Ostracods as indicators of Late Quaternary aquatic and monsoon system changes on the southern Tibetan Plateau

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To

My affectionate husband, Jeremiah Nii Mama Akita for your endless love.

"*..Whatever you ask for in prayer, believe that you have received it and it will be yours*."

~ Mark 11:24

Dreams are possibilities. What I once dream of is now reality.

"*Now all glory to God, who is able, through his mighty power at work within us, to accomplish infinitely more than we might ask or think.*"

~ Ephesians 3:20

“*Nothing excites the imagination more than the study of the Quaternary*”

~ Maurice Gignoux (1881-1955)

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Manuscripts overview

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[1] **<u>Akita, L.G.,</u>** Frenzel, P., Wang, J., Börner, N., Peng, P., ***in press***. Spatial distribution ecology of the Recent Ostracoda from Tangra Yumco and adjacent waters on the southern Tibetan Plateau: a key to palaeoenvironmental reconstruction. ***Limnologia***

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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					
beteiligt an					
	Lailah Gifty Akita	Peter Frenzel	Junbo Wang	Nicole Börner	Ping Peng
Konzeption des Forschungsansatzes	**X**	X			
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[3] **<u>Akita, L.G.,</u>** Frenzel, P., Haberzettl, T., Kasper, T., Wang, J., Reicherter, K., **2015**. Ostracoda (Crustacea) as indicators of subaqueous mass movements: An example from the large brackish lake Tangra Yumco on the southern Tibetan Plateau. ***Palaeogeography, Palaeoclimatology, Palaeoecology 419, 60-74.***

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[4] **Akita, L.G.,** Frenzel, P., Wang, J., Börner, N., Peng, P., ***submitted.*** Ostracoda as environmental indicators of Late-Holocene climate variability in the brackish lake, Tangra Yumco on the southern Tibetan Plateau. ***Quaternary Research***

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Ich bin mit der Abfassung der Dissertation als publikationsbasiert, d.h. kumulativ, einverstanden und bestätige die vorstehenden Angaben. Eine entsprechend begründete Befürwortung mit Angabe des wissenschaftlichen Anteils der Doktorandin an den verwendeten Publikationen werde ich parallel an den Rat der Fakultät der Chemisch-Geowissenschaftlichen Fakultät richten.

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Abstract

You invoke a new future when you envision your past in the light of your present.”—
Eric Micha'el Leventhal

High-mountain saline closed lakes and their organisms (e.g., meiobenthos) are very sensitive to environmental and climate change and corresponding impacts on precipitation/ evaporation balance. The primary aim of this work is to evaluate ecology and palaeoecology of ostracods (small crustaceans) in a large brackish lake, Tangra Yumco, and adjacent waters on the southern Tibetan Plateau thereby contributing to the understanding of past, present and future environmental and climate changes in central Asia.

This study provides the first ecological data and informationon the habitats and ecology of **eleven Recent Tibetan ostracods** (nine living and two empty shells) in high mountain aquatic ecosystems (lakes Tangqung Co, Tangra Yumco, Monco Bunnyi, Xuru Co and adjacent waters like rivers, ponds, streams and springs) on the southern Tibetan Plateau. Cluster analysis indicates two types of ostracod groups: (i) **permanent lacustrine species** – *Leucocytherella sinensis*, *Leucocythere*? *dorsotuberosa*, *Fabaeformiscandona gyirongensis*, *Limnocythere inopinata* and *Candona xizangensis* and (ii) **species of temporary freshwater** – *Tonnacypris gyirongensis*, *Candona candida*, *Heterocypris incongruens*, *Ilyocypris* sp. *Heterocypris salina* and *Potamocypris* cf. *villosa* (one valve only). Spearman and multivariate analyses indicate a significant relationship between living ostracods to environment variables. **Multivariate analysis** indicates **conductivity and habitat types** to be controlling presence and abundance of ostracods.

The documented ostracod species were present and abundant in specific aquatic habitats. **I**ndicator species include: (i) *L. sinensis* dominating Ca-depleted brackish waters despite being commonly present in diverse aquatic habitats; (ii) *L.*? *dorsotuberosa* inhabiting fresh to brackish waters; (iii) *L. inopinata* predominating in mesohaline to polyhaline waters; (iv) *F. gyirongensis* inhabiting exclusively brackish lacustrine deeper waters; (v) *C. candida* colonising freshwaters; (vi) *T. gyirongensis* and *Ilyocypris* sp. populate shallow temporary waters; and (vii) *H. incongruens* occurring in ponds.

Water-depth-indicators within the lakes include (i) *L. sinensis*, *L. inopinata* and *C. xizangensis* as **phytal shallow-water species** and (ii) *F. gyirongensis* and *L.*? *dorsotuberosa* as **deep-water** fauna.

The first calibration on shell chemistry ($\delta^{18}O$, $\delta^{13}C$, Mg/Ca, Sr/Ca, Fe/Ca, Mn/Ca and U/Ca) of four Recent ostracods (*L. sinensis*, *L.*? *dorsotuberosa*, *L. inopinata* and *T. gyirongensis*) reveals species-specific stable isotope fractionation and elemental incorporation into the calcitic ostracod shell. Ostracod shell chemistry ($\delta^{18}O$, $\delta^{13}C$) is related to water chemistry with variable disequilibrium. There is a significant linear relationship between $\mathrm{Mg/Ca_{shell}}$ and $\mathrm{Sr/Ca_{shell}}$ and $\mathrm{Mg/Ca_{water}}$ and $\mathrm{Mg/Ca_{water.}}$ The $\mathrm{Mg/Ca_{shell}}$ reflects a change in $\mathrm{Mg/Ca_{water}}$ and salinity of the waterbody. There is a linear relationship between shell chemistry of *L.*? *dorsotuberosa* and water chemistry; $\mathrm{Sr/Ca_{shell}}$ is related to $\mathrm{Sr/Ca_{water}}$ and significantly correlates with specific conductivity of the water. The shell chemistry of *L.*? *dorsotuberosa* is a good indicator of changes in $\mathrm{Sr/Ca_{water}}$ reflecting salinity variability bound to lake water volume balance. In this study, the incorporation of both Mg and Sr into ostracod calcite was temperature-

independent. Fe/Ca, Mn/Ca and U/Ca ratios of ostracods shells are evidence for redox and oxygen conditions of the aquatic ecosystems they dwell in.

A first conceptual model of lacustrine sub-aquatic mass transport was developed and tested using ostracod associations and sediment features. The very low abundance or the lack of ostracod valves in event sediment layers are evidence of subaqueous sediment flows from a steep slope to the deep basin of Tangra Yumco. Ostracods (valves of *L. sinensis*, *L.*? *dorsotuberosa*, *L. inopinata* and *F. gyirongensis*) are lacking in sediment events layers due to coarser sediment accumulation caused by bottom currents as well.

This study provides the first continuous reconstruction of Late Holocene environment and climate variability of Tangra Yumco (last 3,300 years) inferred from palaeoecological analysis of ostracod associations and shell chemistry ($\delta^{18}O$, $\delta^{13}C$, Mg/Ca, Sr/Ca) together with sedimentological analysis. Ostracod assemblages and abundance reflect mainly **lake level**, **salinity** and **productivity** of **Tangra Yumco**. The five phases of **Late Quaternary climate transitions are**:

(i) *Leucocythere sinensis* predominates (87.5%), other lacustrine-brackish ostracod species are scarce, low species richness (3), low $\delta^{18}O_{shell}$ and Mg/Ca_{shell}, high $\delta^{18}C_{shell}$ and Sr/Ca_{shell}, slowly increasing values of total inorganic carbon (TIC) in **3300 to 2320 cal BP**, suggesting a high lake level and relatively low salinity (fresh to oligohaline) and moderate productivity in a relatively cool and wet climate. This was caused by relatively high precipitation (strengthening of monsoon) with high freshwater input into the lake and decreasing evaporation. During this period, Tangra Yumco was an open lake system with an outflow into Tangqunq Co.

(ii) A decline in *L. sinensis* abundance and transition to *L.*? *dorsotuberosa* dominance (51.5%) with increased species richness (6) and both shallow and deep water ostracod taxa, high total organic carbon (TOC) indicate a decreasing lake level marked by a gradual increased salinity (oligohaline) and highest productivity in a warm and dry climate from **2300 to 1760 cal BP**. This is triggered by decreasing precipitation due to weakening of monsoon acitivity and increasing evaporation. During this period, Tangra Yumco begins to separate from Tangqunq Co becoming a closed lake system. The lake remains closed until today.

(iii) The very low abundance of ostracods (average 13.6 valves/ml) and very high total inorganic carbon in **1740 to 1104 cal BP** indicate falling of the lake level accompanied by increasing salinity (oligo- to mesohaline) and extreme low productivity induced by decreasing precipitation (weakening of monsoon) in a dry climate.

(iv) A gradual recovering of ostracod assemblages and prevalence of *L. inopinata* (61.7%), rise in species richness (4) and diversity, high $\delta^{18}O_{shell}$ and Mg/Ca_{shell}, low $\delta^{18}C_{shell}$ and Sr/Ca_{shell}, coarser grains with a maximum at the onset of the Little Ice Age, very high potassium, highest TOC and high TOC/TN (atomic) in a cold and driest climate are indicated from **1065 to 444 cal BP**. The Little Ice Age period from c. 650 – 100 cal BP is characterised by a lowering of lake level marked by increased salinity (mesohaline) and high productivity. This is caused by low precipitation (weakening of the monsoon) and increasing evaporation due to cool and dry climate.

(v) During **405 cal BP to present**, there was a transition of *L. inopinata* predominance to *L. sinensis* dominance, with low adult/juvenile ratio, low carapace/valve ratio, low K and TOC in a cool and relatively wet climate, suggesting lake expansion but with low lake level and moderate salinity (oligo-mesohaline) and high productivity. The lake system was influenced by relatively high precipitation (strengthening of monsoonal rainfall) and minimal increase of evaporation due to increased temperatures.

In conclusion, ostracod assemblages and associations, abundance and diversity can be successfully used to characterise (i) water types, permanence, depth and salinity; (ii) hydrology, primary production, redox conditions and oxygen availability; (iii) subaqueous sediment transport, depositional environments in a deep lacustrine basin and (iv) aquatic ecology, environment and climatic conditions. Ostracods are sensitive bioindicators/proxies suitable for palaeoenvironmental and palaeoclimate research on the Tibetan Plateau.

Zusammenfassung

Saline Hochgebirgsseen mit hydrologisch geschlossenem Einzugsgebiet und ihre Fauna, beispielsweise das Meiobenthos, reagieren sensibel auf Umwelt- und Klimaveränderungen sowie auf damit verbundene Schwankungen des Niederschlags-/Verdunstungs-Verhältnisses. Wichtigstes Ziel der vorliegenden Arbeit ist die Untersuchung der Ökologie und Paläoökologie von Ostrakoden (Kleinkrebse) in dem großen, brackischen See Tangra Yumco und umliegenden Gewässern auf dem südlichen Tibetplateau. Damit werden Erkenntnisse zum besseren Verständnis vergangener, gegenwärtiger und zukünftiger Umwelt- und Klimaveränderungen in Mittelasien gewonnen.

Die vorliegenden Untersuchungen behandeln erstmals Habitatpräferenzen und Ökologie von elf rezenten Tibetischen Ostrakodenarten aus alpinen Ökosystemen des südlichen Tibetplateaus, nämlich den Seen Tangqung Co, Tangra Yumco, Monco Bunnyi und Xuru Co sowie Flüssen, Bächen, Tümpeln und Quellen ihrer Umgebung. Neun dieser Arten konnten lebend nachgewiesen werden, zwei nur durch leere Klappen. Durch Clusteranalysen lassen sich zwei Gruppen von Arten unterscheiden: (1) **Arten permanenter Seen** – *Leucocytherella sinensis*, *Leucocythere*? *dorsotuberosa*, *Fabaeformiscandona gyirongensis*, *Limnocythere inopinata* und *Candona xizangensis*. (2) **Arten temporärer Süßgewässer** – *Tonnacypris gyirongensis*, *Candona candida*, *Heterocypris incongruens*, *Ilyocypris* sp. *Heterocypris salina* und *Potamocypris* cf. *villosa*, letztere nur durch eine leere Klappe belegt. Spearman-Korrelations- und multivariate Analysen belegen einen siginfikanten Zusammenhang zwischen der Verbreitung lebender Ostrakoden und verschiedenen Umweltparametern. Vor allem **Leitfähigkeit und Habitattypen** kontrollieren danach das Vorkommen und die Abundanz der Ostracodenarten.

Die dokumentierten Ostrakodenarten sind für spezifische aquatische Habitate charakteristisch. Indikatorarten sind: (1) *L. sinensis* dominiert in Ca-abgereichertem Brackwasser, aber kommt auch in den meisten anderen aquatischen Habitaten vor; (2) *L.*? *dorsotuberosa* lebt in Süß- und Brackwasser der Seen; (3) *L. inopinata* herrscht bei mesohaliner bis polyhaliner Salinität vor; (4) *F. gyirongensis* kommt ausschließlich im tieferen Brackwasser der Seen vor; (5) *C. candida* besiedelt verschiedene Süßgewässer; (6) *T. gyirongensis* und *Ilyocypris* sp. sind für flache, temporäre Gewässer typisch; und (7) *H. incongruens* wurde nur in Tümpeln gefunden.

Wassertiefen-Indikatoren der Seen sind (1) *L. sinensis*, *L. inopinata* und *C. xizangensis* als **Flachwasserarten des Phytals** und (2) *F. gyirongensis* und *L.*? *dorsotuberosa* als **TIefwasserarten**.

Erstmalig wurde eine Kalibration zur Schalenchemie (δ^{18}O, δ^{13}C, Mg/Ca, Sr/Ca, Fe/Ca, Mn/Ca und U/Ca) von vier rezenten tibetischen Ostrakodenarten durchgeführt (*L. sinensis*, *L.*? *dorsotuberosa*, *L. inopinata* und *T. gyirongensis*). Sowohl artspezifische Fraktionierungen von stabilen Isotopen, als auch artspezifischer Einbau von Spurenelementen in den Kalzit der Schalen konnten dabei belegt werden. Die Isotopie der Ostrakoden (δ^{18}O, δ^{13}C) steht mit jener des Habitatwassers in einem variable Ungleichgewicht. Es besteht ein signifikanter, linearer Zusammenhang zwischen Mg/Ca$_{\text{Schale}}$ und Sr/Ca$_{\text{Schale}}$ mit Mg/Ca$_{\text{Wasser}}$ und Mg/Ca$_{\text{Wasser.}}$ Das Mg/Ca-Verhältnis der Schalen spiegelt Veränderungen im Mg/Ca-Verhältnis und die Salinität des umgebenden Wassers wider. Es besteht eine lineare Korrelation zwischen der Schalenchemie von *L.*? *dorsotuberosa* und der Wasserchemie; Sr/Ca$_{\text{Schale}}$ korreliert mit Sr/Ca_{Wasser} und der Spezifischen Leitfähigkeit des Wassers signifikant. Die Schalenchemie von *L.*? *dorsotuberosa* ist ein guter Indikator für Veränderungen des Sr/Ca-Verhältnisses des Wassers, das mit der Salinität und entsprechenden Volumenänderungen des Sees in Zusammenhang steht. Die Daten der vorliegenden Untersuchungen zeigen einen temperaturunabhängigen Einbau von Mg und Sr in den Kalzit der Ostrakodenschalen. Fe/Ca-, Mn/Ca- und U/Ca-Verhältnisse der Ostrakodenschalen können für die Rekonstruktion von Redoxbedingungen und Sauerstoffverfügbarkeit in den aquatischen Ökosystemen genutzt werden.

Ein erstes konzeptuelles Modell lakustriner subaquatischer Massentransporte beruhend auf der kombinierten Analyse von Ostrakodenassoziationen und Sedimenteigenschaften wurde in der vorliegenden Dissertation entwickelt. Eine sehr geringe Abundanz oder das Fehlen von Ostrakodenklappen in Ereignislagen aus dem untersuchten Sedimentkern belegen vom steilen Osthang des Tangra Yumco-Beckens ausgehende Turbiditströme. Lakustrine Ostrakoden (*L. sinensis*, *L.*? *dorsotuberosa*, *L. inopinata* und *F. gyirongensis*) fehlen ebenso in einer durch Bodenströmungen verursachten grobkörnigen Sedimentlage.

Die Analyse der Ostrakodenfauna des Sedimentkerns TAN10/4 ist die erste kontinuierliche Rekonstruktion spätholozäner Umwelt- und Klimaveränderungen im Gebiet des Tangra Yumco für die letzten 3300 Jahre. Diese auf paläoökologischen und schalenchemischen Analysen ($\delta^{18}O$, $\delta^{13}C$, Mg/Ca, Sr/Ca) beruhenden Untersuchungen wurden in einem Multi-Proxy-Ansatz mit sedimentologischen Analysen kombiniert. Die Ostrakodengemeinschaften und ihre Abundanz spiegeln vor allem die Höhe des **Seespiegels, Salinität** und **Produktivität** des Tangra Yumco wider. Es lassen sich fünf Entwicklungsphasen unterscheiden:

(I) *Leucocythere sinensis* dominiert (87,5 %), andere lakustrin-brackische Ostrakodenarten sind selten, die Artenzahl ist gering (3), $\delta^{18}O_{Schale}$ und Mg/Ca_{Schale} sind niedrig, $\delta^{18}C_{Schale}$ und Sr/Ca_{Schale} dagegen hoch, der inorganische Kohlenstoff (TIC) steigt zwischen **3300 und 2320 cal BP** langsam an, was auf einen relativ hohen Seespiegel und relativ niedrige Salinität (Süßwasser bis oligohalin) bei mittlerer Produktivität in relativ kühlem und feuchtem Klima hinweist. Relativ hohe Niederschläge durch einen verstärkten Monsun führten zu einem höheren Süßwassereinstrom und relativ geringerer Evaporation. Zu dieser Zeit war der Tangra Yumco ein hydrologisch offener See mit einem Überlauf in den Tangqunq Co.

(II) Ein Rückgang von *L. sinensis* und Übergang zur Dominanz von *L.*? *dorsotuberosa* (51,5 %) mit höherer Artenzahl (6) und sowohl für das Flachwasser als auch für das Profundal typischen Arten sowie hohe Gehalte an organischem Kohlenstoff (TOC) belegen einen fallenden Seespiegel und langsam steigende Salinität (oligohalin) bei höchster Produktivität in warmem und trockenem Klima zwischen **2300 und 1760 cal BP**. Durch geringere Monsunintensität abnehmende Niederschläge und eine Zunahme der Evaporation lösten diese Entwicklung aus. In dieser Phase wurde der Tangra Yumco endgültig vom Tangqunq Co abgetrennt und verwandelte sich in ein geschlossenes Seesystem. Der See blieb von dieser Entwicklungsphase an bis heute ein geschlossenes System.

(III) Die sehr geringe Abundanz der Ostrakoden (durchschnittlich 13,6 Klappen/ml) und sehr hohe Gehalte inorganischen Kohlenstoffs (TIC) zwischen **1740 und 1104 cal BP** zeigen einen fallenden Seespiegel, begleitet von zunehmender Salinität (oligo- bis mesohalin), und eine sehr niedrige Produktivität an, was durch den weiteren Rückgang der Niederschläge (geringere Monsunintensität) in einem trockenen Klima hervorgerufen wurde.

(IV) Die langsame Erholung der Ostrakodenpopulation und das Vorherrschen von

L. inopinata (61,7 %), die Zunahme der Artenzahl (4) und Diversität, hohe Werte von $\delta^{18}O_{Schale}$ und Mg/Ca_{Schale}, niedrige $\delta^{18}C_{Schale}$ und Sr/Ca_{Schale}, gröbere Korngrößen mit einem Maximum zu Beginn der Kleinen Eiszeit, sehr hohe Konzentrationen von Kalium, höchste TOC und hohe TOC/TN-Werte zeigen ein kaltes und das trockenste Klima zwischen **1065 und 444 cal BP** an. Der Zeitabschnitt der Kleinen Eiszeit (ca. 650 – 100 cal BP) ist durch einen zurückgehenden Seespiegel und erhöhte Salinität (mesohalin) sowie höhere Produktivität gekennzeichnet. Dies wird durch geringe Niederschläge (weiterer Rückgang des Monsuns) und relativ hohe Verdunstung in kühlem und trockenem Klima hervorgerufen.

(V) In der Phase von **405 cal BP bis heute** löste *L. sinensis L. inopinata* als dominierende Art ab, das Adult/Juvenil-Verhältnis war niedrig, wie auch der Anteil doppelklappig erhaltener Ostrakoden, K- und TOC-Gehalte, was auf ein relativ feuchtes Klima und eine allmähliche Vergrößerung des Sees bei moderater Salinität (oligo- bis mesohalin) bei höherer Produktivität hinweist. Größere Niederschlagsmengen (Zunahme des Monsuns) und nur geringfügig erhöhte Verdunstung aufgrund der etwas höheren Temperaturen sind anzunehmen.

Zusammenfassend kann festgestellt werden, dass Ostrakodengemeinschaften und –assoziationen sowie ihre Abundanz und Diversität erfolgreich für die Charakterisierung von (1) Gewässertypen und ihrer Permanenz, Wassertiefe, Salinität, (2) Hydrologie, Primärproduktion, Redoxbedingungen und Sauerstoffverfügbarkeit, (3) subaquatischen Sedimenttransport und Sedimentationsbedingungen in großen lakustrinen Becken sowie (4) für aquatischer Ökologie, Umwelt- und Klimaforschung eingesetzt werden. Ostrakoden sind sensible Bioindikatoren und Proxys in Paläomilieuanalysen und Paläoklimaforschung auf dem Tibetplateau.

Chapter 1

Introduction

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Chapter 1

1.0 Introduction

"Species would die out gradually and new ones will slowly evolve, one after another, both on land and in the waters, but the mean complexity of life would not alter and its basic designs, created at the beginning, would endure to the end of time." ~ Charles Darwain, On the Origin of Species (1859).

The organisms and their fossil (dead remains) provide long records of natural variability of environmental, ecological and climate in time (Jablonski and Sepkoski, 1996; Alverson et al., 2000; Curry, 2003; Dietl and Flessa, 2011). The **ecology** (biological interactions) is the study of living organisms and their environment (both, **biotic**-all relationship of organisms and **abiotic factors**-physical, chemical, climatic, food, compositions of water and soil) (Begon et al., 1996; Beeby and Brennan, 1997; Williams, 2006; Walter and Hengeveld, 2014). The **palaeoecology** (fossil records) is the study of ancient ecologies, life relations of prehistoric organism, interaction of past organisms and their ancient environment (Dodd and Stanton, 1990; Hardt et al., 2007; Benton, 2009; Seppä, 2009). Both ecology and palaeoecology are different approaches towards a common objective: ecological understanding of the biosphere (Benton and Harper, 2009; Rull, 2010; Birks, 2012; Bjune et al., 2014; Davies et al., 2014).

Biological monitoring (structure of biological communities and indicator organisms; ecology and palaeoecology) supports evidence of spatial and temporal environmental and climate changes (Elliott, 1990; Courtemanch, 1994; Curry, 1999; Külköylüoğlu, 2004; Daufresne et al., 2009). Aquatic environment monitoring through biological systems is essential for ecosystems sustainability policy in water resources management and biodiversity conservation (Likens and Bormann, 1985; Barnes and Mann, 1991; Polunin, 2008; Dietl et al., 2015).

1.1 Ostracoda

The class Ostracoda (Bivalved: Arthropoda) is within the subphylum Crustacea, with two major subclasses, Podocopa and the Myodocopa (Fig. 1-2) (Horne et al., 2002; Newman, 2005; Rodriquez-Lazaro and Ruiz-Muñoz, 2012). Ostracoda provides information on environmental processes, biological activities, ecological, sedimentary events, geological and climatic conditions (Carbonel, 1988; De Deckker and Forester, 1988a; Smith and Delorme, 2010; Scott et al., 2012). It is oldest fossil arthropod group (The Cambrian to Early Ordovician period and the present) with living representatives (about 65, 000 living species) (Maddocks, 1982; Kempf, 1996; Newman, 2005; Willams et al., 2008). The global diversity of Ostracoda estimates about 20,000 living species from marine and transitional waters (Martens et al., 2008). The success of ostracods to invade freshwater habitats is due to efficient osmotic physiological adapation (calcification in low mineralsation waters) and wide tolerance to different salinity regimes (Iglikowska, 2014; Iglikowska and Pawlowska, 2015).

Ostracods are efficient colonisers of new habitats (Newman, 2005; Iglikowska, 2014). The wide geographical distribution and simulateous appearance in palaeocontinents indicate their rapid dispersal, reproductive modes and wide environmental tolerance (Willams et al., 2008).

1.1.1 Environmental conditions

Ostracods are small crustaceans without appendages on the abdomen and the second major group of freshwater entomostracans (cladoceras and copepods) (Morgan, 1930; Frey, 1964; Cronin, 2009). Ostracods (clam shells, soft body enclosed two low Mg calcite valves joined by hinged) are mainly 0.7-1.0 mm long, but their size ranges between 0.3 and 5.0 mm in freshwater systems (De Deckker, 1981a; Danielopol et al., 1993; Henderson, 2002). They live in nearly all types of aquatic environments from marine, brackish (lake, lagoons and estuaries), freshwater (lake, rivers, springs, streams), temporary pools (ponds, ground water), mosses, on aquatic plants and semi-terrestrial environment (Morgan, 1930; Bronshtein, 1988; Benzie, 1989; Frenzel and Boomer, 2005; Griffiths, 2006). Species specific occupy spatial-temporal pattern of distribution due to varying environmental and climatic parameters (De Deckker, 1981a; Carbonel, 1988; Griffiths, 2006; Walter and Hengeveld, 2014). Each species is specifically adapted to a subset of environmental and climatic factors (De Deckker, 1981a; Forester, 1983, 1986; Carbonel, 1988; Griffiths, 2006; Walter and Hengeveld, 2014). Ostracod reproduces by sexually (copulation) and asexually (parthenogenesis) (Kesling, 1961; Cohen and Morin, 1990; Chaplin et al., 1994; Griffiths and Butlin, 1995). Ostracods ("Seed Shrimp") are mostly microbenthos but few are planktonic (Delorme, 1989; Griffiths and Holmes, 2000). Lacustrine ostracods live in phytal to deeper depths and commonly preserved as fossils in lake sediments (Decrouy, 2009a).

1.1.2 Palaeoecology

The linking of past and present conditions (thus intepreparing fossil record and reconstructing past life forms using modern life forms) is based on the *Principle of Uniformitarianism* (Actualism), "***The present is the key to the past***"(Lyell, 1835; Darwin, 1889; Birks and Birks, 1980; Gould, 1984; Etter, 1994):

I. Laws of nature do not change on Earth in time and space.
II. Process that influenced geological phenomena in the past occurs in the same manner in present day.
III. The speed of geological and biological process does not change.
IV. In the past the same materials and the same conditions existed.

The ancient ecosystems is reconstructed using fossil records and understanding of process that influence life forms in the past, evolving systems bsed on three critical factors (Behrensmeyer, 1992; Etter, 1994; Hardt et al., 2007). This is based on **three critical** factors (Behrensmeyer, 1992; Etter, 1994; Hardt et al., 2007):

I. Accurate determination and systematic classification of the collected specimen.
II. Putting all investigated profiles in a temporal and stratigraphical precise order.

III. Understanding of ecological context and specific adaptation of the organism that influence the ability to survive in a particular environment

The fossil shells (dead remains) of ostracods are a source of carbonate for biostratigraphical and geochemical analysis in reconstruction of lake environment, hydrology and climate (Bate and East, 1972; Benson, 1981; Griffiths et al., 1992; Holmes, 1992; Sepkoski, 2000). Ostracods are very abundant in alkaline sediments. Ostracod populations are mainly controlled by environmental parameters (e.g., temperature, salinity, water depth, habitat preference, dissolve oxygen concentration and among many) (Benzie, 1989; Griffiths and Holmes, 2000). The presence and absence and relative abundance are valuable environmental indicators (Benzie, 1989; Griffiths and Holmes, 2000). The (palaeo)-ecology and geochemical information of ostracods are useful palaeoenvironmental and climate indicators (Holmes, 1996; Cronin, 2010). Knowledge on living species is the basis for usage of the fossil communities reconstruction of past aquatic ecosystem dynamics (Boomer, 2002; Boomer et al., 2003; Vermeij and Herbert, 2004). The fossil (dead) associations are assumed to be related to the living communities (Gall, 1983). The quantitative estimation of both living and empty valves (dead) ostracod associations is important for understanding past ecology of fossil assemblages and their deposition in ancient environments. Most of Quaternary ostracod has the living representatives. Modern classification of Quaternary and living ostracods consist of 10 suborders and 16 superfamilies of the orders Myodocopida, Halocyprida, Platycopida, Podocopida and Palaeocopida (Horne et al., 2002; Horne, 2005; Rodriquez-Lazaro and Ruiz-Muñoz, 2012) (Fig. 1-2). The different taxonomic groups are distinguished either by either "soft part" (primarily limbs or appendages) or "hard part" (calcified valves) morphologies (Horne et al., 2002; Rodriquez-Lazaro and Ruiz-Muñoz, 2012) (Fig. 2). Fossil ostracods (taxonomic groups) are characterised by mainly carapace morphologies (ornamental pattern) and muscle scars (Benson, 1981). There are rarely fossil ostracods with soft parts (exceptional, oldest ostracods with preserved soft anatomy- myodocopes) (Willams et al., 2008).

Quaternary freshwater ostracods are good indicators of Recent environmental and climatic change (Fig. 2) (Benson and Macdonald, 1963; Frey, 1964; Cronin et al., 2002; Holmes and Chivas, 2002). The ecological niches of modern species can be used to infer palaeoecology of fossil assemblages and past changes of environmental and climate parameters. There is strong relation between the recent ecology and ancient ecology (palaeoecology), although with little variability (Tab. 1) (Hardt et al., 2007; Seppä, 2009). The palaeoecology of fossil assemblages is based on the assumption that they reflect ecology of living associations (Tab. 1) (Ladd, 1957; Holmes, 1992; Smol et al., 2001; Smol, 2002; Birks, 2008)).

1.1.3 Ostracoda shell chemistry

Ostracods grow by successive moulting (ecdysis) shedding of valves, about 8-9 times prior to adulthood and maturity (Kesling, 1951). Each calcitic precipitation (calcium carbonate) is a snapshot of the water chemistry at a point in time. The secretion of ostracods shells occurs fairly rapidly, a few hours to a few days, and directly takes up elemental composition from ambient water (Turpen and Angell, 1971a; Chivas et al., 1983a; Chivas et al., 1986b; Roca and Wansard, 1997). The low-

Mg calcite of ostracods are derived directly from the ambient water chemistry (Ca, Sr and Mg incorporated into calcite carapace) and only at the time of calcification (Turpen and Angell, 1971; Chivas et al., 1983; Chivas et al., 1986; Roca and Wansard, 1997).

The geochemistry (trace-elements and stable isotopes) of ostracod shells is a biomarker of ambient water chemistry at time of secretion (conductivity, dissolved ions and solute compositions) (Forester, 1983; Griffiths, 2006; Ito and Forester, 2009b; Deocampo, 2010; Yang et al., 2014b). The geochemical information stored in ostracod shells (e. g., low Mg/Ca) is commonly used for palaeo-environmental evolution of continental water bodies (Forester, 1986; Holmes, 1996; Xia et al., 1997a; Xia et al., 1997c; Ito et al., 2003a). The ecology and geochemistry of ostracods is a reliable tool for reconstruction of past aquatic environmental and climatic conditions (Chivas et al., 1983a; Gasse et al., 1987; Carbonel, 1988; De Deckker, 1988; De Deckker and Forester, 1988a; Decrouy et al., 2011a).

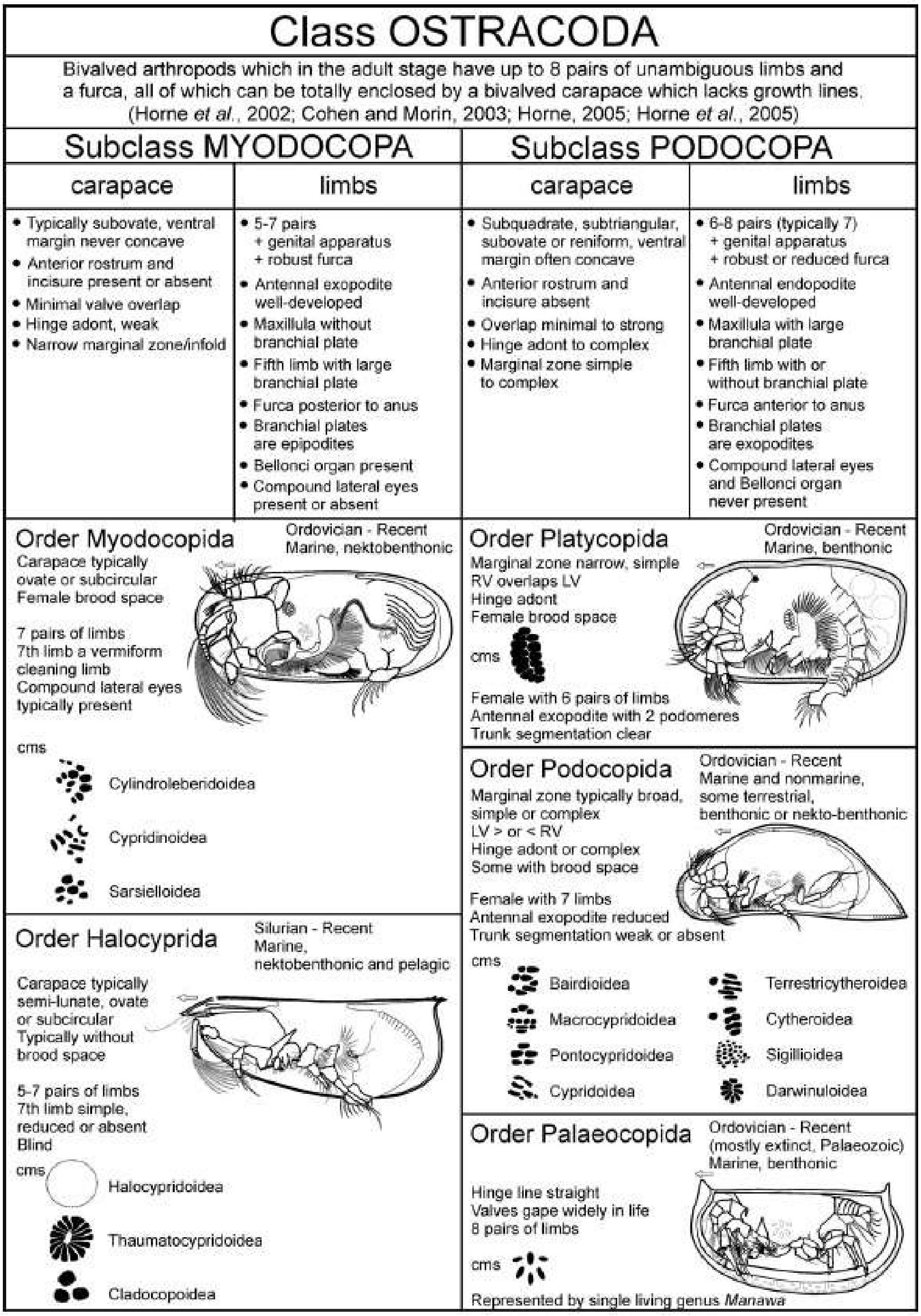
The chemical shell compositions (Mg, Sr, Na and Ba) are useful for reconstruction of past water temperature, water balance and salinity (Chivas et al., 1983a; Griffiths and Holmes, 2000; Gouramanis and De Deckker, 2010). The changes in Sr/Ca ostracod shell are believed to reflect changes in salinity while the changes in Mg/Ca shell to reflect both salinity and water temperature (Forester, 1986; Ito and Forester, 2009b). Ostracod cations (Chivas et al. 1983; 1985; 1986) can be used for quantitative salinity reconstruction (Chivas et al., 1983a, 1985; Chivas et al., 1986b; Chivas et al., 1993; Xia et al., 1997a; De Deckker et al., 1999a). Nonetheless, recent research suggest theoretical and practical uncertainties within quantitative salinity inferences (Wansard et al., 1998a; Ito, 2002; Ito and Forester, 2009b; Gouramanis and De Deckker, 2010; Gouramanis et al., 2010). Yet still the goal of initial objective of ostracod-based quantitative salinity reconstruction has not been abandoned (Shen et al., 2001; Zhang et al., 2004a).

Ostracod isotopic composition (δ^{18}O andδ^{13}C) is used to infer past temperature changes in deep lakes (von Grafenstein, 2002) and hydroclimatic evolution of the continental waters (von Grafenstein et al., 1999; Ito, 2002; Schwalb, 2003b; Wrozyna et al., 2010; Börner et al., 2013b). The isotope and trace-element composition of ostracods shells records chemical conditions of the lake water (e.g., temperature, salinity, dissolved ion composition, hydrology, conductivity) (Smith, 1993; Holmes, 1996; Shen et al., 2002; Mischke et al., 2007). However, ostracods from perennial springs may be an exception as they tend to be at a constant temperature and can show the isotope values of the precipitation that feeds the spring (Emi Ito personal communication). Geochemistry of ostracod shells is useful proxy of past water chemistry, temperature and salinity, although the chemical composition of each genera is complex and poorly understood (Holmes, 1996; De Deckker et al., 1999a; Ito et al., 2003a). Furthermore, a careful hydrological and climate inferences should be made using geochemistry of ostracod shells due to uncertainties of the carbonate biomineralisation (Holmes, 1996; Xia et al., 1997a; Ito et al., 2003a; Decrouy et al., 2011a).

1.1.4 Palaeoenvironment

Ostracods are excellent proxies for palaeoenvironmental reconstructions (Holmes, 1996; Boomer and Eisenhauser, 2002; Ito et al., 2003a). Nonetheless, Late Quaternary and living ostracods from mountain ecosystems are still poorly known. Understanding of auto-ecology (e. g., micro-habitats and life cycle) and geochemistry of living and

Recent ostracods is critical for the application of fossil ostracods for environmental and climate reconstructions (Decrouy et al., 2012b; Börner et al., 2013b; Börner et al., re-submitted). The simultaneous application of both isotopic composition and trace element ratios combined with palaeoecological and sedimentological investigations provide detailed palaeoenvironmental and palaeoclimate reconstructions (Holmes, 1992; Chivas et al., 1993; Janz and Vennemann, 2005; Mischke et al., 2015).



Class OSTRACODA

Bivalved arthropods which in the adult stage have up to 8 pairs of unambiguous limbs and a furca, all of which can be totally enclosed by a bivalved carapace which lacks growth lines. (Horne *et al.*, 2002; Cohen and Morin, 2003; Horne, 2005; Horne *et al.*, 2005)

Subclass MYODOCOPA		Subclass PODOCOPA	
carapace	limbs	carapace	limbs
• Typically subovate, ventral margin never concave • Anterior rostrum and incisure present or absent • Minimal valve overlap • Hinge adont, weak • Narrow marginal zone/infold	• 5-7 pairs + genital apparatus + robust furca • Antennal exopodite well-developed • Maxillula without branchial plate • Fifth limb with large branchial plate • Furca posterior to anus • Branchial plates are epipodites • Bellonci organ present • Compound lateral eyes present or absent	• Subquadrate, subtriangular, subovate or reniform, ventral margin often concave • Anterior rostrum and incisure absent • Overlap minimal to strong • Hinge adont to complex • Marginal zone simple to complex	• 6-8 pairs (typically 7) + genital apparatus + robust or reduced furca • Antennal endopodite well-developed • Maxillula with large branchial plate • Fifth limb with or without branchial plate • Furca anterior to anus • Branchial plates are exopodites • Compound lateral eyes and Bellonci organ never present

Order Myodocopida
Ordovician - Recent
Marine, nektobenthonic
Carapace typically ovate or subcircular
Female brood space
7 pairs of limbs
7th limb a vermiform cleaning limb
Compound lateral eyes typically present
cms
Cylindroleberidoidea
Cypridinoidea
Sarsielloidea

Order Halocyprida
Silurian - Recent
Marine, nektobenthonic and pelagic
Carapace typically semi-lunate, ovate or subcircular
Typically without brood space
5-7 pairs of limbs
7th limb simple, reduced or absent
Blind
cms
Halocypridoidea
Thaumatocypridoidea
Cladocopoidea

Order Platycopida
Ordovician - Recent
Marine, benthonic
Marginal zone narrow, simple
RV overlaps LV
Hinge adont
Female brood space
cms
Female with 6 pairs of limbs
Antennal exopodite with 2 podomeres
Trunk segmentation clear

Order Podocopida
Ordovician - Recent
Marine and nonmarine, some terrestrial, benthonic or nekto-benthonic
Marginal zone typically broad, simple or complex
LV > or < RV
Hinge adont or complex
Some with brood space
Female with 7 limbs
Antennal exopodite reduced
Trunk segmentation weak or absent
cms
Bairdioidea
Macrocypridoidea
Pontocypridoidea
Cypridoidea
Terrestricytheroidea
Cytheroidea
Sigillioidea
Darwinuloidea

Order Palaeocopida
Ordovician - Recent (mostly extinct, Palaeozoic)
Marine, benthonic
Hinge line straight
Valves gape widely in life
8 pairs of limbs
cms
Represented by single living genus *Manawa*

Fig. 1 Quaternary and living ostracods: synoptic characteristics o the **two subclass** and **five orders**. Cms. Central muscle cars, characteristic patterns. (Rodriquez-Lazaro and Ruiz-Muñoz; fig. 1.4).

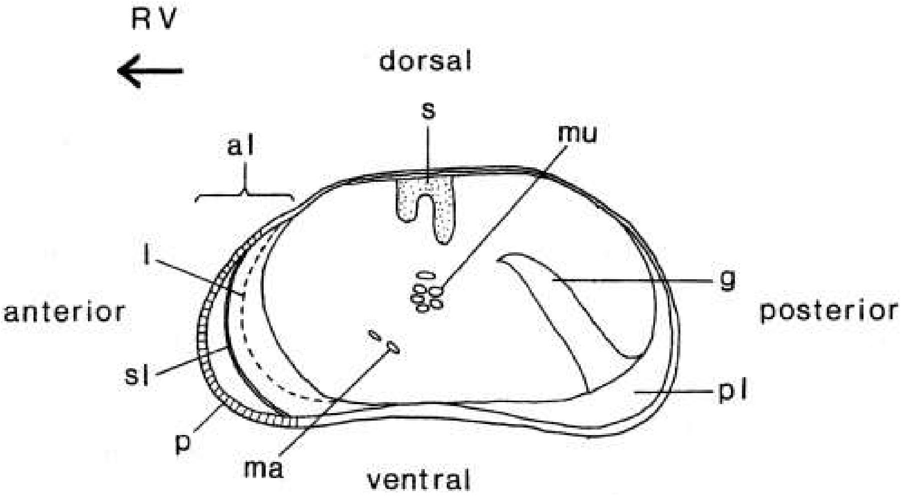


Fig. 2 Freshwater ostracod internal view of a right valve (RV): Al = anterior inner lamella; g= gential impression; l = list; ma = mandibular scars; mu = muscle scars; p = pore; pl = posterior inner lamella; s = sulci; sl = selvage. (Griffiths et al., 1992; fig. 24).

Table 1 The difference between current auto-ecology and palaeoecology (modified, Hardt et al. 2007).

Current auto-ecology	**Palaeoecology**
Current living organisms are true biological communities (intact) and indicators of ecosystems	Fossil assemblages and age estimation data are needed
Precise and comprehensive description of environment and organism in an ecosystem is possible, parameters can actually be measured	Mostly characterization of a former milieu in order to subsequently state inference on environmental factors and organisms factors
Potentially that all faunal and flora components are available in the observed biocoenosis	Fossils are the only documents available; hardly ever is the fossil record complete and many questions stay unanswered
Data acquisition is limited to a few years or even months and days only	Excavated facies span a time of thousands and even millions of years.

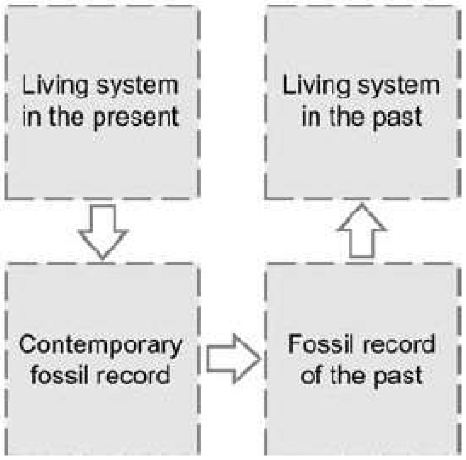


Fig.3a Linking of the past and the present ecosystems. The present-day ecosystems and its biota are treated largely from historical viewpont. The contempeorary fossil are used as the basis for the inference about the past (Hardt et. al. 2007; fig. 17:1)

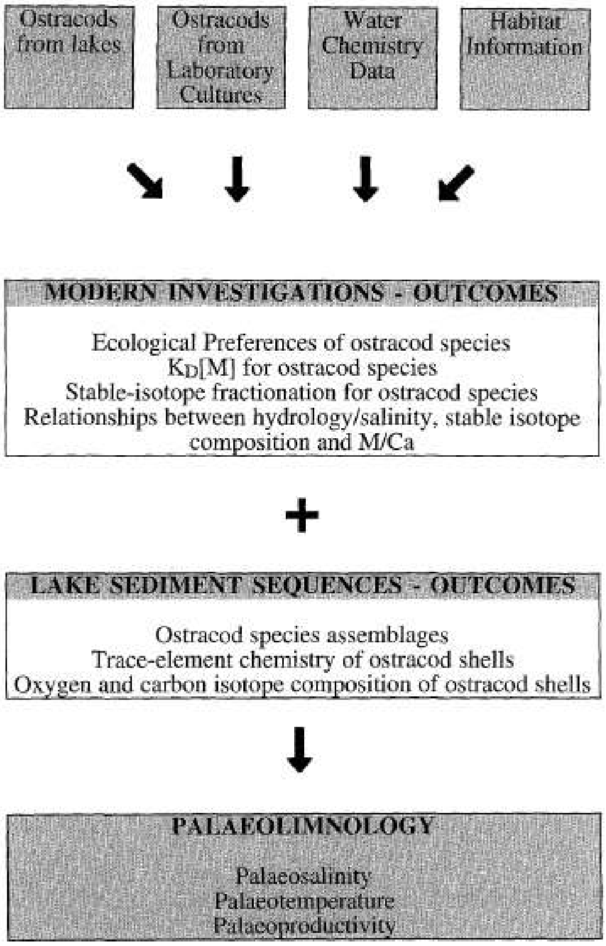


Fig. 3b Summary of methods in application of ecology and chemistry of ostracod shells in palaeolimnology (Holmes, 1992; fig. 2)

1.2 The Tibetan Plateau

1.2.1 General Environment

"I will open rivers in high places, and fountains in the midst of the valleys: I will make the wilderness a pool of water and the dry land springs of water." Isaiah 41: 18

The Tibetan Plateau is highland with complex interactions (e.g., atmospheric, biospheric, cryospheric, geological, climatic, hydrological and environmental processes.) and plays a key role in the Earth's climate, biodiversity, water cycle and ecoystems (Fig. 1) (Yao et al., 2011a; Yao et al., 2012a).

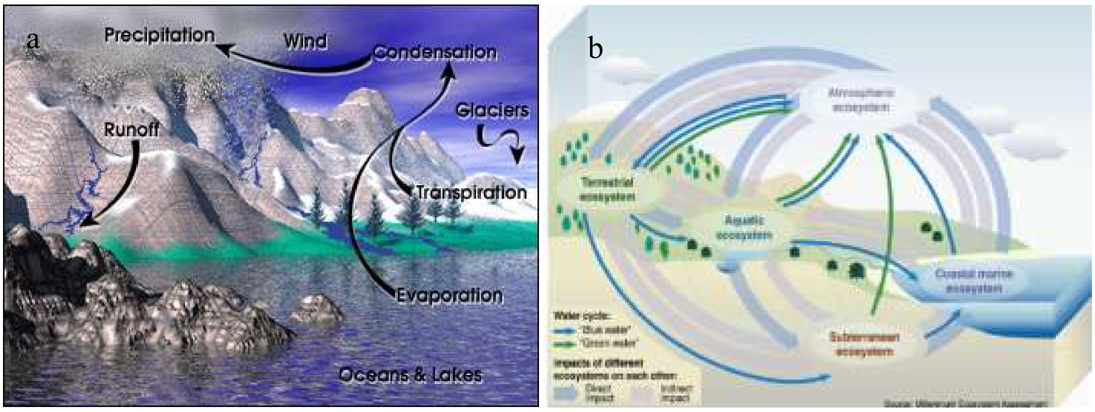


Fig. 1. The water cycle on Earth; (a) The four major processes are evaporation, transpiration, condensation and precipitation-Source: http://earthobservatory.nasa.gov/Library/Water/water.html **(b) Ecosystems interactions**-Source: Millennium Ecosystem Assessment. Ecosystems and Human Well-Being: Wetlands Synthesis .Word Resources Institute; Washington, D.C. 2005.

1.2.2 The geography of Tibetan Plateau

The Tibetan Plateau (TP) is situated in 75－105° E, 27.5－37.5°N, with an average elevation of 4000 - 5000 meters above sea level (a.s.l) and covers a total area of about 2.5 million km^2 (Li et al., 1983; Molnar, 1989; Tuttle and Schaeffer, 2013). The Tibetan Plateau is surrounded by the Himalayas and Gangdise 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 (terrain accreted into Eurasia continent) (Fig. 2) (Dewey et al., 1988; Lehmkuhl and Haselein, 2000; Lehmkuhl and Owen, 2005; Yao et al., 2012a). It is known as the "Roof of the World`" due to it's complex terrain, ecological variability, high plateau environment heterogeneity and climatic variability (Qiu, 2008; Yao et al., 2011a; Chen et al., 2015).The vegetation is ecologically variable, scarce and patchy distributed, influencing the climate (Fig. 2) (Chang, 1981b; Yu et al., 2010; Liang et al., 2012; Tian et al., 2014) (Fig. 2). The high mountains ranges are intercepted with lakes and rivers, unique flora and fauna (Zheng et al., 2000a; Yao et al., 2011b). It is the third sensitive "hot spot" akin to the Arctic and the Antarctic, for the assessment of environmental, ecological and climate change (Yao et al., 1997; Myers et al., 2000; Ma et al., 2009). It is the highest and largest plateau in the world with a variety of climate and pristine ecosystems (Fang, 1991; Gasse et al., 1991; An et al., 2001; Owen et al., 2005; Duan et al., 2006; Harris, 2006).

The earth's climate is influenced strongly by the presence of mountains and plateaus (Overpeck et al., 2005; Steffen et al., 2005; Ruddiman, 2008; Kohler and Maselli, 2009). The Tibetan Plateau exerts profound influences not only on the local climate and environment but also on the global atmospheric circulation through its topographic features, sensible and latent forcing (Yanai et al., 1992; Liu and Yanai, 2001; Yanai and Wu, 2006). It plays an important role in the Asian monsoon system by acting as an anomalous mid tropospheric heat source (Li and Yanai, 1996; Zhisheng et al., 2001; Taniguchi and Koike, 2007; Duan et al., 2008; Park et al., 2012). The global climate system and its interaction such as landscape components as vegetation, geology, topography, and soil are highly nonlinear (Beniston, 1994). Many of the modern geographic patterns of temperature, precipitation, and wind are explained by the presence of topographic barriers (Trewartha, 1968; Zhao and Moore, 2004) and experiments with numerical climate models have confirmed these relationships (Hahn and Manabe, 1975; Manabe and Broccoli, 1990). Additionally, significant surface uplift (increased elevation) of the Tibetan Plateau in the past 10-20 million years (Harrison et al., 1992; Molnar et al., 1993) and several other major plateau systems during the Cenozoic further described these phenomena(Kutzbach et al., 1989; Ruddiman and Kutzbach, 1990).

The mountains play a significant role in water resources of the world (Northrop, 1887; Viviroli et al., 2003; Viviroli and Weingartner, 2004; Kohler and Maselli, 2009). The Tibetan Plateau directly life-supports about a tenth of humankind and indirectly sustains more than one-half humankind (Ives and Messerli, 1989; Boos and Kuang, 2010). The third pole environment (variable topography boundaries) is characterised by semi-humid-summer steppe climate with cold and dry winter, due to the variability of topography and different monsoon systems (Webster et al., 1998; Zheng et al., 2000a; Bookhagen and Burbank, 2006; Molnar et al., 2010).

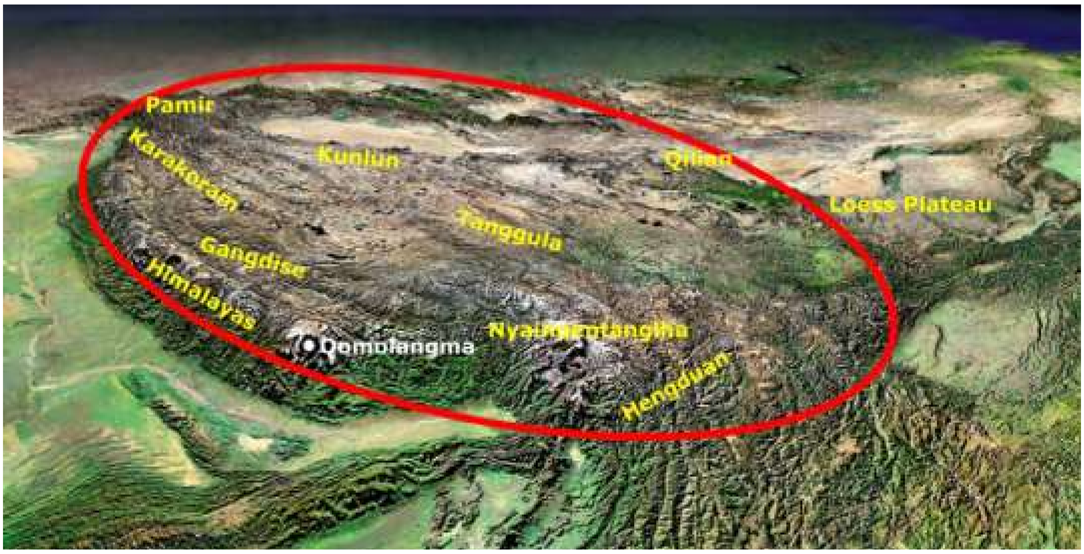


Fig. 2 The geography of Tibetan Plateau and surrounding mountains (Yao et al. 2012: fig.1).

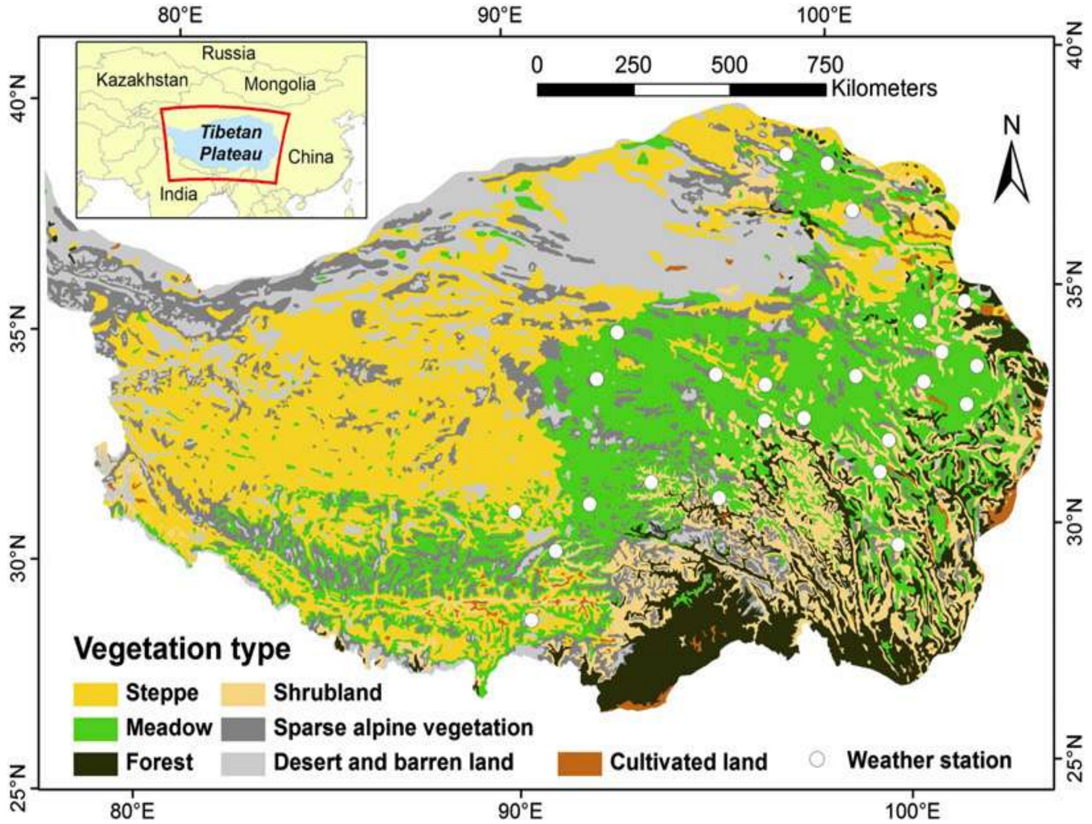


Fig. 3 The vegetation types and weather stations on the Tibetan Plateau (Yu et al. 2010: fig.1). The vegetation distribution is controlled by summer precipitation gradient in southeast to northeast. The vegetation changes from forest to meadow, to steppe and to desert.

1.2.3 The Tibetan Plateau and monsoons

The Tibetan Plateau is created by the India-Asia collision (Flohn, 1987; Shen, 1987; Dewey et al., 1988; Xiao and Li, 1995; Chen and Wang, 1996; Pan et al., 2012; Chatterjee et al., 2013). The uplift of the Himalayan-Tibetan orogen has played a major role in controlling local and global climates on long and short time scales over the last 50 Ma (Kutzbach et al., 1989; Ruddiman and Kutzbach, 1989; An et al., 2001; Dettman et al., 2003; Molnar et al., 2010). It plays a great role in climate evolution in South-East Asia, formation and development of Asian Monsoon (He et al., 1987; Yanai et al., 1992; Li and Yanai, 1996; Webster et al., 1998; Wang et al., 2005) and of atmospheric circulation in the Northern Hemisphere (Murakami, 1987; Ruddiman and Raymo, 1988; Ruddiman and Kutzbach, 1991; Harrison et al., 1992; Raymo and Ruddiman, 1992; Molnar et al., 1993; Murphy et al., 1997; Harris, 2006). The Tibetan Plateau is located in the interaction zone of monsoon climatic systems (polar air masses from Arctic, continental air masses through central Asia (Westerlies), Indian summer monsoon and East Asian summer monsoon) (Fig. 4-5) (Prell and Kutzbach, 1992; Raymo and Ruddiman, 1992; Molnar et al., 1993; Lal et al., 1994; Herzschuh, 2006). The uplift of Tibetan Plateau, due to India-Asia collision, is the primary cause of monsoon initiation and intensification (Kutzbach et al., 1989; Coleman and Hodges, 1995; An et al., 2001; Harris, 2006; Chatterjee et al., 2013). Moisture penetrating into the southeastern Tibetan Plateau is predominantly derived from monsoonal air masses originating from the Bay of Bengal and transported into the eastern Himalayan syntaxis along the Brahmaputra River (Hamilton, 1977; Hren et al., 2009; Yao et al., 2012b; Chatterjee et al., 2013). However, monsoonal-derived moisture is progressively mixed with central Asian air masses in the western and northern parts of the Tibetan Plateau (Hren et al., 2009; Zhang et al., 2012b; Zhao et al., 2012).

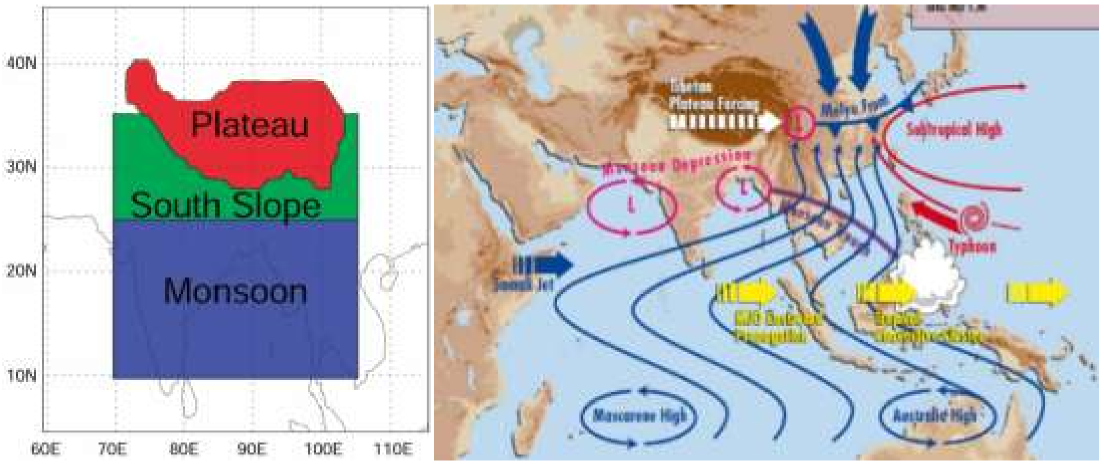


Fig. 4. The Tibetan Plateau (elevation of 3 km within 70–105°E and 25–40°N, south slope (3 km within 70–105°E and 25–35°N) and the monsoon (70–105°E, 10–25°N) (Fu et al. 2006a: fig.1;Yao et al., 2011b;fig. 3).

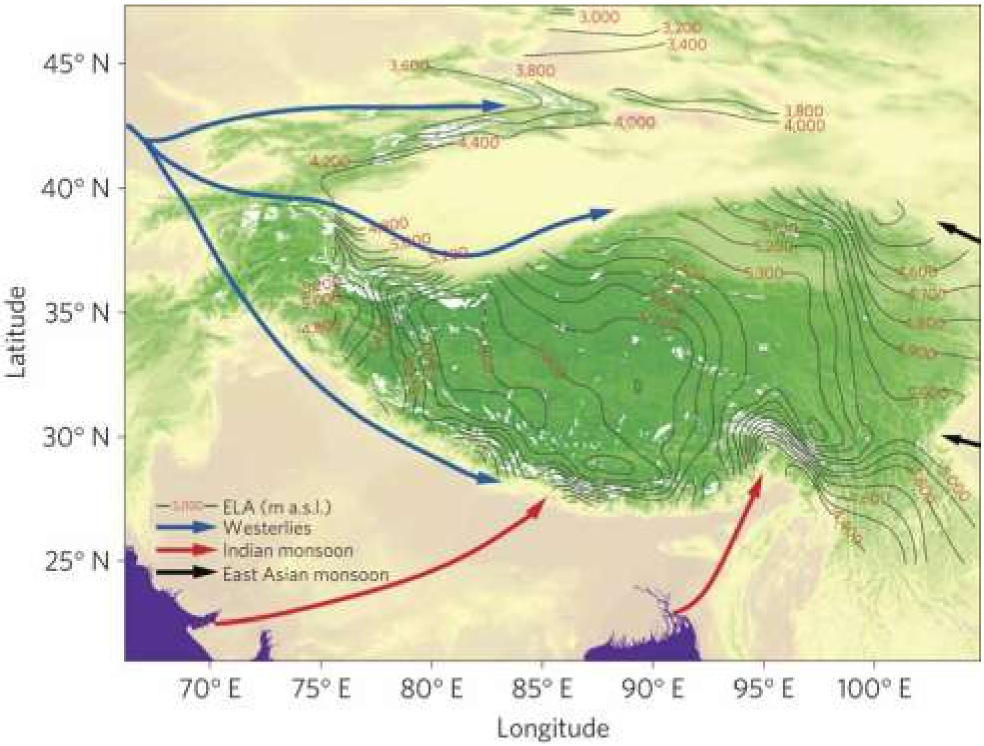


Fig. 5 The monsoon circulation on the Tibetan Plateau (Yao et al. 2012b: fig.1).

The Tibetan Plateau-Himalayas region is characterised by spatial heterogeneity in precipitation (Fig. 6-7) (Molnar et al., 1993; Immerzeel et al., 2005; Anders et al., 2006; Vaid and Liang, 2015). The variability of precipitation is due to uneven topography and four major climatic systems. The climatic system consist of the Siberian high-pressure systems to the north, the mid-latitude Westerlies to the west, the East Asian Monsoon to the east and the Indian Summer Monsoons (ISM) to the south (Fig. 6-7) (Hamilton, 1977; Schickhoff, 2000; Bookhagen and Burbank, 2006; Fu et al., 2006a). During the summer period, moisture is transported from the Bay of Bengal and Southeast Asia northwest along the range front, where it is orographically lifted and adiabatically cooled producing heavy monsoonal rainfall Indian (Chang, 1981a; Fu et al., 2006a). On the eastern edge of the range, moisture penetrates the Himalaya along the Siang–Brahmaputra river valley bringing seasonal monsoonal moisture fluxes to the southern Tibetan Plateau (Fu et al., 2006b; Immerzeel and Bierkens, 2010a). The mean annual precipitation across the Himalaya and TP ranges from greater than 3 m/yr south of the Himalaya along tributaries of the Siang to less than 0.2 m/yr in central and western Tibet (Bookhagen and Burbank, 2006; Immerzeel, 2008). The contribution of summer precipitation (May to Oct) is ~80% in the south and 95% in the uppermost reaches of the Brahmaputra and central Tibetan Plateau (Haigh, 2000; Bookhagen and Burbank, 2006; Immerzeel, 2008; Bookhagen, 2010).

The component crossing through gaps into Indochina, the southern Tibetan Plateau-Himalayas range (e.g., Brahmaputra, Mekong, Jinsha, Salween and among othe large headwaters, all flow out) delivers the largest part of precipitation on the south central Tibetan Plateau (Chang, 1981a; Spicer et al., 2003; Immerzeel and Bierkens, 2010b). The eastern part of the plateau gets its rain from the East Asian summer monsoon (Clark et al., 2004; Lehmkuhl and Owen, 2005; Böhner, 2006; Fu et al., 2006a; He et al., 2006; Zhao et al., 2007).

The Tibetan Plateau-Himalayan realm is characterised by two main rainfall gradients: an approximately five-fold east-to west gradient related to the distance from the moisture source (Bay of Bengal) and a ten-fold south-to-north rainfall gradient reaching from the monsoon-soaked Ganges Plain to the arid Tibetan Plateau that lies in the lee of the Himalayan orographic barrier (Fig. 6-7) (Hamilton, 1977; Chang, 1981a; Clark et al., 2004; Bookhagen, 2010). The mean daily summer (May–October) monsoon rainfall on the Ganges Plain ranges from 10 to more than 20 mm day^{-1} south of the Shillong Plateau (Fig. 6-7) (Li and Yanai, 1996; Clark et al., 2004; Bookhagen, 2010). The Tibetan Plateau receives overall less than 5 mm day^{-1} rainfall, with significantly drier western areas (Bookhagen, 2010). The summer (May–October) monsoon rainfall provides more than 80% of the annual moisture budget for large parts of the Ganges Plain and central Himalaya (Fig. 6) (Bookhagen, 2010). The western and eastern areas receive lower rainfall during the summer and their moisture budget is dominated by the westerlies and during winter by the East Asian monsoon (Bookhagen, 2010; Rajagopalan and Molnar, 2013).

The Tibetan Plateau thermal and sensible force both in summer and in late winter and spring can influence the variation of Eastern Asian summer rainfall (Ye, 1981; He et al., 1987; Qian et al., 2011; Jin et al., 2013). A combined index using both snow cover over the Tibetan Plateau and the ENSO index in winter shows a better seasonal forecast (Webster and Chou, 1980; Yanai et al., 1992; Li and Yanai, 1996; Liu and Yanai, 2001).

Strong sensible heating over the Tibetan Plateau in spring contributes significantly to anchor the earliest Asian monsoon being over the eastern Bay of Bengal (BOB) and the western Indochina peninsula (Lau et al., 2000; Liu et al., 2002b; Kau et al., 2003; Schneider et al., 2003; Wu et al., 2011). The heating over the Tibetan Plateau significantly influences the variability of the atmospheric circulation (Schneider and Lindzen, 1977; Ye, 1981; Ruddiman and Kutzbach, 1991; D. and Chan, 2005; Roe, 2005; Harris, 2006; Zhao et al., 2007).

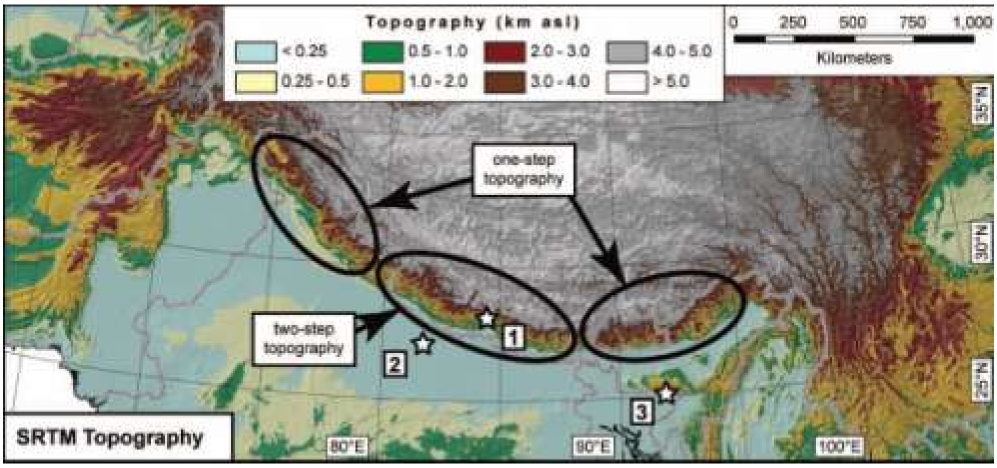


Fig. 6. Topography of Tibetan Plateau-Himalayan mountain ranges. The western and eastern of southern front are characterised by one-step topography. While the central border is characterised by two-step topography, which consist of two distinctive rainfall peaks. White stars represent extreme rainfall (Bookhagen, 2010; fig.1).

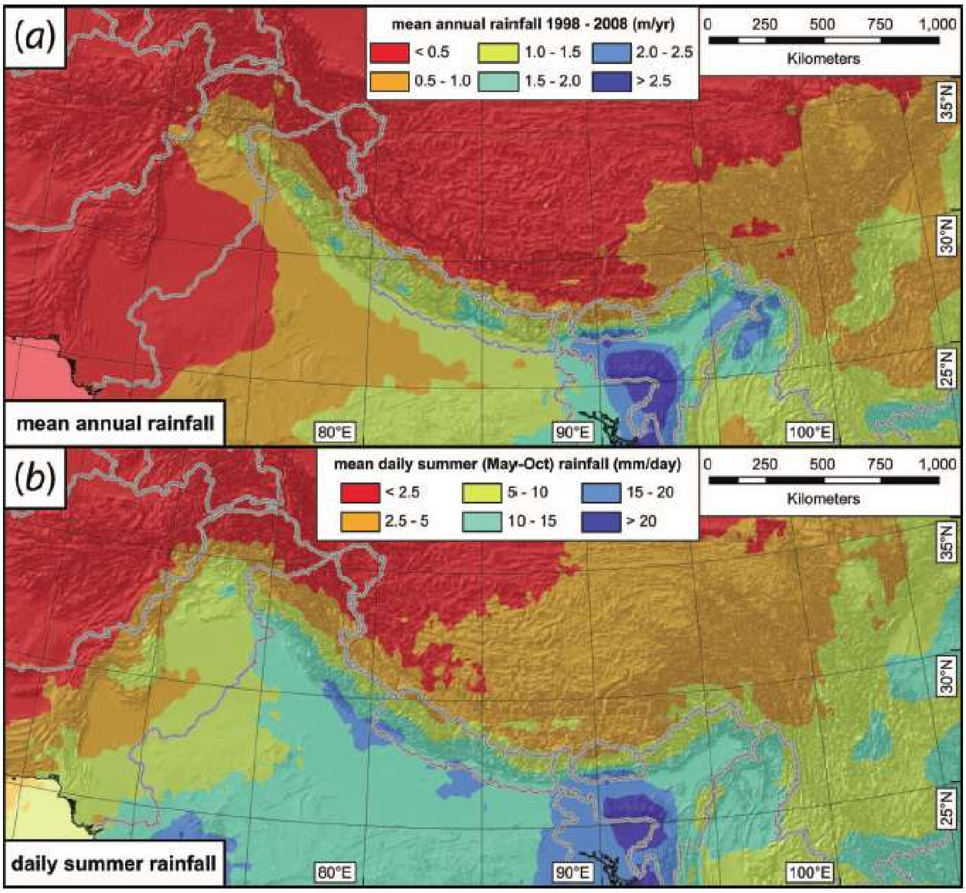


Fig. 7 The two distinct rainfall gradients on the Tibetan Plateau-Himalaya (Bookhagen, 2010: fig.3).

1.2.4 The monsoon systems

The monsoon originates from the Arabic word "*Mausam*", which means season (Ramage, 1971; Webster et al., 1998; Chao, 2000).The monsoon is circulation system associated with change in land-sea thermal contrast induced by seasonal evolution of solar radiation (Fig. 8-9) (Lau and Bua, 1998; Webster et al., 1998; Holton, 2004; Kottek et al., 2006; Wang, 2006). The monsoon is annual seasonal reversal of surface winds (at least 120° between January and July) and change in rainfall pattern (distinct wet/dry seasons) (Fig. 8-9) (Ramage, 1971; Webster et al., 1998; Chao, 2000). The low – level winds of the "wet" summer monsoon flows from the ocean to the continent and high – level winds "dry" winter monsoon flows from the continent to the ocean (Fig. 7) (Ramage, 1971; Webster et al., 1998; Chao, 2000).

In summer time, the lower tropospheric winds flow toward heated continents away from the colder oceanic regions of the winter hemisphere (Ramage, 1971; Charney and Shukla, 1981; Krishnamurti et al., 1989; Webster et al., 1998). In the upper troposphere the flow is reversed, with flow from the summer to the winter hemisphere (Ramage, 1971; Charney and Shukla, 1981; Webster et al., 1998). In summer precipitation is centered in time on either side of the summer solstice and located over the heated continents and the adjacent oceans and seas in the vicinity of a trough of low pressure referred to as the 'monsoon trough' (Webster et al., 1998; Clift and Plumb, 2008; Sanyal and Sinha, 2010). Most summer rainfall is associated with synoptic disturbances that propagate through the region (Ramage, 1971; Webster et al., 1998; Bollasina and Ming, 2013). However, these disturbances are grouped in periods lasting from 10 to 30 days (Ramage, 1971; Webster et al., 1998; Bollasina and Ming, 2013). The envelopes of disturbed weather and heavy rainfall are referred to as 'active periods of the monsoon' (Ramage, 1971; Hamilton, 1977; Webster et al., 1998; Krishnan et al., 2000). The intervening periods of mini drought are referred to as 'monsoon breaks'(Ramage, 1971; Hamilton, 1977; Webster et al., 1998; Krishnan et al., 2000). The monsoon trough (axis of heavy precipitation) is located poleward of the oceanic intertropical convergence zone (ITCZ) (Fig. 8-9), surface low pressure with clouds and rainfall (Wang, 1994; Wang and Wang, 1999). The ITCZ is known as Doldrums and near-equatorial trough, east–west band of deep conveyor belt that circulates the globe (Chao, 2000; Raymond et al., 2006). It is a junction of convergence of northeast and southeast trade winds (driven by heating and moisture) (Wang and Wang, 1999; Sugimoto et al., 2008; Yan et al., 2015). The convergence is parallel to the equator but moves north or south with the earth rotations, which determines the seasons (primarily winter and summer) (Chao, 2000; Sanyal and Sinha, 2010). The ITCZ is also associated with intensive tropical precipitation (Wang, 1994; Chao, 2000; Sanyal and Sinha, 2010). For instance, the rainfall associated with the South Asian monsoon falls at the same latitudes as the great deserts of the planet (Webster et al., 1998; Clift and Plumb, 2008; Sanyal and Sinha, 2010).

Monsoon circulations, particularly those in Northern Hemisphere (boreal) summer, strongly affect the general atmospheric circulations (Fig. 8-9) (Charney and Shukla, 1981; Webster, 1994; Webster et al., 1998). The monsoons are continental- and seasonal-scale sea breeze circulations (Fein and Stephens, 1987; Harrison et al., 1992; An et al., 2000). The south Asian and North American summer monsoons are deep circulations, with closed anticyclones extending up to at least 70 hPa in the stratosphere in June-July (Fig. 8-9) (Krishnamurti et al., 1989; Dunkerton, 1995; Liu et al., 2002b; Wu et al., 2012). The two monsoon circulations are different in magnitude, horizontal extent and depth, but similar in their forcing (a high-altitude land mass of the Himalayan-Tibetan or Colorado plateau to the north, and warm ocean regions of the Bay of Bengal or the Gulf of Mexico to the south (Dunkerton, 1995; Liu et al., 2002b; Wu et al., 2012). These deep circulations may have a significant impact on stratosphere-troposphere exchange and on the entry of air into the stratosphere (Ramage, 1971; Webster, 1994; Roe, 2005; Clift and Plumb, 2008).

The global monsoon climatic systems (changes in annual precipitation in tropical and subtropical regions) are located in Asia (the largest), Austrialia, America and Africa continents (Fig. 9) (Ramage, 1971; Charney and Shukla, 1981; Webster et al., 1998; Qian et al., 2002; Nicholson and Webster, 2007; Sanyal and Sinha, 2010). The global climate classifications is primary linked to precipitation, temperature and vegetation (Fig. 10) (Lamb, 1969; Kottek et al., 2006; Nicholson, 2011; Blunden and Arndt, 2014). Each of monsoon system is characterised by different intensity and interactions with other circulations (Ramage, 1971; Webster et al., 1998; Qian et al., 2002; Wang et al., 2012a; Wang et al., 2014). The global summer monsoon precipitation regulate the annual cycle of the Earth climate system (e.g., temperature, hydroclimate, and heat transport from tropics to higher latitude) (Hoyos and Webster, 2007; Liu et al., 2012; Wang et al., 2012a; An et al., 2015).

Tropical monsoonal circulations, between tropics and extratropics (e.g. moisture extracted from the subtropical ocean under the Pacific trade winds converges over eastern Asia and the western Pacific warm pool providing fuel for the deep convection over both land and ocean) is a key regional components of the global circulation system (Webster, 1983, 1987; Trenberth and Solomon, 1994; Wang and Ding, 2008). They represent a large portion of the global hydrological cycle: the transport of water within and between the different reservoirs in the earth's climate system, some transports involving phases changes (such as evaporation and precipitation), which are very nonlinear due to the relationships between dynamics and thermodynamics (Webster, 1994; Webster et al., 2001; Roe, 2005). Monsoonal circulations are sensitive to the interaction of atmospheric processes, water cycle and climate dynamics (Chao, 2000; Rosenfeld et al., 2001; Chase et al., 2003; Ramanathan et al., 2005; Levermann et al., 2009; Sun and Liu, 2015). The winter monsoon is a flow of cool and highly polluted air mass off the Southeast Asian continent to the relatively warm waters of the ocean (Ramanathan et al., 2005; Liu et al., 2011; Sun and Liu, 2015). The polluted clouds over land need to grow beyond 6 km in height to start precipitating (Rosenfeld et al., 2002). The atmospheric pollutants (aerosols) are particles of sulfate, black carbon and organic carbon and nitrate from human activities (biomass burning) and dust, sea salt and volcanic ash (Ramanathan et al., 2005; Remer et al., 2008; Yu et al., 2008; Sayer et al., 2012). The anthropogenic aerosols affects the earth's energy (solar radiation), the water cycle (thus act as cloud condensation nuclei) and climate (Sokolik and Toon, 1996; Haywood and Boucher, 2000). Asia is one of the major aerosol-laden (strong dust storms) regions of the world due to rapid population growth, economic and human activities (Ramanathan et al., 2005; Lau et al., 2006; Remer et al., 2008; Yu et al., 2008; Sayer et al., 2012).

The Asian monsoon system, consist of two subsystems, East Asian and Indian (or South Asian) monsoons (Yanai et al., 1992; Webster et al., 1998; Liu and Yanai, 2001; Schiemann et al., 2008). It exerts a dominant influence on Asian climate and plays a significant role in regulating regional and global climate (Tang and Reiter, 1984; Krishnakumar and Lau, 1998; Trenberth, 1998; Krishnan et al., 2000; Wang et al., 2003). It is a prominent Earth's climate system, involving complex interactions of the atmosphere, the hydrosphere and the biosphere (Flohn, 1987; Chen and Wang, 1996; Trenberth et al., 2007; Trenberth, 2011). The monsoon transports abundant water vapor from the Pacific and Indian Oceans to the Asia monsoon region, which greatly affects the rainfall and water budget in the region (Elegene and Jongnam, 2003; Fu et al., 2006b; Fu et al., 2008).

