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Loisel, J., Yu, Z., Beilman, D. W., Camill, P., Alm, J., Amesbury, M. J., Anderson, D., Andersson, S., Bochicchio, C., Barber, K., Belyea, L. R., Bunbury, J., Chambers, Frank M ORCID logo ORCID: <https://orcid.org/0000-0002-0998-2093>, Charman, D. J., De Vleeschouwer, F., Fia kiewicz-Kozie, B., Finkelstein, S. A., Ga ka, M., Garneau, M., Hammarlund, D., Hinchcliffe, W., Holmquist, J., Hughes, P., Jones, M. C., Klein, E. S., Kokfelt, U., Korhola, A., Kuhry, P., Lamarre, A., Lamentowicz, M., Large, D., Lavoie, M., MacDonald, G., Magnan, G., Makila, M., Mallon, G., Mathijssen, P., Mauquoy, D., McCarroll, Julia, Moore, T. R., Nichols, J., O'Reilly, B., Oksanen, P., Packalen, M., Peteet, D., Richard, P. J., Robinson, S., Ronkainen, T., Rundgren, M., Sannel, A. B. K., Tarnocai, C., Thom, T., Tuittila, E.-S., Turetsky, M., Valiranta, M., van der Linden, M., van Geel, B., van Bellen, S., Vitt, D., Zhao, Y. and Zhou, W. (2014) A database and synthesis of northern peatland soil properties and Holocene carbon and nitrogen accumulation. *Holocene*, 24 (9). pp. 1028-1042. doi:10.1177/0959683614538073

Official URL: <http://dx.doi.org/10.1177/0959683614538073>

DOI: <http://dx.doi.org/10.1177/0959683614538073>

EPrint URI: <https://eprints.glos.ac.uk/id/eprint/2504>

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Published in *The Holocene*, and available online at:

<http://hol.sagepub.com/content/24/9/1028>

We recommend you cite the published (post-print) version.

The URL for the published version is <http://dx.doi.org/10.1177/0959683614538073>

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A database and synthesis of northern peatland soil properties and Holocene carbon and nitrogen accumulation

Journal:	<i>The Holocene</i>
Manuscript ID:	HOL-13-0128.R1
Manuscript Type:	Paper
Date Submitted by the Author:	20-Dec-2013
Complete List of Authors:	Loisel, Julie; Lehigh University, Earth and Environmental Sciences Yu, Zicheng; Lehigh University, Department of Earth and Environmental Sciences; Beilman, David; University of Hawaii at Manoa, Camill, Philip; Bowdoin, Environmental Studies Program and Department of Biology Carbon Network, Holocene; Lehigh University, Earth and Environmental Sciences
Keywords:	Northern peatlands, Data synthesis, Climate change, Soil carbon and nitrogen, Biogeochemical cycles, Long-term ecosystem dynamics
Abstract:	<p>Here we present results from the most comprehensive compilation of Holocene peat soil properties with associated carbon and nitrogen accumulation rates for northern peatlands. Our database consists of 268 peat cores from 215 sites located north of 45°N. It encompasses regions within which peat carbon data have only recently become available, such as the West Siberia Lowlands, the Hudson Bay Lowlands, Kamchatka in Far East Russia, and the Tibetan Plateau. For all northern peatlands, carbon content in organic matter was estimated at $42 \pm 3\%$ (S.D.) for Sphagnum peat, $51 \pm 2\%$ for non-Sphagnum peat, and at $49 \pm 2\%$ overall. Dry bulk density averaged 0.12 ± 0.07 g cm⁻³, organic matter bulk density averaged 0.11 ± 0.05 g cm⁻³, and total carbon content in peat averaged $47 \pm 6\%$. In general, large differences were found between Sphagnum and non-Sphagnum peat types in terms of peat properties. Time-weighted peat carbon accumulation rates averaged 23 ± 2 (S.E.M.) g C m⁻² yr⁻¹ during the Holocene on the basis of 151 peat cores from 127 sites, with the highest rates of carbon accumulation ($25\text{-}28$ g C m⁻² yr⁻¹) recorded during the early Holocene when the climate was warmer than the present. Furthermore, we estimate the northern peatland carbon and nitrogen pools at 436 and 10 gigatons, respectively. The database is publicly available at https://peatlands.lehigh.edu.</p>

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12 5 Northern peatland database and synthesis
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15
16
17 7 Authors

