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Long-term variability of zooplankton community under climate warming in tropical eutrophic man-made lake

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Abstract. *Sunardi, Yoshimatsu T, Junianto N, Istiqamah N, DeWeber T. 2016. Long-term variability of zooplankton community under climate warming in tropical eutrophic man-made lake. Biodiversitas 17: 634-641.* The climate warming is increasingly acknowledged as an important driver of lake ecosystems. However, there are no generic patterns of how the aquatic species/community responds the warming climate; instead the changes are complicated by interactions of many factors. To regard the important role of zooplankton in the lake ecosystems, this paper questions whether the climate warming affects their community structure in tropical eutrophic man-made lake. We analyzed a series of data resulted from a long water quality monitoring activities in the Cirata Lake, Indonesia. We anticipated that there would be a strong association between the climates warming with the response of zooplankton community after 19 years. Our result suggested that the lake has been becoming slightly warmer following the atmospheric temperature. Instead of decreasing, the shifting water temperature tend promotes a greater species richness, density, and diversity of the zooplankton. Relevant changes in species composition have been observed. It seems that the magnitude of the shift of the temperature, and the eutrophication status played an important role in shaping the changes of the zooplankton community structure.

Keywords: Cirata Lake, climate warming, eutrophic, tropics, zooplankton

INTRODUCTION

Climate change is a challenge for species survival and ecosystems sustainability. Globally, temperature and precipitation have changed dramatically and are predicted to change even more (Meehl et al. 2007), thus, threats of the climate change to all life-forms are believed to remain in the next few decades. Researches have reported that freshwater ecosystems, such as lakes, rivers, streams, and wetlands, are vulnerable to climate change (eg. Magnuson et al. 1997; Sahoo and Schladow 2008; Sunardi and Wiegleb 2016). Climate warming will likely affect inland waters more than ocean (Christensen et al. 2007), as warming over land is expected to be greater than global annual warming due to the smaller thermal inertia and less available water for evaporative cooling on land.

Climate change is increasingly acknowledged as an important driver of lake ecosystems (Adrian et al. 1995; IPCC 2014), but the understanding of the mechanisms by which climate affects lakes is still patchy (Keller 2007). The complexity of the issue of lake responses to climate change arises from the fact that the various climatic components act on lake physical, chemical, and biological characteristics through many interconnected pathways (Battarbee 2000; Leavitt et al. 2009). Various components of the climate system have been shown to relate to temporal dynamics of natural plankton communities on time scales varying from days (diel periodicity) to years (seasonal periodicity). With our environment changing at an unprecedented rate, an important challenge is to assess the impact of climate change on the temporal plankton dynamics of lake ecosystems (Christensen et al. 2007).

The community structure and ecological role of zooplankton in natural and man-made lakes are issues of fundamental concern to aquatic productivity and/or ecosystem stability. Zooplankton communities are highly diverse and thus perform a variety of ecosystem functions. Arguably, the most important role of zooplankton is as the major grazers in aquatic foodwebs, providing the principal pathway for energy from primary producers to consumers at higher trophic levels, such as planktivorous fish, macroinvertebrate, and turtles. In view of their grazing activities and role in nutrient recycling, zooplankton actually or potentially exert both subtle and gross effects on phytoplankton populations, which in turn have a prime bearing on water quality (Mavuti1990).

A possible effect of climate warming is that the water temperatures would increase to levels that are suboptimal or lethal for aquatic organisms, particularly to those with limited dispersal ability like zooplankton. Temperature affects nearly all biological process rates, from biochemical kinetics to species generation time, with higher temperatures typically resulting in higher rates until an optimum is reached, above which rate processes usually decrease rapidly (Kingsolver 2009). Life history parameters (e.g., growth, development, reproduction), respiration, behavior, and survival of aquatic poikilotherms are affected by temperature (Goss and Bunting 1983).

