# Species diversity and community structure of crustacean zooplankton in the highland small waterbodies in Northwest Yunnan, China

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Small waterbodies are a unique aquatic ecosystem with an increasing recognition for their important role in maintaining regional biodiversity and delivering ecosystem services. However, small waterbodies in Northwest Yunnan, one of the most concerned global biodiversity hot-spots, remain largely unknown. Here, we investigated the community structure of crustacean zooplankton and their relationships with limnological, morphometric and spatial variables in the highland small waterbodies in Northwest Yunnan in both the dry (October 2015) and rainy (June 2016) seasons. A total of 38 species of crustacean zooplankton were identified in our study, which is significantly higher than many other reported waterbodies in the Yunnan-Guizhou plateau as well as in the Yangtze River basin . This suggests that the highland small waterbodies are critical in maintaining regional zooplankton diversity in Northwest Yunnan. Meanwhile, we found limnological variables could explain most variation of crustacean zooplankton community, comparing to the morphometric and spatial variables in both the rainy and dry seasons. Our study revealed the diversity and community structure of crustacean zooplankton in the highland small waterbodies in Northwest Yunnan and highlighted the importance of small waterbodies in maintaining regional biodiversity.

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## Abstract

Small waterbodies are a unique aquatic ecosystem with an increasing recognition for their important role in maintaining regional biodiversity and delivering ecosystem services. However, small waterbodies in Northwest Yunnan, one of the most concerned global biodiversity hot-spots, remain largely unknown. Here, we investigated the community structure of crustacean zooplankton and their relationships with limnological, morphometric and spatial variables in the highland small waterbodies in Northwest Yunnan in both the dry (October 2015) and rainy (June 2016) seasons. A total of 38 species of crustacean zooplankton were identified in our study, which is significantly higher than many other waterbodies in the many other reported waterbodies in the Yunnan-Guizhou plateau as well as in the Yangtze River basin. This suggests that the highland small waterbodies are critical in maintaining regional zooplankton diversity in Northwest Yunnan. Meanwhile, we found limnological variables could explain most variation of crustacean zooplankton community, comparing to the morphometric and spatial variables in both the rainy and dry seasons. Our study revealed the diversity and community structure of crustacean zooplankton in the highland small waterbodies in Northwest Yunnan and highlighted the importance of small waterbodies in maintaining regional biodiversity.

**Keywords:** Northwest Yunnan; Small waterbodies; Biodiversity; Crustacean zooplankton

## Introduction

Small waterbodies are critical for regional biodiversity and are increasingly recognized for their essential role in maintaining biodiversity and providing ecosystem services (*Williams et al., 2004; Biggs, von Fumetti & Kelly-Quinn, 2017; Kuczyńska-Kippen, 2020*). Small waterbodies with low or even absence of fish and abundant submerged vegetation could support high biodiversity of aquatic organisms and contributed a large proportion of rare or endemic species to local freshwater habitats (*Williams et al., 2004; Oertli et al., 2005; Scheffer et al., 2006*). Meanwhile, small waterbodies have important ecological functions (*Céréghino et al., 2014; Biggs, von Fumetti & Kelly-Quinn, 2017*). Small waterbodies can significantly reduce nutrient concentrations and protect downstream waters (*Cheng & Basu, 2017*). On the other hand, small waterbodies are sensitive and vulnerable because of their small size and will respond directly to environmental changes (*Biggs, von Fumetti & Kelly-Quinn, 2017*).

Crustacean zooplankton is an important group in freshwater ecosystems because they occupy central positions in aquatic food webs, transferring energy to higher trophic levels (*Sommer et al., 1986; Fussmann, 1996*). In addition, crustacean zooplankton is sensitive to climate and environmental change (*Keller & Conlon, 1994; Jones & Gilbert, 2016*). For quite a long time, the research on crustacean zooplankton in freshwater ecosystems ~~are~~ mainly focused on lakes (*Barbiero et al., 2019*) and reservoirs (*Liu et al., 2020*). Yet, the ecology of crustacean zooplankton in highland small waterbodies remains seldom addressed.

Northwest Yunnan, located in Southwest China, has been designated as a global biodiversity "hot-spot" by World Wildlife Fund (WWF) and International Union for Conservation of Nature (IUCN) because of its rich biodiversity, unique and diverse highland landscape (*Mackinnon et al., 1996; Xu & Wilkes, 2004; Trizzino et al., 2014*). This region is in the upper stream of the Yangtze (Jinsha) River, the Mekong (Lancang) River, the Salween (Nujiang) River, and the Irrawaddy (Dulongjiang) River, attracting extensive attention of local and international communities (*Xu & Wilkes, 2004; Ao et al., 2021*). Currently, most ecology and biodiversity related studies in this region focus on the terrestrial vegetation and endangered wild animals (*Xu & Wilkes, 2004; Li et al., 2014*), yet still few studies addressed the aquatic ecosystems, especially for small waterbodies ecosystems ~~in this region~~.

