 36 psu [25] or even under an extreme condition of salinity lower than 1 psu to 72 psu [26]. On the other hand, the abundance of true marine zooplankton, e.g. hydromedusae, salps, larvaceans and chaetognaths, tended to increase in the offshore areas with salinity usually higher than 28 psu. After the flood disaster in 2011, calanoid copepods were also the dominant zooplankton in the Inner Gulf of Thailand but decreased in proportion from 24% to 46% while the other zooplankton groups increased their contributions during 2012 to 2018 (Fig. 2).

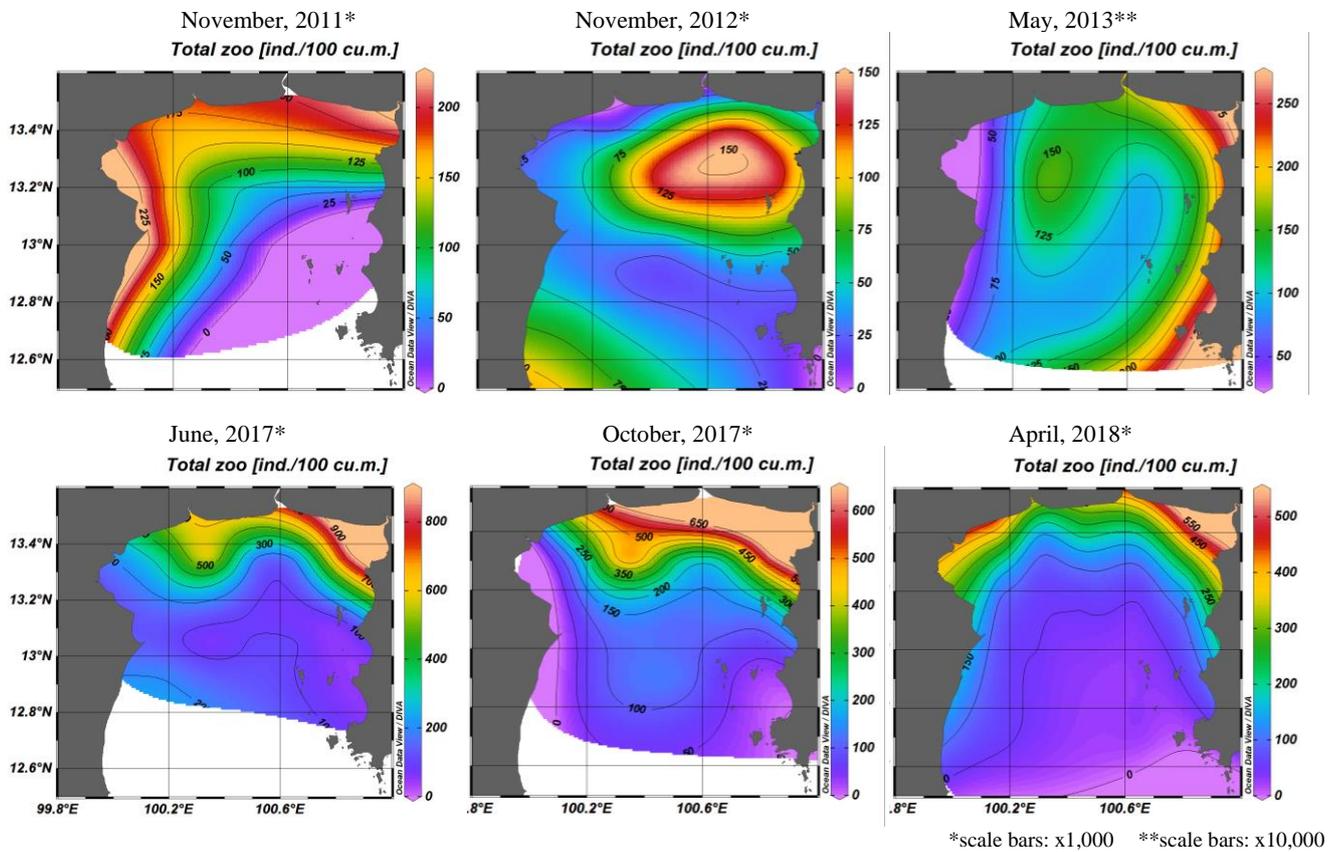


Fig. 3. The distribution of total zooplankton density (ind./100 m³) in the Inner Gulf of Thailand during 2011 to 2018.