It is proven that water temperature plays a key factor in species distribution and richness along elevational and altitudinal gradients (Ward 1985; Reyjol et al. 2001). Climate warming will consequently, to some extent, shape the structure of zooplankton community of lakes, rivers and other water bodies. On one hand, zooplanktons are poikilotherms whose development rate at each life stage is determined by temperature. Nevertheless, locality of the climate shows that increase in temperature will not always be so extreme or a deadly levels. As a matter of fact, the tropical ecosystems experience relatively less variability in temperature compared to those in temperate areas. On the other hand, zooplankton inhabiting the eutrophic lakes may respond differently to the climate warming compared to those living in oligotrophic lakes. This might be due to differences of resource availability and environmental factor complexity. Research suggested that eutrophic waters are generally characterized by high nutrient concentration, organic matters, and turbidity, and hence attenuation of solar radiation (e.g. Wunderlich and Elder 1973; Imai et al. 2001; Parikesit et al. 2005). Alric et al. (2013) stated that lake vulnerability and responses to climate warming are modulated by lake trophic status. Therefore, such variabilities of the environment make prediction of the climate warming effects on zooplankton community more difficult because the components interconnect one another.

Indeed, research on how climate warming affects the zooplankton community in tropical eutrophic lakes will enrich our knowledge of ecological processes in tropical ecosystems, which left behind the temperate areas. In this paper, we question if the climate warming in the eutrophied Cirata Lake shows a clear link to the variability of the zooplankton community in a long perspective. We anticipate that the long-term increase of temperature will pose a significant threat to the zooplankton community.

MATERIALS AND METHODS

Study site

The study was carried out in Cirata man-made lake situated at West Java Province, Indonesia. The lake covers about 62 km^2 of inundated area which is a part of Bandung Barat, Cianjur, and Purwakarta District. The lake has average depth of about 40 m with maximum temperature difference between water layers is 4^oC. Permanent sampling stations are distributed throughout the lake as established during the Environmental Impact Assessment (EIA) of the project (Figure 1). Cirata was built in 1987 with main purpose of generating electricity to supply Java and Bali by hydropower. The lake receives water discharge from twelve rivers, and the catchment is characterized by a very dense-populated city (Bandung Metropolitan) and intensive agricultural practices. As the time has passed, the lake function has expanded to include wider uses. Beside energy production, Cirata also serves for aquaculture, irrigation, and as a tourism site. There is a fast growing number of floating net cage aquaculture in the lake, which has increased from less than 1,000 unit in the early time of its development (1988) to 53,000 units in 2011 (PT. PJB 2012). Recently, the lake has been experiencing severe eutropication, organic pollution, and high levels of other chemical contaminants (Institute of Ecology 2013).

Data source and sampling protocols

A database of plankton and environmental quality parameters from quarterly water monitoring activities was used in this study. Samples collections were generally conducted in February, May, August, and November each year. The Institute of Ecology-Padjadjaran University organized the monitoring activities from 1995 to 2013 in service to PT. PJB (state electricity company), the authority of the Cirata Lake. During that period, some sampling was carried out by two different institutions and the data generated by the institutions were verified before use to ensure the uniformity of the data, and thus, the analysis.

Over the entire study period, the Institute of Ecology and the other two laboratories employed the same procedures and techniques. Data on biology, the zooplankton, and environmental parameters, water temperature and transparency, were obtained from regular cruises on a speed-boat. Samplings normally started from about 11.00 AM and finished at 14.00 PM. Water temperature and transparency were measured on-site using an Hg thermometer and a Secchi-disc, respectively (APHA 1989). Water samples were collected from 20 cm water depth for other physico-chemical analysis. Meanwhile, the biological samples were collected using plankton net no. 25 (mesh size 0.55 µm). The zooplankton were identified to the highest taxonomic separation possible and counted in a Sedgwick Rafter under a light microscope. Following determinants of plankton community structure were obtained: species richness, density, Shannon-Wiener diversity index, and functional groups.

In addition, the data on air temperature was collected from the nearby source, i.e. Cirata weather station. The air temperature was collected from hourly record every day, and is presented as daily temperature corresponding to that obtained from water measurement.

Data analysis

The data on the zooplankton community structure were correlated to the data on the water temperature and transparency. The linear regression and correlation analysis were done using the R statistical environment (R Core Development Team 2015). Meanwhile, the changes of zooplankton community structure were described through species and functional group composition.

RESULTS AND DISCUSSION

Results

Our study found that the average daily atmospheric temperatures were lower than the midday water temperatures. In the Cirata lake area, however, inter-annual water and air temperature exhibited a clear warming tendency over time regardless the magnitude. In fact, the phenomenon of climate warming has determined the water temperature of that tropical aquatic ecosystem (Figure 2). Over 19 years, the average increase in water temperature was 0.53°C which corresponds to 0.03°C per year. However, there was also a remarkable seasonal variation of water temperature in the lake; in dry-season the water temperature could rise up to 3°C higher than that in rainy-season. Therefore, the shift in water temperature in the long run was clearly within the range of seasonal temperature variability.

