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Spatial distribution and ecology of the Recent Ostracoda from Tangra Yumco and adjacent waters on the southern Tibetan Plateau: A key to palaeoenvironmental reconstruction

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ABSTRACT

We elucidate the ecology of Recent Ostracoda from a deep brackish lake, Tangra Yumco (30°45′–31°22′N and 86°23′–86°49′E, 4595 m a.s.l.) and adjacent waters on the southern Tibetan Plateau. Ostracod associations (living and empty valves) in sixty-six sediment samples collected from diverse aquatic habitats (lakes, estuary-like water and lagoon-like water waters, rivers, ponds and springs) were quantitatively assessed.

Eleven Recent Ostracoda were found (nine living and two as empty valves only). Cluster analysis established two significant ($p < 0.05$) habitat specific associations; (i) *Leucocytherella sinensis*, *Limnocythere inopinata*, *Leucocythere*? *dorsotuberosa*, *Fabaeformiscandona gyirongensis* and *Candona xizangensis* are **lacustrine fauna**. (ii) *Tonnacypris gyirongensis*, *Candona candida*, *Ilyocypris* sp., *Heterocypris incongruens* and *Heterocypris salina* are **temporary water species**.

Ostracod distribution and abundance are significantly ($p < 0.05$) correlated to physico-chemical variables. The first two axes of a canonical correspondence analysis (CCA) explain 30.9% of the variation in the species abundance data. Conductivity and habitat types are the most influential ecological factors explaining the presence and abundance of ostracods. Spearman correlation analysis reveals that: (i) Two species, *L.*? *dorsotuberosa* ($r = 0.25$) and *L. inopinata* ($r = 0.36$) have a significant positive correlation with conductivity while one species, *T. gyirongensis* ($r = -0.68$) displays a significant negative correlation with conductivity. *Limnocythere inopinata* correlates significantly positive ($r = 0.37$) with alkalinity. *Fabaeformiscandona gyirongensis* correlates significantly positive ($r = 0.28$) with water depth.

Key indicator living assemblages are: (i) *L. sinensis* dominates Ca-depleted brackish waters although ubiquitously distributed; (ii) *L.*? *dorsotuberosa* dwells in fresh to brackish waters; (iii) *L. inopinata* predominates in mesohaline to polyhaline waters; (iv) *F. gyirongensis* inhabits exclusively brackish-lacustrine deeper waters; (v) *C. candida* populates freshwaters; (vi) *T. gyirongensis* and *Ilyocypris* sp. are restricted to shallow temporary waters; (vii) *H. incongruens* occurs in ponds.

Water depth indicators are *F. gyirongensis* and *L.? dorsotuberosa*, useful in ostracod assemblages for palaeo-water depth reconstruction.

Our results expand the knowledge of the ecological significance of Recent Tibetan Ostracoda ecology. This is a new insight on habitat chacteristics of both living assemblages and sub-Recent associations of ostracods in mountain aquatic ecosystems. The new modern ostracod dataset can be used for the quantitative reconstruction of past environmental variables (e.g., conductivity) and types of water environment. The key indicator ostracods are relevant in palaeolimnological and climate research on the Tibetan Plateau.

1. Introduction

Ostracods (also known as seed shrimps, size range ca. 0.4–3 mm) are a class of bivalved aquatic Crustacea that secrete a calcitic shell (carapace) and easily fossilise (Griffiths and Holmes, 2000). They are commonly found in diverse aquatic habitats, including lakes, ponds,

