



**Terrestrial and aquatic responses to climate change and human impact on the southeastern Tibetan Plateau during the past two centuries**

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Keywords:	Tibetan Plateau, Climate change, Human impact, Compositional species turnover, Procrustes Rotation, Pollen, Diatoms
Abstract:	<p>Rapid population growth and economic development have led to increased anthropogenic pressures on the Tibetan Plateau, potentially causing significant land cover changes with partly severe ecological consequences. To assess whether these pressures are also affecting the remote montane-boreal lakes on the SE Tibetan Plateau, fossil pollen and diatom data from two lakes were synthesised to explore the interplay of aquatic and terrestrial ecosystem response, in respect to climate variability and human activity over the past 200 years. Non-metric multidimensional scaling and procrustes rotation analysis were applied to assess the similarity and synchronicity of response to environmental change between the corresponding pollen and diatom assemblages of each lake. Detrended canonical correspondence analysis was used to develop quantitative estimates of compositional species turnover. Despite instrumental evidence of significant climatic warming on</p>

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	<p>the southeastern Plateau, the pollen and diatom records indicate very stable species composition throughout their profiles and show only very subtle responses to environmental changes over the past 200 years. The compositional species turnover (0.36-0.94 SD) is relatively low in comparison to the species reorganisations known from the periods during the mid- and early-Holocene (0.64-1.61 SD) on the SE Plateau, and also in comparison to turnover rates of sediment records from climate - sensitive regions in the circum-arctic. Our results indicate that climatically-induced ecological thresholds are not yet crossed, but that human activity has an increasing influence, particularly on the terrestrial ecosystem in our study area. Synergistic processes of post Little Ice Age warming, 20th century climate warming and extensive reforestations since the 19th century have initiated a change from natural oak-pine forests to semi-natural, likely less resilient pine-oak forests. Further warming and anthropogenic disturbances would possibly exceed the ecological threshold of these ecosystems and lead to severe ecological consequences.</p>

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1 **Terrestrial and aquatic responses to climate change and human impact on the**  
2 **southeastern Tibetan Plateau during the past two centuries**

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20 *Key words: Tibetan Plateau, Climate change, Human impact, Compositional species*  
21 *turnover, Procrustes rotation, Pollen, Diatoms*

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24 **Running title: Recent pollen and diatom response in SE Tibet**

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3 **25 Abstract**  
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6 26 Rapid population growth and economic development have lead to increased  
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8 27 anthropogenic pressures on the Tibetan Plateau, potentially causing significant land  
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10 28 cover changes with partly severe ecological consequences. To assess whether these  
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12 29 pressures are also affecting the remote montane-boreal lakes on the SE Tibetan  
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14 30 Plateau, fossil pollen and diatom data from two lakes were synthesised to explore the  
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16 31 interplay of aquatic and terrestrial ecosystem response, in respect to climate  
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18 32 variability and human activity over the past 200 years. Non-metric multidimensional  
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20 33 scaling and procrustes rotation analysis were applied to assess the similarity and  
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22 34 synchronicity of response to environmental change between the corresponding pollen  
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24 35 and diatom assemblages of each lake. Detrended canonical correspondence analysis  
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26 36 was used to develop quantitative estimates of compositional species turnover. Despite  
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28 37 instrumental evidence of significant climatic warming on the southeastern Plateau, the  
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30 38 pollen and diatom records indicate very stable species composition throughout their  
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32 39 profiles and show only very subtle responses to environmental changes over the past  
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34 40 200 years. The compositional species turnover (0.36-0.94 SD) is relatively low in  
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36 41 comparison to the species reorganisations known from the periods during the mid-  
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38 42 and early-Holocene (0.64-1.61 SD) on the SE Plateau, and also in comparison to  
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40 43 turnover rates of sediment records from climate - sensitive regions in the circum-  
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42 44 arctic. Our results indicate that climatically-induced ecological thresholds are not yet  
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44 45 crossed, but that human activity has an increasing influence, particularly on the  
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46 46 terrestrial ecosystem in our study area. Synergistic processes of post Little Ice Age  
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48 47 warming, 20<sup>th</sup> century climate warming and extensive reforestations since the 19<sup>th</sup>  
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50 48 century have initiated a change from natural oak-pine forests to semi-natural, likely  
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52 49 less resilient pine-oak forests. Further warming and anthropogenic disturbances would  
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4 50 possibly exceed the ecological threshold of these ecosystems and lead to severe  
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6 51 ecological consequences.  
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## 52 **Introduction**

53 Due to its potential to influence regional and global climate patterns, the Tibetan  
54 Plateau has become a focus study area of past and recent climate and ecosystem  
55 change. Studies focusing on the past 200 years report a significant mean annual and  
56 winter temperature increase (Liu & Chen 2000; You *et al.* 2007), permafrost  
57 degradation (Wu & Zhang 2008) and significant glacial retreat (Su & Shi 2002;  
58 Berthier *et al.* 2007), suggesting that the Tibetan Plateau, and particularly the  
59 southeastern Tibetan Plateau, is very sensitive to global warming. Additionally, the  
60 Plateau has been under the pressure of rapid population growth and economic  
61 development. The population of China has increased 2.5 times in the past 50 years  
62 (Zhang *et al.* 2000), and also the population of the Tibet Autonomous Region has  
63 grown from 1.2 million to 2.2 million since 1960 (Cui & Graf 2009). Livestock and  
64 meat production on the Tibetan Plateau has increased by up to three times since 1978  
65 (Du *et al.* 2004) and the demand in timber has resulted in extensive forest clearances  
66 since the 1950s (Zhang *et al.* 2000), particularly at the steep forested slopes of the  
67 southeastern Tibetan Plateau (Studley 1999). Overgrazing, grassland degradation and  
68 desertification (Cui & Graf 2009), decline in natural woodlands, fragmentation of  
69 natural habitats and an alarming loss in plant and wildlife species are problems in  
70 wide parts of the Plateau (Studley 1999; Zhang *et al.* 2000). In summary, the  
71 pressures on the Tibetan Plateau are manifold and whether these are caused by  
72 climate change or human activity, they result in significant land cover changes with  
73 partly severe and irreversible consequences for ecosystems and mankind.

74 At the same time, the Tibetan Plateau is known for its heterogeneous mountain  
75 landscape and therefore highly complex temperature and moisture patterns (An *et al.*  
76 2000; Niu *et al.* 2004; You *et al.* 2010). Additionally, anthropo-zoogenic pressures are

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3 77 not evenly spread and lead to regions on the Plateau that are more affected by land  
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5 78 cover changes than others (Cui & Graf 2009). Therefore, global climate models are  
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8 79 still imprecise in estimating possible future land cover changes on the Tibetan Plateau  
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10 80 as they lack the spatial and temporal resolution of climatic, ecosystem and  
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12 81 anthropogenic parameters in that topographically challenging landscape (Cui & Graf  
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14 82 2009). Therefore, it is necessary to establish a dense and integrated network of  
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16 83 instrumental, palaeoecological and archaeological studies, to help to reduce the  
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18 84 uncertainties of climate variability and anthropo-zoogenic activities and associated  
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20 85 land cover changes in the past and present, and to assess their future impact on  
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22 86 ecosystems on the Tibetan Plateau.  
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27 87 To date, only a few and spatially widespread proxy studies have investigated  
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29 88 environmental changes on the Tibetan Plateau focusing on the last few centuries  
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31 89 (Henderson *et al.* 2003; Bräuning & Mantwill 2004; Bräuning 2006; Liang *et al.*  
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33 90 2009; Fan *et al.* 2010; Henderson *et al.* 2010; Lami *et al.* 2010; Wrozyzna *et al.* 2010;  
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35 91 Yang *et al.* 2010; Wang *et al.* 2011; Wischnewski *et al.* in revision) – a time period  
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37 92 strongly affected by increasing land use activity. Pollen and diatoms in particular,  
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39 93 have not received much attention on centennial and decadal time scales, despite their  
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41 94 potential to reflect vegetation, land use and climate change reliably (Douglas & Smol  
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43 95 2001; Lotter *et al.* 2001; Zhao *et al.* 2008; Schlütz & Lehmkuhl 2009; Herzschuh *et*  
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45 96 *al.* 2010).  
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50 97 Here we present the results of fossil pollen and diatom records from two  
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52 98 montane-boreal lakes (LC6 Lake and Wuxu Lake) on the southeastern Tibetan  
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54 99 Plateau. Our aim is to evaluate the comparability of aquatic and terrestrial proxy  
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56 100 responses in respect to climate variability and human activity, using rigorous  
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58 101 statistical methods. We focus on the following questions: (a) Do pollen and diatom  
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3 102 records reflect similar and synchronous species shifts in response to environmental  
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5 103 changes on the southeastern Tibetan Plateau? (b) How sensitive are the pollen and  
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8 104 diatom assemblages to environmental change in the past 200 years, and is the  
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10 105 magnitude of compositional species turnover comparable to the magnitude of change  
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12 106 at other sites on similar and longer time scales? (c) What are the potential causes of  
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15 107 ecosystem change on the southeastern Tibetan Plateau? As such, this paper exhibits  
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17 108 one of the very few studies in the region that directly compares aquatic and terrestrial  
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19 109 proxy response within and between two different lake sites and provides insights to  
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22 110 recent environmental change on the southeastern Plateau.  
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## 111 **Regional setting and study sites**

112 Wuxu Lake and LC6 Lake (working name) are located on the southeastern Tibetan  
113 Plateau. This part of the Plateau is characterised by the strong and varied relief of the  
114 Hengduan Mountains, which stretch across western Sichuan, northwestern Yunnan  
115 and the easternmost part of the Tibet Autonomous Region. Altitudes of over 5000 m  
116 above sea level (asl) in the northern parts of the southeastern Tibetan Plateau drop to  
117 less pronounced features of ~ 1500 m asl towards the southern limit of the Tibetan  
118 Plateau (northwestern Yunnan) causing steep environmental gradients in the region.  
119 Mean annual summer temperatures range from 8°C to 20°C, and mean annual  
120 precipitation varies from 400 mm to 1400 mm (Sun 1999; Yu *et al.* 2001). The  
121 southeastern Tibetan Plateau is affected by two major circulation systems. The mid-  
122 altitude westerly circulation brings limited moisture to the region from November to  
123 March, while the Asian summer monsoon circulation, particularly the Indian monsoon  
124 system, is responsible for the majority of precipitation from May to September  
125 (Domrös & Peng 1988; Su & Shi 2002). This results in abundant rainfall and high  
126 temperatures in summer, which contrast to cool and relatively dry winters.

