# n-Alkane-based reconstructions of peat accumulations and depositional conditions at four locations around a shallow maar lake in the Changbai Mountains, northeastern China

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#### Abstract

A high-resolution *n*-alkane biomarker study of peat cores from four locations around the Yuanchi maar lake in the Changbai Mountains of northeastern China, has revealed different histories of peat deposition in the closely located sequences, although they experienced the same paleoclimate changes. Comparisons of the *n*-alkane distributions of modern plants around the lake and those in the peat cores suggest that the disparate peat development patterns in the four sites are the consequence of different peat-forming communities growing around the lake. These floral differences were in turn controlled by different water depths associated closely with the volcanogenic lava- and tephra-shaped topography of the lake basin. Moreover, the *n*-alkane-inferred variations in peat development patterns and inferred recent climate changes around Yuanchi Lake relate closely to the histories of volcanic forcing in the tropical Pacific and local volcanic eruptions of the Changbai Mountains. These events evidently led to alterations of local climate that affected growth of land plants at the four locations. Finally, anthropogenic impacts since 1950 CE have had an additional effect on peat accumulation in the Changbai Mountains region.

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20	Key points:
21	• <i>n</i> -Alkane-based reconstruction of peat accumulation history around a maar lake.
22	• Hydrological conditions and plant communities related to lake basin caused by volcanism lead to unsynchronized
23	peat depositional processes.
24	• Volcanism and anthropogenic have important impacts on local peat development.
25	

#### 26 Abstract

A high-resolution *n*-alkane biomarker study of peat cores from four locations around 27 28 the Yuanchi maar lake in the Changbai Mountains of northeastern China, has revealed different histories of peat deposition in the closely located sequences, although they 29 experienced the same paleoclimate changes. Comparisons of the *n*-alkane distributions 30 of modern plants around the lake and those in the peat cores suggest that the disparate 31 peat development patterns in the four sites are the consequence of different peat-forming 32 communities growing around the lake. These floral differences were in turn controlled 33 34 by different water depths associated closely with the volcanogenic lava- and tephra-shaped topography of the lake basin. Moreover, the *n*-alkane-inferred variations 35 in peat development patterns and inferred recent climate changes around Yuanchi Lake 36 37 relate closely to the histories of volcanic forcing in the tropical Pacific and local volcanic eruptions of the Changbai Mountains. These events evidently led to alterations 38 of local climate that affected growth of land plants at the four locations. Finally, 39 anthropogenic impacts since 1950 CE have had an additional effect on peat 40 accumulation in the Changbai Mountains region. 41

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43 Keywords: peat deposition, *n*-alkanes, local conditions, volcanic eruption,
44 anthropogenic activities, Changbai Mountains

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46 **1. Introduction** 

Peat is the partially preserved remains of former plant communities that contains a 47 high proportion of organic matter (OM). Peatlands therefore can be either sources or 48 sinks of carbon depending on environmental conditions (Kayranli et al., 2010; Naafs, et 49 al., 2019). Different types of peatlands are defined by their distinctive combinations of 50 hydrology and chemistry that support characteristic plant communities (Andersson et al., 51 2012). Lipid biomarkers have special features of relative source specificity and 52 resistance to decomposition. The composition and abundance of biomarkers in peat are 53 54 mainly derived from waxes of plants that grew where the peat accumulated (e.g. Nichols et al., 2006; Zheng et al., 2007; Zhou et al., 2005; Andersson et al., 2011; Zhang et al., 55 2014, 2016, 2017). Lipid biomarkers in continuous peat cores consequently can provide 56 57 information on variations in former plant communities that contributed to peat deposition and provide site-specific records of in situ environmental histories (e.g. 58 Regnery et al., 2013; Zhang et al., 2018; Naafs et al., 2019). 59

60 Peatlands are widely distributed in northeast China. Many studies have focused on them to provide detailed paleoenvironmental reconstructions on centennial and 61 millennial age-scales (e.g. Hong et al., 2001; Zhou et al., 2005; Zhang et al., 2015, 2016; 62 Zhang et al., 2014, 2017). The Changbai Mountains in northeastern China are comprised 63 of a group of volcanoes. Most peatlands in these mountains have developed in 64 lava-dammed lakes or shallow crater lakes, and apparent differences in the initial time 65 and development of peat deposition exist between the two types of volcanogenic 66 landforms (Yang, 1995; Xing et al., 2019). Unlike the Jinchuan and Hani peatlands that 67

evolved from lava-dammed lakes and began to accumulate before 10 ka, more recent 68 peatlands such as the Yuanchi and Chichi peatlands developed from maar lakes that 69 70 formed in shallow and irregular depressions resulting from inactive volcanic craters. Therefore, both the accumulation time and the thickness of the peat deposited in those 71 72 regions are smaller than those in the peatlands that evolved from lava-dammed lakes (Yang et al., 1995). To date, studies of the longer-lived peatlands have yielded valuable 73 information about the long-term regional climate changes (e.g. Hong et al., 2001; Seki et 74 al., 2009; Zhou et al., 2010). However, little is known about modern peat deposition 75 76 process and its possible controlling factors in the peatlands that derived from the shallow crater lakes in the Changbai Mountains. 77

Even small volcanic eruptions commonly inject large quantities of aerosols and ash 78 79 into the atmosphere that alter the radiative balance and chemical equilibrium of the stratosphere, thereby impacting regional climate (Xu et al., 2012; Sun et al., 2014, 2015). 80 A Plinian eruption in the Changbai Mountains around 1000 years ago (the Millennium 81 82 Eruption), which was accompanied by an earthquake with a magnitude of  $\sim$ 7, was one of the most violent eruptions in history (Sun et al., 2014, 2015). Hereafter, three 83 small-scale volcanic eruptions, in 1668 CE, 1702 CE, and 1903 CE, also documented in 84 the Mountains (Xu et al., 2012). In addition, population growth and economic 85 development around the Changbai Mountains area in recent years also have had a 86 significant impact on local conditions (Gao et al., 2016; Bao et al., 2019). These 87 88 volcanism and anthropogenic impacts on local conditions consequently could have had important impacts on plant growth that directly affected peat accumulations. However, 89

90 scant information is available about details of the peat deposition process and its91 potential responses to volcanic or anthropogenic activities in this region.

