Zooplankton diversity in Lake Tondano, Indonesia

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Abstract. Study on freshwater ecology have been long focused on subtropical habitats with few references to tropical regions including Indonesia. Zooplankton, in particular, is an important component of aquatic ecosystem as they are key player of aquatic food webs, thus a solid understanding of their community structure can be of direct benefit to freshwater ecosystem management. The spatial patterns of zooplankton diversity in Lake Tondano, Celebes Island – Indonesia were studied in 2013, with the main aim was to understand how local environmental and habitat heterogeneity driving the zooplankton community structure. We performed field samplings to collect zooplankton using a vertical tow with a 156 µm mesh plankton net from 1 meter above sediment to the surface and to measure environmental parameters using portable multi probes water quality checker from three different water columns. The sampling sites were selected to include different habitats within the lake to look at diversity of the entire zooplankton communities including Rotifers, Cladocerans, and Copepods in Lake Tondano, Indonesia. A total of 21 species of cladocerans, 31 copepods, and 60 rotifers were identified from Lake Tondano. Our result indicates a relatively low number of cladocerans which is may be associated with high predatory pressure from planktivorous fish, especially within the open pelagic zone.

Keywords: Lake Tondano; tropical lake; zooplankton diversity

1. Introduction

Zooplankton are among the most abundant organisms and the key player in aquatic ecosystem food webs as primary consumer [1, 2]. Their community structure (species richness and species composition) is driven by complex interaction of many physico-chemical and environmental factors such as temperature, salinity, and nutrient concentration [3, 4]. Their distribution also depends on interaction of biotic factors including phytoplankton and macroinvertebrate and fish predation [5]. Rotifers, Cladocera’s, and Copepods are considered the most important zooplankton to study community structure in relation to environmental heterogeneity.

In lakes ecosystems, zooplankton was identified as a top-down force for the phytoplankton yield and microbial community through preferential grazing and filter-feeding which increases water clarity [1, 6]. On the other hand, the bottom-up forces, such as high nutrient loading, may responsible for the phytoplankton growth and alga blooms which are known to be related to the decrease of zooplankton abundance and biomass, particularly due to the reduction of larger size zooplankton [7]. Furthermore, the present of submerge macrophytes in the lakes may inhibit phytoplankton growth through competition over nutrient uptake from the water column, thus maintain the clarity of water [8]. Submerge macrophyte beds also play an important role in zooplankton community structure by...
providing refuge for zooplankton especially when predation pressure is high due to increased water clarity (reference).

A significant number of studies have suggested that many factors may be responsible for zooplankton community structure in lake ecosystems. These include: water chemistry [1, 9, 10], land use and watershed disturbance [11-13], urban development [14], nutrient and phytoplankton assemblages [6], fish predation [15, 16] and biological invasion [17].

Lakes in the agricultural-dominated catchments, for instance, were found to have a lower species number of zooplankton as compared to those in relatively least-agricultural impacted [10, 13]. While Dodson, Everhart, Jandl, and Krauskopf [10] suggest that increased nutrient was responsible for the increased phytoplankton biomass and was associated with the reduced of zooplankton richness, [18] suggest that increased cyanobacteria biomass is linked with the shift in the size of zooplankton communities which further influence the functioning of lake systems.

Studies explored the relationship between environmental variables and zooplankton community structure has been the interest of limnologist for many decades [19-21], and zooplankton diversity has been widely used as bio-monitoring tools for freshwater ecosystems. However, the focus has been given toward northern temperate region with few references toward tropical region, and especially, almost no references have been reported from freshwater ecosystems in Indonesia. This study was designed to outline the spatial distribution pattern of zooplankton along with environmental heterogeneity in Lake Tondano, Indonesia.

2. Methodology

2.1. Study area

This study was carried out in Lake Tondano, situated between 1°10’ N and 124°55’ E in Sulawesi Island in the province of North Sulawesi, Indonesia (figure 1). Climate is identified as rainy tropical (monsoon) marked by a rainy season from November to April (mean temperature of 22 °C) and dry season from May to October (mean temperature of 25 °C). Annual mean precipitation is around 2400 mm (NEO, TRMM).

