Current Research

Chironomidae (Diptera) in the Himalayan Lakes – A study of sub-fossil assemblages in the sediments of two high altitude lakes from Nepal

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Abstract

Chironomid head capsules were identified from sediment cores taken from Lake Gokyo (4750 m) and Lake Gosaikunda (4350 m) in the east-central Himalaya, to determine taxonomic composition of chironomid assemblages over time. The sedimentation rate of Lake Gosaikunda was estimated at 0.05 cm/yr and that of Gokyo was estimated at 0.07 cm/yr by ^{210}Pb and ^{137}Cs dating. *Micropsectra* sp. was dominant in the sediments of both lakes. Lake Gokyo sediments also contained *Pseudodiamesa* sp., *Eukiefferiella/Tvetenia* sp., *Orthocladius/Cricotopus* sp. and *Rheocricotopus* sp. The concentration of headcapsules was nearly an order of magnitude greater in the Lake Gosaikunda core, which contained mostly *Micropsectra* sp. and *Pseudodiamesa* sp. These taxa are typical of cold oligotrophic lakes. Differences in lake depth, dissolved minerals, plus epi- and hypolimnetic temperature and dissolved oxygen suggest that stratification and temperature-induced increases in primary production may affect chironomid assemblages in these pristine lakes. Palaeolimnological studies of Himalayan lakes should include replicate cores within lake, to increase headcapsule sample sizes given potentially high rates of sedimentation from glacial runoff.

Introduction

High-altitude lakes are considered to be very sensitive to climate change (Parry et al. 2007). Climate change is an especially pressing environmental issue for a country like Nepal with its location in the Central Himalaya. The normal seasonal pattern of monsoon rainfall appears to be changing, but there is little data on variation in the form and amount of precipitation across the Himalaya, and consequently much uncertainty about the fate of Himalayan glaciers in the face of climate warming (Bolch et al. 2012). Shrinkage of many of these glaciers affects the discharge of rivers and lakes in the region. Palaeolimnological techniques present the possibility to infer change in environmental conditions over time, such as lake water temperature (Walker et al. 1991) using sub-fossil chironomid head capsules preserved in lake sediments. However, climate reconstruction modeling requires a calibration dataset based on samples of chironomid head capsules from a large number of lakes spanning a gradient of average temperature. The strong association between lake temperature and lentic chironomid distribution has been well-established by numerous calibration datasets from Western Europe and the Nearctic (Eggermont and Heiri 2011). A calibration dataset for Nepalese lakes has not yet been constructed: this study represents a necessary first step towards establishing the relationship between chironomid assemblages and temperature for Himalayan lakes by sampling two remote very high altitude lakes. There is hardly any information available on chironomid assemblages and temperature for Himalayan lakes and this study is therefore a necessary first step, based on which several other high altitude lakes are planned to be studied in the future.

The chironomid fauna of the high altitude lakes in the Nepalese Himalaya in particular are poorly known. This is due to the physical difficulty in reaching these lakes, as well as government restrictions on access. Fortunately, most of the high altitude lakes in Nepal are protected by law and categorized as National Parks and Nature Reserves and thus have experienced relatively little direct human disturbance. Limnological studies in the Nepal Himalaya have focused on low altitude lakes (Bhandari 1993; Swar 1980) due to the visible impact of nutrient enrichment and eutrophication. In contrast, the water chemistry of high-elevation lakes is mainly determined by weathering of rocks (Tartari et al. 1998); similar high altitude lakes in Sikkim and Kashmir (Zutshi1991; Khan and Zutshi 1980; Sharma and Pant 1979) exhibited very low concentrations of dissolved nutrients and minerals and also low phytoplankton abundance.