The water transparency decreased over time (Figure 3) showing a continuous augmentation of load of particulate matters. Such particulate matters might consist of organic and non-organic materials which could have either direct (such as food recruitment, survival, mobility) or indirect (such as growth and community structure) effects on zooplankton responses.

With regard to community metrics, our results showed that the elevated water temperature had a positive association with species richness, density, and diversity index (Temperature vs Species Richness: *y = 2.497x-56.295, r = 0.32*; Temperature vs Density: *y = 14282x-324133, r = 0.12*; Temperature vs Heterogenity: *y = 0,03706x + 0,39162, r = 0.07*) (see Figure 4a, b, and c). The correlations between water temperature and the community indicators seemed to be poor (as indicated by *r* values); but nonetheless there was a slight increased tendency of the three parameters were observed. The long-term increase in lake water temperature had increased the species richness, density, and diversity. It seems that the warming water have promoted the zooplankton species to develop better than the previous environments.

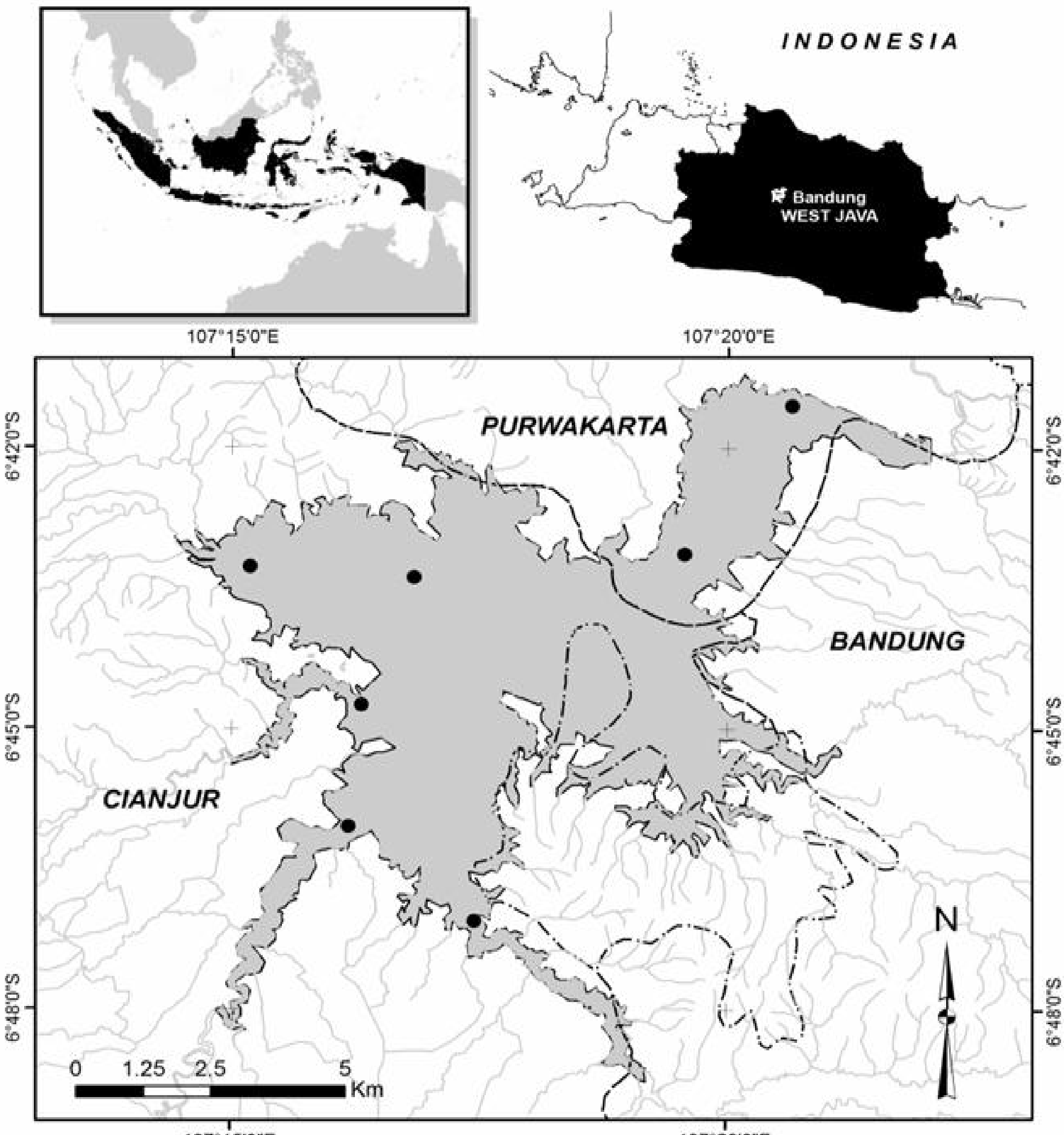


Figure 1. The study site: the Cirata Lake in West Java Province-Indonesia (solid dots show the water sampling sites)

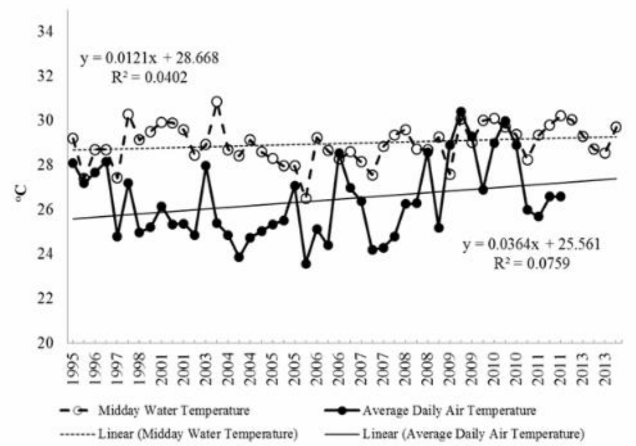


Figure 2. Trend in air and water temperature in the Cirata lake

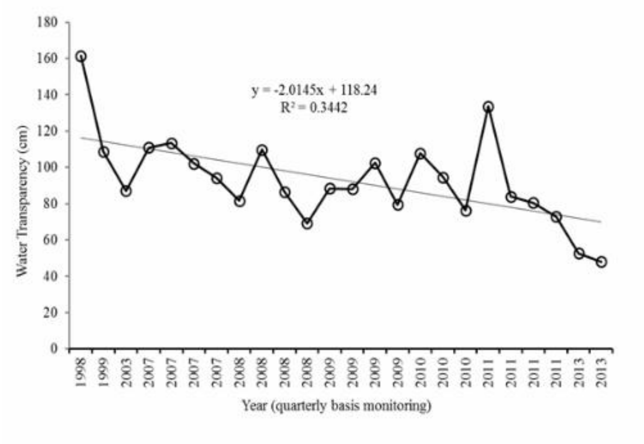
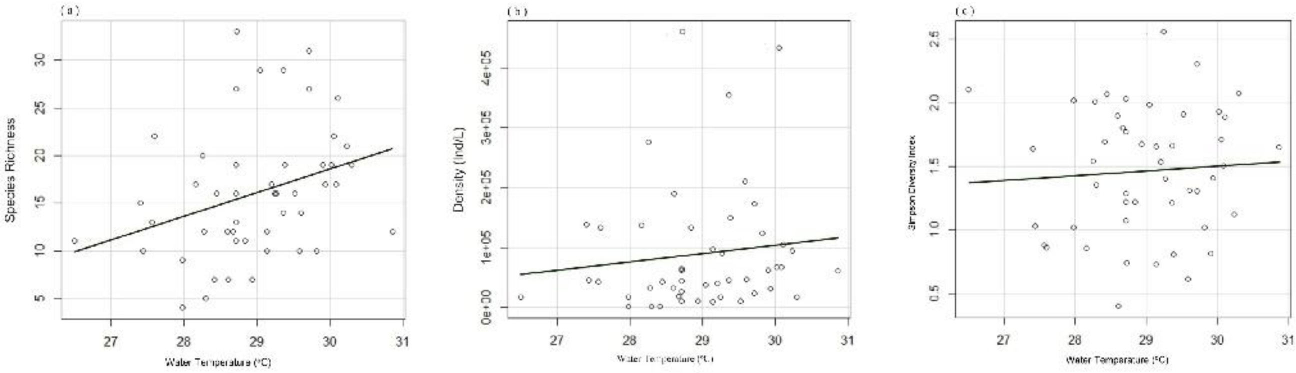