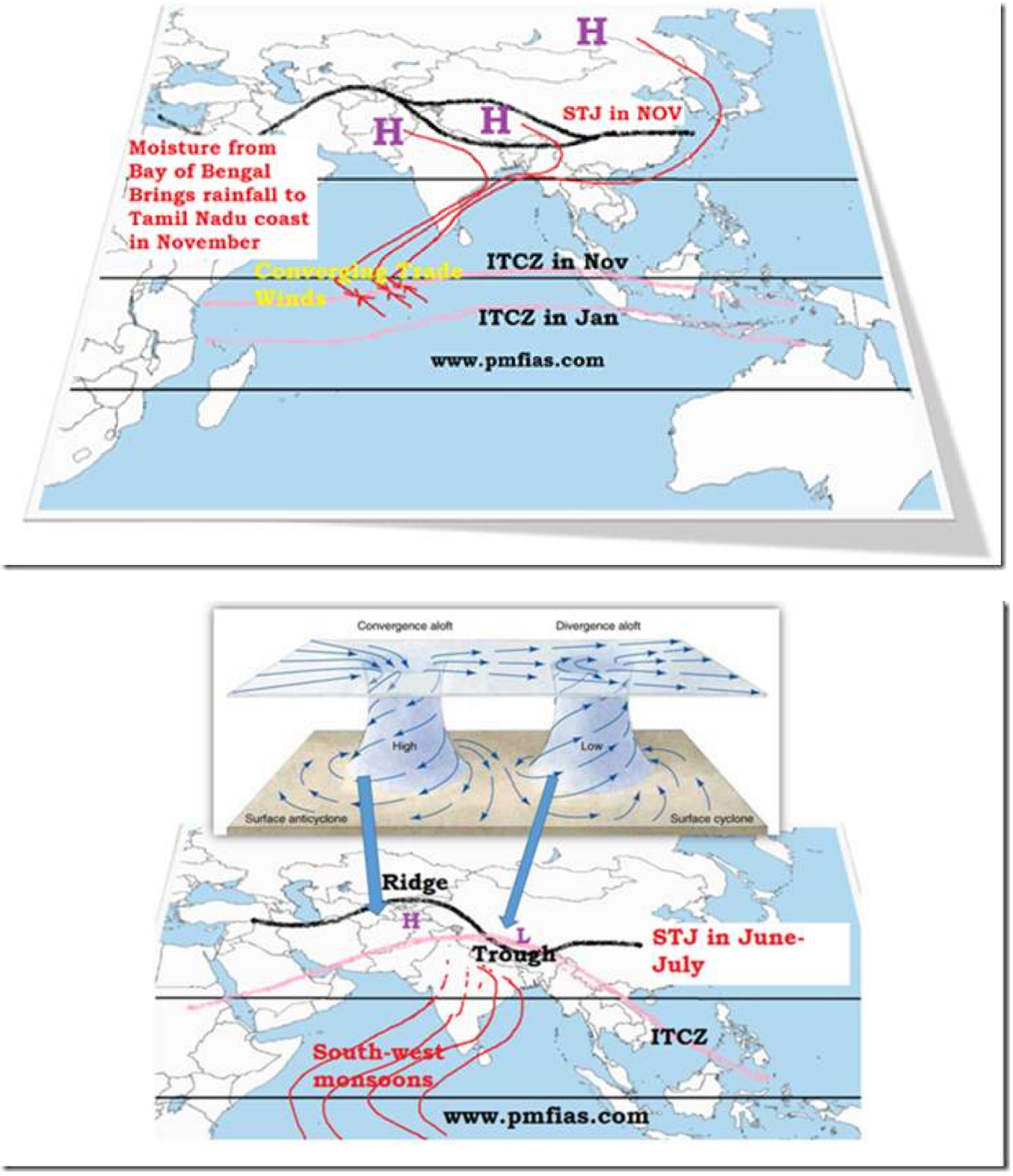


Fig. 8 Monsoon circulation in January and June with oceanic intertropical convergence zone (ITCZ). Source: www.pmfias.com

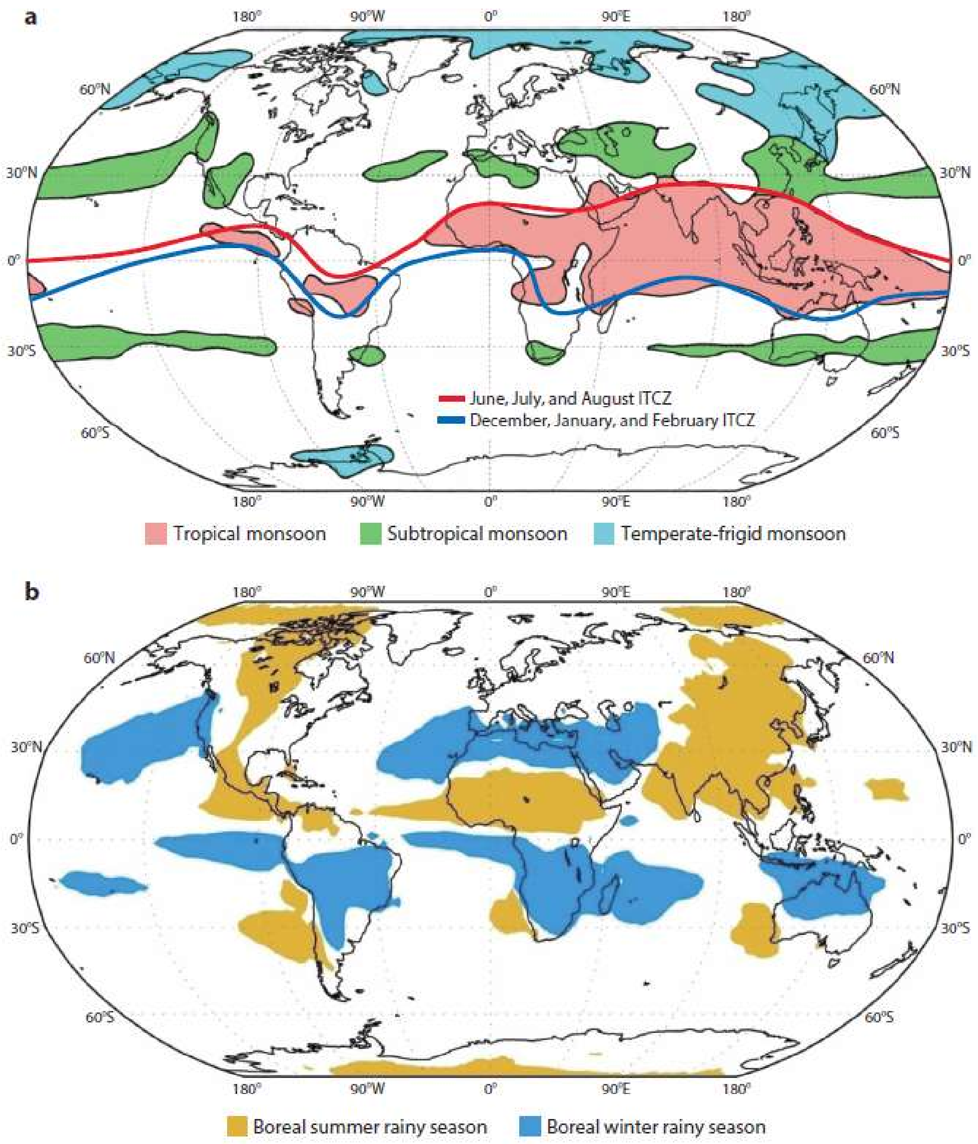


Fig. 9 Geographical extent of the global surface monsoons. The red and blue thick lines represent the ITCZ in summer and the winter respectively. The southwesterly and southeasterly monsoons converge in the Asian-Australian monsoon region (0◦–20◦N, 140◦E–20◦W) within the **Northern Hemisphere** in June, July, and August (JJA). It reverses to a northeasterly wind in December, January, and February (DJF), with prevailing northwesterlies in the **Southern Hemisphere** (0◦–10◦S, 20◦E–160◦E). (Charney and Shuika 198; An et al., 2015).

The Asian monsoon front is an important geoclimatic boundary that divides coastal mid-latitude Asia into two distinct climatic regimes; northwest of the front is under a strong influence of the Siberian (continental) air mass, characterised by low humidity and large seasonal temperature variability, whereas southeast of the front is governed by the Pacific (oceanic) air mass, characterised by wet and smaller seasonal temperature variability (Webster, 1987; Ruddiman and Kutzbach, 1991; Kau et al., 2003; Nakagawa et al., 2006; Li et al., 2010; Chen et al., 2014). The climate of the

West Pacific and coastal East Asia tends to be characterised by clear seasonality because the monsoon front seasonally migrates across these regions (Webster, 1987; Ruddiman and Kutzbach, 1991; Nakagawa et al., 2006). The East-Asian monsoon consists of Southeast-Asian summer monsoon and winter monsoon (Hamilton, 1977; An et al., 2015). The first is driven by warm moist air mass over the subtropical and tropical SE-Pacific in summer (Hamilton, 1977; Hoyos and Webster, 2007; Loo et al., 2015). The winter monsoon is driven by the cold dry mass of the Mongolia Siberia high pressure cell in winter. Asian monsoon is a dynamic system tightly coupled to global teleconnections that change their magnitudes at varying timescales (Hahn and Manabe, 1975; Webster, 1987; Harrison et al., 1992; Murphy et al., 1997; Spicer et al., 2003; Harris, 2006). The monsoon circulations (rainfall) undergoes abrupt changes (especially in central Asia) during the Holocene and the last glacial period (Liu et al., 2004; Nakagawa et al., 2006; Levermann et al., 2009; Allen et al., 2010; Zhang et al., 2014).

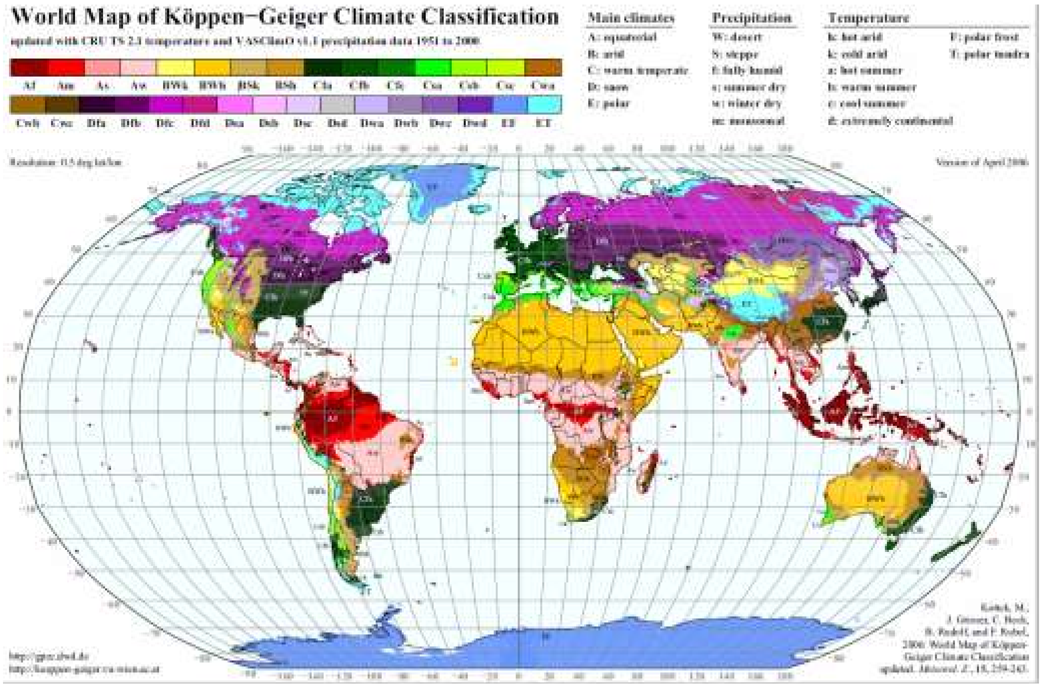


Fig. 10 World map of Köppen- Geiger effective climate classification The light blue colour indicate areas with polar tundra climate based on mean annual temperatures between 0°C and 10° C (Kottek et. al., 2006).

1.2.5 The hydrological significance of Tibetan Plateau

The Himalayas and Tibetan Plateau region (HTP) is “third pole”, due to third largest storage of ice outside the north and south polar regions, radiative energy and climate (Yao et al., 2012a). There are about 46,000 glaciers distributed over the major mountain ranges such as Pamir, Karakoram and Himalaya mountain covering almost 50,000 km^2 on the Tibetan Plateau (Yao et al., 2007b; Yao et al., 2012b). It is a land of many lakes (fresh and saline), wetlands and rivers. It is the origin of Asian great rivers: (Amu Darya, Tarim (Dayan), Indus, Ganges, Brahmaputra (Yarlungtsanpo), Irrawaddy, Salween (Nu), Mekong (Langcang), Yangtze (Jinsha), and Yellow (Huanghe) (Fig. 11) (Yao et al., 1997; Yao and Greenwood, 2009; Chellaney, 2011; Fan et al., 2015). The major rivers flow to 18 downstream countries and contributed to transboundary water resources and ecological security in Asia (He et al., 2014). The Tibetan Plateau significantly contributes to fresh water resources for over 1 billion people through feeding the river systems (Barnett et al., 1988; Viviroli and Weingartner, 2004; Unger-Shayesteh et al., 2013). The Tibetan Plateau is known as the "**Land of Snows**" and "**Water Tower of Asia**" (Fig. 11) (Lu et al., 2005a; Viviroli et al., 2007; Xu et al., 2008b; Qui, 2010; Chellaney, 2011; He et al., 2014). The glacial and snow melt waters are important contributors of water resources (Yao et al., 2004; Barnett et al., 2005; Immerzeel et al., 2010; Immerzeel et al., 2013). The snow and glacial melt are important hydrologic processes in the region and changes in temperature and precipitation will seriously affect the melt water characteristics (Yao et al., 2004; Barnett et al., 2005; Nayar, 2009; Immerzeel et al., 2010; Qui, 2010; Immerzeel et al., 2013). The precipitation in the upstream parts of the basins falls partly in the form of snow, causing a natural delay of river discharge (Viviroli et al., 2003; Immerzeel et al., 2008; Immerzeel and Bierkens, 2010a). Snow cover dynamics on the Qinghai-Tibetan–Plateau may influence the water availability downstream in the major river basins of Asia, specifically in spring at the onset of the (irrigation) growing season (Viviroli et al., 2003; Immerzeel et al., 2008; Immerzeel and Bierkens, 2010a; Qui, 2010)

Fig. 11a The ten Asia's largest rivers originate from Tibetan Plateau (Barnett et al., 2005).

1.2.6 Mountains freshwater resources and climate change

The global climate warming rate in 21st century is increasing temperature (e.g., 1° to 4° C rise in global average temperature by 2100) and largest effect on precipitation (Fig. 12-13) (Giorgi et al., 1997; Gitay et al., 2002; IPCC, 2007a; Bates et al., 2008; Xu et al., 2008a; Giorgi et al., 2011). The amount of freshwater on Earth is finite, but its distribution varied driven by primarily natural cycles of freezing and thawing and fluctuations in precipitation, water runoff patterns and evapotranspiration (Ford and Thornton, 1992; Connor et al., 2009; Coates, 2010; Wang et al., 2012a). Water is important to the health of human and aquatic ecosystems (Cosgrove, 2007; Connor et al., 2009; Coates, 2010). Climate Change (long term temperature fluctuation) is the main drivers of changing in water resources (Ford and Thornton, 1992; Connor et al., 2009; Coates, 2010; Lee et al., 2015). The climate change is prominent in Asia region (Cruz et al., 2007). Climate change caused by human activities (increasing carbon dioxide via burning of fuel fossils) affects ecosystems (e.g., sustainability and environmental disruptions) and people (e.g., economic loss, health problems) mainly by affecting water availability (e.g., increase frequency and intensity of heat waves and extreme events; flooding-heavy precipitation and drought-less rainfall) (Gitay et al., 2002; UNEP/GRID-Arendal, 2005; Cruz et al., 2007; Meehl et al., 2007; UNFCCC, 2007; Connor et al., 2009).

The global mountains (principal source of freshwater resources) are the major headwaters of the world (Fig. 15a-c and Fig. 17-18)(Lee et al., 2015). The mountain glaciers are indicators for climate change (Gitay et al., 2002; IPCC, 2007a; Kohler and Maselli, 2009). The climate change is expected to intensify the hydrological cycle (e.g., more precipitation and more evapotranspiration) especially in high-mountains region (e. g., Himalayan-Tibetan Plateau) (Gitay et al., 2002; IPCC, 2007a; Bates et al., 2008; Kohler and Maselli, 2009). Snow and ice accumulation in mountain areas determine for a large part the surface hydrology and the temporal distribution of the availability of water (Fig. 16) (Barnett et al., 1988; Gitay et al., 2002; Viviroli and Weingartner, 2004; Barnett et al., 2005). The hydrological function will be altered with a significant rise in surface air temperatures. Increased melting of sea ice and freshwater influx from melting glaciers and ice sheets also has the potential to influence global patterns of ocean circulation (UNEP/GRID-Arendal, 2005; Meehl et al., 2007; UNFCCC, 2007; Connor et al., 2009). The warming is expected to be greatest over land and at most high northern latitudes, where snow cover is projected to shrink and hot temperature extremes, heat waves, and heavy precipitation events will continue to become more frequent in mountain basins (Barnett et al., 2005; IPCC, 2007a; Bates et al., 2008; UNEP, 2012). The diminishing role of snow and ice as a natural store for water supply will have a tremendous impact (e.g., melting of glaciers in Himalayas-Tibetan Plateau) (Fig.17a-b) (Singh and Bengtsson, 2004; Arora et al., 2008; Nayar, 2009; Kaser et al., 2010). The spatial variation in observed and projected climate change is large and mountain ranges and their downstream areas are particularly vulnerable due to:

- The rate of warming in the lower troposphere increases with altitude, i.e. temperatures rise in high mountains is greater than at low altitudes (Bradley, 1985; Giorgi et al., 1997).
- There is a large high natural variation in climate because of the large difference in altitudes over small horizontal distances. This renders mountain areas more susceptible to climate change (Beniston, 1994).
- Mountains play an important role in the water supply to downstream areas. About

1.3 billion people depends on water supplied by mountains and changes in hydrology and water availability are expected to be large in mountain basins (Fig. 15a-c, and 16-17a-b) (Viviroli et al., 2003; Viviroli and Weingartner, 2004; Barnett et al., 2005; Viviroli et al., 2011).

Climate change will lead to an intensification of the global hydrological cycle, which will affect local, regional and global water resources (Arnell, 1999; Vörösmarty and Sahagian, 2000; Arnell et al., 2001; Dai and Trenberth, 2002; Arnell, 2004; Viviroli et al., 2011). For instance, human activities are releasing tiny particles (aerosols) into the atmosphere. The aerosols enhance scattering and absorption of solar radiation. They also produce brighter clouds that are less efficient at releasing precipitation. These in turn lead to large reductions in the amount of solar irradiance reaching Earth's surface, a corresponding increase in solar heating of the atmosphere, changes in the atmospheric temperature structure, suppression of rainfall and less efficient removal of pollutants (Chou and Lan, 2012; Trenberth et al., 2015). These aerosol effects can lead to a weaker hydrological cycle, which connects directly to availability and quality of fresh water, a major environmental issue of the 21st century (Sokolik and Toon, 1996; Kulshreshtha, 1998; Toon, 2000; Ramanathan et al., 2005).

Global warming, due to the enhanced greenhouse gases (e.g., carbon dioxide), is likely to have significant impacts on the hydrological cycle (IPCC, 1996; Trenberth, 1998; Alverson et al., 2000; Bates et al., 2008; Trenberth, 2011). The hydrological processes (water cycle) will be intensified, with more evaporation and more precipitation, but the extra precipitation will be unequally distributed across the globe (Trenberth, 1999b, a; Adam et al., 2006; Sanderson et al., 2011). There are different levels of precipitation variability (extreme events, intensity and frequency); (i) major alterations in the timing of wet and dry seasons (ii) spatial and temporal and (iii) local, region and global. Some parts of the world may experience significant intense precipitation (flooding) while other regions could have reduced precipitation (droughts) (Trenberth, 1998; Trenberth et al., 2003; Trenberth, 2011). The change in mean precipitation is associated with changes not only in precipitation intensity but also in precipitation frequency (Solomon et al., 2009; Wang et al., 2012a; Lee et al., 2014). Changes in the total amount of precipitation (frequency and intensity) directly affect the magnitude and timing of run-off and the intensity of floods and droughts (Trenberth, 1998). However, at present, specific regional effects are uncertain (IPCC, 1996, 2001; Trenberth et al., 2003; IPCC, 2007b; Schewe et al., 2014).

Water vapor is an important greenhouse gas (Kiehl and Trenberth, 1997). Changes in water vapor amount is a major determinant of earth's climate (radiation and energy feedbacks) and moisture dynamics (Held and Soden, 2000; Trenberth et al., 2005; Held and Soden, 2006; Voigt and Shaw, 2015). The Clausius–Clapeyron equation predicted a temperature increases by 1K and the water-holding capacity of the atmosphere to increases by 7.8 % (Trenberth et al., 2005; Voigt and Shaw, 2015). Climate warming has intensified the moisture in the atmosphere (Trenberth et al., 2003; Stephens and L'Ecuyer, 2015). There are extreme precipitation events (especially in arid to semiarid regions) due to global warming (IPCC, 2007b). Atmospheric moisture contributes to 70 to 90% of precipitation (Trenberth et al., 2005; van der Ent et al., 2010). The water vapor in the lower troposphere is a crucial factor for precipitation and precipitation releases latent heat, which affects the diabatic heating structure in the troposphere (Kiehl and Trenberth, 1997; Held and Soden, 2000; Trenberth and Stepaniak, 2003). The availability of water is determined by the amount of precipitations (Krishnamurti and Biswas, 2006; Trenberth and Fasullo, 2013). Changes in precipitation have impacts on societies, economies and ecosystems (Hoyos and Webster, 2007; Wang et al., 2012b). The response of precipitation to global warming is a critical issue in climate science (Voigt and Shaw, 2015). Climate models robustly project an increase of global-mean precipitation at a rate of 1–3% per degree warming (IPCC, 2001; Held and Soden, 2006).

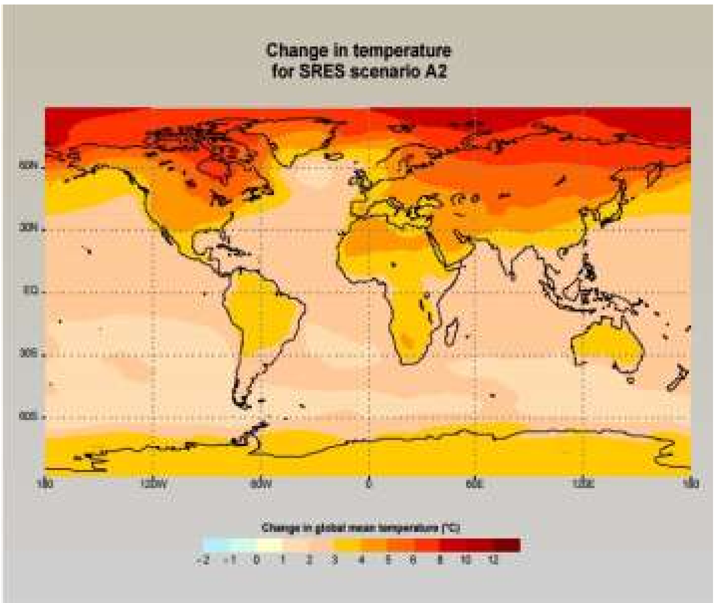


Fig. 12 Annual mean change in temperature for the SREs; indicating the period 2071-2100 relative to the period 1961-1990. The projections based on atmospheric general circulation models. The global mean annual average warming of the models is 1.2- 4.5°C for A2 (Gitay et al., 2002).

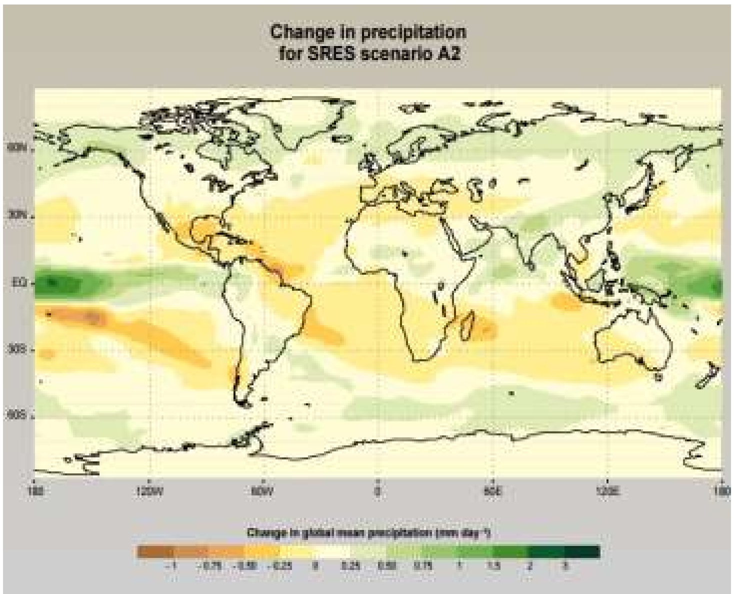
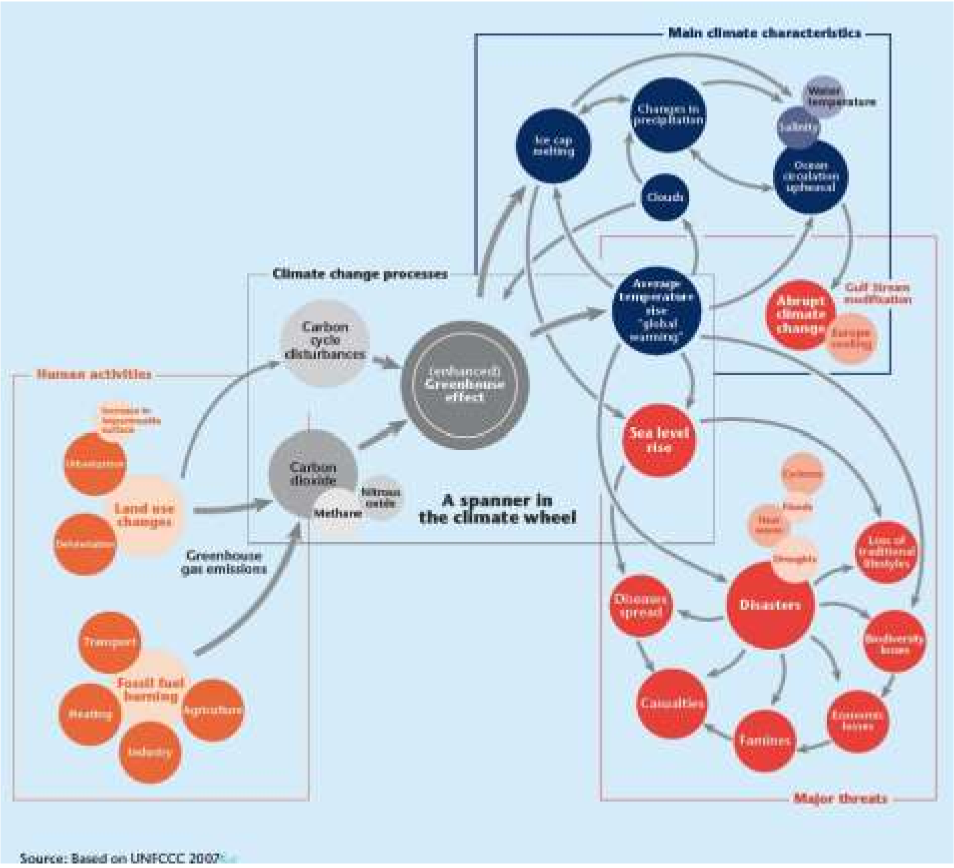


Fig. 13 Annual mean change of precipitation for the SRES scenario A2; the period of 2071-2100 relative to the period 1961-1990. The projections based on atmospheric general circulation models. (Gitay et al., 2002; fig. 5).



Source: Based on UNFCCC 2007

Fig. 14 Climate change: processes, characteristics and threats. **Source**: UNEP/GRID–Arendal, 'Climate change: processes, characteristics and threats', http://maps.grida.no/go/graphic/climate_change_processes_characteristics_and_threats (UNEP/GRID–Arendal, 2005; UNFCCC; 2007; fig. 11-1).

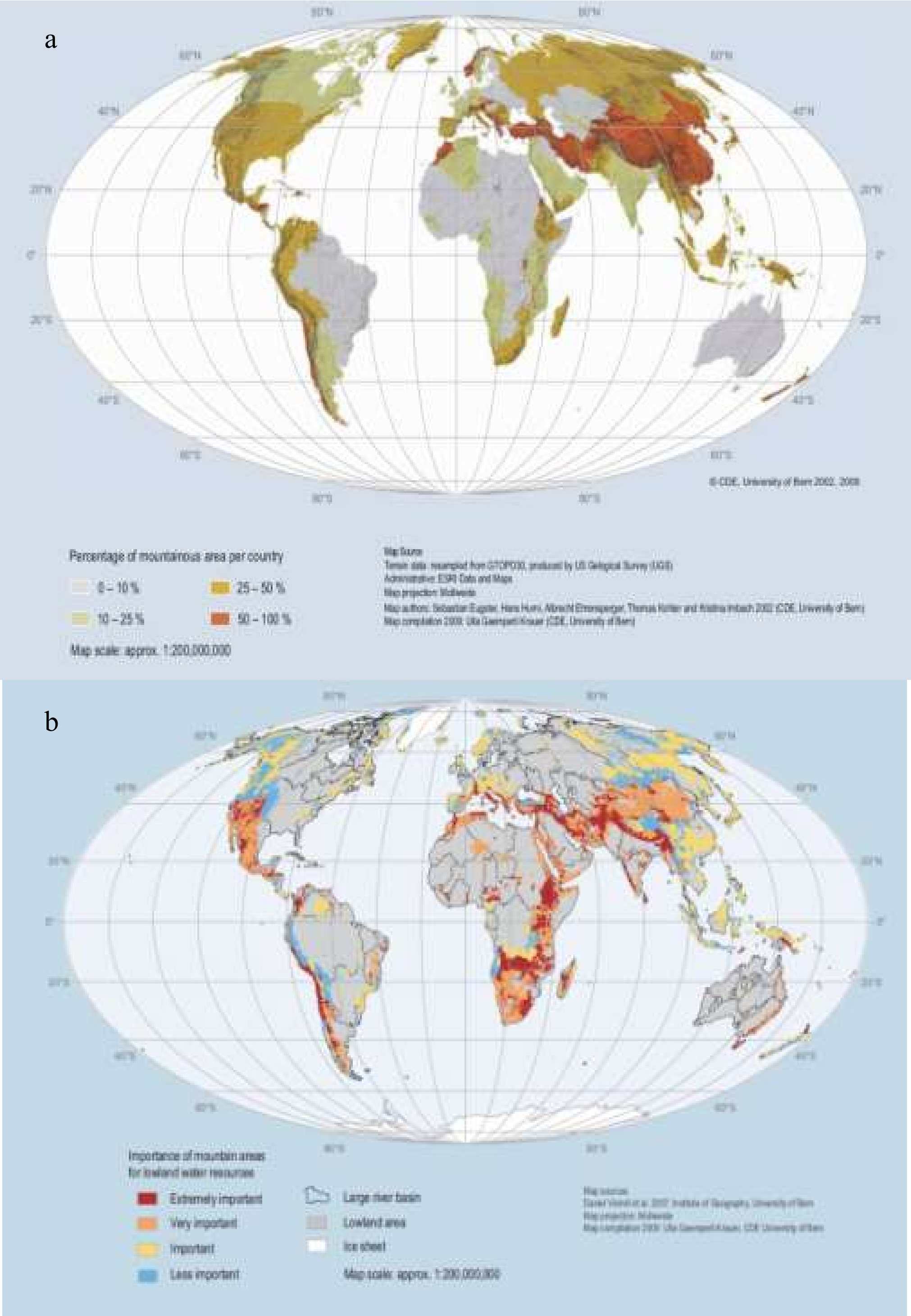


Fig. 15a-b Importance of mountains as "Water Towers" of the world (Viviroli et al., 2003; Kohler and Maselli, 2009).

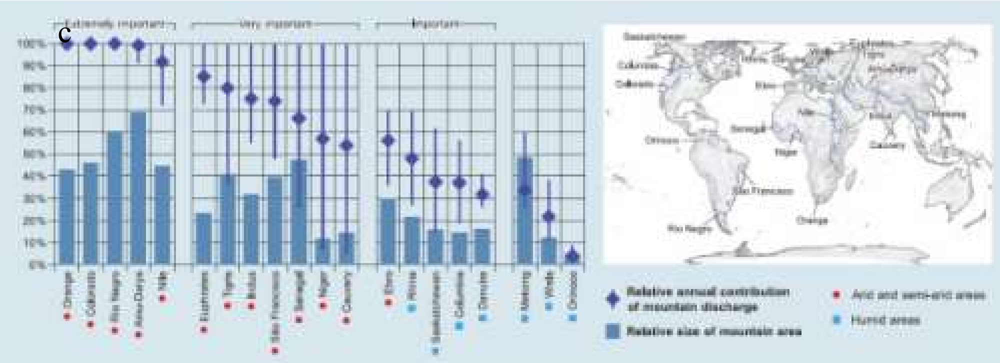


Fig.15c Contribution mountain area to total discharge, and size of mountain area as compared to total basin area for selected rivers world-wide (Viviroli et al., 2003; Kohler and Maselli, 2009).

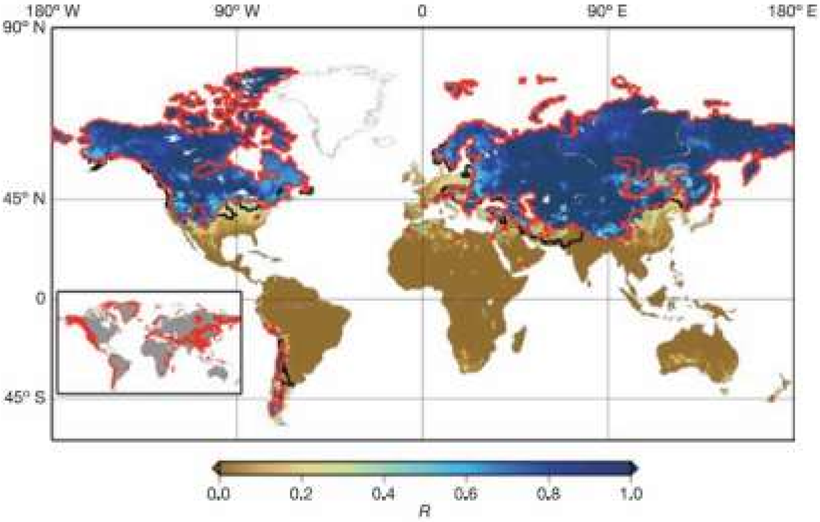


Fig. 16 Accumulated annual snowfall divided by annual runoff over the global land regions. The value of this dimensionless ratio lies between 0 and 1 and is given by the colour scale, R. The red lines indicate the regions where streamflow is snowmelt-dominated, and where there is not adequate reservoir storage capacity to buffer shifts in the seasonal hydrograph. The **black** lines indicate additional areas where water availability is predominantly influenced by snowmelt generated upstream (but runoff generated within these areas is not snowmelt-dominated). The inset indicates regions of the globe that have complex topography (Adam et al., 2006; fig.1 Barnett et al. 2005; fig.1).

On a regional scale, the precipitation enhancement occurs worldwide, except for the two zonal bands (30°S and 30°N; reduced precipitation), with different variability (Chou and Lan, 2012; Voigt and Shaw, 2015). The annual precipitation enhancement is mainly associated with larger upward trends of maximum precipitation, smaller upward trends and downward trends of minimum precipitation (Chou and Lan, 2012). The dominant mechanism is vertical moisture advection, both on regional and global scale (Chou and Lan, 2012). The vertical moisture advection and moisture convergence induced by vertical motion are influenced by two processes; (i) the thermodynamic component, which is associated with increased water vapor and (ii) the dynamic component, which is associated with changes in circulation (Chou and Lan, 2012). The thermodynamic component enhances the annual precipitation, while the dynamic component tends to reduce it (Chou and Lan, 2012). Evaporation has a positive contribution to both maximum and minimum precipitation and a smaller effect to the annual precipitation (Chou and Lan, 2012). Evaporation and horizontal moisture advection are important on a regional basis and have a small effect on a global scale (Chou and Lan, 2012).

The Tibetan Plateau precipitation variability will potentially affect the socio-economic activities (e.g., food security, safe drinking, agriculture farming), increased water stress (health of aquatic ecosystems and biodiversity) and more than 2 billion people in the bordering countries (Fig.17-18) (Yanai et al., 1992; Webster et al., 1998; Qian et al., 2011). For example, one-quarter of the population of China lives in the western regions, where glacial melt provides the primary water source during the dry season (Gao et al., 2012). The climate warming will affect glacial melt and the river flow regimes due to hydrological extremes (Fig. 17-18) (Haines et al., 1988; Kattleman, 1989; Liu et al., 2007; Yang et al., 2014a). The glaciers in Himalayans-Tibetan Plateau region are retreating at a faster rate and predicted to disappear completely by 2035 (Fig. 17b) (Cruz et al., 2007; Meehl et al., 2007; Nayar, 2009; Qui, 2010). The warming may cause early melting and rising of floods in winter and prolong summer drought (Trenberth, 2011; Immerzeel et al., 2013; Manandhar et al., 2013; Yang et al., 2014a). Local climate warming promotes vegetation growth and accelerates land degradation by affecting water conditions (increase in evapotranspiration) (Zhang et al., 1996; Schickhoff, 2000; Du et al., 2004).

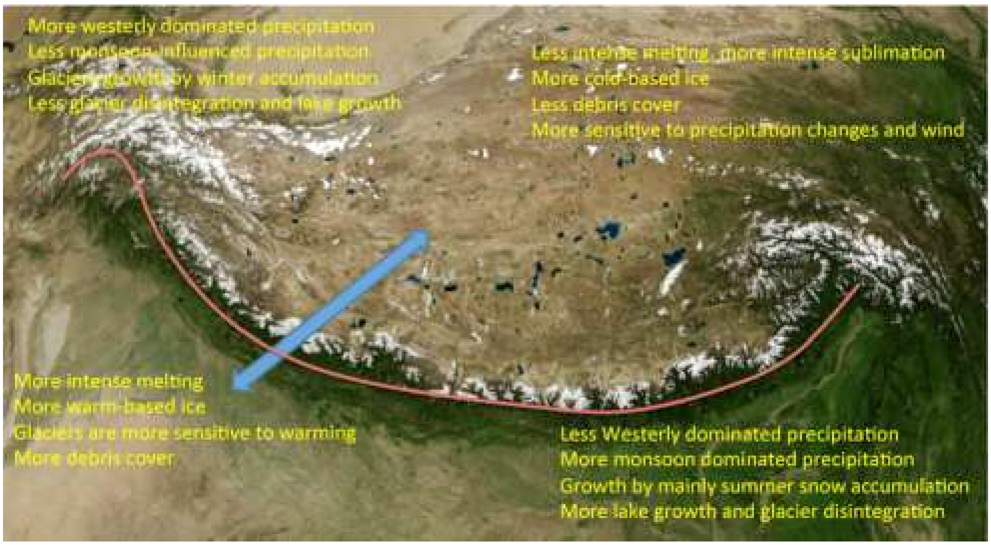


Fig. 17a Climatic variations in the Himalaya-Tibetan Plateau region. The climate differs between the east and west and between the north and south, with variations in sources and type of precipitation and in glacier behaviour and dynamics. Background image from ESRI ArcGlobe 10.0. (Barnet et al., 2006; UNEP, 2012; **fig. 5**;).

Fig. 17b. Melting of glaciers in mountainous region (Nayar, 2009).

Fig. 18 Predicted percentage of glacial melts contributing to basin flows in the Himalayan-Tibetan Plateau basins. Shape files superimposed on background image from ESRI ArcGlobe 10.0 (Xu et al., 2008a; UNEP, 2012).

1.3 Quaternary environmental change

The Quaternary Period (Pleistocene and Holocene) is characterised by great variability in environmental and climate in the Earth history (e.g., continental ice sheets, sea level and lake level fluctuations) (Bradley, 1985; Dawson, 1992; Mann, 2002; Bell and Walker, 2005; Anderson et al., 2007). The Quaternary period (last 2.6 million years) alternate between the great cold (glacial, stadials) and with relatively greater warmth (interglacials, interstadials) due to the differences in mean temperature (Bowen, 1978; Bradley, 1985; Dawson, 1992; Bell and Walker, 2005).The Quaternary is subdivision of the geological time which includes the present day (Bowen, 1978; Karl et al., 1989; Bradley, 1990; Alverson, 2007). The contemporary surrounding is part of the Little Ice Age (Bowen, 1978; Karl et al., 1989; Bradley, 1990; Alverson, 2007). The modern environment and organism is used as reference to draw conclusions from ancient ecosystems and its biota. The contempeorary processes and spatial distributions serve as the basis for the inference about the prehistorical ecological, geological and climatic shift (Bowen, 1978; Karl et al., 1989; Bradley, 1990; Alverson, 2007)

The Tibetan Plateau is sensitive to global climate change (e.g., temperature rise) during Quaternary (Yao and Meixue, 2004; Mischke and Zhang, 2010; Zhu et al., 2015). High lake-water-levels across in Africa, Arabia and India (monsoon rains over the Sahara and the Indian subcontinent (between 10,000 and 5000 years B.P., before present) is evidence strengthen of monsoon climate with subsequent weak monsoons and glacial maximum at 18,000 years BP (Street and Grove, 1979; An, 2000). However, the Holocene (wholly recent) environmental and climatic records from Tibetan Plateau are still inadequate (Zheng et al., 2000a; Liu et al., 2002a; Overpeck et al., 2005; Herzschuh et al., 2006; Morrill et al., 2006).

Understanding of monsoon variability is critical due to climate change effect on water resources (Liu et al., 2012; Wang et al., 2012a). Direct measurement of precipitation (hydrological monitoring) on longer time scale (millennial to decadal) is lacking (Karl et al., 1989; Lee et al., 2014). Therefore, indirect inference, proxy archives (ice cores, lake sediments, biological organism) are often used to assess past natural variability of monsoon (hydrology), aquatic ecosystems, environment and climate dynamics on Tibetan Plateau (Mischke et al., 2008b; Gornitz, 2009). Palaeoclimate records (ice cores and lake sediment and ostracods) showed significant climate fluctuations over the Tibetan Plateau during the Late Glacial and Holocene period (Thompson et al., 1997; Yao and Meixue, 2004; Jin et al., 2011; Bird et al., 2014). The majority of Holocene environmental evolution is reconstructed from lake records in the northeastern and western Tibetan Plateau (Gasse et al., 1991; Lister et al., 1991; Li et al., 1994; Gasse et al., 1996). There are few palaeo-records from southern Tibetan Plateau (Mischke and Herzschuh, 2003; Guo et al., 2013; Ma et al., 2014b). The reconstruction environmental and climate history is significance to understanding past climate events, recent climate change and forecasting future climate variations (Karl et al., 1989; Bradley, 1990).

The Quaternary environment is characterised by cold climate in the early to middle glacial period with increased precipitation and cold dry climate in late period (Gu et al., 1993; Rost, 2000; Mann, 2002; Mischke and Zhang, 2010). During the last glaciations, maximum advancement of small glaciers occurs at relatively humid and cold period between ca. 32 and 23 ka (Derbyshire, 1996; Rost, 2000; Larocque-Tobler et al., 2010). The dry cold stage between ca. 23 and 13 ka is characterised by slower glacial advancement (Derbyshire, 1996; Rost, 2000; Larocque-Tobler et al., 2010). The Quaternary environment is primarily characterised **two phases; first, glacial period**, cold dry winter monsoon climate and **second interglacial period**, a warmer and more humid climate (Derbyshire, 1996; Rost, 2000; Larocque-Tobler et al., 2010). The past monsoon dynamics is reconstructed from palaeohydrology, periglacial dynamics, dust flux and soil formation and sedimentations (e.g., lake sediments, alluvial terraces and palaeo-shorelines) (Derbyshire, 1996; Larocque-Tobler et al., 2010).

There was a strong abrupt rainfall change in China and India during the Holocene and last glacial period (Gasse and Derbyshire, 1996; Owen et al., 2005; Levermann et al., 2009; Amidon et al., 2013). The last interglacial is associated with an increase of precipitation throughout Asia (Owen et al., 2005; Amidon et al., 2013). Marine Isotopic Stage 4 provides no evidence whatsoever of humid conditions. Two wetter episodes occurred during Stage 3. A major rainfall decrease everywhere is associated with the Last Glacial Maximum (21-15 ka in most regions), the arid or semi-arid zones extending several hundred kilometers southwards, relative to the present-day pattern (Owen et al., 2005; Amidon et al., 2013). The two abrupt deglaciations and the Younger Dryas are recorded in all of the most sensitive regions, at the margins of the present-day monsoonal range in Asia. During the Holocene, the precipitation increased everywhere (by 100-400 mm, relative to the present-day values), the optimum at 8.5-6.5 ka (Yan and Petit-Maire, 1994). A climatic deterioration indicates an irregular pattern of dry/wet episodes due to different geographic conditions. The humid phase terminated at 3.5-3 ka in the whole transitional zone (Yan and Petit-Maire, 1994). Temperature rise rapidly and gradually fall during the last inter-glacial period. (Thompson, 1992; Herzschuh et al., 2011; Yao et al., 2012b). The environmental and climatic change is also linked to early Holocene insolation maximum in low latitudes of the northern hemisphere and the strengthening of monsoons (Berger and Loutre, 1991). Nonetheless, there spatial heterogeneous in Holocene climate evolution on the Tibetan Plateau (Zheng et al., 2000a; Wu et al., 2006; Mischke et al., 2008b; Zhao et al., 2011).

Temperature had been rising gradually in the last 2000 years and sharp rise in recent decades causing a warm late Holocene (Thompson et al., 2000; Thompson et al., 2006; Wang et al., 2007). There are different time scales of climate change on the Tibetan Plateau (Davis and Thompson, 2004; Bird et al., 2014). There are also spatial differences and regional heterogeneity in monsoon dynamics in the Tibetan Plateau during the Late Glacial and Holocene (Owen et al., 2005; Mischke and Zhang, 2010; Amidon et al., 2013; Ma et al., 2014a). The inconsistencies may be due to spatial (local) and region differences in geomorphology of study sites (e.g., type of basin, geophysical features and hydrologic sensitivity), monsoons circulations and analytical techniques employed (e.g., number of cores, types of evidence and type of dating) (Duan et al., 2012; Mischke, 2012; Yang et al., 2014a; Mischke et al., 2015).

1.3.1 Environmental Reconstruction: lake system and its biota

Quaternary environmental change can be reconstructed with surface fresh water indicators (e.g., lake sediments, freshwater shells, ostracods, pollens and diatoms (Larocque-Tobler et al., 2010; Moss, 2010; Lowe et al., 2014). There more than 300 lakes with surface areas greater than 10 km^2 on the Tibetan Plateau (Yu et al., 2001a). Lake evolution is significance in the study of global environmental change (Zhu et al., 2004). Lake is an inland body of water (Smol, 2002). Modern lakes are often reffered as “indland seas” (Smol, 2002). Lake response to climatic forcing through physical, chemical and biological effects is recorded within the system (Talbot and Allen, 1996; Anderson et al., 2007; Gary, 2009).

The area of a closed basin lake represents equilibrium between runoff from the catchment and the water deficit over the lake surface (Street-Perrott and Harrison, 1985; Lodge, 2001). Closed lakes are indicators of hydrological changes (Chen et al., 2008). The expansion and shrinkage of closed lakes are a natural response to punctuations in precipitation and evaporation, linked closely to changes in strength and position of atmospheric circulation (Chen et al., 2008). In closed lake basins, especially in sub-humid to semi-arid regions, the volume and chemistry of lake water are sensitive to the ratio of precipitation to evaporation over the catchment, which is, in turn, closely coupled to climate (Smith, 1992; Gary, 2009). In open lake basins, the water balance is complicated by contributions from surface and subsurface inflows and outflows (Gary, 2009). Nonetheless, this depends on the hydrology of a lake. Closed basin lakes may only preserve low-frequency changes depending on the residence time, whereas open lakes may show high-frequency changes but with small amplitude so difficult to decipher (Emi Ito personal communication).

Lake sediments preserve physical, chemical and biological information for reconstruction of past aquatic environments (Smol et al., 2001; Fritz, 2003; Williamson et al., 2009; Juggins and Birks, 2012). Lake sediments also record other types of environmental information such as catchment disturbance and nutrient status (Talbot and Allen, 1996). Variations in these characteristics may be climatically controlled and related to human activity (Holmes, 1992). Lake sediments are natural archives for reconstruction of past environmental and climate impacts (Talbot and Allen, 1996; Lodge, 2001; Schindler, 2009). Lakes provide continuous and long records of sediment accumulation over time (Last et al., 2001). Lake sediments are particularly suited for climate reconstruction as both high (decades to centuries) and low-frequency (thousands of years) climate variability components are preserved in the sediments (Talbot and Allen, 1996; Lodge, 2001; Schindler, 2009).

All biological species occur in a given habitat with limited range of environmental factors and are most abundant with particular environmental optimum (Walter and Hengeveld, 2014). Therefore, a change in compositions of biological communities is influenced by a change in environmental variables (Walter and Hengeveld, 2014). Fauna successive (species replacement) is due to variation in the environments and time (ter braak and Prentice 1988). Biostratigraphic units is characterised by one or more fossil species, which described specific depositional environment. Quantitative reconstruction is expressed by the value of an environmental variable as a function of biological proxy data (e.g., ostracod assemblages) (Birks, 2003). The proxy data are expressed as quantitative counts (percentages, or proportions, estimate of relative abundance and presence and absence) (Birks, 1998; Birks, 2003). Qualitative studies involve indicator fauna and different biological indices (diversity) (Birks, 2003). Species specific abundances change with change in environment. Species abundance is influenced by more than one environmental variable (Birks, 2003).

Understanding lake system and their organisms response is critical to understanding of ecosystem dynamics, policy formulation, water resources management and biodiversity conservation in the face of climate change (Haigh, 1989; Vorosmarty et al., 2000; von Storch, 2009; Grafton et al., 2013).

1.3.2. Tangra Yumco

Tangra Yumco (86°23′–86°49′E, 30°45′–31°22′N and average elevation of 4600 m a.s.l) is one of the three largest saline ancient lakes on the southern Tibetan Plateau (Fig. 19a-c). It is situated about 100 km east of Zhari Nam Co and about 450 km northwest of Lhasa in the Tibet Autonomous Region of China, Nima County (Fig. 19a-c) (Long et al., 2012).

Tangra Yumco is a holy lake with surface area of 836 km^2 and a catchment of ~8220 km². It is 70 km in length, 20 km in width and with a maximum depth of 214.8 m (Wang et al., 2010b). The lake is an elongated S-shape with two separate parts (northern part, ~220 m is much deeper than the southern, ~100 m) (Wang et al., 2010b). Its maximum extension is ~70 km in north-south direction and ~19 km in west-east direction. The lake has a salinity of 8.2‰ (specific conductivity of 10.6 mS/cm) and pH of 9.6.

Ancient large lakes provide continuous records for the Late Quaternary environmental and climate change (Fig. 19a-c) (Martens, 1994; Zhu et al., 2004; Zhang et al., 2007; Barker, 2009; Günther et al., 2015). Tangra Yumco lake undergoes the strongest Quaternary lake level changes on the Tibetan Plateau (Fig. 19a-b) (Miehe et al., 2011; Miehe et al., 2014). The high palaeo-shorelines, high-stand (e.g., 181–183 m) and massive sedimentary carbonate in the catchment of Tangra Yumco is an indicative of ancient high water events in geological history (Kong et al., 2011b; Möbius, 2011; Long et al., 2012; Rades et al., 2013b; Ahlborn et al., 2015b). The northern catchment of Tangra Yumco is characterised by fossil freshwater stromatolites, indicating high carbonate precipitation in the early Holocene (Peter Frenzel personal communication). The high lake recessional terrace occurs at 4, 700 m a.s.l (by lake sediment and peat records at 160 m above present) during the Pleistocene and Holocene transition (10.1 – 7.6 cal ka B.P.) (Long et al., 2012; Rades et al., 2013b; Miehe et al., 2014; Ahlborn et al., 2015b). However, a deep lake system exist in 11.0- 11.5 cal ka B.P. at 4, 720 m a.s.l (by lake sediment and ostracods records at 180 m above present) with a gradual decrease after the early Holocene maximum (Rades et al., 2013b; Miehe et al., 2014; Ahlborn et al., 2015b).

The cold *Artemisia* steppe climate of Tangra Yumco is chiefly influenced by oceanic India Summer Monsoon, with annual precipitation 500- 600 mm (Miehe et al., 2011; Miehe et al., 2014). (Mischke et al., 2008b). Tangra Yumco is is situation at interaction of three climatic systems, with a major influenced by the India Summer Monsoon (Liu et al., 2007). The Westerly have a minor influence during the winter season. Tangra Yumco has been selected to complete (palaeo)-environmental and climate records (south transect; East to West) on the southern Tibetan Plateau. Palaeoenvironmental reconstructions using multi-proxies (sedimentology, geochemistry and micropaleontology) will help to decipher Late Quaternary environmental and climate variability in Tangra Yumco.

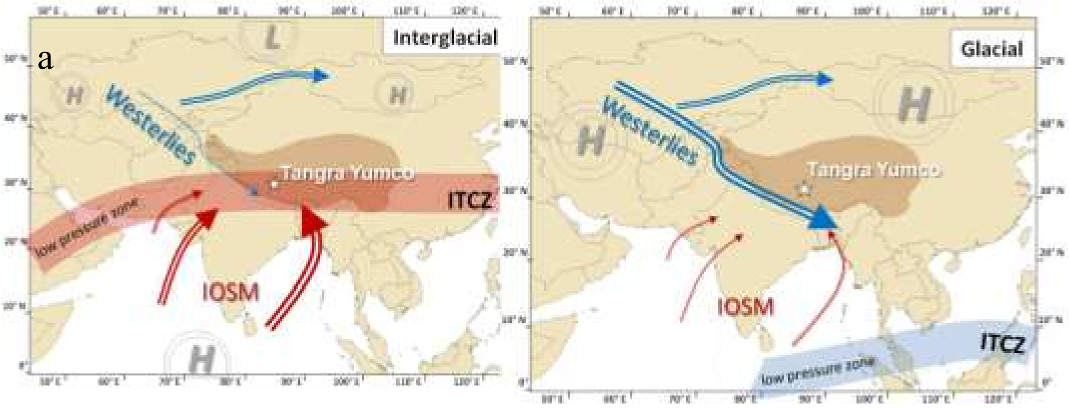


Fig. 19a Quaternary monsoon dynamics (Indian Ocean Summer monsoon and the Westerlies) at Tangra Yumco on the southern Tibetan Plateau. (Modified; Güther et al., 2015).

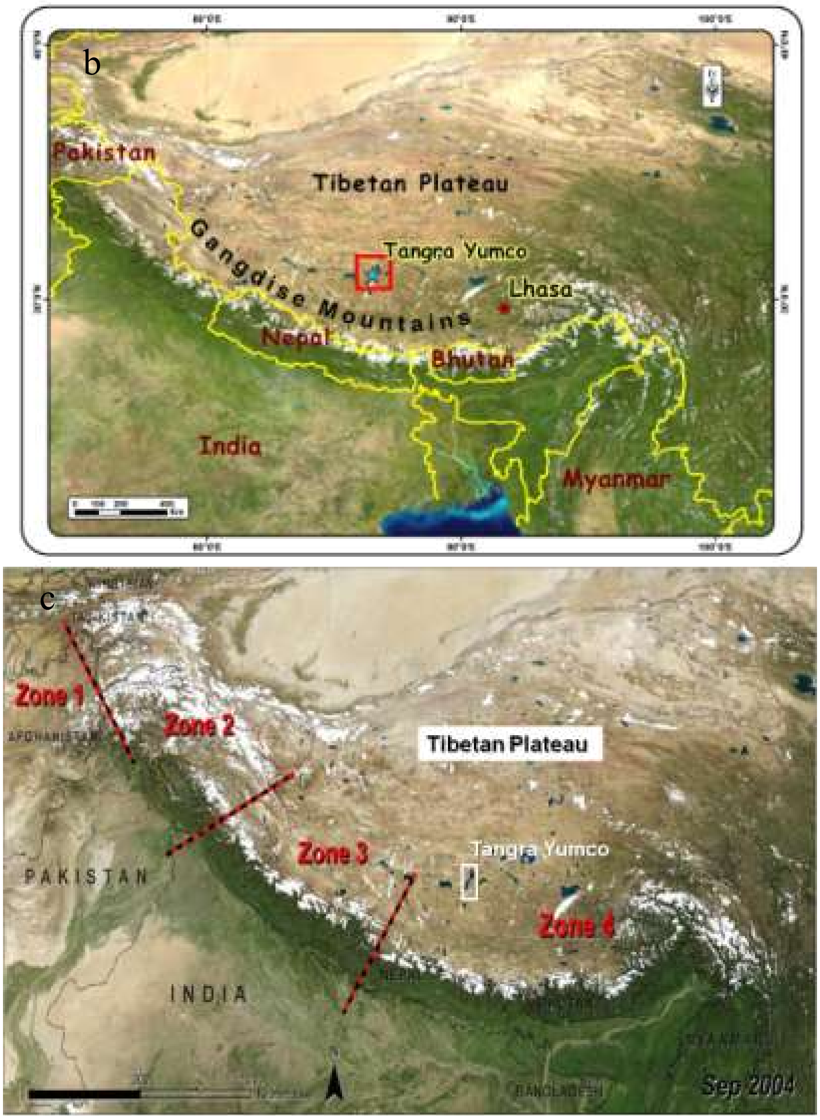


Fig. 19b-c. A Climatic variation (change in glaciers) on **Himalayas-Tibetan Plateau** and insert, location of **Tangra Yumco**: Zone 1 – Mainly in Afghanistan, this area has relatively stable or very slowly retreating glaciers; Zone 2 – The Northwestern Himalayas including the Karakoram have highly varied glacier behaviour, with many surge glaciers, many advancing, stable, and retreating snouts and comparatively few large lakes. Glaciers in the Pamir Mountains of Tajikistan are generally retreating while further south, behaviour of the Karakoram glaciers is mixed, but lacking wholesale, rapid disintegration of glacier tongues and rampant lake growth; Zone 3 – Chiefly in India, southwestern Tibet and western Nepal, this area has mainly stagnating, retreating snouts and time variability with periods of slower retreat for some glaciers during parts of the 20th and 21st centuries. There are fewer lakes than in the eastern Himalayas, but large lakes may be a growing phenomenon as glaciers thin and tend to stagnate and Zone 4 – Primarily Nepal, Bhutan, Sikkim and southeastern Tibet, this area has many large glacier lakes, especially since the 1960s. Many glaciers are rapidly disintegrating as they stagnate and thin. Glaciers on the south side generally have more debris cover than they do on the north side Image from NASA Blue Marble and MODIS data (UNEP, 2012).

1.4 PhD Framework

1.4.1 The Framework of the DFG Priority Program 1372: TiP Tibetan Plateau: Formation – Climate – Ecosystems

This PhD thesis is formulated within joint research “**Lake systems response to Late Quaternary monsoon dynamics on the Tibetan Plateau**”. This is part the German Research Foundation, thus “**Deutschen Forschungsgemeinschaft (DFG)**”, **Priority Programme 1372**; “**Tibetan Plateau: Formation – Climate – Ecosystems (TiP)**” in cooperation with the Institute of Tibetan Plateau Research, Chinese Academy of Sciences. The goal is to evaluate the monsoon climatic history, environmental evolution (past, present and future) and anthropogenic impact on the sensitive ecosystems of the Tibetan Plateau (Fig. 20) (http://www.tip.uni-tuebingen.de/index.php/de). The **key schematics** of TiP are in **three scales**:

I. Plateau formation and climate impact on the ecosystems during the last millions to several tens of millions of years (ca.70 millions years).
II. Late Cenozoic climate evolution and environmental response to monsoon dynamics during the last hundreds of thousands years (decadal to centennial resolution).
III. Human impact and global change on ecosystems dynamics (present, past ca.8000 years, and future perspectives).

Fig. 20 Logos of the TiP Priority Project with focus on the **interlinked arid-environment processes**; **Plateau Formation** – **Climate evolution** — **Human impact** and their driving forces on **ecosystems**.

1.4.2 Thesis outline

The primary objective is to investigate ostracods (tiny aquatic arthropods) as potential biological indicators for environmental reconstructions and environmental monitoring of aquatic ecosystems (e.g., lake evolution and monsoon dynamics) on the southern Tibetan Plateau.

1.4.3 Specific objectives are to:

- Assess Recent ostracod ecology in Tangra Yumco and adjacent aquatic ecosystems.
- Calibrate the valve chemistry of Recent Ostracoda from the southern Tibetan Plateau.
- Evaluate ostracods as bioindicators of subaqueous sediment gravity flows in Tangra Yumco.
- Investigate the Late-Quaternary environment and climate history in Tangra Yumco: Sedimentary and Ostracoda perspective.

1.4.4 Thesis structure

This PhD thesis is structured as:

- Chapter 2 explores the spatial distribution and auto-ecology of Recent Ostracoda from Tangra Yumco and adjacent aquatic habitats (**in press** in Limnologica).

- Chapter 3 evaluates the geochemistry of Recent Ostracods shells from southern Tibetan lakes (**resubmitted**, Hydrobiologia).

- Chapter 4 describes the potential of Ostracoda as indicators of subaqueous mass transport (**publication**, Palaeogeography, Palaeoclimatology, Palaeoecology, 419, 60-74).

  Chapter 5 focuses on multi-discipline (sedimentology, geochemistry and micropaleontology) reconstruction of Late Holocene palaeoenvironmental and climate dynamics in Tangra Yumco (**submitted** to Quaternary Research, December 2015).

  Chapter 6 syntheses of previous chapters (ostracods as environmental indicators of aquatic ecosystem and monsoon dynamics). A new dimension of auto-ecology and (palaeo)-ecology as a great biological tool for interpreting lacustrine environment and climatec change. Finally, highlights on the future outlook of (palaeo)-environmental and climate research. This contributes to understanding of mountain aquatic ecosystems and their microbenthic organisms (e.g., ostracods) and the need for long–term ecological monitoring due to climate change.

Appendix (I-V) is numerical data about bio-chemical and physical factors of the mountain aquatic ecosystems investigated. Numerical data (in tables) coordinates and environmental factors of waterbodies (lakes, rivers, ponds, and springs), living, dead (empty shells) and total association of ostracods, are presented.

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Chapter 2

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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Chapter 2

2.0 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 brackishlacustrine 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 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.

2.1 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, streams, rivers, estuaries, oceans and semi-terrestrial environments (Danielopol, 1989; 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., 1985b; 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) influenced the spatial distribution and abundance of living ostracods. The ecology of Recent Ostracoda is significant in palaeoenvironmental reconstruction on the Tibetan Plateau.

2.2 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. 2.1a). 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, Tab. 2.1). Tangqung Co, Tangra Yumco, Monco Bunnyi, 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 total annual precipitation (~60%) 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 (Tab. 2.1) (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 (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.

Tab. 2.1 Limnological characteristics of Tangqung Co, Tangra Yumco, Monco Bunnyi and Xuru Co. NA = no data available.

	Tangqung Co	**Tangra Yumco**	**Monco Bunnyi**	**Xuru Co**
Other names	Dangqiongco, Tangra Qonco, Small Tangra Yumco	Dangra Yum Tso, Tanghlha Yumco, Yamzho Yumco, Dangre Yongcuo	Mun Tso	Shun Tso
Latitude [°N]	31° 31′ - 31° 37′	30° 45' - 31° 22’	30° 67′	30° 10′ - 31° 36′
Longitude [°E]	86° 41′ - 86° 48′	86° 23' - 86° 49'	86° 22′	86° 15′- 86°29′
Altitude [m a.s.l]	4475	4550	4689	4720
Catchment [km^2]	861	8220	886	1913
Lake surface area [km^2]	57	818	144	206
Maximum depth [m]	NA	230	NA	210°
Conductivity [mS cm^{-1}]	144.8	12.41	3.9	4.0
Salinity	105.0	8.9	2.8	2.9
Mean annual precipitation [mm/yr]	298	305	316	NA
Lake type	hypersaline	mesohaline	oligohaline	oligohaline

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. 2.1). Tangra Yumco is also called Lake Dangra, Dangra Yumtsho, Dangra gyumtsho, Dang-ra 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).

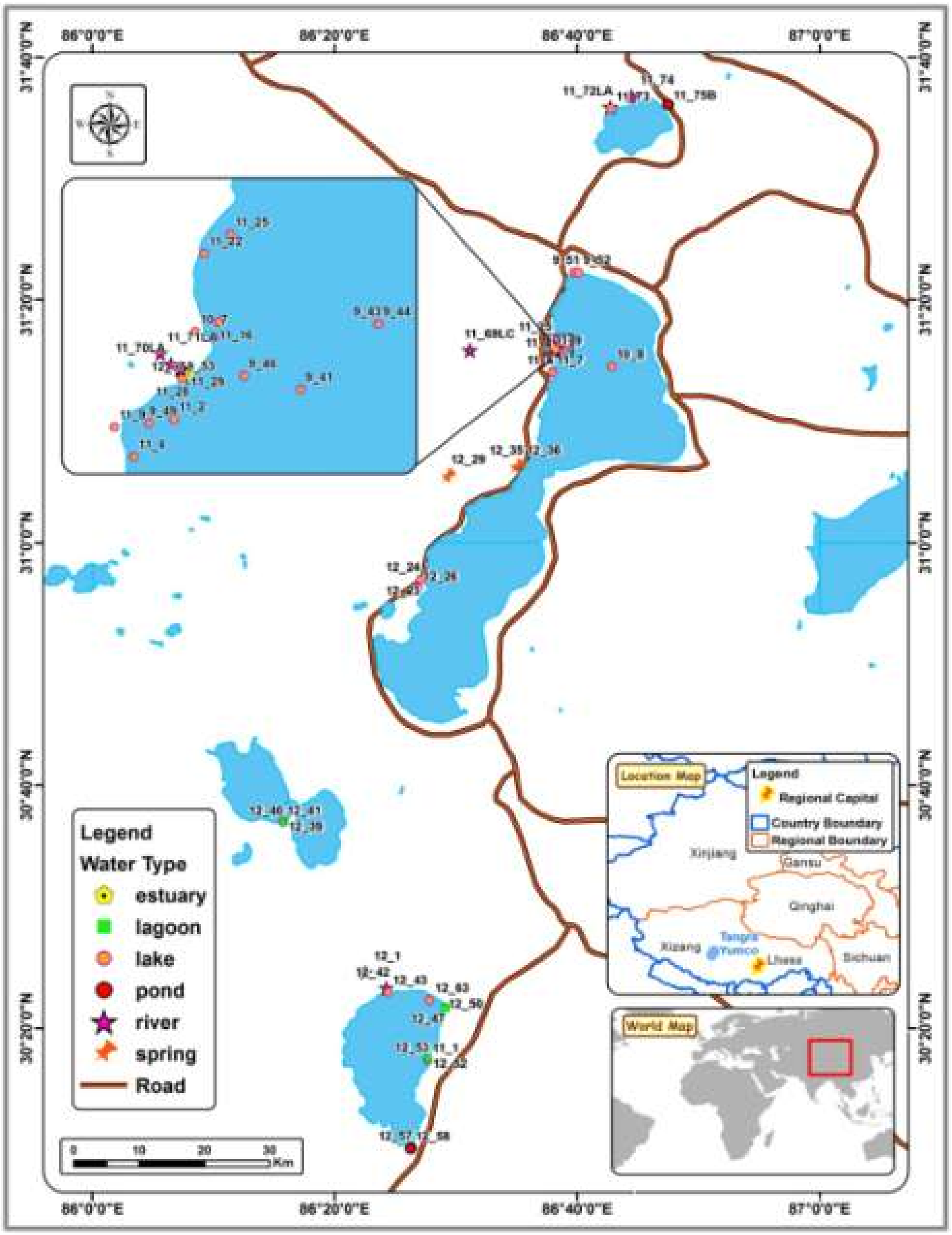


Fig. 2.1 Location of samples (year of sampling and sample number; e.g., 12_1)

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-shoreline 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.

2.3 Materials and methods

2.3.1 Physico-chemical measurements and sediment sampling

The coordinates of the random sampling (altitudes, 4510 – 5091 m above sea level) were obtained using Global Positioning System (Garmin GPS, WGS 84) (see GoogleEarth file, electronic attachment). The samples have been geoarchived at System for Earth Sample Registration (SESAR; www.geosamples.org). A sample can be identified using International Geo Sample Number (IGSN) (http://www.geosamples.org/search_by?group_id=80). Sampling sites represent a variety of aquatic habitats: (i) permanent waters: four lakes – Tangqung Co, Tangra Yumco (major), Monco Bunnyi, and Xuru Co, and (ii) temporary waters (estuary-like water, lagoon-like water, rivers, ponds and springs) connected to the lakes (Fig. 2.1). Sampling was carried out in September 2009, 2010 and 2011 and additionally in June 2012, covering a total land surface area of approximately 165 x 40 km.

Physico-chemical variables (conductivity, water temperature, pH, dissolved oxygen concentration) were measured *in situ* using a *WTW Multi* 340*i* probe. Water-depth (<50 cm) was estimated for shallow aquatic habitats while measured for lake systems using an echo sounder. Salinity was computed from measured specific conductivity by a conversion factor of 0.725 (Hölting, 1992). The alkalinity was determined from a 100 ml aliquot by titration with 0.1 N HCl to pH 4.5 endpoint using the field kit Macherey-Nagel *visocolor HE* Alkalinity AL7 test. The titrated alkalinity of water refers to the total concentration of bases expressed as milliequivalents per liter, where meq/l is 1/50 times mg/L equivalent calcium carbonate ($CaCO_3$) (Maiti, 2001; Snoeyink and Jenkins, 1980). Bio-Environmental data are archived in the EarthChem Library (http://www.earthchem.org/library and http://dx.doi.org/10.1594/IEDA/100482).

Water samples (500 ml each) were collected using a Niskin Bottle Sampler (*KC 60.050)* for chemical analyses. Water samples were filtered through a 0.45 µm pore size Whatman GF/C glass microfiber filter and stored in double capped glass bottles. Filtered water (250 ml per sample) for cation determination was acidified (e.g., nitric acid, HNO_3) (Crompton, 2002), but not acidified for anion measurements and prepared by standard methods (Greenberg et al., 1985; Clesceri et al., 1998). The cation concentrations (Ca^{2+}, Mg^{2+}, Na^+ and K^+) were determined quantitatively using Inductive Coupled Plasma Optical Emission Spectrometry (ICP-OES) (Boss and Fredeen, 1997; Morishige and Kimura, 2008). The anions (Cl^-, SO_4^{2-}) were determined using High Performance Liquid Chromatography (HPLC) (Hou and Jones, 2000). The elemental ionic concentrations (mg/l) were converted to meq/l. The ionic concentration was analysed at Technical University of Braunschweig, Germany.

Sediment samples (uppermost 1 – 2 cm depth) were collected using a Birge-Ekman box-corer (extraction area 15 cm x 15 cm) operated from a small boat on the lakes (Ekman, 1905; Blomqvist, 1990). A hand net (100 µm mesh size) was used in sampling temporary water bodies. Macroflora and meiofauna with associated habitat characteristics were documented. In the field, living ostracods were separated from sediment using an exhauster and then preserved in ethanol (Viehberg, 2002). Sediment samples were immediately preserved in 70 % ethanol for further laboratory processing.

2.3.2 Laboratory processing of sediment and meiofauna analysis

The sediment samples were washed with tap water and filtered through standard-size sieves (200 µm and 500 µm) (Griffiths and Holmes, 2000). The sieve residues were transferred to petri dishes using 99 % ethanol. Living adult ostracods (carapace with well-preserved soft parts) were picked from the wet residues, identified and preserved in 70 % ethanol for future taxonomical description of soft body parts. The residues were dried at room temperature. The empty valves (carapace = two valves) were extracted from the dried residues by hand-picking under a binocular microscope using a wetted fine brush.

All ostracod valves below 300 were counted. However, ostracod rich samples (>500 valves) were sub-sampled using a micro-splitter (Danielopol and Casale, 1988). If >500 valves were present, a minimum of 300 were counted.

Since the different habitats (lake, estuary-like water, lagoon-like water, rivers, ponds and springs) were not sampled equally due to heterogeneity among individual habitats, the number of samples from each single habitat type was taken as a common base for comparing the presence-absence data (occupancy of a species at a specific habitat) (Delorme, 1990). We calculated the preference index (PI) (adapted from Delorme, 1990) to determine species-specific habitat preferences as follows:

Species X occurrence probability at a particular habitat ($C_{i)} = B_i / A_i$ (1)

Preference Index (PI) [%] = $C_i \times 100 / D$ (2)

Where A_i = sum of samples (sites) collected for a particular habitat;

B_i = number of samples with species X occurring within a particular habitat;

D = sum of species X occurrence probability for each of the habitats ($C_i + C_{ii} + C_{iii} \ldots + C_n$) (common base).

The preferences index (PI) is calculated for each species for the living fauna and empty valves collected for a particular habitat.

If PI = 100 %, then the species is present in one habitat only and is missing in other habitats sampled. Higher PI values indicate habitats preferred by species X in contrast to other habitat types (the best ecological niche).

Taxonomic identification is based on morphological characteristics of hard and soft parts. Taxonomic descriptions of Tibetan ostracods (Huang, 1982; Hou et al., 2002; Hou and Gou, 2007; Wrozyna et al., 2009b; Yu et al., 2009) and other freshwater ostracod faunas were used for identification (Karanovic, 2012). Adult living ostracods (few individuals) were mounted in *Hydro-Matrix* with a cover slip to avoid crushing. Adult specimens were dissected using fine entomological needles and observed under a binocular microscope x 300 with transmitted light. Empty valves and carapaces were photographed using light microscopy and Scanning Electron Microscopy at the Institute of Geosciences and the Institute of Zoology, Friedrich Schiller University Jena, Germany.

The Tibetan ostracod material can be accessed as of 2016 at the Nanjing Museum of Palaeontology, China.

2.3.3 Data analysis

To identify both relations between ostracod communities and the diverse sampled habitats, cluster analyses were performed. To construct similarity dendrograms of ostracod assemblages, the hierarchical agglomerative clustering method was employed. Group linkage was performed on a Bray-Curtis similarity for both presence-absence (Sørenson Coefficient) and log-transformed [ln (x+1)] abundance data (Bray and Curtis, 1957; Clarke et al., 2006; Bellier et al., 2012). We use ostracod assemblages with more than fifty valves for the analyses. A SIMPROF test ($\alpha = 0.05$; 999 permutations) was also performed to distinguish significant groups (similar associations) in the cluster (Ernst, 2004; Clarke et al., 2008; Somerfield and Clarke, 2013). Characteristic ostracod biotopes were classified by clustering of samples based on Euclidean distance (Legendre and Legendre, 1998). The Shannon diversity index (H') was calculated for each sample collected from the various aquatic habitats (Spellerberg and Fedor, 2003; Magurran, 2004). Statistical analyses were carried out using PAST and PRIMER 6 software (Hammer et al., 2001; Clarke and Gorley, 2006).

The Spearman rank correlation analysis was used to evaluate relationships among physico-chemical variables, among living ostracod communities and between ostracods and physico-chemical variables using SPSS version 16.0 (Leech et al., 2011; Somerfield and Clarke, 2013). We used the presence-absence data (eight living species) in relation to environmental factors (six physico-chemical variables and water ionic concentrations). Environmental variables were $\log_{10}$ transformed.

To investigate further, the relationship between living ostracods (log-transformed abundance) and six physico-chemical variables (water depth, conductivity, water temperature, pH, dissolved oxygen concentration, alkalinity), multivariate ordination, canonical correspondence analysis (CCA) was performed (ter Braak and Verdonschot, 1995; Šmilauer and Lepš, 2014). Interactive selective forward selection detected a subset of physico-chemical variables which best explain the faunal matrix. A Monte-Carlo permutation test ($\alpha = 0.05$; 999 permutations) was used to test the effects of each physico-chemical variable on the explanation of total variation in living ostracod abundance data. A generalized linear model (GLM) (Quadratic model option, Poisson distributions) was used to test and display the response of ostracod abundance with the most significant environmental predictor. This was performed using Canoco software version 5.03 (Šmilauer and Lepš, 2014).

2.4 Results

2.4.1 Physico-chemical variables and habitat characteristics

Sixty-six samples were collected from Tangra Yumco and adjacent waters (Appendix A). Sample metadata profiles (coordinates, physico-chemical variables and habitat characteristics of each sample) can be accessed at http://app.geosamples.org/sample_display.php?igsn=IETIP0001. The investigated lakes displayed a wide range in conductivity (salinity) (Tab. 2.1): Tangqung Co – hyperhaline; Tangra Yumco – mesohaline; Monco Bunnyi and Xuru Co – oligohaline. The lakes are Ca^{2+} depleted with high alkalinity. The seven major lake water ionic concentrations are potassium (K^+), bicarbonate (HCO_3^-), chlorine (Cl^-), sulphate (SO_4^{2}-), magnesium (Mg^{2+}), sodium (Na^+) and calcium (Ca^{2+}) (orders of decreasing mean concentrations (Tab. 2.2 and 2.3), thus $HCO_3^- =$ alkalinity). Secchi depths were measured at 9.5 m (September 2009) and 3.9 m (September 2011) for Tangra Yumco and 14 m for Xuru Co (June 2012). The low Secchi depth in Tangra Yumco was caused by suspended sediment. Tangra Yumco is well oxygenated; oxygen concentration (O_2) in deep water depths were: 4.6 mg/l at 200 m (September 2010) and 2.1 mg/l at 225 m (September 2011).

The aquatic habitats were significantly different comparing their physico-chemical values ($p < 0.05$). The sediment samples were collected from various aquatic habitats: lake (29 samples), river (13 samples), estuary-like water (10 samples) and lagoon-like water (8 samples), pond (3 samples) and spring (3 samples). Twenty-four of the lake sediment samples were collected from Tangra Yumco (water depth of 10 cm to 223 m). Sediments were composed mainly of greenish-brown detritus mud within the lakes (Fig. 2.2a) and medium to coarse sand and gravel within the surf zone of the lakes, rivers and estuary-like waters (Fig. 2.2b). The phytal zone of Tangra Yumco extends from 0.4 to 20 m water depth. Submerged macrophytes as *Potamogeton* sp. and charophytes (green algae) were found growing within the phytal zones of Tangra Yumco, Monco Bunyi, and Xuru Co (Fig. 2.2c-d) and in small standing waters. The aquatic plants and algae support primary productivity and serve as substrates for fish and macro-micro fauna communities (e.g., ostracods, chironomids and cladocerans) in these water bodies.

The sediment texture in river habitats is dominated by coarse sand and gravel beds with large interstitial spaces (Fig. 2.2e). The lagoon-like water habitats are characterised by muddy substrate (Fig 2.2h). The ponds are situated in wetlands within *Kobresia* meadows (Fig. 2.2g). The substrate is composed of mud with detritus and floating filamentous algae. The sediment within the spring environments is composed of coarse sand covered by filamentous algae (Fig. 2.2h).

Tab. 2.2 Physico-chemical variables measured for Tangra Yumco and adjacent waters: Min = minimum, Max = maximum values and SD = standard deviation

Parameter	Min – Max	Median	Mean (SD)	Samples (n)
Water depth [m]	0.01 – 223	0.1	9.5 (32.2)	66
Conductivity [mS/cm]	0.07 – 144.8	3.8	7.8 (18.3)	66
Water temperature [^{o}C]	2.2 – 25.7	13.6	14.0 (4.9)	66
pH	6.8 – 12.8	9.5	9.4 (0.8)	66
O_2 concentration [mg/l]	1.3 – 12.2	6.2	6.1 (2.2)	64
Alkalinity [mmol/l]	1.3 – 344	19.9	29.2 (48.2)	66
Ca^{2+} [meq/l]	0.19 – 85.7	1.14	9.5 (20.5)	47
Mg^{2+} [meq/l]	0.3 – 73.6	15.1	14.7 (13.8)	47
Na^{+} [meq/l]	0.03 –228.5	4.6	8.3 (31.3)	52
K^{+} [meq/l]	0.09 – 1977.4	83.9	109.4 (273)	52
Cl^{-} [meq/l]	0.02 – 1729	17.3	64.1 (272)	40
SO_4^{2-} [meq/l]	0.09 – 978.6	10.4	52.6 (158.5)	38

Tab. 2.3 Summary of physico-chemical variables measured for Tangra Yumco and adjacent waters

Aquatic habitats		**WD**	**CD**	**WT**	**pH**	**O_2**	**Al**	**Ca^{2+}**	**Mg^{2+}**	**Na^+**	**K^+**	**Cl^-**	**SO_4^{2-}**
Lake water	Mean	21.5	15.8	12.8	9.4	6.5	46.9	4.6	21.9	13.9	176.8	125.3	103.1
	SD	46.3	25.4	5.2	0.7	2.8	60.4	10.2	13.1	42.2	358.4	389.7	229.6
	Min	0.01	0.08	2.2	7.1	2.0	10.6	0.2	2.4	0.5	1.3	0.1	8.7
	Max	223.0	144.8	22.3	9.4	12.8	344.0	46.5	73.6	228.5	1977.4	1729.1	978.6
	n	**29**	**29**	**29**	**29**	**28**	**29**	**26**	**26**	**28**	**28**	**19**	**17**
Estuary-like waters	Mean	0.1	0.4	14.3	9.8	6.1	17.4	38.3	0.9	0.2	9.2	0.9	0.9
	SD	0.2	0.3	0.6	0.3	1.4	49.4	39.4	0.6	0.2	3.0	1.3	1.1
	Min	0.1	0.2	13.5	9.4	4.8	1.6	1.3	0.3	0.4	7.4	0.1	0.2
	Max	0.5	0.9	15.3	10.1	9.3	158.0	79.3	1.6	0.4	13.7	2.9	2.6
	n	**10**	**10**	**10**	**10**	**9**	**10**	**4**	**4**	**4**	**4**	**4**	**4**
Lagoon-like waters	Mean	0.1	5.4	18.2	9.5	6.1	34.1	8.8	11.7	3.2	53.8	22.5	28.0
	SD	0.04	4.6	5.6	0.3	0.9	15.8	18.5	12.3	3.3	57.6	20.8	27.7
	Min	0.01	0.16	11.1	9.0	4.5	13.0	0.18	0.5	0.11	0.4	0.07	0.4
	Max	0.15	12.4	25.7	10.0	7.6	57.0	46.5	26.6	7.8	125.8	46.5	59.3
	n	**8**	**8**	**8**	**8**	**8**	**8**	**6**	**6**	**7**	**7**	**6**	**6**
Ponds	Mean	0.14	0.4	18.1	9.3	6.4	3.7			0.5	2.5		
	SD	0.06	0.4	7.6	0.01	2.2	3.9			0.4	4.0		
	Min	0.08	0.18	9.4	9.29	4.2	1.4	6.22	1.53	0.1	0.1	0.2	0.6
	Max	0.2	0.91	23.6	9.32	8.6	8.2			0.9	7.2		
	n	**3**	**3**	**3**	**3**	**3**	**3**	**1**	**1**	**3**	**3**	**1**	**1**
Rivers	Mean	0.1	0.3	12.9	9.7	6.3	1.9	17.9	6.4	2.1	42.9	7.1	8.6
	SD	0.04	0.3	1.7	0.5	1.2	0.9	33.3	8.0	2.5	47.7	11.3	18.9
	Min	0.1	0.14	10.9	8.3	4.2	1.3	0.9	0.4	0.03	0.1	0.02	0.1
	Max	0.2	0.9	16.7	10.1	8.9	4.6	85.7	18.2	5.7	104.1	25.4	47.9
	n	**12**	**12**	**12**	**12**	**11**	**12**	**6**	**6**	**6**	**6**	**6**	**6**
Springs	Mean	0.3	1.7	14.8	7.9	3.7	21.4	2.9	2.2	1.1	14.6	0.7	3.8
	SD	0.4	2.3	7.4	0.9	2.3	33.3	2.1	2.1	1.8	21.5	0.8	5.5
	Min	0.01	0.3	8.7	6.8	1.3	2.6	0.9	0.9	0.1	0.4	0.1	0.3
	Max	0.1	5.1	24.4	9.2	6.2	71.0	5.9	3.9	3.8	45.9	1.8	11.9
	n	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**

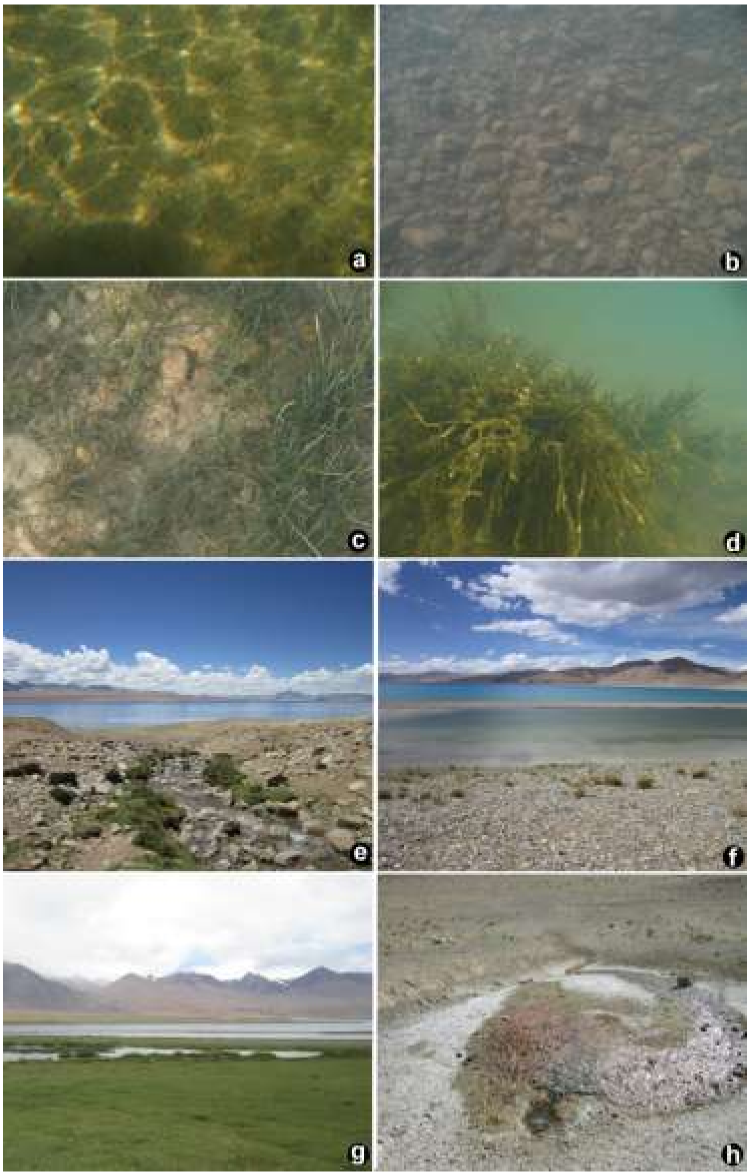


Fig. 2.2 Aquatic habitats of Tangra Yumco and adjacent waters: (a) greenish-brown detritus mud within the littoral zone of Tangra Yumco (TYC), (b) gravel surf zone of TYC) (c) *Potamogeton* floating in the phytal zone of TYC, (d) macrophytes covered by green algae within a lagoon-like water, separated from TYC by a sandbar, (e) small river flowing into TYC, (f) lagoon-like water separated from Monco Bunnyi by a sandbar, (g) pond situated in wetlands meadow adjacent to Xuru Co, (h) spring, situated at the west of TYC. Width of photos a-d: c. 50 cm. The diameter of the wet spot in photo h is c. 2 m. Photos e-g are landscape impressions. Photos a-d by Steffen Mischke.

2.4.2 Ostracoda

2.4.2.1 General observations

Ostracods were absent in eight of the 66 samples (sampling year and number: 9_46, 12_22, 12_36, 12_37, 12_39, 12_42, 12_43, 12_52). These samples were collected from high turbulence shallow waters with sandy-gravel substrate (excluding sample 9_46 composed of pelitic substrate).

Living ostracods (carapace with soft parts) were found in forty-one sediment samples (Appendix B). Although the abundance of living ostracods was generally low, three samples contain higher numbers (> 100). Seventeen sediment samples contain only empty carapaces and valves.