18
19
20 8 Julie Loisel^{1*}, Zicheng Yu^{1*}, David W. Beilman², Philip Camill³, Jukka Alm⁴, Matthew J.
21
22 9 Amesbury⁵, David Anderson⁶, Sofia Andersson⁷, Christopher Bochicchio¹, Keith Barber⁸,
23
24 10 Lisa R. Belyea⁹, Joan Bunbury¹⁰, Frank M. Chambers¹¹, Daniel J. Charman⁵, François De
25
26 11 Vleeschouwer¹², Barbara Fiałkiewicz-Kozieł¹³, Sarah A. Finkelstein¹⁴, Mariusz Gałka¹³,
27
28 12 Michelle Garneau¹⁵, Dan Hammarlund¹⁶, William Hinchcliffe⁵, James Holmquist¹⁷, Paul
29
30 13 Hughes⁸, Miriam C. Jones¹⁸, Eric S. Klein¹, Ulla Kokfelt¹⁹, Atte Korhola²⁰, Peter Kuhry⁷,
31
32 14 Alexandre Lamarre¹⁵, Mariusz Lamentowicz¹³, David Large²¹, Martin Lavoie²², Glen
33
34 15 MacDonald¹⁷, Gabriel Magnan¹⁵, Markku Mäkilä²³, Gunnar Mallon⁸, Paul Mathijssen²⁰,
35
36 16 Dmitri Mauquoy²⁴, Julia McCarroll¹¹, Tim R. Moore²⁵, Jonathan Nichols²⁶, Benjamin
37
38 17 O'Reilly¹⁴, Pirita Oksanen²⁷, Maara Packalen²⁸, Dorothy Peteet²⁶, Pierre J.H. Richard²⁹,
39
40 18 Stephen Robinson³⁰, Tiina Ronkainen²⁰, Mats Rundgren¹⁶, A. Britta K. Sannel⁷, Charles
41
42 19 Tarnocai³¹, Tim Thom³², Eeva-Stiina Tuittila⁴, Merritt Turetsky³³, Minna Väliranta²⁰,
43
44 20 Marjolein van der Linden³⁴, Bas van Geel³⁵, Simon van Bellen²³, Dale Vitt³⁶, Yan Zhao³⁷,
45
46 21 Weijian Zhou³⁸
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23 Revised manuscript submitted on 19 December 2013 as a Research Paper for the special
24 issue *Holocene Peatland Carbon Dynamics in the Circum-Arctic Region*.

25

26 Affiliations

27 ¹Department of Earth and Environmental Sciences, Lehigh University, Bethlehem, PA
28 18015, USA

29
30 ²Department of Geography, University of Hawaii – Manoa, Honolulu, HI 96822, USA

31
32 ³Department of Earth and Oceanographic Sciences, Bowdoin College, Brunswick, ME
33 04011, USA

34
35 ⁴School of Forest Sciences, University of Eastern Finland, Joensuu, FI 80101, Finland

36
37 ⁵Department of Geography, University of Exeter, Exeter, EX4 4RJ, UK

38
39 ⁶Department of Geography, Eton College, Windsor, Berkshire SL4 6DW, UK

40
41 ⁷Department of Physical Geography and Quaternary Geology, Stockholm University,
42 Stockholm, 106 91, Sweden

43
44 ⁸Geography and Environment, University of Southampton, Southampton, SO17 1BJ, UK

45
46 ⁹School of Geography, Queen Mary University of London, London, E1 4NS, UK

47
48 ¹⁰Department of Geography and Earth Science, University of Wisconsin – La Crosse, La
49 Crosse, WI 54601, USA

50
51 ¹¹Centre for Environmental Change and Quaternary Research, University of
52 Gloucestershire, Cheltenham, GL50 4AZ, UK

53
54 ¹²CNRS and Université de Toulouse, Castanet Tolosan, 31326, France

55
56 ¹³Department of Biogeography and Paleoecology, Adam Mickiewicz University, Poznan,
57 61-680, Poland

58
59 ¹⁴Department of Earth Sciences, University of Toronto, Toronto, ON M5S 3B1, Canada

60
61 ¹⁵Departement de Géographie and GEOTOP, Université du Québec – Montréal,
62 Montréal, QC H3C 3P8, Canada

63
64 ¹⁶Department of Geology, Lund University, Lund, SE-223 62, Sweden

- 1
2
3 65
4 66 ¹⁷Department of Geography, University of California – Los Angeles, Los Angeles, CA
5 67 90095, USA
6
7 68
8 69 ¹⁸U.S. Geological Survey, Reston, VA 20192, USA
9 70
10 71 ¹⁹Department of Geosciences and Natural Resource Management, University of
11 72 Copenhagen, Copenhagen, DK-1350, Denmark
12 73
13 74 ²⁰Department of Environmental Sciences, University of Helsinki, Helsinki, FIN-00014,
14 75 Finland
15 76
16 77 ²¹Department of Chemical and Environmental Engineering, University of Nottingham,
17 78 Nottingham, NG7 2RD, UK
18 79
19 80 ²²Département de Géographie and Centre d'études nordiques, Université Laval, Québec,
20 81 QC G1V 0A6, Canada
21 82
22 83 ²³Geological Survey of Finland, P.O. Box 96, Espoo, 02151, Finland
23 84
24 85 ²⁴School of Geosciences, University of Aberdeen, Aberdeen, AB24 3UF, UK
25 86
26 87 ²⁵Department of Geography and Global Environmental and Climate Change Centre,
27 88 McGill University, Montreal, QC H3A 0B9, Canada
28 89
29 90 ²⁶Lamont-Doherty Earth Observatory, Columbia University, Palisades, NY 10964, USA
30 91
31 92 ²⁷Centre for Economic Development, Transport and the Environment, Vaasa, 65101,
32 93 Finland
33 94
34 95 ²⁸Department of Geography, University of Toronto, Toronto, ON M5S 3G3, Canada
35 96
36 97 ²⁹Département de Géographie, Université de Montréal, Montréal, QC H2V 2B8, Canada
37 98
38 99 ³⁰Champlain College – Dublin Campus, Dublin, Ireland
39 100
40 101 ³¹Agriculture and Agri-Food Canada, Ottawa, ON K1A 0C6, Canada
41 102
42 103 ³²Yorkshire Peat Partnership, Yorkshire Wildlife Trust, York, YO24 1GN, UK
43 104
44 105 ³³Department of Integrative Biology, University of Guelph, Guelph, ON N1G 2W1,
45 106 Canada
46 107
47 108 ³⁴BIAX Consult, Zaandam, 1506 AL, The Netherlands
48 109
49
50
51
52
53
54
55
56
57
58
59
60