Figure 3. Trend in water transparency in the Cirata lake

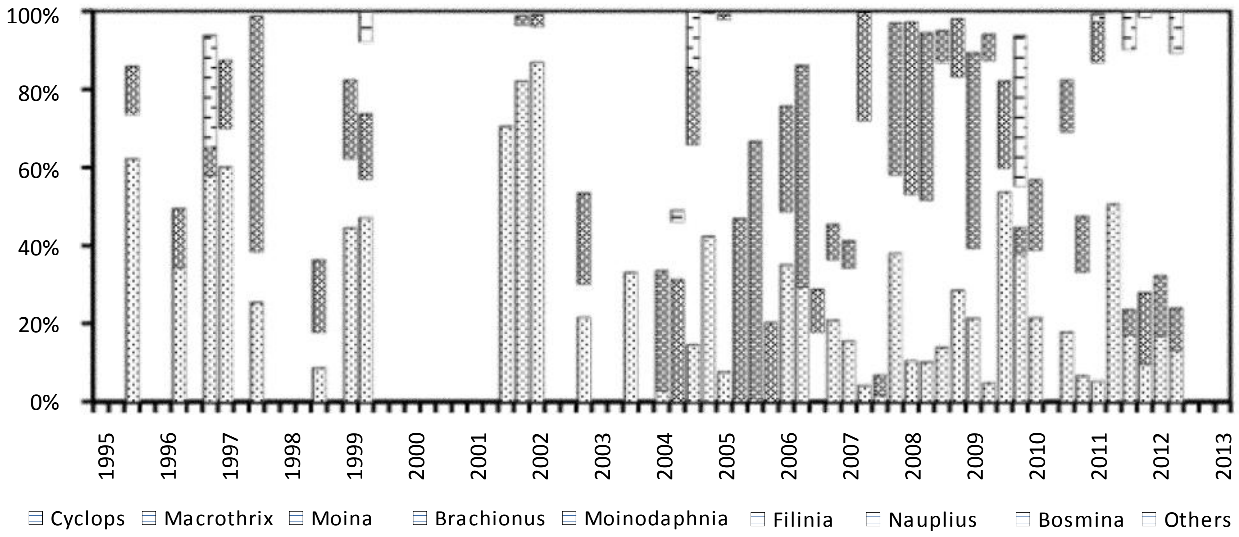


A **B** **C**

Figure 4. The relation between water temperature and zooplankton community metrics: A. Species richness, B. Density, and D. Diversity index

The number of zooplankton species fluctuated over the study period showing that species composition changed dynamically. Species alternately dominated the community over time; in term of abundance there was no single species remained at the top of the community (Figure 5a). Eight species observed to be predominant in the Cirata Lake were *Cyclops* sp., *Brachionus* sp., *Macrothrix* sp., Nauplii, *Bosmina* sp., *Filinia* sp., *Moina* sp. and *Moinodaphnia* sp. The result showed that some species (such as *Cyclops* sp., *Brachionus* sp., and *Macrothrix* sp.) remained in higher number of individuals compared to the other species. They seemed to be more adaptable to changes of the water temperature and of the eutrophication status. There was also a short period where some species (*Moinodaphnia* sp., *Filinia* sp.) occasionally dominated the community, but again disappeared in the other years.

Interestingly, if we refer to higher taxonomic groups the structure and variability of the zooplankton community was more visible. Cladocerans, copepods, and rotifers seemed to be the main components of the eutrophic lake (Figure 5b). It was expected that the three groups would be more common in term of biomass. In the early years, copepods were well developed and dominated the community structure, but in the later years their population decreased gradually. In contrast to that, cladocerans were found less abundant in the early time but then it tends to be dominant in the later years. Meanwhile, the populations of rotifers were generally constant over the time even though in the most recent period it was found less frequently.