92 We present here a well-resolved record of the amounts and distributions of *n*-alkane biomarkers in modern plant communities and associated peat cores from four different 93 sites around a modern peatland that evolved from a shallow maar lake (Yuanchi Lake) in 94 the Changbai Mountains. The main objectives of this study are (1) to reconstruct a 95 decade-scale history of peat-forming communities that influenced peat deposition 96 around the maar lake, (2) to understand the localized responses of peat depositional 97 98 processes to variations in plant assemblages and local conditions caused by volcanic eruptions, and (3) to explore the influences of volcanism and modern anthropogenic 99 impacts on peat deposition in this region. 100

101 **2. Materials and methods** 

102 *2.1 Study area* 

The Changbai Mountains are in the Jilin Province of northeastern China and extend 103 104 along the boundary between China and North Korea. The area has a continental monsoon climate with long, cold winters and short, cool summers. More detailed 105 descriptions on the regional character have been described by Bao et al. (2010) and Gao 106 et al. (2016). Many lakes that formed from volcanic dams and in volcanic craters exist in 107 this region. Both the climate conditions and the topographic features in the region result 108 in extensive development of peatlands from lava-dammed lakes or shallow crater lakes 109 110 (Chai, 1990).

111 Yuanchi Lake (42°01'52"~42°01'58" N, 128°26'03"~128°26'10" E; elevation ca. 1280

112	m asl) has a diameter of 180 m and a catchment area of 4.1 hm <sup>2</sup> , located on the eastern
113	slopes and about 30 km from the main peak of the Changbai Mountains (Figs.1 and 2). It
114	partially fills a volcanic crater and has no significant inflow or outflow from surface
115	water or groundwater (Yang, 1995; Bao et al., 2010). Peatlands are distributed around
116	the perimeter of the lake and are populated by different peat-forming plant communities
117	(Fig.2). The modern biomes in the surroundings of the lake are trees and shrubs,
118	including L. olgensis, B. fruticosa, V.uliginosum, R.parvifolium and L. palustre. The
119	plant community on the west side of YC lake $(YC_W)$ is dominated by C. lasiocarpa and
120	Sphagnum spp, and some P. australis and S. triqueter grow near the lake shore. On the
121	south edge of lake $(YC_S)$ , the peat-forming plants are dominated by C. lasiocarpa, and
122	extensive developments of emersed vascular plants (T. orientalis and P. australis) are in
123	this location. On the east side of the lake (YC <sub>E</sub> ), the peat-forming plants are dominated
124	by shrubs, including V. uliginosum, R. parvifolium, and L. palustre, and some Sphagnum
125	mounds are distributed among the shrubs. The north side of the lake $(YC_N)$ is dominated
126	by Sphagnum spp. Large amounts of shrubs (V. uliginosum and Rhododendron
127	parvifolium) mixed with L. olgensi, B. fruticosa and Lonicera caerulea also appear in
128	this location.

129 *2.2. Sample collection and stratigraphy* 

Four peat-mud cores were collected around the edges of Yuanchi Lake ( $YC_E$ ,  $YC_W$ , YC<sub>s</sub> and YC<sub>N</sub>) with a Wardenaar peat sampler in September, 2006. The lithologies of each core show that the cores contain distinctive stratigraphic sequences based on texture, peat color, plant remains, and TOC contents (Fig.3). For YC<sub>w</sub>, the top 8 cm

consists of brown peat having a small amount of partially decomposed *Carex* remains, 134 then a layer from 8 cm to 29 cm containing dark brown peat with a high degree of 135 decomposition, and finally black mud underlying the peat sequence. In the YCs core, the 136 peat layer in the top 13 cm is composed of brown peat, the interval from 13 cm to 28 cm 137 is dark brown peat, and black mud occupies the bottom of the core. For YC<sub>E</sub>, the brown 138 peat layer comprises the top 8 cm, dark brown peat with higher degree of decomposition 139 occupies the interval from 7 to 35 cm, and black mud is present below 35 cm. In the 140 YC<sub>N</sub> core, a brown moss-peat layer dominated by *Sphagnum* spp. constitutes the top 14 141 142 cm, then a brown peat layer occupies the interval from 14 to 21 cm, the interval from 21 cm to 28 cm is dark brown peat with a high degree of decomposition, then the black 143 mud occupies the bottom of the core. The cores were subsampled on-site by slicing into 144 145 1 cm intervals that were stored in polyethylene bags for transport to the laboratory for analysis. 146

#### 147 2.3. Chronology of the peat-mud sequence

The peat cores were dated at 1 cm intervals by <sup>210</sup>Pb analysis. A collective total of 120 peat samples from the four cores were analyzed using a low-background  $\gamma$ -ray spectrometer with a high-purity Ge semiconductor (ORTEC Instruments Ltd., USA) at the State Key Laboratory of Lake Science and Environment, Nanjing Institute of Geography and Limnology, CAS. The radioisotope results and the age-depth model were described in more detail by Bao et al. (2010). Peat accumulation rates (PAR, cm/yr) were estimated from the 1 cm depth intervals and the corresponding <sup>210</sup>Pb ages.

155 2.4. Laboratory analysis

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The peat samples taken at 1 cm intervals from the peat cores were dried at 105 °C and then combusted in a muffle furnace at 550 °C for 4h to determine their loss on ignition (LOI) values (Heiri et al., 2001). TOC concentration of each sample was estimated from OM content expressed as LOI values by multiplying the LOI by 0.5, and organic carbon accumulation rates (CAR, g C/m<sup>2</sup>/yr)) were calculated from the TOC concentrations and the PAR values (Bao et al., 2010).

For *n*-alkane analyses, air-dried samples (1g) were extracted three times with MeOH/dichloromethane (1:1, v:v) for 15 min in an accelerated solvent extractor. The three extracts were combined after filtration and concentrated using a rotary evaporator. The *n*-alkanes were isolated using silica gel column chromatography by elution with 20 ml *n*-hexane. The eluate was concentrated with a N<sub>2</sub> stream and transferred to vials for gas chromatography-mass spectrometry (GC-MS) analysis. Details of the *n*-alkane analysis and determination are described by Zhang et al. (2014, 2016).