127       The LC6 Lake is located in the Nyaintêntanglha Mountain range, a western  
128 branch of the Hengduan Mountains (Fig. 1). The LC6 Lake lies at 4230 m asl. The  
129 closest weather station is in Nyingchi at 3000 m asl, 26 km to the south of the lake,  
130 which records mean  $T_{\text{July}}$  15.6°C, mean  $T_{\text{Jan}}$  0.2°C, and mean  $P_{\text{ann}}$  657mm (85% of  
131  $P_{\text{ann}}$  falling between May and September). Based on a lapse rate of - 0.5°C/100 m  
132 (Böhner 2006), estimated mean temperatures for July are ~ 9.6°C and for January ~ -  
133 5.5°C at the LC6 Lake. According to climate station-based calculations from Böhner  
134 (2006) annual precipitation is 1450 mm, and the evaporations rate 800 mm at the lake  
135 site. The LC6 Lake has a small lake area of 0.6 km<sup>2</sup> and is mainly fed by runoff from

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3 136 surrounding, moderately steep sloping mountains which generally peak around 4700  
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5 137 m asl. The lake's outflow cascades into another lake to the southwest. Dense  
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8 138 *Rhododendron* shrubs and coniferous forests (*Picea likiangensis* var. *balfouriana*,  
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10 139 *Abies georgii* var. *smithii*), and patches of *Kobresia pygmaea* meadow characterise  
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12 140 the vegetation in the catchment. Lichens are typical epiphytes on surrounding shrubs  
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14 141 and trees. No signs of immediate, catchment-scale human impact were observed  
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16 142 during fieldwork.  
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20 143 Wuxu Lake is located ~ 680 km to the west of LC6 Lake in an eastern branch  
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22 144 of the Hengduan Mountains (Fig. 1). Wuxu Lake lies on 3705 m asl. The closest  
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24 145 weather station is Litang at 3948 m asl, 140 km northwest of the lake, which records  
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26 146 mean  $T_{\text{July}}$  10.5°C, mean  $T_{\text{Jan}}$  -6°C, and mean  $P_{\text{ann}}$  720 mm (90% falling between May  
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28 147 and September). The lake area (0.5 km<sup>2</sup>) is comparable with that of LC6 Lake, with a  
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30 148 small catchment area comprised of steep sloping mountains to the sides. A tributary  
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32 149 feeding from perennial snow covered peaks and glaciers to the northwest, feeds into  
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34 150 the lake. Wuxu Lake has one outflow to the southeast. The vegetation in the  
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36 151 catchment is characterised by coniferous (*Picea likiangensis*, *Abies squamata*) and  
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38 152 sclerophyllous trees (*Quercus aquifoliodes*, *Q. pamosa*), intermixed with  
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40 153 *Rhododendron* sp. and *Salix* sp. shrubs. A day trip away from Jiulong Town, Wuxu  
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42 154 Lake is destination of minor tourism. Some Tibetan summer tents are pitched along  
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44 155 the shorelines and yaks graze in the area during summer. General information about  
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46 156 both lakes and their catchment are summarised in Table 1.  
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4 157 **Material and methods**  
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7 158 *Field sampling and dating of lake sediment cores*  
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10 159 LC6 Lake and Wuxu Lake were sampled in summer 2005 and winter 2007,  
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12 160 respectively. A 45-cm sediment core was taken at the deepest part (23 m) of LC6  
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14 161 Lake; at Wuxu Lake a 40-cm sediment core was taken at 30 m water depth. Both  
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16 162 cores were taken using a UWITEC gravity corer and were sectioned at site in 0.5-cm  
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18 163 intervals directly after coring.

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21 164 Both cores were dated using  $^{210}\text{Pb}$ ,  $^{226}\text{Ra}$ , and  $^{137}\text{Cs}$  analyses by direct gamma  
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23 165 assay in the Liverpool University Environmental Radioactivity Laboratory.

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26 166 Radiometric dates were calculated using both the constant rate of supply (CRS) and  
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28 167 constant initial concentration (CIC)  $^{210}\text{Pb}$  dating models (Appleby & Oldfield 1978).

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30 168 The 1963 depth was determined from the  $^{137}\text{Cs}$  stratigraphic record. Discrepancies  
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32 169 between the  $^{210}\text{Pb}$  models were resolved using the methods described in Appleby  
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34 170 (2001). Dates of points below the base of the unsupported  $^{210}\text{Pb}$  record were  
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36 171 calculated by extrapolation of the  $^{210}\text{Pb}$  depth/age curve using a best estimate of the  
37  
38 172 sedimentation rate for this part of the core. For Wuxu Lake, two additional  
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40 173 radiocarbon dates from bulk sediments were obtained by the AMS (accelerated mass  
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42 174 spectrometry) method at the Leibnitz-Laboratory for Radiocarbon Dating and Isotope  
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44 175 Research, Kiel to support the extrapolated age.  
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51 176 *Pollen Analysis*  
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53 177 Sediments for pollen analyses for both lakes were treated using standard laboratory  
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55 178 methods (Fægri & Iversen 1989), including treatment with HCl (10%), KOH (10%),  
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57 179 and HF (50%, 2 h boiling), followed by acetolysis, sieving (7  $\mu\text{m}$ ) in an ultrasound  
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59 180 bath, and mounting in glycerine. Two tablets of *Lycopodium* spores (10 979  
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3 181 spores/tablet) were added to calculate the pollen concentrations. At LC6 Lake, 30  
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5 182 horizons (5 to 12-year intervals) were analysed and at least 600 (mean 1070)  
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8 183 terrestrial pollen were counted for each level. For Wuxu Lake, 26 horizons (7 to 20-  
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10 184 year intervals) were analysed with counts between 360 and 650 (mean 470) terrestrial  
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12 185 pollen for each level. Pollen identifications followed relevant literature (Moore *et al.*  
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14 186 1991; Wang *et al.* 1997; Beug 2004; Fujiki *et al.* 2005). Pollen taxa, occurring in at  
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16 187 least one sample at >1% were used to develop pollen diagrams and implement  
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18 188 numerical methods.  
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### 20 21 22 23 189 *Diatom Analysis*

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26 190 Diatom analysis followed standard procedures using the water bath technique  
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28 191 (Renberg 1990; Battarbee *et al.* 2001). Slides were mounted using Naphrax®. Diatom  
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30 192 concentration was estimated using divinylbenzene microspheres (Battarbee & Kneen  
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32 193 1982). At LC6 Lake 400 to 500 valves were counted for 45 horizons (2 to 11-year  
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34 194 intervals). At Wuxu Lake 630 to 1200 valves were counted for 27 horizons (7 to 20-  
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36 195 year intervals), using phase contrast at x1000 magnification. Taxonomic  
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38 196 identifications primarily followed Krammer & Lange-Bertalot (1986-1991), Lange-  
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40 197 Bertalot & Metzeltin (1996), Zhu & Chen (2000) and Camburn & Charles (2002).  
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42 198 Diatom taxa with percentages of >1% in at least one sample were used for the  
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44 199 illustrations and all statistical analyses.  
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### 50 51 200 *Data treatment and statistical analyses*

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53 201 The significance of pollen- and diatom-based biostratigraphic zones was calculated by  
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55 202 cluster analysis using constrained incremental sum of squares (CONISS) (Grimm  
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57 203 1991) and the Edwards and Cavalli-Sforza's chord distance as the dissimilarity  
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59 204 coefficient.  
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3 205 The ordination technique non-metric multidimensional scaling (nMDS) was  
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6 206 used to explore patterns of variation in the pollen and diatom data sets (Minchin  
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8 207 1987). The dissimilarity matrix, needed for nMDS, was calculated using the Bray-  
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10 208 Curtis coefficient (Faith *et al.* 1987). NMDS was run on a two-dimensional model,  
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12 209 being the most parsimonious model compared to higher dimensional models, which  
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14 210 did not produce significantly lower stress values (a measure of the variation  
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16 211 explained).