1
2
3 110 ³⁵Institute for Biodiversity and Ecosystem Dynamics, University of Amsterdam,
4 111 Amsterdam, 1098 XH, The Netherlands
5 112
6 113 ³⁶Department of Plant Biology, Southern Illinois University, Carbondale, IL 62901, USA
7 114
8 115 ³⁷Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of
9 116 Sciences, Beijing, 100101, China
10 117
11 118 ³⁸Institute of Earth Environment, Chinese Academy of Sciences, Xi'an, 710075 Shaanxi,
12 119 China
13 120

17 121 Corresponding authors

19 122 Julie Loisel email: jul208@lehigh.edu phone: 610-758-3660

20 123 Zicheng Yu email: ziy2@lehigh.edu phone: 610-758-6751

21 124

22 125 Abstract

23 126 Here we present results from the most comprehensive compilation of Holocene peat soil
24 127 properties with associated carbon and nitrogen accumulation rates for northern peatlands.
25 128 Our database consists of 268 peat cores from 215 sites located north of 45°N. It
26 129 encompasses regions within which peat carbon data have only recently become available,
27 130 such as the West Siberia Lowlands, the Hudson Bay Lowlands, Kamchatka in Far East
28 131 Russia, and the Tibetan Plateau. For all northern peatlands, carbon content in organic
29 132 matter was estimated at $42 \pm 3\%$ (S.D.) for *Sphagnum* peat, $51 \pm 2\%$ for non-*Sphagnum*
30 133 peat, and at $49 \pm 2\%$ overall. Dry bulk density averaged $0.12 \pm 0.07 \text{ g cm}^{-3}$, organic
31 134 matter bulk density averaged $0.11 \pm 0.05 \text{ g cm}^{-3}$, and total carbon content in peat
32 135 averaged $47 \pm 6\%$. In general, large differences were found between *Sphagnum* and non-
33 136 *Sphagnum* peat types in terms of peat properties. Time-weighted peat carbon
34 137 accumulation rates averaged $23 \pm 2 \text{ (S.E.M.) g C m}^{-2} \text{ yr}^{-1}$ during the Holocene on the
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3 138 basis of 151 peat cores from 127 sites, with the highest rates of carbon accumulation (25-
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5 139 28 g C m⁻² yr⁻¹) recorded during the early Holocene when the climate was warmer than
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10 141 436 and 10 gigatons, respectively. The database is publicly available at
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12 142 <https://peatlands.lehigh.edu>.
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17 144 Keywords

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20 145 Northern peatlands, Data synthesis, Climate change, Soil carbon and nitrogen,
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22 146 Biogeochemical cycles, Long-term ecosystem dynamics
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26 27 148 **Introduction**