169 *2.5 n-Alkane proxies* 

170 We employ a suit of *n*-alkane molecular ratios as proxies to identify changes in the origins of the biomarker molecules and in their relative amounts of preservation, two 171 parameters that are commonly sensitive to climate changes. These ratios include the 172 total *n*-alkane concentrations normalized to TOC (µg total *n*-alkanes/g TOC), carbon 173 preference index (CPI), average chain length (ACL), and the proportion of aquatic 174 components ( $P_{aq}$ ). These derived ratios collectively summarize variations of *n*-alkane 175 distributions in the peat sequences (e.g. Naafs et al., 2019. The n-alkane CPI values 176 reflecting the odd-over-even predominance of the carbon-chain-length have been 177

interpreted as an indicator of extensive microbial degradation of *n*-alkanes in peat 178 sequences (Zhou et al., 2010). The n-alkane ACL describes the weighted mean lipid 179 chain length and reflects the dominant chain-lengths of the *n*-alkanes. We calculated the 180 CPI and ACL values over the carbon atom range of 20-33. The  $P_{aq}$  was defined using 181 lacustrine vegetation (Ficken et al., 2000), but it is also used to reconstruct the 182 proportions of aquatic plants or mosses in peat, which is a parameter that indicates peat 183 hydrological conditions (e.g, Zhou et al., 2005, Nichols et al., 2006; Zhang et al., 2016, 184 2017). 185

- 186 **3. Results**
- 187 3.1 The age-depth chronologies, TOC concentrations and PARs of the four peat
  188 sequences

189 The YC<sub>w</sub> age-depth scale indicates that the 29-cm thick peat layer in this sequence was deposited during the past ca. 400 years, from 1600 to 2000 CE (Fig.3a). The TOC 190 concentration ranges from 19.5 to 48.2%, with a mean value of 40.3±8.5%. Continuous 191 192 increases in TOC concentrations occur in the bottom of the peat core, and notably high and stable values (mean  $44.6\pm2.9\%$ ) appear in the upper 20-cm section that corresponds 193 to peat deposition since 1800 CE (Fig.3b). PAR varies from 0.03 to 0.33 cm/yr in the 194 YC<sub>w</sub> sequence (Fig.3b). The rate is initially very slow (~0.04 cm/yr) and increases 195 slightly to 0.1 cm/yr in the interval from 20 to 13 cm (from 1800 to 1900 CE). Then the 196 rates increase markedly and peak at 8 cm (ca.1950 CE). 197

The peat in the upper 28 cm of the YCs sequence was deposited during the last 200 years, from 1800 to 2000 CE (Fig.3c). TOC concentrations range from 3.4 to 39.5 %, with a mean value of  $28.8\pm10.5\%$ . Relatively higher TOC values (mean  $31.6\pm7.0\%$ ) occur in the top 25 cm, corresponding to deposition since 1850 CE (Fig.3d). PAR ranges between 0.04 and 0.33 cm/yr in the YC<sub>s</sub> peat section (Fig.3d). Lower rates less than 0.1 cm/yr occur below 25 cm, then the rate increases gradually to a maximum (0.33 cm/yr) at 8 cm (ca. 1950 CE) before decreasing sharply to ~0.1 cm/yr in the top 5 cm of the core.

The age-depth scale of the  $YC_E$  sequence indicates that the peat in the top 35 cm was 206 deposited during the past ca. 400 years, from 1600 to 2000 CE (Fig.3e). The TOC 207 208 concentrations in the peat vary between 10.7 and 51.1%, with a mean value of 33.6±8.3%. High values (>30%) and a gradually increasing trend starting at 28 cm 209 correspond to accumulation since 1800 CE (Fig.3f). The PAR in the YC<sub>E</sub> peat section 210 211 fluctuates between 0.04 and 0.59 cm/yr (Fig.3f). Markedly lower values occur below 28 cm (before 1800 CE), then the rates start to increase slightly but fluctuate strongly, and 212 relatively higher values appear in the upper 8 cm (since 1950 CE). 213

The YC<sub>N</sub> peat layer was deposited during the past ca. 250 years, from 1750 to 2000 CE (Fig.3g). The TOC concentrations range from 13.1 to 51.4% (mean  $38.4\pm11.5\%$ ), with obviously high and ever-increasing values (mean  $43.2\pm6.5\%$ ) in the upper 25 cm that corresponds to peat deposition since 1800 CE (Fig.3h). The PAR has lower values at the bottom of this peat section below 25 cm, and higher values occur from 22 to 19 cm. Markedly lower values (~0.08 cm/yr) appear again from 19 to 10 cm (1850 to 1950 CE) before increasing markedly in the top 10 cm (since 1950 CE) (Fig.3h).

221 *3.2. n-Alkane distributions* 

The *n*-alkane distributions from the different layers in the four peat sequences range 222 similarly from C<sub>20</sub> to C<sub>33</sub> and have an odd/even predominance with a dominance of 223 middle and long chain components (Fig.4). The n-alkane distributions in the whole YC<sub>w</sub> 224 peat core have a strong dominance of the  $C_{27}$  component, and  $n-C_{23}$  also contributes 225 high proportions in the upper and bottom peat units. The YC<sub>s</sub> peat core is characterized 226 by strong dominances of C<sub>23</sub>, C<sub>25</sub> and C<sub>27</sub> n-alkanes in different peat layers. For the YC<sub>E</sub> 227 peat core, the distribution in the brown peat unit is dominated by the  $C_{23}$  and  $C_{31}$ 228 *n*-alkanes and in the dark brown peat by the  $C_{27}$  and  $C_{31}$  *n*-alkanes. In the YC<sub>N</sub> peat core, 229 230 long-chain  $C_{29}$  and  $C_{31}$  *n*-alkanes are the major components in the upper unit and the bottom of the core, and the middle brown moss peat layer has abundant middle chain  $C_{23}$ 231 and  $C_{25}$  in subequal proportions with the long chain *n*-alkanes. 232

#### 233 3.3. n-Alkane concentrations and their molecular ratios

We focus on *n*-alkane-based reconstruction of the peat deposition history and paleoenvironmental information in the Yuanchi Lake region. Here we present the results of the changes in TOC concentrations, the PARs, the CARs, and the *n*-alkane concentrations and their derived molecular climate proxies (CPI, ACL and  $P_{aq}$ ) for the four peat sequences that we collected around Yuanchi Lake (Figs.5-8).

The total *n*-alkane concentrations normalized to TOC in the YC<sub>w</sub> core range between 42.2 and 595.7  $\mu$ g/g TOC, with a mean value of 188.5±176.3  $\mu$ g/g. Markedly higher values occur before 1800 CE and lower values appear from 1800 CE to present (Fig.5c). The *n*-alkane CPI varies between 2.1 and 4.2, with a mean value of 3.2±0.5 (Fig.5d).

ACL and  $P_{aq}$  values range from 24.3 to 26.4 (mean 25.6±0.5) and 0.5 to 0.9 (mean

244 0.7±0.09), respectively (Fig.5e and f). Gradually increasing CPIs exist before 1800 CE, 245 and lower ACL but higher  $P_{aq}$  values occur in this interval. Markedly decreasing CPIs, 246 higher ACL but lower  $P_{aq}$  values appear from 1800 to 1900 CE, corresponding to the 247 highest TOC concentrations (Fig.5a). The interval from 1940 to present is characterized 248 by the lowest CPI and ACL values and the highest  $P_{aq}$  value, coinciding with the higher 249 TOC concentrations and higher PAR and CAR values (Fig.5a and b).