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19 212 Detrended canonical correspondence analysis (DCCA) was applied to estimate  
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21 213 the overall compositional species turnover measured in standard deviation (SD) units  
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23 214 (as beta diversity), which provides an estimate of compositional change along an  
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25 215 environmental or temporal gradient (ter Braak & Verdonschot 1995). To estimate the  
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27 216 amount of compositional change of the LC6 Lake and Wuxu Lake records over the  
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29 217 last ~200 years, <sup>210</sup>Pb derived sample ages were used as the only constraining variable  
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31 218 in DCCA. In DCCA, species data were square-root transformed, no rare species  
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33 219 down-weighting was applied, and non-linear rescaling and detrending by segments  
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35 220 was used. To place the degree of compositional species turnover into relation, SD  
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37 221 units were compared to studies from Smol *et al.* (2005), Birks (2007) and Hobbs *et al.*  
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39 222 (2010) that used DCCA as a tool to estimate compositional species turnover and  
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41 223 established that changes greater than 1 SD units were deemed ecologically substantial.  
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48 224 To assess whether the corresponding pollen and diatom data sets of the LC6  
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50 225 Lake and Wuxu Lake show significant similarities and synchronicity in their  
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52 226 variability over time, Procrustes rotation and the associated PROTEST permutation  
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54 227 test were implemented (Gower 1971; Jackson 1995; Peres-Neto & Jackson 2001). As  
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56 228 Procrustes and PROTEST require ordination (e.g. nMDS) scores of like-for-like data,  
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58 229 the four data sets (1) *LC6 diatom*, (2) *LC6 pollen*, (3) *Wuxu diatom*, and (4) *Wuxu*  
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3 230 *pollen* had to be harmonised and adapted to a common time scale before applying  
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5 231 nMDS. Therefore, all diatom and pollen samples in taxa percentages from the original  
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8 232 data sets were interpolated (by simple linear interpolation) and then re-sampled in  
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10 233 five-year intervals from 2000 to 1810 A.D..

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12 234 All nMDS, Procrustes analysis and PROTEST were performed in R (The R  
13  
14 235 Development Core Team 2008) using the *vegan* package (Oksanen *et al.* 2008). The  
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16 236 PROTEST function in R, which performs a random permutation test, was modified to  
17  
18 237 allow restricted permutations for time series data (Besag & Clifford 1989). DCCA  
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20 238 was implemented using the program CANOCO 4.5 for Windows (ter Braak &  
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22 239 Šmilauer 2002) and the interpolation and re-sampling was carried out in AnalySeries  
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25 240 2.0.4.2. (Paillard *et al.* 1996).  
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4 241 **Results**  
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8 242 *Dating*  
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10 243 A detailed description and interpretation of the LC6 Lake age-depth model is given in  
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12 244 Wischnewski *et al.* (in revision). Therefore, only major features of the model are  
13  
14 245 outlined here. Results of the radiometric dating are summarised in Figure 2. Dry mass  
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16 246 sedimentation rates at the core site have been relatively uniform during much of the  
17  
18 247 past 100 years ( $0.15 \text{ cm yr}^{-1}$ ), apart from a period of rapid sedimentation rates  
19  
20 248 between 8 and 27 cm core depth. The discrepancy between raw  $^{210}\text{Pb}$  dates calculated  
21  
22 249 using the CRS dating model and a well-defined 1963  $^{137}\text{Cs}$  date (Appleby 2001)  
23  
24 250 suggest that an extreme event, possibly a landslide or sub-surface sediment slump  
25  
26 251 caused these anomalous sedimentation rates, occurring in the late 1940s or early  
27  
28 252 1950s. This is coincident with the Assam-Tibet earthquake, recorded in August 1950  
29  
30 253 in North India, just  $\sim 280$  km southeast to the site. Therefore, samples from 8-27 cm  
31  
32 254 core depth were excluded from further analyses. Dates below the base of the  
33  
34 255 unsupported  $^{210}\text{Pb}$  record were extrapolated back to ca. 1800 A.D..  
35  
36  
37  
38  
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40

41 256 The age chronology for Wuxu Lake is outlined in Figure 3. Unsupported  $^{210}\text{Pb}$   
42  
43 257 activity declines more or less exponentially with depth, suggesting relatively uniform  
44  
45 258 sedimentation rates ( $0.10 \text{ cm yr}^{-1}$ ) during the past 100 years. Small irregularities  
46  
47 259 appear between 4-6 cm depth, corresponding to the early 1960s, but differences  
48  
49 260 between the CRS model and the alternative CIC model were relatively small.  $^{137}\text{Cs}$   
50  
51 261 activity has a well-defined peak in the 5-5.25 cm section, which almost certainly  
52  
53 262 marks 1963. The  $^{210}\text{Pb}$  dates place 1963 slightly below the depth suggested by the  
54  
55 263  $^{137}\text{Cs}$  record, possibly caused by the short-term fluctuations in the sedimentation rate  
56  
57  
58 264 mentioned above. The equilibrium between total  $^{210}\text{Pb}$  activity and supporting  $^{226}\text{Ra}$   
59  
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3 265 was reached at 12 cm depth. Dates below this point were extrapolated back to ca.  
4  
5 266 1652 A.D.. Two additional  $^{14}\text{C}$  AMS dates, using the leaching residue, support the  
6  
7  
8 267 extrapolated  $^{210}\text{Pb}/^{137}\text{Cs}$  chronology. The reservoir-effect was calculated by  
9  
10 268 subtracting the last reliable  $^{210}\text{Pb}/^{137}\text{Cs}$  age (WX 23) from the non-calibrated  
11  
12 269 radiocarbon age of the same horizon (see Table 2). After reservoir-effect correction  
13  
14 270 (1337±30 years) and age calibration using Calib Rev. 6.0 (Stuiver & Reimer 1993)  
15  
16 271 the base of the core (WX 51) dates back to 1433 A.D. - 1645 A.D. ( $2\sigma$ -range), which  
17  
18 272 moderately agrees with the  $^{210}\text{Pb}$ -extrapolated date. As high radiocarbon dating  
19  
20 273 residuals and a radiocarbon plateau between ~ A.D. 1780 - 1600 contribute to high  
21  
22 274 uncertainty, radiocarbon ages are regarded as supporting material only. Therefore, the  
23  
24 275  $^{210}\text{Pb}/^{137}\text{Cs}$  chronology is primarily used for the Wuxu Lake age model. The results of  
25  
26 276 the  $^{14}\text{C}$  AMS dates and calculated reservoir effect are summarised in Table 2.  
27  
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### 33 277 *Pollen Analysis*

34  
35 278 The results of the pollen analysis for LC6 Lake are summarised in Figure 4. The  
36  
37 279 cluster analysis CONISS calculated a total sum of squares of 1.3. Therefore, no  
38  
39 280 distinct first-order pollen biostratigraphic zones were established. The pollen  
40  
41 281 spectrum is dominated by arboreal and shrub taxa, amongst which *Pinus* (~ 19%),  
42  
43 282 *Quercus* (~ 19 %), *Betula* (~ 11%), *Picea* (~ 4%), and *Rhododendron* (~ 3%) are the  
44  
45 283 most abundant pollen taxa. Herbaceous taxa contribute with mainly *Artemisia* (~  
46  
47 284 12%), Cyperaceae (~ 7%) and *Polygonum* (~ 4%) to the spectra in moderate amounts.  
48  
49 285 In general, arboreal taxa show a slight increase since the late 1890s, mostly linked to  
50  
51 286 the increase of *Pinus*, *Betula*, *Abies* and *Salix*, whereas herbaceous taxa decline on the  
52  
53 287 expense of *Polygonum*, *Artemisia*, Poaceae and *Gentiana*. Grazing-taxa (i.e.,  
54  
55 288 Apiaceae, Liliaceae) show slight increases in the 1870s to 1940s and taxa most likely  
56  
57 289 introduced through human cultivation (i.e., *Humulus*, Fabaceae) increased in the  
58  
59  
60



1  
2  
3 290 1870s to 1940s and in the 1970s. The DCCA revealed a low and non-significant  
4  
5 291 compositional species turnover of 0.81 SD ( $p= 0.25$ ) for the last 200 years (Table 3).  
6  
7

8 292 Figure 5 summarises the results from the Wuxu Lake pollen record. Similar to  
9  
10 293 the LC6 Lake, no distinct first-order biostratigraphic zone were calculated by the  
11  
12 294 cluster analysis CONISS (total sum of squares of 1.3). The pollen spectra are  
13  
14 295 dominated by arboreal taxa, such as sclerophyllous *Quercus* (~ 37%), *Pinus* (~ 23%),  
15  
16 296 *Betula* (~ 6%) and *Abies* (~ 5%). Herbaceous taxa, mainly comprised of *Artemisia*,  
17  
18 297 *Cyperaceae* and *Poaceae* contribute with abundances between 2-4%. As at LC6 Lake,  
19  
20 298 herbaceous taxa decrease since the 1870s in favour for arboreal taxa (mainly *Pinus*.  
21  
22 299 and *Quercus*). Cultivated plants contribute with insignificant amounts to the pollen  
23  
24 300 spectra and do not show distinct appearances, however, grazing-indicating-taxa (e.g.,  
25  
26 301 *Rumex*, *Sanguisorba*) are present throughout the core with abundances of ~ 1-2%. The  
27  
28 302 DCCA yielded a low and non-significant compositional species turnover of 0.36 SD  
29  
30 303 ( $p=0.09$ ) over the last 200 years (Table 3).  
31  
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### 37 304 *Diatom Analysis*

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40 305 The diatom stratigraphies of LC6 Lake and Wuxu Lake are illustrated in  
41  
42 306 Figures 6 and 7, respectively. The common feature of both diatom data sets is the  
43  
44 307 small degree of compositional species turnover throughout both cores. In both cases  
45  
46 308 CONISS revealed a low total sum of square (1.0 at Wuxu Lake, 1.7 at LC6 Lake),  
47  
48 309 indicating the absence of first-order biostratigraphic zones. The DCCA yielded a beta-  
49  
50 310 diversity of 0.55 SD ( $p= 0.03$ ) for Wuxu Lake and 0.94 SD ( $p= 0.59$ ) for LC6 Lake  
51  
52 311 over the last 200 years (Table 3). The diatom taxa of LC6 Lake and Wuxu Lake are  
53  
54 312 plankton-dominated taxa and common in slightly acidic to circumneutral habitats.  
55  
56 313 Many are cosmopolitan species that are commonly found in freshwaters of high-  
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3 314 latitude and alpine regions (Lotter & Bigler 2000; Sorvari *et al.* 2002; Rühland &  
4  
5 315 Smol 2005).