In this study, we focus on the community structure and species diversity of crustacean zooplankton in highland small waterbodies in Northwest Yunnan, China. ~~As far as our knowledge, the ecology of crustacean zooplankton in highland small waterbodies of Northwest Yunnan remains largely unknown~~. Besides the limnological variables (e.g. water temperature, nutrients), previous studies have reported that morphometric variables (e.g. surface area, depth) and spatial variables (e.g. distance) also have critical effects on zooplankton diversity and community composition (*Dodson, 1992; MacLeod, Beisner, et al, 2006, Keller & Paterson, 2018*). Here, we hypothesized that ~~the~~ crustacean zooplankton in the small waterbodies are co-determined by limnological, morphometric and spatial variables. Specifically, the main aims of our study are to understand: i) the diversity and community structure of crustacean zooplankton in highland small waterbodies in Northwest Yunnan, ii) the difference of community structure ~~of crustacean zooplankton~~ in rainy and dry seasons ~~in this region~~, iii) how the limnological, morphometric and spatial variables ~~determining~~ the spatiotemporal variations of diversity and community structure ~~of the crustacean zooplankton in highland small waterbodies in Northwest Yunnan.~~

## Materials & Methods

### Study sites and field sampling

The study sites were distributed on the east and west sides of a high mountain ridge ~~located~~ in Gong-shan Country, Yunnan province, China (Fig. 1). ~~The altitude of the ridge~~ is 3700 m ~~above~~

~~sea level.~~ The average annual temperature and precipitation (from August 1, 2014 to July 31 2015) was 7.7 ℃ and 2515 mm respectively (*Liu et al., 2018*). ~~The east side of the ridge was defined as "area E" and the west side was defined as "area W".~~ There was a disused road lying across the "area E", which separated this area into Upstream (EU) and Downstream (ED) subgroups. The average elevation and area of small waterbodies are 3131 m and 9.9 $m^2$ for the area W, 3328 m and 13 $m^2$ for the area EU, and 3274 m and 41 $m^2$ for the area ED, respectively. In addition, these ~~temporal~~ small waterbodies ~~were characterized by the absence of~~ fish ~~and~~ abundant macrophytes.

Two ~~field~~ samplings were carried out in the dry (October 2015) and rainy (June 2016) seasons reflecting different hydrological regimes. A total of 32 and 30 small waterbodies were sampled in the dry and rainy seasons, respectively. For each small waterbody, the morphometric and spatial variables, including the water depth, water surface area, coordinates and altitude (using Garmin eTerx20, China) were measured ~~*in situ*~~. The physical parameters, including ~~the~~ conductivity (Cond), dissolved oxygen (DO), pH, and water temperature (WT), were measured by a portable multi-parameter device (YSI Professional plus, USA) ~~*in situ*~~. Water samples for chemical analysis were collected from the center ~~surface~~ of each small waterbodies using a 350 ml plastic bottle. Ammonia nitrogen ($NH_3N$), nitrate nitrogen ($NO_3N$), total nitrogen (TN), phosphate ($PO_4P$), total phosphorus (TP), dissolved silicate (DSi), and dissolved organic carbon (DOC) were analyzed by ~~the~~ segmented flow analyzer (Skalar SAN++, Netherlands), according to the user manual ~~of Skalar~~. ~~Meanwhile,~~ another 350 ml water sample was filtered through a micro-filter (~1.2 μm, GF/C Whatman) for the measurement of chlorophyll a (Chl-a). The concentration of Chl-a was measured with a spectrophotometer (Shimadzu UV-1800, Japan) with the standard method of APHA (*1999*).

Using 2 L buckets to collect crustacean zooplankton samples from the surface of open water by filtering 20 L water sample with a plankton net (64 μm in mesh size). All crustacean zooplankton samples were preserved in 5% formalin ~~solution.~~

**Zooplankton counting and identification**

Crustacean zooplankton was counted and identified under the stereoscope (Zeiss Stereo Discovery V20, German). All crustacean zooplankton samples were identified to the species level as far as possible. Specifically, all samples were screened under the stereoscope because of the low density of the crustacean zooplankters. The major reference books for identification were Chiang and Du (*1979*), Shen (*1979*) and Błędzki and Rybak (*2016*).

**Statistical analysis**

~~The~~ rarefaction ~~method~~ was used to compare species richness and Shannon diversity between the rainy season and dry season because biodiversity was affected by sampling efforts, such as the number of sites and individual numbers (*Chao et al., 2014*). Specifically, we calculated ~~appropriate~~ species richness and Shannon diversity index for the whole ~~of the small~~ waterbodies ~~as the individual numbers were infinity~~ (*Chao et al., 2014*). Then, we plotted individual-based ~~species~~ rarefaction curves ~~for crustacean zooplankton~~ for each season to compare the differences of species richness and Shannon diversity index.