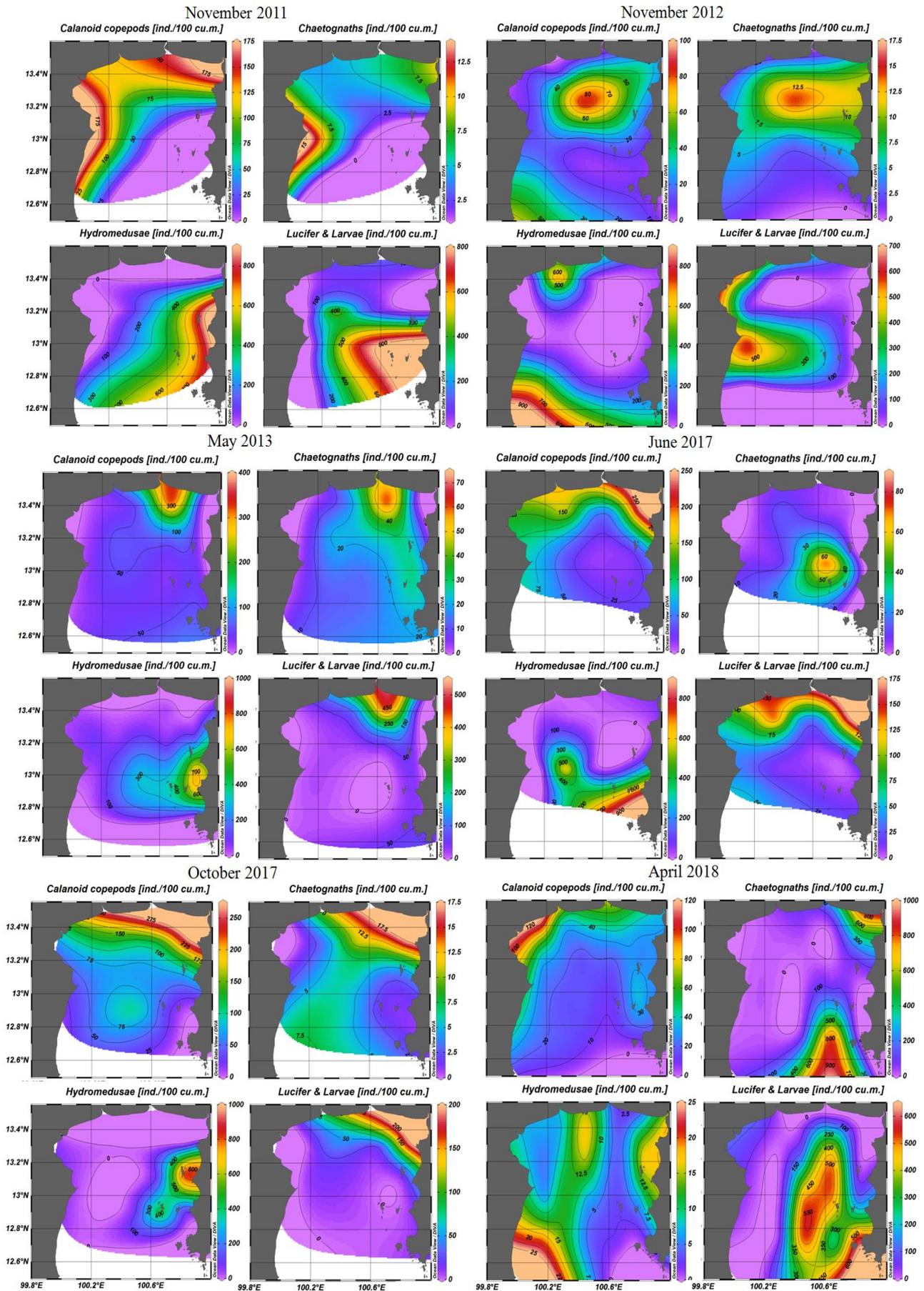


Fig. 4. The distribution of dominant mesozooplankton, calanoid copepods, chaetognaths, hydromedusae and pelagic shrimp (*Lucifer* sp. and larvae), in the Inner Gulf of Thailand during 2011 to 2018. scale bars: x1,000

The distribution of zooplankton in the Inner Gulf of Thailand was usually controlled by water circulation, which

has a large impact on both salinity and nutrient loads, with the later having a major impact on primary production [3], [21]-[23]. However, in 2012, the availability of food sources affected the distribution of zooplankton rather than salinity. High nutrients load through the river runoff and resulted in increasing phytoplankton production and in fluctuations in zooplankton community structure. The types of algae present varied from year to year, with different sizes of algae supporting different zooplankton. For instance, the distribution of chlorophyll *a* concentration, especially for micro-phytoplankton (20-200 μm), in the Inner Gulf of Thailand [21] showed a positive correlation with calanoid copepods (data not shown). This size group of phytoplankton plays a direct role in the abundance of calanoid copepods since these algae are the primary food source for calanoid copepods, e.g. family Acartiidae, [27]-[32]. On the contrary, zooplankton groups with a mucus net feeding-mode, e.g. larvaceans, salps and doliolids, were found in abundance in November 2012 at stations where higher concentrations of chlorophyll *a* was found in smaller cells (i.e., pico- and nano-phytoplankton) which are preferred prey of zooplankton with this mode of feeding [21].

IV. CONCLUSIONS

Mesozooplankton in the Inner Gulf of Thailand included 42 taxa from 12 phyla over the seven years of study (2011-2018). Zooplankton abundance was in range of 1.70×10^4 to 1.26×10^6 ind./100 m^3 . Calanoid copepods were the dominant group during the entire study period, but had the highest proportion in 2011, immediately following the flood disaster, and the percentage was decreased in the later