6  
7  
8 316 The LC6 Lake diatom record revealed 158 species from 39 genera, dominated  
9  
10 317 by monoraphid taxa (*Achnantheidium* sp., *Achnanthes* sp. and *Psammothidium* sp.),  
11  
12 318 *Cyclotella* sp. and fragilarioid taxa, which contribute with up to 40%, 35% and 20%  
13  
14  
15 319 relative abundance. The most common species is the planktonic diatom *Cyclotella*  
16  
17 320 *ocellata* (up to 35%). A subtle but consistent decline of *Cyclotella ocellata* is apparent  
18  
19 321 throughout the core, accompanied with small increases of *Achnantheidium*  
20  
21 322 *minutissimum*, tychoplanktonic *Aulacoseira lirata* var. *lirata* and benthic *Fragilaria*  
22  
23 323 *capucina* and *Cymbella* species (Fig. 6).

24  
25  
26  
27 324 At Wuxu Lake, 120 taxa from 38 genera were identified. The species  
28  
29 325 assemblage was dominated by the planktonic taxa *Cyclotella cyclopunctata* (~ 63%)  
30  
31 326 and *Aulacoseira distans* (~ 15%). *Achnantheidium minutissimum* and varieties (~ 5%)  
32  
33 327 and fragilarioid taxa such as *Fragilaria construens* f. *venter* (~ 3%) and *Staurosirella*  
34  
35 328 *pinnata* (2%) contribute with small percentage abundances to the benthic component  
36  
37 329 of the diatom assemblage. However, no significant species shifts were detected  
38  
39 330 throughout the record, only subtle changes appear from the 1840s onwards, linked to  
40  
41 331 the appearance of some fragilarioid taxa (Fig. 7).

#### 42 43 44 45 46 47 332 *Procrustes Rotation and PROTEST*

48  
49 333 All four nMDS produced stress values between 17% and 20% (Table 4) suggesting a  
50  
51 334 good fit between fitted values and the original distance (Kruskal & Wish 1978; Clarke  
52  
53 335 1993). All nMDS biplots are provided as supplementary material online.

54  
55  
56  
57 336 Procrustes rotation and the associated PROTEST function were performed on  
58  
59 337 (a) both pollen data sets, (b) both diatom data sets, (c) pollen and diatom data sets of  
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338 the LC6 Lake, and (d) on the pollen and diatom data sets of Wuxu Lake. Table 5

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3 339 summarises the diagnostics of Procrustes rotation and PROTEST and Figure 8  
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5  
6 340 illustrates the goodness of fit between all data sets compared. The size of residuals for  
7  
8 341 each time slice between 1810 A.D. and 2000 A.D. is shown. Low residuals indicate a  
9  
10 342 good agreement between data sets, high residuals indicate a weak agreement. The best  
11  
12 343 fit was produced for the within-lake comparison at LC6 Lake (Fig. 8c). The pollen  
13  
14 344 and diatom record produced a significant and well-correlated fit ( $p=0.02$ ,  $r=0.70$ ). A  
15  
16 345 good fit was also produced between the corresponding pollen records from LC6 Lake  
17  
18 346 and Wuxu Lake ( $p=0.02$ ,  $r=0.53$ ) (Fig. 8a). However, several time slices display a  
19  
20 347 lower degree of similarity as indicated by higher residuals. The poorest fit was  
21  
22 348 produced between the corresponding diatom records from both lakes, as suggested by  
23  
24 349 a relatively high  $p$  value and low PROTEST score ( $p=0.13$ ,  $r=0.43$ )(Fig. 8b).  
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4 350 **Discussion**

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7 351 *Biological response to climate and human-induced changes on the SE Tibetan*

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10 352 *Plateau*

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13 353 Regional vs. local response

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16 354 The pollen records from the LC6 Lake and Wuxu Lake have a very similar species

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18 355 composition and changes in the species composition are temporally consistent. This

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20 356 concordance between both data sets is also shown by the significant and well-

21  
22 357 correlated procrustean fit (Fig. 8a), suggesting that the timing, magnitude and

23  
24 358 direction of change in both pollen records is very similar over the last 200 years and

25  
26 359 that changes are likely to occur in response to regional, as opposed to local

27  
28 360 environmental changes. The vegetation pollen assemblages in both records are

29  
30 361 characteristic for the montane forest belt on the southeastern Tibetan Plateau,

31  
32 362 dominated by evergreen oak-pine forests (sclerophyllous *Quercus*, *Pinus*) intermixed

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34 363 with *Abies*, *Picea* and *Betula*, typically found between 3000-4000 m asl (Chang 1981;

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36 364 Winkler 1996; Hou 2001; Yu *et al.* 2001). In the LC6 Lake pollen spectra, herbaceous

37  
38 365 taxa, mainly comprised of *Polygonum*, *Artemisia* and Cyperaceae, are a stronger

39  
40 366 component as at Wuxu Lake. This most likely represents the more widespread

41  
42 367 distribution of alpine meadows, as LC6 Lake is located ~ 400 m higher than Wuxu

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44 368 Lake and therefore closer to the sub-alpine shrubland and alpine meadows, typically

45  
46 369 covering the slopes above 4000 m asl on the southeastern Tibetan Plateau (Chang

47  
48 370 1981; Yu *et al.* 2001).

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50 371 Comparing the diatom records of both lakes with each other, the picture is

51  
52 372 different. The Procrustean rotation produced an insignificant and poorly correlated fit

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54 373 (Fig. 8b), indicating that the timing, duration or magnitude of change of the diatom

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3 374 assemblage in response to environmental changes varies between both lakes and that  
4  
5 375 care needs to be taken when making regional climate inferences from the aquatic  
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7  
8 376 record alone. Lakes can have fundamentally different properties and therefore  
9  
10 377 different climate sensitive thresholds (Battarbee 2000). Procrustean residuals (Fig. 8b)  
11  
12 378 indicate that mismatches between both aquatic data sets were greatest between 1810-  
13  
14 379 1840 A.D. and between 1940-1975 A.D., which correspond with time periods when  
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16 380 compositional turnover is highest in both lake systems (compare DCCA scores in  
17  
18 381 Figures 4 and 5).

### 23 382 Compositional species turnover

24  
25 383 The overall characteristic of both pollen records, is the very stable species  
26  
27 384 composition throughout the entire profile. Species shifts are very subtle over the last  
28  
29 385 200 years (at LC6 Lake) and 350 years (at Wuxu Lake). The low total sum of squares  
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31 386 indicated by CONISS and a low compositional species turnover (0.36-0.81 SD)  
32  
33 387 confirm this. For comparison, Birks (2007) investigated compositional species  
34  
35 388 turnover on Holocene pollen-stratigraphical sequences from southern Norway and  
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37 389 associated DCCA scores above 1.0 SD units with high compositional turnover and  
38  
39 390 ecologically substantial changes. Compared to the dramatic vegetation shifts on the  
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41 391 Tibetan Plateau at the transition from the Lateglacial to the early Holocene or during  
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43 392 the mid-Holocene (Jarvis 1993; Demske *et al.* 2009; Wischnewski *et al.* 2011), the  
44  
45 393 degree of vegetation change over the last two to four centuries is less significant.  
46  
47 394 Kramer *et al.* (2010) reconstructed a 2-3°C temperature rise at the  
48  
49 395 Pleistocene/Holocene boundary (using a pollen record from Naleng Lake, southeast  
50  
51 396 Tibet) which triggered the spreading of forest on the expense of the steppe and  
52  
53 397 meadow ecotone. The same record shows a considerable reorganisation of the  
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55 398 vegetation during the shorter lived cold event around 8.1 cal. kyr BP, when  
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3 399 temperatures dropped by 1-2 °C (Kramer *et al.* 2010). DCCA scores for these two  
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5 400 time periods (0.64-1.61 SD) indicate substantial ecological changes (unpublished  
6  
7 401 data) (Table 3). You *et al.* (2007) found a ~ 1.4°C warming over the last 40 years for  
8  
9 402 the southeastern Tibetan Plateau, but changes in the vegetation structure did not show  
10  
11 403 a similar strong compositional turnover as over the Holocene time scale, suggesting  
12  
13 404 that the length and magnitude of the recent warming period at our sites has not yet led  
14  
15 405 to the crossing of climatically-induced ecological thresholds. However, a further  
16  
17 406 increase in temperature under current warming rates could cause a ecological  
18  
19 407 threshold crossing, similar to that during the Holocene. A direct comparison of the  
20  
21 408 Holocene with the recent past is, however, difficult as previous environmental  
22  
23 409 conditions, e.g. at the Pleistocene/Holocene boundary, were different and trees were  
24  
25 410 not the dominant vegetation type and the vegetation density was generally low  
26  
27 411 (Kramer *et al.* 2010). With the onset of warmer and moister conditions in the early  
28  
29 412 Holocene, trees could migrate into new niches as climate became more favourable to  
30  
31 413 their growth. During the late Holocene and the recent past these niches were already  
32  
33 414 occupied, so a temperature increase alone would not necessarily cause similar results.