Further, the similarity percentage analysis (SIMPER) was conducted to investigate differences ~~of crustacean zooplankton~~ community composition between the rainy and dry seasons and to determine the contribution of each species to the ~~observed similarities based on~~ Bray–Curtis dissimilarities (Clarke, 1993). ~~Meanwhile,~~ a nonmetric multidimensional scaling (NMDS) was carried out to illustrate taxonomic~~al~~ and abundance similarity between the rainy and dry seasons.

In order to test our hypothesis, we conducted the variation partitioning with redundancy analysis (RDA) to compare ~~crustacean zooplankton~~ variation ~~relationship~~ with the limnological, morphometric and spatial variables. Spatial variables can represent the importance of ~~migration and~~ dispersal on ~~the crustacean zooplankton~~ communities' structure according to the metacommunity theory (*Heino, et al., 2014*). To ~~examine and~~ quantify spatial patterns of crustacean zooplankton, we conducted ~~principal coordinates of neighbor matrices analysis (PCNM)~~ to obtain eigenvectors with positive eigenvalues from the distance matrix (*Borcard & Legendre, 2002*). First, longitude and latitude were converted into Cartesian coordinates (the unit is kilometer). Second, the Euclidian distance matrix among the small waterbodies was calculated. The eigenvectors with positive eigenvalues were used as spatial predictors. Then ~~minimum~~ variables were selected using the "forward selection" (*Blanchet, Legendre & Borcard, 2008*).

To reduce the weight of ~~the~~ abundance ~~species, crustacean zooplankton~~ abundance data were Hellinger transformed before ~~the~~ variation partitioning ~~analyses~~ (*Legendre & Gallagher, 2001*). To avoid collinearity, only ~~the~~ variables with the correlation coefficient below 0.7 were selected in the RDA (*Dormann, et al., 2013*). Finally, TN, $NO_3N$, $NH_3N$, $PO_4P$, DSi, DOC, Cond, WT, Chl-a, area, and depth were ~~selected~~ in RDA. All analyses were implemented with R statistical software (*R Development Core Team, 2020*). ~~The~~ rarefaction was carried out with "*iNEXT*" package (*Hsieh et al., 2016*). ~~PCNM~~ and RDA variation partitioning were performed using "*vegan*" package (*Oksanen et al., 2019*).

## Results

### Community composition

A total of 38 crustacean zooplankton taxa, including 20 Cladocera species and 18 Copepoda species, were identified in all sampled small waterbodies in northwest Yunnan (Table 1). In the rainy season, the most common species in this region were *Cyclops vicinus*, *Mesocyclops leuckarti*, *Alona affinis*, *Microclops varicaricans*, *Moina irrasa, Cyclops strenuuss*, *Ectocyclops phaleratus,* which occurred in more than 50% of the surveyed small waterbodies. In the dry season, *Chydorus ovalis*, *M. varicaricans*, *Tropocyclops prasinus*, *Ceriodaphnia laticaudata*, *Alonella exigua*, had a relative occurrence above 50% in this region (Table 1).

The species accumulation curves showed that we have sampled considerable individuals of crustacean zooplankton in both the rainy and dry seasons (Fig. 2). The observed value of species richness is almost same as the estimated values of species richness in both the rainy and dry seasons. And the species richness in the dry season is significantly higher than that in the rainy season (Fig. 2a). However, Shannon diversity index showed that an explicit overlapping of observed and estimated species richness for the rainy and dry seasons (Fig. 2b).

The results of the Similarity Percentage analysis (SIMPER) are summarized in Table 2. As shown in Table 2, the composition and abundance of crustacean zooplankton changed significantly between the rainy and dry seasons. *M. leuckarti*, *M. varicaricans*, *C. ovalis*, *C. vicinus*, *A. exigua* and *Sinodiaptomus sarsi* are most influential species based on cumulative contribution. Further NMDS showed that species compositions had significant differences between the rainy and dry seasons (Fig. 3).

### Crustacean zooplankton community variation partitioning

The variation explained by limnological variables, morphometric variables and spatial variables differed between the rainy and dry seasons (Fig. 4). In the dry season, the limnological, morphometric, and spatial variables totally explained 23.69% of the crustacean zooplankton community structure (Fig. 4a). The limnological variables explained the most variation of zooplankton community structure (7.01%), which is significantly higher than spatial variables (3.44%) and morphometric variables (1.70%). Variation partitioning revealed 7.31% of the shared variation between limnological variables and spatial variables. However, only 1.48% of the variation was shared between the morphometric and spatial variables.

In the rainy season, all predictors explained 26.65% of the crustacean zooplankton community structure (Fig. 4b), which was slightly higher than the dry season. The limnological variables pure explained 18.12% of the variation. And the spatial variables had a lower contribution (3.45%) and followed by morphometric variables (0.64%).