Previous studies of the chironomid fauna of nine Himalayan lakes, located at altitudes from 4830 m to 5580 m, were conducted by Manca et al. (1998), Reiss (1968), Roback and Coffmann (1987), and Loeffler (1969). The first detailed study on morphometry, bathymetry, physico-chemical, and biology of high altitude lakes in Nepal was provided by Lami et al. (1998), and included a palaeolimnological component. The World Wildlife Fund/ Nepal (2010) reported the first survey of the Lake Gokyo Series, including bathymetrics, sediment-dating and a description of the chironomid fauna.

The aim of this study was to describe the subfossil chironomids assemblages in sediments from the deepest part of two high-elevation Himalayan lakes, in conjunction with temperature and oxygen measurements. These data establish the distribution of lentic chironomid taxa at the low-temperature/high elevation extreme and thus contribute to the construction of a calibration dataset specific to the Himalayan region.

Materials and Methods

Study sites

Two lakes in the main Himalayan range were studied: Gokyo ("Third Lake") which lies in the eastern zone of Everest National Park, and Lake Gosaikunda, lying in the central zone of Langtang National Park (Figure 1, Table 1). Lake Gokyo is fed by drainage from Ngozumba glacier and springs from Renjo La Pass to the north-west. Although there are four other major lakes in the headwaters of Kosi River system, they have no surface-water connection to Lake Gokyo. Lake Gosaikunda is fed by snowmelt and by a perennial spring source to the north-east, considered a holy place by Hindus and Buddhists. There are many lakes in the series connecting Lake Gosaikunda with the River Trisuli in the Gandaki river system. The geology surrounding the lake consists mostly of exposed bedrock and glacier debris (Bortolami 1998). The lake bottom is composed of silt-clay sediment in the deeper water and sand-silt in the littoral zone. The average minimum temperature in the Everest region of these high-altitude lakes is -7.7^{o}C in January, and the average maximum temperature is 16.2^{o}C in August (Tartari et al. 1998). Vegetation in the catchment is sparse but consists of juniper, rhododendron and herbs.

Bathymetric maps of the lakes were compiled using GIS software from sounding data collected us-

Figure 1. Location map and photos of the study area (not in scale). Lake Gokyo (Mt. Everest National Park) is shown to the right and Lake Gosaikunda (Langtang National Park) to the left.

ing a GPS (Garmin Venture SC) in tandem with an Ecosounder model PLASTIMO ECHOTEST II (Sharma et al. 2011). Sediment samples were collected from the deepest part of the lakes (Figure 2) using a Uwitec gravity corer, Ø 60mm diameter (http://www.uwitec.at) operated from an inflatable boat. Sediment dating was performed by analysis of ^{210}Pb and ^{137}Cs isotopes at the Tibetan Plateau Research Institute of the Chinese Academy of Sciences in Beijing (WWF/Nepal 2010). Two core samples were collected from Gokyo Lake, and one from Gosaikunda Lake; cores were cut into 5 mm slices and transported in an ice box. Only the core 2 was actually dated from Lake Gokyo.

Chironomid head-capsule analysis

Although the chitin head capsule of chironomid larvae may remain preserved in lake sediments for thousands of years, they are usually lacking delicate morphological features; yet they can be identified to genus level, or at least grouped into consistent morphotypes. Extraction of head capsules from sediment samples followed the methods of Walker (2001) for air dried sediment samples, but with slight modifications. Samples were deflocculated in 10% KOH overnight (up to 18 hrs) without heating. The sediment was then passed through a 100µm mesh sieve and chironomid head capsules were removed by a fine probe under a stereomicroscope at 40×. After dehydration in 95% ethanol, head capsules were slide-mounted in Euparal. Identifications were made at 400×, based on the keys of Wiederholm (1983), Roback and Coffmann (1987), Walker (2007), and Brooks et al. (2007). Head capsules with a complete mentum or two corresponding halves were counted as one individual. Slides are retained at the Aquatic Ecology Centre of the School of Science, Kathmandu University.

Table 1. Parameters of Lake Gokyo, sampled May 2009, and Lake Gosaikunda, sampled October 2010 (Aquatic Ecology Centre, Kathmandu University, personal communication).