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35  
36 415         Similar to the pollen records, the overall compositional change in both diatom  
37  
38 416 records is very low as well, which is confirmed by low total sum of square scores  
39  
40 417 indicated by CONISS and by a low compositional species turnover (0.55 SD – 0.94  
41  
42 418 SD). For comparison, similar low SD values (0.84 SD) were calculated for diatom  
43  
44 419 records from northern Quebec, where diatom compositional change in agreement with  
45  
46 420 instrumental data suggest no significant warming over the past 150 years (Smol *et al.*  
47  
48 421 2005). In contrast, lots of other palaeoecological records in the circum arctic show  
49  
50 422 significant shifts in the diatom assemblage, starting in the mid-19<sup>th</sup> century, with a  
51  
52 423 compositional species turnover of ~ 1 SD - 2.8 SD units (Smol *et al.* 2005; Hobbs *et*

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2  
3 424 *al.* 2010). Smol *et al.* (2005) and Rühland *et al.* (2008) link these changes primarily to  
4  
5 425 climate and resulting limnological changes (longer growing season, changes in the  
6  
7 426 light and mixing regime, increased nutrient cycling) which promote a shift from  
8  
9 427 benthic (e.g. small fragilarioid species) to planktonic taxa (e.g. small *Cyclotella*  
10  
11 428 species). These taxa shifts could not be detected at LC6 Lake or Wuxu Lake despite  
12  
13 429 evidence of significant temperature and precipitation increase (You *et al.* 2007). So  
14  
15 430 far no diatom records exist in the region for comparison of compositional turnover  
16  
17 431 rates. At both sites, diatom evidence suggests that aquatic ecosystems have been  
18  
19 432 relatively stable during the recent centuries, through periods of distinct climate  
20  
21 433 variability. Unlike other regions, these sites have not yet cross climatically-induced  
22  
23 434 ecological thresholds, although we acknowledge that confounding processes, such as  
24  
25 435 increasing precipitation and persistent cloud cover, may act to subdue the impact of  
26  
27 436 increasing temperatures (Wischnewski *et al.* in revision).  
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### 34 437 *Causes of terrestrial and aquatic ecosystem change*

#### 35 438 The terrestrial system

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37  
38 439 Apart from the low overall compositional change, minor species shifts could be  
39  
40 440 identified in both pollen records. After ~ 1880, both pollen records reveal an increase  
41  
42 441 of arboreal taxa, with an increasing trend lasting until present. This is contradictory to  
43  
44 442 studies that show evidence of forest decline on the Plateau since the mid-Holocene  
45  
46 443 (Shen *et al.* 2005; Kramer *et al.* 2010) and other studies that report on alarming forest  
47  
48 444 loss and habitat defragmentation since the 1950s (Studley 1999). Whilst there is still  
49  
50 445 an ongoing discussion whether forest decline since the mid-Holocene was primarily  
51  
52 446 caused by climatic conditions, human impact, or a combination of both (Yang *et al.*  
53  
54 447 2005; Schlütz & Lehmkuhl 2009; Herzsuh *et al.* 2010; Kramer *et al.* 2010), the  
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3 448 severe loss of natural forest in the recent past (last 2000 years), and particularly in the  
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5 449 past decades (since the 1950s) is attributed to anthropogenic forest clearances as a  
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8 450 consequence of the high timber, grazing and agricultural ground demand of a  
9  
10 451 constantly growing population of China (Studley 1999; Zhang *et al.* 2000; Elvin *et al.*  
11  
12 452 2002; Dearing *et al.* 2008). The forest increase since ~ 1880 in the LC6 Lake and  
13  
14 453 Wuxu Lake catchments is mainly linked to species of *Quercus*, *Pinus*, Cupressaceae,  
15  
16 454 *Abies* and *Larix*. *Pinus*, *Larix* and genera of the Cupressaceae family are fast growing  
17  
18 455 tree species that are used for reforestation purposes within governmental programs  
19  
20 456 (Bao & Jiang 1998; Zhang *et al.* 2000). Furthermore, *Quercus-Pinus* forests are often  
21  
22 457 described as secondary forests, developing after human disturbance. Their growth is  
23  
24 458 promoted by human-induced fires for the purpose of forest clearance (Winkler 1996;  
25  
26 459 Yan *et al.* 2005; Shen *et al.* 2006), suggesting that at least a part of the forest increase  
27  
28 460 results from reforestation, rather than natural forest growth. A historical study of Lake  
29  
30 461 Erhai (SW China) provides evidence that reforestation started as early as the A.D.  
31  
32 462 1780s in some parts on the SE Tibetan Plateau (Elvin *et al.* 2002). Also, the Wuxu  
33  
34 463 Lake pollen record shows high abundances of grazing indicators (Apiaceae, *Rumex*,  
35  
36 464 *Sanguisorba*) from the ~ A.D. 1760s – 1800, indicating anthropo-zoogenic pressures  
37  
38 465 in the study region. The increase of *Pinus*, Cupressaceae (at LC6 Lake), *Larix* and  
39  
40 466 *Abies* (at Wuxu Lake) since the mid-1990s can be linked to China's latest attempts to  
41  
42 467 reforest wide parts of the degraded landscapes in the North, Northwest and Southwest  
43  
44 468 (Three-North Protective Forest Program, start 1978; Natural Forest Conservation  
45  
46 469 Program, start 1998) (Zhang *et al.* 2000; Fang *et al.* 2001). Other studies on the  
47  
48 470 southeastern Tibetan Plateau confirm this trend. Shen *et al.* (2006) identified a sharp  
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50 471 increase in *Pinus* over the past 25 years, and Fang *et al.* (2001) shows evidence of  
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3 472 significant increase in total forest biomass carbon storage since the 1970s, indicating  
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5 473 secondary forest growth.  
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8 474 Apart from direct anthropogenic pressures, changing climate in combination  
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10 475 with a national fire ban that was set to prevent burning practices by herders (Baker &  
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12 476 Moseley 2007) might have also had influence on the slight forest increase in the LC6  
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14 477 Lake and Wuxu Lake catchment. Ice core records indicate warmer and moister  
15  
16 478 conditions, associated with post Little Ice Age warming, over the past ~ 200 years  
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18 479 (Thompson *et al.* 2000; Thompson *et al.* 2006; Hou *et al.* 2007). Furthermore,  
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20 480 instrumental data suggest that annual temperatures, and particularly winter and  
21  
22 481 autumn temperatures, increased by 0.30 °C, 0.37°C and 0.35°C/decade respectively  
23  
24 482 since 1961 on the SE Tibetan Plateau (You *et al.* 2007). The most recent global  
25  
26 483 warming trend is therefore also detectable in regions of the Tibetan Plateau. You *et al.*  
27  
28 484 (2007) also identified rising precipitation trends for the SE Tibetan Plateau since the  
29  
30 485 1980s, which are most obvious in the autumn and spring season. The increase in  
31  
32 486 sclerophyllous *Quercus sp.* since ~1880, observed at the Wuxu Lake pollen record,  
33  
34 487 could be the response to these climatic trends. A dry early spring (temperatures rise  
35  
36 488 before the onset of the monsoon) and milder winters would promote predominantly  
37  
38 489 sclerophyllous taxa (Jarvis 1993). *Abies*, on the other hand, has often been associated  
39  
40 490 with increasing effective moisture (Yan *et al.* 1999; Kramer *et al.* 2010), hence the  
41  
42 491 increase of *Abies* in the second half of the 20<sup>th</sup> century in both pollen records, may be  
43  
44 492 linked to increasing precipitation rates as reported by You *et al.* (2007). Hence, the  
45  
46 493 synergistic processes of post Little Ice Age warming, 20<sup>th</sup> century climate warming  
47  
48 494 and extensive reforestations since the 19<sup>th</sup> century have promoted the growth of semi-  
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50 495 natural pine-oak forests, intermixed with fir and larch.  
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3 496 The aquatic system  
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6 497 Changes in both diatom records after 1880 A.D. are less pronounced than changes in  
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8 498 the pollen spectra, but a slight increase in tychoplanktonic and small fragilarioid taxa  
9

10 499 after the 1930s/50s can be observed in both records. Tychoplanktonic and fragilarioid  
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12 500 taxa, which are known to be *R*-strategists, are better adapted to rapidly changing  
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14 501 environments (Lotter & Bigler 2000) and therefore indicative for higher ecosystem  
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16 502 variability. Furthermore, Kinzie *et al.* (1998), argue that *R*-strategist taxa are better  
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18 503 adopted to increasing ultraviolet radiation (UVR), possibly indicating changing UVR  
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20 504 at the lake site. Higher ecosystem variability during this time was also recorded in  
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22 505 other palaeo-climate records across the Tibetan Plateau (Yang *et al.* 2004; Lami *et al.*  
23

24 506 2010; Wrozyzna *et al.* 2010). Nevertheless, the stability of both diatom assemblages  
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26 507 throughout the cores is indicative of no significant change within the lake systems  
27

28 508 over the past ~200 years. Even though LC6 Lake and Wuxu Lake are located above  
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30 509 3700 m asl, they closer compare to the temperate montane-boreal lake systems in e.g.  
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32 510 North America than to the treeless alpine and arctic lake systems as they are free from  
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34 511 ice cover for most of the year and surrounded by dense forests. At temperate  
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36 512 montane-boreal lakes with a longer open water season, thresholds for diatom  
37

38 513 taxonomic shifts are more gradually met (Hobbs *et al.* 2010). According to recorded  
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40 514 mean monthly temperatures and monthly satellite images from the Landsat archive  
41

42 515 (USGS earth explorer 2010), LC6 Lake and Wuxu Lake are currently eight to ten  
43

44 516 months of the year ice-free, suggesting that much higher magnitudes of temperature  
45

46 517 change would be necessary to significantly shorten/lengthen the growing season or  
47

48 518 alter the mixing regime to effect the diatom composition. Additionally, temperate  
49