In the YC<sub>s</sub> sequence, the total n-alkane concentrations range between 56.6 and 529.4 250  $\mu g/g$  TOC, with a mean value of 226.1±134.6  $\mu g/g$  (Fig.6c). Relatively higher 251 252 concentrations appear before 1850 CE, and the values decrease sharply to the minimum at ca. 1900 CE. Then higher values appear again in the interval between 1900 and 1950 253 CE, and stably lower values occur from 1950 CE to the present. This variation generally 254 255 corresponds to the PAR changes in those time (Fig.6 and c). The *n*-alkane CPIs vary between 2.6 and 4.9 (mean 3.5±0.6), and ACLs vary between 24.5 and 26 (mean 256 25.4 $\pm$ 0.5), and the  $P_{aq}$  values change inversely to the ACL values, ranging from 0.6 to 257 0.85 (mean 0.7 $\pm$ 0.07) (Fig.6d-f). Markedly lower ACLs (<25) but higher  $P_{aq}$  values 258 259 (>0.7) appear before 1850 CE and during the interval between 1900 and 1950 CE, corresponding to the relatively higher PAR, CAR and total *n*-alkane concentrations in 260 these times (Fig.6b and c). 261

In the YC<sub>E</sub> sequence, the total *n*-alkane concentrations range from 3.0 to 482.8  $\mu$ g/g TOC, with a mean value of 83.8±103.4  $\mu$ g/g (Fig.7c). The concentrations are generally higher (~120  $\mu$ g/g) before 1900 CE, but the values are almost below 50  $\mu$ g/g TOC from 1900 to the present. The *n*-alkane CPIs vary widely between 1.3 and 10.7 (mean

3.8±1.9), and most of them are lower than 4.0 before 1950 CE, except for the relatively 266 higher values at ca. 1825 CE and 1900 CE, and in the interval from 1950 to the present 267 (Fig.7d). ACLs and  $P_{aq}$  values fluctuate between 24.4 and 28.3 (mean 26.2±1.0), and 0.3 268 and 1.0 (mean  $0.5\pm0.2$ ), respectively (Fig.7e and f). Relatively higher ACLs (>26) but 269 lower  $P_{aq}$  values (<0.4) appear before 1800 CE, and lower ACLs but higher  $P_{aq}$  values 270 occur during the intervals from 1800 to 1950 CE. The ACLs then increase dramatically, 271 in contrast to CPIs and  $P_{aq}$  values that decrease markedly during the recent decades 272 (Fig.7d-f), coinciding with the highest TOC, PAR and CAR values but with the lowest 273 *n*-alkane concentrations (Fig.5a-c). 274

The total *n*-alkane concentrations in the YC<sub>N</sub> sequence range from 3.7 to 570  $\mu$ g/g 275 TOC, with a mean value of  $172.4 \pm 182.8 \ \mu g/g$  (Fig.8c). Markedly higher concentrations 276 (~400 µg/g TOC) appear before 1850 CE, accompanied with higher PARs but lower 277 CARs (Fig.8b); then the values decrease rapidly and most of them below 100  $\mu$ g/g TOC 278 during the interval from 1850 CE to the present. The *n*-alkane CPIs vary between 1.8 279 280 and 5.5 (mean  $4.0\pm0.9$ ), with relatively high and stable values (mean  $4.4\pm0.7$ ) before 1900 CE (Fig.8d). ACL and  $P_{aq}$  values fluctuate between 26.3 and 29.7 (mean 27.8±1.0), 281 and between 0.17 and 0.5 (mean 0.3±0.1), respectively (Fig.8e and f). The highest ACL 282 and the lowest  $P_{aq}$  values appear before 1800 CE, and relatively lower ACLs (< 27) but 283 higher  $P_{aq}$  values (> 0.4) occur during the intervals from 1800 to 1900 CE; Then 284 markedly higher ACLs (>27.5) but lower  $P_{aq}$  values (<0.3) appear again from 1900 CE, 285 286 which correspond with gradual increases in both CARs and PARs (Fig.8b).

#### 287 **4. Discussion**

288

Yuanchi Lake is in a circular shallow crater that was formed ca. 1060±100 a B.P 289 (Yang et al., 1995) and was likely related to the Millennium Eruption. The peat layers 290 were deposited in the basin of the maar lake over sediments that are represented by the 291 basal black muds in the four cores (Fig.3). The peat sequences provide records of the 292 succession of peat-forming vegetation that has partially filled the maar lake and 293 evidence of conditions important to the production and preservation of the plant remains 294 295 (Fig.3). Peat OM is mainly derived from the remains of local plants and provides information about the kinds and amounts of vegetation that has lived in a specific 296 location and the processes that affect peat preservation (Chai, 1990; Meyers and 297 298 Ishiwatari, 1993; Meyers, 2003; Zhang et al, 2016, 2017). Yuanchi Lake has been filled by ingrowth of peatlands around its edges that have been spreading gradually toward the 299 center of the lake (Yang et al., 1995). The peat <sup>210</sup>Pb-based age-depth models of the four 300 301 sequences around Yuanchi Lake indicate the initial contributions of TOC-rich vascular plants inputs in the four sites are asynchronous (Fig.3). We hypothesize that this process 302 of transformation of a shallow lake into a peatland first started in the YC<sub>w</sub> and YC<sub>E</sub> 303 locations ca. 1600 CE, followed by the YC<sub>N</sub> ca.1750 CE, with the YC<sub>s</sub> starting to infill 304 last since ca.1800 CE (Fig.3). 305

4.1 Peat TOC concentrations and peat accumulation processes around the Yuanchi Lake

Although the total histories of peat sequences differ at the four sites, their initiation times for abundant peat accumulations are similar as indicated by the collectively increasing PAR values at ca. 1800 CE (Fig.3). TOC concentrations and PARs in the four