**Discussion**

One interesting finding of our study is that the species richness in the small waterbodies in our study area is significantly higher than many other reported waterbodies in the Yunnan-Guizhou plateau as well as in the Yangtze River basin (Table 3). For example, Guo (*2009*) identified a total of 36 crustacean zooplankton species in 13 different lakes in the Yunnan-Guizhou plateau with areas ranged from 10.7 to 297.9 km$^2$. Another similar research carried out in the plateau lake (Erhai Lake) in Yunnan province only recorded 11 crustacean zooplankton species for 12 field stations with one-year continuous monthly monitoring (*Yang et al., 2014*). Comparing to the lakes and other waterbodies, small waterbodies usually have a high habitat heterogeneity which can support more diverse species and maintain a high diversity community (*Williams et al., 2004*).

The absence of predation fish and complicated habitat with abundant macrophytes might explain high crustacean zooplankton diversity in the highland small waterbodies in our study. Fish more likely to be absent in small and isolated waterbodies because of high risks of extinction and low chances of colonization (*Scheffer et al., 2006*). In our field survey, we did not observe fish in all small waterbodies. Presence of fish could profound impact on crustacean zooplankton community structure by reducing species richness and simplifying community composition, especially in small waterbodies (*Scheffer et al., 2006*). The predation from fish is an important factor affecting crustacean zooplankton in small lakes (*Pinel-Alloul & Mimouni, 2013*). Meanwhile, some studies also suggested that macrophyte cover is important to maintain zooplankton diversity because of macrophyte provide good habitats for zooplankton (*Celewicz-Goldyn & Kuczynska-Kippen, 2017*). These natural, temporal, and mountain small waterbodies have good water quality and high coverage of macrophytes (*Kuczyńska-Kippen, 2020*), providing lots of available ecological niches and for rare species (such as *Graptoleberis testudinaria* and *A. karua*) or endemic species (such as *T. hebereri* and *N. mariadvigae*).

We found the species composition in the rainy and dry seasons are quite different in the highland small waterbodies in Northwest Yunnan, China. Specifically, *C. ovalis*, *M. varicaricans*, *T. prasinus*, *C. laticaudata*, *A. exigua* were the most common species in the dry season (Table 1). However, in the rainy season, the common species shifted to *C. vicinus*, *M. leuckarti*, *A. affinis*, *M. varicaricans*, *M. irrasa, C. strenuuss*, *E. phaleratus*. Among these species, we found 2 endemic species (*Tropodiaptomus hebereri* and *Neutrodiaptomus mariadvigae*) in the Yunnan-Guizhou plateau (*Shen, 1979*). ~~Meanwhile,~~ we ~~also~~ found 9 common species (e.g. *C. vicinus*, *M. leuckarti*, *A. affinis*, *M. irrasa*) in the Yangtze River basin (*Chiang & Du, 1979*).

~~We identified the~~ limnological variables ~~could~~ explain the most variation of crustacean zooplankton community in both the rainy ($NO_3N$, DSi, Cond, DO) and dry ($NO_3N$ and WT) seasons, ~~comparing~~ to the morphometric and spatial variables. This result is coherent with many other studies which also showed limnological variables ~~are~~ the most important factors in explaining variations of crustacean zooplankton compared to spatial variables. (Heino, et al., 2017; Lévesque et al., 2017; *Brasil et al., 2020*). Our finding suggests that environmental filter played a key role in community structure in the highland small waterbodies in Northwest Yunnan. ~~It was~~ possibly related to ~~the~~ environmental heterogeneity ~~of small waterbodies in the Northwest of Yunnan~~. Previous experience showed that the environmental heterogeneity of small waterbodies in the Northwest of Yunnan depended on the watershed and precipitation (*Liu et al., 2018*).

We should add a caveat that not all potential limnological variables affecting the crustacean zooplankton communities were examined in our study due to ~~the~~ limited data. Some researches suggested that macrophytes cover is important to maintain zooplankton diversity because ~~of~~ macrophyte provide shelter ~~and concealment~~ from predators(*Cazzanelli et al., 2008; Sagrario et al., 2009*). In our study, we ~~didn't~~ address the effects of macrophytes. However, the zooplankton samples were collected in the open water area with no macrophytes, suggesting the direct effect of macrophytes on zooplankton samples ~~we collected may~~ weak. Future works ~~in discovering the~~ factor shaping zooplankton community in small waterbodies could focus on the effect of macrophyte which are probably important to affect zooplankton species assemblages (*Celewicz-Gołdyn et al., 2017*).

## Conclusions

In this study, we reported the crustacean zooplankton community and their relationships with the limnological, morphometric and spatial variables in the highland small waterbodies in Northwest Yunnan for both the rainy and dry seasons. We identified ~~a total of~~ 38 species of crustacean zooplankton ~~in the highland small waterbodies~~, which is significantly higher than many other waterbodies in the Yunnan-Guizhou plateau as well as in the Yangtze River basin. This suggests that small waterbodies are biodiversity hotspot and are important in maintaining regional zooplankton diversity in Northwest Yunnan. Limnological variables could explain the most variation of crustacean zooplankton community, comparing to morphometric and spatial variables in both the rainy and dry seasons. This study improved our understanding of the diversity and community structure of crustacean zooplankton in the highland small waterbodies in Northwest Yunnan and highlighted the importance of small waterbodies for biodiversity conservation and research.