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29 149 Of all terrestrial ecosystems, peatlands are arguably the most efficient at sequestering
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31 150 carbon (C) over long time scales. Northern peatlands cover approximately 4,000,000 km²
32
33 151 or 3% of the global land area (Maltby and Immirzi, 1993) and have accumulated about
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35 152 500 gigatons of C (GtC) mostly during the Holocene, equivalent to ~ 30% of the present-
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37 153 day global soil organic carbon (SOC) pool (Gorham, 1991; Bridgham et al., 2006; Yu et
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39 154 al., 2010). These ecosystems have also played a dynamic role in the Holocene global C
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41 155 cycle as important sinks of carbon dioxide (CO₂) and major sources of methane (CH₄) to
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43 156 the atmosphere (Frolking and Roulet, 2007; Korhola et al., 2010; Yu, 2011). As climate
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45 157 warming positively affects both plant growth and organic matter decomposition, recent
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47 158 and projected climate change could shift the balance between peat production and organic
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49 159 matter decomposition, potentially affecting the peatland C-sink capacity and modifying
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51 160 peat C fluxes to the atmosphere (Frolking et al., 2011; Yu, 2012). This prediction
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3 161 particularly holds true for the northern high-latitude regions, where the intensity of
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5 162 climate change is expected to be greatest (McGuire et al., 2009). The peatland C cycle –
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8 163 climate feedback remains difficult to assess, however, because of (1) limited
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10 164 understanding of peatland responses to climate change (Frolking et al., 2011), (2) data
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12 165 gaps and large uncertainties in regional peatland C stocks (Yu, 2012), and (3) non-linear
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15 166 peatland responses to external forcing (Belyea, 2009).
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19
20 168 Very little is known about the nitrogen (N) budget that accompanies C accumulation in
21
22 169 northern peatlands (but see Limpens et al., 2006 for a review). Assuming a net C
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24 170 sequestration of ~270 GtC (Yu, 2012) and a C/N ratio of 20-30 for fen peat (Bergner et
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26
27 171 al., 1990; Rydin and Jeglum, 2013; results therein) during the early Holocene (11-7 ka),
28
29 172 about 10-13 GtN would have been required to build such peat deposits. It is therefore
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31 173 possible that northern peatlands have been playing an undocumented, dynamic role in the
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34 174 Holocene global N cycle as important sinks of N, potentially limiting the amount of N
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36 175 available for other ecosystems at the global scale (McLauchlan et al., 2013).
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39 176 Alternatively, if the main N input to peatlands was through N₂ fixation by cyanobacteria,
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41 177 these microorganisms might have been more important in driving the C cycle in
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43 178 peatlands than previously thought. Overall, studying the coupling between N and C
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46 179 cycling in northern peatlands is essential for a better understanding of how key
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48 180 biogeochemical processes interact in these systems and for predicting the future of peat C
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51 181 stocks.
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3 183 Here we present the most comprehensive compilation of Holocene C and N data for
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5 184 northern peatlands. This synthesis encompasses regions within which peat C and N data
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8 185 have only recently become available, such as the West Siberian Lowlands in Asian
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10 186 Russia, the Hudson Bay Lowlands in Canada, Kamchatka in the Russian Far East, and
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12 187 the Tibetan Plateau. In addition, we present the most comprehensive synthesis of peat soil
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14 188 properties (such as bulk density, organic matter content, C and N content) from the
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16 189 northern hemisphere. Also, this new database and synthesis work represent a major
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18 190 expansion from Yu et al.'s (2009) synthesis on Holocene peat C dynamics, which was
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20 191 based on 33 sites (vs. 127 sites as reported in this paper). Finally, it constitutes a natural
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22 192 continuation of Charman et al.'s (2013) recent study on peat C accumulation in northern
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24 193 peatlands during the last millennium.
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31 195 In addition to filling regional data and knowledge gaps, the main objectives of this paper
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33 196 are to (1) describe a database of peat soil properties and synthesize this information for
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35 197 different peat types, time intervals, and geographic regions, and (2) produce time series of
36
37 198 Holocene peat C and N accumulation rates in 500-yr bins for comparison with climate
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39 199 history. Key differences in Holocene peat properties between different regions and
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41 200 peatland types are also discussed in light of their implications for long-term peat C
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43 201 stocks. Of particular importance and relevance are the differences between *Sphagnum*
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45 202 and non-*Sphagnum* peat types. Finally, we present new estimates for northern peat C and
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47 203 N stocks for northern peatlands on the basis of the expanded database.
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55 205 **Database and analysis**
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206 Database

207 We compiled a dataset of 268 published and unpublished Holocene peat records from
208 215 sites located in North America and Eurasia (Figure 1, Supplementary Table 1). The
209 difference in the number of peat cores and peatland sites is due to the fact that, in a few
210 instances, multiple cores were collected from a single peatland. As these multiple cores
211 were not designed as true replicates in the original publications, each of these cores was
212 considered as an independent record of peat properties in the present study. However,
213 only the oldest core for each site was used for estimating peat inception age. Finally,
214 when calculating peat C accumulation rates, multiple cores from a single site were each
215 attributed an equal fraction of the weight for that site. For example, for a site with three
216 cores, the peat C accumulation history of each core only accounted for 1/3 of the site's
217 record.

218
219 The latitude of most peatland sites ranges from 45 to 69 °N. The cutoff at 45 °N
220 represents the southern limit for defining what is considered to be the area contributing to
221 the C cycle of the Arctic region (McGuire et al., 2009). Four high-elevation sites found in
222 China (the Tibetan Plateau) and Japan were also included, as they developed under
223 similar 'northern' climatic conditions. The name and coordinates of these four sites are as
224 follows: Zoige (33.5 °N, 102.6 °E), Hongyuan (32.8 °N, 102.5 °E), Hani (42.2 °N, 126.5
225 °E), and Utasai (42.4 °N, 140.2 °E). A total of 155 cores originate from Eurasia,
226 including 112 cores from Russia. The remaining 113 cores come from North America.
227 Approximately 40% of all cores were collected from ombrotrophic bogs (n = 110 cores)
228 and 20% were extracted from minerotrophic fens (n = 50 cores). The remainder (40%)