2.4.2.2 Species composition and abundance

Eleven Recent ostracod species were identified (nine within the living fauna and two preserved as empty valves only) (Fig. 2.3-7). They belong to the families Cyprididae, Limnocytherididae and Candonidae. Each family is represented by three species, except Ilyocyprididae with a single species only.

The total relative abundance of living ostracods is: *Tonnacypris gyirongensis* (Yang, 1982) (44.8 %), *Limnocythere inopinata* (Baird, 1843) (29.4 %), *Leucocytherella sinensis* Huang, 1982 (15.6 %), *Candona candida* (O.F. Müller, 1776) (4.7 %), *Fabaeformiscandona gyirongensis* (Huang, 1982), (1.8 %); *Leucocythere*? *dorsotuberosa* Huang, 1982 (1.8 %), *Ilyocypris* sp. (1.6 %), *Heterocypris incongruens* (Ramdohr, 1808) (0.6 %) and *Heterocypris salina* (Brady, 1868).

The total relative abundance of empty valves is: *Leucocytherella sinensis* (61.1 %), *Limnocythere inopinata* (17.8 %), *Tonnacypris gyirongensis* (9.9 %), *Leucocythere*? *dorsotuberosa* (3.6 %), *Fabaeformiscandona gyirongensis* (2.6 %), *Candona candida* (2.1 %), *Ilyocypris* sp. (1.6 %), *Candona xizangensis* Huang, 1985 (1.1 %, empty valves only), *Heterocypris incongruens* (0.1 %) and *Potamocypris* cf. *villosa* (Jurine, 1820) (one empty valve only).

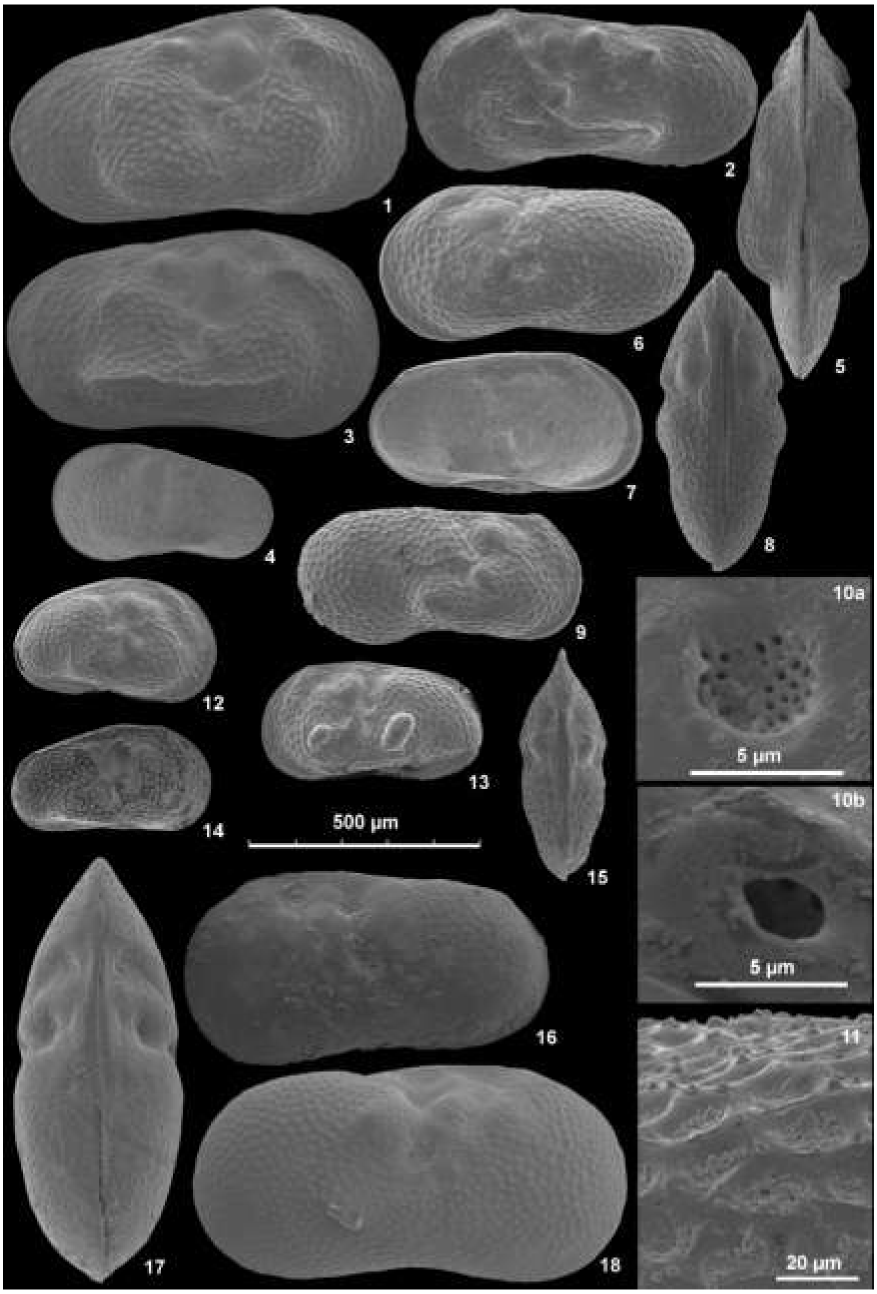


Fig. 2.3 Limnocytheridae and *Ilyocypris*. RV – right valve, LV – left valve, all views are external, unless stated otherwise.
Fig. 1 – 5 *Leucocythere*? *dorsotuberosa* Huang, 1982: (1) female RV, TiP11-67LC; (2) male left valve of forma *postilirata*, TiP11-7; (3) female RV, TiP11-67LC; (4) juvenile LV, internal view, TiP11-69LC; (5) female carapace, ventral view, TiP11-25. Fig. 6 – 10 *Leucocytherella sinensis* Huang, 1982: (6) male LV, TiP11-60LB; (7) female LV, internal view, TiP11-4; (8) female carapace, dorsal view, TiP11-25; (9) male RV, TiP11-4; (10) male LV, details of external view, TiP11-4, (a) slightly depressed sieve pore, (b) sunken sieve pore. Fig. 11 – 15 *Limnocythere inopinata* (Baird, 1843), all from TiP11-2: (11) female carapace in dorsal view, detail of anterior ornamentation; (12) juvenile RV; (13) female LV, strongly noded; (14) juvenile LV, internal view; (15) female carapace in dorsal view. Fig. 16 – 18 *Ilyocypris* sp.; (16) juvenile LV, TiP11-1; (17) adult carapace, dorsal view, TiP11-1; (18) adult RV, TiP11-67LC.

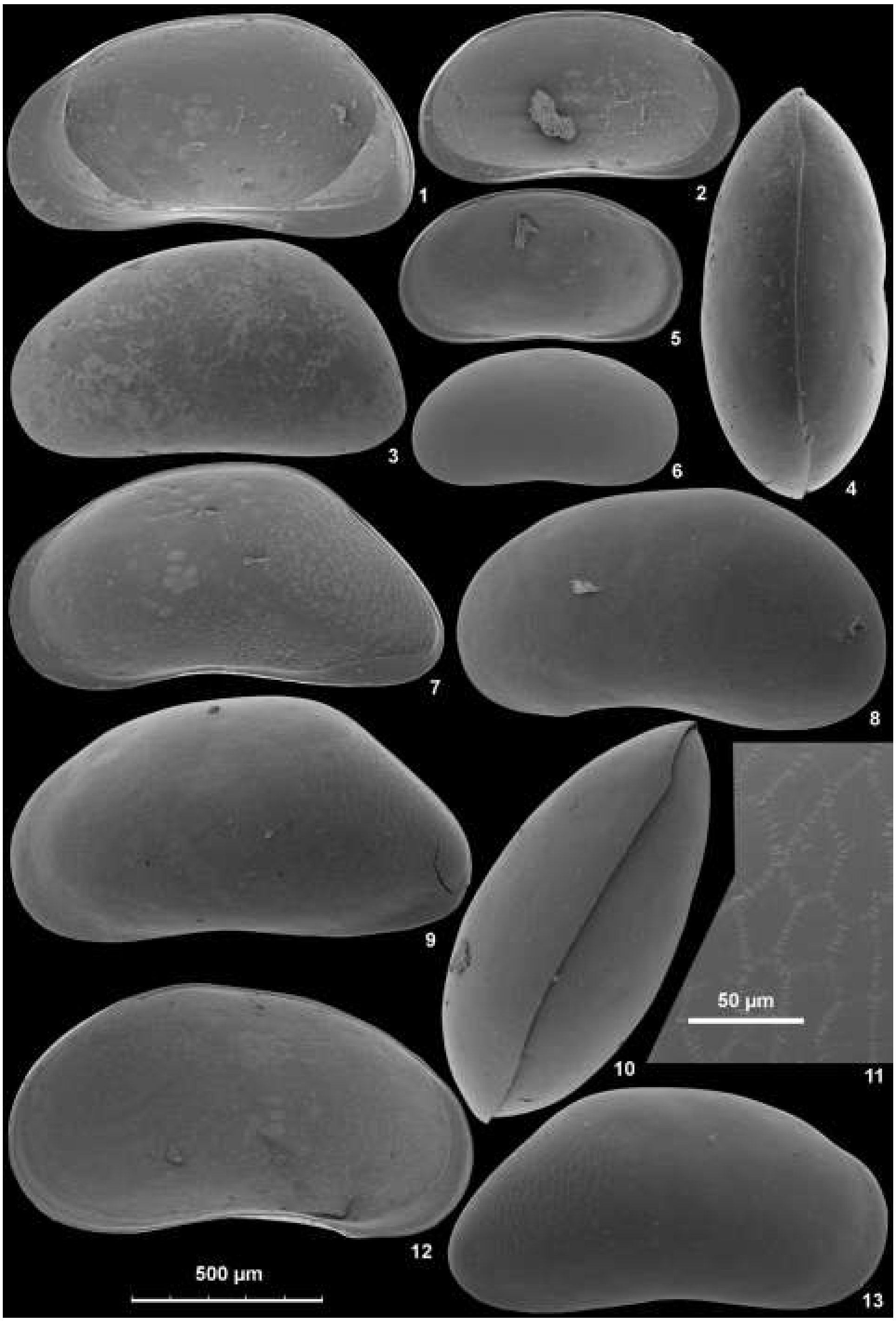


Fig. 2.4 *Candona.* RV – right valve, LV – left valve, all views are external if not stated otherwise.
Fig. 1 – 4 *Candona candida* (O. F. Müller, 1776), all from TiP11-75B: (1) female RV, internal view; (2) juvenile LV, internal view; (3) female LV; (4) female carapace, dorsal view. Fig. 5 – 13 *Candona xizangensis* Huang, 1985: (5) juvenile LV, internal view, TiP11-4; (6) juvenile RV, TiP11-67LC; (7) female RV, internal view, TiP11-67LC; (8) male LV, TiP11-25; (9) female RV, TiP11-25; (10) adult carapace, dorsal view, TiP11-25; (11) surface ornamentation, detail from 13; (12) male LV, internal view, TiP11-25; (13) female RV, TiP11-67LC.

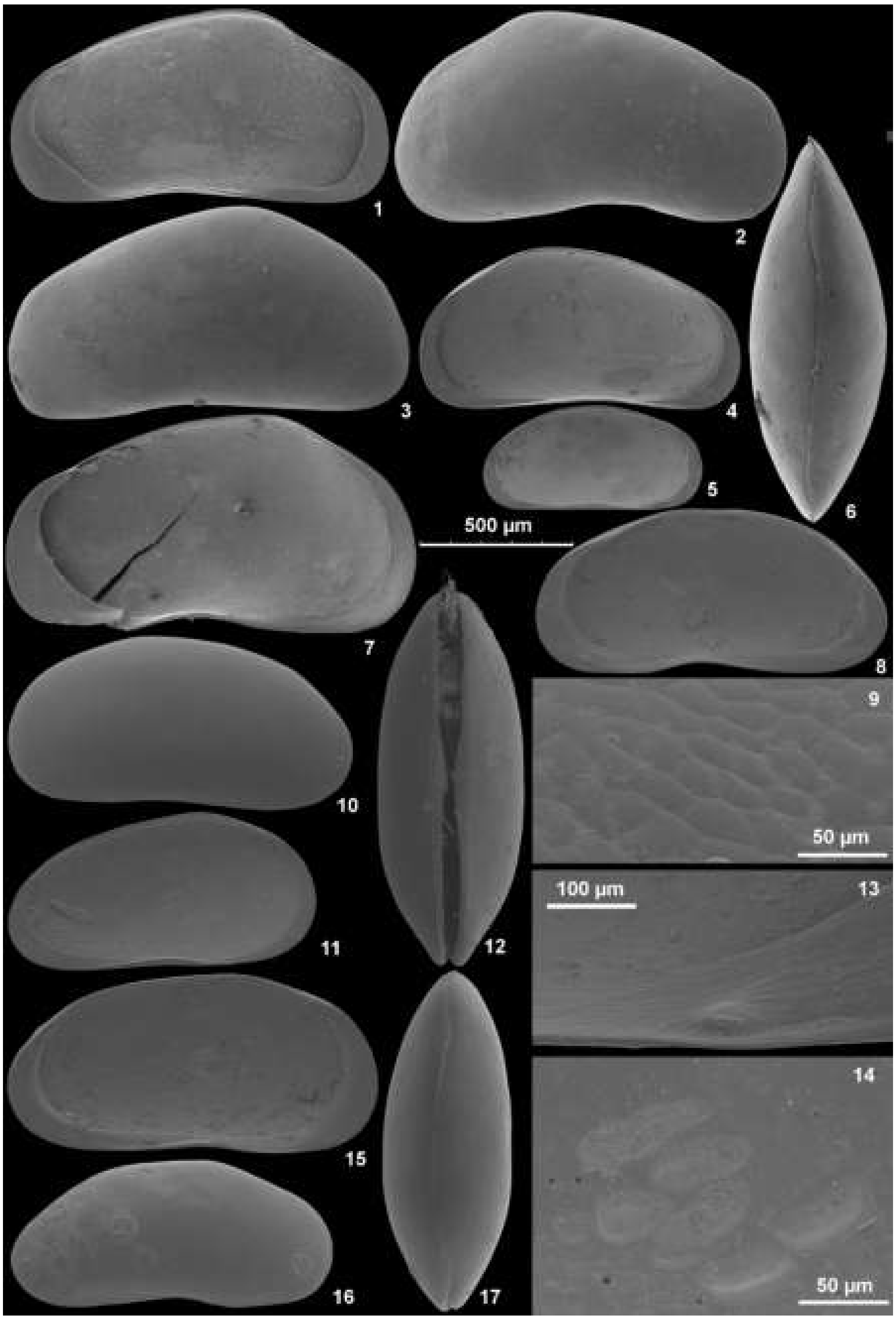


Fig. 2.5 *Fabaeformiscandona* and *Tonnacypris*. RV – right valve, LV – left valve, all views are external if not stated otherwise.

Fig. 1 – 7 *Fabaeformiscandona gyirongensis* (Huang, 1982): (1) female RV, internal view, TiP11-25; (2) male RV, TiP11-25; (3) female LV, TiP11-20; (4) juvenile LV, internal view, TiP11-25; (5) juvenile LV, internal view, TiP11-69LC; (6) adult carapace, dorsal view, TiP11-25; (7) male RV, internal view, TiP11-20. Fig. 8 – 17 *Tonnacypris gyirongensis* (Yang, 1982): (8) adult RV, internal view, TiP11-75B; (9) adult LV, external medio-dorsal surface ornamentation, TiP11-38; (10) adult carapace, left side, TiP11-1; (11) juvenile LV, internal view, TiP11-75B; (12) adult carapace, ventral view, TiP11-75B; (13) adult LV, internal view, antero-ventral tooth on the calcified inner lamella, TiP11-38; (14) adult LV, internal view, central muscle scars, TiP11-29; (15) adult LV, internal view, TiP11-75; (16) adult RV, TiP11-29; (17) adult carapace, dorsal view, TiP11-29.

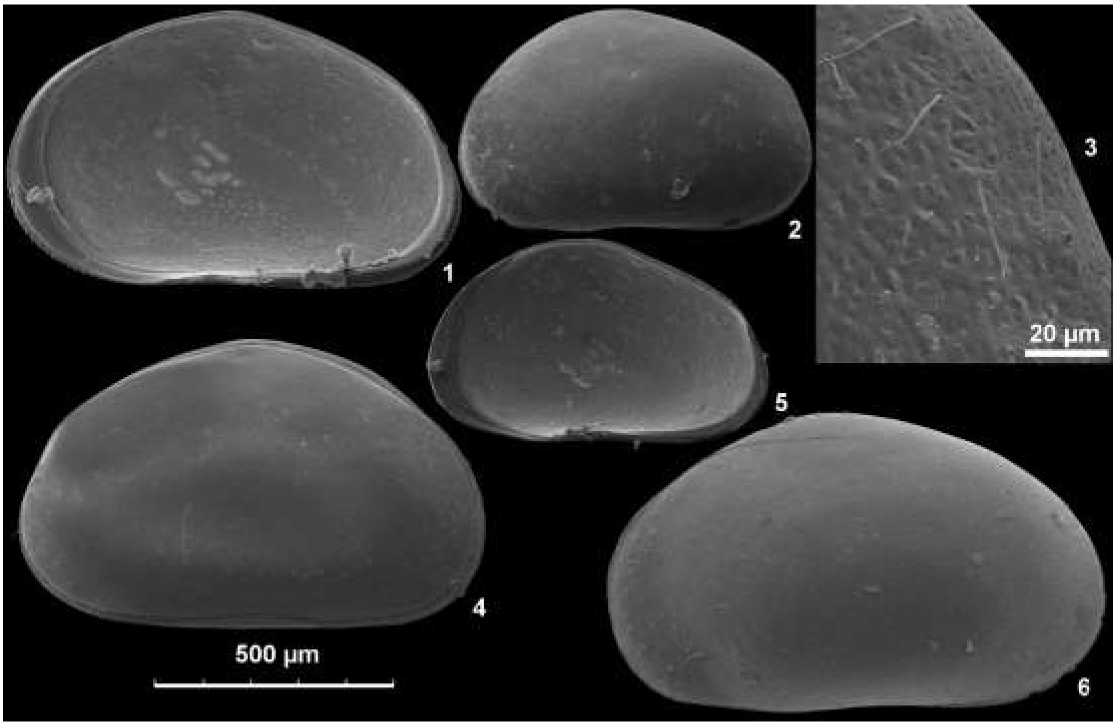


Fig. 2.6 *Heterocypris.* RV – right valve, LV – left valve, all views are external if not stated otherwise.

Tab. 2.4 Living ostracods and physico-chemical conditions of their habitats: Min = minimum, Max = maximum values and SD = standard deviation. WD = water depth [m], CD = conductivity [mS/cm], WT = water temperature [°C], O_2 = dissolved oxygen concentration [mg/l], Al = Alkalinity [mmol/l], cations and anions [meq/l].

Species	N		WD	CD	WT	pH	O_2	Al	Ca^{2+}	Mg^{2+}	Na^+	K^+	Cl^-	SO_4^{2-}
Tonnacypris gyirongensis	582	Mean	0.5	0.9	14.7	9.5	6.2	14.6	27.9	7.6	2.1	40.9	5.6	10.4
		SD	1.7	2.5	3.9	0.7	1.8	35.0	34.1	9.2	2.4	51.5	10.4	17.8
		Min	0.01	0.1	9.4	6.8	1.3	1.3	0.4	0.3	0.1	0.1	0.02	0.1
		Max	8.4	11.9	24.4	10.1	9.3	158	85.7	26.8	6.4	151.3	25.4	47.9
		n	**24**	**24**	**24**	**23**	**23**	**24**	**11**	**11**	**13**	**13**	**10**	**10**
Limnocythere inopinata	382	Mean	7.1	10.5	16.3	9.6	5.3	38.2	13.3	13.4	4.2	81.8	25.5	33.7
		SD	6.9	3.7	4.5	0.3	2.1	13.1	18.6	6.9	1.9	35.3	10.3	15.7
		Min	0.1	1.4	12.8	9.0	3.2	10.6	0.9	0.5	0.1	1.2	0.1	0.4
		Max	20.4	12.9	25.0	10.2	10.5	57.0	46.5	23.1	6.8	126.5	36.1	45.4
		n	**10**	**12**	**12**	**12**	**12**	**12**	**10**	**10**	**10**	**10**	**10**	**10**
Leucocytherella sinensis	200	Mean	3.9	6.1	14.6	9.7	5.9	28.0	14.1	15.5	4.1	80.6	19.2	27.2
		SD	5.9.	5.9	3.1	0.3	2.1	34.6	27.3	8.6	2.5	52.6	15.4	20.1
		Min	0.1	0.1	11.4	9.2	3.2	1.3	0.4	1.3	0.2	0.4	0.02	0.1
		Max	20.4	12.8	23.0	10.2	10.5	158.0	85.7	26.8	6.8	151.3	36.1	47.9
		n	**21**	**21**	**21**	**20**	**20**	**21**	**16**	**16**	**17**	**17**	**13**	**13**
Candona candida	61	Mean	0.11	0.41	14.8	9.4	6.5	3.6	8.7	8.3	1.80	35.90	12.8	24.2
		SD	0.04	0.43	7.6	0.2	2.2	3.9	3.6	9.6	2.60	56.20	17.8	33.4
		Min	0.08	0.14	9.4	9.3	4.2	1.3	6.2	1.5	0.05	0.09	0.2	0.6
		Max	0.15	0.90	23.6	9.6	8.6	8.2	11.3	15.1	4.80	100.7	25.4	47.9
		n	**3**	**3**	**3**	**3**	**3**	**3**	**2**	**2**	**3**	**3**	**3**	**2**
Fabaeformiscandona gyirongensis	24	Mean	3.6	10.5	13.7	9.7	5.6	28.5	11.4	15.1	4.2	87.1	22.2	30.7
		SD	4.8	3.7	1.1	0.3	3.0	15.3	19.7	9.4	2.4	54.2	15.1	18.6
		Min	0.1	3.8	12.8	9.4	3.5	10.6	0.4	1.3	0.2	1.4	0.2	2.9
		Max	9.4	12.8	15.6	10.2	10.5	40.0	46.5	26.8	6.4	151.3	34.0	41.2
		n	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**4**	**4**
Leucocythere? dorsotuberosa	22	Mean	3.6	10.5	13.7	9.7	5.6	28.5	11.4	15.1	4.2	87.1	22.2	30.7
		SD	4.8	3.7	1.1	0.3	3.0	15.3	19.7	9.4	2.4	54.2	15.1	18.6
		Min	0.1	3.8	12.8	9.4	3.5	10.6	0.4	1.3	0.2	1.4	0.2	2.9
		Max	9.4	12.8	15.6	10.2	10.5	40.0	46.5	26.8	6.4	151.3	34.0	41.2
		n	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**4**	**4**
Ilyocypris sp.	21	Mean	0.13	4.8	12.9	9.6	5.4	58.2	29.7	7.7	1.9	30.7	12.3	14.4
		SD	0.10	5.1	2.5	0.3	1.8	67.8	43.0	10.5	2.6	47.6	18.7	22.3
		Min	0.10	0.9	9.4	9.3	3.9	8.2	3.5	1.5	0.1	0.4	0.2	0.6
		Max	0.20	11.9	15.3	9.8	7.8	158.0	79.3	19.9	5.7	101.7	33.9	40.1
		n	**4**	**4**	**4**	**3**	**4**	**4**	**3**	**3**	**4**	**3**	**3**	**3**
Heterocypris incongruens	3	Mean	0.18	0.54	16.5	9.3	6.4	4.8			0.34	3.6		
		SD	0.04	0.50	10.0	0.01	3.1	4.8			0.40	4.90		
		Min	0.15	0.18	9.4	9.29	4.2	1.4	6.22	1.53	0.05	0.09	0.17	0.56
		Max	0.20	0.90	23.6	9.30	8.6	8.2			0.62	7.20		
		n	**2**	**2**	**2**	**2**	**2**	**2**	**1**	**1**	**2**	**2**	**1**	**1**

2.4.2.3 Ostracod abundance and diversity in different aquatic habitats

The distribution of living ostracods indicates specific physico-chemical requirements (Tab. 2.4, 2.5); the frequency of occurrence (preference index) differs in the different habitats (Fig. 2.8). The characteristic ostracod associations (living and empty valves) are dominated by *Leucocytherella sinensis, Tonnacypris gyirongensis* and *Limnocythere inopinata*.

Based on habitat-specific ecological requirements, cluster analysis separated the living ostracods into two groups: *L. inopinata*, *L. sinensis*, *L.? dorsotuberosa* and *F. gyirongensis* are in the first group and *H. incongruens, C. candida*, *Ilyocypris* sp. and *T. gyirongensis* form the second group. The empty valves are grouped into three associations: *T. gyirongensis* and *Ilyocypris* sp. in the first cluster, *F. gyirongensis* and *C. xizangensis* in the second cluster and *L.? dorsotuberosa*, *L. sinensis* and *L. inopinata* in the third cluster. *Candona candida* and *Heterocypris incongruens* are outliers (Fig. 2.7).

The diversity of ostracod associations is generally low (Appendix C). The mean Shannon diversity indices are 0.35 (living individuals) and 0.58 (empty valves). Ponds and lakes record highest indices (Appendix C).

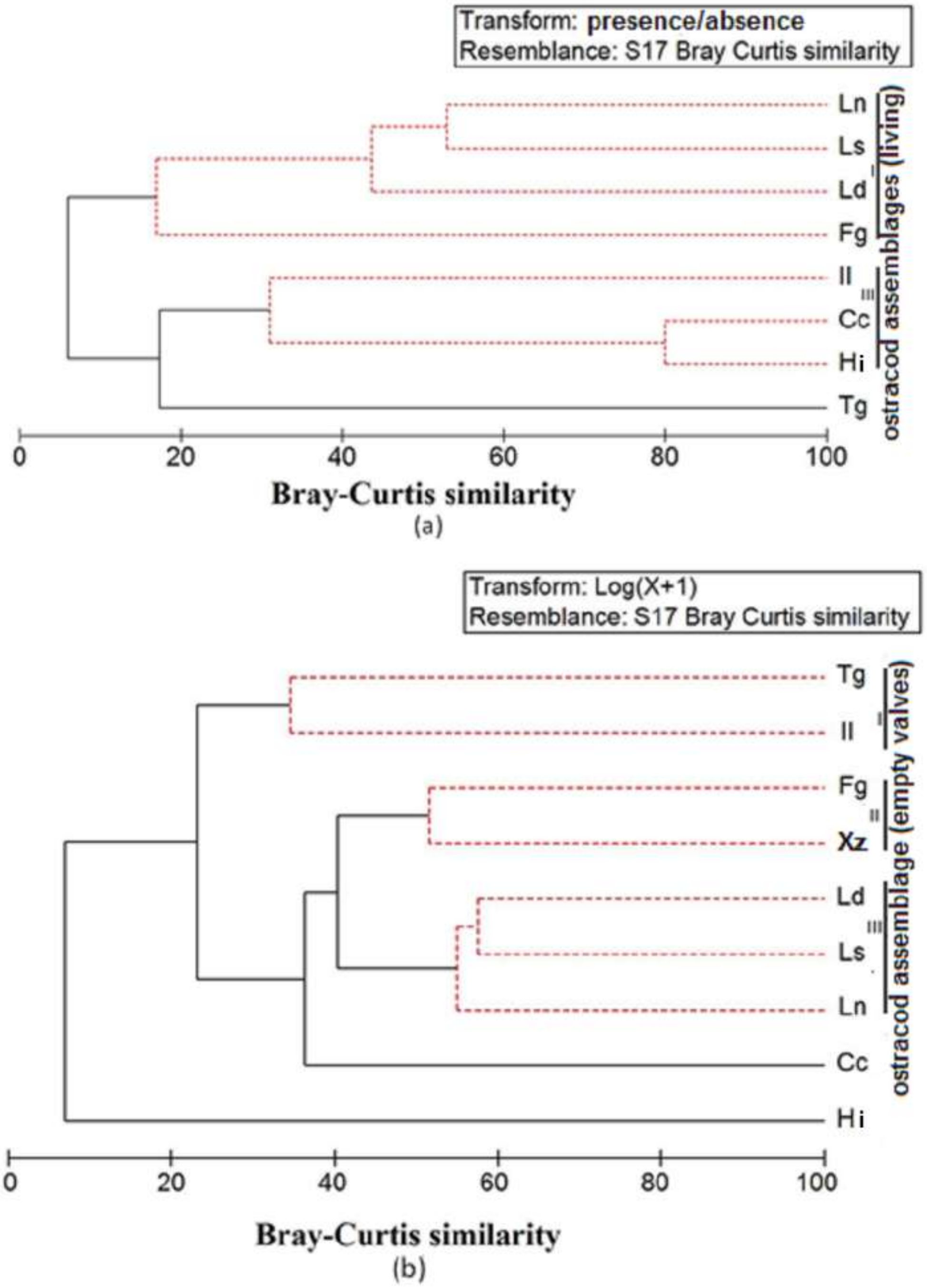
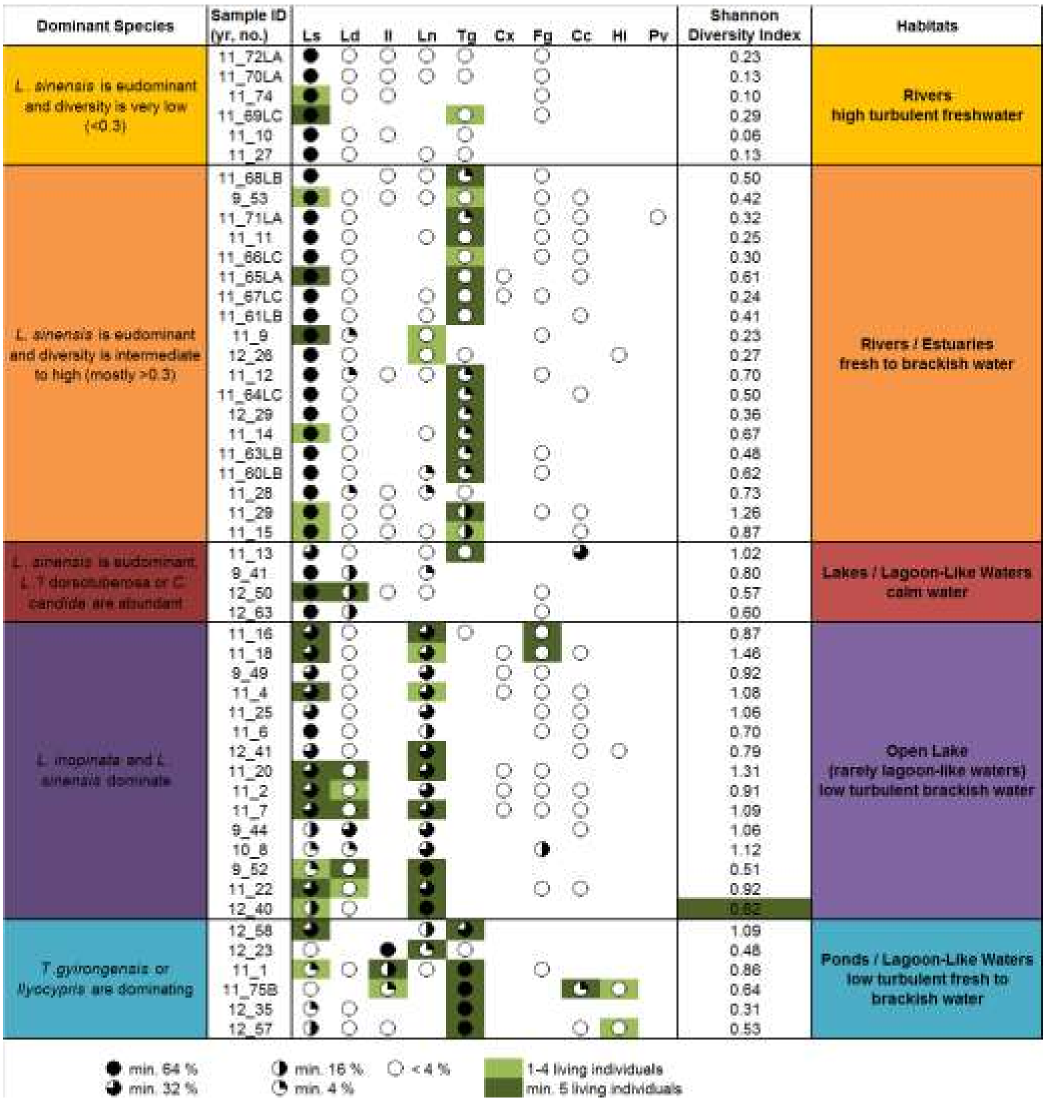


Fig. 2.7 Recent ostracod associations dendrograms (group-average linkage). The continuous lines signify (p = 0.05%) two 'coherent' groups in (a) - living ostracods, and three 'coherent' groups in (b) - empty valves. Dashed lines indicate significant assemblages. Ln = *Limnocythere inopinata*, Ls = *Leucocytherella sinensis*, Ld = *Leucocythere*? *dorsotuberosa*, Fg = *Fabaeformiscandona gyirongensis*, Il = *Ilyocypris* sp., Cc = *Candona candida*, Hi = *Heterocypris incongruens*, Tg = *Tonnacypris gyirongensis* and Cx = *Candona xizangensis*.

Tab. 2.5 Relative abundance of empty valves and abundance of living ostracods and their habitats. Ls = *Leucocytherella sinensis*, Ld = *Leucocythere*? *dorsotuberosa*, Il = *Ilyocypris* sp., Ln = *Limnocythere inopinata*, Tg = *Tonnacypris gyirongensis*, Fg = *Fabaeformiscandona gyirongensis*, Cc = *Candona candida* and Hi = *Heterocypris incongruens*.



Dominant Species	Sample ID (yr, no.)	Ls	Ld	Il	Ln	Tg	Cx	Fg	Cc	Hi	Pv	Shannon Diversity Index	Habitats
L. sinensis is eudominant and diversity is very low (<0.3)	11_72LA	●	○	○	○	○		○				0.23	Rivers high turbulent freshwater
	11_70LA	●	○	○	○	○		○				0.13	
	11_74	● 🟩	○	○				○				0.10	
	11_69LC	● ▩				○ 🟩		○				0.29	
	11_10	●	○	○		○						0.06	
	11_27	●	○		○	○						0.13	
L. sinensis is eudominant and diversity is intermediate to high (mostly >0.3)	11_68LB	●		○	○	◔ ▩		○				0.50	Rivers / Estuaries fresh to brackish water
	9_53	● 🟩	○	○	○	○ 🟩		○	○			0.42	
	11_71LA	●	○			◔ ▩		○	○		○	0.32	
	11_11	●	○		○	○ ▩		○	○			0.25	
	11_66LC	●	○			○ 🟩		○	○			0.30	
	11_65LA	● ▩	○			○ ▩	○		○			0.61	
	11_67LC	●	○		○	○ ▩	○	○				0.24	
	11_61LB	●	○		○	○ ▩			○			0.41	
	11_9	● ▩	◔		○ 🟩			○				0.23	
	12_26	●	○		○ 🟩	○				○		0.27	
	11_12	●	◔	○	○	◔ ▩		○				0.70	
	11_64LC	●	○			◔ ▩			○			0.50	
	12_29	●	○			◔ ▩						0.36	
	11_14	● 🟩	○		○	◔ ▩						0.67	
	11_63LB	●	○			◔ ▩		○				0.48	
	11_60LB	●	○		◔	◔ ▩		○				0.62	
	11_28	●	◔	○	◔	○						0.73	
	11_29	● 🟩	○	○		◑ ▩		○	○			1.26	
	11_15	● 🟩	○	○	○	◑ 🟩			○			0.87	
L. sinensis is eudominant, *L.? dorsotuberosa* or *C. candida* are abundant	11_13	◕	○		○	○ ▩			◕			1.02	Lakes / Lagoon-Like Waters calm water
	9_41	●	◑		◔							0.80	
	12_50	● ▩	◑ ▩	○	○			○				0.57	
	12_63	●	◑					○				0.60	
L. inopinata and *L. sinensis* dominate	11_16	◕ ▩	○		◕ ▩	○		○ ▩				0.87	Open Lake (rarely lagoon-like waters) low turbulent brackish water
	11_18	◕ ▩	○		◕ 🟩		○	○ ▩	○			1.46	
	9_49	◕	○		◕		○	○				0.92	
	11_4	◕ ▩	○		◕ 🟩		○	○	○			1.08	
	11_25	◕	○		◕			○	○			1.06	
	11_6	●	○		◑			○	○			0.70	
	12_41	◕	○		◕ ▩				○	○		0.79	
	11_20	◕ ▩	○ ▩		◕ ▩		○	○				1.31	
	11_2	◕ ▩	○ 🟩		◕		○	○	○			0.91	
	11_7	◕ ▩	○ ▩		◕ ▩		○	○	○			1.09	
	9_44	◑	◕		◕				○			1.06	
	10_8	◔	◔		◕			◑				1.12	
	9_52	◔ 🟩	○ ▩		● ▩							0.51	
	11_22	◕ ▩	○ 🟩		◕ ▩			○	○			0.92	
	12_40	◑ 🟩	○		● ▩							0.62 ▩	
T. gyirongensis or *Ilyocypris* are dominating	12_58	◕ ▩			◑	◕ ▩						1.09	Ponds / Lagoon-Like Waters low turbulent fresh to brackish water
	12_23	○		●	◔ ▩	○						0.48	
	11_1	◔ 🟩	○	◑ ▩	○	● ▩		○				0.86	
	11_75B	○		◔ 🟩		● ▩			◔ ▩	○ 🟩		0.64	
	12_35	◔	○			● ▩						0.31	
	12_57	◑	○	○		● ▩			○	○ 🟩		0.53	

● min. 64 %
◕ min. 32 %
◑ min. 16 %
◔ min. 4 %
○ < 4 %
🟩 1-4 living individuals
▩ min. 5 living individuals

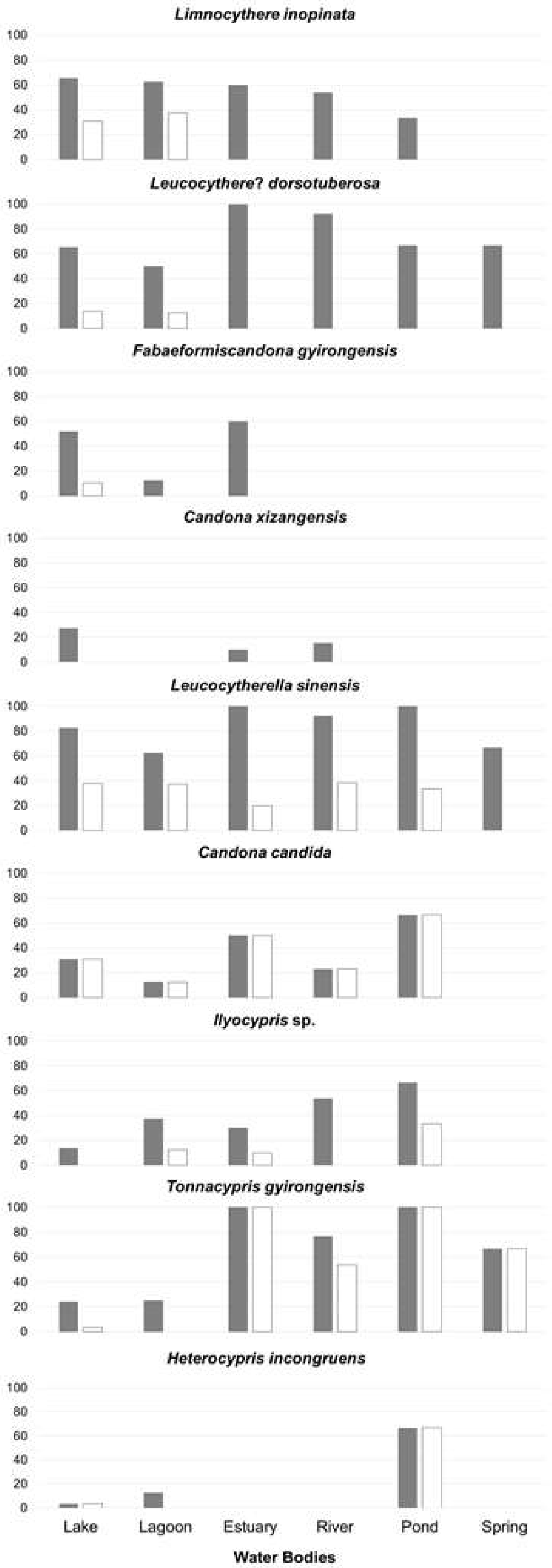


Fig. 2.8 Preference Index (PI)[%]: frequency of occurrence of ostracod species in six habitats; Empty valves – Grey bar. Living ostracod association – white bar.

2.4.2.4 Species and environment

Species relate to the physico-chemical variables (Appendix D). The canonical correspondence analysis (CCA) reveals significant differences among aquatic habitat types (Fig. 2.9a, Appendix E) and separates significant species of such habitat types (Fig. 2.9b). The total variation is 2.5, explanatory variable account for 40.0 % (adjusted explained variation is 31.4 %). The two CCA axes are shown explaining 35.8 % of the total variance (Fig. 2.9a-b, Appendix E). On the first axis species in small and shallow temporary waters are grouped (*Heterocypris incongruens*, *Candona candida*, *Ilyocypris* sp., *Tonnacypris gyirongensis*) and second axis illustrates permanent brackish-lacustrine fauna (*Limnocythere inopinata*, *Leucocytherella sinensis*, *Fabaeformiscandona gyirongensis*, *Leucocythere*? *dorsotuberosa*) (Fig. 2.9b-c).

Best ecological niches of the species may be identified (Fig. 2.9b-c): *Heterocypris incongruens* and *C. candida* live in ponds. *Limnocythere inopinata* and *Ilyocypris* sp. live mainly in lagoon-like waters. *Tonnacypris gyirongensis* lives in rivers, estuary-like waters and spring habitats *Fabaeformiscandona gyirongensis*, *L. sinensis* and *L.*? *dorsotuberosa* are typical in brackish lacustrine waters. Three ostracod species significantly ($p<0.05$) correlate with their habitat: *Heterocypris incongruens* to pond environment, *Tonnacypris gyirongensis* to spring habitat and *Fabaeformiscandona gyirongensis* to lacustrine waters.

Presence and abundance of the ostracod species are significantly ($p<0.05$) related to physico-chemical variables (Fig. 2.10a). The total variation is 2.6, explanatory variable accounts for 40.8 % (adjusted explained variation is 29.7 %) (Appendix E). The first axis explains 24.7 % of the total variation; the second axis adds another 9.6 % (Appendix E). Species' presence and abundance are significantly ($p<0.05$) controlled by three physico-chemical variables (conductivity, alkalinity and water depth) (Fig. 2.10a), and covariate (habitat types). There is colinearity between conductivity and alkalinity. The most influential ecological factors explaining presence and abundance of ostracods are conductivity (explained 21 %, pseudo-F = 9.8, adjusted P = 0.008) and habitat types (explained 9.0 %, pseudo-F = 4.6, adjusted P = 0.034). Conductivity is the key environmental predictor for ostracods (presence and abundance) in Tangra Yumco and adjacent waters. The total variation is 2.6, explanatory variable accounts for 49.3 % (adjusted explained variation is 37.9 %) (Fig. 2.11, Appendix E). The two CCA axes explain 37.9 % of the total variance (Fig. 2.11, Appendix E). On the second axis, *L. inopinata* and *Ilyocypris* sp. live in waters with high conductivity while *L. sinensis*, *F. gyirongensis* and *L.*? *dorsotuberosa* in waters with moderate conductivity. On the first axis, *H. incongruens*, *C. candida* and *T. gyirongensis* are preferring waters with low conductivity (Fig. 2.11).

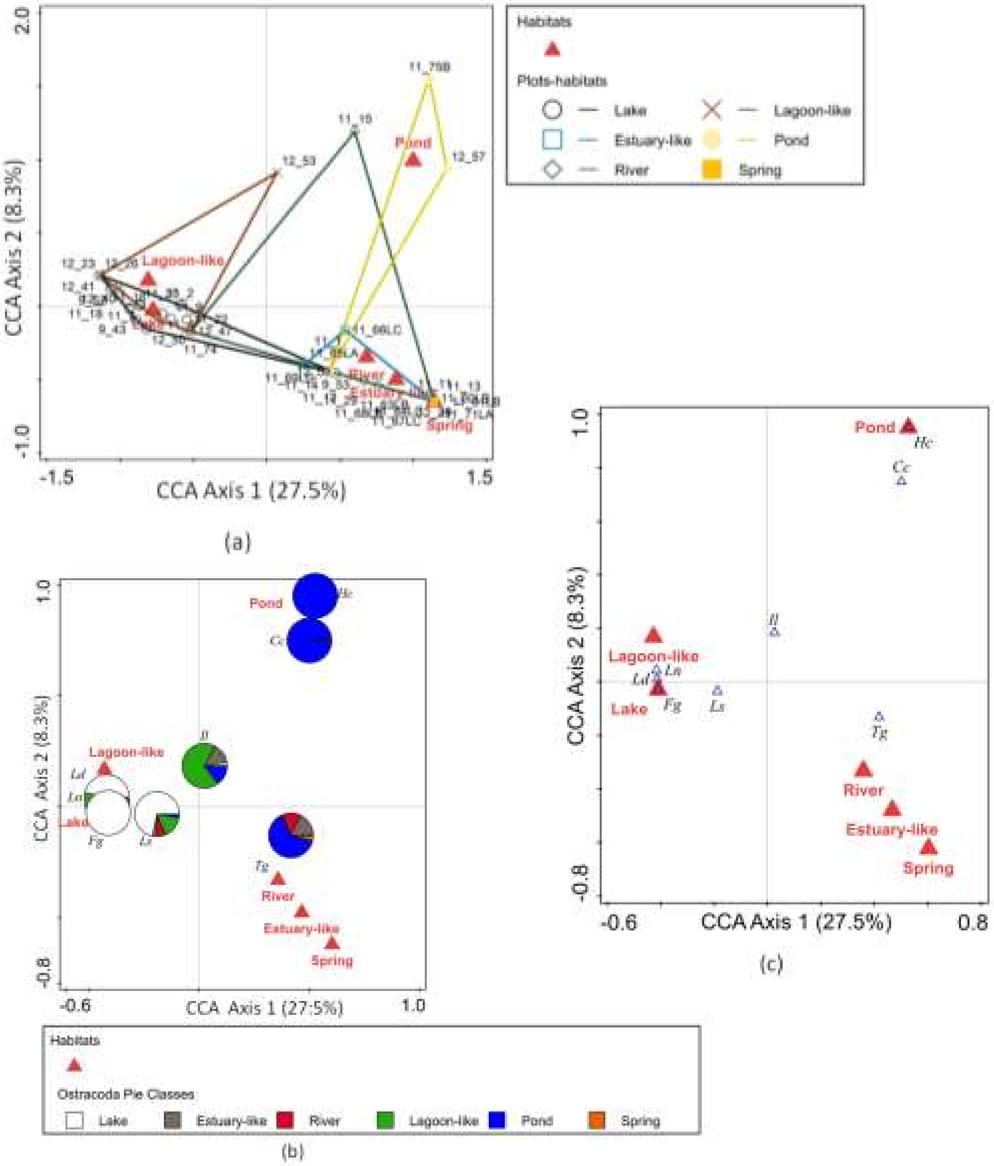
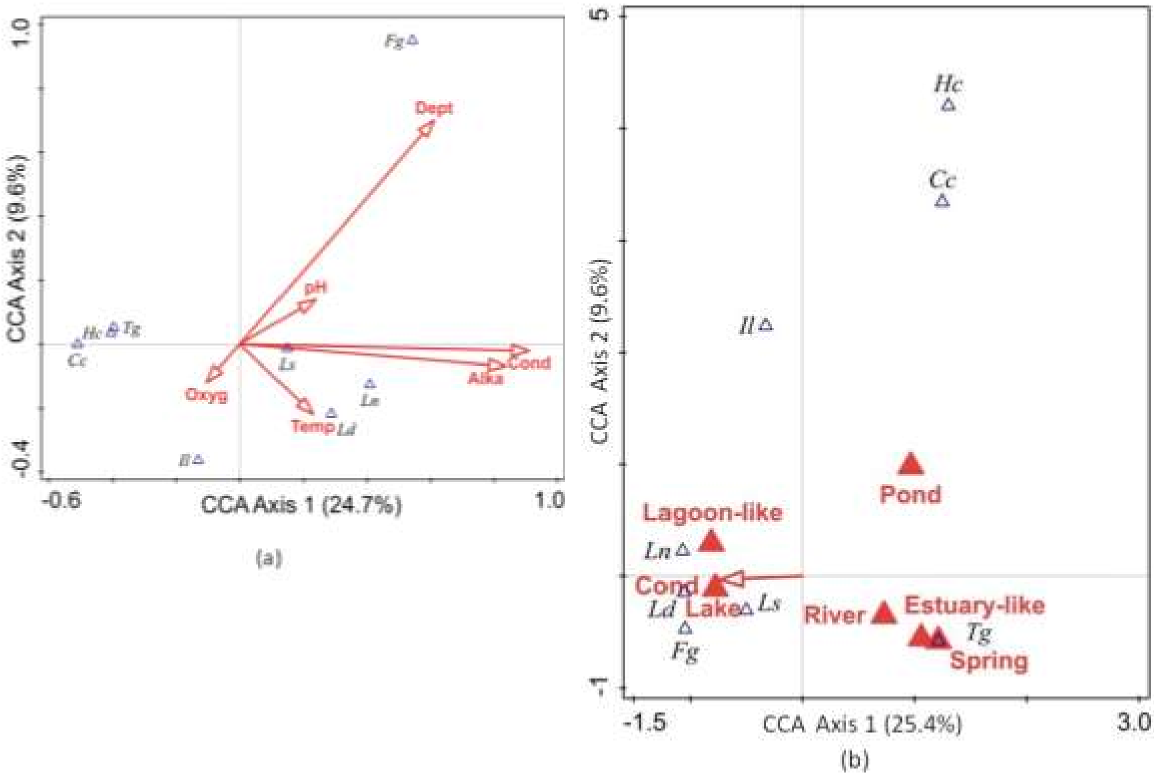


Fig. 2.9 Canonical correspondence analysis (CCA) biplot: (a) samples ID (year/number) and the lines enclose the locations of samples from different habitats. Lines match with the habitat (plots) symbols and categorical variables habitat (filled triangles); (b) Abundance of species in specific-habitats. Pie plots of ostracod abundance (log-transformed abundance data) in the diverse habitats. The boxes match with the habitat symbols and categorical habitat type (filled triangles); (c) species-specific habitats ecology. The first two CCA axes are shown; explaining 35.8% of the total variance. Species code: Ls = *Leucocytherella sinensis*, Ld = *Leucocythere*? *dorsotuberosa*, Il = *Ilyocypris* sp., Ln = *Limnocythere inopinata*, Tg = *Tonnacypris gyirongensis*, Fg = *Fabaeformiscandona gyirongensis*, Cc = *Candona candida* and Hc = *Heterocypris incongruens*.



(a)

(b)

Fig. 2.10 Canonical correspondence analysis (CCA) biplot of species-environmental variables. (a) Indication of physico-chemical variables (arrows). (b) Species-conductivity (most influential environmental predictor). Ls = *Leucocytherella sinensis*, Ld = *Leucocythere*? *dorsotuberosa*, Il = *Ilyocypris* sp., Ln = *Limnocythere inopinata*, Tg = *Tonnacypris gyirongensis*, Fg = *Fabaeformiscandona gyirongensis*, Cc = *Candona candida* and Hc = *Heterocypris incongruens*. Cond = Conductivity, Dept = Depth, Alka = Alkalinity, Temp = Temperature and Oxyg = (Oxygen).

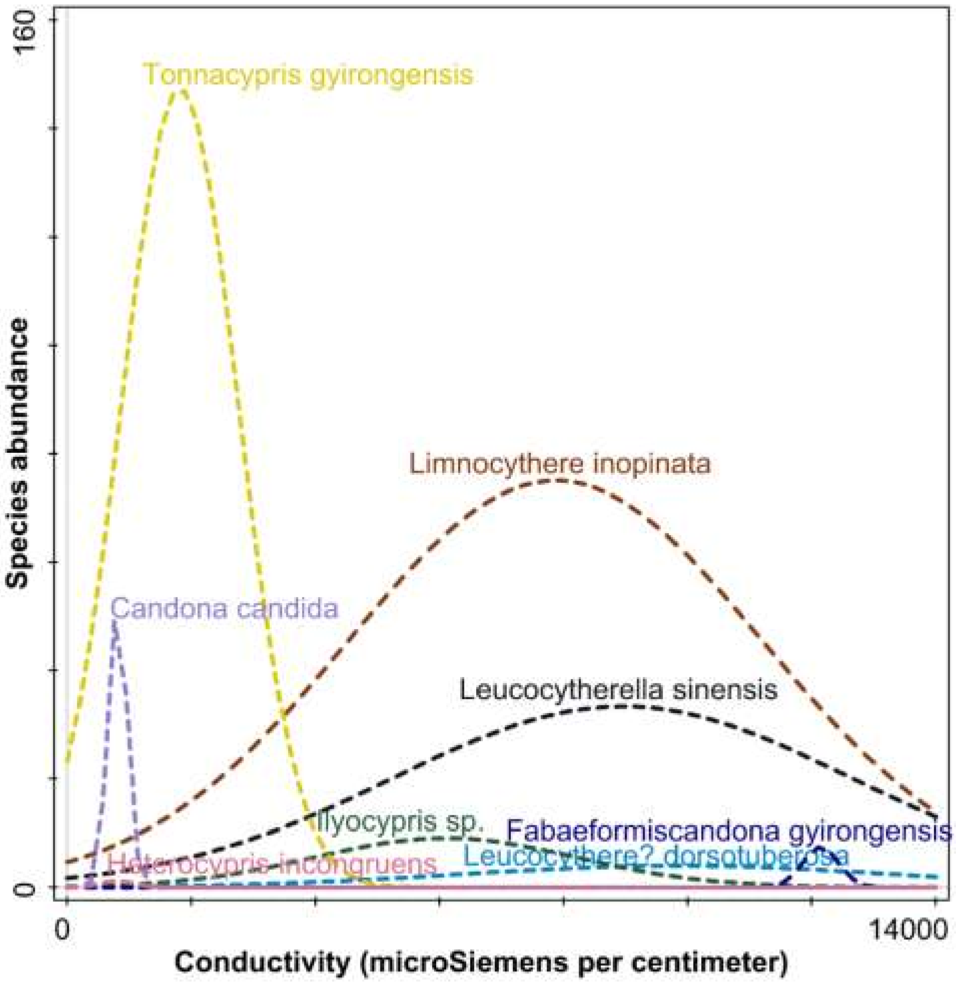


Fig. 2.11 Recent ostracod response curves on conductivity (µScm^{-1}) fitted by a generalised linear model (GLM) with quadratic option and Poisson distribution. *Limnocythere inopinata* has a broad tolerance to conductivity.

Spearman correlation analysis reveals that two species (*L.*? *dorsotuberosa*, r = 0.25, p = 0.043; *L. inopinata*, r = 0.364, p = 0.003) have a significant positive correlation with conductivity and one species (*T. gyirongensis,* r = -0.606, p = 0.000) displays significant negative correlation with conductivity. *Limnocythere inopinata* demonstrates a significant positive correlation with alkalinity (r = 0.368, p = 0.002). *Fabaeformiscandona gyirongensis* displays a significant positive correlation with water depth (r = 0.278, p = 0.024) (Appendix D).

2.4.2.5 Water depth distribution of ostracods

Ostracod distribution and abundance fluctuate with water depth in Tangra Yumco (Fig. 2.12). Water-depth distribution of ostracods can be described in relation to three distinct layers (**epilimnion/phytal**, warm nutrient-rich surface layer, and **hypolimnion**, cold nutrient-poor bottom layer) separated by the **thermocline**, where temperature changes rapidly with depth) of deep lacustrine water. Living ostracods occur only in the phytal zone and empty valves are deposited in sediment of the hypolimnion (Fig. 2.12). Ostracod diversity is higher in the epilimnion (seven species) than in the hypolimnion (five taxa) (Fig. 2.12).

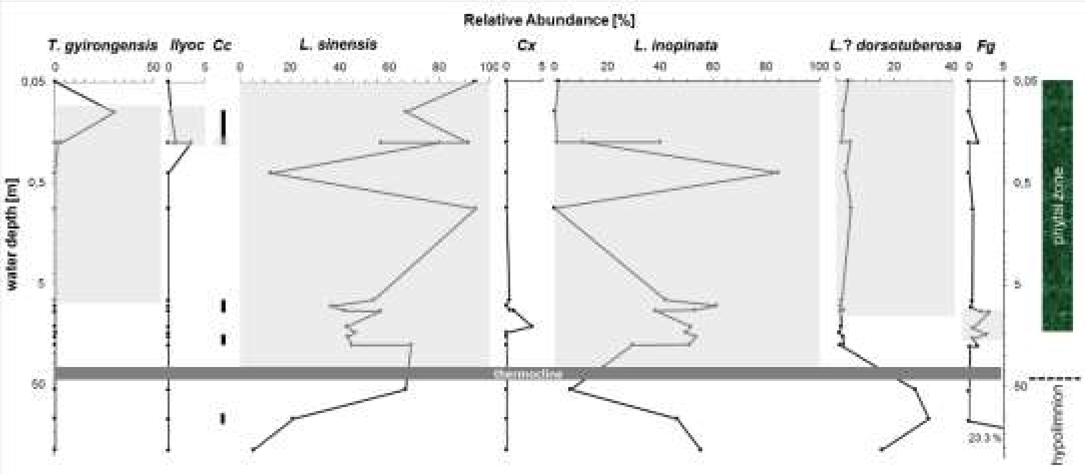


Fig. 2.12 Water depth distribution of Recent Ostracoda from Tangra Yumco. The shaded grey area illustrates the presence of living ostracods. Curves represent the relative abundance of empty valves. The dark grey shaded bar is the thermocline layer (20 – 30 m water depth). Species code: Ilyoc = *Ilyocypris* sp., Cc = *Candona candida*, Cx = *Candona xizangensis*, and Fg = *Fabaeformiscandona gyirongensis.* Ostracod diversity is higher in the phytal zone than in the hypolimnion. *Leucocytherella sinensis* and *L. inopinata* dominate the phytal zone. *Leucocythere*? *dorsotuberosa* (max. 32 % at 110 m) and *F. gyirongensis* (max. 23 % at 223 m) increase in relative abundance with water depth.

Tonnacypris gyirongensis, *Ilyocypris* sp., and *Candona candida* are shallow water fauna present in relative low proportions within the epilimnion of Tangra Yumco. *Leucocytherella sinensis* and *L. inopinata* dominate the epilimnion (phytal zone). *Candona xizangensis* was most abundant with 3.6 % at 13 m water depth (Fig. 2.12).

A reducing relative number of empty valves of *L. sinensis* but increasing for *L. inopinata* occurs in the hypolimnion. Subsequently, *Leucocythere*? *dorsotuberosa* (max. 32 % at 110 m) and *F. gyirongensis* (max. 23 % at 223 m) increase in their relative abundance with increasing water depth (Fig. 2.12).

2.5 Discussion

2.5.1 Ostracod taxa

Species endemic to the Tibetan Plateau are typical lacustrine fauna (*Leucocytherella sinensis*, *Leucocythere*? *dorsotuberosa*, *Fabaeformiscandona gyirongensis* and *Candona xizangensis*) and shallow temporary fauna (*Tonnacypris gyirongensis*). **Cosmopolitan fauna** are *Limnocythere inopinata* (lake species) and temporary water species (*Candona candida, Ilyocypris* sp. and *Heterocypris incongruens*). Although living specimens of *C. xizangensis* were not found, empty valves were largely deposited in the lake sediment, hence we assume preference for lacustrine habitat. The dominance of an endemic ostracod fauna in Tangra Yumco and adjacent waters suggests an adaptation to extreme ecological conditions (low mean temperatures, low oxygen concentrations, high radiation and low nutrient availability) in high altitudes.

The family Limnocytheridae is the dominant group found in Tangra Yumco. It is a common family of continental ostracods which populates lacustrine waters on the Tibetan Plateau (Mischke, 2012). Limnocytheridae is a non-marine ostracod family with wide distribution (Danielopol et al., 1989). The limnocytherid fresh to brackish water genera *Leucocythere*, *Leucocytherella* and *Limnocythere* originate from Mesozoic to Cenozoic lake sediments in China (Huang, 1985; Danielopol et al., 1989). The genus *Leucocytherella* occurs in Pliocene to Holocene sediments of the Tibetan Plateau (Huang et al., 1982; Huang et al., 1985a).

2.5.2. Ostracoda taxonomy

One empty valve of *Potamocypris* cf. *villosa* was found in a spring located in the catchment of Tangqung Co. The valve found is larger than *Potamocypris* cf. *villosa* specimens from Central Europe (Meisch, 2000). *Tonnacypris gyirongensis*, described by Huang et al. (1982) as *Eucypris gyirongensis* Yang, belongs to the genus *Tonnacypris* Diebel & Pietrzeniuk, 1975. A small and blunt antero-ventral tooth can be recognised on the calcified inner lamella of the left valves of *T. gyirongensis* (Fig. 2.5-13). The seta d1 of *T. gyirongensis* is distinctively shorter than d2 on the walking leg of the genus *Tonnacypris* as described by Meisch (2000). We found high variability in morphological characters of *T. gyirongensis* expressed by different shapes and ornamentations. Some of the valves of *T. gyirongensis* are characterised by mesh-like structures with narrow but shallow and thin furrows on their external shell (Fig. 2.5-9). *Tonnacypris gyirongensis* resembles *Tonnacypris estonica* (Järvekülg, 1960) reported from western Mongolia (Van der Meeren et al., 2009). Detailed taxonomical analysis is required to check if *T. gyirongensis* is a younger synonym of *T. estonica*. The genus *Leucocythere* is given with a question mark (thus *Leucocythere*? *dorsotuberosa*) due to the presence of a lophodont hinge. *Leucocythere* Kaufmann, 1892 bears an antimerodont hinge (Danielopol et al., 1989). Adult *Ilyocypris* sp. lack marginal ripplets on the posterior-ventral left valve. It is clear that these are different morphological types of the genus *Ilyocypris* in comparison to *Ilyocypris* cf. *mongolica* from lake sediments of Nam Co (Wrozyna et al., 2009a; Wrozyna et al., 2009b).

2.5.3. Ostracod abundance, diversity and habitat specific biotopes

Ostracod presence and abundance is determined by physico-chemical parameters of a given water body (Tab. 2.4). The ostracod fauna occupies a specific biotope (most favourable ecological niche, Tab. 2.5-2.6). The salinity of continental waters may contribute to the low diversity of ostracods aquatic habitats on the Tibetan Plateau (Mischke, 2007). The lakes and ponds record higher mean diversity (Appendix C). Ostracod numbers increase in waters with stable hydrological conditions, optimum niches and high primary productivity (via terrestrial inputs and aquatic plants). Ostracod abundance is higher in low energy aquatic habitats (Athersuch et al., 1989).

Living ostracod association and empty valves have similar composition and diversity. However, species proportions differ in specific habitats (Appendix C). Diversity of empty valves is also higher in lakes (Appendix C). This is attributed to quiet water environment, seasonal variation of ostracod populations, reworking and post-mortem transport of shallow water specimens into the permanent brackish lake.

Leucocytherella sinensis is a typical component of biocoenosis (life association) and its shells are dominating within thanatocoenosis (dead assemblages) in lake sediment. However, the ability to dwell in various habitats, makes it a characteristic component of thaphocoenosis (autochthonous dead ostracods, which died at the place of burial, and allochthonous, transported from different sites to the place of burial) in shallow waters. *T. gyirongensis* and *C. candida* are typical for biocoenosis of shallow waters but also for taphonocoenosis (allochthonous) in the epilimnion of Tangra Yumco. *Leucocythere*? *dorsotuberosa* is a component of allochthonous assemblage in shallow temporary waters.

Tab. 2.6 Ecological preferences of the nine living ostracods from Tangra Yumco and adjacent waters – biological indicators useful for palaeoenvironmental reconstructions.

Taxon	**Aquatic habitats** *preferred	**Conductivity** [mS/cm] (salinity)	**Substrate**	**Ecology**	**Indicator value**
Tonnacypris gyirongensis	spring*, estuary-like, river, pond, lake	0.08 – 11.89 (0.06 – 8.62)	sandy gravel, mud, phytal	shallow fresh to brackish waters	dominating in temporary fresh to brackish waters
Limnocythere inopinata	lake*, lagoon	1.35 – 12.81 (0.98 – 9.28)	mud, sand, phytal	permanent brackish waters	dominating in meso- to polyhaline water
Leucocytherella sinensis	lake*, pond, estuary-like, river, lagoon-like	0.08 – 12.81 (0.06 – 9.28)	mud, sandy gravel, phytal	permanent fresh to brackish-lacustrine waters	fresh to brackish waters, dominating in Ca^{2+} depleted water
Candona candida	pond*, river	0.14 – 0.91 (0.10 – 0.66)	mud, sandy gravel, phytal	shallow temporary freshwaters	freshwater
Fabaeformiscandona gyirongensis	lake*	11.88 – 12.81 (8.61 – 9.28)	mud, phytal	permanent brackish-lacustrine waters	brackish-lacustrine deep waters
Leucocythere? *dorsotuberosa*	lake*, lagoon-like	3.83 – 12.81 (2.78 – 9.28)	mud, phytal	permanent fresh to brackish waters	fresh to brackish waters
Ilyocypris sp.	pond*, lagoon-like, estuary-like	0.91 – 11.9 (0.66 – 8.63)	mud, sandy gravel, high organic matter	shallow fresh to brackish waters	shallow fresh to brackish waters
Heterocypris incongruens	pond*	0.18 – 0.91 (0.13 – 0.66)	sandy mud, phytal	perennial freshwater	temporary freshwater
Heterocypris salina	hot spring*	N/A	various	perennial freshwater	temporary freshwater

Reworking, transport and distribution of ancient lake sediments facilitates the transport of fossil lacustrine ostracods to shallow temporary waters. Shallow water fauna can be transported into the lake during heavy rainfalls (heavy influx of river water) and subaqueous sediment transport (Akita et.al. 2015).

Water-deep distribution of ostracods illustrates the zonation of the deep lake Tangra Yumco (Fig. 2.12). *Leucocytherella sinensis* and *L. inopinata* occur commonly in the epilimnion of the lake. *Leucocythere*? *dorsotuberosa* and *F. gyirongensis* occurs frequently in the hypolimnion. We assume *L. inopinata* can live in both shallow and deeper water. It occurs commonly in open shallow waters and lakes (Meisch, 2000). However, the species occurs in Lake Qinghai at 27 m water depth (Li et al., 2010).

2.5.4 Ostracod-environmental relationships

Ostracod distribution and abundance are controlled by physico-chemical conditions of waterbody (Tab. 2.4, Appendix D). Species with similar ecological requirements co-exist (clusters dendrograms) in a particular water body (Tab. 2.4, Fig. 2.8-10). Ostracod reflect changes to environmental conditions by changes in their distribution, diversity, relative abundance, presence and absence of taxa, specific ecological tolerances and microhabitat preference (Van der Meeren et al., 2010; Decrouy et al., 2012; Zhang et al., 2013). The dominant ostracods (presence/absence) in a particular habitat are correlated to favourable physico-chemical conditions (Tab. 2.2-2.4). There is a species-specific optimum tolerance (narrow to broad) to conductivity regimes (Fig. 2.11). Conductivity is the key determinant on the distribution of Tibetan ostracods (Mischke et al., 2007a; Mischke, 2012).

2.5.5 Ecological preferences and implications for palaeoenvironmental reconstruction

Ostracod-based reconstructions may be enhanced if the habitats of the modern fauna are largely known. In the following, we present the ecological characteristics of Recent Ostracoda of Tangra Yumco and adjacent waters and compare them with literature. Recent ostracod preference index, environmental requirements and indicator value are emphasised (Tab. 2.6). This new ecological data can be used in palaeolimnological, palaeoclimate and palaeoenvironmental research. We also adopted ostracod fauna ecological characterisation used by Meisch (2000).

***Leucocytherella sinensis* Huang, 1982**

Ecology: *Leucocytherella sinensis* is a cold-stenothermal species of high altitude water bodies (Huang et al., 1985a). It is a ubiquitous ostracod; living individuals were found in diverse aquatic habitats (temporary fresh and permanent brackish waters). *Leucocytherella sinensis* occurs in fresh to brackish waters. **Occurrences of living individuals**: (i) lake (11 samples), lagoon-like water (3 samples), estuary-like water (2 samples), pond (1 sample) and river (5 samples) (ii) **empty valves**: lake (24 samples), river (12 samples), estuary-like water (10 samples), lagoon-like water (5 samples), pond (3 samples) and spring (2 samples). The species prefers shallow waters (0 – 20 m, Tab. 2.4–2.6) and the phytal zone of lakes with different substrates (mud, sand and gravel) (Tab. 2.8, Fig. 2.9b-10b). It thrives in shallow water and reaches its maturity in these aquatic habitats (Zhu et al., 2002, 2010). *Leucocytherella sinensis* occurs in waters with a conductivity of 0.1 - 13 mS/cm (salinity of 0.06 – 9.28 Tab. 2.4 and 2.8). It is absent at high salinity (100) in Tangqung Co. *Leucocytherella sinensis* can survive in water with a salinity of 0 to 13 (Huang et al., 1985b). Living *Leucocytherella trispinosa*, a junior synonym of *L. sinensis*, was found in a salt lake (Tagutagion) with a salinity of 20 (Zheng et al., 1989; Fürstenberg et al., 2015). Living *L. sinensis* **significantly** correlate **positively** ($p = 0.006$, $r = 0.40$) (Appendix D) with **calcium ionic concentrations** (0.4 – 85.7 meq/l) in Tangra Yumco and adjacent waters.

Distribution: *Leucocytherella sinensis* occurs in Miocene to Recent lake sediments from southern, western and central Tibetan Plateau (Huang, 1982; Peng, 1997). *Leucocytherella sinensis* was found in Recent and Holocene sediments from Nam Co

(Wrozyna et al., 2009b), Pumayung Co (Peng et al., 2013), Bangong Co (Fan et al., 1996), Lake Koucha (Mischke et al., 2008), on the western (Fan et al., 1996) and the north-western Tibetan Plateau (Li et al., 1994). It was also found in the Late Pleistocene to Holocene sediments of Peiku Co (Peng, 1997). *Leucocytherella sinensis* appears in Early/Middle Pleistocene sediments of the Qinghaitang formation, Kunlun Mountains, Qinghai Province and the Neogene of the Zhada Basin (Pang, 1985).
Characterisation: *Leucocytherella sinensis* is an endemic species, commonly occurring in lake systems on the south, central and west of the Tibetan Plateau. It is a ubiquitous species, widely distributed and abundant. It populates different aquatic habitats and substrates, including the profundal zone of lakes, shallow temporary and permanent waters. *Leucocytherella sinensis* can live in freshwater to mesohaline brackish water with a salinity of 20. The species dominates Ca-depleted waters with moderate alkalinity. It is classified as oligothermophilic, titanoeuryplastic, freshwater to mesohaline, and rheoeuryplastic species.
Palaeoenvironmental reconstructions: *Leucocytherella sinensis* is ubiquitous on the Tibetan Plateau above 4000 m asl. It develops nodes on the calcitic valves in low salinity waters and can be used as a proxy for palaeosalinity this way (Fürstenberg et al., 2015).

***Leucocythere*? *dorsotuberosa* Huang, 1982**

Ecology: Living *Leucocythere*? *dorsotuberosa* occurs mainly in the lake (phytal and muddy substrate) and lagoon-like water. Empty valves were found in different habitats: lake (19 samples), river (12 samples), estuary-like water (10 samples), lagoon-like water (4 samples), pond (2 samples) and spring (2 samples). The presence of empty valves in small temporary waters may be due to transport of valves from ancient lake sediments. *Leucocythere*? *dorsotuberosa* (empty valves) occurs in higher proportions at deeper water depth (Fig. 2.12). Living *L.*? *dorsotuberosa* occurs in waters with a conductivity of 3.8 – 12.8 mS/cm (salinity range of 2.9 – 9.6) (Tab. 2.4 and 2.8). *Leucocythere*? *dorsotuberosa* weakly but **significantly** correlates ($p = 0.043$, $r = 0.25$) with **conductivity** (Appendix D). The species can tolerate a wide range of salinities: 0.1 – 1.6 in north-eastern Tibetan lakes (Huang et al., 1985a, b), 0.1 – 2.0 (optimum 0.5) in Nam Co (Wrozyna et al., 2009b), and 2 on the north-eastern Tibetan Plateau (Wu, 1995; Mischke et al., 2007a).
Distribution: *Leucocythere*? *dorsotuberosa* occurs on the eastern and central Tibetan Plateau (Wrozyna et al., 2009b). It was also found in late Cenozoic strata of the Qaidam Basin and in Pliocene sediments (Huang et al., 1985a; Mischke et al., 2006; Zhu et al., 2010). **Characterisation**: *Leucocythere*? *dorsotuberosa* is a lacustrine ostracod on the Tibetan Plateau. It lives on soft bottom and prefers deeper water. It can tolerate freshwater to oligohaline salinity up to 10. It is characterised as cold stenothermal, titanoeuryplastic, freshwater to β-oligohaline and oligorheophilic species.
Palaeoenvironmental reconstructions: Indicator of high altitude fresh and brackish waters. It can be used as water–depth indicator. The development of distinct ribs and reduced reticulation is typical for the profundal zone of Tibetan lakes, this morphological type is known as *Leucocythere*? *dorsotuberosa* forma *postilirata* (see Wrozyna et al., 2009a).

Limnocythere inopinata (Baird, 1843)

Ecology: *Limnocythere inopinata* is a common Holarctic ostracod species with broad ecological tolerance (Meisch, 2000). Living *L. inopinata* occur in the phytal habitats and epilimnion with muddy substrate in Tangra Yumco, and lagoon-like waters with sandy gravel. Empty valves are abundant in the profundal zone of Tangra Yumco. Empty valves were found in diverse aquatic habitats: lake (19 samples), river (7 samples), estuary-like water (6 samples), lagoon-like water (5 samples) and pond (1 sample). It occurs in various aquatic habitats including interstitial ground water, salt lakes, small pools, alpine lakes and the Baltic Sea (Meisch, 2000). *Limnocythere inopinata* prefers the shallow zone of European lakes (Schiemer et al., 1969), although it can live in diverse environments (Yin et al., 1999). The species populates water depths of 27 m in Lake Qinghai (Li et al., 2010). The nature of substrate (clay, mud, silt and sand) and organic matter content are major environmental factors influencing the distribution of *L. inopinata* (Jungwirth, 1979). Higher densities of *L. inopinata* were found in soft mud with high organic content (>80 %) and high loss on ignition (>6 %) in Neusiedlersee (Jungwirth, 1979). *Limnocythere inopinata* can survive in waters with a conductivity of 1.4 – 12.9 mS/cm (salinity range of 1.0 - 9.7) in Tangra Yumco and adjacent waters (Tab. 2.4 and 2.8). It prefers waters with a salinity range of 3 – 9 (Holmes et al., 1999), although it can withstand waters with a salinity of up to 25 (Griffiths and Holmes, 2000). *Limnocythere inopinata* can survive in Tibetan lake waters with a salinity of 0 – 25 (Wang et al., 1990). Nonetheless, living *L. inopinata* was found in waters with salinity of 46 and at low calcium concentration (Meisch, 2000). *Limnocythere inopinata* can dwell in waters with high chloride levels, enriched in Na^+ – HCO_3^- – CO_3^{2-} but depleted in Ca^{2+} (Holmes et al., 1999). Living *L. inopinata* is found in Tangra Yumco and adjacent waters with an alkalinity range of 10.6 – 57.0 mmol/l, a chloride range of 1.2 - 126.5 meq/l and a sulfate range of 0.4 - 45.4 meq/l (Tab. 2.4). It can survive in both shallow and deeper waters (Fig. 2.12). Living *Limnocythere inopinata* **significantly** correlate **positively** with **three physico-chemical variables**: conductivity (p = 0.003, r = 0.36), chloride (p = 0.036, r = 0.33) and sulfate ion concentrations (p = 0.017, r = 0.38) and **negatively** with **two variables**: alkalinity (p = 0.002, = r = -0.37) and oxygen concentration (p = 0.039, r = -0.26) (Appendix D).

Distribution: *Limnocythere inopinata* is widely distributed in the Palaearctic region (Bronshtein, 1947). It was found in Pre-Quaternary (Qinghai Basin), Quaternary (eastern Qaidam Basin) and Holocene lake sediments from the Tibetan Plateau (Hou and Gou, 2007). *Limnocythere inopinata* (Recent, sub-Recent) is a common component of ostracod fauna in lakes on the Tibetan Plateau (Mischke et al., 2007a). It also occupies diverse aquatic habitats in Western Mongolia (Van der Meeren et al., 2010) and brackish lakes in Inner Mongolia and Northern China (Zhai et al., 2010; Zhai and Zha, 2014).

Characterisation: *Limnocythere inopinata* is widespread on the Tibetan Plateau and thrives well in brackish waters (salinity greater than 10). High relative abundance is typical for waters rich in Cl^-- and SO_4^{2-}, Ca^{2+}-depleted and high in alkalinity. *Limnocythere inopinata* is characterised as a mesothermophilic, titanoeuryplastic, freshwater to polyhaline and rheoeuryplastic species.

Palaeoenvironmental reconstructions: Indicator of mesohaline to polyhaline permanent waters with high alkalinity.

Ilyocypris sp.

Remark: There are different morphological types of *Ilyocypris* species on the Tibetan Plateau (Mischke, 2012). The ecological preferences for the genus and our findings are discussed below. **Ecology**: The species of the genus *Ilyocypris* occur in a broad range of freshwater habitats from lentic (lakes, ponds and ditches) to lotic waters (rivers) (Meisch, 2000). They swim and crawl in the bottom water. Living *Ilyocypris* sp. occur in higher proportions in shallow temporary waters (ponds, estuary-like water and lagoon-like water waters) than in the permanent brackish lake Tangra Yumco (littoral zone, < 10 cm water depth). The presence of *Ilyocypris* sp. in the littoral zone of Tangra Yumco is due to transport of temporary shallow water ostracods by heavy runoff during the monsoon season to the lake. *Ilyocypris* sp. lives in waters with a conductivity of 0.9 – 11.9 mS/cm (salinity of 0.7 – 8.9, Tab. 2.4 and 2.8). Empty valves were found in diverse habitats: river (7 samples), lake (4 samples), lagoon-like water (3 samples), estuary-like water (3 samples) and pond (2 samples).
Characterisation: *Ilyocypris* sp. is a shallow water species preferring temporary lentic and lotic water bodies. It lives in freshwater and can survive in waters with elevated salinities of c. 9. *Ilyocypris* sp. is characterised as oligothermophilic, titanoeuryplastic, freshwater to mesohaline and rheoeuryplastic species.
Palaeoenvironmental reconstructions: Indicator of shallow temporary fresh and brackish waters.

Tonnacypris gyirongensis (Yang, 1982)

Ecology: *Tonnacypris gyirongensis* is a typical species of rivers on the Tibetan Plateau (Zheng et al., 2011). It was found in the phytal zones of Nam Co and surrounding water bodies (rivers and estuaries) (Wrozyna et al., 2009b). *Tonnacypris gyirongensis* is the most common living shallow water species in our material and was found in estuary-like water (10 samples), river (7 samples), pond (3) and spring (2 samples). Empty valves occur in various water bodies: estuary-like water (10 samples), river (10 samples), lake (7 samples), lagoon-like water (2 samples), spring (2 samples) and pond (1 sample). *Tonnacypris gyirongensis* lives in waters with a conductivity of 0.1 – 11.9 mS/cm (salinity range of 0.1 – 8.9) (Tab. 2.4 and 2.8). It can dwell in Tibetan freshwater to brackish water with a salinity range of 0 – 5 (Huang et al., 1985a; Yang, 1988; Wrozyna et al., 2009b). Living *T. gyirongensis* **significantly** correlate **positively** with **calcium ionic** concentration (p = 0.002, r= 0.43), and **negatively** with **seven variables**: conductivity (p = 0.001, r = -0.6), alkalinity (p = 0.001, r = -0.54), magnesium (p = 0.026, r = -0.32), sodium (p = 0.005, r = -0.38), potassium (p = 0.031, r = -0.30),), chlorine (p = 0.006, r = -0.43) and sulphate (p = 0.015, r = -0.39) ionic concentrations (Appendix E).
Distribution: *Tonnacypris gyirongensis* occurs largely in Holocene sediment from Tibetan lakes such as Nam Co (Wrozyna et al., 2009b), Pumayum Co (Peng et al., 2013), Peiku Co (Peng, 1997), and Qaidam Basin (Mischke et al., 2006). It was also found in Ladakh, North-West India (Shukla et al., 2002).
Characterisation: *Tonnacypris gyirongensis* is typical for shallow temporary freshwater habitats (e.g., rivers with high turbulence). It prefers freshwater but tolerates salinities up to 9. The species can also withstand a broad temperature range and possibly possesses drying resistant eggs. It is characterised as a mesothermophilic, mesotitanophilic, freshwater to β-mesohaline, mesorheophilic

species.
Palaeoenvironmental reconstructions: Indicator of shallow, often temporary waters.

Fabaeformiscandona gyirongensis (Huang, 1982)

Ecology: Living *F. gyirongensis* prefers the littoral zone with abundant macrophytes and organic-rich detritus in Nam Co (Wrozyna et al., 2009b). However, abundant empty valves of *F. gyirongensis* were observed in much greater water depth (> 50 m) as well in Nam Co (Zhu et al., 2010). Living *F. gyirongensis* was found in phytal zone (c. 5 – 8 m) with muddy substrate and a maximum of relative abundance of empty valves in the hypolimnion (223 m water depth) of Tangra Yumco. The species significantly correlates positively but weak with water depth ($r = 0.28$, $p = 0.024$). Empty valves of *F. gyirongensis* were found in a variety of water bodies: lake (14 samples), estuary-like water (7 samples) and lagoon-like water (7 samples). The occurrence of empty valves in temporary waters may be due to reworking of ancient lake sediments. It dwells in water with a conductivity of 11.9 – 12.8 mS/cm (salinity range of: 8.9 – 9.6) in Tangra Yumco (Tab. 2.4 and 2.8). *Fabaeformiscandona gyirongensis* (sub-Recent) seems also to live in less saline waters with a conductivity of 0.1 – 1.7 mS/cm (salinity 0.1 – 1.3) and has an optimum of 0.5 mS/cm (salinity 0.3) (Yu et al., 2001; Mischke et al., 2007b; Wrozyna et al., 2009b). *Fabaeformiscandona gyirongensis* correlates **significantly positive** ($r = 0.28$) with **water depth** (Appendix E).
Distribution: *Fabaeformiscandona gyirongensis* occurs widely in lakes on the Tibetan Plateau (Mischke et al., 2006)
Characterisation: *Fabaeformiscandona gyirongensis* is a brackish-lacustrine species. It can be characterised as coldstenothermal, titanoeuryplastic, freshwater to β-mesohaline, oligorheophilic.
Palaeoenvironmental reconstructions: Indicator of lacustrine waters.

Candona candida (O.F. Müller, 1776)

Ecology: *Candona candida* is known to be highly adaptable to cold conditions (Meisch, 2000) and cryophilic (thriving at low temperature) in freshwater (Zheng et al., 2011). The classification as cold stenothermal form is not attributed to the water type in which it dwells but to peculiarities of development at low temperature (Bronshtein, 1947; Carbonel et al., 1988; Meisch, 2000). *Candona candida* can live in the shallow zone of lakes (Carbonel et al., 1988; Danielopol et al., 1993) and in deeper waters (Huang et al., 1985a). It inhabits diverse water bodies, permanent and temporary, lotic and lentic, marshes, streams, canals, springs and large lakes down to a water depth of 250 m (Bronshtein, 1947). Living *C. candida* of the Tangra Yumco area is abundant in shallow temporary waters with high organic matter content. Living specimens and empty valves were found in lake (9 samples), estuary-like water (5 samples), river (sandy gravel, 3 samples) pond (muddy phytal, 2 samples) and lagoon-like water (1 sample). We found living *C. candida* inhabits waters with a conductivity of 0.14 – 0.9 mS/cm (salinity range of 0.1 – 0.7) (Tab. 2.4 and 2.8), although it can survive in Tibetan lake-waters within a salinity range of 0.1 – 5.8 (Zhu et al., 2010). *Candona candida* populates the coasts of the Baltic Sea with a salinity range of 0 – 5.7 (Frenzel et al., 2010b). Living *C. candida* **significantly** correlates **negatively with alkalinity** (r = -0.266, p = 0.031) (Appendix E). It occurs in high alkaline waters of small creeks and ponds (pH 8.49 – 8.64) of Lake Van (pH 9.59) in the high mountain region of North-eastern Turkey (Külköylüoğlu et al., 2012). The species can also survive acidic conditions (pH 4.6) in peat bogs (Henderson, 1990). *Candona candida* is abundant in lakes with Mg/Ca>1. It can also withstand high conductivity waters with elevated sulphate content (Bunbury and Gajewski, 2005).