Name of lake	Gokyo	Gosaikunda
Coordinates	86°41'N	28°5′N
	27°57' E	85°25′ E
Elevation	4750 m	4426 m
Surface area	42.9 ha	13.8 ha
Max. depth	42.0 m	24.0 m
Temp (top/bottom)	8.0/4.5 ºC	9.2/7.5 ºC
DO (top/bottom)	8.3/6.3 mg/L	6.1/3.6 mg/L
Na	0.37 mg/L	1.93 mg/L
K	0.26 mg/L	1.80 mg/L
Fe	0.78 mg/L	0.80 mg/L

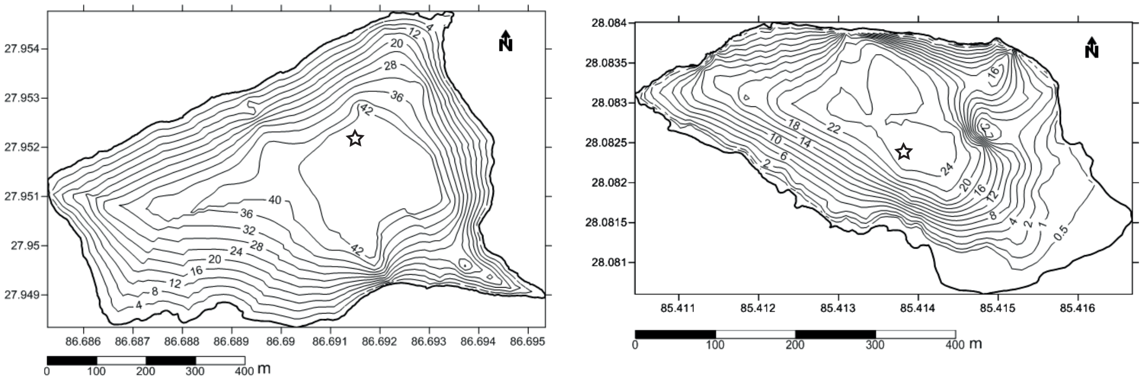

Figure 2. Bathymetric map of Lake Gokyo (left) and Lake Gosaikunda (right). Stars indicate sites where the sediment cores were taken.

Results

In Lake Gosaikunda, the number of head capsules per sub-sample within the core ranged from 62 to 175, whereas in Lake Gokyo the concentration of head capsules was lower, from 7 to 41 per subsample of core 1 and from 8 to 30 for core 2 (Figure 3). In Lake Gokyo, numbers decreased from the sediment surface to 4 to 5 cm depth; density then started to increase towards 6 cm depth, and then decreased at 15 to 10 cm depth in core 2. The natural sedimentation rate in Lake Gokyo was estimated at 0.07 cm, and in Lake Gosaikunda as 0.05 cm per annum on average. Extrapolation of this value to the sediment cores suggests that cores from Lake Gokyo might represent a time span of approximately 140 years, and that of Lake Gosaikunda as 1000 years. However, a single core does not necessarily reflect sediment loading for the lake as a whole (Lami et al. 1998).

The sub-fossil chironomid assemblage in Lake Gokyo was dominated by *Micropsectra* sp. (Tanytarsini) and Orthocladiinae, with some *Pseudodia-*