309	peat sections exhibit increasing trends from 1800 to 1950 CE, suggesting a continuous
310	and growing input of TOC-rich vascular plants promoted peat accumulation around
311	Yuanchi Lake. However, we observe that the mean TOC concentration (~44.6%) in the
312	$YC_w$ peat sequence is higher than in the other three locations (mean 28.8% at YC <sub>s</sub> , 36%
313	at YC <sub>E</sub> , and 39% at YC <sub>N</sub> ) since 1800 CE. Nevertheless, mean PAR in the YC <sub>w</sub> peat
314	sequence is slightly lower (~0.12 cm/yr) than those values in the other three cores (mean
315	0.17 cm/yr in YC <sub>s</sub> , 0.22 cm/yr in YC <sub>E</sub> , and 0.17 cm/yr in YC <sub>N</sub> peat cores) (Fig.3). In
316	addition, differences in peat accumulation between the four locations is evident since
317	1950 CE, when marked decreases in PAR values occurred in the $YC_w$ and $YC_s$ locations,
318	and the rates in the $YC_E$ and $YC_N$ peat sequences showed rapidly increasing PARs during
319	recent decades (Fig.3). We also observe that the four different locations around Yuanchi
320	Lake are dominated by different vegetation communities (Fig.2), representing settings
321	with different water depths that are likely responsible for the asynchronous peat
322	accumulations. Except for C. lasiocarpa, the modern vegetation communities in the $YC_w$
323	and $YC_s$ sites are dominated by emersed aquatic vascular plants (T. orientalis and P.
324	australis) that could contribute to higher OM inputs but would be less likely to increase
325	peat accumulate in recent decades as the water became shallower. Moreover, modern
326	vegetation communities at the $YC_E$ and $YC_N$ sites are dominated by <i>Sphagnum</i> spp and
327	shrubs growing in shallow water depths that are more likely to promote peat
328	accumulation than Carex and the emersed aquatic vascular plants that dominate the $YC_w$
329	and $YC_s$ sites in deeper-water conditions (Figs.2 and 3).

*4.2. Biomarker distributions in the Yuanchi peat sequences* 

## *4.2.1. n-Alkane biomarkers of modern plants around Yuanchi Lake*

332	<i>n</i> -Alkane biomarkers in peat originate mainly from plant waxes and bacteria and are
333	recognized as important proxies for indicating changes in the plant communities and
334	reflecting any alterations from in situ processes that peat deposits may experience after
335	their formation (Zhang et al., 2018). The <i>n</i> -alkane distribution patterns vary considerably
336	among different peat-forming plant species, a feature that provides important evidence
337	of the main sources of these biomarkers in the peat (e.g. Kirkels et al., 2013; Zhang et al.,
338	2016, 2017). The dominant plants observed at the four sites around Yuanchi lake are
339	clearly different (Fig.2). We compiled published information about the dominant
340	n-alkane homologues found in modern plant species like those around the lake to
341	interpret the main sources of the <i>n</i> -alkanes in the peat and thereby to provide a
342	biomarker record for reconstructing the <i>in situ</i> conditions at the four sites (Table 1).
343	The modern plants in the YC <sub>w</sub> site are dominated by C. lasiocarpa, S. triqueter, and P.
344	australis, all of which have a predominance of $n-C_{29}$ in their n-alkane distributions
345	(Cranwell et al., 1984; Street et al., 2013; Ronkainen et al., 2013). Some Sphagnum spp
346	characterized by prominent abundances of C <sub>23</sub> and C <sub>25</sub> <i>n</i> -alkanes (Cranwell et al.,1984;
347	Street et al., 2013) also develop in this site. The C. lasiocarpa and E. fauriei, which are
348	respectively dominated by $n$ -C <sub>29</sub> and $n$ -C <sub>27</sub> (Tarasov et al., 2013; Ronkainen et al., 2013),
349	are the major modern species growing at the $YC_S$ site. In addition, abundant emersed
350	aquatic vascular plants (T. orientalis and P. australis), both having a predominance of
351	<i>n</i> -C <sub>29</sub> , and some submerged aquatic plants with prominent abundances of C <sub>23</sub> and C <sub>25</sub>
352	<i>n</i> -alkanes (Cranwell et al., 1984; Ficken et al., 2000) are also prevalent in this site under

deeper water conditions. The modern vegetation covering both the YC<sub>E</sub> and YC<sub>N</sub> sites is mainly dominated by *Sphagnum* spp and shrubs (*V. uliginosum* and *R. parvifolium*) under drier condition that are characterized by n-C<sub>29</sub> and n-C<sub>31</sub> (Salasoo, 1987; Tarasov et al., 2013; Street et al., 2013). Moreover, the two sites are surrounded by trees (*L. olgensi*, *B. fruticosa and L. caerulea*) that have a major predominance of the C<sub>27</sub> n-alkane (Tarasov et al., 2013).

#### 4.2.2 Biomarker origins in each of the peat cores from Yuanchi Lake

The chain-length distributions of *n*-alkanes in the four peat sequences range from 360 C<sub>20</sub> to C<sub>33</sub> with an odd/even predominance (Fig.3), indicating a major input from 361 terrigenous plant waxes (Eglinton et al., 1967). The dominant *n*-alkane components have 362 different distributions among the four sequences, which can be attributed to origins from 363 364 different plant types associated with different water levels in their growth locations. Based on the dominant *n*-alkane homologues found in the modern plant covering on the 365 four sites (Table 1), we can infer probable origins of the biomarkers in each of the peat 366 367 cores (Fig.4).

The strong dominance of *n*-alkane  $C_{23}$ ,  $C_{25}$  and  $C_{27}$  components in the bottom peat units in the YC<sub>w</sub> peat core mainly originated from a combination of aquatic plants in a deeper water lake setting and trees from surrounding area. Shallower water along the western edge of the lake and larger amounts of terrestrial plant contributions resulted in the strong dominance of long-chain *n*-alkane in the middle section of the peat core (Fig.4). The abundances of  $C_{23}$  and  $C_{25}$  components that occur in the upper section is likely associated with increased amounts of *Sphagnum* spp input in recent years. A

375	strong dominance of $C_{23}$ , $C_{25}$ and $C_{27}$ <i>n</i> -alkanes in the YC <sub>s</sub> peat core relate to major
376	contributions from both aquatic plants under high water level condition and terrestrial
377	plants around the area. The <i>n</i> -alkane distributions in the $YC_E$ and $YC_N$ peat cores have
378	the long-chain $C_{29}$ and $C_{31}$ <i>n</i> -alkanes that are diagnostic of shrub communities in these
379	peat sites (Table 1). In addition, significant proportions of $C_{23}$ and $C_{25}$ <i>n</i> -alkanes in the
380	middle and upper sections of the two peat cores suggest important contributions from
381	Sphagnum spp, which is consistent with modern plant coverage on the two sites (Fig.2).