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streams, rivers, estuaries, oceans and semi-terrestrial environments (Danielopol, 1989; Horne et al., 2002; Smith and Delorme, 2010 Horne et al., 2002; Smith and Delorme, 2010). Ostracoda are widely used as proxies in palaeoclimatic reconstruction of marine and non-marine environments because of their small size, ecological sensitivity, shell chemistry signature, long stratigraphic range (Ordovician—present) and occurrence in sediments from lakes, estuaries, bays and oceans etc. (Griffiths and Holmes, 2000). Ostracods are palaeo-indicators of temperature, water depth, substrate type, permanence of water body and ionic concentration (salinity/conductivity) (De Deckker et al., 1979; Frenzel and Boomer, 2005; Mischke and Wünnemann, 2006; Horne, 2007; Mischke et al., 2007a; Frenzel et al., 2010a). The species-specific tolerance and optimum ecological requirements reflect spatial and temporal distribution of environmental parameters (Külköylüoğlu and Dugel, 2004; Dügel et al., 2008). Knowledge on the ecology of living fauna will enhance the reconstruction of environmental and climatic variables (Eagar, 1999; Holmes and Chivas, 2002).

Ostracods are one of the important biological proxies used in palaeoenvironmental reconstruction on the Tibetan Plateau (Mischke, 2012). Knowledge on the ecology of living ostracods from high altitudes (>3000 m a.s.l.) is mostly limited to regions such as Western Europe and United States of America (Delachaux, 1928; Laprida et al., 2006; Külköylüoğlu and Sari, 2012; Pinto, 2013). The ecology of Quaternary and living ostracods from continental Asia is still largely unknown (Zhang, 2000; Van der Meeren et al., 2010). This is due to higher altitude, complex terrain, inaccessibility of the aquatic ecosystems (e.g., lakes) and insufficient investigation on micro-crustaceans from the region (Zhang, 2000; Long et al., 2012; Zhai and Zha, 2014). Literature on taxonomy and ecology of Tibetan ostracods is mostly published in Chinese language, making it largely inaccessible to the international scientific community (e.g., Huang, 1964, 1982; Huang et al., 1985a). Furthermore, habitat characteristics of non-marine ostracods from the Tibetan Plateau are mostly inferred from Sub-Recent ostracods (Huang et al., 1985a,b; Mischke et al., 2005; Wrozyna et al., 2009a; Wrozyna et al., 2009b; Zhang et al., 2013). Hence, knowledge on modern ecology and habitats of Recent fauna is urgently needed.

The primary objective of the present study is to investigate the Recent Ostracoda in Tangra Yumco and adjacent waters (smaller lakes, estuary-like water, lagoon-like water, rivers, ponds and springs). This is achieved by assessment of species distribution, composition, abundance and the importance of physico-chemical variables. Related objectives are to: (i) characterise habitats and their typical associations; (ii) rank the influence of physico-chemical variables on ostracod distribution and abundance and (ii) to evaluate water depth distribution of species in the deep brackish lake Tangra Yumco. We hypothesised that species abundance is dependent on physico-chemical variables. Our results revealed that environmental factors (conductivity and habitat types) influence the spatial distribution and abundance of living ostracods. The ecology of Recent Ostracoda is significant in palaeoenvironmental reconstruction on the Tibetan Plateau.

2. Study area

The Tibetan Plateau is surrounded by the Himalayas to the south, the Karakoram Range and the Pamirs to the west, the Hengduan Mountains to the east and the Kunlun and Qilian Mountains to the north (Lehmkuhl and Owen, 2005; Yao et al., 2012). The uplift of the Tibetan Plateau influences the East Asian and Indian summer monsoon systems. This causes a cold dry winter and heavy rainfall during summer (An et al., 2001; Abe et al., 2013).