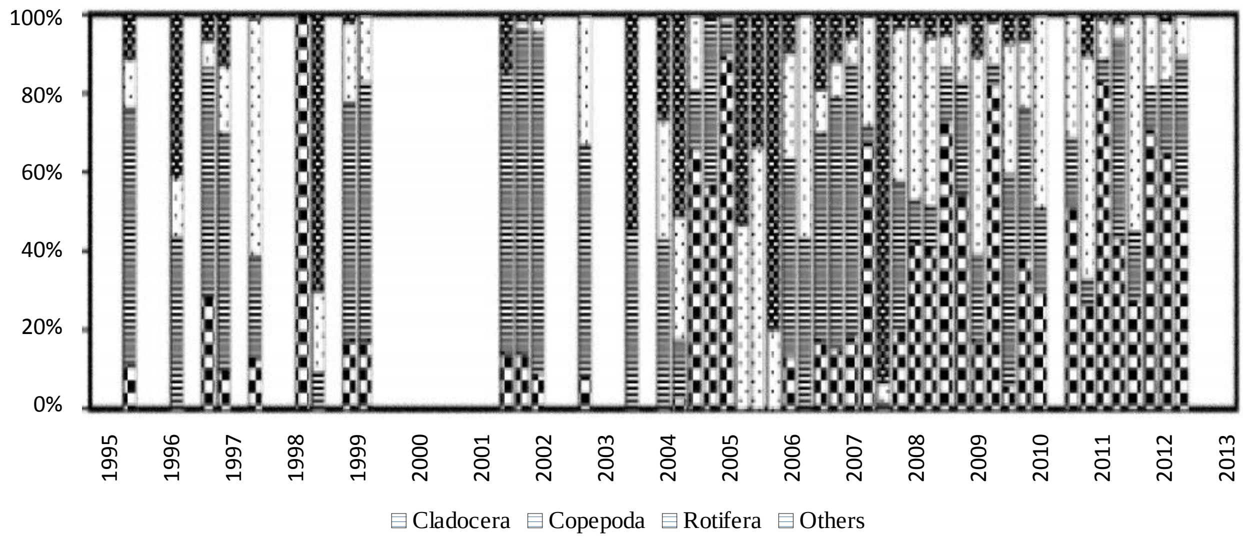


Figure 5. Long-term variability in species composition (above) and functional groups (below) of zooplankton in the Cirata Lake (Blank spots between bars stand for missing data on the relevant periods).

Discussion

The climate warming is truly influence the global environments, no exception of the tropical aquatic ecosystems. The water of the Cirata Lake has been warming following the increase in global atmospheric temperature. Nevertheless, the shift of the water temperature after a long period was very low (< 1^{o}C) confirming the present research which demonstrated that tropical areas have lower variabilities in temperature (Lowe-McConnell 1987). The magnitude of amplifying thermal regime in water system depends on many environmental factors. It has been reported that the level of suspended matters contributes to the heating process of the natural water systems (Dwivedi 2014; Bonalumi et al. 2012; Paaijmans et al. 2008). Water turbidity affects water temperature, as suspended particles in a water column absorb and scatter sunlight and hence determine the extinction of solar radiation. When the water is turbid, sunlight will warm it more efficiently. The warming contribution of suspended particles in water may strengthen the threats of already increased temperature to water-inhabiting organisms such as phytoplankton, zooplankton, fish, etc.

In case of eutrophied lakes, levels of eutrophication and water transparency/turbidity may pose additional forcing to climate warming effects on aquatic organisms as heating can be substantially facilitated. The suspended particles may be either inorganic or organic. Research reported that eutrophic waters usually associate with higher suspended matters loads originated from high siltation and organic pollution (e.g. Wunderlich and Elder 1973; Imai et al. 2001; Parikesit et al. 2005). That is truly the case of the Cirata Lake (Institute of Ecology 2013). High amount of organic matters and or high assemblage of phytoplankton in eutrophic waters benefit and may help the zooplankton compensate the stress posed by elevated temperature. In such case, it is more difficult to predict whether increased temperature will exclude or promote the zooplankton species, thereby difficult to expect generic trajectories of the community changes driven by climate warming.

It is commonly discovered that climate warming has negative effects on zooplankton species diversity and aquatic ecosystem stability (Bonecker et al. 2013; Deksne et al. 2011). Drake (2005) pointed out that temperature variability has a major effect on zooplankton growth rate and generation times. Existing evidence showed that climate warming has decreased the total abundance of zooplankton and species diversity (Deksne et al. 2011), trophic structure and the dynamic of the population (Wrona et al. 2006), and likely affect the survival, reproduction and growth, distribution, persistence and diversity of species (Leveque et al. 2005). Purvina et al. (2009) suggested that the increasing water temperature can lead to decrease in food assimilation and the filtration rate by the zooplankton grown-up representatives, as well as to the eggs' degeneration and even its abortion.