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3 229 was collected in peatlands currently affected by permafrost (n = 108 cores). Note that
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6 230 peatland type was identified independently for each site by the original investigators.
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8 231 From an ecosystem functioning perspective, distinguishing bogs from fens and
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10 232 permafrost peatlands is important, as these peatland types are characterized by different
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12 233 hydrological regimes, vegetation communities, and peat-growth trajectories, all of which
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14 234 impact long-term rates of peat C sequestration (Rydin and Jeglum, 2013). Bogs are
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16 235 mineral-poor, rain-fed peatland ecosystems with relatively low plant net primary
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18 236 production (NPP) and slow peat decomposition rates. In contrast, fens are hydrologically
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20 237 connected to surface or ground water, thereby receiving more mineral nutrients.
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22 238 Generally speaking, fens have greater NPP but also faster peat decay rates than bogs
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24 239 (Blodau, 2002). Finally, in the sub-Arctic and Arctic regions, peatland hydrology,
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26 240 structure, and peat C balance are sensitive to the underlying permafrost aggradation and
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28 241 degradation dynamics (Camill, 1999; Turetsky et al., 2007). For the analysis, peat
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30 242 plateaus (87 out of 108 cores), permafrost bogs (18 out of 108 cores), and collapse scars
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32 243 (3 out of 108 cores) were grouped under the peatland type ‘permafrost peatlands’.
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34 244 Original peatland categories can be found in Supplementary Table 1.
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43 246 The database was built to include as many peat records as possible. Therefore, we
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45 247 included any peat core that was extracted north of 45 °N (or at high elevation) and for
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47 248 which bulk density or organic matter bulk density data were available. Information
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49 249 related to peat-core location, peatland type, peat properties, age, and data source can be
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51 250 found in Supplementary Table 1. Additional information related to the type of coring
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53 251 device used and the year of coring can be found in the original publications. Data used in
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3 252 this synthesis are readily accessible from the Holocene Peatland Carbon Network website
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5 253 (<https://peatlands.lehigh.edu>). This database will be useful in future studies of ecosystem
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8 254 – C cycle – climate interactions and for modeling long-term peatland dynamics.
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12 256 In the following sub-sections, we present the criteria for site selection and the protocols
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14 257 used to develop the database. In an effort to only analyze and synthesize *peat* samples,
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16 258 inorganic-rich horizons often found at the base of the peat cores were removed from the
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18 259 database. When available, stratigraphic information was used to distinguish peat vs. non-
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20 260 peat material. For example, gyttja (organic-rich lake sediments) was excluded from the
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22 261 dataset, as well as marshy, clayey, and silty sediments. When stratigraphic information
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24 262 was not available, a bulk density value of 0.5 g cm^{-3} was used as a cut-off between peat
25
26 263 and non-peat material. This value was chosen on the basis of stratigraphic information
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28 264 from peatland records where peaty sediments with bulk density values up to 0.5 g cm^{-3}
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30 265 were identified. We acknowledge that this cut-off value is arbitrary, and that our dataset
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32 266 likely contains some non-peat samples. Inorganic horizons (e.g., tephra layers) were also
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34 267 excluded from the database.
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41 269 Peat properties

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43 270 A total of 232 peat cores (181 sites) were used for characterizing peat properties, though
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45 271 not all cores have all types of peat properties available (Figure 2a). This dataset contains
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47 272 139 cores from Eurasia (including 109 cores from Russia) and 93 cores from North
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49 273 America (Figure 1). While approximately half of these cores were sampled and analyzed
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51 274 at high resolution (1-5 cm increments), the remainder was sampled at lower resolution,
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3 275 typically at 10 cm increments. Dry bulk density (BD; g cm⁻³), organic matter content
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5 276 (OM%; gravimetric %), as well as elemental C and N concentration values were
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8 277 compiled and synthesized. On the basis of these raw datasets, C/N mass ratio and organic
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10 278 matter bulk density (OMBD; g OM cm⁻³) were calculated. These peat geochemical values
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12 279 are examined in light of peat stratigraphy, peat ages, and geographic regions. The
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14
15 280 following paragraphs briefly describe the protocols used to obtain these values.
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19
20 282 Peat stratigraphic information was obtained for 83 peat cores ('peat types' in Figure 2a)
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22 283 for which plant macrofossil analysis or detailed peat description had been performed
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24 284 following standard techniques (e.g., Troels-Smith, 1955; Mauquoy and van Geel, 2007).
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27 285 This peat stratigraphic information was condensed into the following five peat types:
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29 286 *Sphagnum*, herbaceous, woody, brown moss, and humified peat. In a few cases, the
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31 287 investigators only ascribed a general peat type to the samples (e.g., 'bog' vs. 'fen' peat, or
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33 288 '*Sphagnum*' vs. 'herbaceous' peat). In these cases, the uncertainty associated with
34
35 289 classifying peat samples mostly relates to the uniformity of naming convention used
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37 290 among the investigators. For example, a peat sample that contains sizable fractions of
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39 291 brown moss and humified peat may be classified by an investigator as 'brown moss peat'
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41 292 and by another one as 'humified peat'. We recognize that, due to their nature, brown
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43 293 moss and humified peat types might be less uniform than *Sphagnum* or herbaceous peat
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45 294 types. We included as much stratigraphic information as possible in the database, though
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47 295 ambiguous or imprecise descriptions were left out to avoid further confusions.
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3 297 Dry bulk density and organic matter content were determined following standard
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5 298 procedures (Dean, 1974; Chambers et al., 2011). Peat samples of a known fresh volume
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7 299 were either freeze-dried or oven-dried at ca. 100 °C until constant weight was reached
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9 300 and weighed to determine bulk density, then burned at 500-600 °C for one to four hours
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11 301 and weighed again to determine organic matter content. The accuracy of these
12
13 302 measurements mostly depends on sample handling (care must be taken to prevent peat
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15 303 compaction in the field and in the laboratory) and the analytical error associated with
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17 304 weighing. The product of bulk density (BD; g cm⁻³) and organic matter content (OM%)
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19 305 of each peat sample was used to calculate organic matter bulk density (OMBD; g OM
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21 306 cm⁻³), also referred to as ash-free bulk density (AFBD) or organic bulk density (OBD) in
22
23 307 the literature (Yu et al., 2003; Björck and Clemmensen, 2004). We compiled a total of
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25 308 21,220 bulk density measurements, 18,973 organic matter content values, and computed
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27 309 18,544 organic matter bulk density values (Figure 2a).
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31 311 Total peat C and N content were directly measured by combustion and elemental analysis
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33 312 of dry peat samples (Chambers et al., 2011). We compiled 3741 C and 3365 N
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35 313 measurements (Figure 2a). We also computed a total of 3362 C/N mass ratio values.
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39 315 Finally, the regression between peat C content (C%) and peat organic matter content
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41 316 (OM%) for each peat type is presented as an estimate for C content in organic matter
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43 317 (OC%). A total of 995 samples were used in this analysis. The slope of each one of these
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45 318 regressions is interpreted as the 'conversion factor' from OM% to OC%, such that it
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3 319 provides an indirect way for estimating the C% content of ash-free peat for investigators
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6 320 who do not perform elemental C measurements directly.
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10 322 Peat-core chronology