50 519 lakes are potentially not so sensitive to small changes in climate or nutrient input  
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52 520 (Rühland *et al.* 2008), in part due to the edaphic stability of their catchments  
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3 521 (Heegaard *et al.* 2006). Furthermore, several studies have shown that the composition  
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6 522 and distribution of aquatic organisms is often correlated to changes in the terrestrial  
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8 523 environment of the lake (Heegaard *et al.* 2006). The relative stable vegetation  
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10 524 composition in the LC6 Lake and Wuxu Lake catchment over the past two decades,  
11  
12 525 could have contributed to the limited aquatic response. Other factors, such as local  
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15 526 temperature peculiarities, increasing precipitation and cloud cover (Wischnewski *et*  
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17 527 *al.* in revision), or negative climate feedbacks due to a constant supply of cold glacier  
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19 528 meltwaters (Rühland *et al.* 2006) introduced to the lakes, could further explain the  
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21 529 limited diatom response despite the well-established climate warming on the  
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24 530 southeastern Tibetan Plateau.  
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4 531 **Conclusions**  
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7 532 Despite instrumental and palaeo-climatological evidence of recent climate warming  
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9 533 on the southeastern Tibetan Plateau, diatom and pollen records from two montane-  
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11 534 boreal lakes show only very subtle species compositional changes over the past two to  
12  
13 535 four centuries. The subtle species changes observed, are similar and synchronous in  
14  
15 536 both pollen records, but less similar in the corresponding diatom records, suggesting  
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17 537 that the terrestrial records summarise primarily regional environmental changes,  
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19 538 whereas the aquatic records possibly capture rather local environmental changes. The  
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21 539 combination of aquatic and terrestrial proxies is therefore valuable, to move from a  
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23 540 local to a regional scale, but also to understand the many facets of the  
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25 541 microenvironments in that complex mountain landscape of the Tibetan Plateau.  
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30 542 The overall limited response of the pollen and diatom assemblages from LC6  
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32 543 Lake and Wuxu Lake over the last 200 to 350 years suggest that both lakes and their  
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34 544 catchments seem to be resilient against the current rate and magnitude of climate  
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36 545 warming and that climatically-induced ecological thresholds are not yet crossed. In  
37  
38 546 comparison to the extensive reorganisations of the vegetation in the Holocene that  
39  
40 547 underwent temperature changes of 1-3°C, or to the significant recent shift in diatom  
41  
42 548 communities in many circum-arctic lakes, the current shifts in species and species  
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44 549 abundance on the SE Tibetan Plateau are insignificant.  
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49 550 More influential and alarming than the current rate of climate warming are the  
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51 551 consequences of human-caused land cover change, that have already caused forest  
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53 552 degradation and habitat defragmentation in wide parts of China. Even though our  
54  
55 553 remote montane-boreal sites are not severely affected yet, anthropogenic signs are  
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57 554 clearly visible. Humans have been shaping the landscapes of the southeastern Tibetan  
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59 555 Plateau for several thousands of years by extensive forest clearances and  
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4 556 reforestations as a consequence of rapid population and economic growth, making it  
5  
6 557 difficult to establish how the natural forest in these regions originally looked like. Our  
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8 558 records indicate, that over the past two centuries, human activities have initiated a  
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10 559 conversion of the forest structure, i.e. a trend to less resilient, secondary pine-oak  
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12 560 forests, whilst post-Little Ice Age and 20<sup>th</sup> century warming have contributed to their  
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14  
15 561 growth, promoting the regeneration of these semi-natural forests on the southeastern  
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17 562 Tibetan Plateau. To disentangle to effects and causes of natural climate variability and  
18  
19 563 anthropogenic impact are therefore difficult, in fact synergistic processes are more  
20  
21  
22 564 likely. A further temperature increase of 3.7°C on the Tibetan Plateau, as predicted in  
23  
24  
25 565 a coupled atmosphere-ocean global climate model (Lal & Harasawa 2001), and any  
26  
27 566 further anthropogenic disturbance, will surpass the ecological threshold of these  
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29 567 vulnerable secondary forests and cause the further degeneration of the vegetation  
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31  
32 568 structure and defragmentation with severe ecological consequences, like reduced  
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34 569 water retention capacity, biodiversity reduction and increasing natural disasters (Yan  
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36 570 *et al.* 2005; Cui *et al.* 2007).

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For Review Only

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823 **List of Tables**

824 **Table 1** Selected physical and chemical characteristics of LC6 Lake and Wuxu  
 825 Lake

	<b>LC6 Lake</b>	<b>Wuxu Lake</b>
<b>Latitude</b>	29.82515	29.15319
<b>Longitude</b>	94.45615	101.406
<b>Elevation</b>	4132 m asl	3705 m asl
<b>Genesis</b>	Glacial lake	Glacial lake
<b>Lake area</b>	2000 x 300 m, 0.6 km <sup>2</sup>	1000 x 500 m, 0.5 km <sup>2</sup>
<b>Catchment area</b>	~ 7.2 km <sup>2</sup>	~6.5 km <sup>2</sup>
<b>Max. water depth</b>	23.0 m	30.8 m
<b>Secchi depth</b>	6.9 m	5.3 m
<b>Conductivity</b>	0.013 mS/cm	0.033 mS/cm
<b>pH</b>	7.00	7.67
<b>Alkalinity</b>	0.4 mmol/l	0.4 mmol/l
<b>Inflow</b>	Mountain runoff	Mountain runoff
<b>Outflow</b>	One outlet	One outlet

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828 **Table 2** Accelerator mass spectrometry radiometric data for Wuxu Lake.

829 Calibration was performed using CALIB Rev. 6.0 (Stuiver &amp; Reimer 1993).

Sample	Depth (cm)	Material	<sup>14</sup> C age Leaching residue (a BP)	Calculated reservoir effect (yrs) ( <sup>14</sup> C age – Pb/Cs dated WX 23 age)	Calibrated and reservoir effect corrected age (a A.D.)	<sup>14</sup> C age Humic acid (aBP)	Calculated reservoir effect (yrs) ( <sup>14</sup> C age – Pb/Cs dated WX 23 age)	Calibrated and reservoir effect corrected age (a BP)
WX 23	11.5	Bulk sed.	1430±30	1377±30	-	1490±25	1437±25	-
WX 51	35.5	Bulk sed.	1755±35	1377±30	1433-1645	1655±30	1437±25	1718-1827

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832 **Table 3** DCCA axes 1 scores (in SD units) estimating compositional species  
833 turnover

Lake	Proxy	Time period	SD units
Wuxu	Pollen	Last 200 yrs	0.36
	Diatoms	Last 200 yrs	0.55
LC6	Pollen	Last 200 yrs	0.81
	Diatoms	Last 200 yrs	0.94
Naleng	Pollen	Lateglacial/Holocene	1.51
	Pollen	Pleistocene/Holocene boundary	1.61
	Pollen	“8.2 event”	0.64

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3 835 **Table 4** NMDS stress scores and applied distance measure. Data sets 1 - 4 refer  
4 836 to analyses on harmonised (interpolated and resampled in 5 year intervals between  
5 837 1810 and 2000 AD) pollen and diatom counts.

<b>Data set</b>	<b>Distance measure</b>	<b>nMDS stress score (%) for 2D model</b>
1. LC6 Lake Diatoms (resampled between 1810 -2000)	Bray Curtis	19.33
2. LC6 Lake Pollen (resampled between 1810 -2000)	Bray Curtis	17.31
3. Wuxu Lake Diatoms (resampled between 1810 -2000)	Bray Curtis	19.62
4. Wuxu Lake Pollen (resampled between 1810 -2000)	Bray Curtis	20.77

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**Table 5** Procrustes rotation and PROTEST diagnostics. PROTEST is the correlation on a symmetric Procrustes rotation using nMDS axis scores and the associated p value (based on 39 permutations). Bold print indicates a significant fit between data sets.

Comparisons	Procrustes rotation sum of squares	RMSE	PROTEST (r)	P value
(a) LC6 Pollen vs. Wuxu Pollen	0.72	0.13	0.53	<b>0.02</b>
(b) LC6 Diatoms vs. Wuxu Diatoms	0.82	0.14	0.43	0.13
(c) LC6 Pollen vs LC6 Diatoms	0.51	0.11	0.70	<b>0.02</b>
(d) Wuxu Pollen vs Wuxu Diatoms	0.75	0.14	0.49	<b>0.025</b>

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844 **Figure Legend**

845 **Figure 1** Location of LC6 Lake and Wuxu Lake and corresponding coring  
846 locations. Nyingchi and Litang are the closest climate stations. Figure adapted from  
847 Google Earth, Landsat, and the Online Map Creation Tool.

848  
849 **Figure 2** Radiometric chronology for LC6 Lake showing the 1963 depth  
850 determined from the  $^{137}\text{Cs}$ , the piecewise CRS model  $^{210}\text{Pb}$  dates and sedimentation  
851 rates, and the CIC model  $^{210}\text{Pb}$  dates calculated for sections above 7.5 cm and below  
852 30 cm

853  
854 **Figure 3** Age chronology of the Wuxu Lake sediment core showing the CRS  
855 model  $^{210}\text{Pb}$  dates, the approximate 1963 depth determined from the  $^{137}\text{Cs}$   
856 stratigraphy, the extrapolated  $^{210}\text{Pb}/^{137}\text{Cs}$  age and the (calibrated and reservoir-effect  
857 corrected) radiocarbon age ( $2\sigma$ -range) of the core basis.

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859 **Figure 4** Pollenstratigraphy of LC6 Lake. Only taxa with an abundance of  $>1\%$   
860 in at least one sample are shown. The black filled silhouettes represent original pollen  
861 abundance; transparent silhouettes in the background exaggerate the original  
862 abundance of rare species by 4 to ease visibility. The gap captures the sediment slump  
863 between 8 – 27 cm. Italic ages indicate extrapolated ages.