Distribution: *Candona candida* has a Holarctic distribution (Eurasia and North America) (Meisch, 2000) and affinity for cold freshwaters in high altitude regions (Transcaucasia, 1925 m, and the Swiss Alps, 2560 m) (Bronshtein, 1947). *Candona candida* is found in transitional waters connected to Lake Qinghai, Tibetan Plateau (Li et al., 2010). It is deposited in mid-late Holocene sediments of Gyirong and the Quaternary of the Qaidam Basin, Yamzhog Yumco and Yagedong Co (Hou et al., 2002), in Bayan Har Mountains on the north-eastern Tibetan Plateau (Mischke et al., 2008), and Bosten Lake (Mischke and Wünnemann, 2006).

Characterisation: *Candona candida* is a highly adaptive, ubiquitous freshwater species, commonly found in ponds and rivers on the Tibetan Plateau. It occupies waters with Mg/Ca>1 and salinity of up to 6. It is an oligothermophilic, oligotitanophilic, freshwater to oligohaline, rheoeuryplastic species.

Palaeoenvironmental reconstructions: Indicator of freshwater (e.g., ponds and rivers).

Candona xizangensis Huang, 1985

Ecology: *Candona xizangensis* prefers cold freshwater and water depths down to 60 m (Zhu et al., 2010). We found *C. xizangensis* in different water bodies: lake (8 samples; 20m water depth), estuary-like water (1 sample) and river (2 samples). *Candona xizangensis* is lacustrine-brackish, phytal and deep water fauna.

Distribution: *Candona xizangensis* is endemic to the Tibetan Plateau. It was found in Mid-Pliocene to Holocene sediments of a salt lake in Jilong (Gyirong) city (Huang, 1982). Recent specimens occur in Gar (Hou et al., 2002), Nam Co (Wrozyna et al., 2009b), Chen Co (Zhu et al., 2002), and the paleolake Jiuér, Zhongba (Liu et al., 2007).

Characterisation: *Candona xizangensis* is a typical lacustrine freshwater species from the Tibetan Plateau. It can thrive in brackish-lacustrine waters with oligohaline conditions. The species is characterised as cold stenothermal, probably titanoeuryplastic, freshwater to oligohaline and mesorheophilic.

Palaeoenvironmental reconstructions: Indicator of brackish-lacustrine water, phytal and deep-water fauna.

Heterocypris incongruens (Ramdohr, 1808)

Ecology: *Heterocypris incongruens* lives in shallow temporary freshwater bodies (ponds, lagoons and rivers) (Beyer and Meisch, 1996) and permanent water bodies (lakes) with clayey substrate without macrophytes cover (Meisch, 2000). We found living *H. incongruens* dominating in ponds with high organic matter content. Empty valves were found in pond (2 samples), lake (1 sample) and lagoon-like water (1 sample). It is a nektobenthic species (Rossi and Menozzi, 1993) and can withstand a wide range of environmental conditions (Sars, 1928) including high temperature variations (Geiger et al., 1998; Külköylüoğlu, 2004). Its eggs are resistant to desiccation, freezing and high temperature (Angell and Hancock, 1989; Geiger et al., 1998; Henderson, 2002; Meisch, 2000). *Heterocypris incongruens* valves were found in swampy puddles, rivers, springs and man-made pools near Lake Qinghai (Li et al., 2010). We found living *H. incongruens* inhabiting waters with a conductivity of 0.2 – 0.9 mS/cm (salinity range of 0.7 – 1.1) (Tab. 2.4 and 2.8). However, *H. incongruens* can live in waters with a salinity of 12.3 (Li et al., 2010) and 20g/l (Mischke et al., 2003).

Distribution: *Heterocypris incongruens* is a cosmopolitan species (Meisch 2000). The species also occurs in high-mountain (altitude of 1,650 – 2,350 m a.s.l.) water bodies of Turkey (Külköylüoğlu et al., 2012). *Heterocypris incongruens* was found in Lake Qinghai (Mischke et al. 2003; Li et al. 2010). It also occurs in Western and Inner Mongolia and Northern China (Van der Meeren et al., 2010; Zhai and Zha, 2014)

Characterisation: *Heterocypris incongruens* inhabits temporary ponds on the Tibetan Plateau. It can withstand high temperature and a salinity of up to 20. It is a mesothermophilic, freshwater to mesohaline, mesorheophilic species.

Palaeoenvironmental reconstructions: Indicator of shallow temporary waters.

Heterocypris salina (Brady, 1868)

Ecology: *Heterocypris salina* lives in shallow temporary freshwaters (e.g., springs, and ponds), and salty coastal and inland waters (Wang and Dou, 1998; Meisch, 2000). It prefers low salinity, although it occurs in waters with a salinity of up to 20 (Meisch, 2000). The species may disappear in the cold season leaving diapausing eggs (Ganning, 1971). Living individuals and empty valves of *H. salina* were observed in a hot spring north-west of Tangqung Co.

Distribution: *Heterocypris salina* is a holarctic species (Meisch, 2000). It occurs in fresh to brackish waters on the north-eastern Tibetan Plateau (Mischke et al., 2012).

Characterisation: *Heterocypris salina* is thermoeuryplastic, mesotitanophilic to polytitanophilic, freshwater to polyhaline (Meisch, 2000).

Palaeoenvironmental reconstructions: Indicator of temporary waters.

Potamocypris villosa (Jurine, 1820)

Ecology: *Potamocypris villosa* prefers shallow water (springs, spring-associated habitats, canals, pools, brooks), swamp overgrown with macrophytes and lakes (Beyer and Meisch, 1996; Bronshtein, 1947; Meisch, 2000; Roca and Baltanas, 1993). It occurs in the littoral zone of lakes and artificial basins (Meisch, 2000). *Potamocypris villosa* prefers clean and well oxygenated water bodies (Bronshtein, 1947). It is a temporary water species with a strong affinity to flowing water bodies with low conductivity at high elevation (Beyer and Meisch, 1996). High abundance of *P. villosa* was frequently found in pools with filamentous algae and charophytes producing high oxygen concentrations and calcium carbonate precipitation (Mezquita et al., 2000). The species is reported from Lake Qinghai (pH of 6.6 and salinity of 0.57) (Li et al., 2010). We found only one valve of *Potamocypris* cf. *villosa* in a river (10 cm water depth). This suggests the ability of *P. villosa* to colonise high altitude riverine aquatic habitat.

Distribution: *Potamocypris villosa* is widely distributed in high attitude waters (2350 m a.s.l.) in Asia, Europe, and South America (Bronshtein, 1947; Külköylüoğlu et al., 2012).

Characterisation: *Potamocypris villosa* is described as an oligothermophilic, freshwater and mesorheophilic species (Meisch, 2000).

Application for palaeoenvironmental reconstructions: An indicator of temporary freshwaters.

2.5.6 Water-depth distribution in the deep brackish lake Tangra Yumco

Ostracod assemblages and abundance fluctuate with depth (Fig. 2.12). *Leucocytherella sinensis* can live in different water depths but the relative abundance decreases with water depth. *Tonnacypris gyirongensis*, *C. candida* and *Ilyocypris* sp. occur in the shallow littoral zone (about 10 cm water depth). This zone is characterised by unstable hydrological conditions due to fluctuation in water level and increased terrestrial input. Candonids and *L. inopinata* occur in higher proportions within the phytal zone under more stable ecological conditions (up to 20 m water depth). *Candona xizangensis* valves were found within the phytal zone of the lake. *Fabaeformiscandona gyirongensis* can inhabit both the phytal zone with muddy substrate and deeper waters. The occurrences of shallow water species (*T. gyirongensis*, *Ilyocypris* sp. and *C. candida*) within the epilimnion in less than 1 m water depth is attributed to transport of ostracods (living specimens and empty valves) during heavy rainfall (high summer monsoon precipitation), floods and rising of the lake-water level (Akita et al., 2015).

Fabaeformiscandona gyirongensis and *L.*? *dorsotuberosa* occur in higher number within the hypolimnion of Tangra Yumco. This deep water ostracod fauna also occurs in the hypolimnion of Nam Co, the second-largest saline lake on the Tibetan Plateau (Frenzel et al., 2010b; Wrozyna et al., 2009a). However, the relative abundance of *Limnocythere inopinata* in Tangra Yumco is exceptionally high (thus in two sediment samples from deeper depth), although it rarely occurs in Nam Co (Frenzel et al., 2010b). The salinity of Tangra Yumco (8.3) is higher than in Nam Co (2.0) (Frenzel et al., 2010b), this underlines that *L. inopinata* (salinity tolerant species) prefers waters with high salinity.

2.7 Conclusions

Knowledge on modern ostracods and their environment are needed to understand past ecological conditions, environmental and climate change. We elucidate Recent Ostracoda ecology from the deep brackish lake Tangra Yumco and adjacent waters (smaller lakes, estuary-like waters, lagoon-like waters, rivers, ponds and springs) on the southern Tibetan Plateau. Composition of the ostracod associations and abundance significantly ($p < 0.05$) differ in the diverse habitats. The spatial sampling yielded a low abundance of living ostracods but abundant well-preserved empty shells. Although, there are some potential constraints, we can detect relationships between species and the physico-chemical variables. We summarize our findings as follows:

- Eleven Recent Ostracoda were found (nine alive and two empty valves). The two major ostracod associations (cluster) based on habitat preferences are: (i) **permanent water species** – *Leucocytherella sinensis*, *Leucocythere*? *dorsotuberosa*, *Fabaeformiscandona gyirongensis*, *Limnocythere inopinata* and *Candona xizangensis* (empty valves only); (ii) **shallow temporary water species** – *Tonnacypris* *gyirongensis*, *Candona candida*, *Heterocypris incongruens*, *Ilyocypris* sp. *Heterocypris salina* and *Potamocypris* cf. *villosa* (one valve only). The two types of ostracod association (lacustrine and temporary fauna) can be used to categorise water types in sediment records.

- Indicator species are: (i) *L. sinensis* dominates Ca-depleted brackish waters although ubiquitous distributed; *(*ii*) L.*? *dorsotuberosa* dwells in fresh to brackish waters; (ii) *L. inopinata* predominates in mesohaline to polyhaline waters; (iv) *F. gyirongensis* inhabits exclusively brackish-lacustrine deep waters*;* (*v) C. candida* populates freshwaters; (vi) *T. gyirongensis* and *Ilyocypris* sp., are restricted to shallow temporary waters; (vii) *H. incongruens* predominate in ponds, whereas *H. salina* was only found in a hot spring.
- 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 correlates negatively (*T. gyirongensis*, r = -0.68). *Limnocythere inopinata* significantly correlates positively (r = 0.37) with alkalinity. *Fabaeformiscandona gyirongensis* significantly correlates positively (r = 0.28) with water depth.
- Ostracod presence and abundance is largely determined by the **conductivity** (salinity) of the waterbody and **habitat types**.
- Water depth distribution of ostracods can be used to establish different ecological niches within a deep lake. The epilimnion (phytal zone) of Tangra Yumco supports high species richness. *Fabaeformiscandona gyirongensis* and *L.? dorsotuberosa* are water depth indicating ostracods, useful for palaeo-water depth reconstruction.
- We confirm the potential usage of modern ostracods (thus **species-specific ecological preferences**) to **differentiate types of aquatic habitat**.

The new ostracod ecological dataset can be used as a baseline to detect past and future disturbances (e.g., environmental and climate changes) on aquatic ecosystems on the southern Tibetan Plateau. Regular and long-term ecological monitoring is highly needed to assess the effect of climate change on high mountain aquatic ecosystems. We recommend science advocacy on microcrustacean biodiversity conservation, water resource management and environmental stewardship.

2.8 Appendix

Appendix 2.A Sediment samples from Tangra Yumco and adjacent waters (southern Tibetan Plateau).

Sampling	**Main localities**	**Aquatic habitats**	**Sample ID**	**IGSN**	**Number of samples**
Sept. 2009	Tangra Yumco	lake	41, 43, 44, 46, 49, 51-53	IETIP0001-8	8
Sept. 2010	Tangra Yumco	lake	7, 8	IETIP0009 IETIP000A	2
Sept. 2011	Xuru Co	estuary-like	1	IETIP000B	1
	Tangra Yumco	lake	2, 4, 6,7, 9,16,18, 20, 22, 25, 28	IETIP000C-G, IETIP000N-R,T	11
		estuary-like	11, 12, 13, 60,61, 63-66	IETIP000I-K,V-Z, IETIP0010	9
		lagoon-like	27,	IETIP000S	1
		river	10, 14, 15, 29, 67-71	IETIP000H,L-M, U IETIP0011	9
					30 (sub-total)
	Tangqung Co	lake	73	IETIP0017	1
		river	72, 74	IETIP0016,18	2
		pond	75	IETIP0019	1
					4 (sub-total)
June 2012	Tangra Yumco	lake	24, 26, 37	IETIP001D-E, I	3
		lagoon-like	22-23	IETIP001B-C	2
		springs	29, 35, 36	IETIP001F-H	3
					8 (**sub-total**)
	Monco Bunnyi	lake	39	IETIP001J	1
		lagoon-like	40, 41	IETIP001K-L	2
					3 (**sub-total**)
	Xuru Co	lake	43, 52, 63	IETIP001N,Q,U	3
		river	1, 42	IETIP001A, M	2
		lagoon-like	47, 50,53	IETIP001O-P, R	3
		pond	57, 58	IETIP001S-T	2
					66 (Grand-total)

Appendix 2B Occurrences of ostracods in sediment samples with identification number

Species	Number of occurrences	Sample ID (year, number)	International Geo Sample Number (IGSN)
Tonnacypris gyirongensis	24	9_53, 11_1, 11_11 to 15, 11_22, 11_29, 11_60LB to 61LB, 11_63LB, 11_64LC, 11_65LA, 11_66LC to 67LC, 11_68LB, 11_69LC, 11_71LA, 11_75B, 12_29, 12_35, 12_57 to 58	IETIP0008, IETIP000B, IETIP000I to M, IETIP000Q, IETIP000U to Z,IETIP0010 to 13, IETIP0015, IETIP0019, IETIP001F to G, IETIP001S to T
Leucocytherella sinensis	21	9_43, 9_52 to 53, 11_1 to 2, 11_4, 11_7, 11_9, 11_14 to 16, 11_18, 11_20, 11_22, 11_29, 11_65LA, 11_69LC, 11_74, 12_40, 12_50, 12_58	IETIP0002, IETIP0007 to 8, IETIP000B to D, IETIP000F to G,IETIP000L to Q, IETIP000U, IETIP000Z, IETIP0013, IETIP0018, IETIP001K, IETIP001P, IETIP001T
Limnocythere inopinata	12	9_52, 11_4, 11_7, 11_9, 11_16, 11_18, 11_20, 11_22 to 23, 12_26, 12_40 to 41	IETIP0007, IETIP000D, IETIP000F to G, IETIP000N to Q, IETIP001C , IETIP001E, IETIP0001K to L
Leucocythere? *dorsotuberosa*	5	9_52, 11_2, 11_20,11_22, 12_50	IETIP0007, IETIP00C, IETIP000P to Q, IETIP001P
Ilyocypris sp.	4	11_1 to 2, 11_75B, 12_53	IETIP000B to C, IETIP0017, IETIP001R
Candona candida	3	11_15, 11_75B, 12_57	IETIP000M, IETIP0019, IETIP001S
Fabaeformiscandona gyirongensis	3	9_43, 11_16, 11_18	IETIP0002, IETIP000N to O
Heterocypris incongruens	2	11_75B, 12_57	IETIP0019 to IETIP001S

Appendix 2C Ostracod abundance and diversity.

Aquatic habitats	**Ostracoda valves per sample**			**Shannon diversity**
	Mean	**Min - Max**	**Total**	**(mean, SD)**
Live ostracods				
Lake (n = 12)	62	4 – 246	744	0.60 (0.4)
Estuary-like (n = 10)	22	2 – 80	219	0.15 (0.3)
Lagoon-like (n = 6)	85	9 – 253	512	0.02 (0.4)
Pond (n = 3)	297	32 – 764	891	0.73 (0.5)
River (n = 8)	24	4 – 54	189	0.28 (0.5)
Spring (n = 2)	23	2 – 44	46	—
Total samples (n = 41)	**63**	**2 – 764**	**2,601**	**0.35 (0.4)**
Empty valves only				
Lake (n = 24)	865	2 – 4,873	20,762	0.73 (0.3)
Estuary-like (n = 10)	571	263 – 2,441	5,714	0.52 (0.2)
Lagoon-like (n = 5)	737	75 – 1,188	3,686	0.40 (0.2)
Pond (n = 3)	1,373	33 – 9,400	4,118	0.73 (0.2)
River (n = 11)	613	23 – 1,686	6,739	0.37 (0.3)
Spring (n = 3)	250	51 – 633	751	0.31 (0.1)
Total samples (n = 56)	**746**	**2 – 4,873**	**41,770**	**0.58 (0.3)**
Live plus empty valves				
Lake (n = 24)	896	2 – 4,873	21,506	0.78 (0.4)
Estuary-like (n = 10)	593	271 – 2,452	5,933	0.60 (0.2)
Lagoon-like(n = 7)	599	9 – 1, 201	4,198	0.40 (0.3)
Pond (n = 3)	1,670	65 – 3,646	5,009	0.75 (0.3)
River (n = 11)	630	23 – 1,694	6,928	0.46 (0.4)
Spring (n = 3)	266	53 – 633	797	0.30 (0.1)
Total samples (n = 58)	**765**	**2 – 4,873**	**44,371**	**0.61 (0.4)**

Appendix 2D Spearman Correlation between environmental variables and ostracods. Significant correlations are **bolded**. Two stars (**) indicate $p < 0.01$ and one star (*) $p < 0.05$. WD = water depth, CD = conductivity, WT = water temperature, O_2 = oxygen concentration, Ls = *Leucocytherella sinensis*, Ld = *Leucocythere*? *dorsotuberosa*, Il = *Ilyocypris* sp., Ln = *Limnocythere inopinata*, Tg = *Tonnacypris gyirongensis*, Fg = Fabaeformiscandona *gyirongensis*, Cc = *Candona candida*, and Hi = *Heterocypris incongruens*.

	WD	**CD**	**WT**	**pH**	**O_2**	**Al**	**Ca^{2+}**	**Mg^{2+}**	**Na^+**	**K^+**	**Cl^-**	**SO_4^{2-}**	**Ls**	**Ld**	**Il**	**Ln**	**Tg**	**Fg**	**Cc**	**Hi**
WD	1																			
CD	__0.33**__	1																		
WT	__-0.35**__	-0.06	1																	
pH	0.19	-0.01	-0.02	1																
O_2	0.003	0.04	-0.2	0.09	1															
Al	0.08	__0.69**__	0.14	-0.16	__-0.31*__	1														
Ca^{2+}	-0.01	__-0.49**__	0.06	0.09	__-0.36*__	__-0.31*__	1													
Mg^{2+}	__0.36*__	__0.68**__	-0.05	__0.29*__	0.26	__0.50**__	__-0.61**__	1												
Na^+	__0.35*__	__0.77**__	-0.12	0.26	0.18	__0.57**__	__-0.57**__	__0.91**__	1											
K^+	__0.32*__	__0.68**__	-0.09	__0.35*__	0.09	__-0.55**__	__-0.51**__	__-0.91**__	__-0.91**__	1										
Cl^-	0.20	__0.79**__	0.10	__0.38*__	-0.18	__0.75**__	__-0.43**__	__0.82**__	__0.81**__	__0.86**__	1									
SO_4^{2-}	0.12	__0.81**__	0.17	__0.33*__	-0.08	__0.75**__	__-0.38*__	__0.82**__	__0.87**__	__0.86**__	__0.97**__	1								
Ls	0.13	-0.02	0.09	0.17	-0.07	0.02	__0.40*__	0.08	0.05	0.14	0.10	0.15	1							
Ld	0.17	__0.25*__	-0.02	0.14	-0.02	0.17	0.24	0.05	0.03	0.08	0.11	0.12	__0.45**__	1						
Il	-0.01	0.04	-0.06	0.02	-0.10	0.15	0.28	-0.12	-0.19	-0.19	-0.04	-0.11	0.09	0.14	1					
Ln	0.23	__0.36**__	0.19	0.03	__-0.26*__	__0.37**__	0.12	0.19	0.18	0.24	__0.33*__	__0.38**__	__0.42**__	__0.40**__	-0.12	1				
Tg	-0.18	__-0.61**__	0.14	0.09	0.09	__-0.54**__	__0.43**__	__-0.32*__	__-0.38**__	__-0.30*__	__-0.43**__	__-0.39*__	0.07	-0.13	0.07	__-0.28*__	1			
Fg	__0.28*__	0.23	-0.12	0.20	-0.08	0.12	-0.02	0.15	0.19	0.20	0.17	0.14	__0.31*__	-0.07	-0.06	__0.27*__	-0.17	1		
Cc	0.02	-0.20	-0.06	-0.10	0.06	__-0.27**__	0.23	-0.10	-0.19	-0.19	-0.06	0.01	0.01	-0.07	__0.25*__	-0.10	__0.29*__	-0.05	1	
Hi	0.06	-0.10	0:02	-0.14	0.01	-0.17	0.14	-0.14	-0.23	-0.27	-0.13	-0.17	-0.13	-0.06	__0.33**__	-0.08	0.23	-0.04	__0.84**__	1

Appendix 2E Summary results of Canonical Correspondence Analyses (CCA).

Parameter	Axis 1	Axis 2	Axis 3	Axis 4	Total inertia
Species-habitat					
Eigenvalues	0.691	0.210	0.091	0.012	2.5
Explained variation cumulative	27.5	35.8	39.4	39.9	
Pseudo-canonical correlation	0.927	0.766	0.481	0.251	
Explained fitted variation (cumulative	68.7	89.6	98.6	99.7	
Percentage of total variation					40.0 %
Species-physico-chemical variables					
Eigenvalues	0.612	0.253	0.094	0.044	2.6
Explained variation cumulative	24.7	34.3	37.9	39.6	
Pseudo-canonical correlation	0.890	0.797	0.562	0.299	
Explained fitted variation (cumulative)	60.5	84.1	92.8	96.9	
Percentage of total variation					40.8 %
Species-Conductivity					
Eigenvalues	0.669	0.329	0.184	0.074	2.6
Explained variation cumulative	25.4	37.9	44.8	47.7	
Pseudo-canonical correlation	0.906	0.825	0.677	0.447	
Explained fitted variation (cumulative)	68.	89.6	98.6	99.7	
Percentage of total variation					49.3 %

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Chapter 3

Calibration of valve geochemistry of Recent ostracods from the Tibetan Plateau, China

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Chapter 3

3.0 Abstract

This study evaluates the present-day relationship between environmental conditions and the geochemical composition of ostracod valves from the southern Tibetan Plateau. Stable oxygen and carbon isotope values and trace element contents of the four most abundant species were analyzed together with hydrochemical properties of host waters at the time of sampling. Results indicate species-specific stable isotope fractionation and trace element incorporation into the ostracod calcite. Stable isotope values significantly correlate with the respective water stable isotope composition, reflecting salinity and productivity. The offsets between $\delta^{18}O_{valve}$ and $\delta^{13}C_{valve}$ and equilibrium calcite suggest valve formation during the monsoon season and influence of pore water $\delta^{13}C$. Mg/Ca_{valve} is primarily influenced by water Mg/Ca ratios and salinity and confirms the use as proxy for precipitation-evaporation balance and lake level.

Oxygen isotopes and Mg/Ca_{valve} ratios are unaffected by water temperature. Observed effects of water Sr/Ca or salinity on Sr/Ca incorporation are small and biased by the presence of aragonite precipitation, which removes bioavailable Sr from the host water, resulting in low Sr/Ca_{valve} values. The negative correlation between $\delta^{13}C$, reflecting organic matter decay, and Fe/Ca, Mn/Ca and U/Ca in ostracod valves shows the potential to infer changes in redox conditions.

3.1 Introduction

On the Tibetan Plateau ostracods represent the most abundant calcareous organism remains in lake sediments and are thus extremely valuable Quaternary paleoenvironmental indicators. Their valves are used as source material for geochemical analysis in paleolimnological reconstructions of lake-hydrochemistry and climate. Stable oxygen and carbon isotopes values in ostracod valves reflect mainly changes in temperature and salinity, and productivity, respectively (De Deckker and Forester, 1988b; Lister, 1988; Von Grafenstein et al., 1992; Schwalb et al., 1994). Information about precipitation to evaporation (P/E) balance, water source, and meltwater or groundwater inflow, can be derived (Lewis and Anderson, 1992; Last et al., 1994; Cohen et al., 2000; Schwalb, 2003a) as well as modes of decay of organic matter (Schwalb et al., 2013). The most commonly used trace element proxies are Mg/Ca and Sr/Ca ratios. Mg/Ca ratios permit to reconstruct temperature and salinity changes, whereas Sr/Ca ratios are mainly dependent on salinity and Sr/Ca ratios of the ambient water and thus allow for the reconstruction of P/E balance, water source and lake level changes (Chivas et al., 1983b; Hu et al., 2008; Ito and Forester, 2009a; De Deckker et al., 2011). Other elemental ratios have only been exploited by a few studies and results are summarized by Börner et al. (2013a). Chivas et al. (1983b) tested the dependency of Ba/Ca ratios on temperature changes, Ricketts et al. (2001) used U/Ca ratios to infer oxygenation cycles, vertical water mixing and organic matter decay, Gasse et al. (1987) used Fe and Mn to characterize redox conditions, and Zhu et al. (2009b) reported a correlation between Li/Ca and temperature.

In most freshwater habitats the incorporation of various trace elements and stable isotopes into the ostracod valve is not only controlled by one environmental factor alone. In order to validate the relationship between environmental conditions and their translation into the elemental ratios of ostracod valves, it is essential to establish a calibration using modern data, because it is important to assess how valve chemistry is affected by regional and seasonal trends in solute evolution of host waters. Especially if quantitative reconstructions are pursued, sampling has to be carried out shortly after molting because ostracods calcify their low-Mg calcite valves within a few hours to several days (Turpen and Angell, 1971b). This approach has been undertaken by several authors. Multiple studies focused on the calibration of stable isotope ($\delta^{18}O$, $\delta^{13}C$) and trace element (Mg/Ca, Sr/Ca) uptake into ostracod valves, either by culture experiments (De Deckker et al., 1999b; Kondo et al., 2005; Li and Liu, 2010) or by collecting living specimens from natural habitats over an annual cycle (Cronin et al., 2005; Wetterich et al., 2008; Decrouy, 2009b; Marco-Barba et al., 2012). Decrouy et al. (2012a) analyzed stable isotopes and Mg/Ca and Sr/Ca ratios of different species in western Lake Geneva (Switzerland) during one year, and developed models to describe the relationships between ostracod Mg/Ca and Sr/Ca and temperature, as well as $\delta^{18}O_{H2O}$, $\delta^{13}C_{DIC}$ and Mg/Ca_{H2O}, Sr/Ca_{H2O}. Marco-Barba et al. (2012) calibrated valve chemistry data of Cyprideis torosa and established correlations of ostracod valve Sr/Ca to water Sr/Ca and $\delta^{18}O$ to Total Dissolved Solids (TDS), but also discussed possible restrictions to these relationships. For example, in waters with Mg/Ca ratios below 6, no effect of temperature nor Mg/Ca_{H2O} on the uptake of Mg/Ca in the ostracod valve could be detected. The same species was also analyzed by Keatings et al. (2007) who found no relationship between valve Mg/Ca and Sr/Ca ratios and the respective composition of the ambient water. De Deckker et al. (1999b) described a temperature dependence of ostracod Mg/Ca for waters within a range of Mg/Ca ratios of 1 to 30 for Cyprideis australiensis. A critical assessment of the importance to calibrate hydrochemical controls on the element incorporation in ostracod calcite is given by Dettman and Dwyer (2012).

Although ostracods are abundant in Tibetan Plateau lakes and sediments, little is known about the relationship between their geochemical signatures and those of their host waters. In order to better exploit their fossil records as paleoenvironmental proxies, this study investigates relationships and possible controlling factors for the incorporation of stable isotopes and trace elements into the ostracod valve calcite. To achieve this, the stable isotope and trace element content of the most abundant ostracod species was compared to the environmental parameters of the ambient waters. Our results should advance the understanding of the effects environmental conditions exert on isotope fractionation and trace element partitioning and thus increase the value of ostracod valve chemistry as paleoenvironmental proxy on the Tibetan Plateau.

3.2. Geographical Settings

The Tibetan Plateau is one of the most sensitive regions to climate change due to its high elevation exceeding 4000 m a.s.l. (Kang et al., 2010a). Consequently, air temperatures are low with daily temperature differences exceeding annual variations. Mean annual air temperature is 0°C to 5°C, with lowest values in the northeast (far below 0 °C) and highest in the region around Lhasa (>5°C). Mean temperature in the warmest month (July) is 7-15°C, in the coldest month (January) -1°C to -7°C (Immerzeel et al., 2005). Additionally, the Tibetan Plateau is also affecting the global climate system as it acts as heat source and moisture sink (Hsu and Liu, 2003). Precipitation is mainly brought by the East Asian Monsoon and the Indian Summer Monsoon, delivering highest rainfall in the summer month (June to August), and by the Westerlies in the winter month. Annual precipitation is highest in the southeast and shows a decreasing trend towards the northwest.

The Tibetan Plateau hosts more than 300 lakes with a surface area greater than 10 km² (Yu et al., 2001b). We studied nine lakes including their catchments located on a west-east transect in the central and southern part of the Tibetan Plateau: Taro Co, Tangra Yumco, Tangqung Co, Monco Bunnyi, Xuru Co, Nam Co, Npen Co, Yamzho Yumco and Chen Co (Fig. 1). Thus, we cover different climate conditions, from cold and dry in the northwest to warmer and moister in the southeast. Information about location, altitude, lake and catchment area, annual precipitation as well as selected hydrological parameters is given in Table 1.

Lake Taro Co, a freshwater lake, is located in the western part of the Tibetan Plateau and thus in the driest area studied. Further east lies the Tangra Yumco lake system, consisting of Tangra Yumco, Tangqung Co, Xuru Co and Monco Bunnyi. Ancient shorelines and lake terraces suggest that three of these lakes (excluding Monco Bunnyi) may have formed one large ancient lake in the late Quaternary that was separated in more recent times (7.6 ka BP) due to drier climate conditions (Liu et al., 2013a; Rades et al., 2013a). Tangra Yumco is the largest lake within this lake system and consists of two sub-basins, the southern basin with a water depth of 100m and the northern basin with a maximum depth of 230 m, making Tangra Yumco the deepest lake on the Tibetan Plateau (Wang et al., 2010a). The lake sits in a hydrologically closed basin, and is fed by several partially glacier fed streams. Tangra Yumco is a brackish lake (salinity = 7.3 ‰), showing a clear summer stratification with a thermocline between 20 and 25 m. The small brine lake Tangqung Co is located north of Tangra Yumco, and less saline lakes Monco Bunnyi and Xuru Co are located south of Tangra Yumco. All these lakes are hydrologically closed. Nam Co and Npen Co are located in the eastern part of the Tibetan Plateau (Fig. 1). This region is characterized by the highest annual precipitation in the study region. Nam Co, the second largest lake in China, is a brackish water lake within a hydrologically closed basin, which is mainly fed by monsoonal precipitation and, to a lesser extent, by meltwater runoff from the Nyainqengtanglha mountain range (Keil et al., 2010). Npen Co is a freshwater lake northeast of Nam Co with an outflow to Bam Co in the northwest. The Yamzho Yumco lake system is located further south on the northern foothills of the Himalayan Mountains. Part of the huge Yamzho Yumco lake system is Chen Co, the smallest lake in this study. Both lakes are hydrologically closed, precipitation is the main water supply and meltwater from glaciers accounts for just 16 % of total water supply (Zhang et al., 2012a).

3.3 Material and Methods

3.3 1 Sampling

During five fieldtrips to the Tibetan Plateau, taking place each September in 2008 to 2011 and in June 2012, we collected living and sub-Recent ostracods from 326 sites, including lakes, lagoons, rivers, ponds and springs. Lake sediment and water samples were taken from water depths of 2 m to 85.7 m. The lagoons were separated from the open lake waters by sand or gravel bars forming shallow waterbodies featuring limited mixing with the main water body and thus higher susceptibility to climatic changes. The sampled lagoons, ponds and rivers were partly dry in the summer before the monsoon season. Lake sediment samples were taken using an Ekman Bottom Grab, samples from shallow sites, e.g. rivers and lagoons, by using a hand-net. All sediment samples were stored in Whirl-Pak bags and 70 % ethanol was added. For each surface sediment sample a corresponding water sample was taken from the same location using a Niskin type water sampler. Hydrochemical parameters, such as temperature, electrical conductivity, pH, and dissolved oxygen were measured at each site with a multi-sensor probe (WTW340i). Alkalinity was determined using the field titration kit visocolor HE (Macherey-Nagel). Water samples were filtered in the field through 0.45 µm or 1.2 µm membranes (Whatman GF/C) and stored in polyethylene bottles. Samples collected for cation analysis were fixed with 1ml HNO_3. Samples collected for carbon isotope analysis were stored in 12 ml amber glass bottles prepared with a few drops of $HgCl_2$. Sediment samples were sieved using 63 and 200 µm mesh size, rinsed with deionized water and transferred to petri dishes using 99 % ethanol. From the 200 µm size fraction intact adult ostracods (carapaces with well-preserved body parts) were picked with a fine brush under a low magnification stereoscopic microscope, identified and stored in ethanol again. Prior to chemical analysis, articulated valves were separated and soft parts removed.

Ostracod species and ecology

The most abundant ostracod species are *Leucocytherella sinensis* Huang, 1982, *Limnocythere inopinata* (Baird, 1843) and *Tonnacypris gyirongensis* (Yang, 1982). Less abundant are ?*Leucocythere dorsotuberosa* Huang, 1982, Fabaeformiscandona *gyirongensis* (Huang, 1982), *Candona candi*da (O.F. Müller, 1776), *Candona xizangensis* Huang, 1982, and *Ilyocypris* cf. *mongolica* Martens, 1991. Only a few or no living specimens were found, for example, of *Heterocypris salina* (Brady, 1868) that just occurred in some hot springs north of Tangqung Co. Thus, for geochemical analysis only ? *Leucocythere dorsotuberosa*, *Leucocytherella sinensis*, *Limnocythere inopinata* and *Tonnacypris gyirongensis* were used.

Leucocytherella sinensis is by far the most abundant species on the southern and central Tibetan Plateau, covering between 50 % and 90 % of the relative abundance. It is a cold-stenothermal species and endemic to the southern, central and western Tibetan Plateau (Wrozyna et al., 2009a). It is found on all substrate types in all habitats, but prefers shallow waters (up to 20 m). *Leucocytherella sinensis* has a high propagating ability and a strong adaptability (Li et al., 2002). From our observations we conclude that *L. sinensis* molts starting in late spring (May/June) and produces several consequent generations throughout the summer season (Fürstenberg, personnel communication). Living specimens of ? *Leucocythere dorsotuberosa* were only found in lakes, with highest abundances in deep water below the thermocline (20-25 m). ?*L. dorsotuberosa* probably molts in late spring and again in autumn (September) (Fürstenberg, personnel communication). The assignment of *L. dorsotuberosa* to the genus *Leucocythere* was questioned by Wrozyna et al. (2009a) because our specimens bear a lophodont hinge contrary to the description of the genus *Leucocythere*, which possesses a characteristic hinge with the anterior tooth on right valve considerably smaller than the posterior tooth and a crenulated intercardinal bar (compare Danielopol et al. 1989). Therefore, a question mark was assigned to the genus.

Limnocythere inopinata has a palearctic distribution and colonizes a wide range of habitats and substrate types (Meisch, 2000a). In our samples 85 % of the living specimens were found on muddy sediment in Tangra Yumco. In addition, *L. inopinata* is the only species we found dwelling within the sediment. Highest numbers were found in the upper two centimeters, but *L. inopinata* penetrates down to at least 25 cm (Akita et al., submitted-a). *L. inopinata* was described as a summer form with several succeeding generations and adults calcify from late spring to early autumn (von Grafenstein et al., 1999). Tonnacypris gyirongensis (formerly assigned to the genus Eucypris) is a species typical of shallow and turbulent freshwater habitats (Akita et al., submitted-a). Most living specimens originate from river habitats or springs but the time of molting is unknown. Further information about species assemblages and species ecology for most of the studied sites can be found in Wrozyna et al. (2009c) for Nam Co, Akita et al. (submitted-a) for the Tangra Yumco lake system, and Guo et al. (in press) for Taro Co.

Analytical procedures

Water samples were analyzed for cations by Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES), and anions were analyzed by ion chromatography at the Institute of Geographical Sciences, Freie Universität Berlin, Germany, and at the Max Planck Institute for Biogeochemistry, Jena, Germany (2012). Measurements were calibrated using standard solutions (SRM 1643e Trace Elements in Water). Element concentrations for water samples are reported in meq/l, elemental ratios are always given in mol/mol (water and ostracods). The analysis of stable oxygen and hydrogen isotopes was done with a Cavity Ring-Down Spectrometry (CRDS) analyzer (L1102-i, Picarro, Sunnyvale, CA, USA) (Brand et al., 2009) at the Max Planck Institute for Biogeochemistry, Jena, Germany. Water samples (1 ml) were injected using an A200SE autosampler (CTC Analytics, Zwingen, Switzerland). Standardization was done by co-injected lab reference water, which is calibrated against IAEA, VSMOW; SLAP and GISP reference materials (Gehre et al., 2004). Analytical precision is about 0.1 % for $\delta^{18}O$ and <1 % for δD. All values are given in the standard delta notation in ‰ vs. VSMOW (Vienna Standard Mean Ocean Water). Water samples were analyzed for $\delta^{13}C_{DIC}$ at the University Erlangen-Nürnberg, Germany, using an automated equilibration unit (Gasbench 2, Thermo Finnigan) in continuous flow mode coupled to a Thermo Finnigan Delta plus XP isotope ratio mass spectrometer. All samples were measured at least in duplicates. All values are given in the standard delta notation in ‰ vs. VPDB (Vienna Pee Dee Belemnite). The data sets were corrected for machine drift during the run and normalized to the VPDB scale. External reproducibility was better than 0.1 ‰ (1 sigma) for $\delta^{13}C_{DIC}$.

Geochemical analysis of ostracod valves was carried out on adult specimen of *Limnocythere inopinata* (Baird, 1843), ?Leucocythere dorsotuberosa Huang, 1982, Leucocytherella sinensis Huang, 1982 and Tonnacypris gyirongensis (Yang, 1982). To determine the carbon and oxygen isotope ratios, valves were bleached for 24 hours in 2.4 % NaOCl to remove organic matter and afterwards rinsed with double deionized water. Sample weight was at least 100 µg (6-15 valves). Isotopes were measured with a Kiel II coupled to a Finnigan MAT252 Mass spectrometer at the University of Minnesota, USA. Samples are normalized with respect to carbon using NBS-19 and LSVEC standards. Samples are normalized with respect to oxygen using NBS-19 and NBS-18. Analytical precision was 0.1 % for $\delta^{18}O$ and $\delta^{13}C$. The isotope results are reported in standard delta notation in ‰ vs. VPDB. Values for equilibrium calcite were calculated after Friedman and O'Neil (1977) for $\delta^{18}O$, and fractionation of $\delta^{13}C$ between DIC and calcite is 0.8 ‰ (Bottinga, 1968).

Trace element analysis of ostracod valves was carried out at the Department of Earth, Ocean and Atmospheric Sciences, University of British Columbia, Vancouver, Canada. In total, 110 samples were analyzed, thereof are 54 samples of L. sinensis, 19 samples of L. inopinata, 13 samples of ?*L. dorsotuberosa*, and 24 samples of *T. gyirongensis*. We prepared replicate measurements for all sites. To determine the trace element content in ostracod valves we used the flow-through time-resolved analysis (FT-TRA) technique, a continuous leaching approach developed by Haley and Klinkhammer (2002). FT-TRA allows for a complete monitoring of the cleaning and dissolution over time, and thus to distinguish the biogenic signal from secondary calcite or contaminants by their differences in solubility (Klinkhammer et al., 2004). Single valves were loaded into a leaching module (customized Dionex Gradient Pump system) linked to an Agilent 7700x quadrupole ICP-MS. Procedure applied started with a 10 min rinse with deionized water, followed by dissolution with nitric acid solutions, made from ultrapure HNO_3 (Seastar Chemicals Inc., 15.6 M). After the initial rinse, the acidity of the nitric acid is increased to 25 mM over 2 min time, constant at to 25 mM for 8 min, followed by an increase to 50 mM over 2 min and constant until the final increase to 155 mM HNO_3. The moment when the acidity is increased to 155 mM HNO_3 is sample-specific, depending on when the Ca peak, which is associated with the dissolving ostracod valve, reaches baseline. This is determined by live monitoring of Ca counts per second, and the switch to 155 mM HNO_3 is done manually. The increase to 155 mM HNO_3 is needed to dissolve low solubility phases, such as clay. Flow-rate was constant at 0.7 ml/min.

To minimize spectral interferences, He was used as an inert collision gas in the Octopole Reaction System. For internal standardization indium (^{115}In) was used. Double-charging and oxide effects were monitored and were less than 4 % and 0.8 %, respectively. To calculate normalized concentrations for each isotope, a standard curve was generated using known dilutions of a high standard solution (2 ppm Ca, 50 ppb Mg, 100 ppb P, 10 ppb Sr, Mn, Fe, Al, 5 ppb Li, As, Ba, Be, Cd, Mo, Ti, Zn, and 1 ppb Ce, U, Th). Analytic reproducibility was tested using BCS-CRM No. 393 (ECRM 752-1) Limestone and is approximately ±2.5 %. A mathematical correction is applied to account for surface contamination on the ostracod valves (Klinkhammer et al., 2004), detected by increasing Al and Ti values indicative for the clay phase. Me/Al molar ratios (Me being the element of interest, e.g. Mg or Ca) in the contamination phase (e.g. clay) are calculated to subtract the element concentration associated with the clay phase from the original biogenic signal using the following equation:

$$Me_{corr} = Me_{measured} - (Al_{measured} * Me/Al_{clay}) \qquad (1)$$

In addition, we can account for uneven element distribution within the ostracod valve. Heterogeneity in the ostracod valve is displayed in the time-resolved element/calcium ratios by higher or lower Me/Ca ratios compared to the original biogenic signal, which is constant below the Ca peak. These were excluded from the calculation of the biogenic signal. A detailed description of the application of FT-TRA to ostracod valve chemistry is in preparation (Börner et al.).

3.4 Results

3.4.1 Hydrochemistry

The sampled sites show large variation in their chemical water properties (Appendix, Table 2). Electrical conductivity ranges between 0.14 mS/cm and 12.8 mS/cm, pH ranges from 6.8 up to 10.7, and water temperature from 4.8°C to 23°C. The most prominent anion in most waterbodies is HCO_3^-, except in Chen Co and Yamzho Yumco, which are dominated by SO_4^{2-} (Fig. 2b). Samples from Tangra Yumco contain nearly equal amounts of HCO_3^- and SO_4^{2-}. Most dominant cations are Na^+ and K^+, except for Npen Co, NamCo inflow and the ponds, where Ca^{2+} is more abundant (Fig. 2a), and Taro Co with equal amounts of Na^++K^+ and Ca^{2+} and nearly void of Mg^{2+}. Our dataset did not include waterbodies dominated by Cl^- or Mg^{2+}. The ionic composition seems mainly affected by the geological setting of the waterbodies. The calcite saturation index was positive for most of the waterbodies suggesting calcite saturation (Appendix, Table 2). The lakes Chen Co, Nam Co, Npen Co, Yamzho Yumco and two Taro Co and one Tangra Yumco inflow show negative CSI (-0,1 to -2,6) indicating calcite dissolution. Most waters evolve along the calcium-carbonate and Mg-Ca carbonate trajectories. Highest Ca^{2+} content was found in some of the studied rivers (up to 119.75 meq/l), and highest Mg^{2+} content was measured in Tangra Yumco (29 meq/l). The molar Mg/Ca ratios of the waters span a wide range from 0.0001 to 75.64. River and spring waters show the overall lowest ratios (<0.5) followed by Npen Co and Taro Co lake waters with 0.65 and <1.0, respectively. Highest Mg/Ca ratios occur in Tangra Yumco, with values up to 75 in 2009, but in the following sampling years molar Mg/Ca ratios reached a maximum of 23. Figure 3c shows the relationship between Mg/Ca_{H2O} and TDS ($r^2=0.60$) and reflect the calcium depletion trend in the sampled waterbodies. Sr/Ca ratios range from 0.0006 to 0.02135, but are not regionally separable like the Mg/Ca ratios. Sr/Ca ratios show no correlation to TDS (Fig. 3d).

The $\delta^{18}O$ and δD values range from -18.8 ‰ to -0.35 ‰ and -145.75 ‰to -65.13 ‰, respectively, and are significantly positively correlated ($r^2=0.96$; Fig. 4a) as expected. All lake samples are located on a local evaporation line below the Global Meteoric Water Line (GMWL) indicating closed basins mainly affected by evaporation. The $\delta^{18}O$ and δD values are -6.58 ‰ and -76.8 ‰ for Tangra Yumco and -5.72 ‰ and -69.3 ‰ for Taro Co, respectively, and are different to spring, pond and river waters, which are characterized by very low $\delta^{18}O$ (-18 ‰) and δD (-138 ‰) values plotting on the GMWL. These very low isotopic values are caused mainly by influx of high-altitude precipitation and also by glacial meltwater. The $\delta^{18}O$ values of the lagoon samples are even more distant from the GMWL as they are more exposed to evaporation due to their shallow water depth and limited mixing with the main water body. In addition, the $\delta^{18}O$ values correlate with TDS ($r^2=0.44$, Fig. 3a) reflecting the effect of evaporation on both $\delta^{18}O$ and salinity. The carbon isotope composition shows several distinct features. Overall $\delta^{13}C_{DIC}$ values range between -11.86 ‰ and 5.78 ‰ vs. VPDB. The carbon isotope values show no correlation to measured $\delta^{18}O$ and TDS , but two clusters (Fig. 3b, 4b). Lake water samples are characterized by positive $\delta^{13}C_{DIC}$ values and thus enrichment in ^{13}C, whereas catchment waters (river and springs) show more depleted and negative values. The $\delta^{13}C_{DIC}$ between different lakes differs slightly with values of 5.0 ‰ at Tangra Yumco, 3.4 ‰ at Xuru Co and 2.4 ‰ at Taro Co. In addition, $\delta^{13}C_{DIC}$ show a slight decrease from surface water to bottom water of approximately 2‰.

3.4.2 Geochemistry of ostracod valves

Stable isotope data are available for three species: Limnocythere inopinata, *Leucocytherella sinensis* and *Tonnacypris gyirongensis* (Fig. 5). In general, $\delta^{18}O_{valve}$ and $\delta^{13}C_{valve}$ values show variation between species and sites. $\delta^{18}O_{valve}$ values range from -16.5 ‰ to -3.99 ‰ and $\delta^{13}C_{valve}$ values range from -4.51 ‰ to 4.23 ‰. *L. inopinata* and *L. sinensis* belong to the family Limnocytheridae and show similar isotope patterns with values ranging from -9 ‰ to -4 ‰ for $\delta^{18}O_{valve}$ and 0.5 ‰ to 3.2 ‰ for $\delta^{13}C_{valve}$, respectively. In contrast, $\delta^{18}O$ and $\delta^{13}C$ values of *T. gyirongensis,* belonging to the family Cyprididae, show clearly more negative values ranging from -16.5 ‰ to -13.3 ‰ for $\delta^{18}O_{valve}$ and -4.5 ‰ to 4.2 ‰ for $\delta^{13}C_{valve}$. $\delta^{18}O_{valve}$ and

$\delta^{13}C_{valve}$ values of all species correlate positively with the respective isotope value of the ambient water (Fig. 5a,b). A correlation between $\delta^{18}O_{valve}$ and $\delta^{13}C_{valve}$ could not be observed, as samples cluster into two groups, one group formed by *L. sinensis* and *L. inopinata*, the other by *T. gyirongensis* (Fig. 5c). Stable carbon and oxygen isotope values of all analyzed species show an offset from calculated values for inorganic calcite. Ostracod valves show a negative offset of -7 ‰ to -17 ‰ in ^{18}O compared to inorganic calcite, except *L. sinensis* valves from the rivers and springs, showing just a slight negative offset (-2 ‰ to 0.2 ‰) (Fig. 5b). Ostracod $\delta^{13}C_{valve}$ show a positive offset from inorganic calcite in the catchment waters (rivers, ponds, lagoons, springs) and a negative offset when originating from lakes. A significant relationship of $\delta^{18}O_{valve}$ to temperature could not be observed, but it is influenced by TDS ($r^2=0.45$).

Molar Mg/Ca ratios of all analyzed samples span a wide range, 0.0012 – 0.032 in *T. gyirongensis*, 0.0056 – 0.0846 in *?L. dorsotuberosa,* 0.0175 – 0.052 in *L. inopinata* and 0.0015 – 0.0415 in *L. sinensis*. The Mg/Ca ratio shows a significant correlation to TDS ($r^2=0.4$ for L. sinensis up to $r^2=0.9$ for *T. gyirongensis*) and a modest correlation to the Mg/Ca ratio of host water (Fig. 7a; $r^2=0.2$ for *L. sinensis* up to $r^2=0.6$ for *T. gyirongensis*). The observed molar Sr/Ca_{valve} ratios span a total range of 0.00023 – 0.0126: 0.00023 – 0.0024 in *T. gyirongensis,* 0.00098 – 0.0037 in *?L. dorsotuberosa*, 0.0009 – 0.0017 in *L. inopinata*, and 0.00051 – 0.0126 in *L. sinensis*. However, no significant correlation to TDS could be found and only a weak relationship of Sr/Ca_{valve} values to the Sr/Ca of the host waters could be detected (Fig. 7b; $r^2=0.2$). Ba/Ca_{valve} ratios range from 0.018×10^{-3} to 0.00058 and correlate with Mg/Ca_{valve} and the Ba/Ca content of the ambient water. Molar Fe/Ca ratios in modern valves range from 0.05×10^{-6} to 0.0038. The Mn/Ca_{valve} values are significantly higher than Fe/Ca_{valve}, ranging from 0.024×10^{-3} to 0.0048. The U/Ca ratios are between 0.13×10^{-9} and 0.015×10^{-3}. Mn/Ca, Fe/Ca, and U/Ca show strong positive correlations among each other within each respective species and are negatively correlated to $\delta^{13}C_{DIC}$ (Fig. 8). The observed patterns are displayed in the principal component analysis (PCA, Fig. 6). Trace element ratios in ostracod valves cluster in two groups. One group is mainly affected by the TDS and, to a lesser extent, the Mg/Ca ratio of the host water. This group consists of the ostracods Mg/Ca, Sr/Ca and Ba/Ca ratios and is accompanied by the ostracods $\delta^{18}O$ content. In the second group all redox sensitive trace elements (Fe/Ca, Mn/Ca and U/Ca) cluster together and are influenced by $\delta^{13}C_{DIC}$ and O_2. All available data on stable isotope and trace element composition in ostracods from southern Tibet is summarized in Table 3 (Appendix).

3.5 Discussion

Our comparison of the trace element and stable isotope composition of ostracod valves sampled from natural lacustrine environments on the southern Tibetan Plateau is based on single sampling occasions because of the size and remoteness of the study area, and we were thus not able to monitor the evolution in water chemistry through time. Hence a direct measurement of the exact hydrochemical properties at the time of calcification was not possible. Uncertainty may arise as water chemistry may have evolved between the time of valve calcification and sampling caused by changes in temperature, precipitation and evaporation. Nevertheless, the observed water properties show distinctive variation and are well suited to investigate their influence on the chemical composition of ostracod valves.

3.5.1 Stable isotopes in ostracod valves

The carbon isotopic composition of ostracod valves represents the $\delta^{13}C$ signature of the dissolved inorganic carbon (DIC) at the time of valve calcification, which provides information about carbon sources and productivity (Mischke et al., 2010a; Decrouy et al., 2011b; Pérez et al., 2013). Processes that affect the carbon isotopic composition include the exchange of CO_2 with the atmosphere, groundwater inflow, changes in pH, photosynthesis, organic matter decay, and bacterial activity, for example. For our samples we observed just a weak correlation between $\delta^{13}C_{valve}$ and $\delta^{13}C_{DIC}$ (Fig. 5a), but all values scatter around the predicted values for inorganic calcite, probably depending on the amount of organic matter decay at the sediment-water interface during valve formation. A relationship between $\delta^{13}C_{valve}$ and $\delta^{18}O_{valve}$ was not observed (Fig. 5c). The $\delta^{13}C_{valve}$ values from different sites also vary just slightly, with ostracod valves from Tangra Yumco and Taro Co being slightly enriched in ^{13}C compared to valves from rivers. High $\delta^{13}C_{valve}$ in ostracods from lakes reflect high DIC carbon isotope values of lake waters, which are most likely caused by high primary productivity, especially in habitats with high abundance of Potamogeton such as in Taro Co. Tangra Yumco and Taro Co are stratified lakes and due to limited mixing of the water column we could observe decreasing $\delta^{13}C_{DIC}$ from the surface waters to the bottom waters, which may add to the observed scatter in $\delta^{13}C_{valve}$. In their catchment waters, where DIC carbon isotope values are lower than in the lakes, attesting to lower primary productivity, ostracods show the most negative $\delta^{13}C_{valve}$ values. High primary productivity increases surface water $\delta^{13}C_{DIC}$, but at the sediment-water interface, where ostracods live, organic matter decay leads to depletion in ^{13}C. In addition, the constant supply of freshwater or groundwater may shift the $\delta^{13}C$ signal toward lighter values. Rivers are in addition affected by meltwater runoff, characterized by low $\delta^{13}C_{DIC}$.

The carbon isotope fractionation during ostracod valve formation is out of equilibrium with $\delta^{13}C_{DIC}$, and observed differences between $\delta^{13}C_{DIC}$ and $\delta^{13}C_{valve}$ ($\Delta^{13}C = \delta^{13}C_{valve} - \delta^{13}C_{DIC}$) are highly variable. Carbon isotope values of ostracods from lakes are generally lower compared to $\delta^{13}C_{DIC}$ (*L. inopinata:* -3.5 ± 0.9 ‰; *L. sinensis*: -2.29 ± 0.97 ‰) and show a negative offset compared to inorganic calcite (*L. inopinata*: -4 ‰; *L. sinensis*: -3 ‰). Ostracods from catchment waters show higher $\delta^{13}C_{valve}$ values (*L. sinensis*: +4.8 ± 0.9 ‰) compared to inorganic calcite and $\delta^{13}C_{DIC}$. This variation of $\Delta^{13}C$ is most likely caused by shifts in $\delta^{13}C_{DIC}$ between the time of valve calcification and sampling. Ostracod valves molted earlier in the year when primary productivity in the lakes was lower than during sampling time. This may also explain why the carbon isotope composition of L. sinensis valves from the catchment waters show nearly the same values as in the lakes, although the measured $\delta^{13}C_{DIC}$ is 5 ‰ to 10 ‰ lower in the rivers.

Another factor causing this apparent disequilibrium may be that some of the studied ostracods molt in the sediment and may be influenced by the $\delta^{13}C$ signature of the pore waters. von Grafenstein et al. (1999) found that $\delta^{13}C$ in valves of ostracods molting in interstitial waters are expected to be lower than the measured $\delta^{13}C_{DIC}$ caused by organic matter decay. $\delta^{13}C_{DIC}$ in pore waters is also expected to show high variability within a basin due to differences in sediment composition, groundwater discharge, primary productivity, and organic matter decay (Marco-Barba et al., 2012), which may explain the scatter of $\delta^{13}C_{valve}$ in the studied basins. In our study L. inopinata, showing a high negative offset in $\delta^{13}C_{valve}$, penetrates deep into the sediment and is therefore also influenced by the $\delta^{13}C$ of the pore waters. The overall lowest $\delta^{13}C_{valve}$ values were observed for *T. gyirongensis*, living in shallow river waters. Based on our results, we also suggest that T. gyirongensis molts at the sediment-water interface or even within the sediment, as their negative $\delta^{13}C_{valve}$ suggests an influence by ^{13}C-depleted interstitial water.

Factors influencing the oxygen isotopic composition in ostracods are water temperature as well as the isotopic composition of the host water. In closed basin lakes the $\delta^{18}O_{H2O}$ is mainly controlled by isotopic changes in precipitation resulting from air temperature variations (Von Grafenstein et al., 1992; Schwalb et al., 1994; Schwalb et al., 2002b). In addition, meltwater or groundwater input influence the $\delta^{18}O_{H2O}$ (Lewis and Anderson, 1992; Cohen et al., 2000). In our study, a weak correlation between $\delta^{18}O_{valve}$ and temperature is only given in samples originating from rivers, springs or ponds. Ostracod valves from lakes show a wide range of δ^{18}O values (-4‰ to -7‰) at nearly the same temperatures (12.9 - 13.8°C) as available δ^{18}O data for specimens living in the lakes all originate from the upper 20 m. Deeper and thus colder parts (minimum 2°C) of the lakes yielded not enough living specimens for isotopic analysis. In addition, water temperatures of shallow water bodies or lake surface water are highly variable, thus we are uncertain about the temperature at the time of valve formation.

The observed $\delta^{18}O_{valve}$ values correlate with the respective δ^{18}O values of the ambient water (Fig. 5b) and also with TDS (Fig. 6). Increasing salinity results in increased $\delta^{18}O_{H_2O}$ and more ^{18}O is consequently incorporated into ostracod valves. The degree to which this relationship is affected by temperature, however, could not be resolved in this study. The oxygen isotope composition in ostracod valves is apparently out of equilibrium as they generally incorporate less ^{18}O compared to inorganic calcite. In culture experiments a species-specific vital offset was reported to be constant relative to the equilibrium value of inorganic calcite (Keatings et al., 2002), but the offset may become more variable in stressful environmental conditions (Marco-Barba et al., 2012). In our study, the oxygen isotope values of ostracods are clustered into three groups (Fig. 5b). The first group are ostracods from the lakes, which are high in TDS and have highest $\delta^{18}O_{H_2O}$, show also the highest $\delta^{18}O_{valve}$ with an offset of -11 ‰ from inorganic calcite formed in equilibrium. The second cluster shows an offset nearly as high (-8 ‰) and consists of *T. gyirongensis f*rom the catchment waters. The lowest offset from equilibrium calcite (-1 ‰) is shown by *L. sinensis* living in the catchment waters, forming the third cluster. The overall low oxygen isotope values in the rivers are caused by influx of meltwater as well as high-altitude, continental precipitation, which is characterized by low δ^{18}O values. Oxygen isotope values for waters and ostracods from brackish lakes reflect the evaporative enrichment in ^{18}O. The high negative offset of ostracod δ^{18}O from equilibrium calcite, especially in the lake waters is caused by the time lag between the calcification and collection of the ostracods. Most of our samples were collected during the end of summer, a period characterized by high evaporation. Our ostracod species calcify from late spring during the summer, which coincides with the monsoon season (end of June until end of August), bringing precipitation to the southern Tibetan Plateau. In the lakes, the observed very negative offset of *L. sinensis* and *L. inopinata* $\delta^{18}O_{valve}$ from equilibrium calcite is due to valve formation taking place during the monsoon season, when the host waters had lower oxygen isotope values compared to the time of ostracod sampling, when evaporative enrichment already increased $\delta^{18}O_{H2O}$. The $\delta^{18}O_{valve}$ of *T. gyirongensis* from river habitats show also a high offset from equilibrium calcite, indicating that the $\delta^{18}O_{valve}$ is influenced by the negative δ^{18}O signatures of meltwater runoff. Thus, we propose that T. gyirongensis molts in spring with the onset of spring runoff. Hence, our results confirm that the life cycle of the studied ostracod species is adapted to the monsoon season. Thus, habitat characteristics and seasonal history can be identified by the comparison of ostracode and host water isotope signals. Low $\delta^{18}O_{valve}$ and the very negative $\delta^{18}O$ values of river and spring waters reflect stable systems with groundwater inflow that are unaffected by evaporative enrichment. High $\delta^{18}O_{valve}$ in ostracods from lakes with brackish water conditions and higher $\delta^{18}O_{H2O}$ values indicate evaporative enrichment.

The difference between $\delta^{18}O_{H2O}$ and $\delta^{18}O_{valve}$ ($\Delta^{18}O = \delta^{18}O_{valve} - \delta^{18}O_{H2O}$) shows the same pattern as already observed for $\delta^{13}C$ values. Ostracod valves are enriched in ^{18}O compared to $\delta^{18}O_{H_2O}$. In waters most depleted in ^{18}O, corresponding to small waterbodies and rivers, $\Delta^{18}O$ for *L. sinensis* is 10 times higher than for ostracods living in waters with higher $\delta^{18}O$ values. Variable disequilibrium effects for ostracods were also reported by Marco-Barba et al. (2012) and Chivas et al. (2002) for ostracods living in stressful hydrochemical environments. For example, Marco-Barba et al. (2012) reported a large decrease in $\Delta^{18}O$ ($\Delta = \delta^{18}O_{valve} - \delta^{18}O_{H_2O}$) at high TDS (> 50 g/l). In all our samples TDS is below 8 g/l, and thus far below the reported values by these authors (72 g/l), but our results also show the lowest $\Delta^{18}O$ in the most saline samples from Tangra Yumco. Nevertheless, the most critical factor is the time lag between the calcification and collection of the ostracods, thus we are not able to test

3.5.2 Elemental ratios in ostracod valves

The Mg/Ca ratios have been widely used as indicator for temperature (Chivas et al., 1986a; Holmes et al., 1992; De Deckker et al., 1999b) and salinity changes (Engstrom and Nelson, 1991; Van der Meeren et al., 2011) as the Mg incorporation into ostracod valves is considered to be a function of temperature and the Mg/Ca content of the host waters. Especially in marine environments, where Mg/Ca is constant over time, changes in water temperature can be reconstructed using Mg/Ca in ostracods. In continental waters Mg/Ca is highly variable due to, for example, mineral dissolution, carbonate precipitation, and evaporation. Thus, the effect of Mg/Ca of the water on the Mg-incorporation in ostracod calcite is much larger, exceeding the temperature-dependence (De Deckker et al., 1999b). Strontium incorporation has been found to be a direct function of the Sr/Ca content of the host water but independent of temperature (Wansard et al., 1998b; De Deckker et al., 1999b; Ito and Forester, 2009a). A strong relationship between salinity and Mg/Ca as well as Sr/Ca ratios in ostracod valves has been shown in numerous studies, but this relationship depends strongly on solute evolution pathways (Wansard et al., 1998b; Ito et al., 2003b; Ito and Forester, 2009a). Mischke et al. (2008a) reported that the Mg/Ca_{valve} and Sr/Ca_{valve} ratios in ostracods from the northern Tibetan Plateau reflect changes in the precipitation to evaporation balance and water source, as they were related to the respective Mg/Ca and Sr/Ca content of the host water as well as to salinity, but all studied lakes were located on the bicarbonate enrichment trend. Most of the lakes in our study also follow the bicarbonate enrichment trend with the exception of Chen Co and Taro Co, following a Ca-enrichment trend.

In our study, the molar Mg/Ca ratios of ostracods show no significant correlation to measured water temperature. There seems to be an effect of Mg/Ca_{H_2O} on Mg/Ca_{valve} (Fig. 7), although the values show a large scatter. The effect of changing Mg/Ca_{H_2O} on the Mg/Ca_{valve} may also exceed the effect of temperature, as suggested by De Deckker et al. (1999b) and thus mask a possible temperature relationship. In addition, the lack of covariance between Mg/Ca_{valve} and temperature is likely caused by shifts in water temperature and solute evolution between the time of valve calcification and sampling. A significant relationship between Mg/Ca_{valve} and TDS just exists for ?*L. dorsotuberosa* and *T. gyirongensis*. During evaporative enrichment, the increase of Mg/Ca_{H2O} in the lakes on the bicarbonate enrichment trend is higher than the increase in salinity, because calcite precipitation removes Ca, whereas Mg concentrations increase due to evaporation. A correlation of Mg/Ca_{H2O} and salinity is true for most of our study sites, except for Tangra Yumco (Fig. 3c), which may explain why *L. sinensis* and *L. inopinata* show just a weak to moderate correlation between Mg/Ca_{valve} and TDS. In addition, we observe a significant correlation between Mg/Ca_{valve} and the Mg^{2+} content of the host water. Thus, for our study area it is possible to use the ostracod Mg/Ca ratio to infer changes in solute evolution and TDS. The large scatter we observe may again be due to the time lag between ostracod calcification and sampling, so that the hydrochemical properties of the host waters have evolved during this time. In addition, it has been shown by several authors that ostracods calcifying in stressful environments show higher variation in their Mg/Ca content. In culture experiments De Deckker et al. (1999b) found that ostracods living in waters with high Mg/Ca (>30) are not able to control their Mg incorporation sufficiently resulting in higher variation of Mg/Ca_{valve}. In our samples the Mg/Ca ratios of the host water have values up to 76 and as low as 0.0001, which may indicate stressful conditions and explain the large scatter at both ends of the range. Especially the high scatter in Mg/Ca_{valve} from Tangra Yumco may be explained by insufficient control of Mg-uptake, as molar Mg/Ca_{H2O} ratios reach up to 75. The correlation between Sr/Ca_{valve} and the respective Sr/Ca_{H_2O} and TDS (salinity) is very weak *(Fig. 7)*. A salinity-dependence of Sr/Ca_{valve} was described by many authors (Engstrom and Nelson, 1991; Holmes et al., 1992; Cohen et al., 2000), but the authors stated also that this signal can be biased by aragonite precipitation in the lake waters. Aragonite is a carbonate mineral which takes up Sr into its structure and removes Sr and also Ca from the water, thus controlling the Sr-bioavailability (Engstrom and Nelson, 1991). Today, aragonite forms in Tangra Yumco, whereas in Nam Co and Taro Co calcite is the dominant carbonate. For the other lakes the type of carbonate mineral is unidentified. For example, the Sr/Ca_{valve} ratios of *L. sinensis* from Tangra Yumco show low values (< 0.002) and little scatter. Further insight into carbonate mineralogy is needed for all study sites in order to establish a correlation usable for quantitative reconstructions. A negative correlation is observed between Sr/Ca_{valve} and water temperature for *L. sinensis* and ?*L. dorsotuberosa*. The incorporation of Sr into ostracod calcite, however, is not temperature dependent, the observed relationship actually emphasizes the correlation between Sr/Ca_{valve} and Sr/Ca_{H_2O}, as in our dataset cold lake waters show higher Sr/Ca and shallow waters, which are warmer, have lower Sr/Ca.

Our data also shows a covariance between Sr- and Mg-incorporation into ostracod valves. Precipitation rate and Mg content of calcite may exert a strong effect on the Sr incorporation, biasing the relationship between Sr/Ca_{valve} and Sr/Ca_{H_2O}, which was first shown by Mucci and Morse (1983) for inorganic calcite, but also by Xia et al. (1997b) for ostracods. This is also true for Ba/Ca_{valve}. Kitano et al. (1971) reported an increase in Ba-coprecipitation with increasing Mg/Ca_{valve} for inorganic calcite. This is in agreement with our observations, as both, Ba/Ca_{valve} as well as Sr/Ca_{valve}, are influenced by the Mg content of the ostracod calcite. Molar Ba/Ca_{valve} ratios correlate just slightly with the respective Ba/Ca ratios in the host waters and show a wide scatter. A relationship of Ba/Ca_{valve} to either TDS or temperature has not been observed for any of the studied species.

Very few studies exist that address the potential of iron, manganese and uranium in ostracod valves as paleoenvironmental proxy (Gasse et al., 1987; Holmes, 1997; Ricketts et al., 2001). The authors relate increasing element concentrations to low oxygen waters and thus increased uptake of iron, manganese and uranium into the ostracod valve. The cycling of Fe, Mn and U is mainly controlled by the redox conditions, hence oxygenation, of the host water. In well oxygenized waters all elements are insoluble, either complexed or adsorbed on mineral surfaces. Ionic forms occur in oxygen-deficient waters (low redox potential) and become then available for incorporation in ostracod valves. A correlation between Fe/Ca_{valve} and Mn/Ca_{valve} and the respective Fe/Ca and Mn/Ca content of the ambient water was not observed. This may be explained by valve calcification taking place several weeks prior to sampling, which is also suggested by the very negative $\delta^{18}O$ values. Thus, the Mn and Fe concentrations of the host waters at the time of sampling were not the same as at the time of valve formation. During all sampling periods we never encountered anoxic conditions, and the oxygen concentration ranged from 1.98 mg/l to 12.6 mg/l for all sites, thus a correlation between redox sensitive element concentration and oxygenation was not expected. Interestingly, the Fe/Ca_{valve}, Mn/Ca_{valve} and U/Ca_{valve} ratios are all positively correlated to each other (Fig. 6), suggesting the same mechanism controlling the Fe, Mn and U incorporation into the ostracod valves. Also, ostracod valves from both peat sites, where reducing conditions at least temporarily exist and which feature the lowest observed O_2 concentrations (1.98 mg/l) serve as test for elemental behavior under low oxygen conditions. They display some of the highest ratios for Mn/Ca, Fe/Ca and U/Ca. Compared to $\delta^{13}C_{DIC}$ values, all three elemental ratios show an increasing trend with decreasing $\delta^{13}C_{DIC}$ (Fig. 8). As suggested by Holmes (1997), this may reflect better availability of Fe, Mn and U ions during phases of carbon input from organic matter decay, which leads to reducing conditions. The only exceptions are valves of *L. inopinata* showing a positive correlation between Fe, Mn, U and $\delta^{13}C_{DIC}$, but this may be an artifact as the $\delta^{13}C_{DIC}$ range of waters, where living L. inopinata were found, is relatively narrow compared to the other species.

3.6 Conclusion

This is the first study to assess how valve chemistry of ostracods from the southern Tibetan Plateau is influenced by regional changes in host water hydrochemistry. Results from the four most abundant ostracod taxa show that the life cycle is synchronized to the wet season. The seasonal history of the lakes can be identified by the offset of ostracod isotope values from inorganic calcite precipitating in equilibrium. The scatter we observe in our dataset and the negative oxygen isotope values of ostracods suggest that the valves were formed in fresher water during the monsoon season in early summer when precipitation and meltwater (low $\delta^{18}O$) are most abundant, in contrast to our sampling period when evaporative enrichment caused an increase of the isotopic composition. The time lag between ostracod valve formation and collection is reflected by the large negative offset of $\delta^{18}O$ from equilibrium calcite values. The key findings are summarised as:

(1) There is a positive correlation between $\delta^{18}O_{valve}$ and $\delta^{18}O_{H_2O}$, as well as TDS, underlining that $\delta^{18}O_{valve}$ is a valuable indicator for changes in salinity.

(2) The correlation between $\delta^{13}C_{valve}$ and $\delta^{13}C_{DIC}$ is weak but reflects changes in primary productivity and organic matter decay. The observed scatter of $\delta^{13}C_{valve}$ close to

predicted values for inorganic calcite, indicates different intensities of organic matter decay at the sediment-water interface during valve formation. An influence of pore water $\delta^{13}C_{DIC}$, which shifts the $\delta^{13}C_{valve}$ to more negative values, is given for L. inopinata and maybe also for T. gyirongensis.

(3) In our dataset all stable isotope values and trace element ratios in ostracod valves are independent of temperature. Absence of a possible relationship between temperature and ostracod $\delta^{18}O_{valve}$ and Mg/Ca_{valve} is most likely caused by changing water temperatures between the time of ostracod sampling and valve formation, and the effect of Mg/Ca_{H_2O} on the Mg/Ca_{valve} may exceed a possible temperature effect. Hence, using the current data, Mg/Ca_{valve} as well as $\delta^{18}O_{valve}$ are not suited to reconstruct variations in temperatures.

(4) Mg/Ca_{valve} is primarily a function of the Mg/Ca content of the host water, except at high TDS, where ostracods are not able to control their Mg incorporation sufficiently as shown by high scatter. Mg/Ca_{H2O} correlates with salinity, reflecting the dominant solute evolution in Tibetan lakes towards bicarbonate enrichment. Thus, for our study area, the ostracod Mg/Ca ratio can be used to quantitatively reconstruct salinity changes and infer changes in precipitation-evaporation balance and lake level.

(5) Sr/Ca_{valve} is weakly correlated to Sr/Ca_{H_2O} and to host water conductivity. The presence of aragonite precipitation, as occurring in Tangra Yumco, biases the effects of Sr/Ca_{H_2O} or salinity on the Sr/Ca incorporation in ostracod valves, because bioavailable Sr^{2+} is removed from the host water. Thus, without information about carbonate mineralogy Sr/Ca can only be used as qualitative proxy reflecting changes in P/E and salinity.

(6) Ba/Ca_{valve} and Sr/Ca_{valve} correlate with Mg/Ca_{valve}, suggesting that the incorporation of Ba and Sr is strongly influenced by the Mg content of the ostracod calcite.

(7) The cross-correlations of Fe/Ca, Mn/Ca and U/Ca ratios and their negative correlation to the carbon isotopic composition of the host waters underlines their potential to infer changes in redox conditions and oxygenation cycles. Organic matter decay leads to oxygen depletion and decreasing $\delta^{13}C_{DIC}$, which increases the bioavailability of redox sensitive ions, such as Fe, Mn and U. More work, however, is required to understand the mechanisms controlling the uptake of Fe, Mn and U into ostracod valves.

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Figure Caption

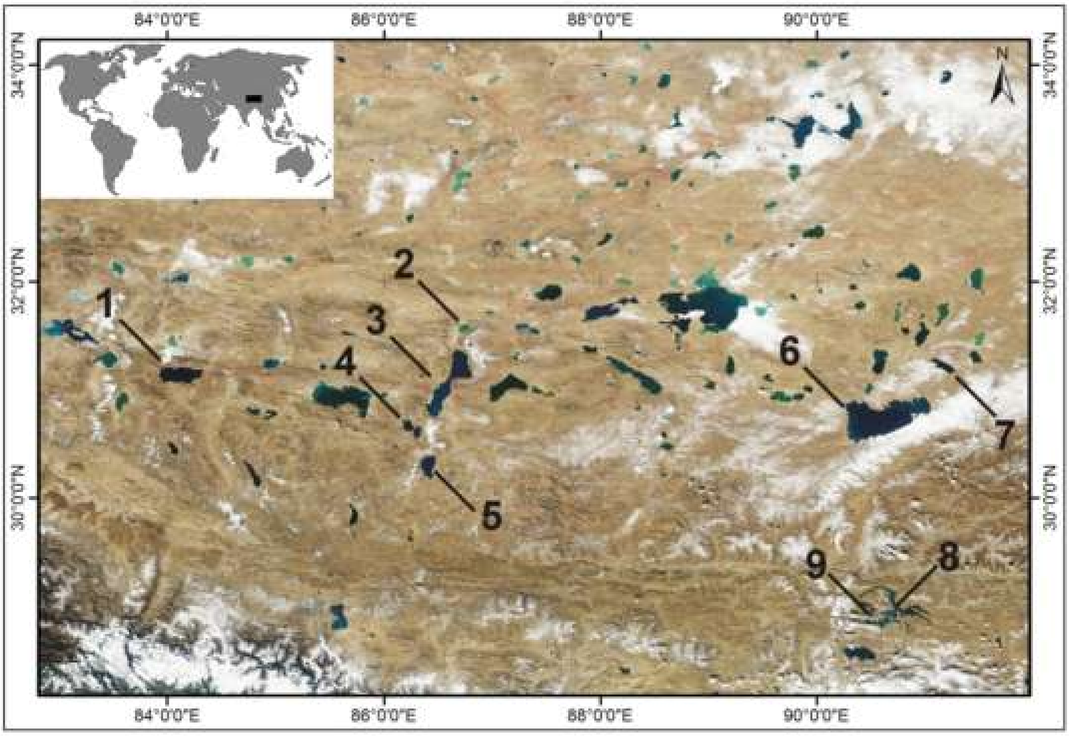

Fig. 1 Map of the Southern Tibetan Plateau with position of sampled lake systems: 1 Taro Co, 2 Tangqung Co, 3 Tangra Yumco, 4 Monco Bunnyi, 5 Xuru Co, 6 Nam Co, 7 Npen Co, 8 Yamzho Yumco and 9 Chen Co.

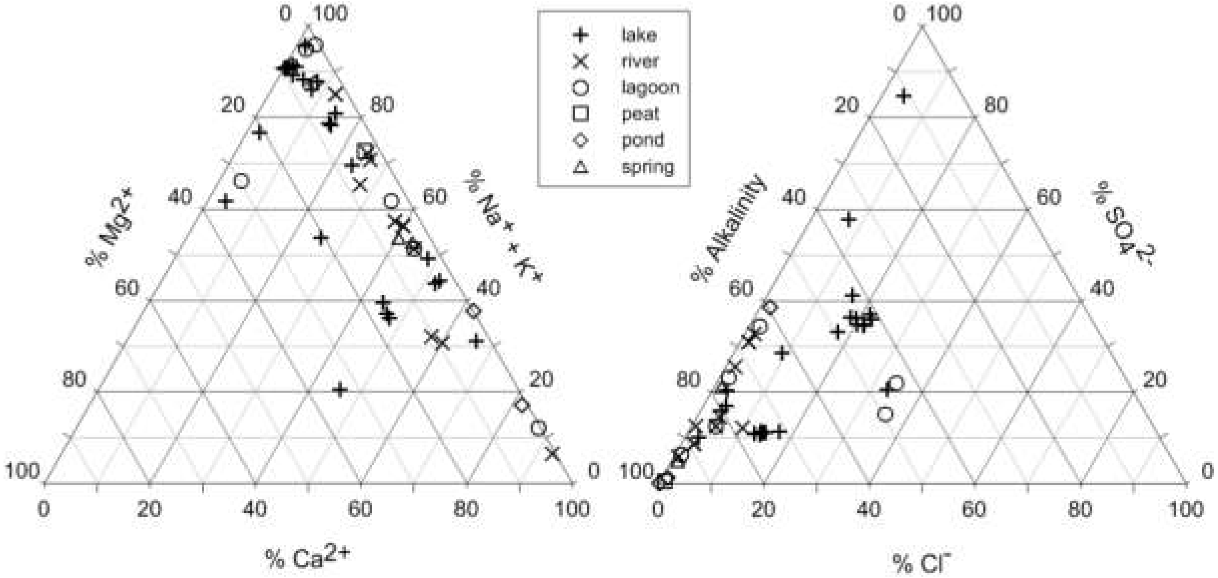

Fig. 2 Ternary Diagrams of the cation and anion composition of all studied locations.

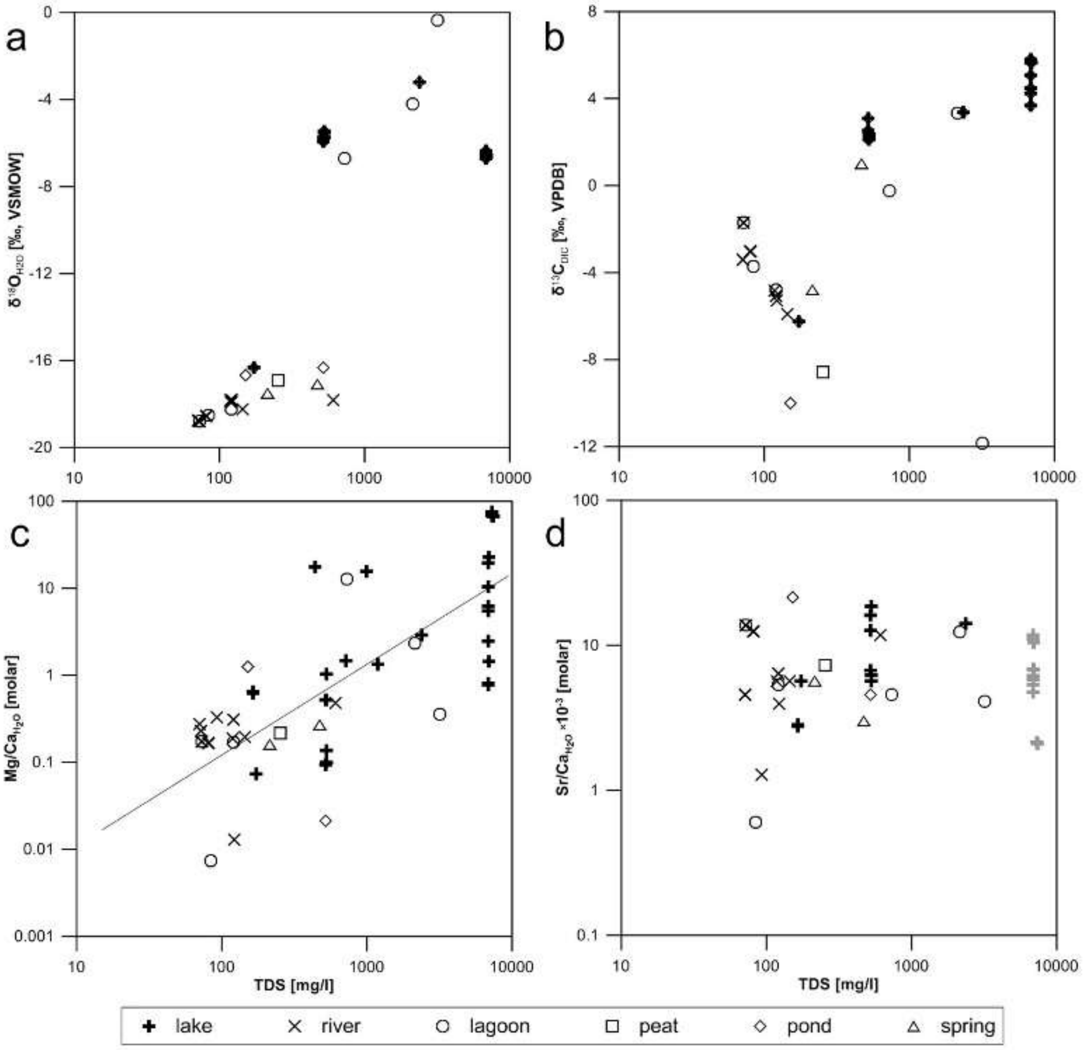

Fig. 3 Stable isotopes ($\delta^{18}O$, $\delta^{13}C_{DIC}$) and trace element ratios (Mg/Ca and Sr/Ca) vs. TDS.

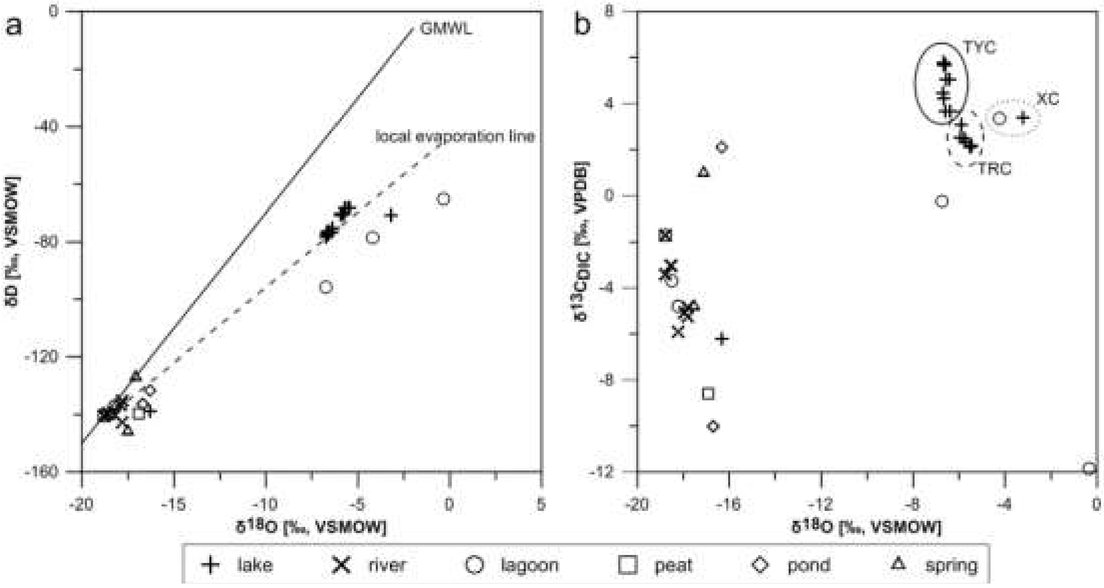

Fig. 4 Isotopic composition of studied lake systems. (a) $\delta^{18}O$ vs. δD (‰ vs. VSMOW) including Global Meteoric Water Line (GMWL; (Craig, 1961) and local evaporation line. (b) $\delta^{13}C_{DIC}$ (‰ vs. VPDB) vs. $\delta^{18}O$ (‰ vs. VSMOW), solid line represents Tangra Yumco (TYC), dashed line represents Taro Co (TRC) and dotted line represents Xuru Co (XC).