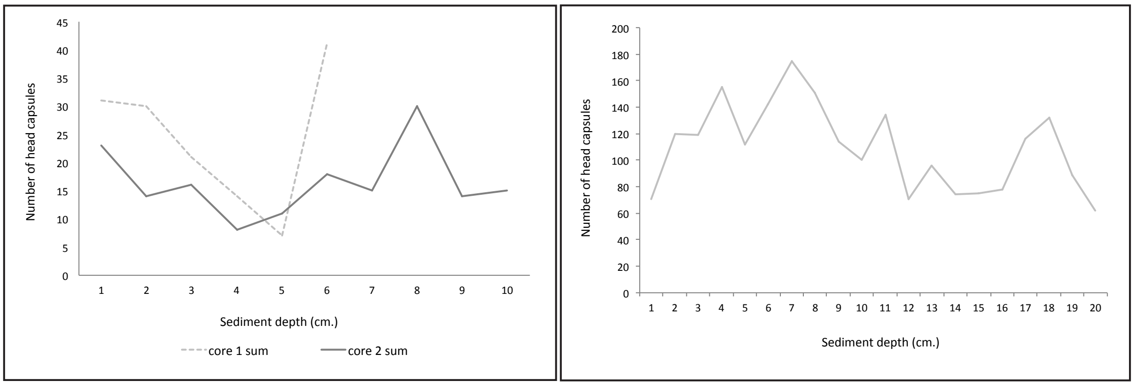

Figure 3. Head capsules count in two different cores from Lake Gokyo (left), and single core in Lake Gosaikunda (right).

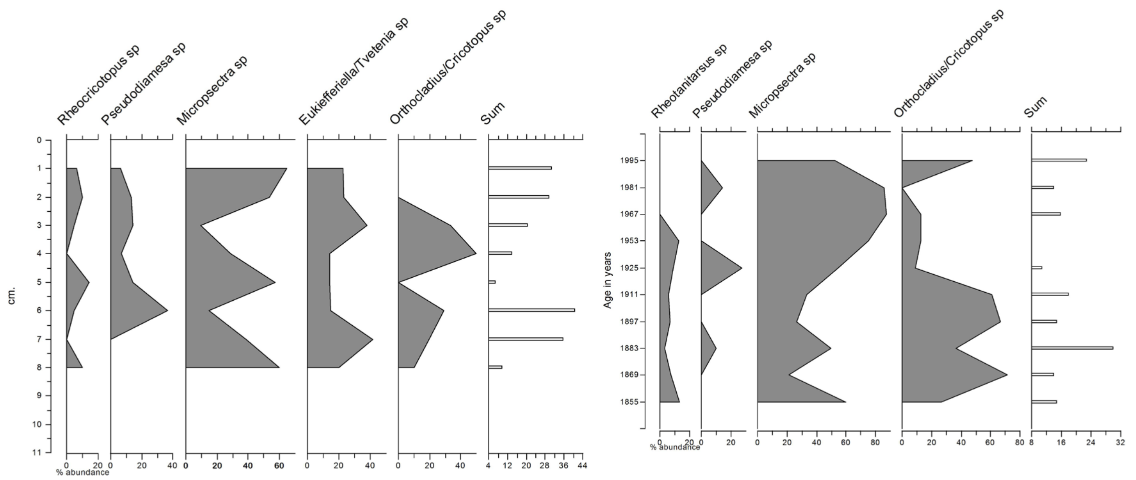

Figure 4. Chironomid stratiography of Lake Gokyo in core 1 (left), and core 2 (right). Chironomid taxa are given as % abundance; sum represents the total number of head capsules.

mesa (Diamesinae; Figure 4). The Orthocladiinae were represented by an *Orthocladius* / *Cricotopus* morphotype and an *Eukiefferiella* / *Tvetenia* morphotype. The remaining orthoclad, *Rheocricotopus* sp. was distinctive and was found in both of the Gokyo cores. In contrast, Lake Gosaikunda was dominated by *Micropsectra* sp. followed by *Pseudodiamesa* sp. (Figure 5) with occasional occurrence of *Orthocladius* sp.