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12 323 Peat-core chronologies were almost exclusively based on radiocarbon (^{14}C) dates that
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14 324 were determined mostly by accelerator mass spectrometry (AMS) on terrestrial plant
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16 325 macrofossils or bulk peat (Piotrowska et al., 2011). A few older chronologies were based
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18 326 on conventional ^{14}C dating of bulk samples. Because no systematic offset has been
19
20 327 observed in the ^{14}C age of bulk vs. non-woody plant macrofossils (G.M. MacDonald,
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22 328 pers. comm. 2013), the use of bulk dates is justifiable. For the purpose of this study, all
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24 329 ^{14}C dates were calibrated to calendar years before present (cal. BP) using the program
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26 330 CALIB 6.1.0 (Stuiver and Reimer, 1993) with the IntCal09 calibration dataset (Reimer et
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28 331 al., 2009). In this paper, ages are reported in thousands of calibrated years before present
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30 332 (ka).
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39 334 Age-depth relationships were established for all continuous peat cores for which at least
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41 335 five age determinations were available ($n = 151$ cores). Except for a few
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43 336 palynostratigraphic and tephrochronologic markers, nearly all records have chronologies
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45 337 exclusively based on ^{14}C ages (Supplementary Table 1). Chronologies were obtained
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47 338 through linear interpolation of calibrated ages between dated horizons. Single-age
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49 339 estimates were taken from the mid-point of each calibrated 2σ probability distribution.
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51 340 This parsimonious approach captures general patterns of temporal changes in peat
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53 341 accumulation and allows for analysis of peat C accumulation trajectories (e.g., Telford et
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3 342 al., 2004). Although more sophisticated approaches are possible (e.g., Charman et al.,
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5 343 2013), we seek to make the fewest or simplest assumptions for this analysis because the
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7 344 temporal resolution target for peat C accumulation rate calculations is relatively low (at
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9 345 500 years). In the cases where the original investigator identified hiatuses (e.g., peat loss
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11 346 caused by erosion or fire) or depositional anomalies (e.g., thick tephra layers that
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13 347 interrupted peat accumulation) along their peat records, these gaps were taken into
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15 348 consideration when building age-depth relationships (Glaser et al., 2012). Otherwise, peat
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17 349 records were assumed to be continuous.

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24 351 In an effort to assess the representativeness of our samples in terms of peatland inception
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26 352 timing, peat basal ages were compiled and compared to results from large datasets
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28 353 (MacDonald et al., 2006; Gorham et al., 2007; Korhola et al., 2010). Peat inception ages
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30 354 from 199 sites (Supplementary Table 1) were summed and binned in 500-year intervals.

34 355

36 356 *Long-term rates of carbon and nitrogen accumulation*

38 357 A total of 151 peat cores from 127 sites were used for estimating rates of peat C
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40 358 accumulation. This dataset contains 96 cores from 78 North American sites and 55 cores
41
42 359 from 49 Eurasian sites (Figure 1). Of the 33 sites presented in Yu et al.'s (2009) study, 25
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44 360 were used in the present study (Supplementary Table 1). The remaining 8 sites did not
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46 361 fulfill our dating quality criterion (presented below). The dating quality of each record
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48 362 was determined by the quotient of the calibrated peat basal age and the number of age
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50 363 determinations. For example, a 10,000-year-old peat core with a chronology constrained
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52 364 by 10 ¹⁴C dates was attributed a dating quality of one date per 1000 years. About 58% of
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3 365 our 151 cores were characterized by an acceptable dating quality of one to two ^{14}C dates
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5 366 per 1000 years (Figure 2b). These resolutions are well suited to capture millennial-scale
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7 367 variations in C accumulation. Several peat cores with more than two ^{14}C dates per 1000
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9 368 years ($n = 35$ cores) were available from North America and Europe. The lower dating
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11 369 quality cores (<1 date per 1000 years,) were unevenly distributed and comprise 44% of
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13 370 the North American records and 40% of the Eurasian records.
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20 372 The long-term rate of peat C accumulation was calculated for each core following one of
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22 373 the following five approaches (Supplementary Table 1): (1) whenever possible, peat core
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24 374 chronology was combined with bulk density and C% for each depth increment ($n = 47$
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26 375 cores); (2) in the cases where direct C measurements were lacking, peat core chronology
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28 376 was combined with organic matter bulk density measurements and a mean organic C
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30 377 value of 49% in organic matter ($n = 57$ cores); (3) for cores that lacked organic matter
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32 378 bulk density and direct C%, peat core chronology was combined with bulk density
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34 379 measurements and a mean C content of 47% in total peat ($n = 3$ cores); (4) whenever
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36 380 neither bulk density nor C% was directly available from the cores, long-term rate of peat
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38 381 C accumulation was calculated for each core by combining time-dependent bulk densities
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40 382 (0.08 g cm^{-3} at 0-0.5 ka; 0.12 g cm^{-3} at 0.5-6 ka; 0.14 g cm^{-3} at 6-12 ka) with a mean C
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42 383 content of 47% in total peat for each dated interval ($n = 32$ cores), and (5) peat C
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44 384 accumulation rates for the remaining 12 cores were directly obtained from published
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46 385 figures and tables. For all the cores, time-weighted peat C accumulation rates were
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48 386 summed and binned in 500-year intervals. It is important to note that such reconstructions
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50 387 are ‘apparent rates’ that are different from true rates of C accumulation in peatlands,
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3 388 because decomposition processes have been affecting old peat layers for thousands of
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5 389 years (Turunen et al., 2002). Finally, the long-term rate of peat N accumulation was
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8 390 calculated by combining our binned peat-C accumulation rates with time-dependent C/N
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10 391 values (65 at 0-6 ka, and 40 at 6-10 ka).