#### 4.2.3 Changes in plant communities and site-specific conditions around Yuanchi Lake

383 The *n*-alkane-based reconstruction of peat deposition in the four settings reveals differences in the rates and composition of peat deposited around Yuanchi Lake (Figs. 384 5-8). In the  $YC_w$  site, inputs of vascular plant residues to the paleolake sediments 385 386 beginning around 1600 CE initiated accumulations of TOC and elevated n-alkane concentrations (Fig.5 a and c). The plant communities that developed in this location 387 before 1800 CE were probably dominated by abundant aquatic plants that are typified by 388 389 short and middle chain lipids (Fig.5e and f). Terrigenous vascular plants characterized by TOC-rich and long-chain lipids began to dominate since 1800 CE, as indicated by the 390 highest TOC concentrations, higher ACL and lower Pag values from 1800 to 1900 CE 391 (Fig.5 a, e and f). These features imply that the relative water depth at this site dropped 392 quickly from 1600 CE as this lakeshore location filled in starting ca. 1800 CE, leading to 393 greater expansion of subaerial TOC-rich vascular plants that promoted peat 394 395 accumulation. The peat entered a rapid accumulation interval since 1940 CE as evident from the increases in the TOC concentrations and peaks in the PAR and CAR (Fig.3a 396

and b). Based on the *n*-alkane compositions of modern plants in this site, the lowest CPI and ACL values and the highest  $P_{aq}$  values (Fig.5 d-f) suggests a higher contribution of *Sphagnum* spp residues that are more resistant to decomposition and commonly accumulates in peat during shallow water conditions (Andersson et al., 2012; Loisel et al., 2014; Zhang et al., 2016, 2018).

At the YC<sub>s</sub> site, the modern plants are characterized by emersed aquatic vascular 402 plants (T. orientalis and P. australis) and other aquatic plants associated with relatively 403 deeper water than at the other sites (Fig.2). Lower TOC concentrations, *n*-alkane CPI 404 405 and ACL values and higher Paq values, collectively imply a lacustrine condition with smaller subaerial plant inputs before 1850 CE (Fig.6 a, d-f). Higher n-alkane 406 TOC-normalized concentrations in this time might have resulted from algae and bacteria 407 408 that are characterized by short chain *n*-alkanes (Fig.6 c-f). Higher TOC, *n*-alkane concentrations, CPI and ACL values, and lower Paq values indicate greater inputs of 409 terrigenous vascular plants associated with continual lake infilling, promoted peat 410 411 accumulation from 1850 to 1900 CE (Fig.6). An evident rise in water depth occurred from 1900 to 1950 CE when the aquatic plants became the major communities as 412 indicated by the highest TOC-normalized *n*-alkane concentrations, lowest *n*-alkane ACL 413 but the highest Paq values (Fig.6 c, e and f). Obvious decreases in both TOC and 414 415 TOC-normalized *n*-alkane concentrations (Fig.6 a and c) imply smaller inputs to the peats from terrigenous vascular plants (Eglinton and Hamilton, 1967). However, PAR 416 417 reached a maximum and CAR also increased during this interval, although the terrigenous vascular plant contribution to the peat was less (Fig.6b). Peat preservation 418

and accumulation are mainly controlled by the combination of the kind of OM from the 419 peat-forming plant inputs and microbial activity related to climate conditions (Zhou et 420 al., 2005, 2010; Zhang et al., 2016). The variations in peat *n*-alkane CPIs are closely 421 associated with peat-forming plants, temperature condition and microbial activity (e.g. 422 Zhou et al., 2005; Andersson and Meyers, 2012; Naafs et al., 2019). We suggest that the 423 weaker microbial activity that is indicated by relatively higher CPI values (Fig.6 d) in an 424 inferred high water-level setting from 1900 to 1950 CE was a major factor for limiting 425 peat decomposition. Since 1950 CE, the variations in TOC, PAR, TOC-normalized 426 427 *n*-alkane concentrations and *n*-alkane proxies reflect local conditions, and the relative water level diminished to be like that in the period before 1900 CE (Fig.6). 428

Unlike YC<sub>w</sub> and YC<sub>s</sub> locations, the YC<sub>E</sub> site was dominated by terrigenous vascular 429 plants dominated by long-chain n-alkanes in low water depth conditions before 1800 CE 430 (Fig.7). Major inputs to the peats from large amounts of terrigenous plants started at 431 1800 CE, when obvious increases in TOC concentrations appear in the YC<sub>E</sub> location 432 433 (Fig.7 a). Marked changes in *n*-alkane distributions of the peat core imply variations in 434 vegetation communities in the YC<sub>E</sub> locations since 1800 CE (Fig.7 c-f); Based on the *n*-alkane compositions of modern plants in this site, higher PARs and CARs from 1800 435 CE can be interpreted in terms of a greater contribution of Sphagnum spp. growing 436 437 under wetter conditions that were the major contributors of middle chain carbon lipids, leading to higher *n*-alkane concentrations, elevated CPI and P<sub>aq</sub> values, and the lowest 438 ACL values in peat (Fig.7b-f). 439

440 Like the  $YC_E$  location, the peat in the  $YC_N$  site has clearly lower TOC

concentrations and accumulation rates during the initial time from 1750 to 1800 CE 441 (Fig.8a and b), when fewer terrigenous vascular plants dominated by long-chain 442 *n*-alkanes developed under drier *in situ* conditions (Fig.8d-f). Subsequently, the peat 443 sequence received a high contribution of the middle-chain *n*-alkanes that are diagnostic 444 of Sphagnum spp under inferred cold and wet conditions that stimulated peat TOC 445 preservation and peat accumulation from 1800 to 1900 CE (e.g. Zhou et al., 2010; 446 Andersson and Meyers, 2012; Naafs et al., 2019). After this period the n-alkane 447 distributions are dominated by long chain carbon *n*-alkanes as evidenced from rapid 448 449 decreases in CPI and P<sub>aq</sub> values and an increase in ACL values (Fig.8 d-f), providing more evidence of inputs from predominantly terrigenous vascular plant such as Carex 450 and shrubs during an interval of shallow water depths since 1950 CE. 451

452 Both the plant communities that contribute to the peat deposits and the degree of preservation can be the results of different hydrological conditions (Andersson et al., 453 2012). Compared to other three sites, the  $YC_N$  site evidently was deposited under a 454 455 lower relative water level, given that the peat sequence has higher mean value of the *n*-alkane CPI (4.0  $\pm$ 0.9) and ACL (27.8 $\pm$ 1.0) but has lower  $P_{aq}$  values (0.3 $\pm$ 0.1) (Table 2), 456 indicating that the peat originated mostly from terrigenous vascular plants. In contrast, 457 the YC<sub>w</sub> and YC<sub>s</sub> peat cores have lower ACL (~ 25.4) but higher  $P_{aq}$  (~0.7) values 458 459 (Table 2), implying the prevalence of aquatic plants typified by middle-chain *n*-alkanes under deeper water depth conditions at the two sites (e.g. Cranwell et al., 1984; Ficken 460 et al., 2000; Andersson and Meyers, 2012; Naafs et al., 2019). The initial peat deposition 461 in the YC<sub>S</sub> site of the Yuanchi Lake was more than 200 years later than in the other three 462

sites (Fig.3). Therefore, we speculate that the Yuanchi Lake shallow basin that is composed of massive volcanic lava and tephra (Yang et al., 1995) is uneven and has a gradient with a higher north side and lower south and west sides. This topography results in different water depths around its edges and explains the contrast between the four peat sequences.