There are more than 300 lakes with surface areas greater than 10 km^2 on the Tibetan Plateau (average altitude of 4500 m.a.s.l.) (Zheng, 1997; Wang and Dou, 1998; Yu et al., 2001; Ma et al., 2011). A majority of lakes is distributed in the central-western section of the Tibetan Plateau. The lakes occur in tectonic depressions caused by west-east and north-south trending faults (Meyer et al., 1998; Mitsuishi et al., 2012). The 300 km long and 40 km wide graben containing the lakes Tangqung Co, Tangra Yumco, Monco Bunnyi, and Xuru Co is termed as Tangra Yumco lake system (Fig. 1a). It is induced by a north-south trending rift and normal faults cutting through the western part of the Lhasa block on the south-central Tibetan Plateau and northern slope of Gangdise Mountains (Zheng, 1997; Gao et al., 2007; Kong et al., 2011). These continental Tibetan lakes have characteristic limnological features (e.g., hypersaline to oligohaline waters, Table 1). Tangqung Co, Tangra Yumco, and Xuru Co belonged to a large ancient lake during the Quaternary period (Zheng, 1997; Zhang, 2000). The large lake gradually disaggregated into independent smaller lakes during the early and late Holocene due to an extensive drop of water level (Zheng, 1997; Zhang, 2000; Zhu et al., 2004; Liu et al., 2013).

The Tangra Yumco lake system lies in a unique climatic transition between the central and western Tibetan Plateau controlled by the Indian Monsoon. The rainfall on the Tibetan Plateau is highest in the monsoon summer month of July and ∼60% of total annual precipitation falls between May and October (Singh and Nakamura, 2009; Guo et al., 2014; Maussion et al., 2014). Mean annual precipitation for the Tangra Yumco lake system ranges from 298 to 316 mm/year (Table 1) (Hudson and Quade, 2013). The mean annual temperature ranges from 0 to 5 °C in the central and southern part of the Tibetan Plateau (Conroy and Overpeck, 2011). Monco Bunnyi, Tangra Yumco, and Xuru Co do not freeze up completely in some years because of their elevated salinity (Kropacek et al., 2013).

The Tangra Yumco lake system is surrounded by temporary shallow water bodies such as estuary-like water mixing zones of both fresh and brackish waters with highly unstable hydrological conditions, lagoon-like water shallow isolated brackish water bodies separated from the lakes by sand or gravel bars, rivers, ponds and springs.

Tangra Yumco (30°45′—31°22′N and 86°23′—86°49′E, elevation of 4595 m above sea level, a.s.l) lies about 100 km east of Zhari Nam Co and about 450 km northwest of Lhasa (Fig. 1). Tangra Yumco is also called Lake Dangra, Dangra Yumtsho, Dangra gyumtsho, Dangra rgyal-mo, and Ocean Turquoise Lake. The holy lake is situated at the prime centre of the Ancient Zhang Zhung Kingdom, 150 km from Nima County (Bellezza, 1997). It is a closed lake with a surface area of 818 km^2, a drainage area of 8219 km^2, length of 71.70 km and mean width of 11.65 km (maximum, 19.40 km) (Long et al., 2012). Tangra Yumco is the third-largest lake on the south-central Tibetan Plateau and the second-deepest lake in China (Wang et al., 2010). It stretches from north-east to south-west, forming an elongated S-shape (two parts joined by a narrow strip). The northern basin (∼230 m) is much deeper than the southern basin (∼100 m). Moderately glacial fed rivers and streams originating from the west and the south drain into Tangra Yumco (Long et al., 2012). The lake water is recharged primarily by precipitation and rivers such as Daguo Tsangpo, Buzhai Tsangpo, and Mainongqu (Shao et al., 2008). The thermocline of Tangra Yumco is situated between 20 and 30 m water depth (Wang et al., 2010). The lowest temperature measured within the hypolimnion was 1.6 °C (Wang et al., 2010). The cold semi-arid climate supports alpine steppe vegetation (e.g., *Kobresia pygmaea* and *Artemisia*) (Shao et al., 2008; Miehe et al., 2014).

Remnant palaeo-shorelines and lake terraces are located about 200 m above the present day lake level of Tangra Yumco (Rades et al., 2013), indicating a Holocene shrinkage of a large ancient lake (Liu et al., 2013; Long et al., 2012). Beach rocks, formed by the precipitation of secondary carbonates, and ancient shorelines are common features within the catchments of Tangra Yumco and Tangqung Co. Holocene stromatolites and tufa can be found in the north of Tangqung Co.