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## Table 1(on next page)

Relative occurrences of crustacean zooplankton species in all samples, samples in area E, and samples in area W in the rainy (32 samples) and dry (30 samples) seasons.

| species | Rainy season | | | Dry season | | |
|---|---|---|---|---|---|---|
| | % of all samples | % of E samples | % of W samples | % of all samples | % of E samples | % of W samples |
| *Alona affinis* | 65.6 | 72.7 | 50.0 | 0.0 | 0.0 | 0.0 |
| *Moina irrasa* | 56.3 | 54.5 | 60.0 | 0.0 | 0.0 | 0.0 |
| *Chydorus ovalis* | 40.6 | 31.8 | 60.0 | 93.3 | 90.1 | 100.0 |
| *Diaphanosoma sp.* | 31.3 | 31.8 | 30.0 | 12.5 | 9.9 | 0.0 |
| *Bosmina coregoni* | 21.9 | 27.3 | 10.0 | 3.3 | 4.5 | 0.0 |
| *Alona guttata* | 12.5 | 18.2 | 0.0 | 3.3 | 4.5 | 0.0 |
| *Ceriodaphnia laticaudata* | 0.0 | 0.0 | 0.0 | 53.3 | 45.5 | 75.0 |
| *Alonella exigua* | 0.0 | 0.0 | 0.0 | 53.3 | 59.1 | 37.5 |
| *Alona karua* | 0.0 | 0.0 | 0.0 | 30.0 | 31.8 | 25.0 |
| *Graptoleberis testudinaria* | 0.0 | 0.0 | 0.0 | 20.0 | 18.2 | 25.0 |
| *Alona rectangula* | 0.0 | 0.0 | 0.0 | 23.3 | 22.7 | 25.0 |
| *Moina rectirostris* | 0.0 | 0.0 | 0.0 | 16.7 | 13.6 | 25.0 |
| *Ceriodaphnia quadrangula* | 0.0 | 0.0 | 0.0 | 20.0 | 9.1 | 50.0 |
| *Alonella globulosa* | 0.0 | 0.0 | 0.0 | 16.7 | 13.6 | 25.0 |
| *Ceriodaphnia reticulata* | 0.0 | 0.0 | 0.0 | 13.3 | 18.2 | 0.0 |
| *Alona quadrangularis* | 0.0 | 0.0 | 0.0 | 10.0 | 13.6 | 0.0 |
| *Chydorus barroisi* | 0.0 | 0.0 | 0.0 | 6.7 | 9.1 | 0.0 |
| *Alonella sp.* | 0.0 | 0.0 | 0.0 | 6.7 | 9.1 | 0.0 |
| *Alona sp.* | 0.0 | 0.0 | 0.0 | 3.3 | 0.0 | 12.5 |
| *Alonella nana* | 0.0 | 0.0 | 0.0 | 3.3 | 0.0 | 12.5 |
| *Cyclops vicinus* | 71.2 | 63.6 | 90.0 | 0.0 | 0.0 | 0.0 |

| | | | | | | |
|---|---|---|---|---|---|---|
| *Mesocyclops leuckarti* | 71.2 | 63.6 | 90.0 | 0.0 | 0.0 | 0.0 |
| *Microclops varicaricans* | 62.5 | 50.0 | 90.0 | 90.0 | 86.4 | 100.0 |
| *Ectocyclops phaleratus* | 59.4 | 38.5 | 90.0 | 6.7 | 9.1 | 0.0 |
| *Cyclops strenuuss* | 56.3 | 45.5 | 80.0 | 3.3 | 0.0 | 12.5 |
| *Limnoithona sinensis* | 46.7 | 36.4 | 80.0 | 26.7 | 4.5 | 87.5 |
| *Nitocra lacustri* | 43.8 | 54.5 | 20.0 | 0 | 0 | 0 |
| *Sinodiaptomus sarsi* | 43.8 | 31.8 | 70.0 | 0 | 0 | 0 |
| *Eucyclops serrulatus* | 37.5 | 40.9 | 30.0 | 16.7 | 22.7 | 0.0 |
| *Sinocalanus dorrii* | 21.9 | 13.6 | 40.0 | 10.0 | 4.5 | 25.0 |
| *Onychocamptus mohammed* | 21.9 | 27.3 | 10.0 | 46.7 | 27.3 | 100.0 |
| *Neutrodiaptomus mariadvigae* | 15.6 | 13.6 | 20.0 | 10.0 | 0.0 | 37.5 |
| *Bryocamptus sp.* | 9.4 | 13.6 | 0.0 | 3.3 | 4.5 | 0.0 |
| *Tropodiaptomus hebereri* | 6.3 | 9.1 | 0.0 | 13.3 | 0.0 | 50.0 |
| *Tropocyclops prasinus* | 0.0 | 0.0 | 0.0 | 66.7 | 63.6 | 75.0 |
| *Paracyclops fimbriatus* | 0.0 | 0.0 | 0.0 | 16.7 | 18.2 | 12.5 |
| *Paracyclops affinis* | 0.0 | 0.0 | 0.0 | 10.0 | 9.1 | 12.5 |
| *Schmackeria inopinus* | 0.0 | 0.0 | 0.0 | 10.0 | 4.5 | 25.0 |

2

## Table 2(on next page)

Results of SIMPER analysis for species that accounted for the 90% of cumulative contribution.