#### 468 *4.3.* Controls on local climate and peat deposition around Yuanchi Lake

Because Yuanchi Lake is a closed system with no inflow or outflow (Bao et al., 2010), 469 its hydrology is mainly controlled by evaporation and precipitation. Volcanic eruptions 470 471 become important natural contributors to regional climate changes on many timescales, and large explosive volcanism is a leading forcing agent of natural climate changes on 472 an interannual timescale (e.g. Robock, 2000; Liu et al., 2016). In general, air 473 474 temperatures are reduced for several years after large or high frequency eruptions, because aerosols generated by volcanic eruptions could diminish solar radiation and 475 thereby impact regional and sometimes global climates (Huang et al., 2013; Liu et al., 476 2015). n-Alkane-inferred climate reconstructions in the Great Hinggan Mountain, 477 northeastern China, have revealed that cold climate intervals are associated with periods 478 with a higher frequency of tropical Pacific volcanic eruptions (Mann et al., 2005; Zhang 479 et al., 2014). In the Yuanchi peatland, the initial peat deposition occurred at the  $YC_w$  and 480 YC<sub>E</sub> locations around 1600 CE (Fig.3). Coincidentally, high frequency volcanic 481 activities had occurred in the tropical Pacific in this period (Mann et al., 2005) and 482 483 volcanic eruptions also occurred in the Changbai Mountains in 1668 and 1702 CE (Xu et al., 2012). We therefore postulate that lower OM accumulations accompanied with 484

higher ash contents in the sediments before 1700 CE in these two sites record tephra
delivery and that cold climate conditions are consequences of the frequent volcanic
activities in the Pacific and the local eruptions in the Changbai Mountains (Fig. 9 f and
g).

The initial stage of transformation of lake edges into peatlands around 1800 CE 489 corresponds to a time of warmer and drier climate in northeastern China (Hong et al., 490 2001; Lin et al., 2004; Zhang et al., 2014). Decreased volcanic activities during the 491 interval from 1700 to 1800 CE led to warmer climate conditions that stimulated more 492 493 terrigenous vascular plant growth and promoted peat accumulation along the shores of Yuanchi Lake (Fig.9). From 1800 to 1900 CE, cool climate condition in the Yuanchi 494 region likely led to smaller OM inputs from terrigenous vascular plants as indicated by 495 relatively lower TOC-normalized total n-alkane concentrations (except for the YCs 496 sequence), lower CPI and ACL values, and higher Paq values in the peat sequences (Fig.9 497 a, c-e). Moreover, the higher ash contents deposited in the cores is likely also a local 498 499 response to an increase in volcanic forcing from the tropical Pacific (Fig.9f and g, Mann et al., 2005) and to volcanic eruptions in the Changbai Mountains in 1898 CE and 1903 500 CE (Huang et al., 2013). Subsequently, *n*-alkane proxies in the peat cores indicate that 501 enhanced inputs of terrigenous vascular plant waxes under warm and dry climate 502 conditions around Yuanchi Lake existed from 1900 to 1950 CE and promoted peat 503 accumulation around the lake (Fig.9a-e). This multi-decadal warm/dry regional 504 505 transition corresponds to the period characterized by diminished volcanic activities in both the Changbai Mountains and the tropical Pacific (Fig.9f). 506

507	After 1950 CE, total <i>n</i> -alkane concentrations in the four sequences drop to their
508	minima, and obvious decreases in PAR values occurred in the high-water level locations
509	(the YC <sub>W</sub> and YC <sub>S</sub> sites) (Fig.9a-b). These <i>n</i> -alkane proxies imply that the Yuanchi
510	region experienced a significantly cooler climate accompanied with decreased
511	terrigenous vascular plant inputs in recent years, as reflected in the higher CPI, lower
512	ACL, and higher P <sub>aq</sub> values in the peat sequences (Fig. 9c-e). This multidecadal period
513	of cold climate might be attributed to a series of volcanic activities in the tropical Pacific
514	(Fig.9f) that released abundant aerosols and thereby diminished solar radiation (Robock,
515	2000; Huang et al., 2013; Liu et al., 2016). In addition, the beginning of the
516	Anthropocene in the Changbai Mountain region could be defined as 1950 CE due to the
517	rapid industrial and urban development after the Reform and Opening-Up of China (Bao
518	et al., 2019). As part of this development, greater combustion of fossil fuels and biomass
519	from expanding anthropogenic sources led to increases in their soot emissions and more
520	black carbon being deposited in peat (Gao et al., 2016). Substantial increases since 1950
521	CE in Pb accumulation rates in the Yuanchi peat further indicate significant deterioration
522	of the mountain environment from magnifying human impacts (Fig.9g). Therefore, we
523	postulate that anthropogenic impacts on the mountain region since 1950 CE likely
524	suppressed growth of land plants, reduced OM inputs from subaerial vascular plants, and
525	slowed peat accumulation.

**5.** Conclusion

*n*-Alkane biomarkers from the four peat cores around Yuanchi Lake in the ChangbaiMountains, northeastern China, record peat depositional processes in a typical maar lake

on a decadal scale. Although different lengths of peat sequences were collected around 529 Yuanchi Lake, the initiation for abundant peat accumulation (ca. 1800 CE) at the four 530 locations was similar. Based on *n*-alkane compositions in modern plants at the four sites, 531 *n*-alkane distributions in the four peat cores indicate that different vegetation 532 communities under different hydrological conditions contributed to differences in peat 533 accumulation rates and compositions of the four peat sequences. We postulate that the 534 differences in peat deposition between the four sites is a consequence of different 535 peat-forming communities growing in different water depths that are the results of the 536 537 uneven basement rock topography of the lake basin caused by volcanogenic origin from lava and tephra. 538

*n*-Alkane-inferred regional climate changes have impacted peat accumulations, but in 539 540 ways that are shared by the four locations. Lower peat accumulation rates record diminished OM inputs from terrigenous vascular plant during two long-term intervals 541 from 1600 to 1700 CE and 1800 to 1900 CE, which both correspond to cooler climate 542 associated with high-frequency volcanic eruptions in the tropical Pacific and in the 543 Changbai Mountains. A lower rate of volcanic eruptions contributed to warm/dry 544 regional conditions from 1700 to 1800 CE and 1900 to 1950 CE, when large terrigenous 545 vascular plant input and promoted peat accumulation. Since 1950 CE, lower peat 546 accumulation rates with diminished OM inputs from terrigenous vascular plants have 547 existed during a significantly cooler climate in the Yuanchi region that coincides with 548 549 both a series of volcanic eruptions and anthropogenic activities.