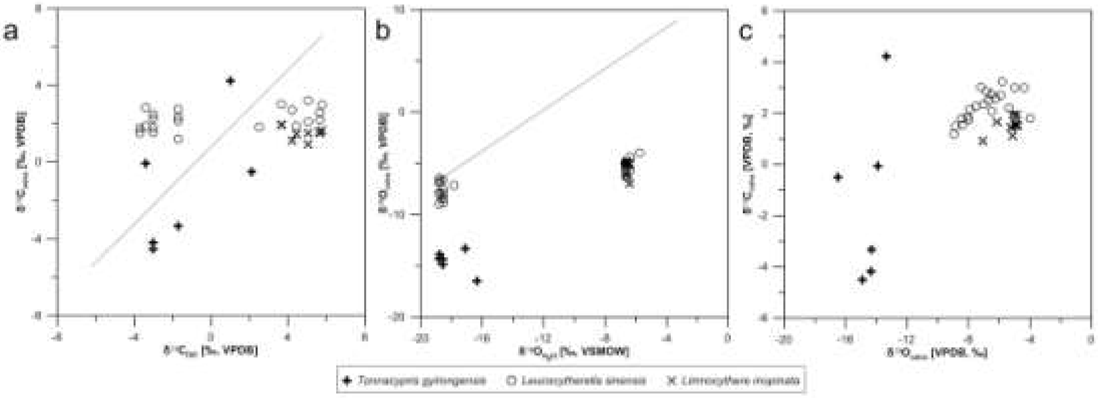

Fig. 5 Carbon and oxygen isotope values in ostracod valves and ambient waters: (a) $\delta^{13}C_{valve}$ vs. $\delta^{13}C_{DIC}$; (b) $\delta^{18}O_{valve}$ vs. $\delta^{18}O_{H_2O}$; (c) $\delta^{18}O_{valve}$ vs. $\delta^{13}C_{valve}$ Solid line represent calculated fit for inorganic calcite from measured $\delta^{13}C_{DIC}$ at 15°C and $\delta^{18}O_{H_2O}$ and temperature of the host water, respectively.

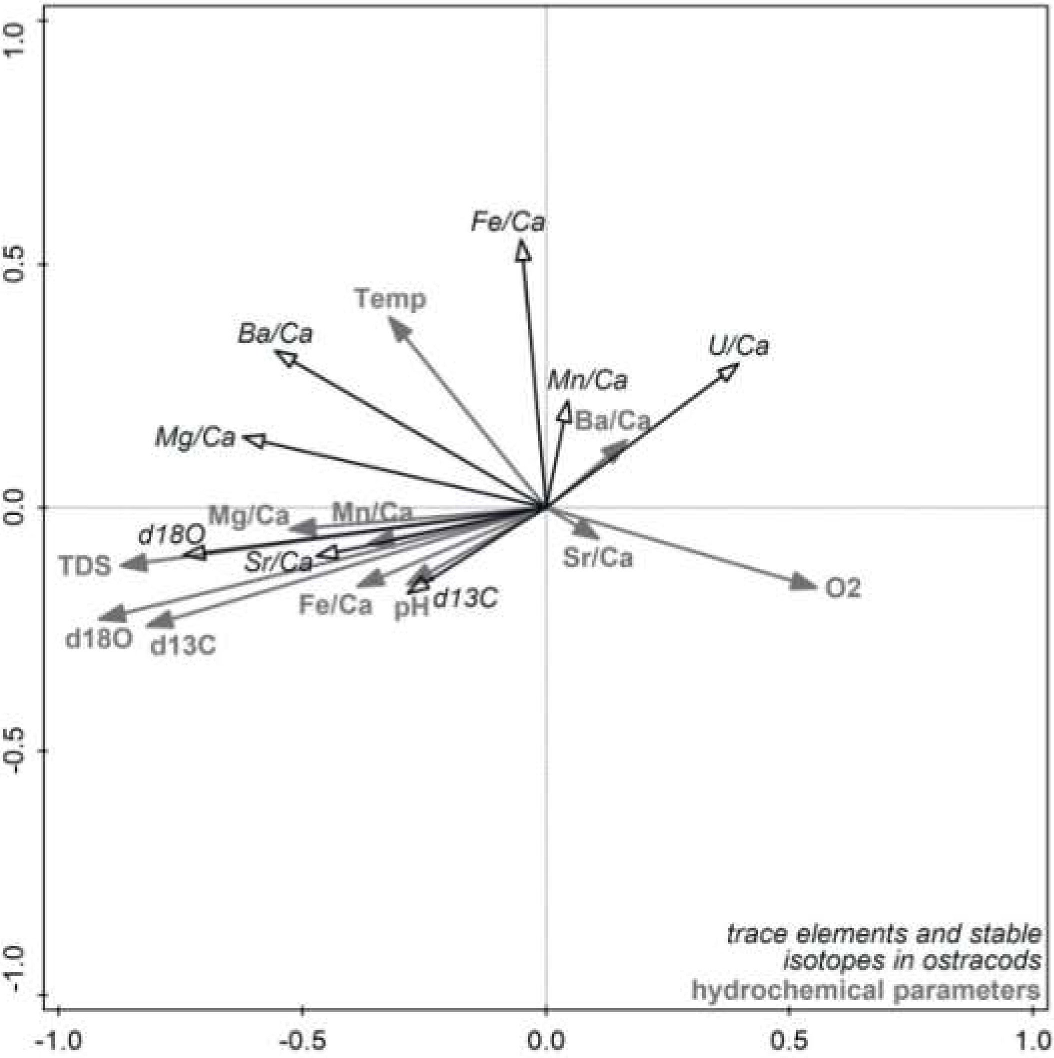

Fig. 6 PCA results for stable isotopes and trace elements in ostracods and host waters.

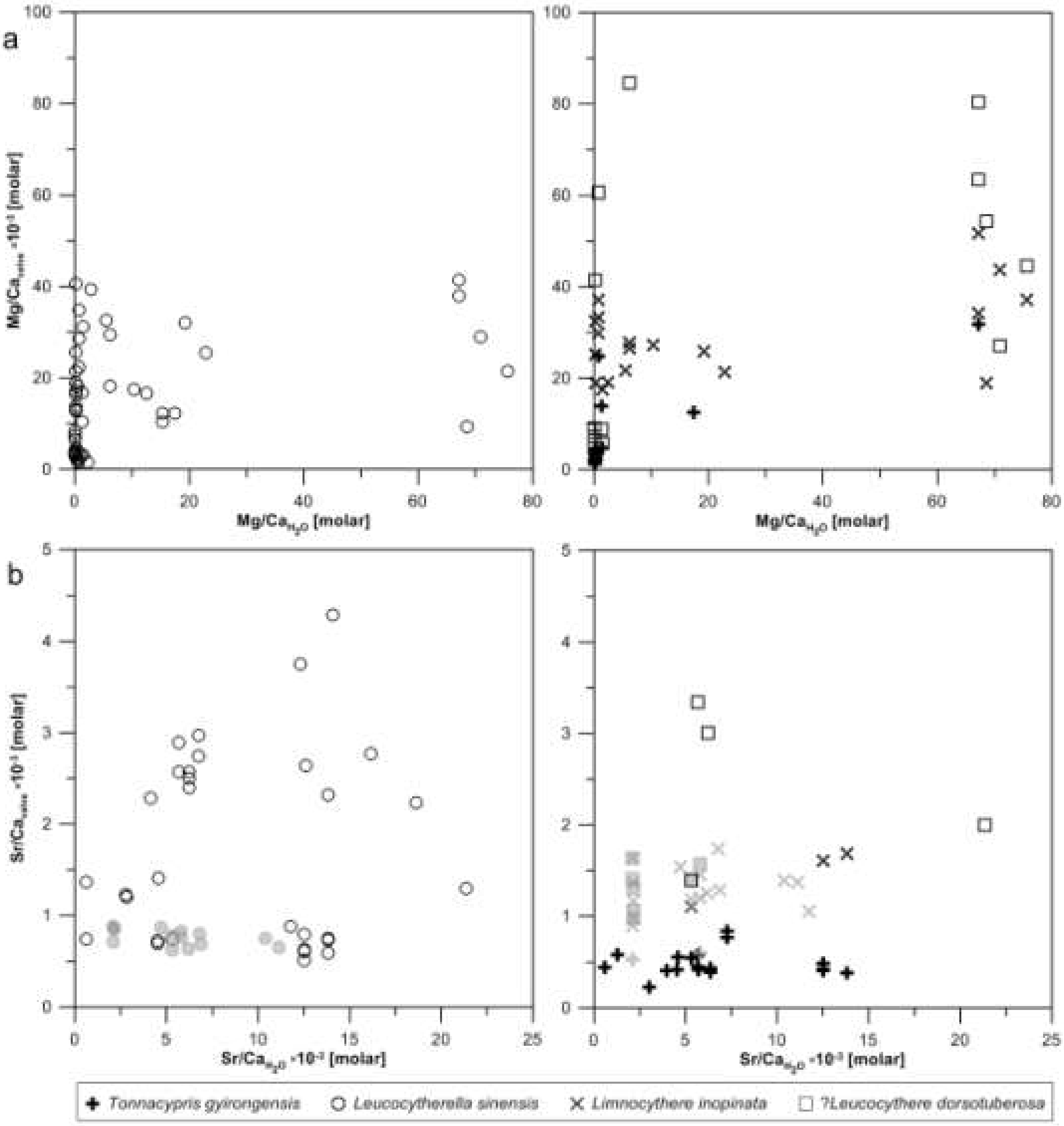

Fig. 7 Plot of Mg/Ca and Sr/Ca ratios in ostracod valves and ambient waters: (a) Mg/Ca_{valve} vs. Mg/Ca_{H2O}; (b) Sr/Ca_{valve} vs. Sr/Ca_{H2O} (gray symbols: values affected by aragonite precipitation).

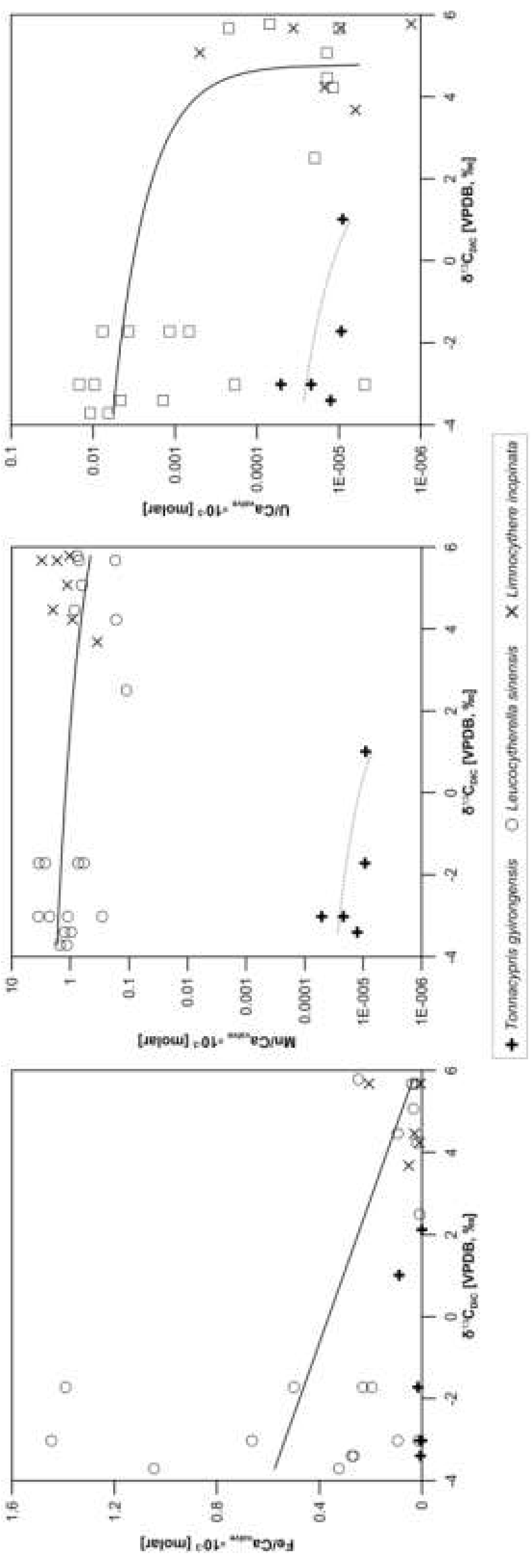

Fig 8 Crossplots of Fe/Ca, Mn/Ca and U/Ca vs. δ^{13}C$_{DIC}$ for *L. sinensis*, *T. gyirongensis* and *L. inopinata*. (a) Fe/Ca$_{valve}$ vs. δ^{13}C$_{DIC}$; (b) Mn/Ca$_{valve}$ vs. δ^{13}C$_{DIC}$; (c) U/Ca$_{valve}$ vs. δ^{13}C$_{DIC}$. Solid line represents linear regression calculated for *L. sinensis*, dotted line represents linear regression calculated for *T. gyirongensis*.

Table 1 Information on the studied lakes.

lake	Lat.	Lon.	Alt.	Sampling Date	Lake area	Catchment area	Supply coefficient	Annual precipitation[1]	Max. water depth [m]	EC [mS/cm]	pH
Chen Co	28.96	90.49	4443	Mid Sept. 2008	38	148	3.9	373	31	1.34	8.5
Monco Bunnyi	30.62	86.26	4692	Late June 2012	143.6	820	5.7	316	n.a.	3.98	9.5
Nam Co	30.67	90.81	4725	Late Sept. 2008	1967	10836	5.5	397	98	1.80	6.8
Npen Co	30.98	91.18	4673	Early Sept. 2009	140	n.a.	11.5	403	71	0.32	8.7
Tangqung Co	31.57	86.74	4475	Mid Sept. 2011	53.8	899.9	16.7	298	n.a.	144.8	9.7
Tangra Yumco	31.27	86.65	4540	Early to mid Sept. 2009, 2010, 2011	824	98934	10.9	305	230	12.5	9.5
Taro Co	31.16	84.21	4579	Late Sept. 2011	474[2]	7423[2]	22	246	130	0.98	9.3
Xuru Co	30.37	86.46	4720	Mid Sept. 2011, late June 2012	206.8	1933	22	298	200	4.22	9.0
Yamzho Yumco	28.78	90.58	4452	Mid Sept. 2008	638[3]	6100[4]	9.6	372	60	2.15	9

[1] Hudson & Quade 2013

[2] Dietze et al. 2014

[3] Zhang et al. 2012

[4] Li et al. 2014

Table 2 Chemistry of the lake waters. Abbreviations are as follow: Lake systems are CC = Chen Co, MB = Monco Bunnyi, NAM = Nam Co, NPC = Npen Co, TAN = Tangra Yumco lake system, TQS = Tangqung Co, TRC = Taro Co lake system, TTL = small spring fed lake above the shore of Tangra Yumco, XC = Xuru Co, YY = Yamzho Yumco. Habitat types are LK = lake, LG = lagoon, P = pond, PT = peat, R = river, S = spring.

Site code	EC	T	pH	O_2	HCO_3^-	Ca	Mg	K	Na	Fe	Mn	Ba	Sr	Cl^-	SO_4^{2-}	$\delta^{18}O$	δD	$\delta^{13}C_{DIC}$	Mg/Ca	Mn/Ca	Fe/Ca	Sr/Ca	Ba/Ca
	mS/cm	°C		mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	[‰, VSMOW]	[‰, VSMOW]	[‰, VPDB]	x 10-3	x 10-3	x 10-3	x 10-3	x 10-3
CC-LK1	1.33		8.5	5.6	72	58.2	47.4	12.3	110.1	0.0260	0.0000			26.7	547.2				1.459		0.343		
MB-LG	1.35	23.0	9.3	6.6	1190	13.7	96.5	31.2	185.0	0.0000	0.0000		0.128	28.7	367.4	-6.72	-95.81	-0.26	12.616		0.643	4.120	
NAM-LK1	1.82		6.8	3.55	463	9.1	78.3	36.8	249.5	0.0000	0.0000			67.7	213.0				15.398				
NAM-LK2	1.82		6.8	3.55	463	9.1	78.3	36.8	249.5	0.0000	0.0000			67.7	213.0				15.398		0.586	2.775	
NAM-R	0.14		8.8	7.44	94	18.7	2.9	0.7	8.8	0.3200	0.0050			11.9	14.6				0.274	0.0044	0.353	5.808	0.0028
NPC-LK1	0.32		8.1	8.34	103	35.4	12.4	3.8	23.2	0.0270	0.0450		0.201	5.6	22.0				0.627			2.835	
NPC-LK2	0.32		8.7	5.9	189	34.3	12.4	4.1	26.5				0.199	5.6	22.1				0.647		0.467	2.791	
NPC-LK3	0.32		8.6	10.11	110	34.5	12.3	3.9	23.8	0.0210			0.197	5.6	22.0				0.639			2.835	
NPC-LK4	0.32		8.7	5.9	189	34.3	12.4	4.1	26.5				0.199	5.6	22.1				0.647	0.0018	0.128	0.604	0.0025
TAN-LG1	0.17	14.1	9.4	4.78	110	1297	5.4	1.9	177.0	0.2166	0.0029	0.0106	1.604	1.4	7.4	-18.51	-139.67	-3.71	0.007	0.0075	0.474	11.116	0.0040
TAN-LG2	0.17	14.1	9.4	4.78	110	1297	5.4	1.9	177.0	0.2166	0.0029	0.0106	1.604	1.4	7.4	-18.51	-139.67	-3.71	0.007	0.0090	0.284	5.315	0.0230
TAN-LG3	0.14	11.9	9.5	6.29	85	161.5	15.6	6.6	180.4	0.0549	0.0017	0.0075	4.566	4.9	12.9	-18.80	-140.57	-1.72	0.173	0.0082	0.261	13.817	0.0146
TAN-LG4	0.14	11.9	9.5	6.29	85	161.5	15.6	6.6	180.4	0.0549	0.0017	0.0075	4.566	4.9	12.9	-18.80	-140.57	-1.72	0.173	0.0031	0.107	4.551	0.0009
TAN-LK1	12.56		8.4	12.24	1509	8.2	326.0	249.0	2985.0				0.036	4.9					70.860	0.0090	0.284	5.315	0.0230
TAN-LK2	12.77		10.2	10.34	943	8.2	308.0	250.0	2853.0				0.035	4.9					67.192	0.0044	0.353	5.808	0.0028
TAN-LK3	12.60		8.7	10.82	1435	8.2	314.0	302.0	2890.0				0.036	5.0					68.585			2.083	
TAN-LK4	12.62		9.1	12.6	1239	8.2	348.0	322.0	3107.0				0.036	4.9					75.642			2.145	
TAN-LK5	12.77		10.2	10.34	943	8.2	308.0	250.0	2853.0				0.035	4.9					67.192			2.135	

TAN-LK6	11.94	12.9	9.9	4.05	2379	225.8	183.0	185.6	2316.0	0.0370	0.0020	0.0043	4.799	900	2300.0	-6.65	-77.58	4.23	1.452	0.0668	5.509	6.185	0.0529
TAN-LK7	11.88	13.2	9.7	3.57	2757	136.5	188.2	193.1	2253.0	0.0633	0.0031	0.0054	3.283	975	1850.0	-6.61	-76.66	3.68	2.469	0.0044	0.353	5.808	0.0028
TAN-LK8	11.9	13.2	9.8	3.9	2440	69.3	241.6	223.8	2337.0	0.0257	0.0008	0.0051	0.754	1200	1928.0	-6.65	-76.72	5.78	6.243	0.0044	0.353	5.808	0.0028
TAN-LK9	11.96	13.4	9.6	4.26	2379	22.0	280.2	267.4	2908.0	0.1327	0.0057	0.0053	0.305	1280	2050.0	-6.58	-76.40	5.67	22.822			2.083	
TAN-LK10	11.89	13.6	9.6	3.5	2440	57.6	176.6	191.1	2217.0	0.0314	0.0014	0.0024	0.557	1060	1980.0	-6.41	-76.71	5.07	5.489			2.145	
TAN-LK11	11.9	13.1	9.6	4.75	2501	406.3	175.4	189.8	1905.0	0.2510	0.0039	0.0052	9.242	1240	2000.0	-6.37	-75.33		0.773			2.135	
TAN-LK12	11.9	13.2	9.8	3.9	2440	69.3	241.6	223.8	2337.0	0.0257	0.0008	0.0051	0.754	1200	1928.0	-6.65	-76.72	5.78	6.243			2.083	
TAN-LK13	11.87	13.6	9.6	3.2	2440	22.6	243.1	218.8	2331.0	0.0616	0.0012	0.0055	0.318	1270	2180.0	-6.71	-78.26	4.46	19.283	0.0177	0.356	11.754	0.0123
TAN-LK14	11.88	13.5	9.6	3.54	2440	33.4	193.0	215.1	2177.0	0.2392	0.0028	0.0057	0.422	1100	1890.0	-6.66	-76.79	5.67	10.365	0.0090	0.284	5.315	0.0230
TAN-LK15	11.85	13.3	9.7	3.89	2501	435.5	196.9	195.5	2130.0	0.2004	0.0024	0.0039	5.176	1000	2000.0	-6.57	-77.15		0.810	0.2044	4.635	6.785	0.0757
TAN-LK16	11.85	13.3	9.7	3.89	2501	435.5	196.9	195.5	2130.0	0.2004	0.0024	0.0039	5.176	1000	2000.0	-6.57	-77.15		0.810	0.0384	0.586	5.324	0.0251
TAN-R1	0.18		9	4.57	177	31.8	5.9	5.8	12.0	0.1070	0.0100		0.083	1.5	25.6				0.331	0.2459	2.584	1.276	
TAN-R2	0.16	13.7	9.7	4.2	98	122.0	11.4	5.4	166.7	0.0583	0.0026	0.0393	3.130	2.7	9.5	-18.55	-139.67	-3.02	0.167	0.0763	0.961	5.650	0.2858
TAN-R3	0.14	11.9	9.5	6.29	85	161.5	15.6	6.6	180.4	0.0549	0.0017	0.0075	4.566	4.9	12.9	-18.80	-140.57	-1.72	0.173	0.0433	2.095	6.880	0.0760
TAN-R4	0.14	11.4	9.6	6.78	79	1717	221.5	223.4	2392.0	0.2391	0.0068	0.0048	15.990	0.8	5.0	-18.77	-140.22	-3.40	0.231	0.0668	5.509	6.185	0.0529
TAN-R5	0.14	11.9	9.5	6.29	85	161.5	15.6	6.6	180.4	0.0549	0.0017	0.0075	4.566	4.9	12.9	-18.80	-140.57	-1.72	0.173			2.083	
TAN-R6	0.14	11.4	9.6	6.78	79	1717	221.5	223.4	2392.0	0.2391	0.0068	0.0048	15.990	0.8	5.0	-18.77	-140.22	-3.40	0.231	0.0082	0.261	13.817	0.0146
TAN-R7	0.16	13.7	9.7	4.2	98	122.0	11.4	5.4	166.7	0.0583	0.0026	0.0393	3.130	2.7	9.5	-18.55	-139.67	-3.02	0.167	0.0031	0.107	4.551	0.0009
TAN-R8	0.16	13.7	9.7	4.2	98	122.0	11.4	5.4	166.7	0.0583	0.0026	0.0393	3.130	2.7	9.5	-18.55	-139.67	-3.02	0.167	0.0166	0.367	12.538	0.1002
TAN-R9	0.16	13.7	9.7	4.2	98	122.0	11.4	5.4	166.7	0.0583	0.0026	0.0393	3.130	2.7	9.5	-18.55	-139.67	-3.02	0.167	0.0166	0.367	12.538	0.1002
TAN-R10	0.16	13.7	9.7	4.2	98	122.0	11.4	5.4	166.7	0.0583	0.0026	0.0393	3.130	2.7	9.5	-18.55	-139.67	-3.02	0.167	0.0166	0.367	12.538	0.1002
TAN-R11	0.28	15.6	9	5.36	122	61.7	6.8	4.0	161.4	0.0772	0.0060	0.0566	0.713	3.0	43.0	-18.23	-140.32	-5.91	0.196	0.0891	3.985	6.373	0.1330
TQC-R	1.14	16.8	9.2	2.2	561	117.6	31.8	18.4	263.5	0.0216	0.0037	0.0170	2.831	30.0	100.0	-17.82	-142.76		0.484	0.0384	0.586	5.324	0.0251

TQC-S	0.89	8.2	10.1	2.9	512	124.6	18.6	2.0	164.4	0.0349	0.0033	0.0360	0.768	6.0	27.0	-17.10	-126.95	1.01	0.267	0.0891	3.985	6.373	0.1330
TRC-LG	0.24	16.6	9.4	2.99	85	89.7	8.6	0.0	158.5	0.0684	0.0044	0.0072	0.977	2.7	46.0	-18.24	-137.17	-4.80	0.171		8.645		
TRC-LK1	0.98	13.1	10.1	3.64	372	102.7	29.9	22.1	280.3	0.1448	0.0038	0.0167	3.397	90.0	59.0	-5.91	-70.69	3.08	0.522	0.0025	0.048	6.731	0.0100
TRC-LK2	0.98	12.6	9.1	4.27	421	305.5	15.9	8.2	248.7	0.0193	0.0010	0.0098	4.208	70.0	60.0	-5.94	-70.15	2.52	0.093	0.0025	0.048	6.731	0.0100
TRC-LK3	0.98	12.6	9.1	4.27	421	305.5	15.9	8.2	248.7	0.0193	0.0010	0.0098	4.208	70.0	60.0	-5.94	-70.15	2.52	0.093	0.0133	0.284	5.678	0.0203
TRC-LK4	0.99	7.2	9.1	5.52	415	239.0	13.3	7.4	236.9	0.0885	0.0041	0.0156	2.777	76.0	63.0	-5.74	-68.21	2.35	0.100	0.0034	0.181	6.236	0.0103
TRC-LK5	0.99	5.2	9.5	5.51	409	366.5	27.8	12.0	295.5	0.0862	0.0016	0.0121	4.677	78.0	61.0	-5.45	-68.29	2.17	0.136	0.0688	4.151	18.635	0.3131
TRC-LK6	0.99	4.8	9.3	4.05	427	25.5	14.7	10.1	277.8	0.1377	0.0022	0.0256	0.972	78.0	61.0	-5.53	-68.24	2.10	1.034	0.0034	0.181	6.236	0.0103
TRC-LK7	0.99	5.2	9.5	5.51	409	366.5	27.8	12.0	295.5	0.0862	0.0016	0.0121	4.677	78.0	61.0	-5.45	-68.29	2.17	0.136	0.0034	0.181	6.236	0.0103
TRC-LK8	0.99	5.2	9.5	5.51	409	366.5	27.8	12.0	295.5	0.0862	0.0016	0.0121	4.677	78.0	61.0	-5.45	-68.29	2.17	0.136	0.0365	1.610	12.611	0.0394
TRC-LK9	0.98	13	9.6	5.3	397	51.2	15.0	9.3	271.3	0.1074	0.0024	0.0065	1.322	78.0	60.0	-5.75	-70.11	2.50	0.525	0.0413	2.451	21.350	0.2005
TRC-LK10	0.99	7.2	9.1	5.52	415	239.0	13.3	7.4	236.9	0.0885	0.0041	0.0156	2.777	76.0	63.0	-5.74	-68.21	2.35	0.100	0.0413	2.451	21.350	0.2005
TRC-P1	0.30	20.5	10.7	6.4	98	29.6	20.7	16.3	332.1	0.0943	0.0016	0.0190	1.291	3.0	63.0	-16.69	-136.36	-10.01	1.254	0.0133	0.284	5.678	0.0203
TRC-PT1	0.49	8.6	9.9	1.98	329	52.0	6.3	0.0	154.0	0.1208	0.0123	0.0184	0.774	3.0	1.5	-16.92	-139.76	-8.59	0.217	0.0082	0.261	13.817	0.0146
TRC-PT2	0.49	8.6	9.9	1.98	329	52.0	6.3	0.0	154.0	0.1208	0.0123	0.0184	0.774	3.0	1.5	-16.92	-139.76	-8.59	0.217	0.0166	0.367	12.538	0.1002
TRC-R1	0.23	18.3	9.5	3.38	92	58.2	6.1	0.0	167.0	0.0943	0.0077	0.0081	0.677			-17.82	-135.34	-4.83	0.188	0.0166	0.367	12.538	0.1002
TRC-R2	0.24	16.7	9.4	3.64	92	2395	17.3	2.9	164.9	0.0891	0.0186	0.0253	19.490	2.4	46.0	-17.81	-135.22	-5.27	0.013	0.0031	0.107	4.551	0.0009
TRC-R3	0.24	15	9.7	4.18	98	22.6	3.9	0.0	151.7	0.1172	0.0026	0.0096	0.295	2.4	45.0	-17.94	-136.57	-5.09	0.312	0.0011	0.025	4.564	0.0033
TRC-R4	0.24	15	9.7	4.18	98	22.6	3.9	0.0	151.7	0.1172	0.0026	0.0096	0.295	2.4	45.0	-17.94	-136.57	-5.09	0.312				
TTL-LK	0.34	14.8	8.9		159	352.0	14.5	6.0	159.8	0.0820	0.0004	0.0071	4.087	6.0	42.0	-16.33	-138.89	-6.24	0.074	0.2044	4.635	6.785	0.0757
TTL-S	0.42	11	7	3.2	201	276.2	24.6	5.9	329.0	0.0731	0.0026	0.0079	3.199	3.5	55.0	-17.52	-145.75	-4.80	0.159	0.1842	1.784	7.275	0.1100
XC-LG1	3.83	15.6	9.4	6.03	793	21.7	28.1	76.5	857.0	0.0000	0.0000		0.546	614	395.5	-4.22	-78.50	3.34	2.319			14.063	
XC-LG2	5.61	15.3	9.7	5.67	1617	47.8	9.6	31.6	1277.0	0.0400	0.0000		0.403	1165	495.7	-0.35	-65.13	-11.86	0.359				

XC-LK	4.22	8	9	6.03	952	18.0	29.0	81.5	932.0	0.0000	0.0000		0.518	679	422.1	-3.21	-70.83	3.38	2.886				
XC-P	0.98	13.5		7.75	9638	1589	18.9	17.1	315.6	0.0519	0.0022	0.0170	14.840	103	125.0	-16.33	-131.56	2.12	0.021	0.0166	0.367	12.538	0.1002
YY-LK1	2.15		9	4.72	113	35.4	26.2	2.5	13.4	0.0000	0.0000								1.324			4.566	
YY-LK2	0.83	13.8	9	4.26	342	11.1	108.6	18.7	174.1	0.0000	0.0000			69.2	564.3				17.456				
YY-P	0.58		8.7	6.67	95	47.1	0.0	28.5		0.5300	7.7690			0.1	0.1				0.000			2.135	

Table 3 Trace element ratios and stable isotope values of Recent ostracods from the southern Tibetan Plateau (Abbreviations see table 4).

Site code	Mg/Ca $x 10^{-3}$	Sr/Ca $x 10^{-3}$	Ba/Ca $x 10^{-3}$	Mn/Ca $x 10^{-3}$	Fe/Ca $x 10^{-3}$	U/Ca $x 10^{-6}$	$\delta^{13}C$ [‰, VPDB]	$\delta^{18}O$ [‰, VPDB]	Sample date
Leucocythere dorsotuberosa									
CC-LK1	5.7720	3.4685	0.0458	1.4039	0.3620	0.0199			13/09/2008
TAN-LK1	27.0503	1.0578	0.2271	1.6479	0.0995	0.0373			06/09/2009
TAN-LK2	63.3101	1.6304	0.2761	2.5905	0.2753	0.3639			06/09/2009
TAN-LK3	54.3207	0.9759	0.2101	0.8389	0.1180	0.1147			07/09/2009
TAN-LK4	44.6204	1.3067	0.1984	0.7076	0.0302	0.0046			07/09/2009
TAN-LK5	80.3596	1.4065	0.3115	4.1836	0.1013	0.0597			07/09/2009
TAN-LK12	84.6268	1.3975	0.3067	2.1537	0.0645	0.0778			12/09/2011
TAN-LK16	60.6227	1.5756	0.2777	3.6862	0.0120	0.0135			12/09/2011
TRC-LG	41.4968	1.3912	0.2472	0.8875	0.0742	0.0185			25/09/2011
TRC-LK7	5.5775	3.0078	0.0991	1.4680	0.1558	0.0329			22/09/2011
TRC-LK10	9.0592	3.3454	0.5728	1.0148	0.1513	0.0708			22/09/2011
TRC-P1	8.8917	1.9936	0.1621	2.2916	0.0812	0.0069			19/09/2011
YY-P	7.0763	3.7033	0.0337	1.6497	0.0076	0.0075			11/09/2008
Limnocythere inopinata									
TAN-LK1	43.7442	1.1672	0.1690	3.2409	0.2688	1.7949			06/09/2009
TAN-LK2	51.7175	0.8990	0.1552	4.8136	0.4775	0.0559			06/09/2009
TAN-LK3	18.9642	0.9748	0.1623	0.9236	0.1131	0.0538			07/09/2009
TAN-LK4	37.1994	1.3677	0.2466	1.8292	0.2185	0.0625			07/09/2009
TAN-LK5	34.3015	1.6388	0.3073	0.7044	0.1329	0.1351			07/09/2009
TAN-LK6	17.4920	1.3863	0.2120	0.9157	0.0096	0.0151	1.11	-5.15	13/09/2011
TAN-LK7	19.1127	1.0473	0.1164	0.3476	0.0516	0.0063	1.93	-4.87	13/09/2011
TAN-LK8	27.7843	1.1108	0.1544	1.0321	0.0000	0.0013	1.66	-6.16	12/09/2011
TAN-LK9	21.3497	1.7375	0.3934	1.6840	0.2066	0.0363	1.51	-4.98	13/09/2011
TAN-LK10	21.7312	1.5381	0.5361	1.1146	3.8491	0.4941	0.91	-7.04	13/09/2011
TAN-LK11	33.3176	1.3692	0.2309	0.5860	0.1508	0.1040	1.95	-5.09	13/09/2011
TAN-LK12	26.5407	1.1810	0.1695	0.4735	0.0899	0.0803			12/09/2011
TAN-LK13	25.9269	1.2825	0.2923	1.9935	0.0294	0.0000	1.46	-5.24	12/09/2011
TAN-LK14	27.2057	1.2547	0.1696	3.0443	0.0052	0.0096	1.57	-4.98	12/09/2011
TAN-LK15	37.0845	1.4542	0.2987	1.3192	0.0169	0.0341	1.51	-4.80	12/09/2011
TAN-LK16	29.8479	1.2009	0.2100	0.7883	0.0118	0.0206			12/09/2011
TAN-R5	25.1520	1.6851	0.4855	1.0690	0.0050	0.0000			14/09/2011
TAN-R10	32.5243	1.6100	0.3395	1.6476	1.5615	0.6477			16/09/2011
TRC-LG	18.9401	1.1011	0.1700	1.5646	0.0843	0.0424			26/09/2011
Leucocytherella sinensis									

CC-LK1	3.0594	2.9305	0.0257	0.7260	0.1959	0.0709			13/09/2008
MB-LG	16.6860	1.4071	0.0703	0.1962	0.1224	2.1187			21/06/2012
NAM-LK1	10.3902	8.0457	0.1844	0.1542	0.5636	0.9236	0.63	-5.40	24/09/2008
NAM-LK2	12.3517	10.5514	0.2279	0.0236	0.0116	0.0022	0.54	-5.65	24/09/2008
NPC-LK1	1.4854	1.2284	0.0455	0.7137	0.0684	0.1196			31/08/2009
NPC-LK2	1.6832	1.2019	0.0472	0.4082	0.3822	1.4042			31/08/2009
NPC-LK3	1.4686	1.2278	0.0707	0.5060	0.2279	0.1922			01/09/2009
NPC-LK4	1.5887	1.1990	0.0566	0.1523	0.0621	0.2449			01/09/2009
TAN-LG1	8.2953	1.3627	0.1012	1.1262	1.0453	10.9162	1.50	-8.81	12/09/2011
TAN-LG2	7.4208	0.7352	0.0888	1.5039	0.3252	6.4904	1.76	-7.95	12/09/2011
TAN-LG3	13.0211	0.7313	0.0800	2.6778	1.3905	7.6689	2.75	-6.50	16/09/2011
TAN-LG4	4.5998	2.3212	0.0812	0.5938	0.2308	1.1582	1.19	-8.94	16/09/2011
TAN-LK1	28.8707	0.8696	0.0907	1.7797	0.3071	0.0491			06/09/2009
TAN-LK2	41.4941	0.7116	0.1019	1.2473	0.0425	0.0305			06/09/2009
TAN-LK3	9.2465	12.6238	0.2964	0.0844	0.0325	0.0364			07/09/2009
TAN-LK4	21.5282	0.8460	0.0968	0.2408	0.0547	0.0001			07/09/2009
TAN-LK5	37.8896	0.8811	0.1176	1.1422	0.1825	0.1936			07/09/2009
TAN-LK6	31.1288	0.7491	0.0600	0.1662	0.0192	0.0118	2.70	-5.91	13/09/2011
TAN-LK8	18.2543	0.6288	0.1044	0.7624	0.2488	0.0697	2.99	-4.99	12/09/2011
TAN-LK9	25.5445	0.8015	0.0952	0.1707	0.0235	0.0100	2.20	-5.40	13/09/2011
TAN-LK10	32.6401	0.8685	0.1828	0.6367	0.0334	0.0141	3.21	-5.81	13/09/2011
TAN-LK11	22.3493	0.6520	0.0857	0.3129	0.0037	0.0058	3.00	-4.39	13/09/2011
TAN-LK12	29.4648	0.7862	0.1316	1.7091	0.5458	0.2631			12/09/2011
TAN-LK13	31.9933	0.6883	0.0665	0.8450	0.0946	0.0140	1.86	-5.02	12/09/2011
TAN-LK14	17.4695	0.6346	0.0488	0.7225	0.0388	0.2217	2.57	-6.25	12/09/2011
TAN-LK15	34.7707	0.8219	0.1089	1.7550	0.0771	0.0112	2.08	-6.45	12/09/2011
TAN-LK16	28.6752	0.7577	0.1394	0.3228	0.0088	0.0002			12/09/2011
TAN-R3	12.8397	0.5938	0.0779	3.4540	0.4992	3.6606	2.14	-7.90	12/09/2011
TAN-R4	18.8730	0.6992	0.1057	1.2495	0.2741	1.4066	2.85	-6.80	12/09/2011
TAN-R5	21.4027	0.7438	0.0635	0.7369	0.1963	0.6696	2.34	-6.98	14/09/2011
TAN-R6	13.1717	0.7252	0.1131	0.9595	0.2663	4.6184	1.86	-8.07	16/09/2011
TAN-R7	16.5027	0.5136	0.0518	3.4950	1.4454	14.7215	1.53	-8.36	16/09/2011
TAN-R8	40.5183	0.6222	0.1603	1.1005	0.0950	0.1870	2.49	-6.66	16/09/2011
TAN-R9	13.8707	0.6133	0.0924	2.2574	0.6621	9.7040	2.26	-7.52	16/09/2011
TAN-R10	25.5840	0.7880	0.1888	0.2878	0.0130	0.0049	1.79	-8.42	16/09/2011
TQC-R	18.2160	0.8744	0.0738	0.1949	0.2018	0.2679	3.01	-7.19	17/09/2011
TRC-LG	17.1340	0.7352	0.1419	1.0961	0.1064	0.0796			27/09/2011
TRC-LK1	3.9693	2.7692	0.0716	0.1460	0.0193	0.0082			20/09/2011
TRC-LK2	2.8371	2.9745	0.0733	0.2210	0.0505	0.0140			20/09/2011
TRC-LK3	3.0404	2.7454	0.1737	0.1830	0.0165	0.0160			20/09/2011

TRC-LK4	3.4097	2.8927	0.0621	0.5585	0.0338	0.0507			22/09/2011
TRC-LK5	3.5049	2.3964	0.1056	1.2159	0.0489	0.2938			22/09/2011
TRC-LK6	3.1240	2.2343	0.0565	1.2316	0.0272	0.0133			22/09/2011
TRC-LK7	3.9955	2.4980	0.0964	1.1311	0.0433	0.0235			22/09/2011
TRC-LK8	3.5894	2.5704	0.0902	1.0337	0.0007	0.0064			22/09/2011
TRC-LK9	2.5874	2.6446	0.1786	0.1106	0.0087	0.0199	1.80	-3.99	22/09/2011
TRC-LK10	3.1309	2.5714	0.0932	0.5308	0.0641	0.0598			22/09/2011
TRC-P1	16.7243	1.2991	0.0496	0.5271	0.0383	0.0097			19/09/2011
TTL-LK	6.6282	9.4677	0.2077	0.1078	0.0533	0.1782			15/09/2011
XC-LG1	1.5941	3.7535	0.0495	0.0717	0.0243	0.0386			22/06/2012
XC-LG2	1.9695	2.2821	0.1331	1.0831	0.3970	0.0878			23/06/2012
XC-LK	39.2747	4.2918	0.2060	0.8460	0.3295	0.4394			24/06/2012
YY-LK1	10.4062	0.7810	0.0491	0.7229	0.1472	0.0737			14/09/2008
YY-LK2	12.2479	1.1238	0.0207	0.0346	0.0245	0.0120	1.27	-4.86	14/09/2008
Tonnycypris gyirongensis									
CC-LK1	4.7683	2.4138	0.0225	1.6386	0.4304	0.3405			13/09/2008
NAM-R	2.2353	0.6304	0.0209	0.9677	0.0239	0.0117			22/09/2008
TAN-LG1	2.1350	0.4454	0.2058	0.2527	0.0012	0.0103			12/09/2011
TAN-LK2	31.8351	0.5286	0.0302	0.7075	0.0645	0.0365			06/09/2009
TAN-LK16	24.9000	0.5971	0.0491	0.7689	0.0227	0.0064			12/09/2011
TAN-R1	4.4436	0.5795	0.0916	0.3052	0.0680	2.0861			14/09/2010
TAN-R2	1.1560	0.4897	0.0378	0.1068	0.0005	0.0005			12/09/2011
TAN-R4	2.2856	0.4212	0.0325	0.2789	0.0060	0.0127	-0.07	-13.89	12/09/2011
TAN-R5	3.4750	0.3821	0.0440	0.3935	0.0157	0.0093	-3.32	-14.32	14/09/2011
TAN-R7	3.3644	0.4230	0.1716	0.2960	0.0005	0.0513	-4.18	-14.35	16/09/2011
TAN-R10	3.4939	0.4102	0.0294	0.1546	0.0063	0.0219	-4.51	-14.89	16/09/2011
TAN-R11	2.7035	0.4535	0.0278	1.1769	0.1135	0.0063			18/09/2011
TQC-S	2.6454	0.2294	0.0852	0.0422	0.0888	0.0090	4.23	-13.34	17/09/2011
TRC-LG	3.8159	0.5455	0.0255	1.1547	0.0138	0.0059			28/09/2011
TRC-PT1	4.1205	0.7644	0.5803	0.8751	0.1134	0.0351			25/09/2011
TRC-PT2	3.0092	0.8320	0.0470	0.7384	0.2141	0.0110			25/09/2011
TRC-R1	3.1590	0.4210	0.0326	0.6943	0.0387	0.0170			23/09/2011
TRC-R2	3.7347	0.4084	0.0321	0.8509	0.0092	0.0091			23/09/2011
TRC-R3	3.5024	0.3902	0.0295	0.6740	0.1009	0.0017			23/09/2011
TRC-R4	2.2303	0.4383	0.1597	1.6708	0.1560	0.0508			24/09/2011
TTL-S	1.6848	0.5702	0.0405	0.0671	0.0302	0.0182			15/09/2011
XC-P	1.4744	0.5555	0.0181	0.3115	0.0001	0.0000	-0.51	-16.49	10/09/2011
YY-LK1	13.8290	0.7564	0.0353	1.5222	0.5354	0.3450			14/09/2008
YY-LK2	12.4427	1.1550	0.0220	0.0631	0.0125	0.0039			14/09/2008
TAN-R2	1.1560	0.4897	0.0378	0.1068	0.0005	0.0005			12/09/2011

TAN-R4	2.2856	0.4212	0.0325	0.2789	0.0060	0.0127	-0.07	-13.89	12/09/2011
TAN-R5	3.4750	0.3821	0.0440	0.3935	0.0157	0.0093	-3.32	-14.32	14/09/2011
TAN-R7	3.3644	0.4230	0.1716	0.2960	0.0005	0.0513	-4.18	-14.35	16/09/2011
TAN-R10	3.4939	0.4102	0.0294	0.1546	0.0063	0.0219	-4.51	-14.89	16/09/2011
TAN-R11	2.7035	0.4535	0.0278	1.1769	0.1135	0.0063			18/09/2011
TQC-S	2.6454	0.2294	0.0852	0.0422	0.0888	0.0090	4.23	-13.34	17/09/2011
TRC-LG	3.8159	0.5455	0.0255	1.1547	0.0138	0.0059			28/09/2011
TRC-PT1	4.1205	0.7644	0.5803	0.8751	0.1134	0.0351			25/09/2011
TRC-PT2	3.0092	0.8320	0.0470	0.7384	0.2141	0.0110			25/09/2011
TRC-R1	3.1590	0.4210	0.0326	0.6943	0.0387	0.0170			23/09/2011
TRC-R2	3.7347	0.4084	0.0321	0.8509	0.0092	0.0091			23/09/2011
TRC-R3	3.5024	0.3902	0.0295	0.6740	0.1009	0.0017			23/09/2011
TRC-R4	2.2303	0.4383	0.1597	1.6708	0.1560	0.0508			24/09/2011
TTL-S	1.6848	0.5702	0.0405	0.0671	0.0302	0.0182			15/09/2011
XC-P	1.4744	0.5555	0.0181	0.3115	0.0001	0.0000	-0.51	-16.49	10/09/2011
YY-LK1	13.8290	0.7564	0.0353	1.5222	0.5354	0.3450			14/09/2008
YY-LK2	12.4427	1.1550	0.0220	0.0631	0.0125	0.0039			14/09/2008

Chapter 4

Ostracoda (Crustacea) as indicators of subaqueous mass movements: An example from the large brackish lake Tangra Yumco on the southern Tibetan Plateau

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Ostracoda (Crustacea) as indicators of subaqueous mass movements: An example from the large brackish lake Tangra Yumco on the southern Tibetan Plateau, China

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Holocene

ABSTRACT

A conceptual model of subaqueous mass movements and ostracod distribution in lacustrine sediment event layers was tested. Integrated methods (geophysical, sedimentological and microfossil analyses) were performed on a short sediment core retrieved from 220 m water depth in the large brackish lake Tangra Yumco on the southern Tibetan Plateau, central Asia. The event layers of the core and their underlying and overlying sediments were investigated. Four major event layers composed of sandy silt with graded bedding are interpreted as turbidites. The fifth layer consisting of fine sand and silt and without graded bedding is characterized as a debrite.

The ostracods, small bivalved aquatic crustaceans, identified are *Leucocytherella sinensis* Huang, 1982, *Leucocythere? dorsotuberosa* Huang, 1982, *Limnocythere inopinata* (Baird, 1843) and *Fabaeformiscandona gyirongensis* (Huang, 1982).

Ostracod evidence is a good proxy for the evaluation of massive sediment event layers formed by subaqueous mass movements. Four assumptions of a conceptual model were confirmed: (i) fine grained sediments of event layers (turbidite deposits) contain very low numbers of ostracods compared to the underlying and overlying sediments; (ii) ostracods are sorted according to size and display high abundance and high proportion of adult valves of *Leucocytherella sinensis* at the base of event layers; (iii) a relatively low number of carapaces is present within the event layers; and (iv) the recolonization of newly event-generated habitats by pioneer assemblages transforming into pre-event association gradually.

1. Introduction

Mass movements (e.g. slumps, mass failures, landslides) can transport large amounts of sediment within a very short time (minutes to hours) in lacustrine and marine environments (Martinsen, 1994; Owen et al., 2011; Sauerbrey et al., 2013). Subaqueous mass movements (e.g., bottom current, turbidity current, debris flows) play a significant role in the transport (Covault, 2011; Talling et al., 2013) and redistribution of sediments from shallow to deep water environment of lakes and oceans (Shanmugam, 1996; Stow et al., 2002; Smith, 2004; Bernhardt et al., 2012; Talling et al., 2012). Turbidity currents and debris flows evolve due to mass failure processes along submerged sediment-covered slopes that may originate from various processes including flooding, lake level fluctuation, rapid sedimentation, earthquake, gravity-flow, density-flow, and glacial and tidal loading (Locat and Lee, 2002; Monecke et al., 2004; Hilbe et al., 2011; Smith et al., 2013). Some of these geological processes act on the submerged slopes over longer periods while others are of instantaneous nature. The local instability of submerged sediment-covered slopes is a common feature in the lacustrine and marine environment and these events can impact offshore and coastal infrastructure (Lee, 2005; Schnellmann et al., 2006; Fanetti et al., 2008). Assessment of event layers caused by subaqueous mass movement may provide a better understanding of the distribution of palaeoseismic events on spatial and temporal scales (Mutti et al., 1984). In some settings, identification of phases of enhanced rapid mass movement due to climatic variation may also provide palaeoclimatic evidence (Mattews et al., 1997). Turbidity currents, suspension of sediment that are sustained by fluid turbulence, are widespread in many deep-water settings and form successions up to kilometers in thickness. Individual turbidite beds range in thickness from a few millimeters to several meters in thickness with gradded bedding (coarse, medium and fine-grained beds). The origin of turbidity currents was first postulated in lakes (Forel, 1892; Girardclos et al., 2012), however the

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lacustrine turbidites (Harrison, 1975; Shiki et al., 2000; Twichell et al., 2005) are less frequently investigated than their marine equivalent (Stow and Bowen, 1980; Middleton, 1993; Dade and Huppert, 1994; Mulder et al., 2003; Satur et al., 2004). The tails of incoming tubidity currents provide high accumulation of sediments and the flow transforms into non-turbulence muddy debris flow (Weaver, 1994). Debris flow deposits (debrites) are classified as a mixture of sediments and water forming a slurry that moves downslope under the action of gravity. Debrites formed are without internal bedding and lamination (Locat and Lee, 2001, 2005). Investigation of massive sediment transported into deep water from an orginal shallow water setting is the most effective and indispensable strategy for identification of past mass movement and the threshold of different types of event sedimentation in the geological record (Einsele et al., 1996; Shiki, 1996). Benthic organisms are sensitive proxies of subaqueous mass movement (Bangs et al., 2000; Oloson and Thompson, 2005).

Ostracods (Crustacea, Arthropoda) are small bivalved crustaceans enclosed by a low-magnesium calcite carapace made up of two valves which are easy to fossilize. They are found in most aquatic habitats and even some terrestrial ecosystems (Forester, 1991; Danielopol et al., 1994; Meisch, 2000; Horne et al., 2002). Lacustrine ostracods are mostly benthonic. They can be found living on aquatic plants, crawling on sediment (epifauna) and within the sediment (infauna). Ostracods have the ability to reflect the environment in fresh, brackish and marine waters (Yang, 1988; Frenzel and Boomer, 2005; Mischke, 2012) due to their specific ecological preference and tolerance (Mezquita et al., 2001; Holmes and Chivas, 2002; Kulkoyluoglu and Sari, 2012). Ostracods are important biological indicators and their microfossils are useful for the description of stratigraphical sequence and palaeoenvironmental change (Mischke et al., 2003; Zhu et al., 2010), habitat type (Mezquita et al., 2000; Kulkoyluoglu, 2004; Kiss, 2007; Dugel et al., 2008), water quality (Padmanabha and Belagali, 2008; Pieri et al., 2012), water depth (Wrozyna et al., 2009a; Frenzel et al., 2010), dissolved oxygen concentration (Boomer and Whatley, 1992; Whatley et al., 2003; Corbari et al., 2004), hydrochemical change (Carbonel and Peypouquet, 1983; Smith, 1993; Curry, 1999; Mischke et al., 2007) and other environmental variables.

Ostracods are commonly found in lake sediments when other important proxy organisms (e.g., diatoms) are not present (Holmes, 2001; Holmes and Chivas, 2002). Fossil ostracod associations are indicators of past environmental and climatic conditions on the Tibetan Plateau (Peng, 1997; Mischke et al., 2005). The use of ostracods as indicators of mass movements is well established in the marine realm (Dingle et al., 1989; Ikeya and Cronin, 1993; Cronin et al., 1994; Arias, 2007). Nonetheless, the application in lacustrine environments is still unknown (De Deckker et al., 1979).

Ostracods are good indicators for the assessment of short-lived sediment events due to (i) their ability to reflect specific depositional environments with depth and time, (ii) their rapid response to environmental disturbances, (iii) potential discrimination of allochthonous from autochthonous valves and shallow water species from deep-water species, which could reflect different types of sediment transport processes, (iv) the ability to quantify fossil remains (expressed in abundance) and (v) by any failure of sedimentary evidence, ostracods could be used to identify subaqueous mass movement.

In this paper, we use ostracods to identify lacustrine subaqueous mass movements in the large brakish lake Tangra Yumco, central Asia. Integrated geophysical, sedimentological and micropalaeontologicial analyses of a short sediment core from this lake are discussed. The objectives are; (i) to characterize sediment event layers formed by subaqueous mass movements and (ii) to examine the potential of lacustrine ostracods as indicators of subaqueous mass movements.

The four criteria defined for our conceptual model of sediment features and ostracod distribution caused by subaqueous mass movement in large lakes, based on theoretical considerations, are:

(i) The thickness of an event-layer varies with the distance from the source. This involves the transport of sediment from a submerged slope (proximal areas) to the depositional environment (distal areas), which is the deeper bottom of the lake basin (Fig. 1A–C). The two characteristics of an event are: (a) coarser grained sediment is eroded from the steep slope at proximal areas. There is successive deposition of suspended subaqueous sediment forming a graded bedding at distal areas. The pre-event to event transition is characterized by an autochthonous ostracod association which is replaced by allochthonous ostracods during the transport of sediment from shallower water to the deeper environment (Fig. 1B–C top). Abundance of ostracods is distinctively lower within the event layer than the underlying and overlying sediments. (b) Sediment is transported as bed load and then accumulated as fine grained sediment at distal areas. The event layer contains fewer ostracods due to sorting out of the heavier valves during transport (Fig. 1B–C bottom).

(ii) A fining-upward gradation of sediment within the event layer (Fig. 1B top). The base of proximal event layer is composed of coarse-grained sediment. Redepostion of sediment involves the settling of smaller grains, which are held in suspension by currents during transport, forming a newly finer-grained muddy sediment with a coarse-grained layer on top of the event layer. The par-autochthonous pre-event ostracod association consist of articulated valves whereas carapaces are lacking from transported ostracod associations within the event layer. This is caused by the separation of articulated valves in the turbidity current. Carapaces may be cemented by sediment casts and encrustation. The sediment infill and encrustation cause the ostracod carapaces to be more stable and heavier creating enrichment of double-valved specimens within the sand-size fraction. The event layer at distal areas does not contain coarse-grained sediment due to the sorting by transport (Fig. 1B bottom). A shift from higher to lower adult/juvenile valve ratios occurs from proximal to distal sedimentation areas due to sorting. Furthermore, juvenile valves are smaller and lighter in weight than adult valves, facilitating transportation.

(iii) Biocoenoses (life assemblages) are buried by a subaqueous mass movement. In this case, the underlying distal event layer is characterized by a higher proportion of carapaces than the sediments underlying and overlying the event layer.

(iv) Recolonization of the post-event sediments (Fig. 1C) by opportunistic species with a high dispersal ability and adapted to newly muddy substrate of the event layer.

2. Study area

Tangra Yumco (30°45′–31°22′N and 86°23′–86°49′E) is located about 450 km northwest of Lhasa, the capital city of the Tibetan Autonomous Region (Fig. 2). Tangra Yumco is also known as Dang Reyongcuo, Dangre Yumtso and Tanghiha Yumco. The large brackish lake is situated at the northern flank of the central section of the Gangdise mountain within a 300 km long and 40 km wide north–south trending graben (Fig. 3), which consists of three sub-basins: Tangqung Co (also called Tangra Qonco) is situated to the north, Monco Bunyi in the middle and Xuru Co to the south (Xu et al., 2006; Cao et al., 2009). The normal faults cut through the western part of the Lhasa block (Gao et al., 2007; Kong et al., 2011). The Tibetan region is prone to frequent earthquakes (Taylor and Yin, 2009; Wu et al., 2013). The Tangra Yumco rift basin is characterized by moderate seismicity based on data from the USGS database (http://earthquake.usgs.gov/earthquakes/eqarchives). A N20-striking trend of epicenters around Tangra Yumco is observed. In the adjacent areas earthquake foci are rather scattered. The earthquakes recorded instrumentally are on the order of around 6 Mmax and have shallow foci. Rare focal mechanisms (http://www.globalcmt.org/CMTsearch.html) of larger earthquakes demonstrate dominant strike-

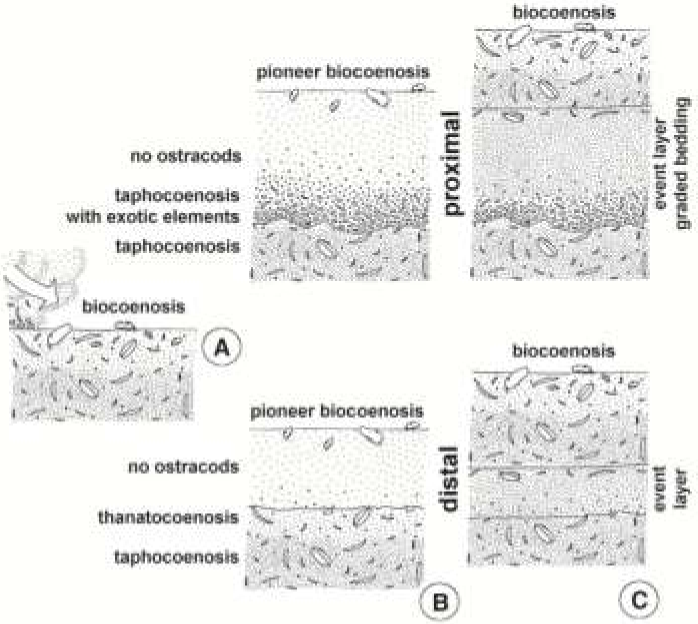


Fig. 1. Conceptual model of subaqueous mass movement and response of ostracod association. Three phases are presented: pre-event (A), event (B) and post-event (C). A) The pre-event lake bottom with epifaunal and shallow infaunal ostracod biocoenoses. B) Lake bottom proximal (top) and distal to source (bottom) of transported sediment. A pioneer biocoenosis of ostracods is recolonizing the newly muddy substrate. C) Situation of event layer sediment proximal (top) and distal to source (bottom) after continuation of normal sedimentation and compaction. The proximal sites are characterized by a distinct graded bedding. The decreasing thickness of the event layer from phase B to C is caused by sediment auto-compaction. The biocoenosis (life ostracod associations), the thanatocoenosis (dead ostracod assemblage) and the taphocoenosis (dead ostracods autochthonous, died at the source of burial, and allochthonous, transported from different sources of burial) are indicated.

slip faulting. Conjugate NE–SW and NW–SE trending faults should be observed, but active faults are extension-related normal faults (Fig. 4). The flanks of the graben are geologically charaterized by volcanic magmatic rocks (e.g., ultrapotassic to potassic lavas) (Gao et al., 2007, 2009). Rapakivi granites and Quaternary alluvial deposits surround the lake (Chen et al., 2006).

Tangra Yumco is the third largest lake on the Tibetan Plateau (Long et al., 2012) and the second-deepest (maximum depth 230 m) lake in China (Wang et al., 2010). The northern basin of Tangra Yumco is much deeper than the southern basin (Table 1). Both basins are joined by a narrow "bottleneck" connection with ~130 m water depth.

The cold semi-arid climate of Tangra Yumco influenced the growth of alpine steppe vegetation of *Kobresia pygmaea* and *Artemisia* (Miehe et al., 2014). The climate of the region is mainly influenced by the Indian Summer Monsoon (Miehe et al., 2014). The annual precipitation ranges from 200 to 350 mm (Miehe et al., 2014). Tangra Yumco is thermally stratified in summer; the lowest temperature of 1.6 °C is recorded in the hypolimnion (Wang et al., 2010). The mean temperature for January is −11.4 °C while the mean July temperature is 10.9 °C (Miehe et al., 2014). The lake is covered by ice during winter, although it does not completely freeze in some years (Kropacek et al., 2013).

Tangra Yumco is a hydrologically closed drainage basin with no outlet other than evaporation. The lake level is maintained largely by precipitation, surface inflows (e.g., Daguo Tsangpo, Buzhai Tsangpo and Mainongqu, which originate from the west and the south of the lake) and partially from glaciers of the western mountains (Shao et al., 2008; Miehe et al., 2014). The oligotrophic lake is dominated by K^{+}–Cl^{-}–HCO^{3-} and depleted in Ca^{2+}.

3. Material and methods

3.1. Geophysical analyses

Sediment coring and sampling were conducted at northern basin of Tangra Yumco in September, 2010 and 2011. Hydro-acoustic bottom profiling using a non-linear 3.5 kHz parametric echo sounder (SES 96 light, Innomar Technologie GmbH, Rostock, Germany) was carried out in Tangra Yumco (Wunderlich and Müller, 2000, 2003). Evaluation of single hydro-acoustic signal was done with the software package low selective electrode, ISE, Version 2.91a (Innomar Technologie GmbH). Bathymetric maps were produced from the acoustic survey data using the mapping software Surfer® (Golden Software, 1997).

In September 2010, two sediment cores (TAN 10/4, 163 cm, 220 m water depth, and TAN 10/1, 168 cm, 186 m water depth, Fig. 5) were retrieved in the center of the northern basin of Tangra Yumco using a modified ETH-gravity corer (Kelts et al., 1986). In September 2011, three supplementary sediment cores (TAN 11/1, TAN 11/2, TAN 11/3, Fig. 5) were taken along a transect across the northern basin of Tangra Yumco using the same coring device.

3.2. Sedimentological analyses

The sediment cores were split longitudinally from the bottom of the section to the top on the core splitter with wire in a dark laboratory (Department of Geography, Friedrich Schiller University) and freshly exposed sediment surface was digitally photographed along with depth scale. The color of the sediment is determined by visual

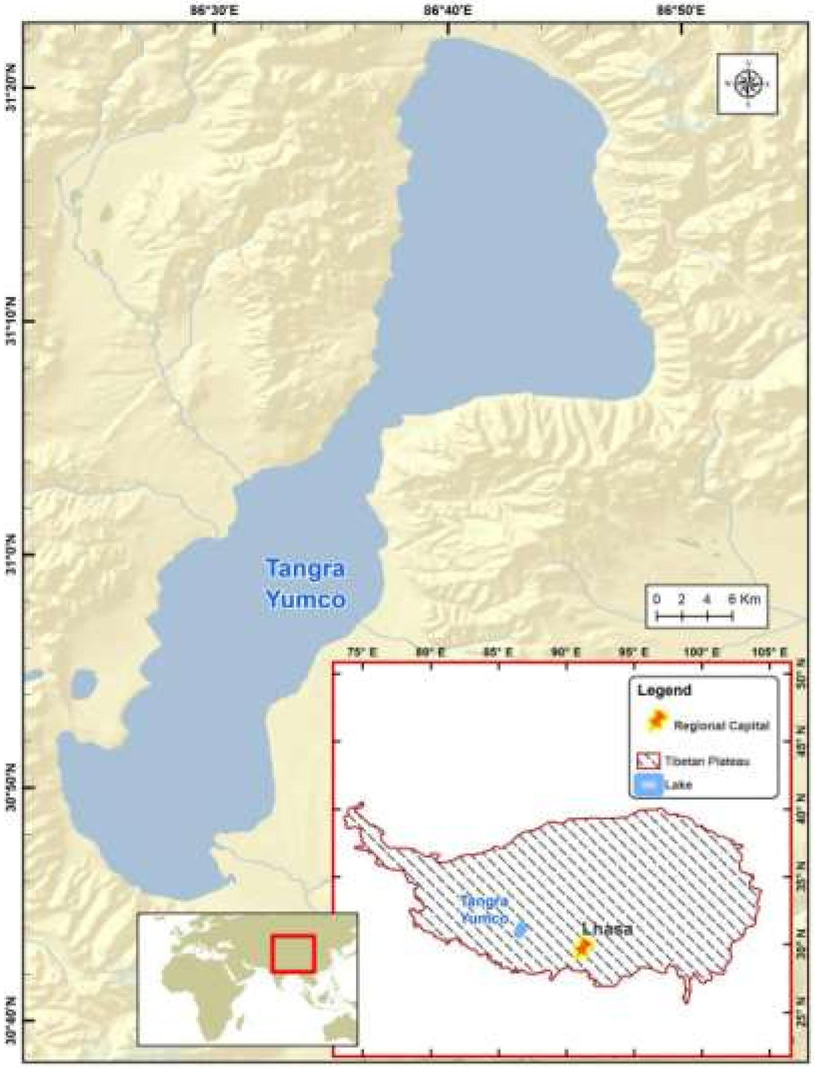


Fig. 2. Map of the Tibetan Plateau with the location of Tangra Yumco.

comparison with Munsell soil color chart (Munsell, 2000; Sanchez-Maranon et al., 2005). The textural properties (grain size and soil texture) of the sediment cores are also described. The mean grain size was determined by the geometric method of moments (Blott and Pye, 2001). The sediment texture is classified based on the German Soil Survey Manual (Ad-hoc AG Boden, 2005). Magnetic susceptibility (κ) was determined using a phototype high resolution (at 2 mm spatial resolution) surface scanning sensor MS2E at a spatial resolution of 2 mm (Bartington Instruments Ltd., 1993, 1995). The lithological descriptions, digital images and magnetic susceptibility patterns of each sediment core were used for stratigraphic correlation between cores (Fig. 6).

Radiographic image of TAN 10/4 was obtained using an ITRAX XRF-core scanner (Croudace et al., 2006) and the corresponding gray values (0–255) were determined using a macro for Microsoft Excel. The sediment cores TAN 10/4 and TAN 11/2 were sub-sampled at 1 cm intervals using the double-L-channel method (Nakagawa, 2007; Nakagawaa et al., 2012). The water content in each sample was gravimetrically determined by weighing the samples before and after oven drying to a constant weight at 105 °C for 48 h. The water mass is the difference between the weights of the wet and oven dried samples (Topp, 2003; Parkin et al., 2007).

The determination of granulometric particle size for the sediment samples (TAN 10/4) requires removal of organic matter, carbonates

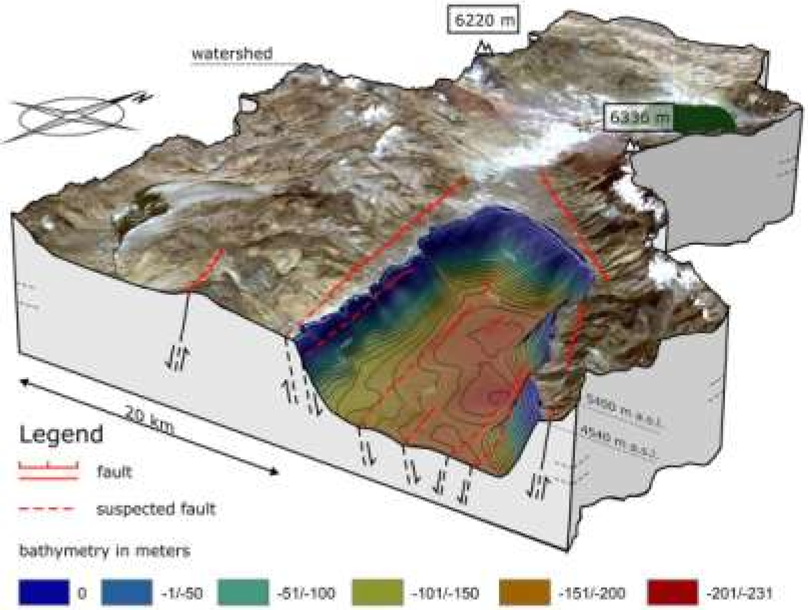


Fig. 3. The basin and graben structure with N-S-trending faults of Tangra Yumco (northern basin).

and sediment dispersion. The sediment samples were treated with 15% to 30% hydrogen peroxide (H_2O_2) for organic matter removal (Murray, 2002; Allen and Thornley, 2004), with 10% to 15% hydrochloric acid (HCl) for carbonate removal (Battarbee, 1986; Battarbee et al., 2001), with 5 ml of sodiumpyrophosphate (Na_2HPO_4-H_2O) and mechanically agitated through shaking for 12 h to enhance separation of particles and facilitation of fractionation. After breakdown of microaggregates for 10 s using an ultra-sonic dispersion (Mayer et al., 2002; Poeplau and Don, 2014), the grain-size distribution of each sample was determined with a Laser Diffraction Particle Size Analyzer (Beckman Coulter, LS 13320) (Murray, 2002; Blott et al., 2004; Eshel et al., 2004). Samples were measured with the Aqueous Liquid Module in several 60 s cycles until a reproducible signal was obtained. The "Fraunhofer" optical model of light scattering was used for computing grain size distribution (Ozer et al., 2010; Storti and Balsamo, 2010; Krawczykowski et al., 2012). The mean grain size of each sample was calculated from the first constant measurement.

For high-resolution grain size distribution analysis, a thin section from the uppermost 7.5 cm of sediment core TAN 11/2 was prepared (http://www.mkfactory.de) (Francus, 1998; Francus et al., 2005; Lapointe et al., 2012; Jouve et al., 2013). Thin section images in plain and cross-polarized light were acquired using a standard flatbed scanner at 2400 dpi resolution (De Keyser, 1999). The digital images were processed using a software developed at the Institute National de la Recherche Scientifique — Eau Terre Environnement Research Centre (INRS-ETE, Québec, Canada) to define forty-four regions of interest (ROIs) which correspond to the grain-size measurements. Backscattering electron (BSE) images with a resolution of 1024 × 768 pixel and 1 μm pixel size were acquired for the ROIs using a Zeiss EVO® 50 scanning electron microscope at 20 kV accelerating voltage, 0° tilt angle and 9 mm working distance (Lapointe et al., 2012). Digital images of 8 bit gray scale were obtained. The images were processed by the method discussed by Lewis et al. (2010) and Lapointe et al. (2012). Particle size indices, i.e., median disk apparent diameter (mD_0), maximum disk diameter ($maxD_0$), percentile 98% (P 98 D_0) and roundness index (mRi), relation of maximum to minimum disk diameter of the single grain-size, were determined (Fig. 7).

3.3. Microfossil analyses

Our conceptual model (Fig. 1) was tested by analyzing the ostracod content in sediment core TAN 10/4. One hundred and sixty-two sediment samples (1 cm intervals) were obtained. Seventy-one of these samples were used for the investigation of ostracod distribution within event layers and their overlying and underlying sediments. The volume for each sediment sample (0.1 to 2.0 ml, mean = 1.4 ml) was determined by displacement of water in a graduated measuring cylinder. The sediment was washed using standard sieves (200 μm and 63 μm) under a gentle stream of tap water. The material remaining on the sieves was rinsed with deionized water, transferred onto a Petri-dish using 97% ethanol and dried at room temperature. Microfossils were quantitavely analyzed from the 200 μm size fraction. Ostracod valves were picked with a wet fine brush from the residue material in a gridded tray under a Wild Herrbrugg M8 binocular microscope (magnifications between 25× and 50×) with a light source. Ostracod valves were identified to species level using key Tibetan Ostracoda references (Hou et al., 2002; Hou and Gou, 2007; Wrozyna et al., 2009b). Juvenile and adult valves were counted for the abundant species *Leucocytherella sinensis*.

Adults and juveniles of *Leucocytherella sinensis* were differentiated by size and shape of the valves. Juvenile valves are more triangular in outline than adult valves. The last ontogenetic stages (A-2, A-1) and adult valves of *L. sinensis* were analyzed. The A-3 stage has a maximum height of 200 μm, making retaining on the 200 μm mesh sieve unlikely. Therefore, an unaltered thanatocoenosis (death assemblage) consists of about one third adult valves. Absolute abundance of ostracods was calculated as the total number of valves per 1 cm^3 (Boomer et al., 2003). The average adult/juvenile ratio of *L. sinensis* (in samples with at least

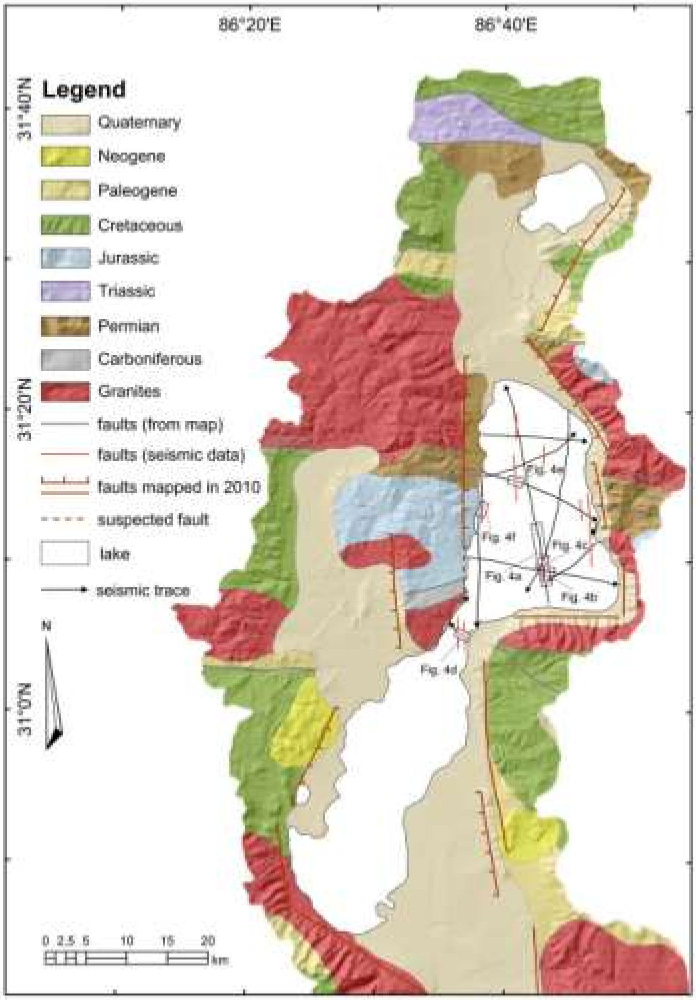


Fig. 4. Geology and seismic traces of Tangra Yumco (northern-basin) and Tangqung Co. Geology adopted from Pan et al. (2004).

30 specimens) occurring in the event layers and their overlying and underlying sediments were calculated. Carapaces of *L. sinensis* were counted as two valves and relative percentages were calculated. Fragmented and stained ostracod valves were documented. Investigated ostracod specimens are stored in the collection at the Institute of Geoscience, Friedrich Schiller University Jena, Germany.

4. Results

4.1. Geophysical analyses

Both, the western and eastern shores of the northern basin of Tangra Yumco are characterized by steep slopes with a very thin sediment accumulation, failure scars, slump structures and sediment relocation (Fig. 6). Different types of subaqueous mass movement (event layers = EL) and homogenous horizontal layering (>25 m thickness without reaching the basement) were also detected on the transition from the slopes to the flat central basin at water depth of >220 m (Fig. 6). In between the layered parts, homogenous layers (up to ~1 m thickness) with low reflectivity were also detected. Fine layered sediment and homogenous event layers were found in sediment cores TAN 10/4 and TAN 11/2. Other observable seismic features in Tangra Yumco include linear structures (e.g., submerged lake level terraces), tectonic features (e.g., series of faults, Fig. 6) and graben structures (data excluded from this paper). Event layer thickness within a single sediment core decreases from west to east.

4.2. Sedimentary analyses

The main investigated core in this study (TAN 10/4) is characterized as heterogenous based on sediment color, grain sizes and micro facies. Sediments are horizontally layered with various thicknesses between

Table 1
Summary of limnological features of Tangra Yumco (September, 2010 and 2011).

Characteristics	Tangra Yumco
Latitude	30°45′–31°22′ N
Longitude	86°23′–86°49′ E
Altitude of lake level	4550 m a.s.l.
Catchment	8220 km^2
Surface area	836 km^2
North–south extension	71.7 km
West–east extension	19.0 km
Mean width	11.7 km
Maximum width	14.4 km
Maximum depth	230 m
Thermocline	18–33 m water depth
Salinity (psu, surface water)	8.3
Conductivity (surface water)	10.6 mS cm^{-1}
pH (surface water)	9.6
O_2 (surface water)	8.2 mg l^{-1}

<1 mm and 5 mm over large parts of the core (Fig. 7). Sediment colors alternate from bright yellowish brown (Munsell: 10YR 7/6) over light brownish gray (Munsell: 7.5YR 7/2) to blackish (Munsell: 7.5YR 1.7/1) (Sanchez-Maranon et al., 2005; Thompson et al., 2013). Grain-size varies from fine sand to medium silt (Fig. 7).

The major event layers (EL) in the core are EL1 – 162 cm to 157 cm (oldest event layer), EL2 – 127.5 cm to 115.5 cm (second oldest event layer), EL3 – 104 cm to 99 cm (third oldest event layer), EL4 – 14.5 cm to 11 cm (second youngest event layers) and EL5 – 4 cm to 2 cm (youngest event layer). The event layer EL1 is composed of fining upward sediments without a sandy silt base. Three event layers (EL2, 3 and 5) are characterized by high proportions of coarse silt with dark brownish to blackish color at the base and fining upward with brownish color at the top (Fig. 7). The event layer EL4 consists of a sandy silt base with ungraded bedding.

The radiographic image and the corresponding gray value is an indicator of sediment density. The blackish colors (low gray values) indicate dense material whereas light brownish colors (high gray values) reveal a lower density (Fig. 7). The event layers (EL1–3 and 5) show high proportions of dark fine sand with corresponding lower gray values and a gradual increase in grain-size upward (Fig. 7). Five event layers (EL1–5) are characterized by low water content between 33% and 50% (compared to the ambient sedimentation with about 60%), high magnetic susceptibility values between 220 and 347 · 10^{-6} SI (<100 · 10^{-6} SI for the ambients sediments). The event layers EL1–3 and 5 are characterized by a coarser mean grain (fine to medium silt) between 15 μm and 33 μm at the base and a fining upward (graded bedding) while EL4 reveals similar sedimentary texture without a graded bedding.

The uppermost parts of sediment core TAN 11/2, at a sediment depth of 5.5 cm to 1.7 cm in TAN11/2 and corresponding depth of 5 cm to 2 cm in TAN 10/4 are characterized granulometrically in a very high resolution with a special emphasis on the youngest event layer EL 5 (Fig. 7). The fining upward trend is detectable in the BSE images (Fig. 7, circled numbers 1 to 4).

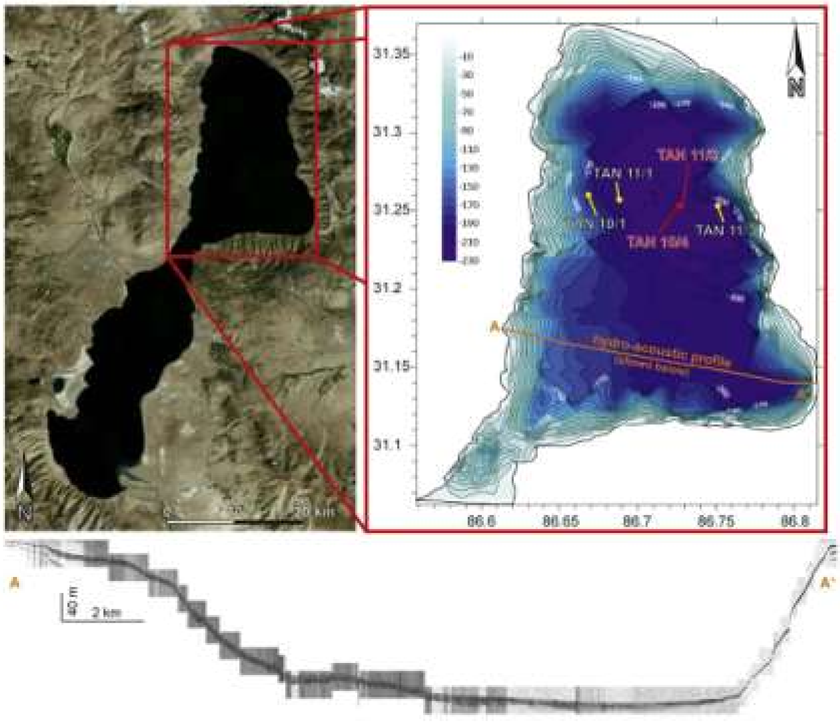


Fig. 5. Tangra Yumco (left) with bathymetrical map of the northern basin (right) and position of the sediments cores (TAN 10/4, TAN 11/2) and supplementary cores. An example of a hydro-acoustic profiling displays steep slopes with low sediment coverage.

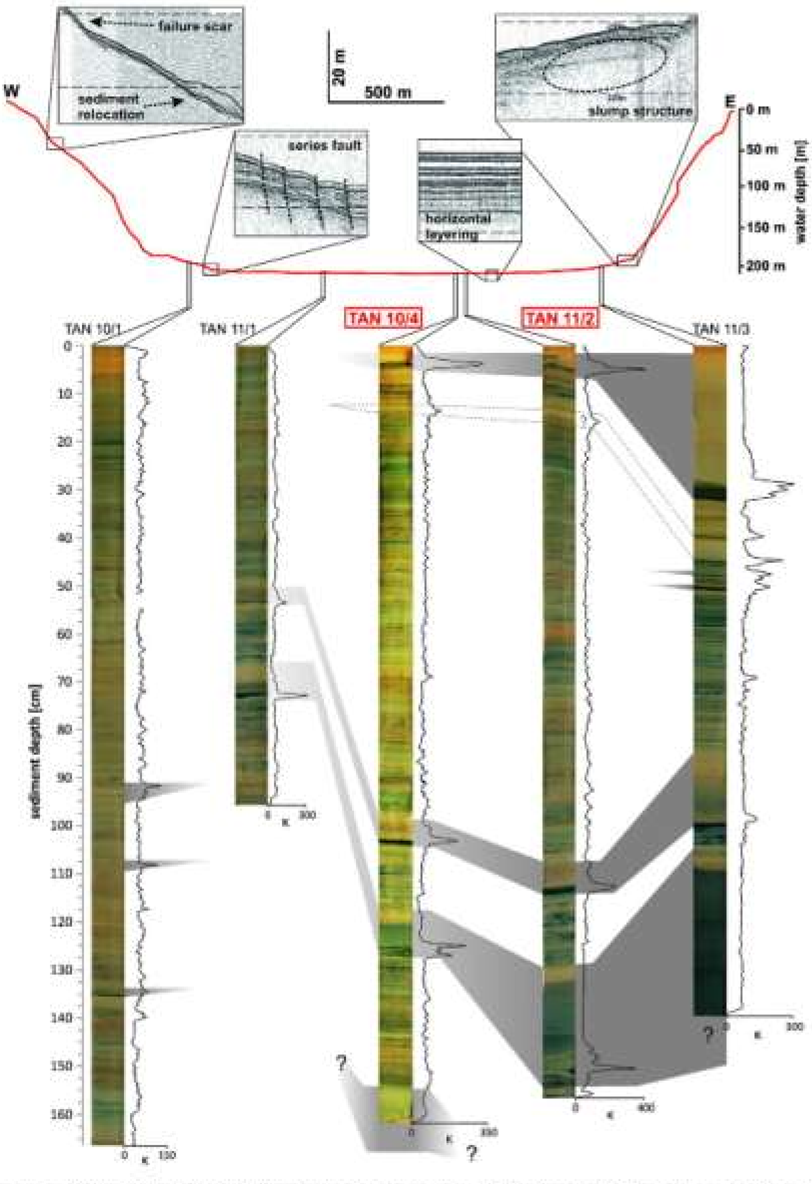


Fig. 6. Tangra Yumco bottom surface with magnified examples of hydro-acoustic sediment properties (i.e. failure, relocation, faults, slump structures and horizontal layering). The sediment core position along W–E transect within the lake is illustrated. The scale for the length of sediment cores differs from the scale of water depth. Magnetic susceptibility (κ in 10^{-6} SI) patterns are plotted for each sediment core (the right side of image) for parallelization. The grey shaded areas connecting the sediment core images indicate event layers and the proposed correlation. Event layer thickness decreases from the eastern slope to the center of the basin.

4.3. *Microfossils*

Ostracods were the only microfossils documented within the >200 µm size fraction. Four ostracod species were identified in the sediment samples analyzed. Represented are mainly Limnocytheridae, namely *Leucocytherella sinensis* (Huang, 1982), *Leucocythere? dorsotuberosa* (Huang, 1982), *Limnocythere inopinata* (Baird, 1843) and the candonid *Fabaeformiscandona gyirongensis* (Huang, 1982) (Fig. 8). The ostracod valves are well preserved (90%) although there are few fragmented valves (10%). The average adult/

juvenile ratio of *L. sinensis* in samples exclusive of the event layers and with at least 30 specimens is 37.3% (standard deviation – SD, 16.5). The summed up adult/juvenile ratio of *L. sinensis* (n = 377) counted within the event layers is 15.1%. The relative percentages of carapaces (articulated valves) of *L. sinensis* are low (average 1.6%, SD 3.8), occuring in less than half of the samples (exclusive of the event layers).