1

| species | Contribution | Standard deviation | Ratio | cumulative contribution | P |
|---|---|---|---|---|---|
| *M.leuckarti* | 0.20879 | 0.20616 | 1.0127 | 0.2313 | 0.675 |
| *M.varicaricans* | 0.15750 | 0.16750 | 0.9403 | 0.4058 | 0.001 |
| *C.ovalis* | 0.10450 | 0.14320 | 0.7297 | 0.5216 | 0.001 |
| *C.vicinus* | 0.07331 | 0.09875 | 0.7424 | 0.6028 | 0.001 |
| *A.exigua* | 0.06395 | 0.14393 | 0.4443 | 0.6737 | 0.019 |
| *S.sarsi* | 0.04930 | 0.12002 | 0.4108 | 0.7283 | 0.091 |
| *E.phaleratus* | 0.02948 | 0.04346 | 0.6783 | 0.7610 | 0.006 |
| *C.laticaudata* | 0.02447 | 0.05694 | 0.4299 | 0.7881 | 0.016 |
| *L.sinensis* | 0.02324 | 0.04526 | 0.5136 | 0.8139 | 0.600 |
| *C.strenuuss* | 0.02290 | 0.04765 | 0.4806 | 0.8392 | 0.034 |
| *M.irrasa* | 0.01874 | 0.03545 | 0.5286 | 0.8600 | 0.008 |
| *E.serrulatus* | 0.01756 | 0.04665 | 0.3765 | 0.8794 | 0.464 |
| *A.affinis* | 0.01276 | 0.01787 | 0.7145 | 0.8936 | 0.001 |

## Table 3 (on next page)

A comparison of the species richness in the small waterbodies in the highland small waterbodies in Northwest Yunnan with other waterbodies in Yunnan-Guizhou plateau and Yangtze River basin.

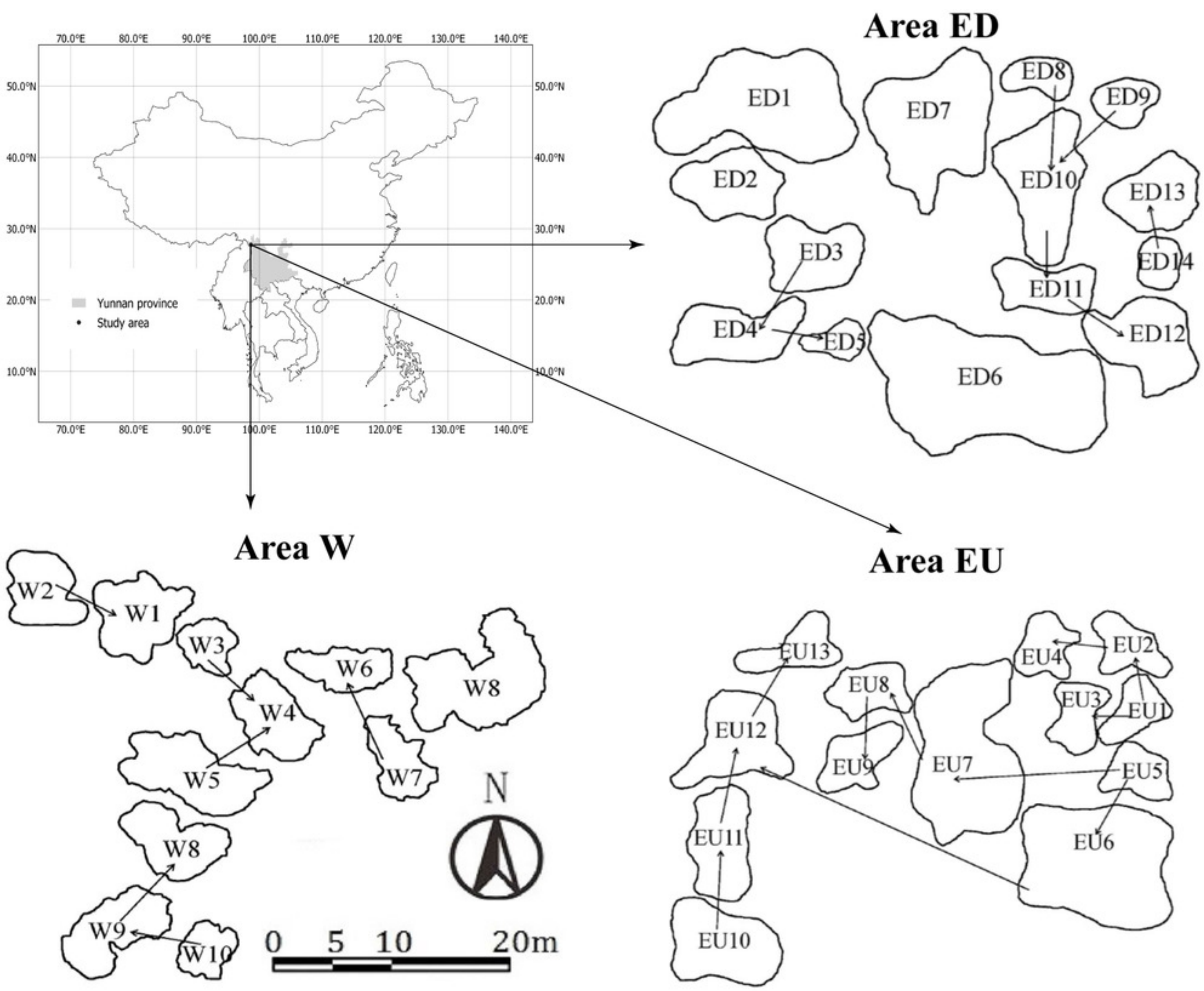
*n* indicating the number of total samples in the reported case.