The lake has a total area varies between 46 km² and 53 km² during dry and wet seasons respectively with total volume of water approximately 410 mil.m³. Long term average water level of the lake carried between 684 and 691 m and was influenced by annual rainfall event. The lake serves as the main freshwater source for domestic and aquaculture practices. However, increasing pressure from anthropogenic activities including aquaculture practices and land-use changes have been identified as the main stressor to water quality deterioration in the lake.

Figure 1. Sampling sites.
2.2. Sampling methodology
Water sample for zooplankton and water quality analysis was collected once during wet season in May 2013. The sampling sites were chosen to include littoral and pelagic zones and inlet and outlet of the lake. Zooplankton samples were collected by vertical tow using a 156 µm mesh size plankton net from 1 meter above the sediment bed to surface and were fixed in 4% formalin until further analysis. Zooplankton sample analysis, species including quantitative estimation and identification to species level (where possible) was done under light dissecting microscope (Nikon). Environmental variables were measured at three different water columns (including surface, Secchi Depth, and near the sediment) and were averaged.

2.3. Data analysis
Zooplankton community structure was displayed as list of species presence and absence, total abundance, and relative abundance of the three functional groups including Cladocera, Copepod, and Rotifera. Ordination technique such as Principal Correspondence Analysis (PCA) was used to see the variability in environmental variables and zooplankton distribution. Multiple regression analysis was used to determine the relationship between the environmental variables and zooplankton abundance, species richness, and diversity index. Zooplankton community structure including species dominance curve and diversity index were assessed using a PC-ORD 6.22 for windows while PCA and multiple regression analysis were done using SigmaPlot 14.

3. Result and discussion
3.1. Environmental variables
Table 1 summaries general environmental parameter and the morphology of the Lake. Lake Tondano has a total lake area of 46-53 km². Mean annual rainfall varied between 1300 mm and 2500mm with an average annual rainfall of 2143 mm. Maximum water depth of 35.5 m with an average water depth of 8.88m while Secchi depth varied between 2 to 3 meters. Ordination biplots of the principles component analysis (PCAs) show that most of the variability in environmental factors was explained by Total nitrogen, pH, Temperature, and Dissolved Oxygen (45% explained variability, figure 2). Based on Carlson’s Trophic Status Index (TSI), Lake Tondano is considered mesotrophic (Carlson Index 50.83), except for TN6 (Eris) which was considered eutrophic (Carlson index 60.81). Eutrophic condition in TN6 was related to intensive aquaculture activities in the area where TN6 is the center for Floating Fish Cage (KJA) activities in the lake. TN 5 (Rombokken) point was also considered eutrophic with TSI index of 55.57. Nutrient concentration in this location was also related to aquaculture activities. The ecological status scoring method indicated that lake Tondano was in fairly good condition with an ecological score of 32 as per May 2013 (Research Centre for Limnology, unpublished report).

Table 1. General characteristic of Lake Tondano and mean values of the main environmental parameters of the studied area.

| Lake area          | Maximum depth | 35.5 m |
|--------------------|---------------|--------|
| Catchment area     | 46-53 km²     |        |
| Lake area: Catchment area | 43 km²   | Mean depth | 8.88 m |
|                    | 1:5.12        | Volume | 410.10⁶ m³ |
| Chlorophyll-a (µgL⁻¹) | 1.3          | TN2    | 1.3 |
| Total Nitrogen (mgL⁻¹) | 1.23         | TN3    | 0.35 |
| Total Phosphate (mgL⁻¹) | 0.036        | TN4    | 1.73 |
| pH                 | 7.49          | TN5    | 0.39 |
| Temperature (°C)   | 24.08         | TN6    | 0.44 |
| Dissolved oxygen   | 6.58          | TN7    | 7.71 |
| Conductivity (mS.cm⁻¹) | 0.229        | TN8    | 8.25 |
| Secchi depth (m)   | 2.2           | TN9    | 0.07 |
| Maximum depth (m)  | 8.0           | TN10   | 0.12 |
|                    | 13.2          | TN11   | 0.63 |
|                    | 19.8          |        |    |
3.2. Zooplankton community structure