Discussion

The greatest difference in chironomid assemblages was seen in the concentration of head capsules in the sediment cores, which was almost an order of magnitude greater in Lake Gosaikunda (Figures 4, 5). This may be due to greater sedimentation rates in Lake Gokyo, which receives direct glacial meltwater. The trend of lower numbers of head capsules at shallower sediment layers might possibly reflect increased sedimentation from glaciers, which have generally been receding in the central and eastern Himalaya (Bolch et al. 2012). The three cores from these two lakes were more similar in terms of relative abundance of chironomid taxa. The Sørensen distance (based on relative abundance data) between the two assemblages from Lake Gokyo was 34.5%, whereas the distances between the Lake Gosaikunda assemblage and those of Lake Gokyo cores 1 and 2 were slightly

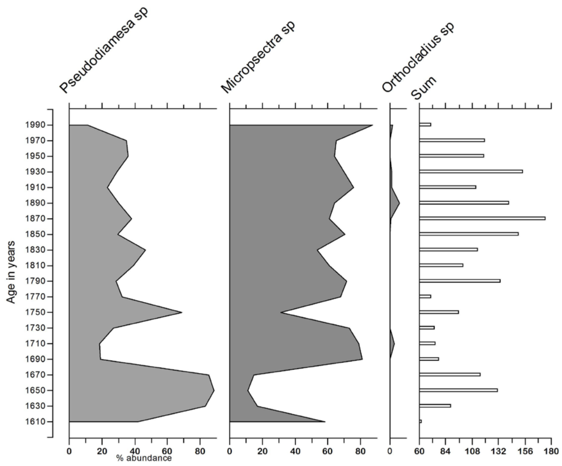

Figure 5. Chironomid stratiography of Lake Gosaikunda. Taxa are given as % abundance and sum represents the total number of head capsules.

larger at 47.4% and 41.0% respectively. Overall, *Micropsectra* sp. was dominant and composed up to half of the individuals per core in both lakes (Table 2). *Pseudodiamesa* was sub-dominant in Lake Gosaikunda (41%), whereas in Lake Gokyo *Orthocladius*/*Cricotopus* was subdominant.

In the Nepal Himalaya above 2000 m, Roback and Coffmann (1987) reported *Micropsectra* sp. as the dominant Chironominae. Manca et al. (1998) also found *Micropsectra* larvae in 27 lakes out of 28 studied, located between 4532 m and 5580 m in the Everest National Park. They believed that there were at least two forms of *Micropsectra* larvae in the region, the most widespread being similar to other undescribed species reported by Roback and Coffmann (1987). Hamerlik et al. (2010) reported *Micropsectra* sp. as the most abundant taxon in the Tibetan lakes they studied, and considered this to represent a species close to *Micropsectra nepalensis* Sawedal, as described in Roback and Coffmann (1987). Across the Holarctic, *Micropsectra* is typical of cold, unproductive lakes (Eggermont and Heiri 2011).

Pseudodiamesa is also a dependable indicator of cold temperature lakes in the Holarctic (Eggermont and Heiri 2011). *Pseudodiamesa* sp. in this study probably represent *Pseudodiamesa* (*Pachydiamesa*) *nepalensis* Reiss as reported by Reiss (1968) above 5000 m a.s.l. in the Nepal Himalaya. Manca et al. (1998) mentioned that in the Himalaya *P. nepalensis* probably replaces both *P. nivosa* (Goetghebuer), which is wide-spread in the palaearctic region, and *P. branickii*, a Holarctic species found at 850-2500 m elevation, and at higher elevations in Central Asia and Nepal (Pagast, 1947; Sæther, 1968).

Manca et al. (1998) reported Orthocladiinae as fairly common and in the Everest region, and composed of three genera, of which the commonest is *Cricotopus*. However, samples of adult chironomids made during this survey contained *Orthocladius* sp. but not *Cricotopus* sp. *Acricotopus* and *Pseudosmitta* were also reported by Löffler (1969) in the region at lower altitudes between 2500-2600 m. *Rheocricotopus* found in both the cores from Lake Gokyo is also reported by Hamerlik et al. (2010) from Sharmar Tso Lake in Tibet.