4.3.1. Event layer EL1

Absolute abundance of ostracods is higher in the overlying sediments than within the oldest event layer, EL1 (Fig. 9: 162 cm to 157 cm). The individual abundance of each species fluctuates with depth. *Leucocytherella sinensis* and *Leucocythere? dorsotuberosa* are the most abundant species in the overlying sediments. *Limnocythere inopinata* and *Fabaeformiscandona gyirongensis* occur in low numbers in our record. Juvenile valves of *L. sinensis* are distinctively more abundant in the overylying sediments than within EL1. Adult valves of *L. sinensis* are absent in EL1 although abundant in the overlying sediments. Carapaces are lacking in EL1 and rare in the overlying layer. Event Layer EL1 is incomplete, underlying sediment samples have not been analyzed for this paper.

4.3.2. Event layer EL2

The maximum number of ostracods accumulated in the underlying and overlying sediments is higher than within the second oldest event layer, EL2 (Fig. 9: core depth, 127.5 cm to 115.5 cm). All ostracod taxa recorded within the core are present at the base of EL2. There is a sharp decrease in absolute abundance and species number at the base (core depth, 124.7 cm) of EL2. *Leucocytherella sinensis* is the only species present at the top of EL2. The juvenile and adult valves of *L. sinensis* are more abundant at the base than at the top of EL2 although adult valves are disappearing at core depth, 124.5 cm to 117.5 cm. The relative percentage of carapaces is higher in the underlying sediments and at the base of EL2 although lacking from core depth 125 cm to 110 cm.

4.3.3. Event layer EL3

The underlying and overlying sediments contain a higher number of ostracods than within the third oldest event layer, EL3 (Fig. 9: 104 cm to 99 cm). *Leucocytherella sinensis* is the most abundant taxon present at the base of EL3. A moderate number of *Leucocythere? dorsotuberosa* and *Fabaeformiscandona gyirongensis* occur in EL3. *Limnocythere inopinata* is missing in the underlying sediments and EL3. Juvenile valves of *L. sinensis* are more abundant than adult valves in the underlying and overlying sediments than in EL3. The relative percentages of carapaces are lower in the events layer than in underlying and overlying sediments.

4.3.4. Event layer EL4

The absolute abundance of ostracods varies distinctively with depth (20 cm to 6 cm). It is higher in the underlying sediments than in the overlying and second youngest event layer, EL4 (Fig. 9: 14.5 cm to 11 cm). Juvenile valves of *Leucocytherella sinensis* dominate the associations throughout the core. The maximum number of adult valves of *L. sinensis* occurs at core depth 16.5 cm. The relative percentages of carapaces are very low in the underlying and overlying layers with no records in the event layer.

4.3.5. Event layer EL5

The absolute abundance of ostracods is higher in the underlying sediments than in the overlying and the youngest event layer, EL5 (Fig. 9: 4 cm to 2 cm). There is a sharp decrease of ostracods at the base of EL5. *Limnocythere inopinata* is the most abundant species in the overlying layer while *Leucocytherella sinensis* is mainly present in EL5. A higher number of juvenile than adult valves of *L. sinensis* occurs in EL5. The relative percentage of carapaces is higher within EL5 than within the other four event layers investigated.

5. Discussion

5.1. Geophysics and sedimentology

The geophysical and sedimentological features indicate that the sediment event layers are generated by subaqueous mass movements (e.g., turbidity currents) (Mulder and Alexander, 2001; Schnellmann et al., 2006). Several structural and textural parameters (sandy silt base and graded bedding with a clayey top) of four major event layers (EL1–3 and 5) in core TAN 10/4 indicate that layers were formed by turbidity flow events (Mulder and Alexander, 2001; Fanetti et al., 2008; Gilli et al., 2013). This is supported by artificially initiated turbidity currents producing similar layers (Middleton, 1993; Shanmugam, 1996, 1997; Baas et al., 2005) where the turbidity beds can vary in thickness according to sedimentary environmental settings (canyon, submarine fan, basin plain etc.) (Ekdale et al., 1984; Middleton and Neal, 1989; Kneller, 2003; Bouma, 2004).

The individual coarse-grained layers are generally organized into Bouma sequences (Bouma, 2004), and the vertical stacking of layers commonly forms thinning-upward and fining-upward cycles. The coarser erosive base and fining upward trend of the event layers (Fig. 7: insets 1 to 4) supports the assumption that the youngest event layer is deposited by subaqueous mass movement. Since all other event layers are sedimentologically very similar, the results of the high-resolution grain size analysis could be applied to the older event layers.

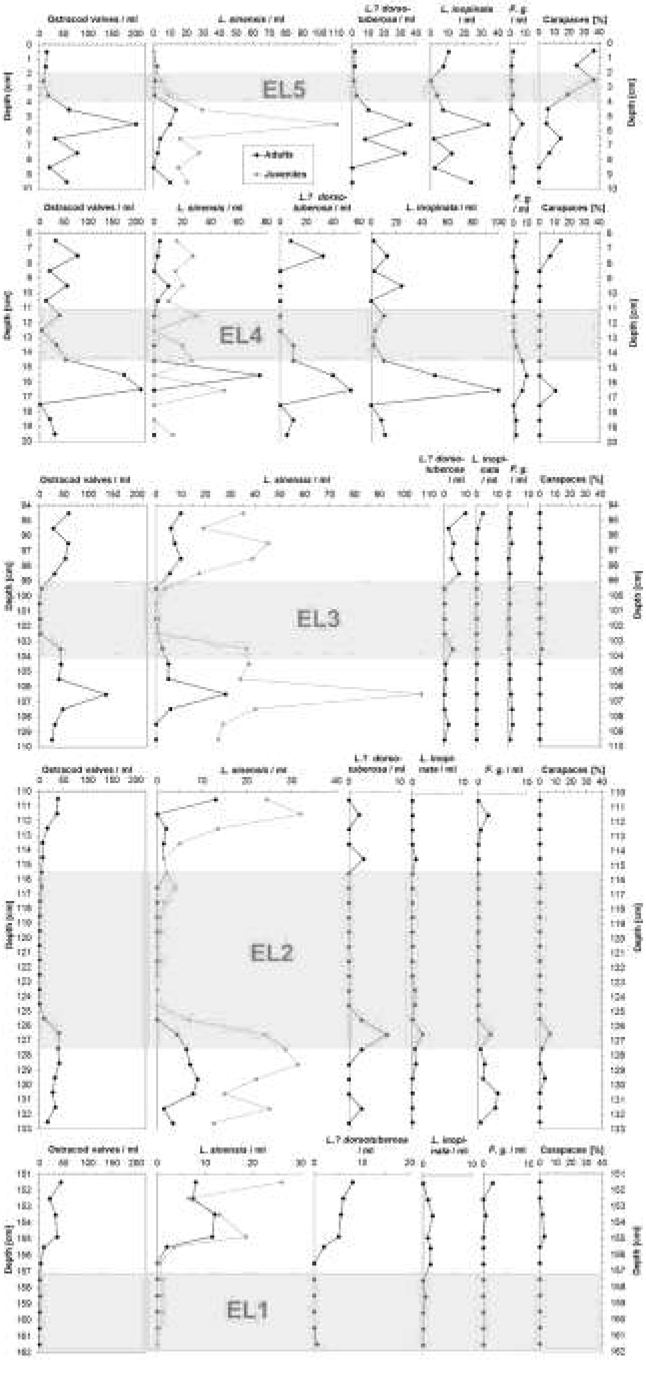
Magnetic susceptibility (κ) parallelisation of the event layers in the different sediment cores along a transect across the lake suggests that mass movements (Fig. 6) originate from the eastern shore of the lake. This is due to thinning of event layers in a single core with rising distance from east to west. However, the particular mechanism that triggers the subaqueous events in Tangra Yumco remains unclear.

Turbidity currents are common features in deep lakes and mostly intersperse the stratigraphy with homogenous turbidite layers (Nelson et al., 1999; Barker, 2009; Sauerbrey et al., 2013). Sediments deposited from suspension currents demonstrate a variety of distinctive features which vary depending on the magnitude and velocity of turbidity currents, the material and the distance from the source area, the morphology of the basin and other factors (Einsele, 1992). The accumulation of the sediment represents deposition on a slope and vertical and lateral successions of sedimentary structures, including traces of bottom dwelling organisms (Einsele, 1992). Cross lamination and rippled beds are missing in the analyzed sediment core, therefore a distal origin of sediment deposition is postulated (Hsü, 1989).

5.2. Ostracod valve preservation

The degree of preservation of ostracod valves is related to the type of sedimentation. In a high-energy environment with rapid sedimentation, ostracod valves will be disarticulated and fragmented (Danielopol et al., 1986). Carapaces are lacking from the event layers EL1–2 (Fig. 9), while the youngest event layer EL5 (Fig. 9), contains a relatively high number of carapaces. The predominance of complete ostracode carapaces in event layer EL5 (Fig. 9) suggests that the assemblage was subjected to rapid burial in a reducing environment (Oertli, 1971). This phenomenon occurs in the deeper parts of lake basins where maximum thicknesses of sediment accumulate (Oertli, 1971). The number of carapaces in the analyzed samples is relatively low. Therefore it is difficult to draw conclusions from their distribution.

Taphonomy, the study of processes that influence preservation of fossils, must also be taken into account to provide a true representation of in situ burial and transport processes (Behrensmeyer and Kidwell, 1985; Martin, 1999; Fernandez-Jalvo et al., 2011; Hart, 2012). The good preservation of the ostracod valves suggests sediment reworking and long-distance transport of valves from outside of the lake to be unlikely (Whatley et al., 1982). Ostracod valves can easily break due to physical agents (e.g. high energy waves and currents) during transport and


Ostracod valves / ml
L. sinensis / ml
L.? dorso-tuberosa / ml
L. inopinata / ml
F. g. / ml
Carapaces [%]
Depth [cm]
Adults
Juveniles
EL5
EL4
EL3
EL2
EL1

during sediment processing (Whatley et al., 1982). The few documented fragmented valves may be attributed to coring and sediment processing in the laboratory.

The adult/juvenile ratio of *Leucocytherella sinensis* in the samples (average, 37.3%) (exclusive of event layers) suggests undisturbed conditions without transport of allochthonous material for the coring sites under the background sedimentation regime. The low proportion of articulated valves of *L. sinensis* reflects a low sedimentation rate within the overlying and underlying sediments (Boomer et al., 2003).

5.3. *Ostracod palaeoecology*

Meiofauna are minute small, motile aquatic animals living mostly in and on soft substrates at all depths in the marine and freshwater environment (Giere, 2009). Ostracods and other group of meiofauna are useful for assessing rapid response to environmental disturbances due to their short life cycles, patchy distribution and efficient dispersal ability (Frenzel et al., 2009).

The ostracod taxa recorded, *Leucocytherella sinensis*, *Fabaeformiscandona gyirongensis*, *Leucocythere? dorsotuberosa* and *Limnocythere inopinata*, represent a typical lacustrine fauna from large brackish lakes on the Tibetan Plateau (Mischke, 2012). The four species can be used as indicators of palaeo-water depth (Wrozyna et al., 2009a; Frenzel et al., 2010; Zhu et al., 2010). Relative abundance of *L. sinensis* weakly correlates negatively with water depth, whereas *L.? dorsotuberosa* displays a positive correlation with water depth (Zhu et al., 2010). *Limnocythere inopinata* populates shallow and profoundal zones of open lakes (Jungwirth, 1979).

The presence of exotic allochthonous microfauna in marine sediments indicates transport from shallow water to deeper marine environments during subaqueous mass movement (Alvarez-Zarikian et al., 2008; Ruiz et al., 2010). However, typical littoral and shallow water ostracod taxa, e.g. *Eucypris gyirongensis* (Yang, 1982), *Candona candida* (O.F. Müller, 1776) and *Ilyocypris* sp. (sensu Wrozyna et al., 2009b), were not found in the analyzed sediment core. The absence of exotic allochthonous shallow water ostracods in the analyzed samples may be due to (i) the large distance (>5 km) of the coring site located in the center of the lake to the foot of the eastern slope. This large distance prevented the transport of ostracod valves to the deep basin. Another explanation are (ii) the narrow and steep littoral zone of Tangra Yumco and (iii) the patchy and small phytal zone, where many shallow water ostracod live. The ostracods within the event layers originate probably from locations below the thermocline, where shallow water ostracod taxa are often absent.

5.4. *Vertical distribution of ostracods*

The absolute abundance of ostracods is higher in the overlying and underlying layers than within event layers. The lower number of ostracods from the event layers could be due to settling of sorted fine grained sediment from the suspension during subaqueous mass movement. Bed load transport of heavier particles including ostracod valves is observed at the base of the event layers EL2, 3 and 5 (Fig. 9). Furthermore, burrowing meiofauna in sediment of event layers (<20 cm thick) could have subsequently caused post-depositional diffusion of the upper boundary, by re-organizing the vertical distribution of valves. Ostracods should be more abundant in proximal areas than distal areas of a subaqueous mass movement. This assumption could be tested by the analyses of additional sediment cores from Tangra Yumco.

Live assemblages buried by rapid sedimentation will escape if the event layer is not too thick. This could be the case for event layer EL5 as well as the recolonization by deeper burrowing ostracods like *Limnocythere inopinata*. Living *L. inopinata*, was found at about 20 cm sediment depth in a lagoon of Tangra Yumco (personal obervation in the field, 2012).

The lower proportion of adult valves of *Leucocytherella sinensis* within the event layers indicates post mortem transport of juvenile valves (Boomer et al., 2003). Juvenile valves are likely to be transported as finer grains to greater distance due to their lighter weight. Juvenile valves represent allochthonous elements of the ostracod taphocoenosis within the event layers. The lower proportion of juvenile valves of *L. sinensis* within the debris deposit EL4 reflects an in situ alteration without input of allochthonous material.

The sediment/water-column processes exert an important influence on meiofaunal recruitment and colonization of new areas (Gallucci et al., 2008). Two distinct patterns exist for recruitment of benthic meiofauna via the sediment or from the water column, influenced by (i) active entry of meiofauna into the water, (ii) passive erosion from the sediments and (iii) passive dispersal of fertilized eggs under slow bottom currents or wave action (Rundle et al., 2002; Boeckner et al., 2009). Benthic opportunistic ostracods are more likely to recover rapidly after a disturbance by (i) migrating actively over short distances and (ii) passively for longer distances colonizing new areas (Frenzel et al., 2009).

Ostracods buried rapidly by voluminous amount of sediment could recover faster after the event due to the shelter of their carapace if the event layer is not too thick for digging. Rapid sedimentation will lead to burial of life assemblages, hence in situ preservation of the biocoenoses (living assemblage) forming a thanatocoenosis (death assemblage) (Fig. 1B). Abundant opportunistic ostracod species adapted to the newly substrate and environmental conditions may start the recolonization. A post-event homogenous muddy substrate at the sites covered by

Table 2
Comparison of characteristic features assumed in the conceptual model for ostracod distribution in event layers caused by subaqueous mass movement with observations from five event layers in Tangra Yumco (TAN 10/4). EL = event layer; n.a. = not applicable.

Feature	EL1	EL2	EL3	EL4	EL5
Low abundance of ostracods within the event layer	✓	✓	✓	(✓)	✓
Higher number of ostracods at the base of the event layer	n.a.	✓	✓	✓	✓
Low number of carapaces within the event layer (except at the top)	✓	✗	✗	✓	✗
Decreasing number of adult valves within the event layer (base to the top)	n.a.	✓	✓	✗	✗
Low number of adult valves within the event layer (except at the top) than the sediments in the underlying and overlying event layer	✓	✓	✓	✓	✓
Recolonization of muddy substrate of the event layer	✓	✓	✓	✗	✓
Allochthonous shallow water species within the event layer	✗	✗	✗	✗	✗
Higher number of carapaces within the event layer (thanatocoenosis)	n.a.	✓	✗	(✓)	✗
Type of event layer	Turbidites			Debrite	Turbidite

Fig. 9. Vertical distribution of ostracods in Tangra Yumco (TAN 10/4) on the southern Tibetan Plateau: Total ostracod abundance, species abundances of *Leucocytherella sinensis*, *Leucocythere? dorsotuberosa*, *Limnocythere inopinata*, *F.g.* = *Fabaeformiscandona gyirongensis* and adult + juvenile valves and percentage of carapaces of *L. sinensis*. The grey shaded boxes represent a specific event layers (EL1–EL5). All species except the cosmopolitan *L. inopinata*, are endemic to the Tibetan Plateau. The absolute abundance of ostracods is lower in the event layers than within the sediments underlying and overlying event layers. There is a sharp decrease in the absolute abundance of ostracods from the base to the top of the event layers.

a mass movement sediment have a poor micro-habitat diversity (Fig. 1C). Species preferring muddy and deep water habitats should be dominant as pioneer assemblage. These are *Leucocythere? dorsotuberosa*, *Limnocythere inopinata* and *Fabaeformiscandona gyirongensis* in Tangra Yumco, which display higher relative abundances at the top of the event layers and within the overlying sediments. *Limnocythere inopinata* digs deepest in the top of the youngest event layer. Ostracod depth penetration increases with water depth in Lake Geneva, species preferring muddy substrate usually penetrate to deeper depth than other (Decrouy et al., 2012). Oxygen levels in sediment porewater and could influence deeper ostracod penetration within the sediment (Corbari et al., 2004). The abundance of *L. inopinata* is very low in the older event layers, possibly due to unfavorable environmental conditions (salinity?).

Comparison of the assumptions of our conceptual model with the result confirms the following ostracod patterns of lacustrine subaquenus mass movement (Table 2): (i) a low abundance of ostracods within the event layers compared to the underlying and overlying sediments; (ii) a sharp decrease in the abundance of ostracods from the base of the event layers; (iii) low proportion of adults than juvenile valves within the event layers; and (iv) recolonization of the new substrate with increase in the number of carapaces.

The following assumptions of the model could not be fully confirmed (Table 2): (i) a lower number of carapaces within the event layers, (ii) a lower number of adult valves within the event layers and (iii) allochthonous shallow water ostracods within the event layers. The first two problems may be due to relatively low ostracod numbers investigated. The third negative finding is explained by a hypolimnic origin of the redeposited sediment in our material.

Ostracod evidence is useful for identifying different types of depositional events (e.g. turbidites and debrites) originated by lacustrine subaqueous sediment flows. The two distinguishing features of debrite from turbidite are: (i) absence of recolonization of overlying layers by pioneer assemblages and (ii) relatively high ostracod abundance within a debris deposit (Table 2).

6. Conclusions

We discuss deep-water sediment events in the large brackish lake Tangra Yumco on the southern Tibetan Plateau, China. To the best of our knowledge, this is the first assessment of lacustrine subaqueous mass movement using ostracods. Four major event layers are established as turbidite deposits (i.e. sandy silt with graded bedding) while the fifth event layer is characterized as a debris deposit (i.e. sandy silt without graded bedding).

Based on the conceptual model and our findings, ostracods can be rated as useful for a successful interpretation of lacustrine turbidite and debris deposits. When sedimentary structures fail to provide good evidence of subaqueous mass movements, it is possible to identify sediment event layers by the use of ostracod. Features appropriate for an identification event layers caused by subaquaeous mass movement are: i) fine-grained sediment horizons (turbidite event layers) contain a lower number of ostracods than the sediments underlying and overlying event layers; ii) sorting of ostracods according to size with higher abundance and higher proportions of adult valves is recognizable at the base of event layers; iii) a relatively lower number of carapaces can be found within the event layers; and iv) a recolonization of the new habitats by a pioneer assemblage transforming into pre-event association is detectable. Allochthonous ostracods from shallow water may be absent within the event layers as our case study demonstrates.

A better understanding of subaqueous mass movement in Tangra Yumco would be possible by a lateral study of event layers in additional cores, a verification of carapace and adult valve proportions with more material and by investigation on the specific origin and mechanisms that trigger deep-water sedimentation events in this basin.

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Chapter 5

Ostracoda as environmental indicators of Late-Holocene climate variability in the brackish lake, Tangra Yumco on the southern Tibetan Plateau

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Chapter 5

5.0 Abstract

Late Holocene environmental and climate change in Tangra Yumco was inferred from micropalaeontological and sedimentological proxies. The Ostracoda identified are: *Leucocytherella sinensis*, *Leucocythere*? *dorsotuberosa*, *Limnocythere inopinata*, *Fabaeformiscandona gyirongensis*, *Candona xizangensis* and *Candona candida*.

The proxy records indicate five environmental phases: (i) wet and cool (3300 – 2320 cal BP), dominance of the euryhaline *L. sinensis* indicating the **highest lake level**, lowest salinity and low productivity with high TIC (ii) dry and warm (2300 – 1760 cal BP), characterised by a more diverse freshwater to mesohaline fauna (*L.*? *dorsotuberosa* dominant) suggesting lake level and **salinity fluctuation** and high productivity (high TOC) (iii) dry (1740 – 1100 cal BP), **lowest ostracod abundance** indicating falling lake level, very low salinity and lowest productivity (highest TIC); (iv) cold and dry (1070 – 440 cal BP), **highest salinity** (mesohaline to polyhaline), *L. inopinata* predominating, high δ18O and Mg/Ca, lowest lake level, moderate productivity and (v) wet and cool (410 cal BP – present day), high abundance of *L. sinensis* indicating a **rising lake level**, moderate salinity and high productivity.

The multiple proxies give good evidence of variabilibty in past lake level, salinity and productivity in a deep lake on the southern Tibetan Plateau.

5.1 Introduction

Recent global environmental and climate change alters the Earth’s environment (MacCracken and Perry, 2002; Bisht, 2008; Janetos, 2008). While the Quaternary was a period of major environmental and climate change in general (Bradley, 1985; Rogers, 1993), the Late Holocene climate is marked by temperature increase and the advancement and retreatment of mountain glaciers (Trinkler, 1930; Mann, 2002; Bahadur, 2004). High elevation ecosystems are particularly vulnerable to climate changes; variation in precipitation may exert great influence on the local climate and environment (Němec and Schaake, 1982; Barry, 1992; Yao et al., 2008; Chavez-Jimenez et al., 2013). Reconstruction of past climate and environmental change is critical to identify past climatic variability, to understand present conditions and to improve future predictions (e.g., effects of a warming climate on water resources) (Lamb, 1969; Bradley, 1985; Bräuning and Mantwill, 2004; Barnett et al., 2005; Duan et al., 2006; Bates et al., 2008; Yang et al., 2014a). The Tibetan Plateau (‘The Roof of the World’) is highly significant to climate and palaeoenvironmental research (Immerzeel et al., 2010; Kang et al., 2010b; Yao et al., 2012b; Favre et al., 2015).

The Tibetan Plateau (‘The Third Pole Environment’) is known for its high altitude, unique landscape and natural geo-ecosystems (Zheng and Li, 1999; Diemberger and Diemberger, 2000; Zhang, 2000; Qiu, 2008; Gao et al., 2010; Yao et al., 2012a; Tian et al., 2014). It has great influence on the Indian monsoon and global climate (Kutzbach et al., 1989; Yanai et al., 1992; Zheng et al., 2000a; Wu et al., 2012). The impact of environmental and climate change on many large continental and saline lakes in Central Asia remains unexplored (Lamb, 1995; Mischke and Zhang, 2011). Little is known about Late Quaternary lake histories (lake-level, salinity and productivity), on the southern Tibetan Plateau. The fluctuation of ancient Tibetan lakes (especially in the Indian Monsoon domains) as quantitative measure of monsoon precipitation is scarce (Liu et al., 2004).

Lake systems interact with different processes (e.g., atmosphere, biosphere and hydrosphere), recording climate and environmental variables at different scales (Battarbee, 2000; Cohen, 2003). Saline lakes are common in arid regions of the world (Hammer, 1986; Zheng et al., 1989). They are controlled by tectonic setting and climate (Hardie et al., 1978; Zheng, 1997a). Lake level fluctuation can be used as an indirect estimate of lake volume balance (Street-Perrott and Roberts, 1983). Lake volume is closely related to precipitation and evaporation over the lake surface, lake-water recharge and discharge of the rivers within the lake basin (Street-Perrott and Roberts, 1983; Zhang et al., 2013a). Lakes (especially continental closed lakes) and biological remains (e.g., ostracods) in lake sediments and their chemical shell composition serve as excellent palaeo-archives of ancient environments and climates (Carbonel et al., 1988; De Deckker and Forester, 1988a; Mischke et al., 2005; Zhang et al., 2009).

The palaeoclimate records (monsoon domains) indicate warm-humid early Holocene and cold-dry mid-late Holocene conditions (Gasse et al., 1996; Zheng et al., 2000b; Zhao et al., 2009; Mischke et al., 2010b). Palaeoclimatic reconstructions are needed to understand past variability of monsoon and hydrological dynamics, global climate warming today and future climate impact on ecosystem changes (Arnell, 1999; Arnell et al., 2001; Liu et al., 2004; Schneider and Mastrandrea, 2007). Palaeoclimate on the Tibetan Plateau has been reconstructed from high-resolution proxy data such as ice cores (Grove, 1988; Thompson et al., 1993; Davis and Thompson, 2004; Yao et al., 2008), tree rings (Brauning and Mantwill, 2004; Gou et al., 2014), lake sediments (Wu et al., 2006; Wünnemann et al., 2006; Mügler et al., 2009b; Kasper et al., 2012; Doberschütz et al., 2013; Kasper et al., 2013; Bird et al., 2014; Kasper et al., 2015; Zhu et al., 2015), pollen (Herzschuh et al., 2011; Ma et al., 2014a; Miehe et al., 2014) and microfossils and their shell chemistry (Mischke et al., 2002; Zhang et al., 2009; Zhao et al., 2009).

Ostracods are minute bivalved crustaceans (adult size of 0.5 to 3.0 mm), which are commonly known as "seed shrimps" (Griffiths and Holmes, 2000; Holmes, 2001; Galassi et al., 2002). The soft body is enclosed in a calcite carapace (Smith, 2001; Smith and Delorme, 2010). Ostracods populate marine and non-marine environments (e.g., oceans, lagoons, estuaries, rivers, lakes, etc.) and can live even in semi-terrestrial environments (Danielopol et al., 1986; Holmes and Chivas, 2002; Smith and Delorme, 2010). The fossil record of Ostracoda and sister groups, with similar hard parts, extends to the early Cambrian and Ordovician period (Horne et al., 2005; Martens et al., 2008; Rodriquez-Lazaro and Ruiz-Muñoz, 2012). Ostracods are increasingly used environmental reconstructions due to their long stratigraphic range, small size, shell calcification, excellent shell preservation, diversity, ecological sensitivity, well-known biology and shell chemistry (Delorme, 1989; Holmes and Chivas, 2002; Cronin, 2009; Horne et al., 2012). Their assemblages are can indicate aquatic ecosystem dynamics (Schornikov, 2000; Ruiz et al., 2013), macrophyte habitats changes (Kiss, 2007), environmental change (Zhu et al., 2002a; Frenzel and Boomer, 2005; Ruiz et al., 2005), water temperature (Dwyer et al., 1995; Viehberg, 2006; Horne, 2007), water depth (Wrozyna et al., 2009b; Frenzel et al., 2010;

Mischke et al., 2010c), solute composition of continental waters (Smith, 1993; Curry, 1999; Schwalb et al., 2002a; Ito and Forester, 2009b) and solute concentration (salinity/conductivity) (De Deckker, 1981b; Mischke and Wünnemann, 2006; Mischke et al., 2007). Furthermore, ostracods have extensively been used for the reconstruction of the environmental and climatic history in high-elevation environments (e.,g., Tibetan Plateau) (Mischke, 2012).

Here, we present the Late Holocene (3, 300 cal BP) environmental and climatic variation in Tangra Yumco. The lake situated in the India monsoon climate and the third largest brackish lake on the southern Tibetan Plateau. This paper address two specific questions: (i) What was the Late Holocene environment of Tangra Yumco? (ii) What can we learn about past lake evolution (e.g., monsoon intensity, lake level and salinity), palaeo-ecology (e.g., ostracod assemblages and abundance). Multi-proxy techniques (sedimentology, geochemistry ad micropalaeontology) were employed for the palaeoenvironmental reconstruction of Tangra Yumco. We hypothesised that the past lake water volume in Tangra Yumco is dependent on Indian monsoon climate. This is a new insight into Late Holocene environment and monsoon climate variability in central Asia.

5.2 Study area

5.2.1 Tibetan Plateau

The Tibetan Plateau (75 — 105° E, 27.5 — 37.5° N, average elevation of 5000 m above sea level, total area of 2.5 million km^2) is the largest and highest plateau of the world (Yeshe, 1986; Zheng et al., 2000a; Tuttle and Schaeffer, 2013). It is a hot spot for palaeoenvironmental research due to its high altitude, size, environmental heterogeneity with different climatic systems (polar air masses from Arctic, continental air masses through central Asia (Westerlies), Indian and East Asian summer monsoons; Fig. 1) and its climatic teleconnections on a global scale (Hahn and Manabe, 1975; Ruddiman and Kutzbach, 1990; Prell and Kutzbach, 1992; Raymo and Ruddiman, 1992; Molnar et al., 1993; An, 2000; An et al., 2001; Wang, 2006; Molnar et al., 2010; Liu and Dong, 2013). Large amounts of water are stored in the form of glaciers, snow fields and lakes (Xu et al., 2008b). The Tibetan Plateau has 36,800 glaciers, with a total area of 49,873 km^2, and a total volume of 4561 km^3 (Yao et al., 2007a). There are about 1055 lakes (> 1.0 km^2) on the Tibetan Plateau accounting for 39% and 51% of the total lake number and area, respectively, in China. The Tibetan Plateau has a great importance for the water cycle is the source of the ten largest Asian river systems (e.g., Mekong, Yangtze, Ganges and Yellow river). This provides the freshwater for the maintenance of aquatic ecosystems and for about 1.4 billion people (Immerzeel et al., 2008). Hence the plateau is often referred to as 'The Water Tower of Asia' (Bai and Xu, 2004; Lu et al., 2005b; Immerzeel and Bierkens, 2010a; Chellaney, 2011).

The Asian monsoon is dominated by precipitation falling in just a few months, hence the perennial flow of the rivers largely relies on the constant flux from the glaciers on the Tibetan Plateau (Immerzeel, 2008; Immerzeel et al., 2010). Most annual precipitation on the Tibetan Plateau (~60-90%) occurs between May and October, Indian Summer Monsoon (ISM) (Xu et al., 2008c; Conroy and Overpeck, 2011). Precipitation decreases from south-east to north-west on the Tibetan Plateau (Immerzeel et al., 2005; You et al., 2010; Hudson and Quade, 2013). Shifts in global, regional and local climatic regimes (especially precipitation), will affect water supply, river flow and impacting socio-economic well-being (Barnett et al., 2005; Yao et al., 2008; Immerzeel et al., 2010; Chellaney, 2011).

5.2.2 Tangra Yumco

Tangra Yumco (‚Ocean Turquoise Lake’, 30°45′ – 31°22′N and 86°23′ – 86°49′E, 4595 meters above sea level) is located at the northern slope of the Gangdise Mountains and about 450 km northwest of Lhasa on the southern Tibetan Plateau (Fig. 2). The southern Tibetan Plateau is dominated by Palaeozoic–Mesozoic carbonate and clastic sedimentary rocks (Galy and France-Lanord, 1999). Tangra Yumco is an endorheic lake formed by active tectonic movement in a north-south trending graben (Armijo et al., 1986; Zhu et al., 2004; Kong et al., 2011a). The flank of the rift and faults is composed of volcanic rocks, granitoid intrusions and potassic lavas (Gao et al., 2007).

Tangra Yumco (‚Lake Dangra’), is known by several names including Dangre-yum-tso, Dang-ra Yumtsho Lake, Dāngrě Yōngcuò and Tángŭlā Yōngmùcu (Bellezza, 1997; Denwood, 2015). It is a famous sacred lake situated about 360 km west of Nam Co, the second largest holy salt lake (Hedin, 1913; Bellezza, 1997; Diemberger and Diemberger, 2000; Bellezza, 2014). It is the centre of the ancient Zhang Zhung Kingdom, a vital cradle of Tibetan civilization (Bellezza, 1997, 2008; Denwood, 2015). The region is characterised by rich archaeological sites; e.g. the megalithic site Sumbug Doring, several forts (e.g., Gyampai Dzong, Khyung Dzong and Ombu Dzong) and the Bon monastery Yubung (Turquoise Mist). (Tulku, 1986; Bellezza, 1997) (http://www.tibettravel.org/top-10-lakes).

The lake has a surface of 818 km^2 and a drainage area of 8219 km^2 (Long et al., 2012). It is the third largest saline lake (salinity of 8.3, conductivity of 10.6 mScm^{-1}, pH 9.6), the deepest lake (maximum water depth of 230 m) on the Tibetan Plateau and the second-deepest lake in China (Zhu et al., 2004; Shao et al., 2008; Wang et al., 2010b). The lake is S-shaped (Fig. 1) with two sub-basins separated by a narrow strip. The northern basin is much deeper (230 m) than the southern one (~100 m). The water cation and ionic composition is dominated by $K^+ – Cl^- – HCO_3^-$ and is depleted in Ca^{2+} (Akita et al., in press). There are numerous rivers and streams, which flow into Tangra Yumco. The lake is surrounded by snow-capped mountains (e.g., Targo Gegen, ‘Ancient Vulnerable Snow Mountain’) (Bellezza, 1997; Diemberger and Diemberger, 2000). The lake-water is recharged mainly by precipitation, streams and rivers (e.g., Daguo Tsangpo, Buzhai Tsangpo and Mainongqu) (Diemberger and Diemberger, 2000; Shao et al., 2008). Most of the snow (ice) caps are missing today due to global warming (Diemberger and Diemberger, 2000). The largest river, Daguo Tsangpo, originates from the Gangdise Mountains (Shao et al., 2008).

The lake is endowed with Holocene beach terraces and palaeo-shorelines (maximum 185 m above the present lake), which record lake level fluctuations (Zheng et al., 2000b; Zhu et al., 2004; Long et al., 2012; Liu et al., 2013b; Rades et al., 2013b; Ahlborn et al., 2015a). Agricultural settlement (around the sacred Mountain, Gangs Lung Lhatse) is recognisable at the south shore of the lake (Bellezza, 1996, 1997). The village of *Kyisum* is one of Tangra Yumco’s major agricultural settlements, cultivating barley and turnips (Bellezza, 1996, 1997).

Tangra Yumco is influenced by the Indian Summer Monsoon (Miehe et al., 2013). The mean annual precipitation ranges from 200 to 350 mm (Miehe et al., 2013). The annual mean temperature for January is -11.4°C while the mean

July temperature is 10.9°C (Miehe et al., 2013). The lake is covered with ice in winter but does not completely freeze in some years (Kropacek et al., 2013). The cold-arid climate supports alpine meadow (e.g., *Kobresia*) and steppe vegetation (e.g., *Artemisia*) (Miehe et al. 2013).

Tangra Yumco is one of the key sites used for palaeoenvironmental investigations within the Sino-German priority research programme TiP "Tibetan Plateau: Formation-Climate–Ecosystem" to assess climate history (past, present and future) and human impact in this sensitive geo-ecosystem of Central Asia (http://www.tip.uni-tuebingen.de/index.php/de/).

5.3 Materials and methods

5.3.1 Sediment coring, lithology and chronology

In September 2010, a 162 cm long sediment core (TAN10/4, 30°15′9.54″N and 86°43′22.14″E, Fig. 3) was recovered using a modified ETH gravity corer (Twinch and Ashton, 1984; Kelts et al., 1986) from 223 m water depth at the centre of the northern basin of Tangra Yumco.

The sediment core was stored in a dark room with temperature of 4°C at the Institute of Geography, University of Jena, Germany. It was split, visually described, photographed scanned for magnetic susceptibility, and sampled in 1 cm intervals for micropalaeontology, sedimentological and geochemical analyses. Lithology, colour and grain size are described in Akita et al. (2015).

Radiocarbon (^{14}C) dating of bulk sediments and a piece of a woody (terrestrial) plant was used to establish the chronology of TAN10/4 using accelerator mass spectrometry (AMS) at Beta Analytic Inc. (Miami, Florida, USA) (Haberzettl et al., 2015). The sediment-water-interface was radiocarbon dated to correct for the reservoir effect (Haberzettl et al., 2015). The method of dating surface sediments and Recent water plants was employed to estimate the carbon-reservoir effect for the chronology of lacustrine records (Kasper et al., 2012; Mischke et al., 2013). The chronology of the core was event corrected by subtracting the sediment event layers (four turbidites and a debrite) (Akita et al., 2015). The online version of the Calib 7.0 program protocols (Stuiver and Reimer, 1993), employing the IntCal13 data set was used for the AMS ^{14}C calibrated median age-depth value (thus after reservoir correction), which has been expressed as 2σ range (Niu et al., 2013; Reimer et al., 2013). Ages between the dated samples were interpolated linearly and verified by magnetostratigraphy (Haberzettl et al., 2015).

5.3.2 Sediment elemental analysis

For the determination of total carbon (TC) and total nitrogen (TN), sediment samples were weighed (20 mg each) tungsten oxide was added and placed in tin-shuttles. Further, aliquot of the sample was treated with hydrochloric acid (30% p. A.) to remove carbonates. After washing and centrifuging, the same sample was used in the determination of total organic carbon content (TOC). The element concentration was measured by element analyser (varioEL cube Elementar Analysensysteme

GmbH). Additionally, the TOC/TN ratio (total bound nitrogen) was calculated.

5.3.3 *Micropalaeontological analysis*

The sediment core was sampled at 1 cm intervals for microfossil analysis. Each sediment sample was placed in a graduated cylinder with a known volume of water. The volume displaced was measured. Sample were washed through 200 µm and 63 µm mesh sieves, rinsed with deionized water and ethanol (75 %) and dried at room temperature (Griffiths and Holmes, 2000).

Ostracods were separated from the residue using a fine brush wetted with deionised water under a binocular microscope with light source. Ostracods were identified to the species level using Tibetan Ostracoda taxonomic keys (Hou et al., 2002; Hou and Gou, 2007; Wrozyna et al., 2009d).

The sediment size fraction >200 µm was used for the quantitative analysis of microfossils(Griffiths and Holmes, 2000). Adult to juvenile ratio was determined for the most common ostracod species, *Leucocytherella sinensis*. Carapaces and valves were separately counted. Complete carapaces are counted as two valves (Danielopol et al., 2002; Boomer et al., 2003). The relative abundance (the percentage of species within the sample) is used to assess changes within the ostracod fauna (Boomer et al., 2003). Samples with lower occurrence of valves, a minimum of forty valves for the estimation of relative abundance and thirty valves for determination of adult/juvenile ratio of *L. sinensis*, were regrouped by summing up numbers of up to three adjacent samples.

Selected ostracod specimens were photographed using a Scanning Electron Microscope. Palaeosalinity was reconstructed using a southern Tibetan ostracod-based transfer function (Peng et al., 2014). Specific conductivity measurements can be used to indicate salinity (De Deckker, 1981a). Hence, specific conductivity measurements were converted into salinity by factor of 0.75 (Hölting, 1992). Salinity is classified based on the Venice System for classification of brackish waters (Symposium, 1958).

5.3.4 *Ostracod shell chemistry*

Adult ostracod valves were picked from sediment intervals with sufficient fossil material for chemical analyses. Shell chemistry analyses were performed by selection of well-preserved valves, for the two most frequent ostracods, *Leucocytherella sinensis* (predominate in older sediment, 1065 – 444 cal BP, 129 – 88 cm) and *Limnocythere inopinata* (dominate in younger sediment, 3300 – 2320 cal BP, 29 – 13 cm).

The shells were photographed prior to cleaning (removal of contamination, loosely attached detritus, organic matter and any other mineral on the skeleton). They were cleaned by soaking (bleaching) in 2.5% sodium hypochlorite (NaOCl), for 15 minutes to 24 hours. The shells are rinsed with de-ionized water to remove any traces of the bleach, followed by rinsing in ethanol (99%), and then dried. Sodium hypochlorite is an effective oxidizing agent for removal of organic matter on carbonate shells (Durazzi, 1977; Gaffey and Bronnimann, 1993; Ito, 2001; Keatings et al., 2006). To obtain enough carbonate for single isotopic analyses, cleaned valves of *L. sinensis* (8 – 9 valves per sample) and *L. inopinata* (20 – 28 valves per sample) were used.

There exist missing data in the intervals, even where *L. inopinata* was abundant due to loss of shells in sample preparation (cleaning of valves). The valves of *L. inopinata* dissolved when soaked in sodium hypochlorite (NaOCl) for 24 hours. The cleaning time of *L. inopinata* in NaOCl was adjusted to less than 20 minutes.

The stable isotope ($\delta^{18}O$, $\delta^{13}C$) and trace element (Mg/Ca and Sr/Ca) analyses were sequentially performed on the same ostracod valves (Xia et al., 1997a).

5.3.5 *Ostracod isotopic measurement*

The calcium carbonate ($CaCO_3$) of ostracod valves (carbonate sample) reacted with 105% phosphoric acid (H_3PO_4) (99.998% ultra-pure P_2O_5) at 70°C (McCrea, 1950; Craig, 1957; Coplen et al., 1983). This results in a conversion of carbonate to carbon dioxide (CO_2) (McCrea, 1950; Craig, 1957; Coplen et al., 1983). Isotopic fractionation occurs since only two oxygens out of three in $CaCO_3$ are converted to CO_2 (Emi Ito personal communication). Furthermore, this allows simultaneous analysis of both $\delta^{18}O$ and $\delta^{13}C$ from the same sample (Craig, 1957; Coplen et al., 1983).

The 'working standard' was Carrara Marble, very pure limestone, with $\delta^{18}O = -1.96‰$ and $\delta^{13}C = +1.96‰$ (http://www.geo.umn.edu/orgs/sil/instrumentation.html). The National Bureau of Standards (NBS) reference is used to obtain precise isotopic values and relations between sets of data from various different laboratories (Craig, 1957). The international standard references materials used for the analysis are: (i) carbon; NIST NBS-18 and NBS-19 LSVEC and (ii) Oxygen; NBS-18 and NBS-19. The δ values of ($\delta^{18}O$ and $\delta^{13}C$) are the mean values of replicate runs. The analytical precision is 0.1‰. The stable isotopes were measured with a Finnigan MAT 252 mass spectrometer connected to Kiel-II device at the Stable Isotope Laboratory, Department of Earth Sciences, University of Minnesota, United States of America.

The stable isotopic composition of oxygen and carbon in the analysed sample is expressed as the "delta notation" or "delta values" (δ) (e.g., $\delta^{18}O$ and $\delta^{13}C$), (equation 1). This is defined as the difference in isotopic ratios, the abundance of isotopes in the sample, relative to an international standard (Sulzman, 2007; Thornton and Burdette, 2013). The δ value is calculated as (Craig, 1957):

δ (in ‰) = $(R_x/R_S-1) \times 1{,}000$ ………. Equation (1)
Where R = the ratio of the heavy to light isotope (e.g., $^{18}O/^{16}O$, $^{13}C/^{12}C$, rare-to-abundant)
R_x = the ratio in the sample
R_s = the ratio in the isotope standard

5.3.6 *Ostracod trace element determination*

The acid-residue from ostracod isotopic analysis (same samples) was used for cation analysis (Chivas et al., 1985; Chivas et al., 1986b; Chivas et al., 1993)). The acid-residue from each sample was diluted 200-fold for element determination (Ca, Mg, Sr) (Yu et al., 2002) by the Thermo Scientific iCAP 6500 duo view Inductive-Coupled Plasma Optical Emission Spectrometer (ICP-OES) at the Aqueous Geochemistry Laboratory, Department of Earth Sciences, University of Minnesota, United States of America. The trace element concentrations are expressed as molar ratios relative to calcium (Mg/Ca and Sr/Ca). The analytical precision is 2%.

5.3.7 *Statistical analysis*

The ostracod-based zonation was obtained by constrained hierarchical clustering using PAST (Hammer et al., 2001). To determined ostracod variability in time, both species richness and diversity were employed.

Species richness is number of species present in a given sample, community or taxonomic group (Magurran, 2004). Species diversity (an index of species richness, e.g., 'Shannon Diversity') is a measure of the diversity within an ecological community (Magurran, 2004). The species diversity (relative abundance of individual species in a community) is influenced by species richness and species evenness (Magurran, 2004). Natural logarithms, In (x+1), was used to record the abundance of ostracods (Townend, 2002).

Shannon Diversity Index (abundance ratios of taxa) was calculated (Shannon and Weaver, 1949; Hill, 1973; Spellerberg and Fedor, 2003; Chiarucci et al., 2011), as:

$H = - \Sigma (n_i / N) \log (n_i / N)$

where

H = Shannon–Wiener's index of species diversity in individuals

n_i = Number of individuals of ith species

N = Total number of individuals

5.3.8 *Ostracod-based conductivity transfer function*

In order to apply an ostracod-based conductivity transfer function (inference model), a calibration (modern training) set consisting of ostracod taxon data (expressed in relative abundance) and their contemporary environmental data was used (Birks et al., 2010; Juggins and Birks, 2012). The modern training data set comprises seventy five surface sediment samples collected from thirty four brackish lakes, distributed from west to east on the Tibetan Plateau, covering a conductivity range of 0.25 to 200 mS/cm (Peng et al., 2014).

Ostracod data was $\log_{10}$ (x+1) transformed (Townend, 2002). The measured conductivity values were log-transformed as well to meet the assumption of normality (Zar, 2010). Weighted averaging partial least squares (WA-PLS) (based on concept of niche-environmental space partitioning and ecological optimum of indicator species) was applied to the full-dataset (nine ostracod taxon, seven environmental data) to produce a calibration – conductivity transfer for estimating past lake-water salinity (ter braak and Juggins, 1993; ter braak, 1995). With this calibration function, the parameters for *m* species are estimated from the modern training set for the environmental variable of interest and consequently used to reconstruct the past environment from these same *m* species in the fossil assemblages (ter braak et al., 1993). The ostracod-based conductivity transfer function was computed using the C2 software (Juggins, 2003). The performance of the transfer function is: $R^2 = 0.68$, RMSEP = 0.30 (Peng et al., 2014).

5.4 Results

5.4.1 *Lithology and chronology*

The lithology of core TAN10/4 is composed of fine-laminated (1-5 mm) greyish silty clay with intercalated dark brownish to blackish fine sandy layers (Fig. 4) (Akita et al., 2015). The normal sedimentation is interrupted by five events layers (four layers are originated from turbidity flows and one was formed by a debris flow) (Akita et al., 2015).

The reservoir effect was used for the determination of the reservoir corrected chronologies. A carbon-reservoir effect of 2120 (+110/-90) years was determined by the age of the sediment (Tab. 1). Only the youngest ages in the stratigraphic order were used for the chronology. The age from the bottom of the sediment core, TAN 10/4 is 3, 300 cal BP (Fig. 5). Magneto stratigraphic analyses confirmed the radiocarbon-base chronology (Haberzettl et al., 2015).

5.4.2 *Ostracod succession*

Ostracods were the only microfossil found within the >200 µm size fraction. The total ostracod valves counted was 5039. Relying on ostracod distribution, five biostratigraphic zones were identified: 129 – 88 cm, 87 – 60 cm, 59 – 30 cm, 29 – 13 cm and 12 – 0 cm sediment depth.

The abundance of ostracods varies with depth (Fig. 6). It is higher at bottom (90 cm – 60 cm) and lower in the upper part (59 cm – 30 cm) (Fig. 6). Mean ostracod abundance is 32 valves per ml (excluding sediment redeposition layers).

Five genera and six species were identified.The ostracod species (order of frequency and relative abundance) are: *Leucocytherella sinensis* Huang, 1982 (60.6%), *Leucocythere*? *dorsotuberosa* Huang, 1982 (18.7%), *Limnocythere inopinata* (Baird, 1843) (15.1%), *Fabaeformiscandona gyirongensis* (Huang, 1982) (4.7%), *Candona xizangenesis* Huang, 1982 (0.5%) and *Candona candida* (O.F. Müller, 1776) (0.2%).

The different assemblages can be used to characterise specific environmental history (Fig. 6). Faunal succession can be found in the oldest to youngest sediment depth (Fig. 6): The ostracod species composition and dominant assemblage (average relative abundance %) are as follows:

(i) 129 – 88 cm: *L. sinensis, L.*? *dorsotuberosa* and *F. gyirongensis*. *Leucocytherella sinensis* (87.5%) is the dominant ostracod in the oldest sediment (Fig. 6: stage I). High adult to juvenile and carapace to valve ratios of *L. sinensis* occurs in 121 cm – 105 cm depth (Fig. 6. stage I).

(ii) 87 – 60 cm: *L.*? *dorsotuberosa*, *L. sinensis*, *L. inopinata, F. gyirongensis, C. xizangenesis* and *C. candida*. *Leucocythere*? *dorsotuberosa* (51.5%) is the dominant species in this depth (Fig. 6. stage II).

(iii) 59 – 30 cm: very low abundance of ostracods (13.9%) in this depth (Fig. 6. stage III).

(iv) 29 – 13 cm: *L. inopinata*, *L.*? *dorsotuberosa*, *L. sinensis* and *F. gyirongensis*. *Limnocythere inopinata* (61.7%) is the dominant species in this depth (stage IV).

(v) 12 – 0 cm: five ostracod assemblages present; *L. sinensis*, *L. inopinata*, *L.*? *dorsotuberosa*, *F. gyirongensis* and *C. candida*. *Leucocytherella sinensis* (44.1%)

predominates the youngest sediment depth (stage V). *Limnocythere inopinata* (26.6%) is the second most abundant ostracod in this depth.

Fabaeformiscandona gyirongensis occurs in relative low proportions throughout the core and shows a maximum at 87 – 60 cm. *Candona xizangensis* appears only at 87 to 60 cm. *Candona candida* is rarest species.

5.4.3 Ostacod shell oxygen isotopic analysis

The two species, *L. sinensis* and *L. inopinata* differ in their carbonate isotopic and trace element composition (Fig. 7). Higher $\delta^{18}O$ values were recorded for *L. inopinata* than for *L. sinensis* (Fig. 7 – 8). The $\delta^{18}O$ values for *L. sinensis* range from -6.05 ‰ VPDB to -3.34 ‰ VPDB (mean = -4.51 ‰ VPDB, standard deviation = 0.58) and $\delta^{18}O$ values for *L. inopinata* are between -4.37 ‰ VPDB and -1.39 (mean = -2.62, standard deviation = 1.05) (Fig. 7 – 8).

High values of $\delta^{13}C$ occur in the lower part of the core (from 129 to 88 cm depth). The measured $\delta^{13}C$ values are stable above 60 cm depth. The $\delta^{13}C$ values for *L. sinensis* and *L. inopinata* from the sediment core differ by 1.5‰ VPDB (vital offset, one sample) (Fig. 8). The $\delta^{13}C$ values for *L. sinensis* range from 1.74 ‰ VPDB to 3.51 ‰ VPDB (mean = 2. 89 ‰ VPDB, standard deviation = 0.35) and $\delta^{18}O$ values for *L. inopinata* are between 0.94 ‰ VPDB and 1.25 ‰ (mean = 1.12, standard deviation =0.11) (Fig. 8).

5.4.4 Ostracod shell trace element analysis

Mg/Ca values for *L. sinensis* range from 0.021 to 0.042 (mean = 0.028, standard deviation = 0.005). In constrast, Mg/Ca for *L. inopinata* ranges between 0.023 and 0.076 (mean = 0.038, standard deviation = 0.019) (Fig. 7).

The Sr/Ca ratios are measured for. *L. sinensis* up to 58 cm core depth (Fig. 7). The Sr/Ca ratios for *L. sinensis* range from 0.610 to 0.779 (mean = 0.648, standard deviation = 0.037), wheares Sr/Ca for *L. inopinata* is between 0.469 and 457.4 (mean = 326.9, standard deviation = 222.9).

The lowest iron/manganese (Fe/Mn) ratio (*L. sinensis*) occurs in the lower part of the core. In contrast, higher values (*L. inopinata*) are typical for the upper part (Fig. 7).

5.4.5 Ostracod-based conductivity transfer function: palaeo-salinity inferences

An ostracod-based conductivity transfer function is employed to estimate palaeosalinity in Tangra Yumco. Tangra Yumco is a mesohaline system today (Akita et al., in press). However, salinity fluctuated during the Late Holocene (Fig. 8, Tab. 2). Five major salinity phases are inferred: I (3300 – 2320 cal BP) – β-oligohaline conditions, the euryhaline species, *L. sinensis* is mainly dominant; II (2300 – 1760 cal BP) – β-oligohaline to β-mesohaline conditions, the fresh to brackish water species, *L.? dorsotuberosa* is dominant; III (1740 – 1104 cal BP) – β-oligohaline range, very low ostracod abundance; IV (1065 – 444 cal BP) – α-mesohaline range, the more salt-tolerant species, *L. inopinata* predominates; V (405 cal BP to present) – α-oligohaline to β-mesohaline, *L. sinensis* prevalence (Fig. 8, Tab. 2).

5.5 Reconstruction and discussion

5.5.1 *Lithology and chronology*

The lithology of sediment core TAN 10/4 is characterised by horizontal layers of fine sand to medium silt with a thickness from <1 mm to 5 mm (Fig. 4) (Akita et al., 2015). The undisturbed sediment layers suggest minimal bioturbation and oxygen deficiency in the profundal zone within a deep lake. Sediment dynamics affect the lake productivity and water column processes (Ahlborn et al., 2015a).

Radiocarbon dating may provide a high resolution chronology of past events and rates of change (Libby et al., 1949). The ^{14}C years do not directly measure calendar years due to variation in the production rate of atmospheric ^{14}C concentration with time (de Vries, 1958; Stuiver and Suess, 1966; Reimer et al., 2009). This is caused by geomagnetic and solar modulation of the cosmic-ray flux and the carbon cycle. The ^{14}C age-models are calibrated to obtain a precise and accurate chronology based on an absolute dated record (Reimer et al., 2013). The ^{14}C age-model provides high resolution of sediment records with reservoir effect of effect of 2120 (+110/-90) for Tangra Yumco (Haberzettl et al., 2015; Wang et al., in press).

5.5.2 *Sediment element compositions*

Sediment element compositions (grain size, K, TOC, TOC/TN, TIC) were variable during the Late Holocene(Ahlborn et al., 2015a). Changes in grain size is used as indicator of palaeo-water movement and turbulence.The significant increased in grain size occurs only at 1065 – 444 cal BP (cold and the driest phase).The sediment element compositions is integrated with ostracod proxies in the Late Holocene environment and climatic inferenceof Tangra Yumco (Fig.10 -12).

5.5.3 *Ostracoda*

There are **four endemic Tibetan ostracods** (*Leucocytherella sinensis*, *Leucocythere*? *dorsotuberosa*, *Fabaeformiscandona gyirongensis* and *Candona xizangensis*) and **two holarctic species** (*Limnocythere inopinata* and *Candona candida*) (Tab. 3). Salt lakes, usually contain **low species** (richness and diversity) but **high endemism** due to geographical isolation (Lodge, 2001).

The **six species** belong to **two families** (Limnocytherididae and Candonidae). The family Limnocytheridae is predominant ostracod fauna found in Tangra Yumco (Akita et al., in press). The family dominates lacustrine waters on the Tibetan Plateau (Wrozyna et al., 2009d; Mischke, 2012). The family Limnocytheridae is non-marine ostracod family with extensive distribution (Danielopol et al., 1989). The *Leucocythere*, *Leucocytherella* and *Limnocythere*, limnocytherid fresh to brackish water genera, originated from the Mesozoic to Cenozoic lake sediments in China (Huang, 1985; Danielopol et al., 1989). The genus *Leucocytherella* occurs in Pliocene to Holocene sediments of the Tibetan Plateau, China (Huang et al., 1982; Huang et al., 1985). The surface morphology of *Leucocythere* and *Limnocythere* differ only in the accessory limbs in the male (Zhu et al., 2007). Both species are adaptable to eurysalinity (hypo- to hypersaline) waters (Zhu et al., 2007). *Leucocytherella sinensis* and *Leucocythere*? *dorsotuberosa* are the dominant ostracod assemblages, inhabiting large and deep lakes on the southwestern and central Tibetan Plateau (Mischke, 2012). High abundance of individual taxa may occur under the most favourable ecological conditions (Tab. 3).

Ostracods found are **cold stenothermal** species except *L. inopinata*, which is adapted to varying temperature (adaptable to cold and warm waters) (Tab. 3) (Meisch, 2000b; Mischke et al., 2008b). The ostracod assemblages are dominated by **titanoeuryplastic** species tolerating poor calcium but alkaline waters (Meisch, 2000b).

The Late-Holocene ostracod fauna, exclusive of (*Candona xizangensis*, empty valves only found in surface sediments), still exist (living and Recent) in the lake system, Tangra Yumco (Akita et al., in press). *Candona candida*, very rare in the sediment core, commonly inhabits temporary fresh waters (pond, rivers) connected to Tangra Yumco (Akita et al., in press). Ostracod ecological preference is related to environmental variables (e.g., specific conductivity) (Akita et al., in press). The ecological requirement of the living and Recent Ostracoda is a powerful tool for environmental reconstruction of fossil assemblages (Tab. 3).

5.5.4. Ostracoda ecology: critical for palaeoecogical interpretations

To infer the past environment and climate using the fossil ostracod assemblage in the sediment core, it is critical to understand the the habitat ecology of living and Recent Ostracoda of Tangra Yumco and other ostracod literature. In the following, we discussed, the **ecological characteristic of ostracod species** found in sediment core, (TAN10/4):

Leucocytherella sinensis **Huang, 1982**

Leucocytherella sinensis is a ubquitous species and the most dominant ostracod found in brackish Tibetan lakes (Mischke et al., 2008b; Fürstenberg et al., 2015) (Huang, 1982). It can thrive in diverse aquatic habitats (lakes, lagoon-like and estuary-like waters, rivers, ponds and springs), with tolerance to varying salinities (Akita et al., in press). *Leucocytherella sinensis* is the most dominant living and Recent ostracod in the phytal assemblage of Tangra Yumco (Akita et al., in press). Although *L. sinensis* can live in varied water depth, the abundance decreases with increasing depth (Akita et al., in press). Junior synonyms are *Limnocytherellina bispinosa* and *Limnocytherellina trisponsa* (Huang, 1982; Fürstenberg et al., 2015). *Leucocytherella sinensis* is adapted to waters with a salinity range of 0 – 13. The synonym species *Limnocytherellina trispinosa* tolerates salinity up to 20, although it can live in waters with a salinity of 173 (Zheng et al., 1989). In the Tangra Yumco area, living *L. sinensis* were found at a salinity minimum of 0.06 (Akita et al., in press). *Leucocytherella sinensis* is abundant in Ca^{2+} depleted but moderate alkaline waters at Tangra Yumco (Akita et al., in press).

The development of tubercles and spines on the valves of *L. sinensis* is linked to the water chemistry (specific conductivity/ salinity and calcium ions) (Fürstenberg et al., 2015). The tubercles and spines occur under low salinity but constant calcium concentration of the water (Fürstenberg et al., 2015).

***Leucocythere*? *dorsotuberosa* Huang, 1982**

Leucocythere? *dorsotuberosa* is a oligorehophilic species, common in fresh and brackish waters (Meisch, 2000b; Mischke et al., 2006; Akita et al., in press). It is also part of the halophilic (salt tolerant) fauna, but can thrive waters with very low salinity as well (Liu et al., 1998; Mischke et al., 2010c). *Leucocythere*? *dorsotuberosa* lives in waters with conductivity range of 205 to 2209 µS/cm (salinity 0.1 – 1.6) and an optimum of 673 µS/cm (0.5) (Mischke et al., 2007). It is an indicator of deep water in lakes (Wrozyna et al., 2009b; Frenzel et al., 2010; Peng et al., 2013; Akita et al., in press). *Leucocythere*? *dorsotuberosa* was found in middle Pleistocene freshwater to oligohaline lakes in the Qaidam Basin (Mischke et al., 2006).

***Limnocythere inopinata* (Baird, 1843)**

Limnocythere inopinata is a holarctic species mainly found in Northern Europe and Northern America) (Bronshtein, 1988; Meisch, 2000b; Henderson, 2002). But also common on the Tibetan Plateau, in western Mongolia and northwestern China (Peng et al., 1998; Yu et al., 2009; Zhai et al., 2010a). It is a junior synonm of *Limnocythere dubiosa* (Lister et al., 1991). It is a polythermophic rheoeuryplastic and mesohaloplastic species (Meisch, 2000b). *Limnocythere inopinata* inhabits diverse aquatic habitats (e.g., lake, rivers, swamps, pondsand streams etc) in fresh to polyhaline waters (Meisch, 2000b; Mischke et al., 2004; Van der Meeren et al., 2010b).

Limnocythere inopinata is a widespread ostracod with tolerance to high salinity and nutrient waters (Meisch, 2000b; Van der Meeren et al., 2010a). High abundance occurs in haline waters (Meisch, 2000b; Mischke, 2012; Van der Meeren et al., 2012). Increased proportions of *L. inopinata* were documented in soft sediment with high organic content (detritus), within the shallow zone of Neusiedlersee lake and sheltered bays (Jungwirth, 1979). *Limnocythere inopinata* is a typical component of phytal ostracod assemblages, but can also survive in deeper parts of lakes (Carbonel et al., 1988; Meisch, 2000b; Mischke et al., 2004).

Living *L. inopinata* is the predominate species in lagoon-like waters at Tangra Yumco, although it has a broad tolerance to specific conductivity, 1. 35 – 12.81 (salinity range of 0.98 – 9.28) (Akita et al., in press). *Limnocythere inopinata* lives in shallow littoral habitats of European lakes (e.g., Klopeiner, Mondsee and Neusiedler (Schiemer et al., 1969; Carbonel et al., 1988; Danielopol et al., 1993; Meisch, 2000b). It is also an abundant ostracod in the shallow littoral zone of Tibetan lakes (Sipanguer Lake, Zhognai Lake Goulu Lake and) (Zhu et al., 2007). Living *Limnocythere inopinata* belong to the phytal assemblage (84% maximum valves in 0.04 m water depth), whereas Living individuals occur more frequent at deeper depth (55% at 223 m) in Tangra Yumco (Akita et al., in press). *Limnocythere inopinata* response to salinity fluctuation is reflected in morphological variability (Yin et al., 1999; Zhai et al., 2010b). Salinity and size both correlated positively to physiological response in *L. inopinata* clones (Geiger et al., 1998; Yin et al., 1999). Female *L. inopinata* grow smaller in length in low salinity waters(Geiger, 1994; Yin et al., 1999). In contrast, male of *L. inopinata* are primary adapted to higher salinities, developing larger valves at maximum salinity (Geiger, 1994; Yin et al., 1999).

Fabaeformiscandona gyirongensis (Huang, 1982)

Fabaeformiscandona gyirongensis is a typical ostracod fauna of brackish Tibetan lakes (Yin and Martens, 1997; Meisch, 2000b). In Tangra Yumco, Recent (living and empty shells) specimens were found only in the deep brackish lake itself (Akita et al., in press). Here, the conductivity varied between 11.88 – 12.81 mS cm^{-1} (salinity of 8.61 – 9.28). Empty shells of *F. gyirongensis* are distributed at all water depth with a peak at deeper depth (23% at 223 m) in Tangra Yumco (Akita et al., in press). This assemblage displaying a positive correlation with water depth (Akita et al., in press). In Tibet, *Fabaeformiscandona gyirongensis* is found in moderate brackish waters, with a conductivity range of 124 µScm^{-1} – 1706 µScm^{-1} (salinity 0.1 – 1.3) and optimum of 460 µScm^{-1} (0.3) (Mischke et al., 2007). It is an indicator of permanent deep brackish lakes and belongs to the ostracod assemblage of the hypolimnion (Akita et al., in press).

Candona xizangensis Huang, 1985

Candona xizangensis is adapted to fresh to oligohaline waters and behaves mesorheophilic (Meisch, 2000b). It belongs to the phytal ostracod assemblage and deep water species (Huang et al., 1985; Wrozyna et al., 2009d; Akita et al., in press). The Recent C. *xizangenesis* inhabits waters with conductivity range of 0.17 to 12.8 mS cm^{-1} and water depth of 0 – 20.4 m (Akita et al., in press). Empty shells were also found in rivers and estuary-like waters (Akita et al., in press). The species may be used as indicator of palaeowater depth (Wrozyna et al., 2009b; Frenzel et al., 2010; Peng et al., 2013).

Candona candida (O.F. Müller, 1776)

Candona candida is a Holarctic freshwater species (Meisch, 2000b; Mischke et al., 2003a; Karanovic, 2012). It is known as a cold climate ostracod (Carbonel et al., 1988). *Candona candida* is characterised as rheoeuryplastic and oligothermophilic (Meisch, 2000b). It prefers diverse shallow temporary waterbodies (e.g., ponds, rivers, springs, swamp lakes and subterranean habitats) (Meisch, 2000b). However, it also exists in permanent waters, peferrably littoral, but survives in low proportions in the profundal zone of lakes (Meisch, 2000b). *Candona candida* is a common benthic ostracod which prefers temporary freshwaters and occupies mainly the shallow littoral zone of lakes on Tibetan Plateau (Mischke et al., 2003a; Mischke, 2012; Song et al., 2015).

Candona candida prefers akaline waters at a pH of 8-10 (Song et al., 2015). But *C. candida* are able to survive in acidic waters as well (pH below 5) (Fryer, 1980). *Candona candida* was found in brackish coastal waters with a salinity up to 5.3 (lower mesohaline range) (Meisch, 2000b). *Candona candida* lives in waters with a conductivity between 0.14 and 0.91 µScm^{-1} (salinity 0.10 – 0.66) (Akita et al., in press). Living *C. candida* occurs frequently in ponds (maxium in ponds with high organic matter, 59 individuals) and rivers (Akita et al., in press). However, empty valves of *C. candida* were found typically in the epilimnion (up to 20 m) and low numbers in the hypolimnion (0.2 % shells at 110 m) of Tangra Yumco (Akita et al., in press). *Candona candida* is most abundant in rivers but also in Lake Luahaizi on the Tibetan Plateau (Mischke et al., 2003b). An optimum water depth of 16.5 m was documented for Lake Donggi Cona (Mischke et al., 2010c).

5.5.5 Ostracod fauna succession; palaeoecological implications

The Late Quaternary ostracod associations (composition and abundance) suggest a variation in lake level (water-volume), salinity and lake productivity through time (Tab. 4). The ostracod associations found can co-occur in the mesohaline lake, Tangra Yumco. However, lake salinity influences the dominance of particular species (Tab. 4) Hammer (1986) observed negative correlation between species richness and salinity. Therefore, it is assumed that salinity is an important determinant of the fauna of saline lakes (De Deckker, 1981a; Carbonel et al., 1988; Williams et al., 1990; Herbst, 2001). Each species has a physiological adaptation to a specified salinity range (De Deckker and Geddes, 1980). Fossil ostracod assemblages in the sediment core from ~3.300 cal BP suggest a general decrease in monsoon strength causing a falling lake-water level and increasing salinity in the Late Holocene. The Late Holocene ostracod fauna reveals distinct transitions of lake water-level, salinity and productivity with and occasional incursion of freshwater.

5.5.6 Ostracod fauna succession: palaeecological interpretations

Ostracoda (e.g., distribution, abundance, productivity) related to environmental variables (e.g., water temperature, salinity, water depth, substrate, water permanence) (Griffiths and Holmes, 2000). Species-specific ecological requirements are sensitivity indicator of aquatic conditions (Van der Meeren et al., 2010a; Akita et al., in press). **Identification and quantification** of different ostracod assemblages in a sediment core is critical to understand of **past sediment deposition**, **aquatic environment** and **climatic conditions**. Ostracoda (total assemblages, species richness, diversity, dominance and shell chemistry) is **excellent biological proxies** for palaeolimnological and palaeoenvironmental reconstruction. The ostracod assemblages found in the sediment core (TAN10/4) are used to characterise environmental and climatic conditions in Tangra Yumco during the past 3300 years. Optimum ecological factors may favour high abundances of individual ostracod species. Species specific ecological niches are: *Leucocytherella sinensis* (ubiquitous fauna), *Leucocythere*? *dorsotuberosa* (fresh-brackish water fauna), *Limnocythere inopinata* (fresh to mesohaline species), *Fabaeformiscandona gyirongensis* (brackish-lacustrine fauna), *Candona xizangensis* (phytal littoral brackish lake fauna) and *Candona candida* (freshwater fauna) (Akita et al., in press) (Tab. 3).

5.5.7 Ostracod assemblages as palaeoenvironmental indicators

Palaeo-water depth indicators

The low proportion of *F. gyirongensis* throughout the sediment core is a **significant environmental** condition. *Fabaeformiscandona gyirongensis* is a typical **deep-water ostracod**, inhabiting -cold hypolimnion zone of Tangra Yumco (Akita et al., in press). Although, lake salinity fluctuates with historical geological time (high, moderate and low), this assemblage suggests prevalence of a deep brackish lake, Tangra Yumco during the Late Quaternary. The maximum abundanceof *F. gyirongensis* at **87 – 60 cm** indicates increased palaeo-water depth (Wrozyna et al., 2009b; Zhu et al., 2009a; Frenzel et al., 2010). Other **water-depth ostracod** assemblages (*L. dorsotuberosa*, and *C. xizangensis*) appear together with *F.*

gyirongensis.

Limnocythere inopinata and *L. sinensis* are phytal ostracods but adapted to different sediment depth (Akita et al., in press).

Candona Candida is shallow-water ostracod assemblage (Meisch, 2000b; Song et al., 2015; Akita et al., in press).

Palaeo-freshwater incursion indicators:

The very low relative abundance *C. xizangensis and C. candida* (rare species found in the sediment core) suggest moderate salinity-water conditions. *Candona candida* and *C. xizangensis* are adapted to fresh to oligohaline waters (Tab. 2 – 3)

Candona candida is restricted to cold temporary freshwater waters (Tab. 2 – 3). But *C. xizangensis* is more adapted to fresh and brackish waters. The genus *Candona* is fresh water ostracods. Therefore, their occurrence in sediment may suggest freshwater incursion induced by increasing precipitation (strengthening of monsoon).

Ostracod-palaeo-salinity indicators

Faunal succession (preserved taxa and individual abundance), are useful for reconstruction of different aquatic environments (local- past aquatic habitats) through time (De Deckker and Forester, 1988a; Cronin, 2009; Rafferty, 2011).

The Late – Quaternary ostracod associations (composition and abundance) suggest a variation in lake-water volume (level), ionic compositions (salinity) and lake productivity through time. The ostracod associations can co – exist in the mesohaline of lake Tangra Yumco. However, lake water-salinity (conductivity) influences the dominance of particular species. Hammer (1986) observed negative correlation between species richness and salinity. Therefore, salinity is assumed to be an important determinant of the fauna of saline lakes (De Deckker, 1981a; Carbonel et al., 1988; Williams et al., 1990; Herbst, 2001). Salinity affects the species richness and diversity of saline lake fauna. Each species has a physiological adaptation to a specified salinity (De Deckker and Geddes, 1980). The relative abundance of species (diversity) decreases as salinity increases but the number of species (richness) that can co-exist in a given lake may not (De Deckker and Geddes, 1980).The water ionic composition determines the abundances of individual fauna. The ostracod faunal successions (maximum abundance within a specific salinity range) illustrate five major fluctuations in salinity regimes (Fig. 9; Tab. 2).

Conductivity (salinity) is the primary environmental factor that influences the distribution and abundance of living ostracods in Tangra Yumco and its adjacent waters (Akita et al., in press). Salinity defines distribution and abundance of saline fauna (De Deckker, 1981a; Carbonel, 1988; De Deckker and Forester, 1988a; Mischke, 2012).

Increasing salinity is associated with enhance evaporation (decreasing precipitation and low lake level). The ostracod faunal successions characterised **palaeosalinity** fluctuations in Tangra Yumco (Fig. 7 – 9; Tab. 2): Stage I – Highest lake level, β-oligohaline conditions, *L. sinensis*, a euryhaline species, dominates; Stage II – more or less stable lake level with slight increase in salinity (β-oligohaline to β-mesohaline condition), *L. dorsotuberosa* dominates, typical fresh to brackish fauna; Stage III – decreasing lake level with moderate salinity (β-oligohaline) and low ostracod abundance; Stage IV – falling lake level with highest salinity (α-mesohaline), *L. inopinata*, a more salt tolerant species dominates; and Stage V – rising lake level with steadily decreasing salinity (α-oligohaline – β-mesohaline) and *L. sinensis* prevalence.

5.5.8 Palaeoenvironmental inferences

The use of multiple proxies within a single lake system is a better approach for reconstruction of environmental and climate history than relying on one proxy alone (Battarbee, 2000). The two proxies, sediment properties (grain size, K, TOC, TOC/TN, TIC) and ostracods (composition of association, abundance, shell chemistry, adult/juvenile rand carapace ratios) indicate fluctuations in lake level, salinity and productivity for the past 3,300 years (Fig. 9 – 11). A reconstruction of the past environment and climate are as follows:

Stage I, 3300 – 2320 cal BP

Freshwater to slightly brackish conditions (fresh water with α to β-oligohaline, Tab. 2-4) prevailed. The highest lake level with lowest salinity in this stage. The lake productivity was moderate with three ostracods present. At this stage, Tangra Yumco overflows (increasing precipitation, cool and wet climate) intoTanqung Co.

Lake-level fluctuation (especially for close basins) is related to regional moisture history (Haberzettl et al., 2005; Sun et al., 2009; Thomas et al., 2009; Long et al., 2010). The strengthening of the monsoon (Indian Monsoon) is linked to increased summer precipitation and subsequent changes in aquatic ecosystems (Fang et al., 2001; Günther et al., 2015). High precipitation means high freshwater flux into the lake system

Lake-water levels rise in the past 3,000 years due to increased summer precipitation (Long et al., 2012). This further enhanced the transport of terrestrial and minerogenic material into the lake. High minerogenic fluvial (high Fe/Mn$_{shell}$) input will lead to increased total inorganic carbon with moderate production (moderate species richness, three species found in this zone). Species richness correlated with variability salinity (high, moderate and low) (Tab. 4).

An abrupt rise in lake-water-level is indicated by increased proportions of ubiquitous and euryhaline fauna, *L. sinensis*, and lower proportions of salt tolerant species, *L. dorsotuberosa* and *L. inopinata* (Fig. 6).

High lake-water level corresponds to lowest salinity indicated by low δ^{18}O of *L.sinensis*. High δ^{13}C values suggest falling temperature with moderate primary production. Low Mg/Ca ratios of *L. sinensis* due to vital effects in the incorporation of Mg ions (Marco-Barba et al., 2013a; Marco-Barba et al., 2013b). Moderate productivity is associated with high/adult and carapce/ratio of *L. sinensis*.

Low Sr/Ca shells suggest a fluctuating salinity. The key climatic parameter precipitation (absence and absence will deter the hydroogical variation) (Ivanov et al., 2007; Chavez-Jimenez et al., 2013). Hydrological variation influence water volume in aquatic ecosystems. This indicates a stable lake conditions with stable outflow and allochthonous terrestrial input. In this period, Tangra Yumco is open lake system, which outflows into Tanqqung Co.

The adult/juvenile ratio of Ostracoda indicates a decreasing trend reflecting decreasing water turbulence (Boomer, 2002; Boomer et al., 2003)The mean grain size and ostracod abundance indicate a rising lake level (Fig. 10). Furthermore, K as an element indicating terrestrial input (Kasper et al., 2013) and our conductivity reconstruction are almost constant for this stage (Fig. 11) as envisaged in stable inflow/evaporation balance. For the last about 700 years of Stage I, $\delta^{18}O$ of ostracod shells increases slightly (Fig. 11). However other proxies are not indicating a shrinking lake, hence we interpret the isotope signal as caused by very slow enrichment over time or a not significant decline of the lake level.

The diversity of Ostracoda decreases (Fig. 11) suggests minimum water turbulence in the shallow waterflow diminishing the reworking and export of valves transported to the central lake basin where core TAN10/4 is located. Alternatively, a change in bottom current circulation could explain this pattern. Productivity-related proxies as ostracod abundance and $\delta^{13}C$ of ostracod shells (Fig. 12) reflect relatively constant conditions. The high values of abundance and $\delta^{13}C$ indicate higher intra-lake productivity than in the other stages of the core. The concave form of TOC and and TOC/TN curves could be caused by relatively higher plankton productivity and subsequent microbial destruction in the middle of this stage. Compared to the following stages the lake level of Tangra Yumco was the highest in Stage I and productivity was relatively high.

Stage II, 2300 – 1760 cal BP

High TOC (high organic matter) indicates high productivity. Increase food availability means high ostracod productivity (highest species richness, six species in this zone). High ostracod abundance reflecting a stable hydrological condition and gradual increase in lake productivity. High TOC suggests increase terrestrial organic debri from dense vegetation in a warm climate (Zhu et al., 2002b; Kasper et al., 2015).

β-oligohaline – β-mesohaline condition (Tab. 2). There is a gradual increase in salinity with change increase ostracod associations. A change dominance of *L. sinensis* (sharp decline in relative abundance to *L.? dorsotuberosa*, fresh to brackish fauna, predominant (Fig. 6). Maximum abundance of *L.? dorsotuberosa* implies deep lake with moderate salinity (Tab. 4). Ostracod assemblages with deep-water affinitiy (*F.gyirongensis* and *C. xizangensis*) were frequent at stage (Wrozyna et al., 2009b; Frenzel et al., 2010; Akita et al., in press). At this stage the lake is an open lake separate from Tanqung Co.

The highest productivity indicates favourable environmental conditions. Lake productivity depends on environmental factors (e.g., nutrients, organic carbon and oxygen) (Wetzel, 1983, 2001). The cascade hypothesis states that abiotic factors (e.g., mixing of water and nutrient supply) promotes potential productivity (Carpenter et al., 1985; Bronmark and Weisner, 1996; Ellis et al., 2011). In contrast, actual productivity influences the food web structure, which depends on the strength of interspecific interactions (Paine, 1980).

Ostracoda productivity is influences by multiple physico-chemical parameters such as warm temperature, stable sediments and plentiful clastic organic food (Carbonel et al., 1988).

Stage III, 1750 – 1100 cal BP

Change in environment and climate implies change in lake structure and function. Any change in the lake function will affect the biological organism. For instance, low temperature and dry climate is accompanied by low productivity of lake systems. Low productivity means minimal availability of food for both plankton and benthic fauna within the lake system.

A dry climate may also favour intensive weathering and soil erosion hence high total organic carbon (TIC). High TIC suggests low organic matter, low productivity and hence low ostracod productivity. Low abundance of ostracods suggests limitation in oxygen levels within the lake water column under extreme environmental stress.

The scarcity of ostracod (very small populations) due to environmental stress (e.g., low productivity and low organic matter). A stratified lake with thermohaline layer could cause oxygen difficiency. Low ostracod (relative abundance, diversity) is an indicator of poor nutrient supply and low productivity of lake. Ostracoda productivity is affected by both biotic and abiotic factors (Griffiths and Holmes, 2000). Under extreme unstable environmental condition, there is competition for the limited food resources.

Stage IV, 1065 – 440 cal BP

High grain size (coarser sediments) occurs at the onset of the Little Ice Age, reflecting high monsoon rainfall (Wang et al., 2012b). Highest sediment grain size is linked to low lake water-level, due to increased transport of terrestrial materials into the lakes (Dietze et al., 2013; Dietze et al., 2014; Mischke et al., 2015). The high fluvial input may cause the transports of freshwater ostracod assemblages (e.g., *C. Candida*) into the mesohaline deep lake.

A wet climate (~ 1500 cal BP and 1150 cal BP) with gradual increase in lake level in Nam Co, southern Tibetan Plateau (Kasper et al., 2013). The Asian climatic periods;1500, 1000 and 500 years is linked to wet and cold (Kravchinsky et al., 2013). Although, there is a steady weakening of the Asia summer monsoon between 3700 cal years BP and 1500 years BP in India and China due to decrease summer insolation (Overpeck et al., 1996; Selvaraj et al., 2007; Liu et al., 2009).

The last interglacial is linked to 1000–1500 yr as a cold, dry period (deMenocal et al., 2000; Bond et al., 2001; Gupta et al., 2003).

The lake-water salinity increased gradually to a maximum (β-mesohaline range) (Tab.2 and 4). Ostracod associations (common lacustrine brackish fauna) gradually recovers and colonise the sediments. The maximum proportions of *L. inopinata* around at 250 cal BP is a reflection of highest salinity conditions. The ostracod assemblage *Limnocythere inopinata* is adaptable to high salinities (Yin and Martens, 1997; Meisch, 2000b). High The dominance of *L. inopinata,* and associated low proportions of *L. sinensis* and *L. dorsotuberosa*, is an indicative of more saline conditions (Ito, personal communication). In a more salineshallow lagoon waters, *L. inopinata* is the sole dominant ostracod (Akita et al., in press). The presence of *L. inopinata* suggest shallow lake conditions. The lake-water salinity varied from β-mesohaline to oligohaline, with a declining salinity (oligohaline) at 90 years.

The decrease salinity is associated with decreasing $\delta^{18}O$ and Mg/Ca values of *L. inopinata*.The $\delta^{18}O$ composition of lacustrine carbonate calcite is useful for reconstruction of palaeohydrological conditions (Clark and Fritz, 1997). In lacustrine system, the $\delta^{18}O_{shell}$ is used as evaluation of water balances, evaporation of lake water causes ^{18}O enrichments in the calicitic bivalve shell (Clark and Fritz, 1997). The low values of $\delta^{18}O$ and Mg/Ca values of *L. inopinata* is intepreted as increasing lake, which facilitated decreasing salinity with reduced evaporation.

The slightly lower abundance and slightly higher adult/juvenile ratio compared to the preding zone indicatea slighty drop of the lake level. Higher $\delta^{18}O$ and Mg/Ca values reflects increase salinity due to high evaporation. Temperature is key climate parameter that control fractionation of salinity (optimum tolerance) in genus *Limnocythere (Curry, 2003). Limnocythere inopinata* is a maker of higher salinity (Akita et al., in press). Maximum proportion of *L. inopinata* occurs with increase water salinity. Little Ice Age in this period (650 - 500 cal BP).

Stages V, 410 cal BP to present:

Indian summer monsoon activitiy has increased over the past 350 years on the southern Tibetan Plateau. Increase monsoon rainfall (high precipitation) means increase riverine flows and transport of terrestrial plant material (carbonate weathering, soil respiration) into reducing primary production (hence low carbon production). Moderate productivity is linked to moderate ostracod productivity. Although, low K and low TOC are observed, ostracod productivity was relatively high (five ostracod assemblage present in this zone). The variabilibity of salinity (oligo to beta-mesohaline) was favourable for surviving of benthic lacustrine-brackish ostracod species. High ostracod productivity occurs in oligo-beta-mesohaline conditions. The increase in monsoon rainfall is due to global warming (Bräuning and Mantwill, 2004). The last ~ 250 years BP is marked by intensive solar radiation in Asia continent (Kravchinsky et al., 2013). The high solar radiation is linked to rising lake level (Frenzel et al., 2010; Kasper et al., 2012; Kasper et al., 2013). In the West Antarctic, global warming within the past 300 years is linked with extreme melting of glaciers and sea level rise (Gomez, 2015). This may facilate increasing lake-water level due to a ocean-land effect (global atmospheric circulation).

The ostracod assemblage displays a further drop in salinity as reflected by decreasing *L. inopinata* relative abundance. The salinity of the oligo-mesohaline range is estimated for the this stage (Tab. 2 and 4). A change of *L. inopinata* dominant to *L. sinensis* in this stage due to variable salinity (moderate saline). *Leucocythere sinensis* regains dominance. *Leucocythere sinensis* suggest increasing freshwater into to a mesohaline lake. The Little Ice Age episodes in 300 - 100 cal BP.

Low adult/juvenile ratio of *L. sinensis* suggest reworking of sediment (allochthonous association) (Akita et al., 2015). The decreasing adult/juvenile ratio is probably caused by a rising lake level (in the last 250 – 150 cal BP). Rising lake-level implies increase transport of juveniles of *L. sinensis* from shallow waters into deeper lake basin (Akita et al., 2015).

5.5.9 Lake-level evaluation – Principal Components Analysis

The first PCI, representing 38.3% of variance, indicates a falling lake level. This corresponds with the major enviromental parameters: salinity, TOC, grain size and δ^{13}O. Minor effects are ostracod abundance, TOC/TN and K (Fig. 13a). The second axis (18.7%) represents reduced water turbulence expressed by proportion of adult ostracods, TIC and Fe/Mn of ostracod shells (Fig. 13a). The PCA confirms the five stages characterised by ostracod and sedimentological data during the last 3,300 years (Fig. 13b). PCA axis one reflects the overall trend of a falling lake level over the first four stages documented.