The list of presence and absence of all species identified from the lake is presented in Table 2. A total of 112 zooplankton species were identified from Lake Tondano during the study including 60 rotifers, 21 cladocerans, and 31 copepods. Zooplankton composition was similar in the lakes in all sampling points and was dominated by rotifers which contributed to ~50% of the total special number and density (Figure 4). Based on species dominance curve analysis (Figure 3), five most dominant species were *Brachionus calyciflorus*, *Trichocerca* sp., *Trichocerca similis*, *Keratella valga*, and *Keratella tropica*; which belonged to Rotifers group. Shanon-diversity index ranged from 1.73 to 1.85 and there were no significant differences between sampling locations.

**Figure 2.** PCA ordination graph showing the variability in environmental factors in Lake Tondano.

**Figure 3.** Species dominance curve showing five most dominant zooplankton in Lake Tondano which belonged to Rotifers group including *Brachionus calyciflorus*, *Trichocerca* sp., *Trichocerca similis*, *Keratella valga*, and *Keratella tropica*. 
Table 2. Zooplankton species list and their presence (*) and absence (0).

| Family      | Species               | TN2 | TN3 | TN4 | TN5 | TN6 | TN7 | TN8 | TN10 | TN11 |
|-------------|-----------------------|-----|-----|-----|-----|-----|-----|-----|------|------|
| Harpaticoidea | Epischura lacustris | *   | *   | *   | *   | *   | *   | 0   | *    | *    |
|             | Epischura sp.         | +   | +   | +   | +   | +   |    | +   |      |      |
|             | Harpacticoid sp.      | +   | +   | +   | +   | +   |    | 0   | *    | *    |
|              | Oxydiaptomus sanguenensis |       |       |       |       |       |       |       |       |       |
| Calanoidea   | Oxydiaptomus birgei  | *   | *   | *   | *   | *   | *   | +   | *    |      |
|             | Leptodiaptomus minutus |       |       |       |       |       |       |       |       |       |
|             | Leptodiaptomus sicilis |       |       |       |       |       |       |       |       |       |
|             | Leptodiaptomus ashlandi |       |       |       |       |       |       |       |       |       |
|             | Skistodiaptomus sp.   | +   | +   | +   | +   | +   |    | 0   |      |      |
|             | Ospartricium sp.      | +   | +   | +   | +   | +   |    | 0   |      |      |
|             | Acaloaiaptomus sp.    | +   | +   | +   | +   | +   |    | 0   |      |      |
|             | Diacyclops sp.        | +   | +   | +   | +   | +   |    | +   |      |      |
|             | Diacyclops robustus   | +   | +   | +   | +   | +   | 0   | +   |      |      |
|             | Cyclops scutifer      | +   | +   | +   | +   | +   | 0   | +   |      |      |
|             | Cyclops edax          | +   | +   | +   | +   | +   |    | +   |      |      |
|             | Tropocyclops sp.      | +   | +   | +   | +   | +   |    | +   |      |      |
|             | Orthocyclops modestus | +   | +   | +   | +   | +   | +   | 0   |      |      |
|             | Diacyclops thomasi    | 0   |      |      |      |      |      |      |      |      |
|             | Macrocylops albidus    | +   | +   | +   | +   | +   |    | +   |      |      |
|             | Eucyclops agilis      | +   | +   | +   | +   | +   |    | +   |      |      |
|             | Eucyclops sp.         | +   | +   | +   | +   | +   | 0   | +   |      |      |
|             | Megacyclops viridis   | +   | +   | +   | +   | +   |    | +   |      |      |
|             | Enecyclops sp.        | +   | +   | +   | +   | +   |    | +   |      |      |
|             | Microcylops varicans  | +   | +   | +   | +   | +   |    | +   | 0    |      |
|             | Tropocyclops sp. 2    | +   | +   | +   | +   | +   |    | +   |      |      |
|             | Paracyclops sp.       | +   | 0   | +   | 0   | 0   |    | +   |      |      |
|             | Macrocylops sp.       | +   | +   | +   | +   | +   | 0   | +   |      |      |
|             | Cyclops sp.           | +   | +   | +   | +   | +   |    | +   |      |      |
|             | Diacyclops sp. 2      | +   | +   | +   | +   | +   |    | +   |      |      |
|             | Acanthocyclops sp.    | +   | +   | +   | +   | +   | 0   | +   |      |      |
|             | Daphnia ambiguca       | +   | +   | +   | +   | +   |    | +   |      |      |
|             | Daphnia pulex          | +   | +   | +   | +   | +   |    | +   |      |      |
|             | Daphnia parvula       | +   | +   | +   | +   | +   |    | +   |      |      |
|             | Daphnia magna         | +   | +   | +   | +   | +   |    | +   |      |      |
|             | Daphnia pulicaria      | +   | +   | +   | +   | +   |    | +   |      |      |
|             | Daphnia longiremis    | +   | +   | +   | +   | +   |    | +   |      |      |
|             | Diaphanosoma birgei   | +   | +   | +   | +   | +   |    | +   |      |      |
|             | Diaphanosoma brachyurum |       |       |       |       |       |       |       |       |       |
|             | Ceriodaphnia sp.      | +   | +   | +   | +   | +   |    | +   |      |      |
|             | Sinocephalus sp.      | +   | +   | +   | +   | +   |    | +   |      |      |
|             | Sida crystallina      | +   | +   | +   | +   | +   |    | +   |      |      |
|             | Eubosmina             | +   | +   | +   | +   | +   |    | +   |      |      |
|             | Bosmina longirostris  | +   | +   | +   | +   | +   |    | +   |      |      |
|             | Eubosmina coregioni   | +   | +   | +   | +   | +   |    | +   |      |      |
|             | Eubosmina longispina  | +   | +   | +   | +   | +   |    | +   |      |      |
|             | Chidorus sp.          | +   | +   | +   | +   | +   |    | +   |      |      |
|             | Leberis aenigmatosa   | +   | +   | +   | +   | +   | 0   | +   |      |      |
|             | Leydigia sp.          | +   | +   | +   | +   | +   |    | +   |      |      |
|             | Alonella sp.          | +   | +   | +   | +   | +   |    | +   |      |      |
|             | Alona sp.             | +   | +   | +   | +   | +   |    | +   |      |      |
|             | Pleuroxus sp.         | +   | +   | +   | +   | +   |    | +   |      |      |