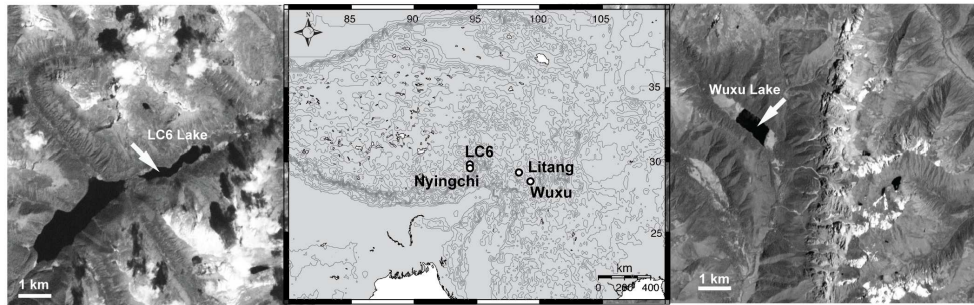
864  
865 **Figure 5** Pollenstratigraphy of Wuxu Lake. Only taxa with an abundance of  
866  $>1\%$  in at least one sample are shown. Black filled silhouettes represent actual  
867 abundance, white silhouettes in background illustrates abundance exaggerated by  
868 factor 4 to ease visibility. Italic ages indicate extrapolated ages.

869  
870 **Figure 6** Diatom stratigraphy of LC6 Lake. Selected taxa are shown in relative  
871 abundance. The gap captures the sediment slump between 8 – 27 cm. Italic ages  
872 indicate extrapolated ages.

873  
874 **Figure 7** Diatom stratigraphy of Wuxu Lake. Selected taxa are shown in relative  
875 abundance. Italic ages indicate extrapolated ages.

876  
877 **Figure 8** Within-lake and between-lake comparisons. Results from nMDS axis 1  
878 scores and impulse diagram of Procrustes Rotation residuals. Height and occurrence  
879 of peaks in impulse diagram indicate the degree of dissimilarity between two data sets  
880 compared. Dashed and solid lines across indicate the first, second and third quartile,  
881 respectively.

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883 **Supplementary figure** nMDS ordination biplots (2D) on interpolated and  
884 resampled data sets. Dashed line indicates division between samples older 1880 AD  
885 and sample younger 1880 AD.

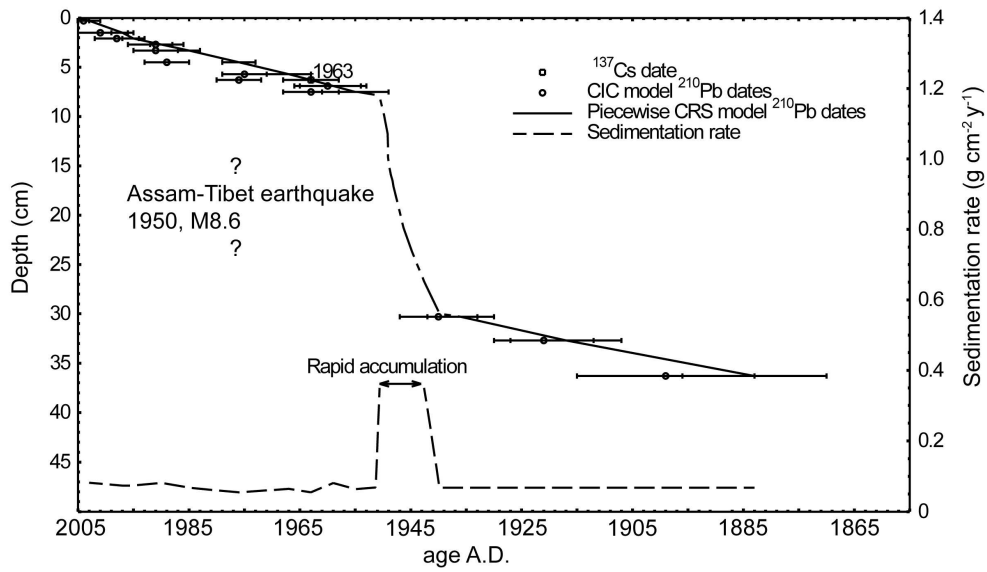


Location of LC6 Lake and Wuxu Lake and corresponding coring locations. Nyingchi and Litang are the closest climate stations. Figure adapted from Google Earth, Landsat, and the Online Map Creation Tool.

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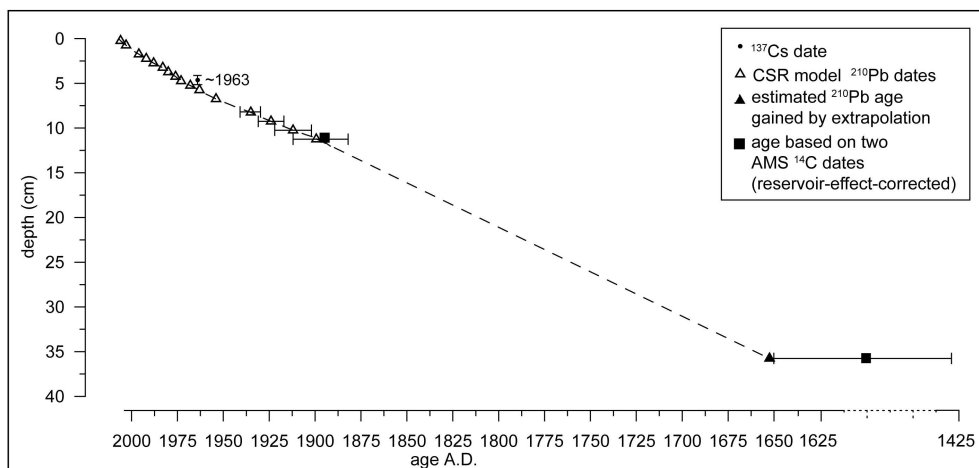
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Radiometric chronology for LC6 Lake showing the 1963 depth determined from the <sup>137</sup>Cs, the piecewise CRS model <sup>210</sup>Pb dates and sedimentation rates, and the CIC model <sup>210</sup>Pb dates calculated for sections above 7.5 cm and below 30 cm  
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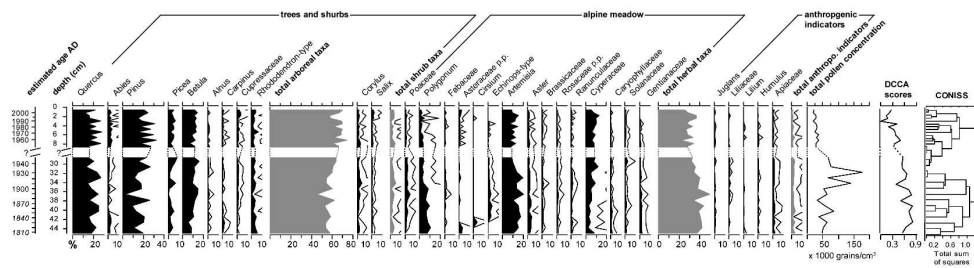
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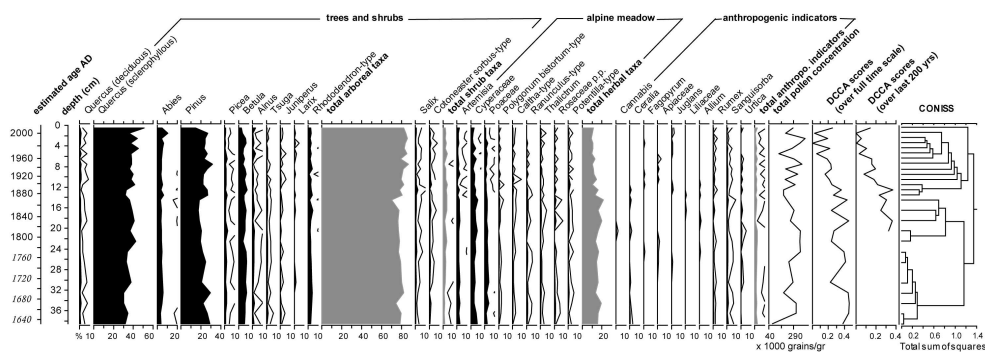
Age chronology of the Wuxu Lake sediment core showing the CRS model  $^{210}\text{Pb}$  dates, the approximate 1963 depth determined from the  $^{137}\text{Cs}$  stratigraphy, the extrapolated  $^{210}\text{Pb}/^{137}\text{Cs}$  age and the (calibrated and reservoir-effect corrected) radiocarbon age ( $2\sigma$ -range) of the core basis.

244x116mm (300 x 300 DPI)



Pollenstratigraphy of LC6 Lake. Only taxa with an abundance of >1% in at least one sample are shown. The black filled silhouettes represent original pollen abundance; transparent silhouettes in the background exaggerate the original abundance of rare species by 4 to ease visibility. The gap captures the sediment slump between 8 – 27 cm. Italic ages indicate extrapolated ages.

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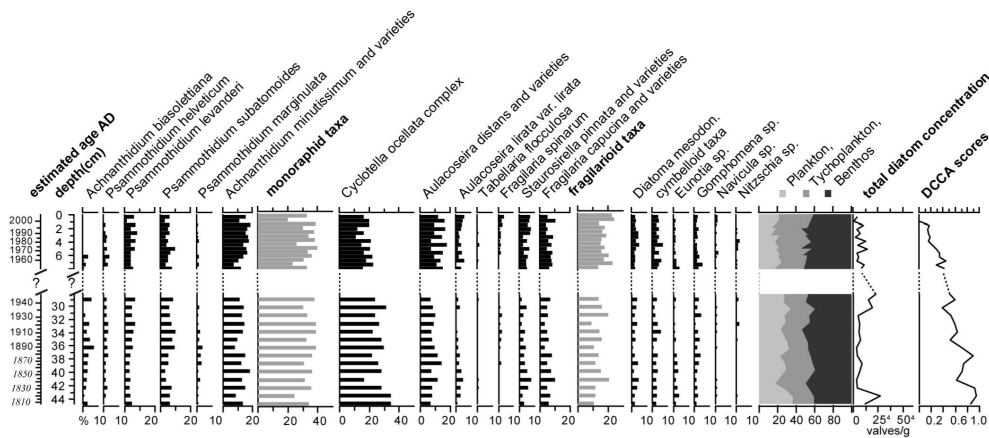


Pollenstratigraphy of Wuxu Lake. Only taxa with an abundance of >1% in at least one sample are shown. Black filled silhouettes represent actual abundance, white silhouettes in background illustrates abundance exaggerated by factor 4 to ease visibility. Italic ages indicate extrapolated ages.