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12 392

13 393 **Results**

14 394 *Peat Properties*

15 395 Descriptive statistics of dataset

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17 396 The frequency distribution of each peat property is shown in Figure 3. Mean values and
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19 397 standard deviations for all peat properties are presented by peat type in Table 1, and by
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21 398 region in Table 2.

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25 400 Bulk density values ($n = 21,220$) ranges from 0.003 to 0.498 g cm^{-3} , with a mean value of
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27 401 $0.118 \pm 0.069 \text{ g cm}^{-3}$ (1 standard deviation (S.D.)). A one-way analysis of variance
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29 402 (ANOVA) reveals an effect of peat type on bulk density ($F(10709) = 941, p < 0.0001$),
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31 403 with all peat types significantly different from each other on the basis of post-hoc
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33 404 Tukey's LSD tests ($p < 0.0001$). In increasing order, mean bulk density of the peat types
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35 405 is *Sphagnum* < Woody < Herbaceous < Brown Moss < Humified (Table 1).

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39 407 Organic matter content ($n = 18,973$) has a mean value of $90.7 \pm 13\%$ (1 S.D.) and a
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41 408 median of 95.7%. The ANOVA reveals an effect of peat type on organic matter content
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43 409 ($F(9512) = 349, p < 0.0001$), with all peat types significantly different from each other

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3 410 (Tukey's LSD: $p < 0.0001$). In decreasing order, mean organic matter content of the peat
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5 411 types is *Sphagnum* > Woody > Herbaceous > Brown Moss > Humified (Table 1).
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10 413 Organic matter bulk density ($n = 18,544$) ranges from 0.003 to 0.452 g OM cm⁻³, with a
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12 414 mean value of 0.105 ± 0.051 g OM cm⁻³ (1 S.D.). The ANOVA reveals an effect of peat
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14 415 type on organic matter density ($F(9081) = 942$, $p < 0.0001$), with all peat types
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16 416 significantly different from each other (Tukey's LSD: $p < 0.0001$). In increasing order,
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18 417 mean organic matter density of the peat types is *Sphagnum* < Herbaceous < Woody <
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20 418 Brown Moss < Humified (Table 1).
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27 420 C content in total peat ($n = 3741$) ranges from 30 to 60%, with a mean value of $46.8 \pm$
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29 421 6.1% (1 S.D.) and a median of 47.8%. While the lowest values (< 35%) are almost
30
31 422 exclusively associated with samples from Alaska, western Canada, Fennoscandia, and
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33 423 eastern Russia, the highest values (> 55%) are characteristic of sites located in the
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35 424 western European Islands and Fennoscandia. The ANOVA reveals an effect of peat type
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37 425 on C% ($F(2494) = 161$, $p < 0.0001$), with *Sphagnum* samples significantly different from
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39 426 other peat types (Tukey's LSD: $p < 0.0001$). Herbaceous and woody peats are distinct
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41 427 from other types, but indistinguishable from one another (Tukey's LSD: $p = 0.238$).
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43 428 Likewise, humified and brown moss peats are distinct from other types, but
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45 429 indistinguishable from each other (Tukey's LSD: $p = 0.448$). In increasing order, mean
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47 430 C% of the peat types is *Sphagnum* < Humified = Brown Moss < Herbaceous = Woody
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49 431 (Table 1). The frequency distribution of C% in peat is also characterized by a second,
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51 432 though minor, mode at 40% (Figure 3d). The latter is mostly associated with *Sphagnum*
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3 433 peat samples, as their average C% is significantly lower than those for other peat types
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5 434 (Table 1). This difference is likely caused by the high content of complex and recalcitrant
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8 435 compounds found in *Sphagnum* tissues such as lipids and waxes, which have lower C%
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10 436 than more labile biopolymers such as cellulose (Cagnon et al., 2009).