years from 2012-2018; this distribution pattern was highly correlated to the size-fractionation data of Chlorophyll *a*, with larger-algal cells supporting calanoid abundance. Chaetognaths, salps, larvaceans and hydromedusae were also co-dominants in the Inner Gulf of Thailand at stations with high salinity while the mucus-net feeding zooplankton (e.g., salps and larvaceans) were abundant in stations where the biomasses of pico- and nano-phytoplankton were high. In addition, other mesozooplankton such as, polychaete larvae, shrimp larvae, bivalve larvae, fish larvae and fish eggs, and pelagic shrimps reached a higher proportion in coastal areas. Overall, the distribution pattern of zooplankton depended on water circulation, salinity and food source availability. The flooding event led to low salinity along the north-western coast in 2011 and allowed calanoid copepods become the dominant zooplankton. The high dominance of calenoids immediately after the flood was likely related to the ability of this copepod to tolerate a wide range of salinity from brackish to marine environments, while the distribution of mesozooplankton in the year 2012 was likely correlated to the food source of zooplankton both large and small fractions. From 2013 to 2018, the mesozooplankton distributions were controlled by the water circulation patterns according to well-known seasonal variations; in other words, following a major shift in zooplankton distribution in November 2011, immediately after the flood, zooplankton abundance and distribution recovered rapidly to historical levels.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Porntep Punarak, Pramot Sojisuporn and Ajcharaporn Piumsomboon conducted the field surveys in 2011 and 2012; Porntep Punarak, Pramot Sojisuporn and Hattaya Jitrapat conducted the field surveys in 2017 and 2018; Porntep Punarak, Ajcharaporn Piumsomboon and Hattaya Jitrapat analyzed the data; Porntep Punarak wrote the paper; all authors approved the final version.

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