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| Family          | Species                                | Sampling location |
|-----------------|----------------------------------------|-------------------|
| Brachionidae    | *Brachionus bidentatus*                | TN2   |
|                 | *Brachionus. leydigi*                 | TN3   |
|                 | *Brachionus calyciflorus*             | TN4   |
|                 | *Brachionus. falcatus*                | TN5   |
|                 | *Brachionus caudatus*                 | TN6   |
|                 | *Brachionus. ulceolaris*              | TN7   |
|                 | *Brachionus. dichotomus*              | TN8   |
|                 | *Platyias quadracornis*               | TN10  |
|                 | *Plutionus patulas*                   | TN11  |
|                 | *Keratella tropica*                   | TN2   |
|                 | *Keratella quadrata*                  | TN3   |
|                 | *Keratella valga*                     | TN4   |
|                 | *Keratella tecta*                     | TN5   |
|                 | *Keratella cochlearis*                | TN6   |
|                 | *Keratella procyrva*                  | TN7   |
|                 | *Keliotica longispina*                | TN8   |
|                 | *Notholca sp.*                        | TN10  |
|                 | *Anuraeopsis sp.*                     | TN11  |
| Collurellidae   | *Corurella sp.*                       | TN2   |
|                 | *Lepadella ehrenbergii*               | TN3   |
|                 | *Lepadella elliptica*                 | TN4   |
|                 | *Lepadella lindau*                    | TN5   |
| Trochosphaeridae| *Filinia longiseta*                   | TN6   |
|                 | *Filinia opolinsis*                   | TN7   |
|                 | *Filinia terminalis*                  | TN8   |
|                 | *Filinia fassa*                       | TN9   |
|                 | *Filinia saltator*                    | TN10  |
|                 | *Filinia pelgeri*                     | TN11  |
|                 | *Filinia austriensis*                 | TN2   |
| Lecanidae       | *Lecane quadridentata*                | TN3   |
|                 | *Lecane cornata*                      | TN4   |
|                 | *Lecane bulla*                        | TN5   |
|                 | *Lecane elachis*                      | TN6   |
|                 | *Lecane sinuate*                      | TN7   |
|                 | *Lecane pusilla*                      | TN8   |
|                 | *Lecane formosa*                      | TN9   |
|                 | *Lecane inermis*                      | TN10  |
|                 | *Lecane grandis*                      | TN11  |
|                 | *Lecane unguata*                      | TN2   |
| Trichoceridae   | *Trichocerca sp.*                     | TN3   |
|                 | *Trichocerca rutmeri*                 | TN4   |
|                 | *Trichocerca flagellata*              | TN5   |
|                 | *Trichocerca kostei*                  | TN6   |
|                 | *Trichocerca similis*                 | TN7   |
|                 | *Trichocerca pusilla*                 | TN8   |
|                 | *Trichocerca stylata*                 | TN9   |
|                 | *Trichocerca myersi*                  | TN10  |
| Nottomatidae    | *Cephalodella mucronata*              | TN2   |
|                 | *Cephalodella tenuiseta*              | TN3   |
|                 | *Cephalodella tantioides*             | TN4   |
|                 | *Drilophaga sp.*                      | TN5   |
|                 | *Eothinia sp.*                        | TN6   |
|                 | *Entroplea sp.*                       | TN7   |
Rotifers exhibit a wide range of habitat adaptation and are indicator of water quality. In Lake Tondano, most dominant species belongs to these taxa with the five-top of dominant species were *Brachionus calicyflorus*, *Trichocerca* sp, *Keratella valga*, *Trichocerca similis*, and *Polyarthra* sp. Lake Tondano is subjected to invasive free-floating macrophyte blooming such as *Eichornia crassipes* and submerged macrophyte such as *Ceratophyllum demersum* (RC for limnology 2014, unpublished). This substrate rich habitat from macrophyte colony provides suitable habitat for benthic organisms such as rotifers which correspond with high frequency and abundance of rotifers in all sampling sites.