| Study area | Province | Area($km^2$) | Species richness | Reference |
| --- | --- | --- | --- | --- |
| Thirteen lakes in Yunnan and Guizhou (*n* = 112) | Yunnan and Guizhou | 10.7~297.9 | 36 | *Guo et al., 2009* |
| Gaoyou Lake (*n* = 26) | Jiangsu | 674 | 26 | *Wei et al., 2017* |
| Chaohu Lake (*n* = 228) | Anhui | 780 | 23 | *Deng et al., 2008* |
| Lugu Lake (*n* = 36) | Yunnan | 57.7 | 23 | *Dong et al., 2014* |
| Fuxian Lake (*n* = 220) | Yunnan | 211 | 8 | *Pan et al., 2009* |
| Erhai (*n* = 144) | Yunnan | 249 | 11 | *Yang et al., 2014* |
| Our study (*n* = 62) | Yunnan | <0.001 | 38 | Our study |

# Figure 1

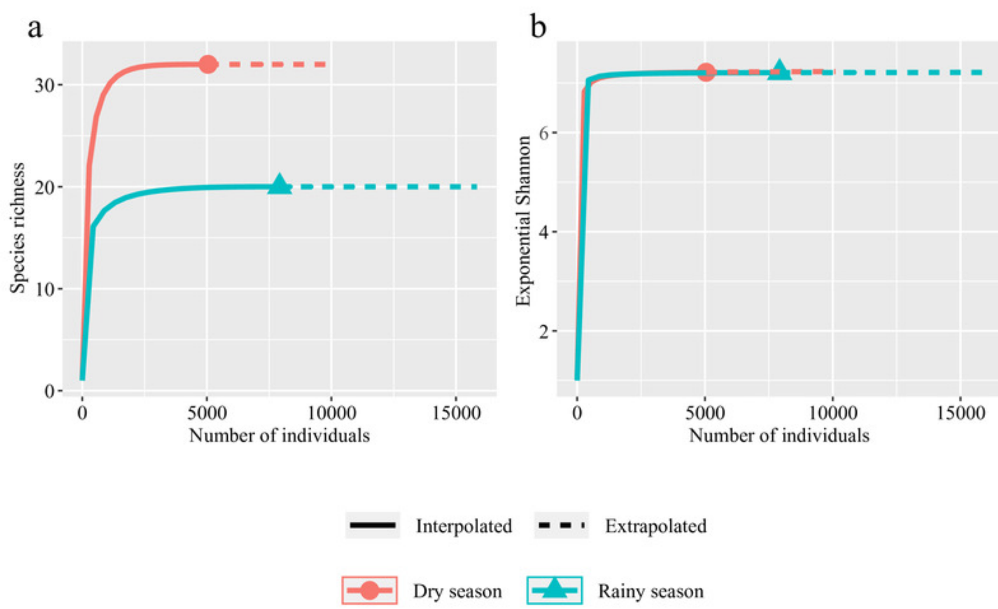
Sampling areas and spatial distribution of small waterbodies in Gongshan County, Yunnan province, China.

The arrows represent the connectivity and water flow direction.