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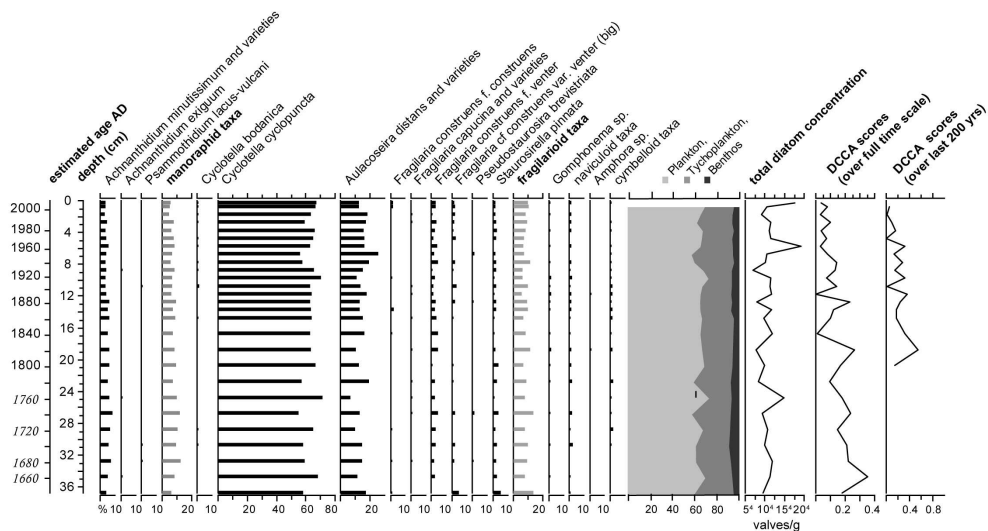


Diatom stratigraphy of LC6 Lake. Selected taxa are shown in relative abundance. The gap captures the sediment slump between 8 – 27 cm. Italic ages indicate extrapolated ages.  
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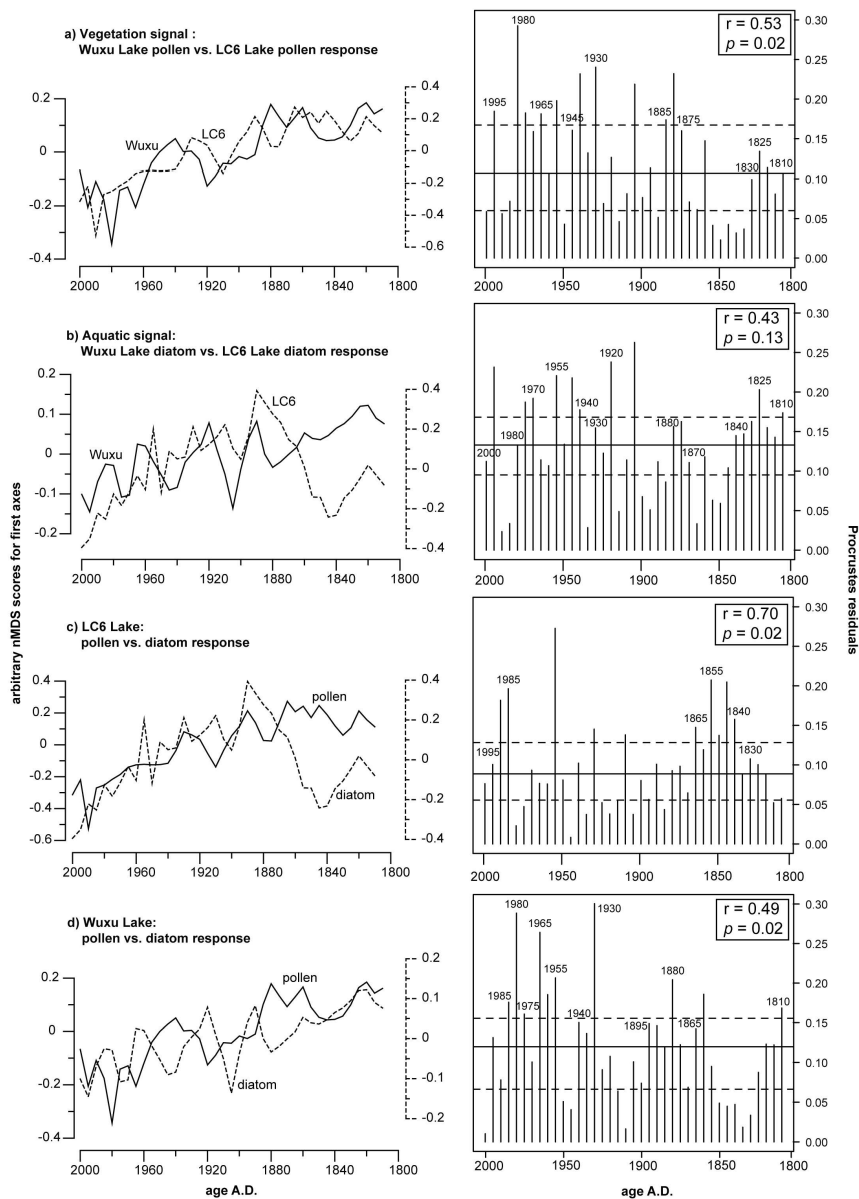




Diatom stratigraphy of Wuxu Lake. Selected taxa are shown in relative abundance. Italic ages indicate extrapolated ages.  
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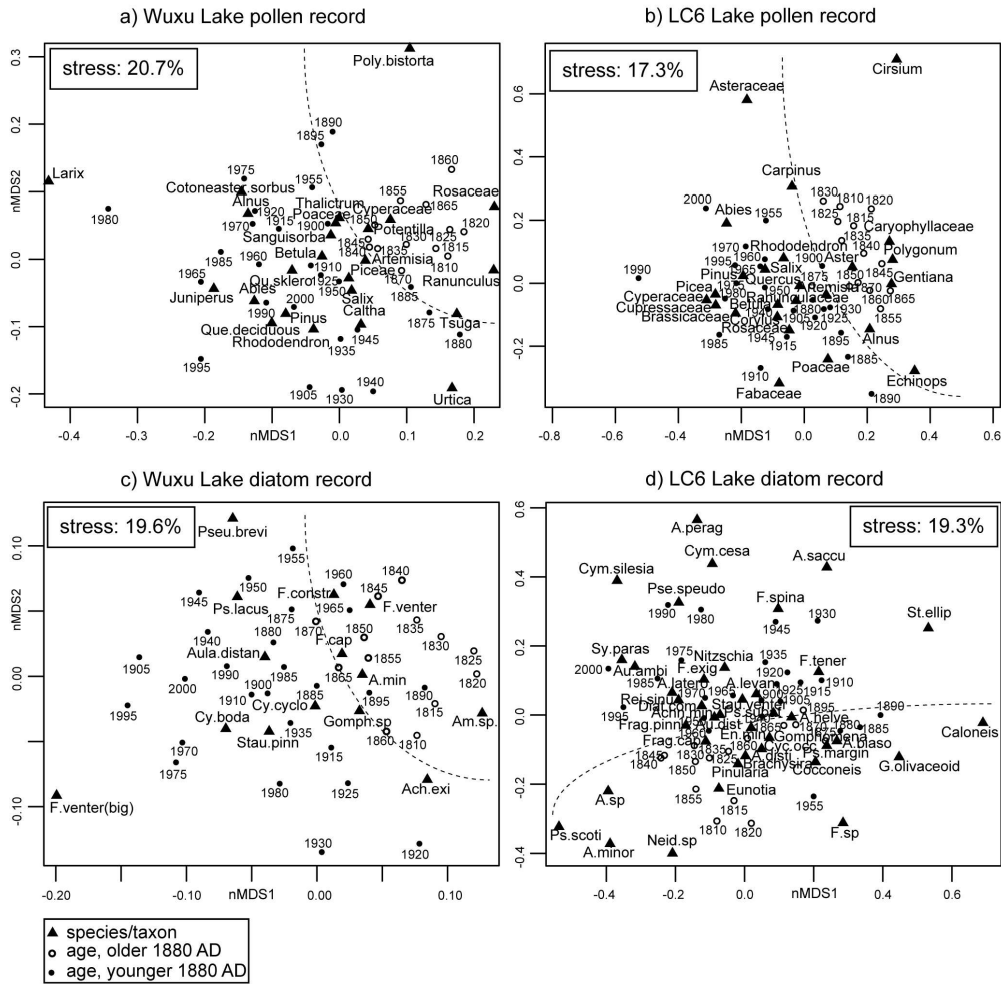
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Within-lake and between-lake comparisons. Results from nMDS axis 1 scores and impulse diagram of Procrustes Rotation residuals. Height and occurrence of peaks in impulse diagram indicate the degree of dissimilarity between two data sets compared. Dashed and solid lines across indicate the first, second and third quartile, respectively.

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nMDS ordination biplots (2D) on interpolated and resampled data sets. Dashed line indicates division between samples older 1880 AD and sample younger 1880 AD.  
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