Copepods were the second dominant group and contributed to 27.6% of the total number. Number of Cladocera’s, on the other hand, was relatively low (18%) and was dominated by small-sized
Cladocera’s including *Daphnia pulex* and *Eubosmina*. Cladocera’s, particularly large *Daphnia* sp., are considered to play important role to control top-down pressure in lake ecosystem due to their ability to filter phytoplankton particle and as food sources for planktivorous fish. Increasing pressure from fish predation in lakes may lead to a shift from *Daphnia* dominated community to a community dominated by rotifers and cyclopoid [16]. The ecosystem of Lake Tondano has been long considered as being strongly affected by increasing fish population (RC for Limnology, unpublished). The fish community in Lake Tondano is characterized by a mixture of native species such as *Ophielaotris aporos* and introduced species *Osteochilus vittatus* and *Oreochromis niloticus*. There is evidence to indicate that fish predation play a role in driven zooplankton community structure in this lake, however, further study is needed to fully understand the tropics interaction which should include the main abiotic community including fish, macroinvertebrate, zooplankton, and benthic communities.

Zooplankton community structure and heterogeneity is the result of a complex interaction between biotic and abiotic component [1, 3]. Our result indicates that there was no significant relationship between environmental factor and the zooplankton abundance and species number (Multiple regression analysis using the environmental factors such as temperature, Total Nitrogen, Total Phosphate and Chlorophyll as independent variables and zooplankton abundance and species number as dependent variables). This can be related to the similarity in environmental variables in all sampling locations, suggested that spatial variability of environmental factors was not identified in Lake Tondano.

4. Conclusion
Zooplankton community composition in Lake Tondano comprised of 112 species and was dominated by rotifers followed by Copepod and Cladocera. Low number of Cladocera species in this lake might be correlated with the pressure of fish predation which is observed to be high in the lake. However, further analysis and study are necessary to confirm this preliminary conclusion.

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