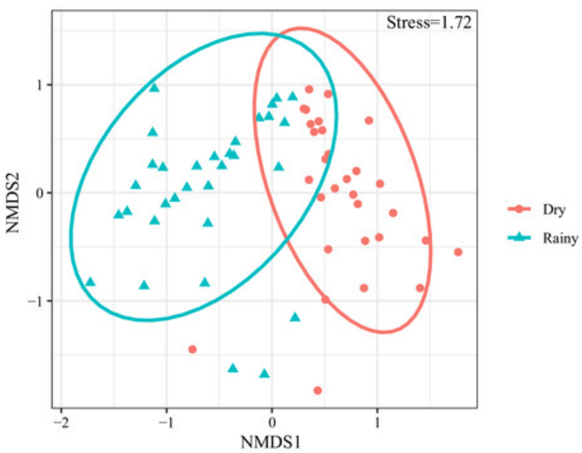
# Figure 2

Individual-based rarefaction for the dry (red) and rainy (green) seasons. Symbols represent species richness (a) and exponential Shannon (b). Continuous lines refer to interpolation, dotted lines refer to extrapolation.



# Figure 3

Non-metric multidimensional scaling ordination (NMDS) of crustacean zooplankton communities.

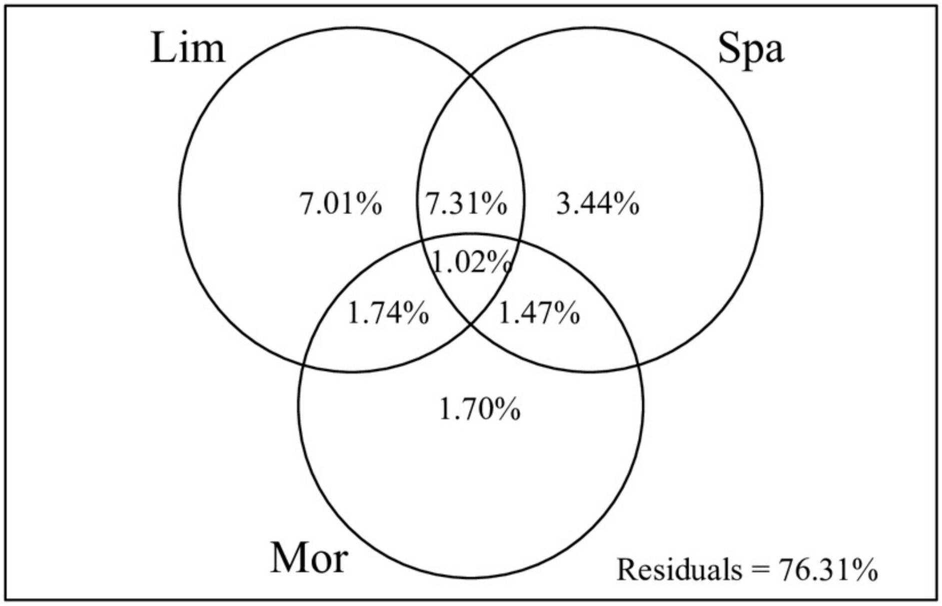


# Figure 4

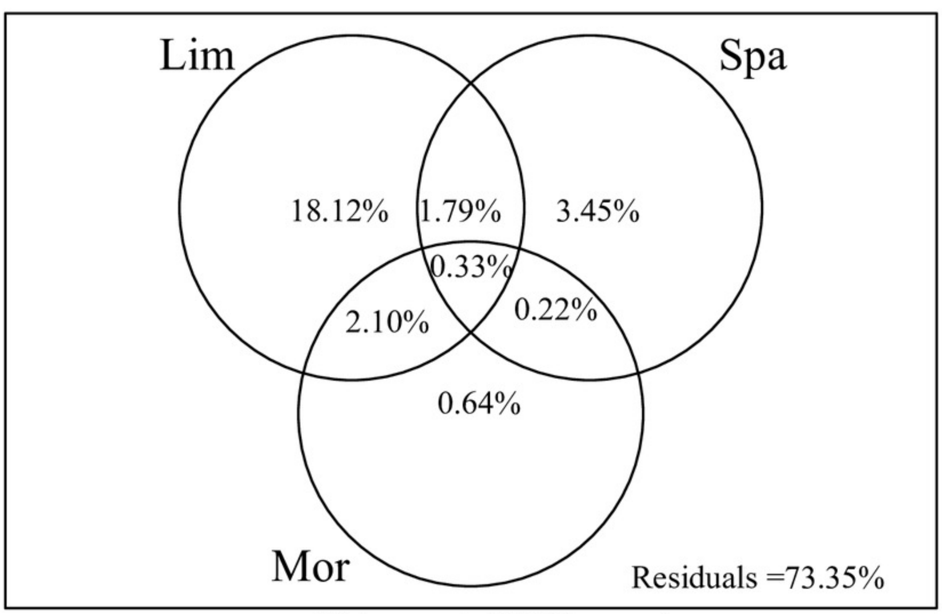
Venn diagram representing the variation partitioning of crustacean zooplankton community composition explained by explanatory variable.

(Lim) Limnological variables. (Spa) spatial variables represented by principal coordinates of neighbour matrices. (Mor) morphometric variables. (a) dry season. (b) rainy season.

a




b




Values <0.001% not shown