#### 550 Data Availability Statement

25

551 Analytical data are available from Deep Blue Data ( ) and from the cited 552 references.

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558 Author Contributions

YZ, CG, SZ, PY, and GW conceived and designed the study. YZ, CG, SZ, and PY
facilitated and conducted the field work. YZ did the lab analyses and analyzed the data.
YZ and PAM wrote the paper. All authors contributed to the drafts of the paper and its

562 final approval.

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### **Figure legends**

Fig. 1. Location of the sampling site from the Yuanchi peatland in the Changbai

700	Mountains, northeastern China.
701	Fig. 2. Panoramic views of Yuanchi Lake and of the four different sampling sites
702	(west, south, east and north) in the peatlands surrounding the lake. (Photos by
703	Guoping Wang)
704	Fig.3. Lithostratigraphy, <sup>210</sup> Pb-inferred age-depth model (a, c, e and g), the TOC
705	concentrations (black lines, Bao et al., 2010) and peat accumulation rates (PAR, red
706	lines) (b, d, f and h) of the four peat cores from the west, south, east, and north sides
707	$(YC_W, YC_S, YC_E, YC_N, respectively)$ around Yuanchi Lake.
708	Fig.4. Distributions relative to the major <i>n</i> -alkane in samples from different depths of
709	the four peat cores around Yuanchi Lake.
710	Fig.5. Downcore variations of TOC concentrations (a), carbon accumulation rates
711	(CAR) (b, black line) and PAR values (red line), Total n-alkane concentrations
712	relative to TOC (c), <i>n</i> -alkane CPI (d), ACL (e) and $P_{aq}$ (f) values from the western site
713	of the Yuanchi peatland ( $YC_w$ ). TOC and CAR values from Bao et al., 2010. The red
714	dotted lines represent the intervals characterized by different variations in those
715	proxies.
716	Fig.6. Downcore variations of TOC concentrations (a), carbon accumulation rates
717	(CAR) (b, black line) and PAR values (red line), Total n-alkane concentrations
718	relative to TOC (c), <i>n</i> -alkane CPI (d), ACL (e) and $P_{aq}$ (f) values from the southern

site of the Yuanchi peatland (YC<sub>s</sub>). TOC and CAR values from Bao et al., 2010. The

red dotted lines represent the intervals characterized by different variations in thoseproxies.

**Fig.7.** Downcore variations of TOC concentrations (a), carbon accumulation rates (CAR) (b, black line) and PAR values (red line), Total *n*-alkane concentrations relative to TOC (c), *n*-alkane CPI (d), ACL (e) and  $P_{aq}$  (f) values from the eastern site of the Yuanchi peatland (YC<sub>E</sub>). TOC and CAR values from Bao et al., 2010. The red dotted lines represent the intervals characterized by different variations in those proxies.

**Fig.8.** Downcore variations of TOC concentrations (a), carbon accumulation rates (CAR) (b, black line) and PAR values (red line), Total *n*-alkane concentrations relative to TOC (c), *n*-alkane CPI (d), ACL (e) and  $P_{aq}$  (f) values from the northern site of the Yuanchi peatland (YC<sub>N</sub>) over the past 150 years. TOC and CAR values from Bao et al., 2010. The red dotted lines represent the intervals characterized by different variations in those proxies.

**Fig.9.** The colored dotted lines represent total *n*-alkane concentrations relative to TOC 734 contents (a), PAR (b), n-alkane CPI (c), ACL (d), Paq values (e) and ash contents (f, 735 ASH%, Bao et al., 2010) of the four sites peat cores, respectively; Red dotted lines in 736 (a-f) represent of those proxies in YC<sub>w</sub> peat core; blue dotted lines represent of YCs 737 738 peat core; black dotted lines represent of YC<sub>E</sub> peat core; green dotted lines represent of YC<sub>N</sub> peat core. Volcanic forcing of the tropical Pacific from a model of the tropical 739 740 Pacific coupled ocean-atmosphere system studied by Mann et al. (2005) (g); Red solid line in (g) represents Pb accumulation rate (Pb AR) in the peat core from Yuanchi 741

742	peatland studied by Bao et al., 2019. The gray shaded areas represent the intervals
743	characterized by cold local conditions associated with high volcanic forcing of the
744	tropical Pacific and anthropogenic activities in the Changbai Mountains region.
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747	Table1.
748	Major modern plant species around Yuanchi Lake in Changbai Mountains with
749	dominant <i>n</i> -alkane homologues in those plants.

Major mode	rn species	Major homologue associated to plant	
Traca	Larix olgensis	$C_{27}, C_{29}{}^{a}$	
Trees	Betula fruticosa	$C_{27}^{a}$	
	Vaccinium uliginosum	$C_{29}^{a}$	
Shrubs	Rhododendron parvifolium	$C_{29}, C_{31}{}^{a,b}$	
	Ledum palustre L.	$C_{29}, C_{31}{}^{a,c}$	
Sedges	Carex lasiocarpa Scirpus triqueter Eriophorum fauriei Equisetum hiemale	$C_{29}^{d}$ $C_{29}, C_{31}^{b}$ $C_{27}^{a}$ $C_{29}^{e}$	
Mosses	Sphagnum spp	$C_{23}, C_{25} d_{f,g,h}$	
Emergent macrophytes	Typha orientalis Phragmites australis	$\mathrm{C}_{29}{}^{\mathrm{i},\mathrm{j}}$	

	Aquatic plants	Submerged and foating plants	$C_{21}$ , $C_{23}$ and $C_{25}$ <sup><i>i</i>,<i>j</i></sup>
750	<sup>a</sup> Tarasov et al. (20	013); <sup>b</sup> Street et al. (2013); <sup>c</sup> Salaso	o (1987); <sup>d</sup> Ronkainen et al. (2013);
751	<sup>e</sup> Andersson et al. (2	2011); <sup>f</sup> Bass et al., 2000; <sup>g</sup> Nichols e	t al., 2006; <sup>h</sup> Bingham et al., 2010; <sup>i</sup>
752	Cranwell et al. (1984	4); <sup>j</sup> Ficken et al. (2000);	

