5.5.10 Lake evolution and palaeoclimatic implications

The Holocene climate of the southern Tibetan Plateau is dominated by the South Asian Monsoon in summer and westerly cyclonic activitiy in winter. The strength of the monsoon is determined by a number of forcing mechanism operating over a variety of scales (Thompson et al., 2000). Strengthening of the monsoon (local rainfall) involves lake level rising and decreasing salinity in hydrologically closed basins. A drier climate causes falling lake level (decreasing monsoon impact).

The Late Holocene ostracod associations of sediment core TAN10/4 reveal the transitions between different water bodies prevailing during the Holocene monsoon climate. Decreasing precipitation will enhanced increase evaporation. Reduce precipitation implies insufficient runoff, are the most probable drivers of these aquatic ecosystem changes. However, changes in the catchment (vegetation, sediment transport, weathering) could cause significant change (shift) in lake dynamics (function and structure).

Stage I: Freshwater to slightly brackish conditions (freshwater-oligohaline; Tab. 2-4) prevailed. The highest lake level with lowest salinity occurred in this stage. The rising lake suggest increasing strengthen of India Summer Monsoon rainfall. Increasing precipation and will lead to high rate of river incursion in cool and wet climate. At this stage, Tangra Yumco overflows into Tanqung Co as an open ancient large lake (Fig. 14). The salinity of Tangra Yumco is much lower, despite the lake level was much lower (shrinking in lake size) than in the early Holocene (Ahlborn et al., 2015b).

Stage II: A gradual falling of lake level with gradual rise salinity (β-oligohaline to β-mesohaline water). This indicates steady decrease in precipitation within a warm and dry climate. Tangra Yumco begins to separate from Tangqung Co.

Stage III: A further falling in lake level with lower salinity (β-oligohaline water) in dry climate. This suggests weakening of monsoon (less precipitation, gradual evaporation). At the stage, Tangra Yumco is gradually becoming a closed lake.

Stage IV: The lowest lake level with highest salinity (α-mesohaline water), indicating a extremely weak monsoon (less precipitation, higher evaporation) in a cold and very dry climate. Tangra Yumco is now a closed lake.

Stage V. Rising lake level with variable salinity (α-oligohaline – β-mesohaline water) implies a sudden enhancing of moonson rainfall (relatively high precipitation, stable evaporation) in a cool and wet climate.

5.6 Conclusions

"**Study the past if you would define the future**" ~Confucius

The ecology of the past is hidden in biological proxies within sedimentary archives (Birks, 2003; Birks et al., 2010). Lake sediments and their benthic fauna (e.g., ostracods) provides senstive records of enivironmental and climate history. Change in lake's physical and chemical parameters causes change in ostracod assemblages. Lake productivity relates to ostracod productivity.

A total of six ostracods were documented: *Leucocytherella sinensis* (ubiquitous fauna), *Leucocythere*? *dorsotuberosa* (fresh-brackish water fauna), *Limnocythere inopinata* (fresh to mesohaline species), *Fabaeformiscandona gyirongensis* (brackish-lacustrine fauna), *Candona xizangensis* (phytal littoral brackish lake fauna) and

Candona candida (freshwater fauna). The past ecology and environment of the ostracod assemblages were inferred using ecology of Recent Ostracoda. Ostracods are valuable booligical proxies for palaeolimnological and palaeoenvironmental reconstruction.

The multi-proxies (biology, geochemistry and sedimentology) indicate lake level, salinity and productivity fluctuation during the past 3,300 years (Fig. 14, Tab. 4). We recognised **three** major **lake environment** and **climate history** are:

(a) A freshwater (limnetic) β-oligohaline water with euryhaline species *L. sinensis* predominant. This suggest the strengthen of India summer monsoon (increased precipitation, less evaporation) linked with the **highest lake level** and **lowest salinity** generated by relatively **cool and wet period** in 3300 – 2320 cal BP

(b) A β-oligohaline to β-mesohaline waters with increased abundance of fresh-brackish water toleratie ostracod fauna *L.? dorsotuberosa*. This indicated the weakening of monsoon (less precipitation, moderate evaporation) related to a lowering of lake level, and variable salinity in **warm and dry climate** dry in 1740 – 1100 cal BP. The highest productivity highest K, highest TOC, high TOC/TN) of the lake in this period is associated with high ostracod productivity (highest species richness and diversty).

(c) A α-mesohaline waters with a more salt tolerant water ostracod, *L. inopinata* dominant. This implies a weak monsoon (reduced precipitation, higher evaporation) related to lower lake level and the **highest salinity** under a **cold and dry climate** in 1070 – 440 cal BP (Little Ice Age in this period). A moderate l ake productivy (highest K, highest TOC, high TOC/TN) is linked with moderate species richness. The oxygen isotopes and Mg/Ca_{shell} of this species are relatively high in this period. However, low carbon isotopes, low Fe/Mn and low Sr/Ca composition in the shells of *L. inopinata*.

A saline lake interracts with climate. Change in climate (e.g. precitipation and temperature) will affect lake system and its components (e.g., biota, catchment processes and hydrology). The **strengthening of the moonsoon** causes increasing precipitation with **continous flowing of freshwater** and an **open lake** system, Tangra Yumco in 3300 – 2320 cal BP. However, decreasing precipitation with enhanced evaporation, changed the **open lake to a closed lake** system in 2300 – 1760 cal BP. In the Late Holocene, the **lowest lake level** is linked to the **weakening of the monsoon**, with minimum precipitation during the **Little Ice Age period** (650 – 100 cal BP). Nonetheless, the last 200 years is linked to higher freshwater input into the Tangra Yumco, a phenomena observed in other Tibetan lakes attributed to increasing precipitation last decades (Zhang et al., 2011). The sedimentology and Ostracoda (biological remains) are evidence of Late Holocene environmental and climatic signals in deep brackish lake, Tangra Yumco.

The decline of aquatic ecosystems due to global warming, will lead to loss of biodiversity. Any loss of lake ecosystem, will also result in loss of ecological and economic value and indirectly affect humankind (life is sustained by water). Long-term research on lake ecosystems is necessary for sustainable management, conservation of its biota and future alternation due to climate change.

A fully comprehensive understanding of different interactions (biological fossils, food webs, geomorphology, hydrology, catchment and biophysical-chemical processes) of a lake system is critical for more precise environmental reconstruction and future climate prediction. Instrumental records of climate (e.g., local precipitation and temperature), will support holistic palaeo-inferences. Climate modelling should incorporate ostracods as excellent biological proxies.

To increase our understanding of Quaternary climate variability in southern Tibetan Plateau, sediment cores covering early Holocene and Pleistocene from Tangra Yumco must be analysed. Evaluation of sediments cores from different of lake systems on the southern Tibetan Plateau, will provide a better understanding of spatial and temporal environmental and climate variability in the region.

The Tibetan saline lakes will continue to play a significant role as "natural laboratories" in the understanding of past, present and future lake-climate dynamics and ecosystem changes under anthropogenic-induced climate.

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Figures

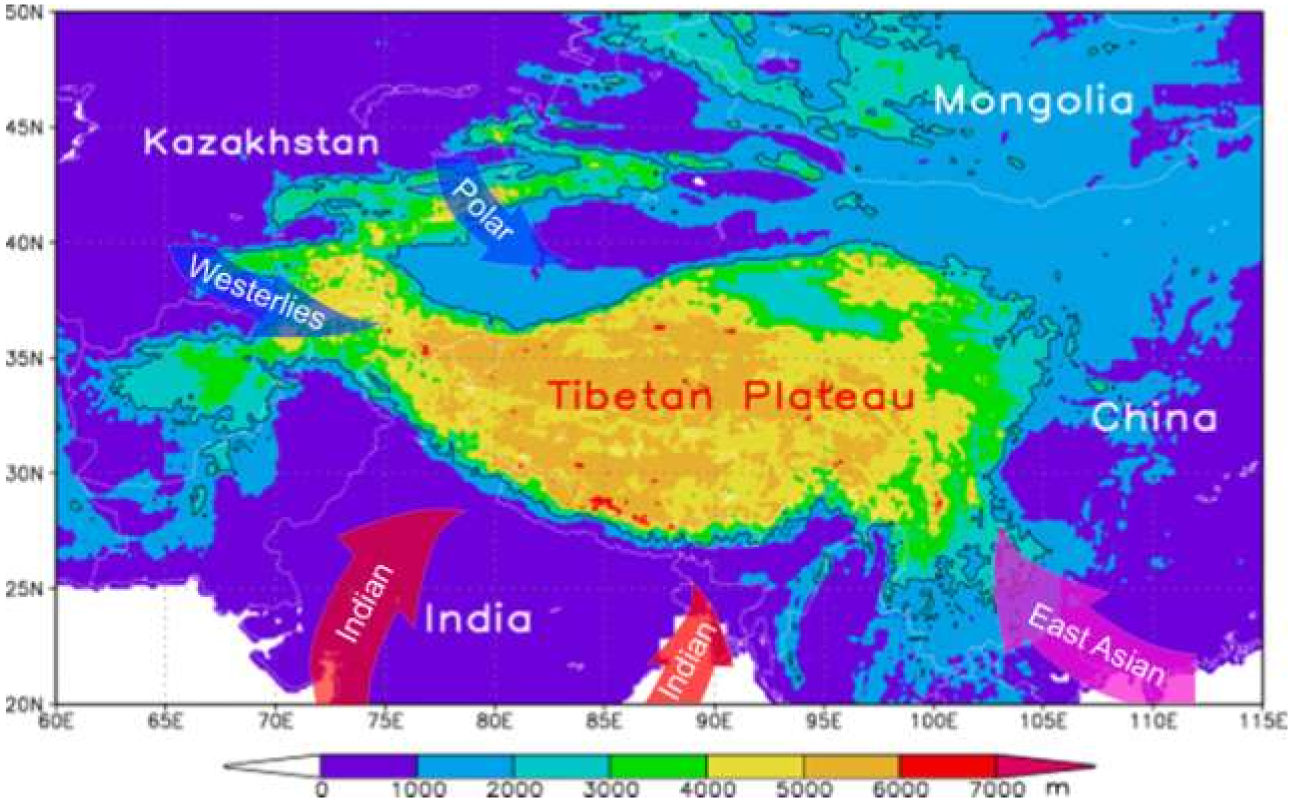

Fig. 1 Map of Tibetan Plateau and four major climate systems (polar air masses, westerly winds, Indian and East Asian Summer monsoons). The scale illustrates the altitude above sea level. Modified (Liu et al 2009).

Fig. 2 Map of Tangra Yumco on the southern Tibetan Plateau. http://earthexplorer.usgs.gov/

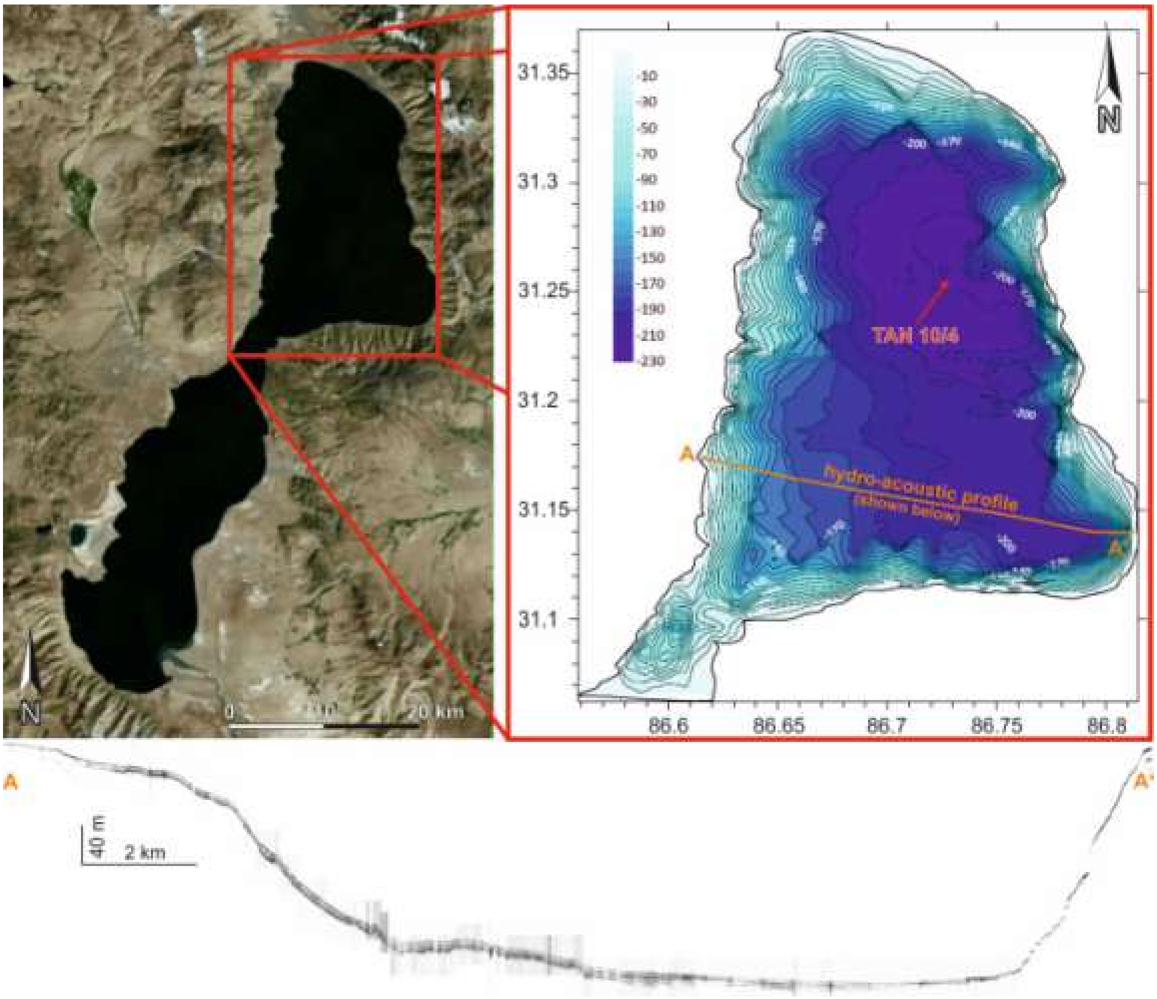

Fig. 3 Bathymetry map of Tangra Yumco and sediment core TAN10/4.

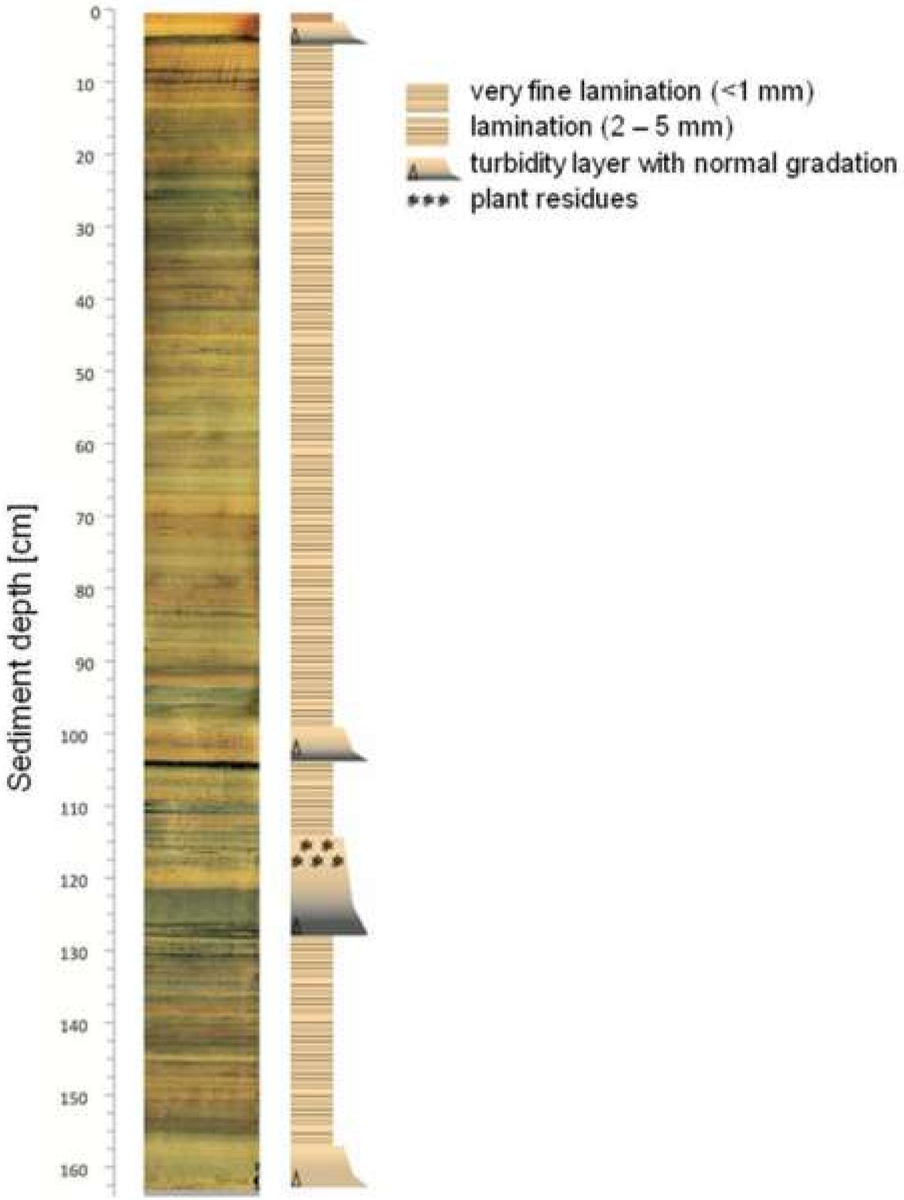

Fig. 4 Lithology and colour as a function of depth in sediment core TAN10/4. Left – photography of sediment core. Right – generalized lithology with indication of four turbidites and a debris flow.

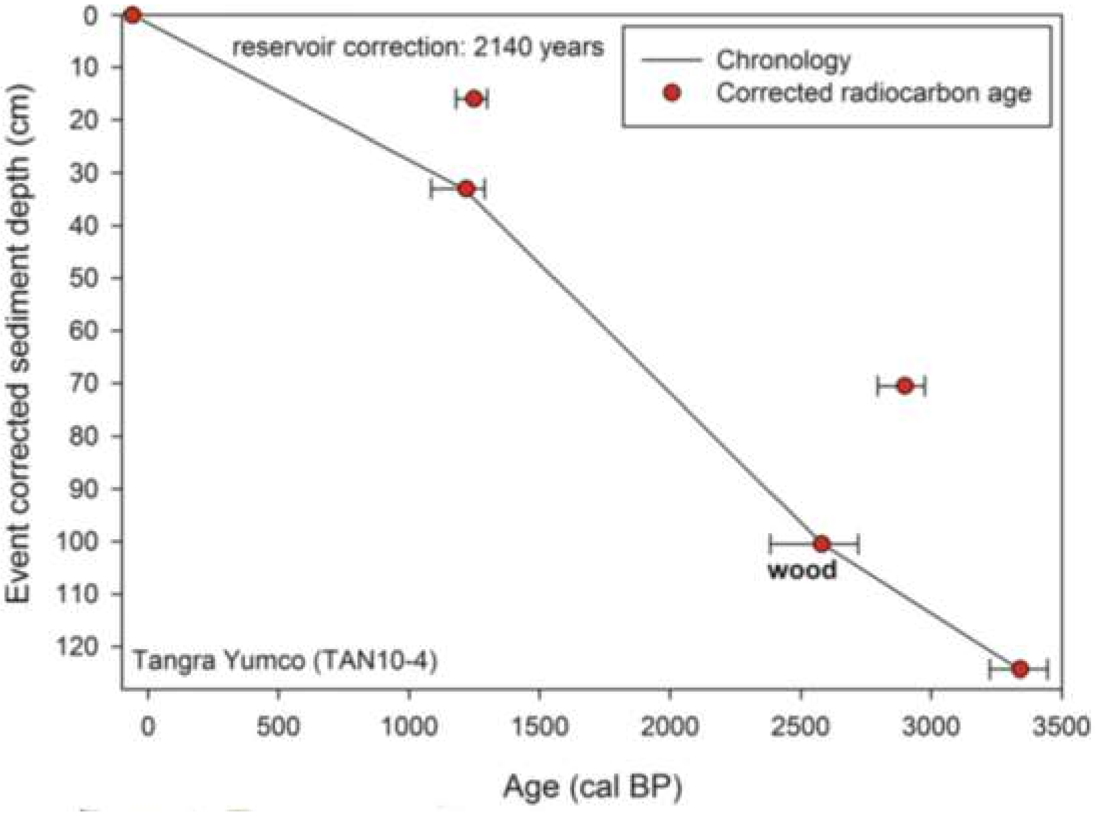

Fig. 5 Corrected sediment depth verse radiocarbon age (cal B.P) for sediment core TAN 10/4. Sediment ages were calculated from a linear interpolation between adjacent calibrated ^{14}C ages.

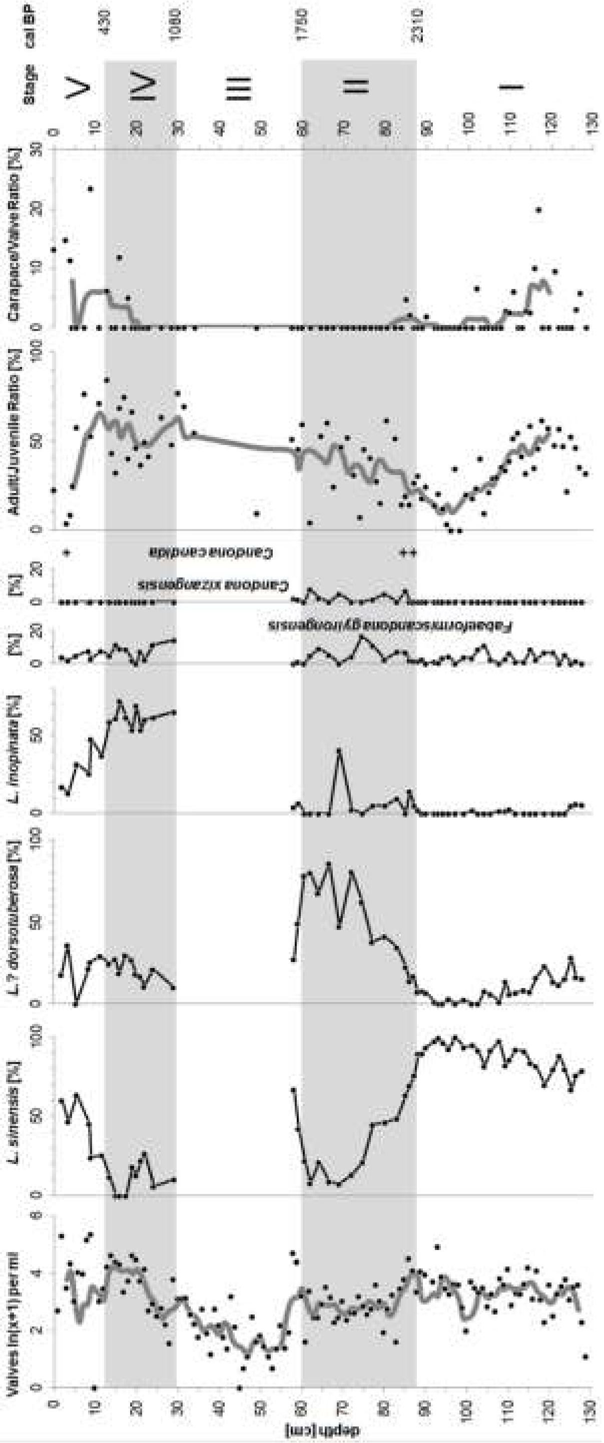

Fig. 6 Distribution of Ostracoda in sediment core (TAN10/4) from Tangra Yumco. Relative abundance varies with depth. The dominant fauna characterised a given depth. **Five lacustrine fauna** (*Leucocytherella sinensis*, *Leucocythere*? *dorsotuberosa*, *Limnocythere inopinata Fabaeformiscandona gyirongensis*, *Candona xizangensis*) and **one freshwater species** (*Candona candida*) typical for smaller water bodies. Adult to juvenile and carapace to valve ratios of *Leucocytherella sinensis*, most frequent ostracod

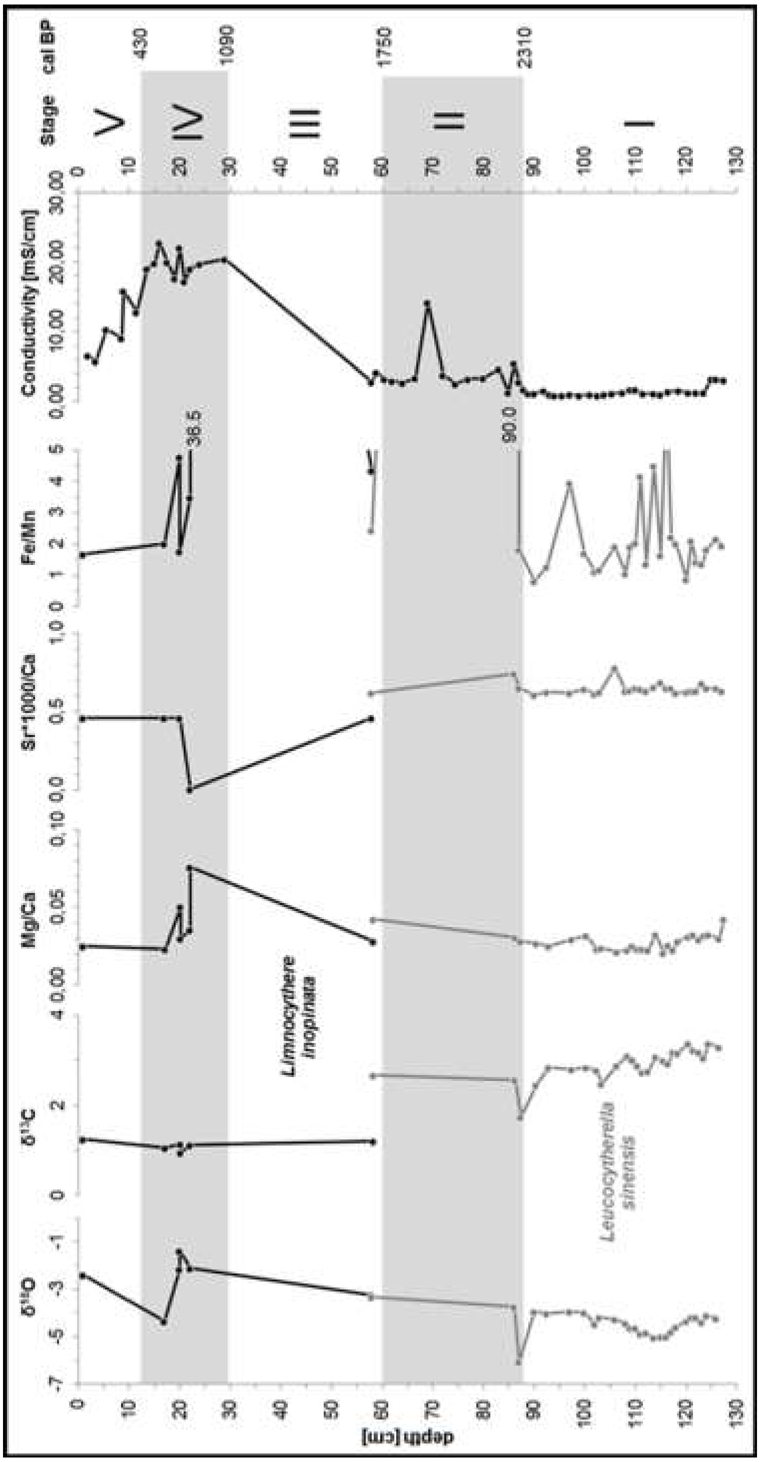

Fig. 7 Change in shell isotopes ($\delta^{18}O$ and $\delta^{13}C$, ‰ VPDB) and trace element composition (Mg/Ca Sr/Ca and Fe/Mn, molar ratios) of two ostracod species, *Leucocytherella sinensis* (lower part of the core) and *Limnocythere inopinata* (upper part of the core). Ostracod-based conductivity [mS/cm] is estimated for palaeo-water ionic conditions (the past 3300 years) in Tangra Yumco.

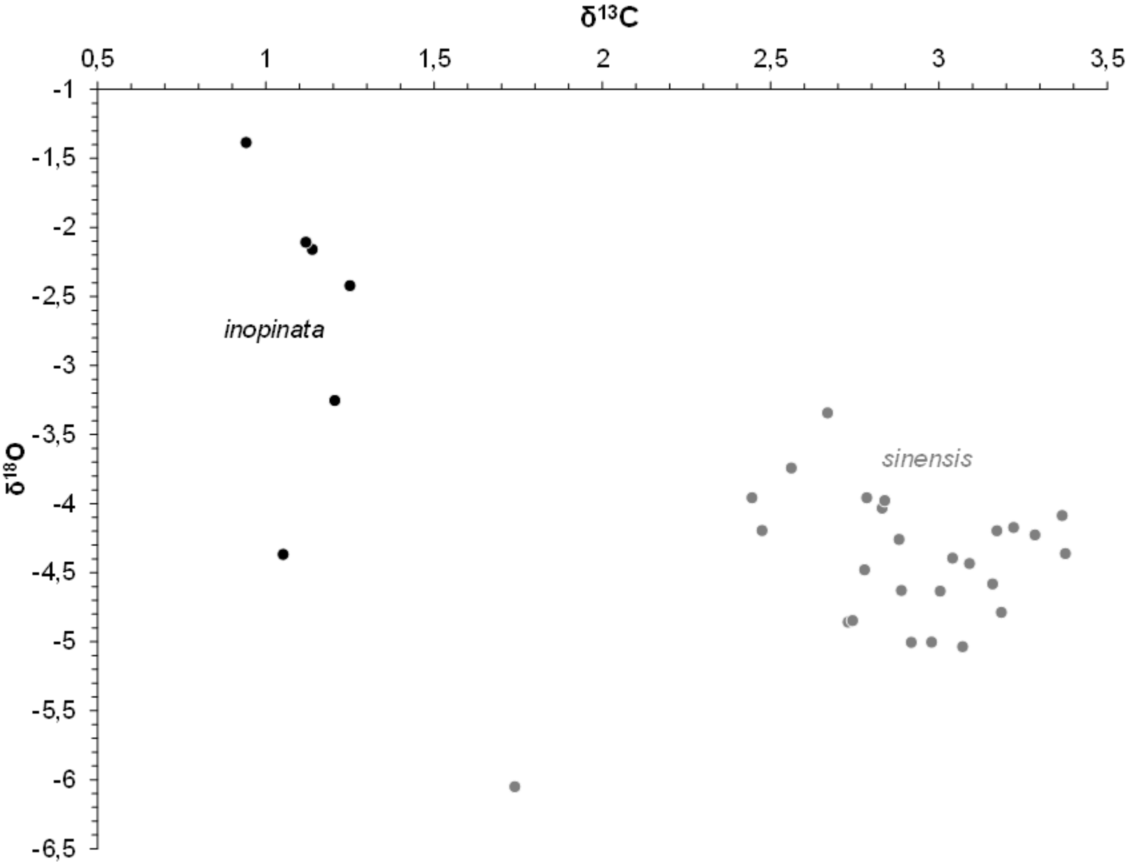

Fig. 8 Isotopic crossplot of $\delta^{18}O$ versus $\delta^{13}C$ values (‰VPDB) for two ostracod species, *Limnocythere inopinata* (top left, black circles) and *Leucocytherella sinensis* (bottom right, grey circles). There is a distinct difference in the isotopic composition of the two ostracod species: higher $\delta^{18}O$ and lower $\delta^{13}C$ for *L. inopinata*, but lower $\delta^{18}O$ with higher $\delta^{13}C$ for *L. sinensis*.

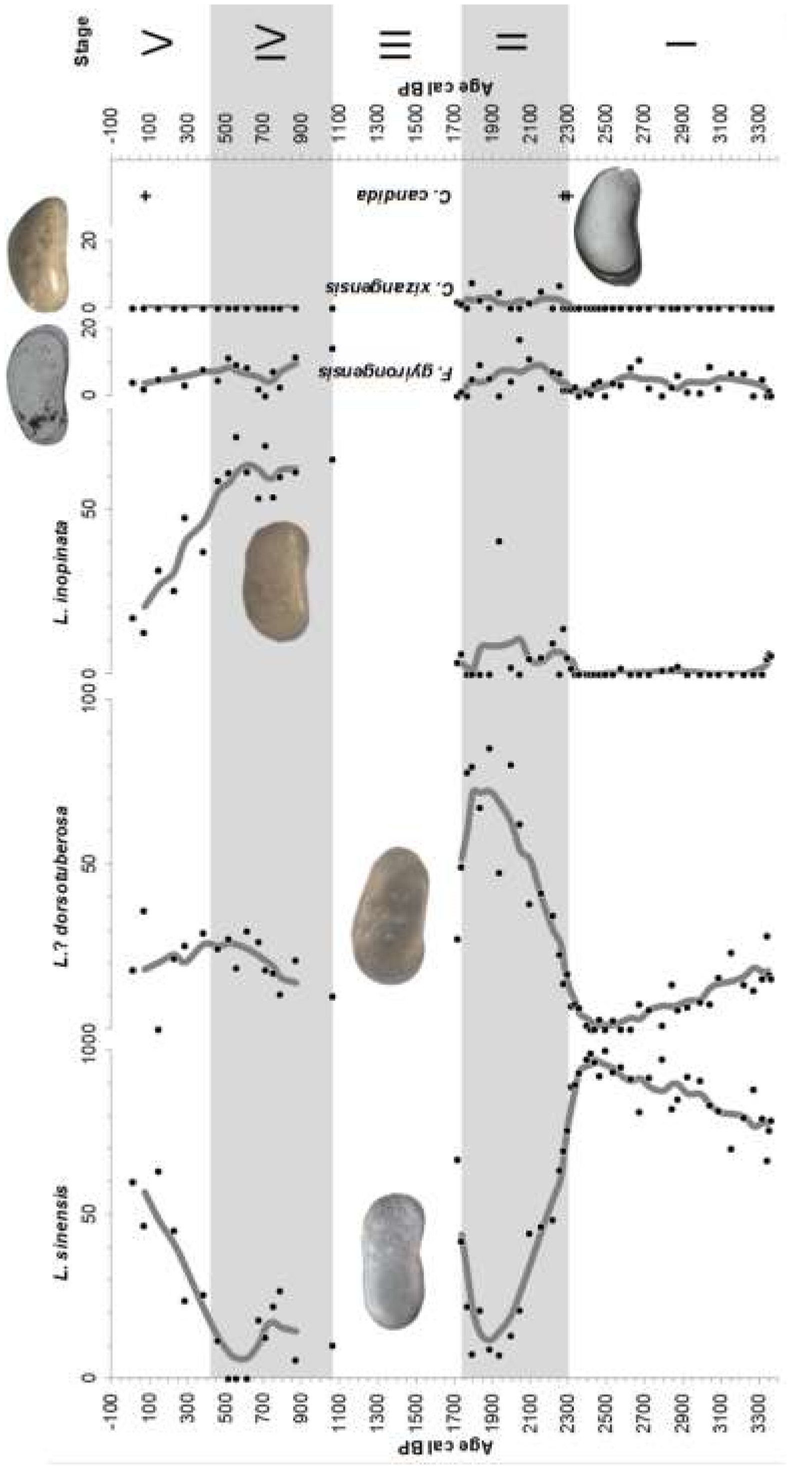

Fig. 9 Variation in relative abundance [%] of ostracod species in core TAN10/4. The salinity tolerances for the six ostracod species are euryhaline for *Leucocytherella sinensis*; fresh to brackish water for *Leucocythere*? *dorsotuberosa*; mesohaline to polyhaline for *Limnocythere inopinata*; freshwater to mesohaline for *Fabaeformiscandona gyirongensis*; freshwater to mesohaline for *Candona xizangensis* and freshwater to oligohaline for *Candona candida*. Grey curves represent three point moving averages of the plotted data points. Ostracod photographs are not scaled

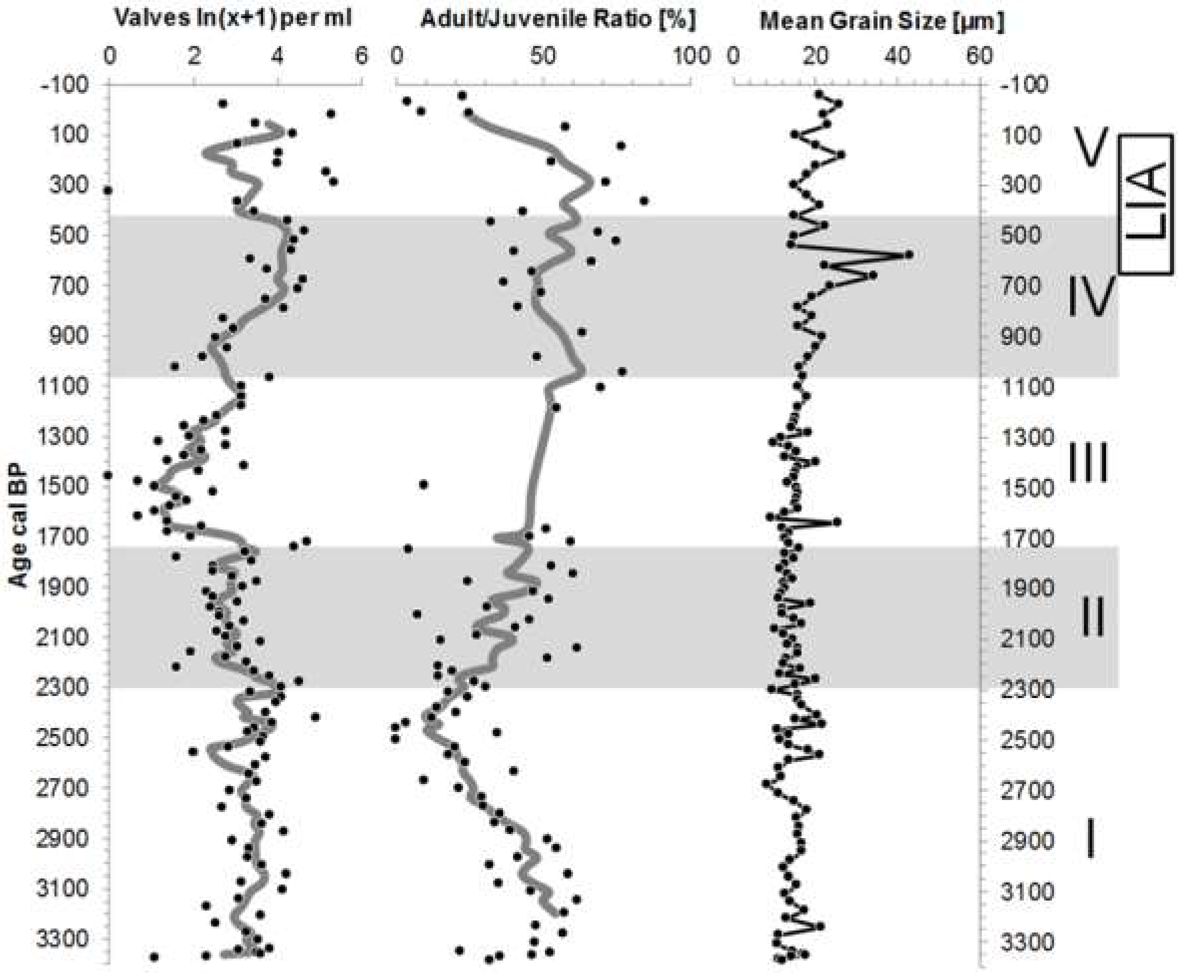

Fig. 10 Proxies related to water depth and turbulence: Ostracod abundance, adult to juvenile ratio of *L. sinensis* and mean sediment grain size. LIA = time frame of the Little Ice Age. Grey curves = mean values of three data points. Grain size data from Ahlborn (2015).

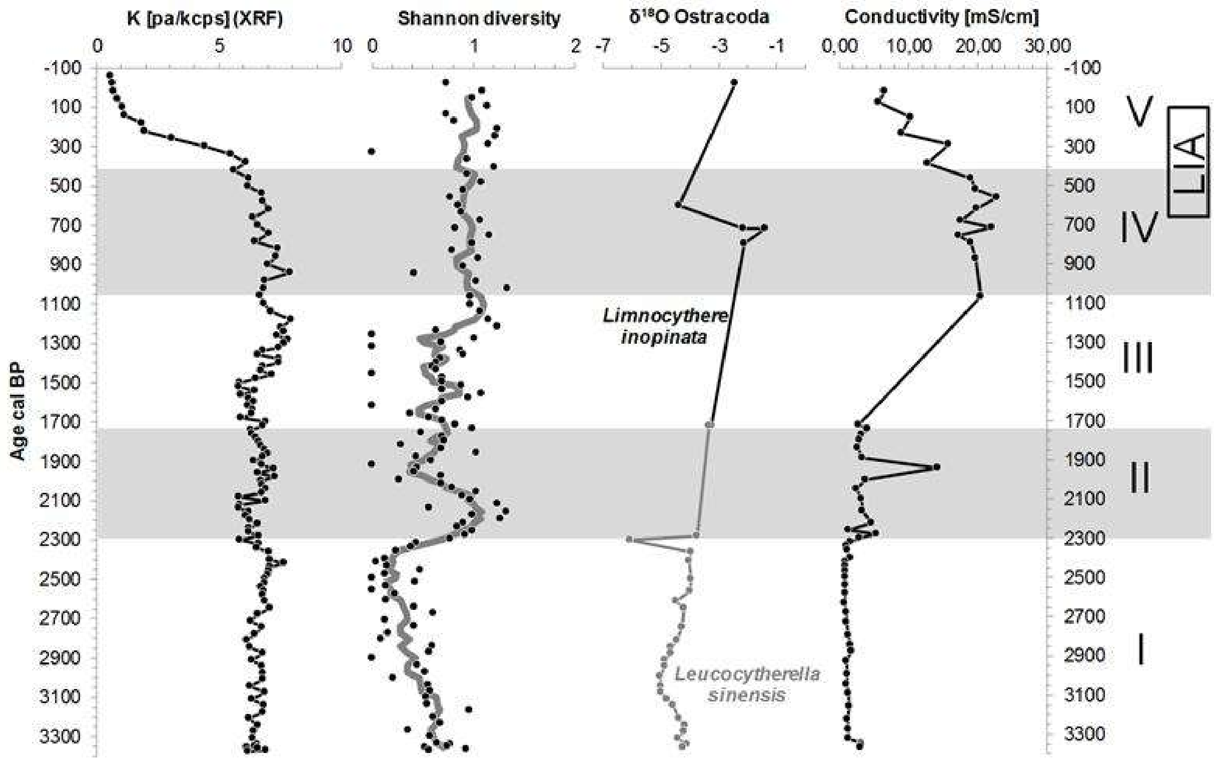

Fig.11 A diagram of palaeo-water turbulence; total ostracod association, adult and juvenile ratio of *L. sinensis* and mean sediment grain size. LIA = Little Ice Age. Grey curves = mean value of three data points.

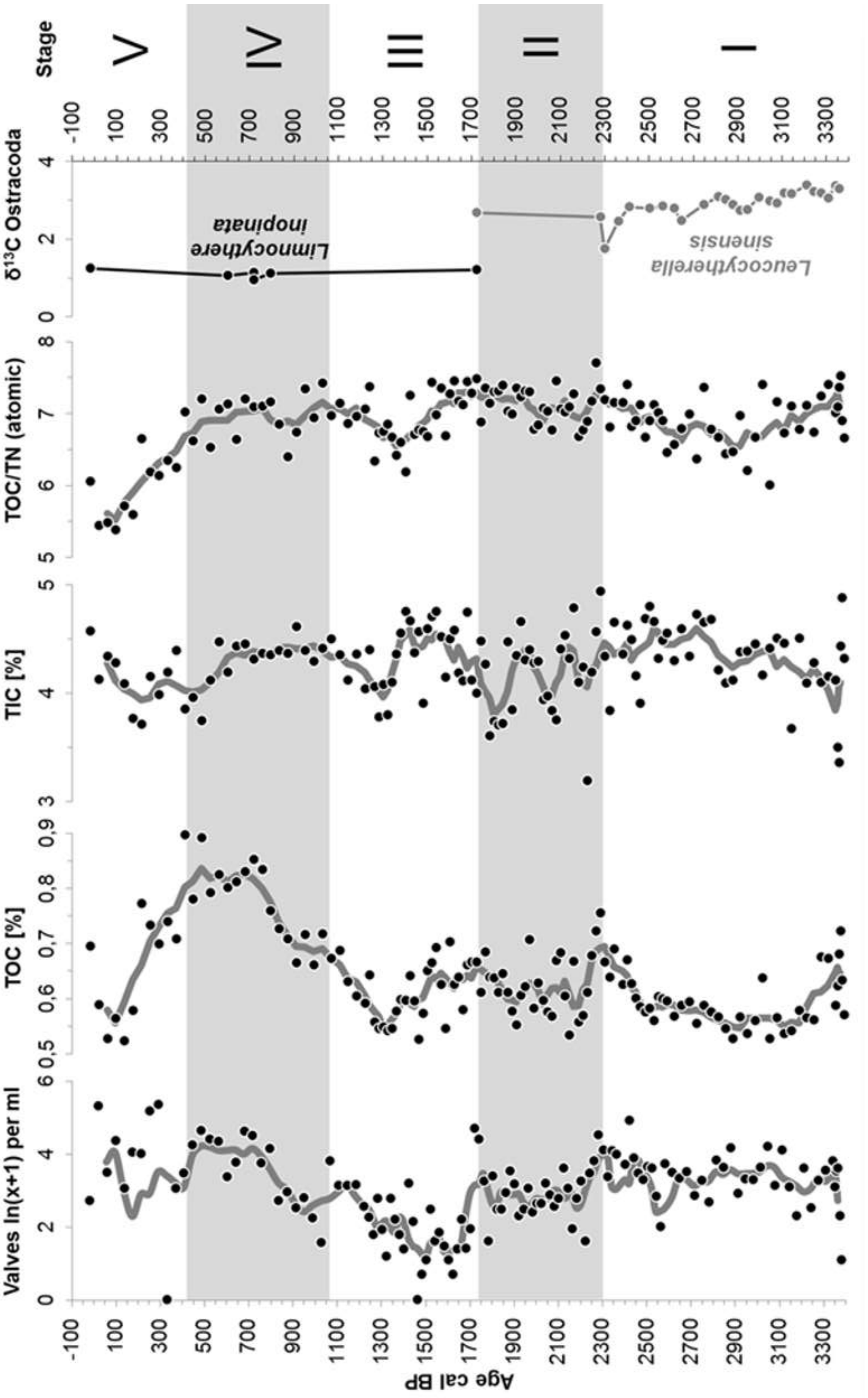

Fig. 12 Bioproductivity proxies (total ostracod assemblages, total organic carbon, total inorganic carbon, total organic carbon and total nitrogen. Grey curves = mean values of three data points. Carbon and nitrogen data from Ahlborn et al 2015.

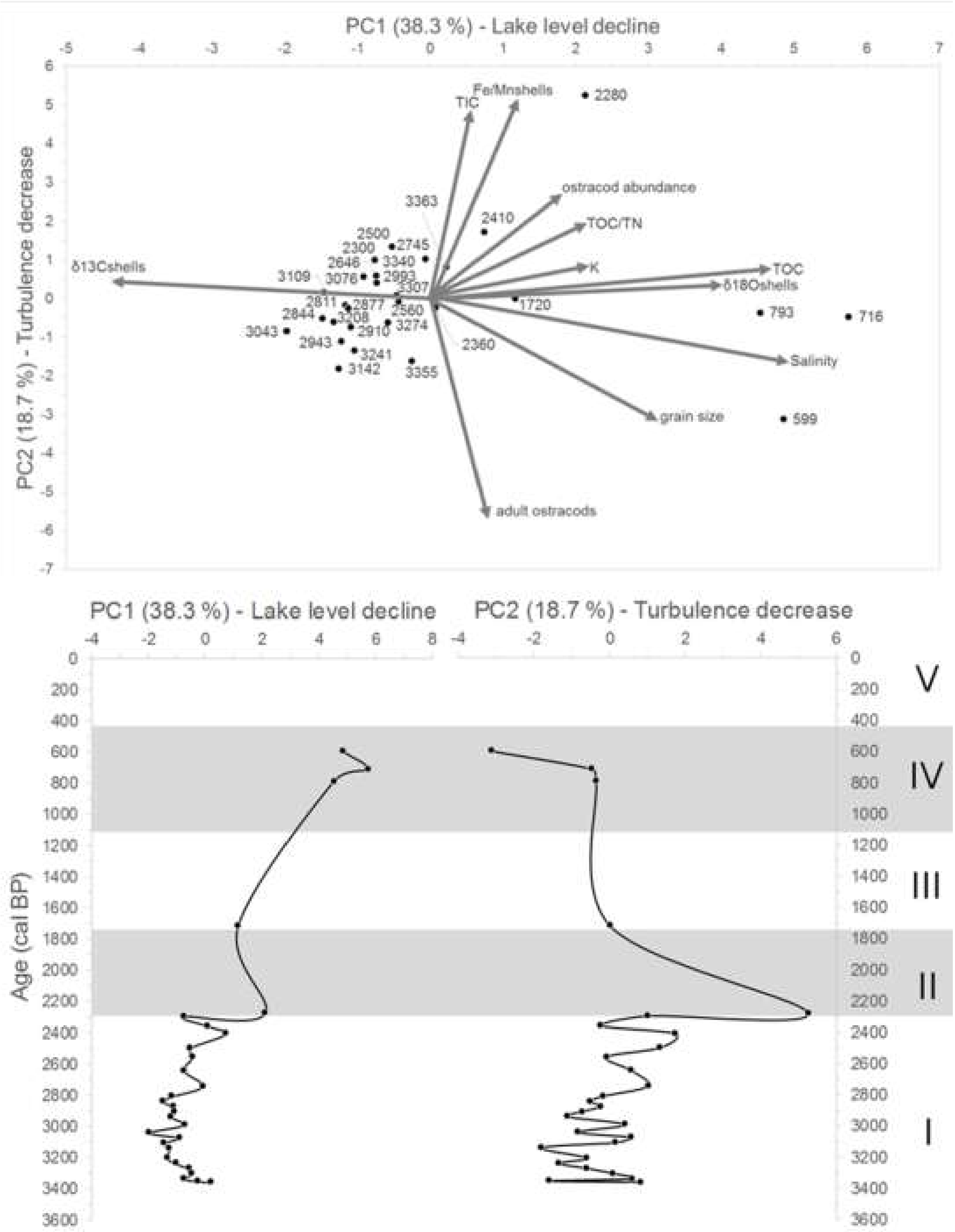

Fig.13 Principal Component Analysis (PCA) of normalised ostracod and sedimentological data (a: upper diagram) and loadings on the first two axes over core TAN10/4 (b: lower diagram).

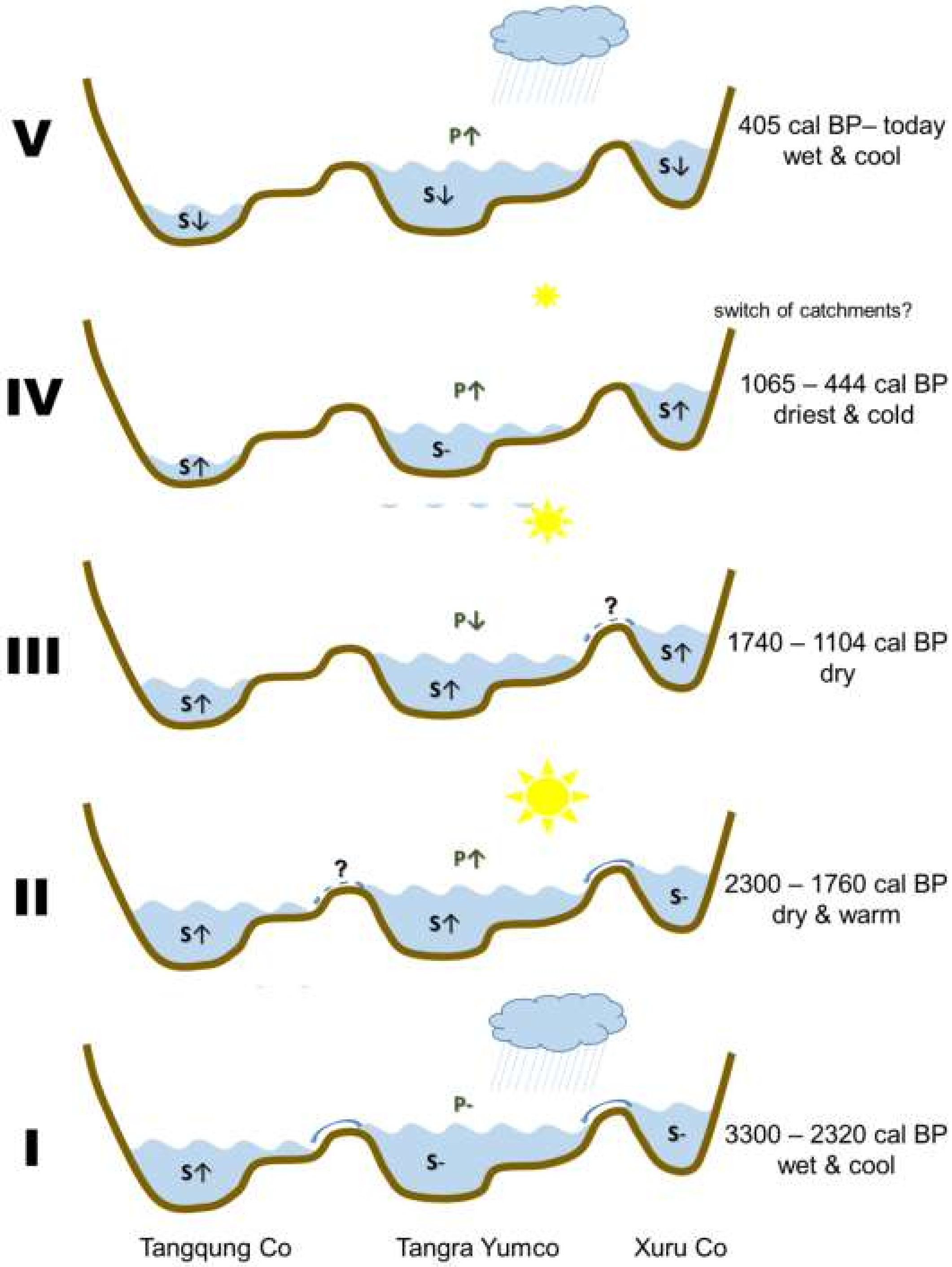

Fig. 14 Lake-water level evolution of Tangra Yumco. It is an ancient large lake, which separate from Tangraqung Co and Xuru C. Lake-water level fluctuation is an indicator of monsoon climate variability in time. S = Salinity, P = precipitation.

Tables

Table 1 Radiometric data for sediment core TAN10/4. Calibration was performed using CALIB 7.0 (Stuiver and Reimer, 1993).
*Year of coring; **age used for reservoir correction; ***no reservoir correction; ****values in italics are not used for chronology.
(Haberzettle et al. 2015).

Sediment depth [cm] / event corrected depth [cm]	Conventional radiocarbon age (BP)	Error	Reservoir corrected radiocarbon age (BP)	Reservoir corrected median age (cal BP)	Reservoir corrected max age (cal BP)	Reservoir corrected min age (cal BP)	Laboratory sample number	Material
modern water plant	2070	40	na	na	na	na	289 070	modern water plant
surface	2140	30		-60*	-60*	-60*	295 002	bulk**
24.0 / 16.0	*3450*	*40*	*1310*	*1250*	*1300*	*1180*	*295 003*	*bulk*****
41.0 / 33.0	3410	40	1270	1220	1290	1085	295 004	bulk
78.5 / 70.5	*4940*	*30*	*2800*	*2900*	*2975*	*2795*	*382 663*	*bulk*****
115.5 / 100.5	2480	30	2480	2580	2720	2385	295 005	wood***
152.2 / 124.2	5260	40	3120	3340	3445	3225	295 006	bulk

Table 2 Palaeosalinity (since 3,300 cal BP) fluctuation inTangra Yumco. Five phases of change in palaeosalinity levels emphasised. Salinity estimated using Ostracoda-conductivity transfer function and Venice System of brackish water classification (Symposium, 1958).

Depth [cm]	**Age [cal BP]**	**Stage**	**Conductivity [mS/cm]**			**Salinity**			**Salinity range**
			Min	Max	Mean	Min	Max	Mean	
12 – 0	405 – present	V	5.7	15.8	10.0	4.1	11.4	7.3	α-oligohaline – β-mesohaline
29 – 13	1065 – 444	IV	17.3	22.8	19.8	12.5	16.5	14.3	α-mesohaline
59 – 30	1740 – 1104	III	2.8	4.1	3.5	2.0	3.0	2.5	β-oligohaline
87 – 60	2300 – 1760	II	1.3	14.2	4.1	1.0	10.3	3.0	β-oligohaline – β-mesohaline
129 – 88	3300 – 2320	I	0.8	3.2	1.4	0.6	2.3	1.0	freshwater – β-oligohaline

Table 3 Ecology and distribution of Late Quaternary ostracods in Tangra Yumco. All ostracod species are cold stenothermal, except *L. inopinata* living in a wide range of temperatures. The six ostracod species are titanoeuryplastic and thus also common in waters poor in calcium. Data sources: Akita et al. (in press), Mischke et al. (2012), Wrozyna et al. (2009) and Meisch (2000).

Taxon	Salinity	Characterisation	Indicator	Distribution
Leucocytherella sinensis	fresh to **β-mesohaline** waters	oligothermophilic, rheoeuryplastic	dominate poor Ca^{2+}, but **moderately alkaline** waters	southwestern and central Tibetan Plateau
Limnocythere inopinata	fresh- to **meso-polyhaline** waters	polythermophilic, rheoeuryplastic	dominate **lentic high alkaline** and **high saline** waters,	holarctic
Leucocythere? *dorsotuberosa*	fresh to **oligo-** and **β-mesohaline** waters	oligorheophilic	**deep** water of lakes	southwestern, eastern and central Tibetan Plateau
Fabaeformiscandona gyirongensis	fresh to **β-mesohaline** waters	oligorheophilic	**deep** water of lakes	northern eastern Tibetan Plateau and Qaidam Basin
Candona xizangensis	fresh to **oligo** and **β-mesohaline** waters	mesorheophilic	**phytal** zone of lakes	northern , eastern Tibetan Plateau
Candona candida	fresh to **oligo** and **α-mesohaline** waters	oligothermophilic, rheoeuryplastic, oligotitanophilic,mesohalophilic	**small freshwater bodies** and littoral zone of lakes	holarctic

Table 4 Summary of Late Holocene environmental and climate history of Tangra Yumco inferred from sedimentological and Ostracoda proxies. TOC = Total organic carbon, TIC = Total inorganic carbon, TN= Total nitrogen.

Age [cal BP]	**Stage**	**Lake system**	**Sedimentological proxies**	**Ostracoda proxies**	**Palaeoenvironment**	**Climate**
410– present	V	**oligo-mesohaline** closed lake	low K, low TOC	high species richness (5), low adult/juvenile and carapace/adult ratios, *L. sinensis* most dominant	relatively high precipitation, **low lake level**, **moderate salinity**, **high** productivity	**cool** and relatively **wet** period
1070 – 440	IV	**mesohaline** closed lake	coarse grain size peak at **Little Ice Age**, highest K, highest TOC, high TOC/TN	low Fe/Mn$_{shell}$, high δ^{18}O$_{shell}$, low δ^{18}C$_{shell}$, high Mg/Ca$_{shell}$, low Sr/Ca, moderate species richness (4), *L. inopinata* dominant	**cold climate** with low precipitation**, lowest lake** level, **highest salinity**, **moderate productivity**	**cold** and **driest** period
1740 – 1100	III	**oligohaline** closed lake	highest TIC	very low number of ostracods	low precipitation, **low lake** level, **low salinity**, **lowest productivity**	**dry** period
2300 – 1760	II	**oligo-mesohaline** lake separated from Tang-qung Co	high TOC	highest species richness (6), high diversity, *L.? dorsotuberosa* prevalent	low precipitation, **low lake** level, **moderate salinity, highest productivity**	**warm** and **dry** period
3300 – 2320	I	**freshwater-oligohaline,** open lake with outflow into Tanqung Co	high TIC	low species richness (3), high Fe/Mn$_{shell}$, low δ^{18}O$_{shell}$, high δ^{13}C$_{shell}$, low Mg/Ca$_{shell}$, high δ^{13}C$_{shell}$, low Mg/Ca$_{shell}$, high Sr/Ca, high adult/juvenile and carapace/valve ratios, *L. sinensis* predominant	relatively high precipitation, **highest lake level**, **lowest salinity**, **slightly low productivity**	relatively **cool** and **wet** period

Chapter 6

Synthesis

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Chapter 6

6.0 Synthesis

Tibetan Plateau is a land endowed with high mountains, glaciers, snows, holy lakes, great rivers, variety of flora, fauna and minerals (Heath, 2005). "*To the human eye Tibet is a place of great beauty and to the heart a sacred land* (Heath, 2005)." Sustainable management of natural resources of Tibetan Plateau is critical to its people, ecosystem protection, future generations and global climate regulation (Reiter, 1993; Xu and Grumbine, 2014).

6.1 Motivation

"*The impact of climate change in Tibet is harsh. As the world focuses on climate action at United Nations' COP21 meetings, Tibet should be central to any progress made. The Tibetan plateau needs protecting, not just for Tibetans, but for the environmental health and sustainability of the entire world. As stewards of their own land, Tibetans'expertise should be part of tackling climate change.*" – The Dalai Lama

The heart of Asia, the Qinghai-Tibetan Plateau, is sensitive semi-arid environment ('Third Pole') due its high altitude, topography and monsoon climate systems (Zhang et al., 2004b; Yao and Greenwood, 2009; Yao et al., 2012a). The high plateaus, (mountains) and highlands are also known as "**World water towers**" since they provide essential freshwater (via many headwaters, river systems) for large human populations both upstream and downstream (Viviroli et al., 2003; Xu and Grumbine, 2014). There are many large fresh and saline lakes on the Tibetan Plateau (Zheng et al., 1989; Zheng, 1997b; Zheng et al., 2000b). It is largest stored of ice (about 46,000 glaciers) outside the polar regions and source of Asia's major river systems (e.g., Yellow, Yangtze and Brahmaputra) (Xu et al., 2008b; Chellaney, 2011; Farmer, 2015). The Tibetan Plateau contributes significantly to freshwater resources and drinking water for millions of people living in Central, Southern and Southeastern Asia (Barnett et al., 2005).

Tectonic uplift of the Tibetan Plateau plays major role in Earth's Quaternary climatic evolution (Dewey et al., 1988; Harrison et al., 1992; Prell and Kutzbach, 1992; Molnar et al., 1993; An et al., 2001; Kitoh, 2004). The Tibetan Plateau is vulnerable to climate change (e.g., warmer temperatures), with potentially effect of on fresh water supply and indirectly impact large populations in Asia and maintenance of aquatic ecosystems (Xu et al., 2008c; Yao et al., 2012b; Yang et al., 2013). The environmental and climate impact on the high-mountain ecosystems is still inadequate (Funnell and Parish, 2001; Viviroli et al., 2003).

Historical instrumentation and direct measurement of past environmental and climate variables is lacking on the Tibetan Plateau (Smol, 1992; Jones et al., 2001; Edwards et al., 2007). Palaeoclimate proxies (e.g., ice cores, lake sediments and ostracods) provide an indirect estimation of natural variability in environmental and climate history (e.g., Little Ice Age and the warming since Industrial Revolution) (Zheng et al., 1989; Thompson et al., 2000; Edwards et al., 2007; Hannah, 2010).

Lacustrine sediment and the benthic fauna (e.g., ostracods) are sensitive indicators of environmental and climate change (Birks and Birks, 1980; Dearing and Foster, 1986; Harrison and Bartlein, 2012). The variation of closed lake water-volume is associated with climate. A change in climate is linked with a change in lake water-level and subsequent change in geochemical, mineralogical, isotopic and biological conditions of the lake (Street-Perrott and Harrison, 1985; Lister et al., 1991).

Ostracods (microscopic crustaceans) inhabit temporary and permanent waters (marine to non marine) and sometimes even semi-aquatic environments. They are *in-situ* components (living organisms) of aquatic habitats and major benthic crustaceans in lakes and ponds (Delorme, 1991; Galassi et al., 2002; Cohen, 2003). They play a critical role in the nutrient recycling and energy flows and food webs in the aquatic environment (Bronshtein, 1988). Ostracods are the most abundant fossil crustaceans, an important microfossil group, with hard parts (calcitic shells), well-preserved in modern and ancient sediments for palaeolimnological research (Green, 1961; Schram, 1982; Smol, 1992). Ostracods are sensitive indicators of aquatic environmental conditions (McKenzie, 1986; Holmes, 1992). The geochemical analysis of ostracod shells contributes to understanding of hydro-chemical dynamics (Forester, 1983, 1986; Ito and Forester, 2009b). The ecology and chemical composition of living and Recent ostracods (especially high mountains ecosystems) is still unknown (De Deckker, 1981a; Fontes et al., 1985). This study contributes to the potential of ostracods as indicators of aquatic ecosystems and monsoon dynamics on the southern Tibetan Plateau.

6.2 Key findings

6.2.1 Spatial distribution and ecology of Recent Ostracoda (Chapter 2)

A total of six samples were collected and analysed from **six waterbodies** (**lakes**-majority from **Tangra Yumco lake system**-along salinity gradient, **river, pond, spring, lagoon-like and estuary-like waters**) on the southern Tibetan Plateau (Fig.1-2). The water bodies are **significantly (p< 0.05**) different. A total of **44, 731 shells** (living = 2601, empty valves = 41,771) counted.

The **relative abundance of ostracods occurrences** are: (i) **living ostracods** associations: *Tonnacypris gyirongensis* (Yang, 1982) (44.8 %), *Limnocythere inopinata* (Baird, 1843) (29.4 %), *Leucocytherella sinensis* Huang, 1982 (15.6 %), *Candona candida* (O.F. Müller, 1776) (4.7 %), *Fabaeformiscandona gyirongensis* (Huang, 1982), (1.8 %); *Leucocythere*? *dorsotuberosa* Huang, 1982 (1.8 %), *Ilyocypris* sp. (1.6 %), *Heterocypris incongruens* (Ramdohr, 1808) (0.6 %) and *Heterocypris salina* (Brady, 1868). (ii) **empty valves** of Recent assemblages are: *L. sinensis* (61.1 %), *L. inopinata* (17.8 %), *T. gyirongensis* (9.9 %), *L.? dorsotuberosa* (3.6 %), *F. gyirongensis* (2.6 %), *C. candida* (2.1 %), *Ilyocypris* sp. (1.6 %), *Candona xizangensis* Huang, 1985 (1.1 %), *H. incongruens* (0.1 %) and *Potamocypris* cf. *villosa* (Jurine, 1820) (one empty valve).

Cluster analysis established significantly (p<0.05) **two groups** of **ostracod** assocations; (i) *L. sinensis*, *L. inopinata*, *L.? dorsotuberosa*, *F. gyirongensis* and *C. xizangensis* are classified as **permanent lacustrine-brackish fauna** and (ii) *T. gyirongensis*, *C. candida*, *Ilyocypris* sp., *H. incongruens* and *H. salina* are classified as **shallow temporary freshwater species**.

Ostracoda occurrence is strongly associated to environmental factors of their habitats. **Canonical Corresponding Analysis (CCA)** indicates correlation of living ostracod species to the environmental parameters. The presence and abundance of ostracods are significantly ($p<0.05$) controlled by **physico-chemical parameters** (conductivity, alkalinity and water depth) and covariate with water types. **Conductivity and water types are the primary environmental factors** influencing spatial distribution of the ostracods (presence and abundance of particular taxa) within a given water body. The **first two axes of a canonical correspondence analysis** (CCA) explain 30.9 % of the variation in the species abundance data**. Spearman correlation** analysis showed that *L.*? *dorsotuberosa* (r = 0.25) and *L. inopinata* (r = 0.36) have a significant positive correlation with conductivity whereas, *T. gyirongensis* (r = -0.68) displays 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.

There are **two kinds of ecological niches. A well-defined-niche** for **biocoenosis** (living assemblage) and **broader niche** for **empty valve** associations:

(a)The **relative abundance** of **living ostracods** in **different waterbodies**: (i) **Lacustrine environment** – *L. inopinata* (48.1 %), *L. sinensis* (39.2 %), *F. gyirongensis* (6.4 %), *L.*? *dorsotuberosa* (5.0 %), *T. gyirongensis* (1.1 %) and *Ilyocypris* sp. (0.1%); **(ii) lagoon-like habitats** – *Limnocythere inopinata* (79.0 %), *L. sinensis* (13. 0%), *Ilyocypris* sp. (5.0 %) and *L.*? *dorsotuberosa* (2.0 %);(iii) **estuary-like habitats** – *T. gyirongensis* (92.0 %), *L. sinensis* (5.0%) and *Ilyocypris* sp. (3.0 %); (iv) **pond habitats** with high organic matter – *T. gyirongensis* (84.1 %) *C. candida* (13.5 %), *L. sinensis* (1.1 %) and *Ilyocypris* sp. (0.7 %) and *H. incongruens* (0.7 %) with high organic content; (v) **river habitats** – *T. gyirongensis* (85.3 %) and *L. sinensis* (13.6 %) and *C. candida* (1.0 %) and (vi) **spring habitats** – *T. gyirongensis*.

(b) The **relative abundance of empty valves** of ostracods in **different waterbodies**: (i) **Lacustrine environment** – *L. sinensis* (52.9. %), *L. inopinata* (34.1 %), *L.? dorsotuberosa* (4.9 %), *F. gyirongensis* (4.8 %), *C. xizangensis* (2.1 %), *T. gyirongensis* (0.1 %), *C. candida* (0.5 %) and *Ilyocypris* sp. (0.03 %); (ii) **lagoon-like habitats** – *L. sinensis* (74.0 %), %), *Ilyocypris* sp. (!3.0 %), *L.*? *dorsotuberosa* (7.0 %), *L. inopinata* (5.0 %), and *C. candida* (1.0 %)*;* (iii) **estuary-like habitats** – *L. sinensis* (85.0 %), *L.*? *dorsotuberosa* (85.0 %), *C. xizangensis* (7.0 %), *H. incongruens* (3.0 %)*, L. inopinata* (2.0 %), *Ilyocypris* sp. (2.0 %), *T. gyirongensis* (1.0 %) and *C. candida* (1.0 %), (iv) **pond habitats** – *T. gyirongensis* (77.0 %) *C. candida* (14.6 %), *L. sinensis* (5.7 %), *Ilyocypris* sp. (1.8 %), *L. inopinata* (0.44 %), *H. incongruens* (0.44 %) and *L.*? *dorsotuberosa* (0.15%), (v) **river habitats** – *L. sinensis* (91.0%), *Tonnacypris gyirongensis* (6.0 %) %), *L.*? *dorsotuberosa* (2.0%), and (vi) **spring habitats** – *Tonnacypris gyirongensis* (65.0 %), *L. sinensis* (34.0. %) and %), *L.*? *dorsotuberosa* (1.0%).

The Shannon diversity index (*H*) indicates high diversity in lakes and ponds with muddy substrates.

Water-depth distribution of ostracods characterised Tangra Yumco into **three distinct** zones (epilimnion, thermocline and hypolimnion). This is typical feature of a deep stratified lake. The **water-depth-indicator fauna** includes (i) *L. sinensis*, *L. inopinata* and *C. xizangensis* as **phytal littoral shallow-water** species and (ii) *F. gyirongensis* and *L.? dorsotuberosa* as **deep-water fauna**.

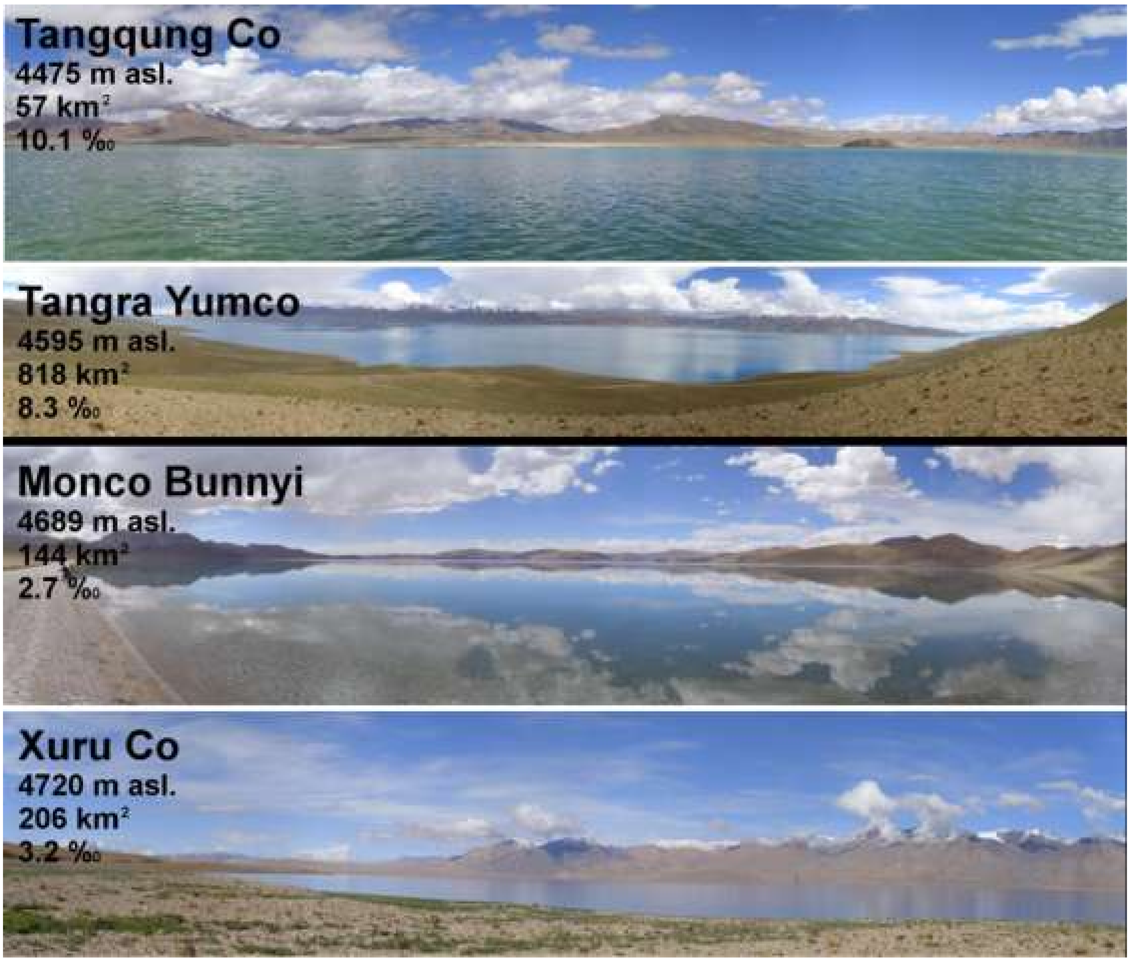

Fig. 1 Limnological features of the Tangra Yumco lake system along a salinity gradient (Photo by Peter Frenzel).

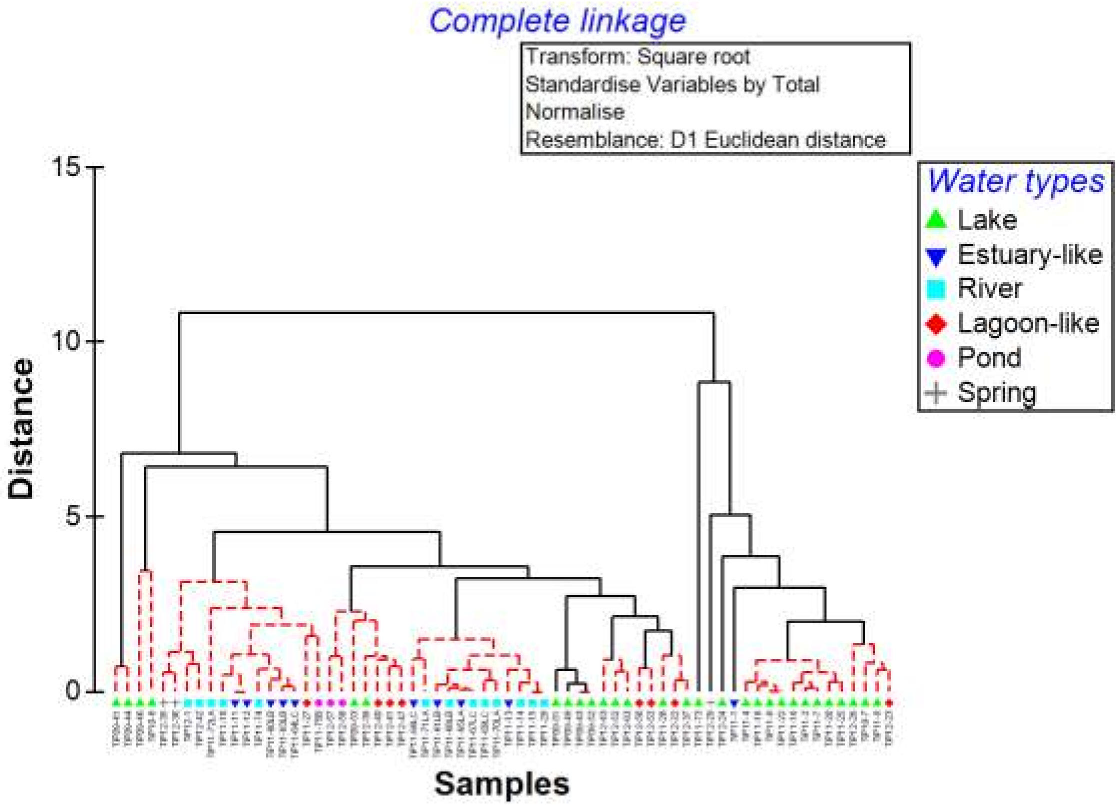

Fig. 2 Sixty-six surface sediment samples analysed from different water types on the southern Tibetan Plateau. Sample ID: project, year of sampling and sample number (e.g., TiP09-41).

6.2.2 Geochemistry of Recent Ostracoda shells (Chapter 3)

This study contributes to **new geochemical data** ($\delta^{13}C$, $\delta^{18}O$, Mg/Ca, Sr/Ca, Ba/Ca, Fe/Ca, Mn/Ca and U/Ca) of four **Recent Tibetan Ostracoda** (*Leucocytherella sinensis*, *Leucocythere dorsotuberosa*, *Limnocythere inopinata*, and *Tonnacypris gyirongensis* and their water chemistry ($\delta^{13}C_{DIC}$, TDS, $\delta^{18}O$) (Börner et al., re-submitted). The geochemistry of Recent Ostracoda shells and the water chemistry from **nine Tibetan lakes** (Taro Co, Tangra Yumco, Tangqung Co, Monco Bunnyi, Xuru Co, Nam Co, Npen Co, Yumzho Yumco and Chen Co) and their catchment waters were analysed.

The water bodies (**lacustrine and freshwater**) are successfully **separated** by **oxygen isotope and deuterium values** ($\delta^{18}O$ and δD). The $\delta^{18}O$ and δD values range from -18.8 ‰ to -0.35 ‰ and -145.75 ‰ to -65.13 ‰ and positively correlated (r^2 = 0.96). In water samples from saline lakes, the local evaporation is below the Global Meteoric Water Line (GMWL). The isotopes ($\delta^{18}O$ and δD) composition of **lacustrine brackish waters** (e.g., Tangra Yumco: $\delta^{18}O$ = -6.58 ‰ and δD = -76.8 ‰; Taro Co: $\delta^{18}O$ = -5.72 ‰ and δD = -69.3 ‰) are **higher than** in **temporary freshwaters** ($\delta^{18}O$ = -18 ‰ and δD = -138 ‰).

The **lake water has a positive $\delta^{13}C_{DIC}$** (enrichment in ^{13}C), although **variable for the different lake** systems (Tangra Yumco = 5.0 ‰, Xuru Co = 3.4 ‰ and Taro Co = 2.4 ‰). The **freshwaters** (river and springs) have **negative $\delta^{13}C_{DIC}$** (depleted). The **oxygen isotopic composition of ostracod** ($\delta^{18}O_{shell}$) **and water** ($\delta^{18}O_{H_2O}$.) are

positive correlated. In contrast, $\delta^{18}O_{shell}$ and $\delta^{13}C_{DIC}$ is weakly correlation. The **lacustrine-brackish species are enriched in $\delta^{18}O$ and $\delta^{13}C_{shell}$** (*L. inopinata*: $\delta^{18}O_{shell}$ = -16.5 ‰ to -3.99 ‰ and $\delta^{13}C_{shell}$ = -4.51 ‰ to 4.23 ‰ and *L. sinensis*: - $\delta^{18}O_{shell}$ = -9 ‰ to -4 ‰ and $\delta^{13}C_{shell}$ = 0.5 ‰ to 3.2 ‰). However, the **freshwater ostracods** (*T. gyirongensis*: $\delta^{18}O_{shell}$ = -16.5 ‰ to -13.3 ‰ and $\delta^{13}C_{shell}$ = -4.5 ‰ to 4.2 ‰) are **depleted**. Nonetheless, the isotopic composition ($\delta^{18}O_{shell}$ and $\delta^{13}C_{shell}$) in *L. sinensis* is significantly positive (r^2 = 0.74) than in *L. inopinata* (r^2 = 0.32), with vital offset for both species. The shell isotopic composition of lacustrine and freshwater ostracod species are not in equilibrium with host waters. The lacustrine-brackish fauna (*L. sinensis* and *L. inopinata*) are more depleted in $\delta^{13}C_{shell}$ than $\delta^{13}C_{DIC}$ but enriched for freshwater ostracods.

Ba/Ca_{shell} and Sr/Ca_{shell} correlated with Mg/Ca_{shell}. Mg/Ca ratios of ostracod shells correlated significantly with conductivity of the host water. However, Sr/Ca ratios of *L. sinensis* and *L. inopinata* do not correlate with conductivity. Furthermore, Sr/Ca ratio of *L. dorsotuberosa* is positively correlated with conductivity. Higher variation of Mg/Ca values in ostracod shells is associated with increased Mg/Ca of the host water. No temperature dependency was observed for Mg/Ca_{shell} and Sr/Ca_{shell}, although lacustrine cold waters have high Sr/Ca while shallow warm freshwaters have lower Sr/Ca. The minor elemental composition (Fe/Ca, Mn/Ca and U/Ca ratios) in ostracod shells are positively correlated with each other and the host water but negative correlated with $\delta^{13}C_{DIC}$ of ambient.

6.2.3 Ostracoda as sub-aqueous sediment indicators (chapter 4)

In Tangra Yumco, sedimentary features show horizontal layering (> 25 m thickness of sediment) from the steep eastern slope to the deepest depth of 220m Tangra Yumco (Akita et al., 2015). The **event layers are characterised by thick and dark sediments** (lack of bioturbation and reducing oxygen conditions) with **fining upward (graded) bedding**, **low reflectivity** (low water content) and **high magnetic susceptibility**. Normal sedimentation comprises brownish fine sand to medium silt with higher reflectivity (high water content) and low magnetic susceptibility. **Five event layers** were **identified** in **sediment core**, TAN 10/4. The event layers of the core and their underlying and overlying sediments were evaluated.