Given that both lakes are fed by glacial meltwater and/or snowmelt in landscapes dominated by bare rock and glacial debris, it is likely that a combination of high sedimentation and low primary production rates explain the low abundance and taxonomic composition of chironomid head capsules in these lakes. Higher concentrations of head capsules obtained from Lake Gosaikunda may reflect the morphometry of Lake Gosaikunda which has a smaller surface area and is almost half as deep than Lake Gokyo (Table 1). Though Lake Gosaikunda was sampled in October (vs. May for Lake Gokyo) the surface water temperatures of the two lakes differed by little more than a degree; in contrast the bottom water of Lake Gosaikunda was three degrees warmer and contained only 57% as much dissolved oxygen compared to Lake Gokyo (Table 1). These data, together with higher concentrations of dissolved Sodium and Potassium from weathering, suggest that Lake Gosaikunda supported slightly higher productivity of chironomids, due to warmth and possibly autochthonous production. Lake depth, the degree of stratification and hypolimnetic oxygen deficit may relate to the differences in chironomid assemblages observed (Heiri et al. 2003; Velle et al. 2010).

The low and variable concentration of head capsules, especially in the Lake Gokyo cores, creates uncertainty in interpretation of the shifts in chironomid composition observed. This variation may reflect changes in silt load from glacial melt-water. In general, it is more difficult to infer recent temperature change, because variation in local environmental factors masks our ability to detect small temperature changes of only a couple of degrees (Velle et al. 2010, Velle et al. 2012, Eggermont & Heiri 2012). Lake morphometry influences variation in sediment cores, due to eco-

Table 2. Relative abundance (in %) of chironomid taxa recorded in the lake sediments of both the lakes.

Taxon	Lake Gokyo		Lake Gosaikunda
	core 1 (6 cm)	core 2 (10 cm)	(20 cm)
Eukiefferiella/*Tvetenia* sp.	25	0	0
Micropsectra sp.	38	53	58
Orthocladius /*Cricotopus* sp.	18	37	0
Orthocladius sp.	0	0	1
Pseudodiamesa sp.	14	5	41
Rheocricotopus sp.	5	5	0

logical responses of chironomid taxa to depth and development of the littoral zone and stratification (Heiri et al. 2003). Chironomid calibration datasets are commonly based on single cores from the deepest part of the lake. A comparison of within-lake spatial variability in chironomid assemblages and its impact on temperature modeling found significant heterogeneity among cores from the deepest part of five lakes, as well bias due to change in assemblage structure in cores along littoral to profundal transects (Heiri et al. 2003). Change in lake trophic status may or may not be related to average temperature change, thus the cause of shifts in chironomid assemblage composition must be interpreted judiciously in temperature reconstruction (Velle et al. 2010).

Given the spatial variability of precipitation within the Himalaya (Bolch et al. 2012) as well as global warming, Lakes Gokyo and Gosaikunda provide valuable baseline data on subfossil chironomid assemblages of high-altitude, unproductive lakes. Given the large amount of variability in lake-specific factors such as morphometry, productivity and exposure of the catchment to persistent snowpacks, future sampling effort may best be directed towards increasing the number of lakes sampled and measuring additional temperature proxies from the cores, e.g. diatoms or pollen (Chase et al. 2008; Velle et al. 2010; Eggermont and Heiri 2012). Thus, across lakes, a clearer signal of regional temperature change may be inferred. Sampling design for construction of a Himalayan calibration dataset must also address covariation of temperature and trophic state: while the coldest, highest altitude lakes are least impacted by human activity, lakes at lower elevations are not only warmer, but are more likely to be impacted by anthropogenic nutrient enrichment. The remote location of Lakes Gokyo and Gosaikunda is a reminder that it can be difficult to quantify average annual air temperature appropriately; however the measurement of epi- and hypolimnion temperature and dissolved oxygen, as reported here, is valuable in modeling the relation of chironomid assemblages to lake temperature (Eggermont and Heiri 2012). Replicate within-lake cores will be vital for future palaeolimnological studies of those Himalayan lakes where sedimentation rates may be high and chironomid productivity is low. In the Himalaya, continued deposition of debris by receding glaciers is forming many new lakes (Bolch et al. 2012), which will provide an opportunity to observe both ontological changes on lake productivity as well as responses to climate change.

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