Interestingly, instead of declining, the zooplankton species richness, density, and diversity index climbed up over the time as the water temperature elevated. In line to this, a research confirmed that temperature variability promotes greater richness of zooplankton species (Shurin et al. 2010). In case of the Cirata Lake, the better condition of the environment (in view of ecosystem concept) may be attributed by two factors: (i) the magnitude of the temperature shift, which was insubstantial (i.e. within the range of tolerance limit), and (ii) high organic resource availability. As it has been noted that the seasonal variabilities of temperature in the Cirata Lake were greater than those in a long run period. Such experience may benefit the zooplankton species to cope with the shifting thermal regime in the water. According to Almén et al. (2014), zooplankton experience widely varying conditions in their physicochemical environment on a diurnal basis. The amplitude of the fluctuations may affect the zooplankton species' ability to respond to climate change.

High productivity of phytoplankton in nutrient-rich waters or suspended organics facilitates more zooplankton species to develop. In the Cirata Lake, the total density of zooplankton exceeded the producers indicating that zooplankton do not consume merely on phytoplankton but also on suspended organics (Institute of Ecology 2013). There are many zooplanktons which feed on organic particulate matters (Hebert 1977). Allochtonous organic carbon often dominates the carbon pools of tropic lakes, and may represent a significant resource for zooplankton consumers (Karlsson et al. 2002; Cole et al. 2006; Jonsson et al. 2007). Strong evidence suggests that zooplankton assimilate significant amounts of terrestrial carbon in some lakes (Carpenter et al. 2005; Cole et al. 2006, 2011). Even though there are some droughts on the designation of terrestrial organic carbon as a resource subsidy (Brett et al. 2009; Jones et al. 2012) due to low nutritional quality. However, it seems that this was not the case of the Cirata Lake. "Moderate" increase in temperature over a long-term period combined with high organic matters seems to promote more zooplankton species to grow, and thereby increase the species richness, density, and diversity.

Zooplankton in lakes is composed mainly of rotifers, cladocerans, and copepods. Perturbation in lake ecosystems by climate warming will significantly affect their community structure. In species level, the trajectory of changes of species composition is hard to generalize. Research suggests that the nature of the plankton responses is diverse as species exhibit complex life-history traits (Adrian et al. 2006). But interestingly, grouping using higher taxa (such as using the dominant taxa: copepods, rotifers, and cladocerans) provide a visible trend. In the early years of the study period, copepods dominated the zooplankton community, but their populations declined over time. On the contrary, cladocerans became dominant in the later years, while rotifers were more or less stable. These changes may be due to the eutrophication process and input level of allochtonous organic contaminants in the lake. Cladocerans are likely the best survivors of the warmer temperature as well as of the eutrophied and high organic contaminated waters. Most cladocerans remove particulate organic matter from water by filtration, have the ability to ingest food of a wider size range, and have higher filtering rates, which could give them competitiveness over the rotifers (Allan 1976; Lynch 1980), and perhaps over the copepods as well.

The greater species richness, total density, species diversity, and overall changes in community structure of the zooplankton in the Cirata Lake may be attributed to the climate warming. However, instead of inhibiting or excluding species, the warmer climate favors zooplankton species to develop or to grow. The magnitude of temperature variability in long-term and the amplitude of short-term (diel and seasonal) temperature variability seems to play an important role in the definition of forces posed to the zooplankton community. The wealth of resources (such as high phytoplankton density and suspended organic matters) in aquatic ecosystems may support the zooplankton harness the "moderate" shift of temperature, or in opposite manner, combat the negative effects of climate warming.

To summary, warming of the water of the Cirata Lake has been observed over 19 years, which was clearly driven by the climate warming. The effects of the climate warming, however, would not be necessarily negative to organisms. Greater species richness, density and diversity of zooplankton indicated that zooplankton species could harness the changing climate. Beside the range of long-term variability of temperature, the eutrophic status of the aquatic ecosystem may concurrently determine the types of their responses. This result confirms the existing paradigm suggesting that the impact of climate change on zooplankton community structure is not straight forward and potentially highly complex. Tropics or temperate, eutrophic status, and other environmental factors work as concomitant forcing which may amplify or hide their individual affects on the studied community.

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