To **assess ostracods as palaeoindicators** of sedimentary events, a **conceptual model of ostracods distribution was developed and tested**. The vertical distribution of ostracod associations within the studied sediment core indicates the process of sub-aqueous sediment transport from shallow waters to the bottom of northern basin of Tangra Yumco. The benthic lacustrine ostracods in sediment are (*Leucocytherella sinensis* Huang, 1982, *Leucocythere? dorsotuberosa* Huang, 1982*, Limnocythere inopinata* (Baird, 1843) and *Fabaeformiscandona gyirongensis* (Huang, 1982). **Ostracods** were **very low in sediment events layers** due to **massive sediment accumulation** (snap-shot intensified events) caused by bottom gravity flows. The **fluid sediment** is characterised by **two grading modes (stratigraphic evidence)**: (i) **proximal deposit** (upper part), coarser grains and (ii) **distal deposit** (lower part), soft fine-grain sediment. **Ostracod associations** describe **two distinct sediment gravity flows**; event layers (four major layers) with **sandy silt with graded bedding** are interpreted as t**urbidites** caused by turbidity currents. In contrast, the event layer (one layer) **with fine sand and silt** and **without graded bedding** is interpreted as **debrite.**

6.2.4 Ostracoda evidence of late-Holocene environmental change in Tangra Yumco (Chapter 5)

A long sediment core, TAN10/4 (162 cm) from Tangra Yumcoo provide **evidence of environmental and climate variability during the past 3,300 years** (Akita et al., submitted-b). The Late Holocene fossil ostracod associations found are *Leucocytherella sinensis, Leucocythere? dorsotuberosa, Limnocythere inopinata*, *Fabaeformiscandona gyirongensis, Candona xizangenesis* and *Candona candida* (Fig. 3). Ostracoda assemblages and the dominance taxa in specific period indicate their ecological response to past environment and climate change (Fig. 3). The ostracod faunal successions characterised **five deposition environment (first inference) and climate (secondary inference)** (Fig. 3, **oldest to youngest sediment**): Stage I-***L. sinensis***, euryhaline species, mainly dominant, **increased lake level** (strengthen of monsoon) with **lowest salinity** (**limnetic to β-oligohaline** condition); Stage II-***L. dorsotuberosa***, fresh to brackish fauna, dominant, stable lake level with **increasing in salinity** (**β-oligohaline to β-mesohaline**); Stage III-**low ostracod abundance,** decreasing lake level with moderate salinity (**β-oligohaline**) ; Stage IV-***L. inopinata***, more salt tolerant species, predominant), **falling lake level** (weakening of monsoon during "Little Ice Age",) with **highest salinity** (**α-mesohaline)** and Stage V-***L. sinensis*** prevalence, rising lake level (enhanced monsoon) with **variable salinity** (**α-oligohaline – β-mesohaline**). The lake water salinity at depth (Stage V) is higher than Stage (III).

Moreover, *F. gyirongensis* occurs in relative low numbers throughout the core. *Candona xizangensis* occurs in specific time (Stage II). *Candona candida* is a rare species.

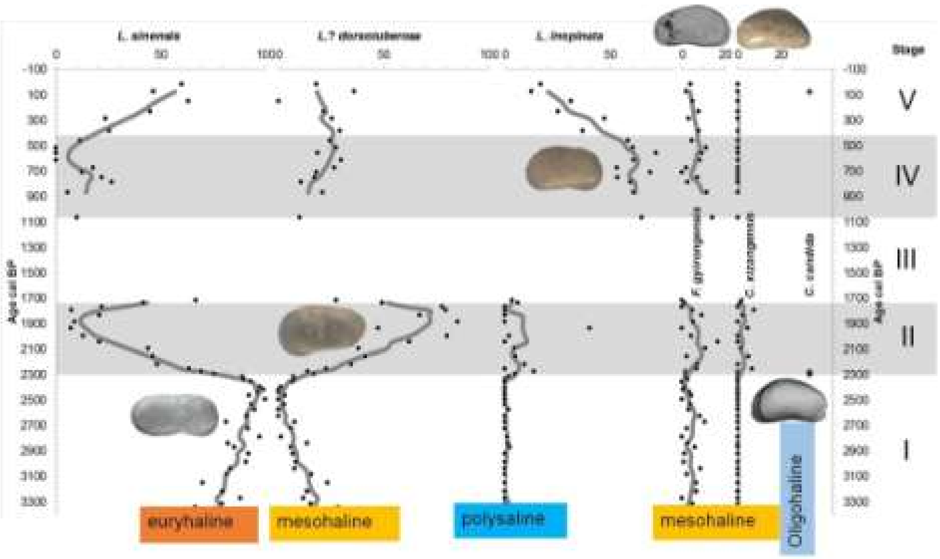

Fig. 3 Late Holocene Ostracoda (palaeo)-salinity tolerance are: *Leucocytherella sinensis* (euryhaline fauna), *Leucocythere? dorsotuberosa* (fresh-brackish water fauna), *Limnocythere inopinata* (mesohaline to polyhaline species), *Fabaeformiscandona gyirongensis* (lacustrine-brackish fauna), *Candona xizangensis* (phytal littoral lacustrine-brackish fauna) and *Candona candida* (freshwater to oligohaline fauna).

6. 3 Discussions

6.3.1 Spatial distribution and ecology of Recent Ostracoda (Chapter 2)

There are limited studies on microcrustacean in high-mountains ecosystems from Eurasia region (particularly from central Asia) (Van der Meeren et al., 2010a; Zhang et al., 2013b). Ostracods reflect changes of environmental conditions by changes in their distribution, diversity, relative abundance, presence and absence of taxa, specific ecological tolerances and microhabitat preference (Van der Meeren et al., 2010a; Zhai et al., 2010b; Zhang et al., 2013b; Akita et al., in press).

This study contributes to habitat ecology of living and Recent Ostracoda and environmental parameters of water bodies. The waterbodies range from **fresh to brackish lacustrine condition** (Tangr**a Yumco lake systems-Tangqung Co, Tangra Yumco, Monco Bunnyi** and **Xuru** and their **temporary waters**) on the **southern Tibetan Plateau**. The **eleven Recent Tibetan Ostracoda** (living and empty valves). **Species-specific ecological requirement** is defined by physico-chemical variables of the waterbody. In samples with increased number of valves (> 500), the split- method was efficient to evaluate similar associations in equal weight of sediments. Assemblages with similar ecological requirements live together in a given habitat (by **clusters of similar associations**). The composition of living ostracods is well represented in the empty valves (dead) associations. There are **five endermic Tibetan fauna** are *L. sinensis*, *L. inopinata*, *L.*? *dorsotuberosa*, *Fabaeformiscandona gyirongensis* and *T. gyirongensis* and **four cosmopolitan species** are *L. inopinata, C. candida H. salina* and *P.* cf. *villosa* (Akita et al., in press). The isolated mountain ecosystems provide higher endermic species with low species diversity. This contributes to ecology of ostracods from high-altitude aquatic ecosystems. Living ostracods relates to their environment variables ($p<0.05$), sensitive ostracods are indicators for reconstruction of aquatic habitats.

Living ostracods correlated with environmental variables. The distribution of living *L. sinensis* correlates ($p < 0.05$) with calcium ions concentration, *L. inopinata* with conductivity, alkalinity, chloride and sulfate ions, *T. gyirongensis* with conductivity, alkalinity, calcium, magnesium, sodium, chloride and sulfate ions, *F .gyirongensis* with water depth. *Leucocythere*? *dorsotuberosa* correlates with conductivity. ***Limnocythere inopinata*** showed broader tolerance to conductivity (salinity) tolerance and affinity for **high saline waters**; **indicator for increased salinity**, ***L.? dorsotuberosa*** is an indicator of **transition of water bodies**, from **fresh to brackish waters**. Environmental salinity (measured as specific conductivity) is the key ecological factor influencing ostracod distribution (freshwater, brackish and marine faunas) (Van Harten, 1986). Conductivity is also confirmed as the key determinant on the distribution of Tibetan ostracods (Mischke et al., 2007; Mischke, 2012; Akita et al., in press).

Living ostracod populations dominate a given aquatic habitat and water depth: (a) (i) *Leucocytherella sinensis* dominate Ca-depleted brackish waters and common in diverse water bodies; (ii) *Leucocythere? dorsotuberosa* inhabit fresh to brackish waters and deep water fauna; (iii) *Limnocythere inopinata* predominates mesohaline to polyhaline waters; (iv) *Fabaeformiscandona gyirongensis* lives exclusively in brackish lacustrine deeper waters; (v) *Candona candida* populates freshwaters; (vi) *Tonnacypris gyirongensis* and *Ilyocypris* sp. occurs in shallow temporary waters; and (vii) *Heterocypris incongruens* dwells in pond habitats

Ostracod associations (cluster of similar associations) and **geochemical data** (stable isotope and elemental composition) distinguish the **two types of water bodies** (lacustrine-brackish and fresh waters) on the southern Tibetan Plateau. **Species–specific ecological preference** describe their most favourable ecological niches: (i) in standing (lotic) waters and flowing (lentic) waters,; (ii) in the warm shallow epilimnion and cold deep waters of lake's hypolimnion and (iii) permanent and temporary water bodies.

The habitat characteristics of biocoenosis (living assemblage) and thanatocoenosis (dead associations) are **valuable indicators** for **environmental** (past, present and future). **and ecological inferences**. The **ostracod indicator value** includes evaluation of: (i) sediment depositional environment and (palaeo)-ecology of fossil ostracods; (ii) sediment transport processes (via distinguishing autochthonous and allochthonous ostracods, shallow and deep water fauna) and (iii) aquatic ecosystems dynamics. The **key sensitive species** are **excellent indicators** for palaeoenvironmental and climate research. The **multiple ecological parameters** (presence-absence of taxa, relative abundance, ecological preferences index, species-environment relationship, richness and diversity) indicates **species-specific sensitivity**, useful for **environmental reconstruction**. Each parameter is a valuable environmental indicator. The ecology and shell chemistry of Recent ostracods can be used to differentiate different types of aquatic habitats on the southern Tibetan Plateau (Akita et al., in press; Börner et al., re-submitted).

Ostracods are sensitive to water depth. The water – depth ostracods indicators (*L. .? dorsotuberosa* and *F. gyirongensis)* are useful **indicators for (palaeo)-water depth estimation**. They are useful for evaluating the variability of palaeo-lake water depth and ancient sediment environment (deposition, modes and transport processes).

6.3.2 Ostracoda as sub-aqueous sediment indicators (chapter 4)

Ostracods are preserved with their dead remains (microfossils) within sediments of the given aquatic habitat. However, the shells can be transported and buried in sediments of different habitats. The transformation of **biocoenosis** (*in situ* life assemblages) to **taphocoenos** is (dead assemblages including transported by reworked remains), helps to recognise transport processes by discriminating autochthonous components from allochthonous assemblages. Lacustrine ostracods have not been fully utilized in the evaluation of sub-aqueous mass movement and sediment transport processes. Benthic communities in lakes are associated with substrate boundaries and water depth (Cohen, 2003). The soft bottom and organisms are controlled by water turbulence, wave energy and current, influenced by proximity to shoreline (Palmer et al., 1997; Cohen, 2003). Lacustrine ostracods are potential tracers of sub-aqueous sediment transport especially in deep lakes. This study contributes to the sedimentological and micropaleontological evidence of sub-aqueous bottom gravity flows (initiated by mass movements such as slump structures, sediment accumulation and relocation) in a deep lake, Tangra Yumco (Akita et al., 2015). Sediment succession is evidence of palaeo-events (sediment gravity flows, palaeo-flood, palaeocurrrents and sea level rise (Penney, 1987).

The **ostracod distribution in turbidites** is **characterised by four features of the conceptual model**: (i) proximal (coarser sediment grains) and distal sources transport, graded bedding either lacking ostracods or very limited number of ostracod valves, compared to underlying and overlying sediments; (ii) ostracods are sorted into different sizes distribution (adult/juvenile ratio) with high abundance and high proportion of adult valves of *L. sinensis* at the base of event-layers; (iii) either lacking or extremely low number of ostracod carapaces within the event layers; and (iv) after event layer, pioneer opportunistic ostracod assemblages re-colonise the newly formed sediment-event habitat, with a gradual transformation to associations similar to association existing prior to event.

Ostracods are **good proxies for characterisation** of specific sedimentation modes and depositional environment due their ability to live (on or in) and to colonise bottom sediment of all types of aquatic habitats. Ostracods are **good tracers of sub-aqueous** sediment flow dynamics (e.g., palaeo-currents).

6.3.3 Geochemistry of Recent Ostracoda shells (Chapter 3)

Lacustrine invertebrates dead remains (fossils record) are sources of palaeoenvironmental information (Holmes, 1992; Smol, 1992). Ostracod carbonate records information because (i) an ostracod moult (ecdysis, shedding of shells) in about 6-8 successive larval stages, before they reach adulthood and maturity (Chivas et al., 1986b) and (ii) old shells are shed and new ones are secreted producing a rich fossil biological remains (Griffiths, 2006). The shedding of larval shells accumulate in the bottom sediments of aquatic habitats (if neither damaged nor carried away by water movement) (Van Harten, 1986). The fossilized shells provide a snapshot of space specific chemical water condition during the time of biomineralisation (Holmes, 1996). Ostracod shell chemistry is assumed to be in equilibrium with the ambient water, chemistry (Holmes, 1996).

The variability of $\delta^{13}C_{DIC}$ (enrichment in ^{13}C) in different lake system may be due to lake basin geomorphology, hydrodynamics and catchment processes. The lagoonal waters are more distinct from GMWL due to intensive evaporation in shallow closed waterbodies. High $\delta^{18}O_{shell}$ in ostracods in lacustrine brackish water conditions and higher $\delta^{18}O_{water}$ values indicate evaporative enrichment. Low $\delta^{18}O_{shell}$ and the very negative $\delta^{18}O$ values of river and spring waters indicate a stable aquatic environment with groundwater inflow but no evaporative enrichment (melt water input). The $\delta^{18}O_{shell}$ positively correlated with $\delta^{18}O_{water}$ and total dissolved solids (TDS). Therefore, $\boldsymbol{\delta^{18}O_{shell}}$ is a **reliable indicator for detection of salinity variability**. The differences in isotopic composition of the ostracod associations may be due to species-specific ecological niches, environmental requirements and life cycles. The negative offset of *L. sinensis* and *L. inopinata* $\delta^{18}O_{shell}$ from equilibrium calcite is due to valve calcification during the monsoon season. During late spring and summer (June to August), the period with higher precipitation (Indian Summer Monsoon), the host water has lower oxygen isotope values.

Chemical composition in both the living associations and Recent shells of *L.? dorsotuberosa* indicates positive correlation with conductivity. Therefore, Leucocythere? dorsotuberosa is a **good indicator for detection of transition of different waters with variable salinity**, due to its adaptation to **fresh and brackish waters** (thus confirmed by the **aute-ecology, palaeoecology and shell chemistry**).

The correlation of Ba/Ca_{shell} and Sr/Ca_{shell} with Mg/Ca_{shell}, suggest the incorporation of both elements (Ba and Sr) to be influenced by the Mg content of the ostracod calcite. **Mg/Ca is a better indicator for salinity**. The trace element composition (Mg/Ca and Sr/Ca) of ostracods are reliable indicators for evaluation of past precipitation and evaporation and salinity changes. However, application for palaeo-salinity inference must be cautiously interpreted. Ba/Ca is a nutrient indicator. Increased decay of organic matter leads to oxygen depletion and a decreased water $\delta^{13}C_{DIC\ water}$. This subsequently causes increase in the speciation in redox-sensitive ions (Fe, Mn and U) in aquatic environment.

The geochemistry of Recent ostracod shells is **useful chemical tracer** for reconstruction of **(palaeo)-hydrological conditions** of aquatic ecosystems on the southern Tibetan Plateau. However, a careful inference is required. The basic uncertainties in geochemical analysis of ostracods are summaried as (Chivas et al., 1986b; Chivas et al., 1993; Griffiths and Holmes, 2000); especially for closed lakes:

I. The Sr/Ca of an ostracod is a function of solute water chemistry (assumes a lake has a constant salinity).
II. The Mg/Ca of an ostracod shell is a function of temperature and solute water chemistry (or salinity).
III. The $\delta^{18}O$ value of an ostracod shell is a function of evaporation/precipitation (thus salinity) and to a minor extent temperature in closed lakes. Shallow lake waters have a larger temperature variability than deeper waters, influencing the fluctuations in $\delta^{18}O$ value of shells (different associations, phytal verse deeper water fauna).

The assumptions (II) and (III) are similar but with different response: an increase in temperature is related to increase in Mg/Ca but decrease in $\delta^{18}O$. But an increased in salinity increases Mg/Ca, Sr/Ca and $\delta^{18}O$ (Chivas et al., 1986b; Chivas et al., 1993; Griffiths and Holmes, 2000).

The **element concentrations** (e.g., Fe/Ca, Ba/Ca and Mn/Ca ratios of ostracods) are **good redox indicators** for reconstruction of (palaeo)-productivity and trophic state of the aquatic ecosystems (Ito et al., 2003a).

6.3.4 Ostracoda evidence of late-Holocene environmental change in Tangra Yumco (Chapter 5)

"We study the past ecological history, with the conscience of the present ecological conditions. This is the key to predict future aquatic ecosystem changes" ~ Lailah Gifty Akita

Without knowledge of the past environmental and climate conditions, we cannot fully understand the present processes and to predict future changes. The study of Late Holocene lake level fluctuations are necessary to understand the lake history in response to environmental and climate change. The changes within the lakes are indicated by biological, physical and chemical records in the sediments (Digerfeldt, 1986). Furthermore, lake complex interactions (e. g., climate, physical, chemical and biological processes) create significant horizontal and vertical heterogeneity in lake sediments (Covich et al., 1999; Lake et al., 2000).

There are many brackish to saline and alkaline closed lakes in arid regions due to increasing evaporation. Closed lakes (there is surface inflow but no outlet) are sensitive to climate change. Lake water level fluctuates with monsoon climate variability. A change in water level induce changes in lake function, which can be detected using chemical, mineralogical, isotopic and biological analysis (Street-Perrott and Harrison, 1985). Present-day, Tangra Yumco is a closed basin with mesohaline salinity of 8.3. We hypothesize that the water volume of Tangra Yumco is primary influenced by India monsoon summer precipitation. The **two-fold** questions are: (i) What is the impact of environmental and climate change in lake ecosystems and their biological communities? (ii) How does the biological communities change through time?. The late Holocene environmental climatic variability is indicated by changes lake water level and ostracod assemblages. The lake water level fluctuates due to variability of monsoons in geological time. Change in lake level is associated with change in water salinity (thus the role of precipitation and evaporation, P/E, in closed lake system) (Street-Perrott and Harrison, 1985). P). Changes in aquatic environment are reflected in variation of fossil ostracod assemblages (abundance, species richness and diversity, relative abundances). Ostracod assemblages reflect modification of aquatic ecosystems through time. *"Our ability to reconstruct past communities and the history of life hinges on thinking like biologist doing field work in ancient environments*."(Vermeij and Herbert, 2004). Change in palaeo-salinity also influenced the total assemblages and dominance taxa (thus due to species-specific salinity tolerance and optimum requirement).

The major **late Holocene environmental and climatic** evolution of Tangra Yumco is **three-folds**:

(i) The predominance of **euryhaline ostracod species**, *Leucocytherella sinensis*, suggest highest lake level and lowest salinity (limnetic to β-oligohaline) linked to relatively high precipitation during a relatively cool and wet period in **3300 – 2320 cal B.P. Other proxies** are; species richness (3), low $\delta^{18}O$ and Mg/Ca_{shell} ratio in *L. sinensis* shells. But a high $\delta^{13}C$, high Fe/Mn and high Sr/Ca ratios in *L. sinensis* shells.

(ii) The **highest ostracod diversity and prevalance** of a fresh and **brackish water fauna,** *Leucocythere*? *dorsotuberosa*, suggests variable salinity with the highest productivity during a falling lake level in **warm and dry climate** from **1740 – 1100 cal B.P.** The **highest productivity** (highest K, highest TOC and high TOC/TN) of the lake in this period is associated with high ostracod productivity (highest species richness (6) and diversty) and

(iii) The **dominant of a more salt tolerant species**, *Limnocythere inopinata*, indicates the **highest salinity** (β-oligohaline to β-mesohaline) linked to the lowest lake level caused by low precipitation under a **cold and dry climate** in **1070 – 440 cal B.P**. A moderate lake productivity (highest K, highest TOC, high TOC/TN) is linked with moderate species richness. Other proxies are: species richness (4), high $\delta^{18}O$ and Mg/Ca_{shell} in *L. inopinata* shells. However a low $\delta^{13}C$, low Fe/Mn and low Sr/Ca in *L. inopinata* shells. The Little Ice Age occurs in this period.

Multi-proxies (palaeoecology, geochemistry and sedimentology) provide a detailed environmental reconstruction (Boomer et al., 2003; Benton and Harper, 2009; Mischke et al., 2015). Ostracods are **excellent biological indicators** for **environmental reconstructions** (e.g., aquatic habitat types, lake level, salinity and productivity). The application of the both aute-ecology and (palaeo)-ecology of ostracods will help to understand ecosystems and environment climate dynamics on the southern Tibetan Plateau.

The Late Quaternary (the past 20,000 years) is period of rapid environmental and climatic changes (Owen, 2000; Hay et al., 2002; Bell and Walker, 2005). The hydrological conditions have varied in geological times especially in Quaternary (Viviroli and Weingartner, 2004; Mügler et al., 2009a; Günther et al., 2015). The monsoon dynamics on different time scales is of great interest due impacts of climate change on water resources (Wang et al., 2014). Proxy records (e.g., pollen and lake sediments) indicate relatively warm wet in the early Holocene and cool dry in the mid to late Holocene (Gasse et al., 1991; Kashiwaya et al., 1991; Lister et al., 1991; Kashiwaya et al., 1995; Van Campo et al., 1996; Zheng et al., 2000a; Herzschuh et al., 2009; Herzschuh et al., 2010).

In Tangra Yumco, a **highest lake level** (strengthening of monsoon) occurs in **3.3 to 2.3 cal ka B.P** (**cold climate**) (Long et al., 2012; Rades et al., 2013b; Akita et al., submitted-b). A **falling lake level** (weakening of monsoon) begins after **2.6 cal ka B.P** and persistent until **1.0 - 0.4 cal ka B.P.** (**warm dry climate**) (Rades et al., 2013b; Miehe et al., 2014; Ahlborn et al., 2015b; Akita et al., submitted-b). A **cold dry early Holocene** (aridity), **cool wet middle Holocene** and **warm dry late Holocene** in Tangra Yumco (Kong et al., 2011a; Long et al., 2012; Rades et al., 2013b; Miehe et al., 2014; Ahlborn et al., 2015b; Akita et al., submitted-b). The **Holocene environmental and climate fluctuations** in Tangra Yumco is also observed other lake systems (e.g., Taro Co, Xuru Co and Nam Co) on the southern Tibetan Plateau) (Xu et al., 2006; Cao et al., 2009; Kasper et al., 2012; Ma et al., 2014b).

6.4 Conclusion

> "*The present defines the future. The future builds on the foundation of the past*"
>
> ~ Lailah Gifty Akita

Understanding the ancient environment requires the knowledge of present ecosystems and their fauna (Hardie et al., 1978). This study contributes to **numerical data** (**ecological, physico-chemical** and **geochemical)** to **Ostracoda database** (especially from Eurasia region, which is rarely available).

A total of **eleven Recent Ostracoda** were found in an ancient large brackish lake, Tangra Yumco and adjacent waters. The **Recent ostracod associations** (**living plus dead**) are (Akita et al., in press): *Leucocytherella sinensis* Huang, 1982 (58 %), *Limnocythere inopinata* (Baird, 1843) (18.5%), *Tonnacypris gyirongensis* (Yang, 1982) (12.0 %), *Leucocythere*? *dorsotuberosa* Huang, 1982 (3.5%), *Fabaeformiscandona gyirongensis* (Huang, 1982) (2.5 %), *Candona candida* (O.F. Müller, 1776) (2.2 %), *Ilyocypris* sp., (1.6 %), *Candona xizangensis* Huang, 1985 (1.0 %), *Heterocypris* incongruens (Ramdor, 1808), (0.1 %), *Heterocypris salina* (Brady, 1868) and *Potamocypris* cf. *villosa* (Jurine, 1820). The **Recent ostracods** are **still living** (excluding **two species**, *Candona xizangensis* and *Potamocypris* cf. *villosa,* only empty shells found at time of sampling).

The **newly calibrated stable isotope and elemental composition** of Recent ostracod shells (δ^{13}C and δ^{18}O, Mg/Ca, Sr/Ca, Fe/Ca, Mn/Ca and U/Ca) and ambient water are **valuable indicators for (palaeo)-environmental reconstruction** (e.g., salinity, redox and oxygen conditions).

Ostracods are **good indicators of sediment dynamics**, past water flow dynamics caused palaeo-bottom currents.

Salinity influences distribution (presence/absence) and abundance of both Recent and fossil ostracod assemblages compositions. The paleoecology fossil assemblages relates to ecology of Recent fauna. This **confirms the assumption that fossil assemblages** relates to the **living communities**. **Change in aquatic environment** is reflected in **variation of fossil ostracod assemblages** (abundance, richness and diversity). Ostracod assemblages (total assemblage and individual taxon) reflect **modification of aquatic ecosystems through time**.

The key findings are summarised as (Fig. 4):

I. **Ostracod distribution (living fauna)** relate significantly ($p < 0.05$) to their environmental parameters (conductivity, alkalinity, water depth and water types).
II. **Conductivity and water types** primarily influence **ostracod presence and abundance** in a **particular aquatic habitat**.
III. The **multiple ecological parameters** (e.g., presence and absence, abundance, indicator sensitive species, ecological preference index, species-environment relationship species richness, and diversity) are **good indicators** for environmental reconstructions.
IV. **Distinctive ostracod** assemblages significantly ($p<0.05$) characterised **specific aquatic habitats**.
V. **Habitat** characteristics of **Recent Ostracoda (living and empty valves)** provide a **new ecological data-base** of **microcrustaceans** in **high-mountain ecosystems**. The basis for palaeoenvironmental and climatic reconstruction in Eurasia region.
VI. The **aute-ecology of modern ostracods** is needed for reconstruction of palaeoecology of fossil remains. **Individual taxon sensitive indicator value** is **excellent biomarker** for palaeolimnology, palaeoenvironmental and climate reconstructions.
VII. The **geochemistry of four Recent ostracod** shells is **a good chemical tracers** for (palaeo)-salinity and (palaeo)-hydrology and aquatic trophic conditions.
VIII. Ostracods are **reliable indicators of sediment flow dynamics** (e.g., and palaeocurrents and palaeofloods) in deep lake system. The sediment modes (events layers; turbidites and debrite flow) can be characterised by ostracods and sedimentological features).
IX. **Climate change drives environmental and ecosystem dynamics**.
X. The **Indian Summer Monsoon climate** controlled **lake water fluctuation** through. Late Holocene. Change in lake water level influenced the change in sedimentologicaly, geochemical and organism (e.g., ostracods, small benthic fauna).
XI. The **composition** (total assemblages and individual taxa) and **shell chemistry** of **ostracod shells** showed response to Late Holocene environmental and climate variability. Each species have limited range of environmental requirements.
XII. Aute-ecology of Recent Ostracoda allowed the palaeoecological inference of fossil ostracod assemblages. Habitat characteristics of Recent Ostracoda enabled reconstruction of ancient environment, palaeo-ecology and climate.

XIII. **Multiple proxies** (e.g., sedimentology, geochemistry and micropalaeontology) allowed **holistic** environmental and climate **inferences**.

The **ecology and geochemistry of Recent Ostraco**da are **excellent environmental indicators for reconstructions** on Tibetan Plateau. The palaeoecology of ostracods is evidence of past environmental and climate variability through time. The **new ecological Ostracoda database** is useful for policy formulation in **biodiversity conservation**, ecosystem management and environmental protection. Environmental stewardship, freshwater resource managers and community-based resource management are needed for **sustainable management of water resources.**

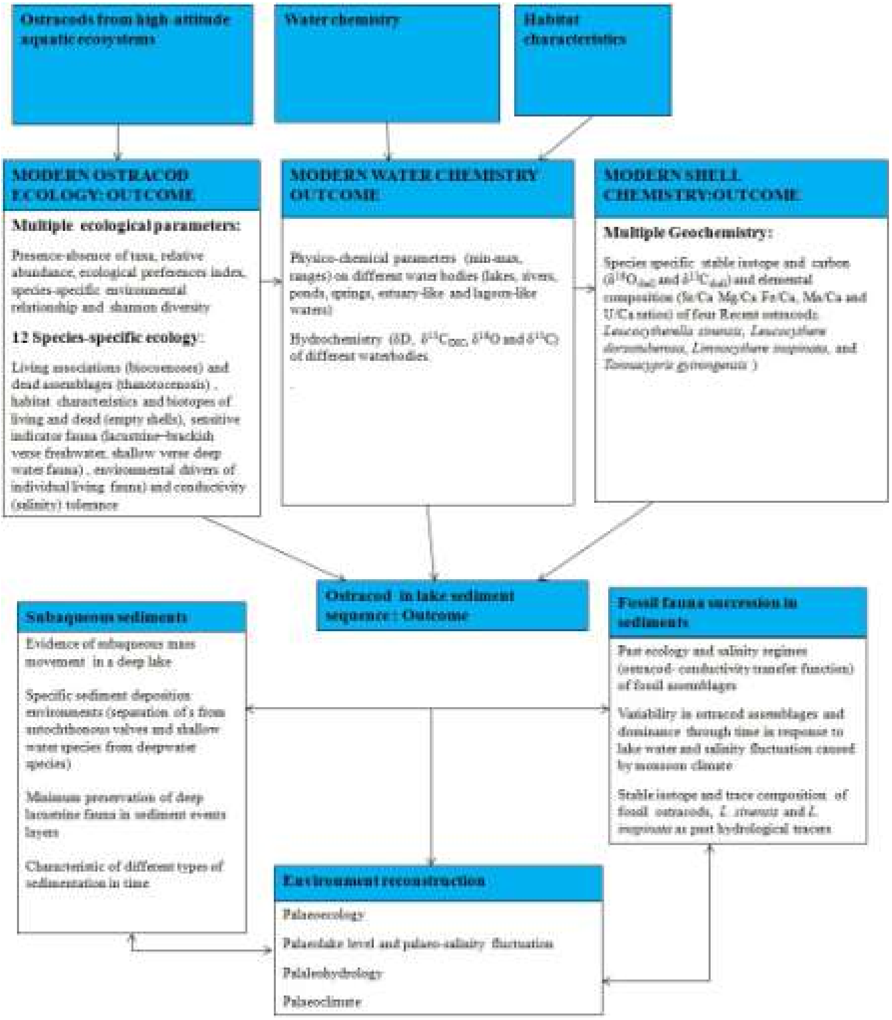

Fig. 4 Summary of research outcome: **ostracod as bioloigical indicators** for environmental reconstruction.

6.5 Future Research

“*Every action in the present prepares us for the future*.” — Lailah Gifty Akita

The existing database (ecological and geochemical data of Recent Ostracoda) is fundamental need in palaeoenlimnological investigations and will help identify long-term ecosystem changes on the southern Tibetan Plateau. Effective ecosystem management involves data management of both modern and historical records and continuing research. Long-term ecological monitoring will help to understand environmental and climate dynamics (Elliot, 1990; Smol, 1992).

The use of different methods of sampling (e.g., box corer, Birge-Ekman box corer, and plankton net) will improve the ability to detect species heterogeneity (patchiness) in spatial and temporal distribution of meiobenthic crustaceans (e.g., ostracods) (Morrisey et al., 1992).

A detailed biological taxonomy is essential for species identification and estimation of environmental data (Birks and Birks, 1980).

The physiology and reproductive strategy of Tibetan ostracods are poorly known. Life history affects morphology and dynamics of species, fossil assemblages and their interpretation (Vermeij and Herbert, 2004). Knowledge of life cycle of living Tibetan ostracods and seasonal ecology will provide information on physiological response and reproductive adaptive strategies. This is urgently needed for interpretation of variability in species-specific isotopic fractionation, vital effect

The first attempt to culture living Tibetan ostracods in the laboratory of the Institute of Geoscience, University of Jena, Germany were moderately successful; cultures survived only 2 – 3 months. There is a need for laboratory culture of living Tibetan ostracods to study their behaviour, reproductive behavior and life-span. Laboratory exposure of living Tibetan ostracods to different environmental parameters (e.g., salinity) will also help to establish ecological tolerances.

Although, calcification of carbonate calcite is assumed to equilibrium with water chemistry, disequilibrium occurs for species-specific fractionation. Knowledge about shell chemistry of living ostracods and their water chemistry will support better understanding of species-specific vital effects in biomineralisation. Inter-laboratory calibration of stable and trace element analyses of ostracod calcite is needed for accurate palaehydrological inferences. The analysed species are selected due to availability of adequate valves for shell chemistry. Laboratory test of species-specific vital effects is needed to establish a relationship of ostracod valve and water ionic chemistry, and to distinguish types of water bodies. Furthermore, geochemical analyses of multiple fossil ostracod species from the same depth (thus with adequate shell preservation), in a sediment core, will provide species-specific hydrological response in a given historical time.

The first attempt to investigate the interstitial depth-distribution of *L. inopinata* in sediment cores from lagoon-like waters connected to Tangra Yumco, indicate a depth distribution to 25 m. Analyses of additional sediment cores from this lagoon will help to establish the water-depth distribution in shallow-waters. There is a need to test the depth distribution of *L. inopinata* and associated shell chemistry; this would help understand the relationship of pore waters and lake waters. This should give a better understanding of the ostracod shell relationship with $\delta^{13}C_{DIC}$ water.

Ostracod assemblage variables (e.g., abundance, adult to valve ratio of *L. sinensis)* can successfully describe past bottom currents and mass transport (e.g., turbidities). However, reevaluation of carapace and adult valve proportions of ostracods in sediment events could provide knowledge on sediment transport origins. The mechanisms (e.g., volcanic activity) which trigger mass movement in Tangra Yumco The potential of ostracods as subaqueous sediment tracers, should be re-evaluated, by analyses of additional sediment cores from Tangra Yumco and other deep lacustrine basins on the southern Tibeta Plateau. Soil information processes (e.g., climate and organisms), must be considered in the interpretation of massive sediment deposition.

The stratigraphic and biostratigraphic sequence provided units and zones of specific depositional environment. However, a complete palaeoenvironmental inference is still unavailable due to large data gaps in sediment records induced by unfavorable environment and climate (Hardt et al., 2007; Benton, 2009). Although it constrained by missing data gaps and inadequate shell preservation (biological evidence), it is still **an essential window into the past environmental, ecological and climatic conditions**.

The Late Holocene environment and climate condition of Tangra Yumco covers the last 3,300 years. Pleistocene (longer time scale) sediment cores from Tangra Yumco must be analysed to complete understanding of the Quaternary environmental and climate changes on the southern Tibetan Plateau.

The biogeochemical processes of Tibetan lakes and their catchment are still largely unknown. The different interactions (e.g., climate, biology, hydrology, primary productivity, catchment and water column processes, etc.) that affect the function and structure of lake systems and their biota, when investigated, should provide a good understanding for precise palaeo-inferences.

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Appendix

Appendix A-1

from: Peter Frenzel Peter.Frenzel@uni-jena.de

to: Daniel Hering daniel.hering@uni-due.de

cc: Lailah Gifty Akita lailah.lailah@gmail.com

date: Tue, Feb 10, 2015 at 12:18 PM
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Peter

----- Weitergeleitete Nachricht von Daniel Hering <Daniel.Hering@uni-due.de> -----
Datum: Tue, 3 Nov 2015 13:01:17 +0100
Von: Daniel Hering <Daniel.Hering@uni-due.de>
Betreff: Re: out of office
An: Peter Frenzel <peter.frenzel@uni-jena.de>

Dear Peter Frenzel,

I confirm that your paper "Spatial distribution and ecology of the Recent Ostracoda from Tangra Yumco and adjacent waters on the southern Tibetan Plateau: a key to palaeoenvironmental reconstruction", authored by Lailah Gifty Akita, Peter Frenzel, Junbo Wang, Nicole Börner & Ping Peng, has been accepted for publication in Limnologica. It will appear in one of the next issues.

Best regards
Daniel Hering
Editor-in-chief Limnologica

Appendix A-2

from: Nicole Börner <nboerner@tu-bs.de>
to: Antje Schwalb <antje.schwalb@tu-bs.de>,
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Antwort an: Hydrobiologia (HYDR) <deepan.selvaraj@springer.com>

An: Nicole Börner <nicole.boerner@tu-bs.de>

Dear Mrs. Börner,

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Appendix A-4

from: **Quaternary Research** <kesp@u.washington.edu>

to: lailah.lailah@gmail.com,
lailahakita@uni-jena.de

date: Wed, Nov 18, 2015 at 11:05 AM

subject: Submission Confirmation

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to: lailah.lailah@gmail.com, lailahakita@uni-jena.de

date: Wed, Nov 18, 2015 at 1:18 PM

subject: A manuscript number has been assigned: YQRES-D-15-00229

Dear Mrs. Akita,

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Appendix I **Sample ID (year, month), locality, date coordinates, and physico-chemical environmental variables**

Sample ID (yr, no)	Locality	Date	Latitude (N)	Longitude (E)	Elevation (m, a.s.l)	WD	CD	WT	pH	O_2	Al
9_41	Tangra Yumco	9/6/2009	31°15'822"	86°38'571"	4554	56	12476	2.6	7.1	12.2	24.7
9_43	Tangra Yumco	9/6/2009	31°27'136"	86°65'598"	4550	8.6	12806	12.8	10.2	10.5	10.6
9_44	Tangra Yumco	9/7/2009	31°27'136"	86°65'598"	4550	110	12638	2.2	7.5	10.8	28.0
9_46	Tangra Yumco	9/7/2009	31°26'617"	86°64'262"	4550	23	12447	3.7	12.8	8.0	20.3
9_49	Tangra Yumco	9/7/2009	31°26'146"	86°63'306"	4550	13.4	12815	12.6	10.3	10.4	15.5
9_51	Tangra Yumco	9/8/2009	31°37'06"	86°66'287"	4550	0.2	12724	12.4	10.3	9.6	23.8
9_52	Tangra Yumco	9/8/2009	31°37'062"	86°66'854"	4547	0.4	12806	12.79	10.21	10.46	10.58
9_53	Tangra Yumco	9/8/2009	31°26'592"	86°63'644"	4548	0.2	77	19.8	9.2	NA	40
10_7	Tangra Yumco	9/17/2010	NA	NA	NA	0.3	10950	18.1	9.5	6.6	32.6
10_8	Tangra Yumco	9/19/2010	31°14'534"	86°42'868"	4540	223	12500	2.4	10.0	4.6	33.6
11_1	Xuru Co	9/10/2011	30°17'24"	86°27'41"	4708	0.1	975	13.5	9.6		158.0
11_2	Tangra Yumco	9/12/2011	31°26'186"	86°63'557"	4546	0.2	11900	13.2	9.8	3.9	40.0
11_4	Tangra Yumco	9/12/2011	31°25'812"	86°63'159"	4546	9.3	11870	13.6	9.6	3.2	40.0
11_6	Tangra Yumco	9/12/2011	31°23'434"	86°63'280"	4546	20.5	11880	13.5	9.6	3.5	40.0
11_7	Tangra Yumco	9/12/2011	31°23'417"	86°63'218"	4546	7.3	11850	13.3	9.7	3.9	41.0
11_10	Tangra Yumco	9/12/2011	31°26'692"	86°63'619"	4550	0.05	159	13.7	9.7	4.2	1.6

WD = water depth[m], CD = conductivity [µS/cm], water temperature [^{O}C], O_2 = dissolved oxygen concentration [mg/l], Alkalinity [mmol/l], NA = not available

Appendix I Continued

Sample ID (yr, no)	Locality	Date	Latitude (N)	Longitude (E)	Elevation (m, a.s.l)	WD	CD	WT	pH	DO	Al
11_11	Tangra Yumco	9/12/2011	31°26'623"	86°63'642"	4546	0.1	165	14.1	9.4	4.8	1.8
11_12	Tangra Yumco	9/12/2011	31°26'623"	86°63'642"	4546	0.1	165	14.1	9.4	4.8	1.8
11_13	Tangra Yumco	9/12/2011	31°15'5784"	86°38'1161"	4546	0.1	296	13.9	9.4	6.2	2.0
11_14	Tangra Yumco	9/12/2011	31°15'596"	86°38'1213"	4550	0.2	143	11.9	9.5	6.3	1.4
11_15	Tangra Yumco	9/12/2011	31°16'023"	86°38'1131"	4546	0.1	141	11.4	9.6	6.8	1.3
11_16	Tangra Yumco	9/13/2011	31°27'001"	86°.63'962"	4546	15.5	11940	12.9	9.9	4.1	39.0
11_18	Tangra Yumco	9/13/2011	31°27'158"	86°64'011"	4546	20.4	11880	13.2	9.7	3.6	45.2
11_20	Tangra Yumco	9/13/2011	31°27'295"	86°63'913"	4550	9.4	11960	13.4	9.6	4.3	39.0
11_22	Tangra Yumco	9/13/2011	31°27'834"	86°63'860"	4550	8.4	11890	13.6	9.6	3.5	40.0
11_25	Tangra Yumco	9/13/2011	31°28'021"	86°64'125"	4550	17	11900	13.1	9.6	NA	41.0
11_27	Tangra Yumco	9/14/2011	31°26'591"	86°63'638"	4546	0.05	156	11.1	10.2	4.5	40.7
11_28	Tangra Yumco	9/14/2011	31°26'591"	86°63'638"	4546	0.2	9370	13.6	10.2	7.0	40.7
11_29	Tangra Yumco	9/14/2011	31°26'668"	86°63'580"	4551	0.1	141	11.4	9.6	6.8	1.3
11_60LB	Tangra Yumco	9/16/2011	31°26'629"	86°63'649"	4552	0.5	165	15.3	10.1	5.6	1.8
11_61LB	Tangra Yumco	9/16/2011	31°26'630"	86°63'648"	4552	0.5	275	14.9	10.1	6.7	1.8
11_61LB	Tangra Yumco	9/16/2011	31°26'630"	86°63'648"	4552	0.5	275	14.9	10.1	6.7	1.8

WD = water depth[m], CD = conductivity [µS/cm], water temperature [^{O}C], O_2 = dissolved oxygen concentration [mg/l], Alkalinity [mmol/l], NA = not available

Appendix I Continued

Sample ID(yr, no	Locality	Date	Latitude (N)	Longitude (E)	Elevation (m, a.s.l)	WD	CD	WT	pH	DO	Al
11_63LB	Tangra Yumco	9/16/2011	31°26'632"	86°63'668"	4552	0.1	172	14.3	10.0	5.4	1.8
11_64LC	Tangra Yumco	9/16/2011	31°26'630"	86°63'680"	4552	0.1	163	14.0	10.0	5.1	1.8
11_65LA	Tangra Yumco	9/16/2011	31°26'649"	86°63'990"	4553	0.1	169	14.0	10.0	6.8	2.0
11_66LC	Tangra Yumco	9/16/2011	31°26'654"	86°63'703"	4553	0.1	974	15.1	10.0	9.3	1.6
11_67LC	Tangra Yumco	9/16/2011	31°26'668"	86°63'580"	4551	0.1	167	14.2	10.0	6.8	1.6
11_68LB	Tangra Yumco	9/16/2011	31°26'694"	86°.63'618"	4561	0.1	170	14.5	10.0	6.7	1.6
11_69LC	Tangra Yumco	9/16/2011	31°26'710"	86°53'585"	4561	0.1	167	13.5	10.0	7.8	1.6
11_70LA	Tangra Yumco	9/16/2011	31°26'738"	86°63'530"	4561	0.1	166	12.1	10.1	7.4	1.6
11_71LA	Tangra Yumco	9/16/2011	31°26'971"	86°63'509"	4559	0.1	181	10.9	10.0	8.9	1.6
11_72LA	Tanqung Co	9/17/2011	31°35'45"	86°42'49"	4528	0.1	1135	16.8	9.2	2.2	9.2
11_73	Tanqung Co	9/17/2011	31°35'45"	86°42'49"	4528	0.1	144800	17.2	9.7	2.0	344.0
11_74	Tanqung Co	9/17/2011	31°61'542"	86°74'274"	4517	0.1	600	16.7	10.1	5.4	4.6
11_75B	Tanqung Co	9/17/2011	31°60'109"	86°79'203"	4510	0.15	910		9.3	4.2	8.2
12_1	Xuru Co	6/14/2012	30°24'389"	86°22'326"	5091	0.2	124	12.9	8.2	4.5	1.7
12_22	Tangra Yumco	6/17/2012	30°95'028"	86°45'146"	4546	0.01	12400	13.0	9.4	6.5	55.0
12_23	Tangra Yumco	6/17/2012	30°94'983"	86°45'187"	4546	0.15	12120	17.1	9.4	5.7	57.0
12_24	Tangra Yumco	6/17/2012	30°94'861	86°44'997"	4539	0.05	32500	20.6	9.0	6.7	120.0

WD = water depth[m], CD = conductivity [μS/cm], water temperature [^{O}C], O_2 = dissolved oxygen concentration [mg/l], Alkalinity [mmol/l], NA = not available

Appendix I Continued

Sample ID (yr, no.)	Locality	Date	Latitude (N)	Longitude (E)	Elevation (m, a.s.l)	WD	CD	WT	pH	DO	Al
12_26	Tangra Yumco	6/17/2012	30°56'133"	86°26'555"	4531	0.05	12920	22.3	9.0	5.2	56.0
12_29	Tangra Yumco	6/17/2012	31°09'034"	86°48'808"	4590	0.01	5140	24.4	6.8	1.3	71.0
12_35	Tangra Yumco	6/19/2012	31°10'423"	86°57'168"	4742	0.01	314	9.4	8.0	6.2	2.6
12_36	Tangra Yumco	6/19/2012	31°10'514"	86°57'208"	4761	0.02	283	8.7	7.9	5.1	2.7
12_37	Tangra Yumco	6/19/2012	31°26'590"	86°63'638"	4546	0.05	11890	13.1	9.4	7.1	46.0
12_39	Monco Bunnyi	6/21/2012	30°36'599"	86°15'446"	4696	0.05	3860	20.6	9.5	6.1	40.5
12_40	Monco Bunnyi	6/21/2012	30°36'596"	86°15'448"	4692	0.05	1349	23.0	9.3	6.6	19.5
12_41	Monco Bunnyi	6/21/2012	30°36'591"	86°15'446"	4694	0.1	3980	25.0	9.4	7.6	32.9
12_42	Xuru Co	6/22/2012	30°23'205"	86°24'145"	4785	0.2	150	11.5	8.3	6.0	2.4
12_43	Xuru Co	6/22/2012	30°22'585"	86°24'239"	4730	0.1	3610	11.0	9.3	6.8	27.0
12_47	Xuru Co	6/22/2012	30°21'455"	86°29'114"	4738	0.08	3680	25.7	9.0	6.3	28.5
12_50	Xuru Co	6/22/2012	30°21'388"	86°29'52''	4733	0.05	3830	15.6	9.4	6.0	13.0
12_52	Xuru Co	6/23/2012	30°17'244"	86°27'421"	4727	0.09	4190	9.1	8.9	6.6	28.0
12_52	Xuru Co	6/23/2012	30°17'244"	86°27'421"	4727	0.09	4190	9.1	8.9	6.6	28.0
12_53	Xuru Co	6/23/2012	30°17'302"	86°27'443"	4727	0.1	5610	15.3	9.7	5.7	26.5
12_57	Xuru Co	6/23/2012	30°10'68''	86°26'177"	4731	0.2	178	23.6	9.3	8.6	1.4
12_58	Xuru Co	6/23/2012	30°10'5''	86°26'157"	4736	0.08	231	21.2	9.3	6.3	1.6
12_63	Xuru Co	6/24/2012	30°22'325'	86°27'880'	4720	78	4220	8.0	9.0	6.0	15.6

WD = water depth[m], CD = conductivity [μS/cm], water temperature [^{O}C], O_2 = dissolved oxygen concentration [mg/l], Alkalinity [mmol/l], NA = not available

Appendix IIa Sample ID (year, month), locality, water type, sediment type, presence of ostracods (live), phyta and other fauna (live)

Sample	Locality	Water type	Sediment type	Phytal cover	Presence of ostracods (live)	Other fauna (live)
9_41	Tangra Yumco	lake	mud			
9_43	Tangra Yumco	lake	mud	grass, 20% phytal	*L. sinensis*, *F. gyirongensis*	chironomids
9_44	Tangra Yumco	lake	mud			
9_46	Tangra Yumco	lake	mud			
9_49	Tangra Yumco	lake	mud	grass, 30% phytal		chironomids
9_51	Tangra Yumco	lake	brown mud			
9_52	Tangra Yumco	lake	sandy gravel	plants	*L. sinensis* , *L. dorsotuberosa* , *L. inopinata*	
9_53	Tangra Yumco	lake	sandy gravel	green algae	*L. sinensis* , *T. gyirongensis*	water insects
10_7	Tangra Yumco	lake	silt, plant residues			
10_8	Tangra Yumco	lake	silt			
11_1	Xuru Co	estuary	sandy gravel		*L. sinensis, Ilyocypris* sp., *T. gyirongensis*	chironomids, cladocera isopods, copepods, fish
11_2	Tangra Yumco	lake	light brown mud		*L. sinensis, L. dorsotuberosa*, *Ilyocypris* sp.	chironomids
11_4	Tangra Yumco	lake	light brown - dark yellow mud	30% phytal, potamogeton	*L. sinensis, L. inopinata*	chironomids insects
11_6	Tangra Yumco	lake	brown mud, sand		*L. sinensis*, *L. dorsotuberosa* , *L. inopinata*	
11_7	Tangra Yumco	lake	brown mud, sand	70% phytal, potamogeton	*L. sinensis* , *L. inopinata*	chironomids
11_9	Tangra Yumco	lake	medium sand, mud			
11_10	Tangra Yumco	river	gravel			chironomids
11_11	Tangra Yumco	estuary	mud, gravel, bacteria films		*T. gyirongensis*	
11_12	Tangra Yumco	estuary	mud, gravel, bacteria films	bacteria films	*T. gyirongensis*	
11_13	Tangra Yumco	estuary	mud, gravel		*T. gyirongensis*	chironomids
11_14	Tangra Yumco	river	gravel		*L. sinensis*, *T. gyirongensis*	chironomids
11_15	Tangra Yumco	river	gravel		*L. sinensis*, *T. gyirongensis*, *C. candida*	chironomids
11_16	Tangra Yumco	lake	dark - grey mud	40% potamogeton	*L. sinensis*, *L. inopinata*, *F. gyirongensis*	chironomids

Appendix IIa Continued

Sample	Locality	Water type	Sediment type	Phytal cover	Presence of ostracods (live)	Other fauna (live)
11_18	Tangra Yumco	lake	brown - dark grey mud	potamogeton	*L. sinensis*, *L. inopinata*, *F. gyirongensis*	
11_20	Tangra Yumco	lake	brown – dark grey mud	20% potamogeton	*L. sinensis*, *L. dorsotuberosa, L. inopinata*	chironomids, gammarids
11_22	Tangra Yumco	lake	brown - dark grey mud	30% potamogeton	*L. sinensis*, *L. dorsotuberosa L. inopinata* , *T. gyirongensis*	chironomids
11_25	Tangra Yumco	lake	dark - light brown mud	potamogeton	*L. sinensis, T. gyirongensis*	
11_27	Tangra Yumco	lagoon	sandy gravel			chironomids
11_28	Tangra Yumco	lake	gravel, interstitial			chironomids
11_29	Tangra Yumco	river	gravel, interstitial		*T. gyirongensis*	chironomids
11_60LB	Tangra Yumco	estuary	fine sand , silt, gravel, detritus	brown algae	*T. gyirongensis*	chironomids
11_61LB	Tangra Yumco	estuary	fine sand, gravel	green filamentous algae	*T. gyirongensis*	chironomids
11_63LB	Tangra Yumco	estuary	sandy gravel		*T. gyirongensis*	chironomids
11_64LC	Tangra Yumco	estuary	fine sand, gravel, detritus	brown algae	*T. gyirongensis*	chironomids
11_65LA	Tangra Yumco	estuary	grey - sandy gravel, (stones)		*L. sinensis, T. gyirongensis*	chironomids
11_66LC	Tangra Yumco	estuary	brown - dark grey sand	potamogeton, brown algae	*T. gyirongensis*	
11_67LC	Tangra Yumco	river	dark - grey sandy gravel		*T. gyirongensis*	
11_68LB	Tangra Yumco	river	grey sandy gravel		*T. gyirongensis*	gammarids
11_69LC	Tangra Yumco	river	sandy gravel, detritus	filamentous green algae	*L. sinensis, T. gyirongensis*	
11_70LA	Tangra Yumco	river	sandy gravel	green filamentous algae, chlorophytes	*T. gyirongensis*	
11_71LA	Tangra Yumco	river	sandy gravel			chironomids
11_72LA	Tangqung Co	spring	fine sand, mud	green algae, brown algae		chironomids
11_73	Tangqung Co	lake	grey dark sand			
11_74	Tangqung Co	river	coarse sand, gravel		*L. sinensis*	

Appendix IIa Continued

Sample	**Locality**	**Water type**	**Sediment type**	**Phytal cover**	**Presence of ostracods (live)**	**Other fauna (live)**
11_75B	Tangqung Co	pond	organic matter 100%	Kobresia, filamentous green algae, 100% phytal	*Ilyocypris* sp. *T. gyirongensis*, *C. candida, H. incongruens*	chironomids, copepods
12_1	Xuru Co	river	coarse sand,	Kobresia 10%		chironomids
12_22	Tangra Yumco	lagoon	sandy gravel, clay		*L. inopinata*	
12_23	Tangra Yumco	lagoon	sandy mud, gravel	5% phytal	*L. inopinata*	
12_24	Tangra Yumco	lake	clay limestone	potamogeton		
12_26	Tangra Yumco	lake	brown mud, clay, dark soil	40% potamogeton		chironomids,
12_29	Tangra Yumco	spring	sandy gravel, dark soil	algae (red and green)	*T. gyirongensis*	
12_35	Tangra Yumco	spring	sandy gravel, dark soil	80% grasses, algae	*T. gyirongensis*	chironomids,copepods
12_36	Tangra Yumco	spring	coarse sand	15% brown algae		
12_37	Tangra Yumco	lake	sandy gravel			
12_39	Monco Bunnyi	lake	sandy gravel			
12_40	Monco Bunnyi	lagoon	sandy gravel		*L. sinensis*, *L. inopinata*	chironomids,
12_41	Monco Bunnyi	lagoon	sandy gravel	plants, grass	*L. inopinata*	chironomids
12_42	Xuru Co	river	sandy gravel			chironomids
12_43	Xuru Co	lake	sandy gravel			

Appendix IIa Continued

Sample	**Locality**	**Water type**	**Sediment type**	**Phytal cover**	**Presence of ostracods (live)**	**Other fauna (live)**
12_47	Xuru Co	lagoon	sandy gravel	70% reddish brown algae	*L. sinensis*	chironomids
12_50	Xuru Co	lagoon	sandy gravel	brown filamentous algae	*L. sinensis*, *L. dorsotuberosa*	oligochaeta, cladocerans, chironomids
12_52	Xuru Co	lake	sandy gravel			
12_53	Xuru Co	lagoon	muddy clay, high organic content	grasses 50% potamogeton?	*Ilyocypris* sp.	
12_57	Xuru Co	pond	sandy mud	brown algae	*T. gyirongensis*, *C. candida, H. incongruens*	fishes, chironomids, oligochaeta
12_58	Xuru Co	pond	sandy gravel	plants, brown algae	*L. sinensis, T. gyirongensis*	
12_63	Xuru Co	lake	brown mud			

Appendix IIb Sample ID (year, month), locality, water type, sediment type, phyta and fauna

Sample	Locality	Water type	Sediment type	Phytal cover	Fauna
9_41	Tangra Yumco	lake	mud		
9_43	Tangra Yumco	lake	mud	grass, 20% phytal	chironomids
9_44	Tangra Yumco	lake	mud		
9_46	Tangra Yumco	lake	mud		
9_49	Tangra Yumco	lake	mud	grass, 30% phytal	chironomids
9_51	Tangra Yumco	lake	brown mud		
9_52	Tangra Yumco	lake	sandy gravel	plants	
9_53	Tangra Yumco	lake	sandy gravel	algae	water insects
10_7	Tangra Yumco	lake	silt , plant residues		
10_8	Tangra Yumco	lake	silt		
11_1	Xuru Co	estuary/lagoon	sandy gravel		Chironomids, isopods, copepods, fish
11_2	Tangra Yumco	lake	light brown mud		
11_4	Tangra Yumco	lake	light brown - dark yellow mud	30% phytal, potamogeton	chironomids insects
11_6	Tangra Yumco	lake	brown mud, sand		
11_7	Tangra Yumco	lake	brown mud, sand	70% phytal, Potamogeton	chironomids
11_9	Tangra Yumco	lake	medium sand, mud		
11_10	Tangra Yumco	river	gravel		
11_11	Tangra Yumco	estuary/lagoon	mud, gravel, bacteria films		
11_12	Tangra Yumco	estuary/lagoon	mud, gravel, bacteria films	bacteria films	
11_13	Tangra Yumco	estuary/lagoon	mud, gravel		
11_14	Tangra Yumco	river	gravel		
11_15	Tangra Yumco	river	gravel		
11_16	Tangra Yumco	lake	dark - grey mud	40% potamogeton	chironomids
11_18	Tangra Yumco	lake	brown - dark grey mud	potamogeton	
11_20	Tangra Yumco	lake	brown - dark grey mud	20% potamogeton	chironomids, Gammarids
11_22	Tangra Yumco	lake	brown - dark grey mud	30% potamogeton	chironomids

Appendix IIb Continued

Sample	Locality	Water type	Sediment type	Phytal cover
11_25	Tangra Yumco	lake	dark - light brown mud	potamogeton
11_27	Tangra Yumco	estuary/lagoon	sandy gravel	
11_28	Tangra Yumco	lake	gravel	
11_29	Tangra Yumco	river	gravel	
11_60LB	Tangra Yumco	estuary/lagoon	fine sand , silt, gravel, detritus	brown algae
11_61LB	Tangra Yumco	estuary/lagoon	finesand, gravel	green algae, filamentous
11_63LB	Tangra Yumco	estuary/lagoon	sandy gravel	
11_64LC	Tangra Yumco	estuary/lagoon	fine sand, gravel, detritus	brown algae
11_65LA	Tangra Yumco	estuary/lagoon	grey - sandy gravel, stones	
11_66LC	Tangra Yumco	estuary/lagoon	brown-dark grey sand	green plants, brown algae
11_67LC	Tangra Yumco	river	dark -grey sandy gravel	
11_68LB	Tangra Yumco	river	grey sandy gravel	
11_69LC	Tangra Yumco	river	sandy gravel, detritus	filamentous green algae
11_70LA	Tangra Yumco	river	sandy gravel	green filamentous algae chlorophytes
11_71LA	Tangra Yumco	river	sandy gravel	chironomids
11_72LA	Tanqung Co	spring	fine sand, mud	green algae, brown algae
11_73	Tanqung Co	lake	grey dark sand	
	Tanqung Co	river	coarse sand, gravel	
11_75B	Tanqung Co	pond	organic matter (100%)	Kobresia, filamentous green algae, 100% Phytal
12_1	Xuru Co	river/stream	coarse sand,	Kobresia 10%
12_22	Tangra Yumco	estuary/lagoon	sandy gravel, clay	
12_23	Tangra Yumco	estuary/lagoon	sandy mud, gravel	5% Phytal
12_24	Tangra Yumco	lake	clay limestone	potamogeton
12_26	Tangra Yumco	lake	brown mud, clay, dark soil	40% potamogeton
12_29	Tangra Yumco	river	sandy gravel, dark soil	algae (red and green)
12_35	Tangra Yumco	spring	sandy gravel, dark soil	80% grasses & algae

Appendix III Sample ID, account data for live ostracods (total valves)

Sample ID	**Ls**	**Ld**	**Il**	**Ln**	**Tg**	**Cz**	**Fg**	**Cc**	**Hc**	**Pv**
9_41	0	0	0	0	0	0	0	0	0	0
9_43	2	0	0	0	0	0	2	0	0	0
9_44	0	0	0	0	0	0	0	0	0	0
9_46	0	0	0	0	0	0	0	0	0	0
9_49	0	0	0	0	0	0	0	0	0	0
9_51	0	0	0	0	0	0	0	0	0	0
9_52	2	16	0	228	0	0	0	0	0	0
9_53	2	0	0	0	4	0	0	0	0	0
10_7	0	0	0	0	0	0	0	0	0	0
10_8	0	0	0	0	0	0	0	0	0	0
11_1	4	0	6	0	70	0	0	0	0	0
11_2	44	3	1	0	0	0	0	0	0	0
11_4	10	0	0	2	0	0	0	0	0	0
11_6	0	0	0	0	0	0	0	0	0	0
11_7	48	6	0	24	0	0	0	0	0	0
11_9	48	0	0	2	0	0	0	0	0	0
11_10	0	0	0	0	0	0	0	0	0	0
11_11	0	0	0	0	11	0	0	0	0	0
11_12	0	0	0	0	40	0	0	0	0	0
11_13	0	0	0	0	6	0	0	0	0	0
11_14	4	0	0	0	50	0	0	0	0	0
11_15	2	0	0	0	1	0	0	2	0	0
11_16	28	0	0	50	0	0	28	0	0	0
11_18	12	0	0	2	0	0	18	0	0	0
11_20	70	8	0	24	0	0	0	0	0	0
11_22	26	4	0	22	4	0	0	0	0	0
11_25	0	0	0	0	0	0	0	0	0	0
11_27	0	0	0	0	0	0	0	0	0	0
11_28	0	0	0	0	0	0	0	0	0	0
11_29	2	0	0	0	38	0	0	0	0	0
11_60LB	0	0	0	0	18	0	0	0	0	0
11_61LB	0	0	0	0	8	0	0	0	0	0
11_63LB	0	0	0	0	26	0	0	0	0	0
11_64LC	0	0	0	0	14	0	0	0	0	0
11_65LA	8	0	0	0	6	0	0	0	0	0
11_66LC	0	0	0	0	2	0	0	0	0	0
11_67LC	0	0	0	0	8	0	0	0	0	0
11_68LB	0	0	0	0	34	0	0	0	0	0
11_69LC	14	0	0	0	8	0	0	0	0	0

Ls = *L. sinensis* , Ld = *L. dorsotuberosa*, Il = *Ilyocypris* sp, Ln = *L. inopinata*, Tg = *T. gyirongensis* ; Cz = Candona *xizangensis;* Fg = *F. gyirongensis*; Cc = *candona candida*, Hc = *H. incongruens*, Pv = *Potamocypris* cf. *villosa*

Appendix III Continued

Sample ID	**Ls**	**Ld**	**Il**	**Ln**	**Tg**	**Cz**	**Fg**	**Cc**	**Hc**	**Pv**
11_70LA	0	0	0	0	0	0	0	0	0	0
11_71LA	0	0	0	0	22	0	0	0	0	0
11_72LA	0	0	0	0	0	0	0	0	0	0
11_73	0	0	0	0	0	0	0	0	0	0
11_74	4	0	0	0	0	0	0	0	0	0
11_75B	0	0	6	0	636	0	0	118	4	0
12_1	0	0	0	0	0	0	0	0	0	0
12_22	0	0	0	0	0	0	0	0	0	0
12_23	0	0	0	20	0	0	0	0	0	0
12_24	0	0	0	0	0	0	0	0	0	0
12_26	0	0	0	4	0	0	0	0	0	0
12_29	0	0	0	0	2	0	0	0	0	0
12_35	0	0	0	0	44	0	0	0	0	0
12_36	0	0	0	0	0	0	0	0	0	0
12_37	0	0	0	0	0	0	0	0	0	0
12_39	0	0	0	0	0	0	0	0	0	0
12_40	3	0	0	134	0	0	0	0	0	0
12_41	0	0	0	253	0	0	0	0	0	0
12_42	0	0	0	0	0	0	0	0	0	0
12_43	0	0	0	0	0	0	0	0	0	0
12_47	9	0	0	0	0	0	0	0	0	0
12_50	55	10	0	0	0	0	0	0	0	0
12_52	0	0	0	0	0	0	0	0	0	0
12_53	0	0	28	0	0	0	0	0	0	0
12_57	0	0	0	0	91	0	0	2	2	0
12_58	10	0	0	0	22	0	0	0	0	0
12_63	0	0	0	0	0	0	0	0	0	0

Ls = *L. sinensis*, Ld = *L. dorsotuberosa*, Il = *Ilyocypris* sp, Ln = *L. inopinata*, Tg = *T. gyirongensis*; Cz = Candona *xizangensis;* Fg = *F. gyirongensis*; Cc = *candona candida*, Hc = *H. incongruens*, Pv = *Potamocypris* cf. *villosa*

Appendix IV Sample ID, account data for dead ostracods (total valves)

Sample ID	**Ls**	**Ld**	**Il**	**Ln**	**Tg**	**Cz**	**Fg**	**Cc**	**Hc**	**Pv**
9_41	249	103	0	23	0	0	0	0	0	0
9_43	2	0	0	1	0	0	2	0	0	0
9_44	86	131	0	190	0	0	0	1	0	0
9_46	0	0	0	0	0	0	0	0	0	0
9_49	240	8	0	290	0	20	3	0	0	0
9_51	20	0	2	2	0	0	0	0	0	0
9_52	72	2	0	277	0	0	0	0	0	0
9_53	285	5	3	3	6	0	4	1	0	0
10_7	2	0	0	0	0	0	0	0	0	0
10_8	22	63	0	221	0	0	93	0	0	0
11_1	43	1	84	1	245	0	2	0	0	0
11_2	881	28	0	622	0	29	4	22	0	0
11_4	1423	82	0	1809	2	80	203	22	0	0
11_6	3351	57	0	1442	0	0	9	14	0	0
11_7	223	7	0	173	0	47	2	6	0	0
11_9	394	18	0	0	0	0	3	0	0	0
11_10	812	5	1	0	2	0	0	0	0	0
11_11	2339	55	1	10	21	0	6	9	0	0
11_12	516	25	3	2	38	0	18	0	0	0
11_13	137	10	0	6	3	0	0	120	0	0
11_14	265	7	0	2	37	0	0	0	0	0
11_15	248	12	1	1	203	0	0	3	0	0
11_16	163	6	0	193	6	9	177	0	0	0
11_18	169	8	0	184	0	97	107	9	0	0
11_20	246	5	0	180	1	51	299	1	0	0
11_22	167	6	0	277	0	0	16	1	0	0
11_25	876	44	0	1279	0	103	69	23	0	0
11_27	1160	22	4	1	1	0	0	0	0	0
11_28	52	3	2	7	1	0	0	0	0	0
11_29	328	5	2	1	104	0	2	2	0	0
11_60LB	339	2	0	29	19	0	3	0	0	0
11_61LB	246	10	0	2	3	0	0	2	0	0
11_63LB	296	1	0	0	31	0	1	0	0	0
11_64LC	343	10	0	0	35	0	0	1	0	0
11_65LA	263	7	0	0	18	7	0	10	0	0
11_66LC	322	7	0	0	8	0	2	2	0	0
11_67LC	1615	14	0	2	39	6	10	0	0	0
11_68LB	342	0	1	1	26	0	4	0	0	0
11_69LC	385	1	0	0	8	1	8	0	0	0

Ls = *L. sinensis* , Ld = *L. dorsotuberosa*, Il = *Ilyocypris* sp, Ln = *L. inopinata*, Tg = *T. gyirongensis* ; Cz = Candona *xizangensis;* Fg = *F. gyirongensis*; Cc = *candona candida*, Hc = *H. incongruens*, Pv = *Potamocypris* cf. *villosa*

Appendix IV Continued

Sample ID	**Ls**	**Ld**	**Il**	**Ln**	**Tg**	**Cz**	**Fg**	**Cc**	**Hc**	**Pv**
11_70LA	796	9	1	1	5	0	1	0	0	0
11_71LA	1156	33	0	0	32	0	3	1	0	0
11_72LA	606	14	1	6	1	0	4	0	0	1
11_73	20	0	2	0	0	0	0	0	0	0
11_74	169	2	1	0	0	0	0	0	0	0
11_75B	5	1	73	0	2191	0	0	594	18	0
12_1	10	13	0	0	0	0	0	0	0	0
12_22	0	0	0	0	0	0	0	0	0	0
12_23	21	0	488	6	16	0	0	0	0	0
12_24	1	0	0	0	7	0	0	0	0	0
12_26	863	36	0	10	2	0	0	0	2	0
12_29	48	1	0	0	2	0	0	0	0	0
12_35	8	1	0	0	58	0	0	0	0	0
12_36	0	0	0	0	0	0	0	0	0	0
12_37	0	0	0	0	0	0	0	0	0	0
12_39	0	0	0	0	0	0	0	0	0	0
12_40	55	1	0	19	0	0	0	0	0	0
12_41	752	6	0	160	0	0	0	25	5	0
12_42	0	0	0	0	0	0	0	0	0	0
12_43	0	0	0	0	0	0	0	0	0	0
12_47	0	0	0	0	0	0	0	0	0	0
12_50	723	215	3	1	0	0	2	0	0	0
12_52	0	0	0	0	0	0	0	0	0	0
12_53	0	0	0	0	0	0	0	0	0	0
12_57	217	5	1	0	975	0	0	5	0	0
12_58	11	0	0	18	4	0	0	0	0	0
12_63	1181	407	0	0	0	0	9	0	0	0

Ls = *L. sinensis* , Ld = *L. dorsotuberosa*, Il = *Ilyocypris* sp, Ln = *L. inopinata*, Tg = *T. gyirongensis* ; Cz = Candona *xizangensis;* Fg = *F. gyirongensis*; Cc = *candona candida*, Hc = *H. incongruens*, Pv = *Potamocypris* cf. *villosa*

Appendix V Sample ID, account data for dead ostracods (total valves)

Sample ID	Ls	Ld	Il	Ln	Tg	Cz	Fg	Cc	Hc	Pv
9_41	249	103	0	23	0	0	0	0	0	0
9_43	4	0	0	1	0	0	4	0	0	0
9_44	86	131	0	190	0	0	0	1	0	0
9_46	0	0	0	0	0	0	0	0	0	0
9_49	240	8	0	290	0	20	3	0	0	0
9_51	20	0	2	2	0	0	0	0	0	0
9_52	74	18	0	505	0	0	0	0	0	0
9_53	287	5	3	3	10	0	4	1	0	0
10_7	2	0	0	0	0	0	0	0	0	0
10_8	22	63	0	221	0	0	93	0	0	0
11_1	47	1	90	1	315	0	2	0	0	0
11_2	925	31	1	622	0	29	4	22	0	0
11_4	1433	82	0	1811	2	80	203	22	0	0
11_6	3351	57	0	1442	0	0	9	14	0	0
11_7	271	13	0	197	0	47	2	6	0	0
11_9	442	18	0	2	0	0	3	0	0	0
11_10	812	5	1	0	2	0	0	0	0	0
11_11	2339	55	1	10	32	0	6	9	0	0
11_12	516	25	3	2	78	0	18	0	0	0
11_13	137	10	0	6	9	0	0	120	0	0
11_14	269	7	0	2	87	0	0	0	0	0
11_15	250	12	1	1	204	0	0	5	0	0
11_16	191	6	0	243	6	9	205	0	0	0
11_18	181	8	0	186	0	97	125	9	0	0
11_20	316	13	0	204	1	51	299	1	0	0
11_22	193	10	0	299	4	0	16	1	0	0
11_25	876	44	0	1279	0	103	69	23	0	0
11_27	1160	22	4	1	1	0	0	0	0	0
11_28	52	3	2	7	1	0	0	0	0	0
11_29	330	5	2	1	142	0	2	2	0	0
11_60LB	339	2	0	29	37	0	3	0	0	0
11_61LB	246	10	0	2	11	0	0	2	0	0
11_63LB	296	1	0	0	57	0	1	0	0	0
11_64LC	343	10	0	0	49	0	0	1	0	0
11_65LA	271	7	0	0	24	7	0	10	0	0
11_66LC	322	7	0	0	10	0	2	2	0	0
11_67LC	1615	14	0	2	47	6	10	0	0	0
11_68LB	342	0	1	1	60	0	4	0	0	0
11_69LC	399	1	0	0	16	1	8	0	0	0

Ls = *L. sinensis* , Ld = *L. dorsotuberosa*, Il = *Ilyocypris* sp, Ln = *L. inopinata*, Tg = *T. gyirongensis* ; Cz = Candona *xizangensis;* Fg = *F. gyirongensis*; Cc = *candona candida*, Hc = *H. incongruens*, Pv = *Potamocypris* cf. *vill*

Appendix V Continued

Sample ID	Ls	Ld	Il	Ln	Tg	Cz	Fg	Cc	Hc	Pv
11_70LA	796	9	1	1	5	0	1	0	0	0
11_71LA	1156	33	0	0	54	0	3	1	0	0
11_72LA	606	14	1	6	1	0	4	0	0	1
11_73	20	0	2	0	0	0	0	0	0	0
11_74	173	2	1	0	0	0	0	0	0	0
11_75B	5	1	79	0	2827	0	0	712	22	0
12_1	10	13	0	0	0	0	0	0	0	0
12_22	0	0	0	0	0	0	0	0	0	0
12_23	21	0	488	26	16	0	0	0	0	0
12_24	1	0	0	0	7	0	0	0	0	0
12_26	863	36	0	14	2	0	0	0	2	0
12_29	48	1	0	0	4	0	0	0	0	0
12_35	8	1	0	0	102	0	0	0	0	0
12_36	0	0	0	0	0	0	0	0	0	0
12_37	0	0	0	0	0	0	0	0	0	0
12_39	0	0	0	0	0	0	0	0	0	0
12_40	58	1	0	153	0	0	0	0	0	0
12_41	752	6	0	413	0	0	0	25	5	0
12_42	0	0	0	0	0	0	0	0	0	0
12_43	0	0	0	0	0	0	0	0	0	0
12_47	9	0	0	0	0	0	0	0	0	0
12_50	778	225	3	1	0	0	2	0	0	0
12_52	0	0	0	0	0	0	0	0	0	0
12_53	0	0	28	0	0	0	0	0	0	0
12_57	217	5	1	0	1066	0	0	7	2	0
12_58	21	0	0	18	26	0	0	0	0	0
12_63	1181	407	0	0	0	0	9	0	0	0

Ls = *L. sinensis*, Ld = *L. dorsotuberosa*, Il = *Ilyocypris* sp, Ln = *L. inopinata*, Tg = *T. gyirongensis* ; Cz = Candona *xizangensis;* Fg = *F. gyirongensis*; Cc = *candona candida*, Hc = *H. incongruens*, Pv = *Potamocypris* cf. *villosa*

Curriculum Vitae

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Date of birth	4th May 1982.
Sex	Female.
Marital Status	Married.
Described as	Passionate, innovative and collaborative.
Objective	To gain in-depth knowledge in **Marine benthic ecology, Meiobenthology** and **Geosciences**.
Professional Interest	Oceanography, benthic ecology and climate change.
Expert Fields	Ecology of Tibetan ostracods (aquatic arthropods), Ecology of Ghanaian *Donax* clams and Palaeoecology and palaeoclimate.
Computer Skills	Microsoft's (Word, Excel, PowerPoint, Forecasting Regressing Excel) Primer 6, Statistical Package for Social Sciences (SPSS), PAST and Canoco 5.

Education	**Institution**	**Award**
2011 to date	Friedrich Schiller University Jena	PhD in Geosciences- **yet to be awarded**.
2010	United Nations Institute for Training and Research	Certificate E –International Environmental Law.
2005 – 2008	University of Ghana, Legon – Accra	MPhil in Oceanography.
2008 – 2009	Bermuda Institute of Ocean Sciences (BIOS)	Postgraduate certificate in Ocean Observatories.
2000 – 2004	Kwame Nkrumah University Of Science And Technology (KNUST), Kumasi.	BSc. (Hons) Renewable Natural Resource Management.
1995 – 1997	Ghana Secondary School, Koforidua.	Senior Secondary School Certificate Examination (SSSCE).

Work experience for Past 6 years

October 2012-March 2013	Research visit at University of Minnesota, USA; Ostracoda shell chemistry (trace and isotopes) analyses and participation in isotope geology course.
June 2011 to date	**PhD student** at Friedrich Schiller University – International Max Planck Research School for Global Biogeochemical Cycles: http://www.imprs-gbgc.de/index.php/People/LailahGiftyAkita Research on Ostracoda (small bivalve) ecology in high-mountain aquatic ecosystems on southern Tibetan Plateau. Ostracod-based palaeoenvironmental reconstruction (ecology, lake water-level and salinity) of large brackish lake, Tangra Yumco on the south Tibetan Plateau.
September 2010	Participated in National Oceanic and Atmospheric Administration (NOAA) –- Department of Marine Fisheries, University of Ghana, initiative to address marine debris in Ghana: Ocean science awareness in schools, involvement of pupils in marine data collection, documentation, and beach cleanup.
April 2010	To understand environmental contaminants (e.g., persistent organic pollutants) in coastal waters of Ghana; participated in sampling of water and sediments at Volta lake, Korle and Chemu lagoons, Pantang dumping site and e-waste site at Agbogbloshie. Plastic pellets collection at Korle, Chemu and Sakumono beaches organised by researchers from University of Agriculture, Tokyo, Japan and Department of Agriculture, University of Ghana.

Conference (selected)

September-October 2014	Joint AWI-SAHFOS summer school on the biological and societal implications of climate change' at Alfred Wegener Institute's Biologische Anstalt Helgoland, Germany.
December 2012	NF-POGO Alumni Network for Oceans (NANO), African project workshop monitoring of coastal pollution and erosion Africa Workshop.Dakar, Senegal.
November 2012	Geological Society of America (GSA) Annual Meeting, Charlotte, North Carolina, USA.
May 2012	Workshop on Atmospheric Deposition: Processes and Environmental Impact. The Abdus Salam International Centre for Theoretical Physics (ICTP), Trieste, Italy.
July 2011	7th European Ostracodologists' Meeting (EOM7), workshop on Northern hemisphere Quaternary and modern nonmarine Ostracoda I" and methods in ostracodology 2, Graz, Austria.
November 2010	Volkswagen Foundation Conference on 'Our Common Future' – Global Young Faculty Climate Group, Hannover – Essen, Germany.

Awards (selected)

2015	Postdoctorate fellowship by Volkswagen Foundation (will commence after defence of PhD).
January 2015	British Council Connecting classroom project: Kiddy Kare School, Abokobi-Ghana & Eaglery Junior High, Bolton United Kingdom.
December 2014	Small Grant for ocean science outreach by Nippon Foundation – Partnership for Observation of Global Oceans (NF–POGO).
September-October 2014	The first AWI-SAHFOS Summer School on time series, their analysis and socio-economic Importance POGO Summer School.
June 2011 to May 2014	PhD Fellowship by International Max Planck Research School for Global Biogeochemical Cycles.

Other Activities (selected)

	Student member- International Association of Limngeology
2012 to date	**Member** – International Association of Limnogeology.
2011 to date	**NF – POGO Alumna**: www.nf-pogo-alumni.org.
2009 to date	**Founder/Executive Director** – Smart Youth Volunteers Foundation.

2005 to date
2005 to date

Educational Project Coordinator – Kiddy Kare Nursery and Preparatory School, Abokobi.

Publications

Peer reviewed Journals

Akita, L.G., Frenzel, P., Haberzettl, T., Kasper, T., Wang, J. (2015): Lacustrine ostracods as indicators of subaqueous mass movements - an example from a large brackish lake, Tangra Yumco, Tibetan Plateau, China. *Palaeogeography, Palaeoclimatology, Palaeoecology, 419: 60–74*. Doi:10.1016/j.palaeo.2014.08.003.

Hosoda, J., Ofosu-Anim, J., Sabi,B., E., **Akita, L.G.,** Onwona-Agyeman, S., Yamashita, R. (2014): Monitoring of PCBs in Ghana by combination of pellet watch with sediment analysis: E-waste as a source of PCBs. *Marine Pollution Bulletin 38 (1-2): 575-581.*

Akita, L.G., Frenzel, P., Wang, J., Börner, N., Peng, P. *(In press*). Spatial distribution and ecology of the Recent Ostracoda of the Tangra Yumco and adjacent waters on the southern Tibetan Plateau; A key to palaeoenvironmental reconstructions. *Limnologica Journal.*

Börner, N., de Baere, B., **Akita, L.G.,** Francois, R., Jochum, K.P., Frenzel, P., Zhu, L., Schwalb, A., *submitted.* Calibration of valve geochemistry of Recent ostracods from the Tibetan Plateau, China. *Hydrobiologia.*

Akita, L.G., Frenzel, P., Kasper, T., Haberzettl, T., Peng, P., Wang, J., Ito, E., Gleixner, G., (Submitted). Ostracods as indicators of Late-Holocene environmental and climatic changes in Tangra Yumco on the southern Tibetan Plateau. *Quaternary Research.*

Abstracts (selected)

Akita, L.G., Frenzel, P., Börner, N., Wang, J., Peng, P., Habertzettl, T. (2015). Ostracods as indicators of subqueous sediment transport in a deep lake, Tangra Yumco, Tibetan Plateau. 8th European Ostracodologists' Meeting, 22-30 July, Tartu, Estonia. p.12 [Poster].

Akita, L.G., Frenzel, P., Börner, N., (2013): The Recent Ostracod fauna of Tangra Yumco lake system, central Tibetan Plateau. - 17th International Symposium on Ostracoda. 23-29 July, Rome, Italy IL Naturalista Siciliano, pp. 27-30. [Extended abstract] [Poster]

Akita, L.G., Frenzel, P., Börner, N., Wang, J., Peng, P. (2012): Distribution of Recent Ostracoda and their use in palaeoenvironmental reconstruction of Tangra Yumco, central Tibetan Plateau environmental significance as proxies for lake systems and monsoon changes on the Tibetan Plateau. Geological Society of America (GSA) Annual Meeting 2012, 3-7 November Charlotte, North Carolina, USA. [Oral].

Akita, L.G., Frenzel, P., Börner, N., Wang, J., Peng, P., Habertzettl, T. (2012): Palaeoclimte and lake level changes in the Tangra Yumco, Tibet: An ostracods perspective. — West African Quaternary Research Association, 3rd International Workshop: 8-12 October, Ghana. pp.7-8. [Oral].

Akita, L.G., Frenzel, P., Börner, N., Wang, J., Peng, P., Habertzettl, T. (2012). Distribution of Recent Ostracoda and their use in palaeoenvironmental reconstruction of Tangra Yumco, central Tibetan Plateau. — Kölner Forum für Geologie und Paläontologie, 21 (VIEHBERG, F.A. & GROMIG, R. (Hrsg.), 14th International German Ostracodologists' Meeting, 11-12 October.p. 4; Köln. [Oral].

Akita, L.G., Frenzel, P., Börner, N. (2012 a): The Recent Ostracod fauna of Tangra Yumco lake system, central Tibetan Plateau 17th International Symposium on Ostracoda. 23-29 July, Rome, Italy. [Poster].

Newsletters

Akita, L.G.(2015). Report on the Joint AWI-SAHFOS Summer School. NF-POGO Alumni E-Newsletter, Volume 08, May 2015, pp 26-27. http://www.nf-pogo-alumni.org/NANO+Newsletter

Akita, L.G., Frenzel, P., Fürstenberg, S., (2014): Impact of Climate Change on Water Resources of the Tibetan Plateau, China. NF-POGO Alumni E-Newsletter, Volume 06, April 2014. pp 2-3, 10. http://www.nf-pogo-alumni.org/NANO+Newsletter

Akita, L.G., Frenzel, P., Takada, T., Koike, T., Ofosu-anim, J., Sabi, E.B. (2012): Thecamoebians and ostracods from Holocene sediment of Volta lake, Ghana. NF-POGO Alumni E-Newsletter, Volume 03, October 2012. http://www.nf-pogo-alumni.org/NANO+Newsletter

Scientific books

Akita, L.G., Andersson, A (2015): The effects of elevated carbon dioxide concentrations on the growth of flat tree oyster, *Isognomon alatus*. ISBN 978-3-659-58986-7. LAP Lambert Academic Publishing, 90 pp.

Akita, L.G., Laudien, J., Armah, K. (2014): Population Dynamics and Ecology of *Donax pulchellus* and *D. rugosus* (Bivalvia: Donacidae) at exposed sandy beaches in Ghana. ISBN 978-659-54304-3. LAP Lambert Academic Publishing, 136 pp.

Inspirational books

Akita, L.G. (2015).The Wings of Hope: Survivor. ISBN-13: 978-1502985750. CreateSpace Publishing. 94 pp.
Akita, L.G. (2014). Think Great: Be Great! Beautiful Quotes. ISBN-13: 978-1502830999. CreateSpace Publishing. 128 pp.
Akita, L.G. (2014). The Alphabet of Success. ISBN-13: 978-1502764836. CreatSpace Publishing. 60 pp.
Akita, L.G. (manuscript): Beautiful Quotes.
Akita L.G. (manucript): Pearls of Wisdom: Great Mind.

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Jena, 15th March 2016

Lailah Gifty Akita

Selbständigkeitserklärung
Statement of authorship

Ich erkläre, dass ich die vorliegende Arbeit selbständig und unter Verwendung der angegebenen Hilfsmittel, persönlichen Mitteilungen und Quellen angefertigt habe.

I declare that I have written this dissertation independently and using the specified tools, personal communication and literature sources.

Jena, 15th March 2016

Akita

Lailah Gifty Akita

The light of knowledge by Lailah Gifty Akita

I yearned and searched for the light,

On my quest to find the light of knowledge,

I traveled to the city of light,

I journeyed onward to the Holy Mountains full of lights,

I encountered great souls with full radiance of the light,

The spark of light illuminated my path, renew mind and rekindle spirit,

Now, I am a beacon of the light of knowledge,

And I carry my candle of light to brighten the world.

Jena, 15th March 2016

Akita

Lailah Gifty Akita

“*While the earth remains, seedtime and harvest, cold and heat,*

summer and winter, day and night, shall not cease.”

~ Genesis 8: 22