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15 438 On the basis of 995 samples for which both OM% and C% were quantified, we
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17 439 developed conversion factors (slopes of linear regressions) for several peat types to
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19 440 estimate OC% (Figure 4). There is a noticeable difference between the slope of
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21 441 *Sphagnum* peat (0.423 ± 0.030 ; $n = 454$) and that of non-*Sphagnum* peat (0.514 ± 0.024 ;
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23 442 $n = 308$). The C content in organic matter (OC%) for *Sphagnum* peat is smaller than
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25 443 expected at $42.3 \pm 3.0\%$ (e.g., Bauer et al., 2006; Beilman et al., 2009; Table 3). As the
26
27 444 majority of our *Sphagnum* samples for this specific analysis are younger than 0.5 ka (304
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29 445 out of 454 samples) and extracted from raised bogs, it is very likely that our estimated
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31 446 OC% biases towards young and undecomposed *Sphagnum*. This ‘young *Sphagnum* peat
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33 447 effect’ heavily influenced the slope of the overall relation between C% and OM% (0.467
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35 448 ± 0.045) due to the overrepresentation of *Sphagnum* samples in the dataset (454 out of
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37 449 995 samples). To minimize this bias when estimating mean OC% in peat, all 304 young
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39 450 *Sphagnum* samples were removed from the dataset, yielding an overall conversion factor
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41 451 of 0.492 ± 0.024 .

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47 453 N content in peat ($n = 3365$) ranges from 0.04 to 3.39%, with a mean value of $1.2 \pm 0.7\%$
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49 454 (1 S.D.). The frequency distribution is asymmetric and characterized by a mode at 0.65%
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51 455 (Figure 3e). The latter is largely due to the overrepresentation of *Sphagnum* peat samples
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3 456 (having low N content) in our database. The ANOVA reveals an effect of peat type on N
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5 457 content ($F(2504) = 666, p < 0.0001$) with *Sphagnum* and herbaceous peat types
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7 458 significantly different from each other and from all other types (Tukey's LSD: $p <$
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9 459 0.0001). Humified and brown moss peats are distinct from other types, but
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11 460 indistinguishable from each other (Tukey's LSD: $p = 0.113$). Likewise, woody and brown
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13 461 moss peats are indistinguishable from one another (Tukey's LSD: $p = 0.240$). In
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15 462 increasing order, mean N% of the peat types is *Sphagnum* < Woody = Brown Moss =
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17 463 Humified < Herbaceous (Table 1).
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24 465 C/N mass ratio ($n = 3362$) ranges from 12 to 217, with a mean value of 55 ± 33 (1 S.D.).
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26 466 The frequency distribution is asymmetric and characterized by a mode at 25 (Figure 3f).
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28 467 While the distribution mode (25) is associated with non-*Sphagnum* peat types, the
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30 468 distribution mean (55) is skewed towards *Sphagnum* peat samples owing to their
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32 469 overrepresentation in our database (Figures 3f). The ANOVA reveals an effect of peat
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34 470 type on C/N ratio ($F(2501) = 174, p < 0.0001$) with *Sphagnum* peat significantly
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36 471 different from all other types (Tukey's LSD: $p < 0.0001$). Woody peat is distinguishable
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38 472 from all peat types except for brown moss peat (Tukey's LSD: $p = 0.665$). Herbaceous
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40 473 and humified peat types are indistinguishable from one another (Tukey's LSD: $p =$
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42 474 0.721). In decreasing order, the mean C/N ratio of peat types is *Sphagnum* > Woody =
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44 475 Brown Moss > Humified = Herbaceous (Table 1).
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53 477 Temporal changes in peat properties
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3 478 We find a decreasing trend in bulk density over the Holocene (Figure 5a), with the
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5 479 densest peat characterizing the oldest samples (8-10 ka) and the least-dense peat
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8 480 characterizing the youngest samples (0-2 ka). This trend is most likely attributable to the
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10 481 progressive decomposition and subsequent compaction of peat over time, as well as to
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12 482 higher ash content in early-stage peat (likely from fens). Conversely, a clear increasing
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14 483 trend in organic matter content (OM%) is found over the Holocene (Figure 5b), with the
15
16 484 greatest OM% characterizing the youngest samples (0-2 ka) and the least OM%
17
18 485 characterizing the oldest samples (8-10 ka). This trend is most likely attributable to
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20 486 higher inorganic material inputs during early-stage peatland development as well as to a
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22 487 greater loss of OM in the deeper portions of peat profiles. Organic matter bulk density
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24 488 (OMBD) remains relatively constant over the Holocene (Figure 5c) because of the
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26 489 opposite trends exhibited by BD and OM% (Figures 5a, 5b). The only exceptions are the
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28 490 low OMBD values characterizing the youngest samples (< 0.5 ka), probably due to the
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30 491 large proportion of young, undecomposed *Sphagnum* peat samples.
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38 493 C content in peat remains uniform over the Holocene (Figure 5d), except for slightly
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40 494 lower C% during the late Holocene. We find a decreasing trend in N% over the
41
42 495 Holocene, such that young peat deposits are associated with low N% (Figure 5e). Peat
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44 496 deposits older than 6 ka are mostly associated with low C/N ratios, whereas peat samples
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46 497 younger than 6 ka are characterized by high C/N values (Figure 5f).
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51 499 In general, *Sphagnum* peat is characterized by lower BD, OMBD, C%, N%, and C/N
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53 500 ratio than samples composed of non-*Sphagnum* peat (Figure 6). Therefore, peatland
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3 501 development could explain much of the aforementioned temporal trends (Figure 5), as
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5 502 early-stage rich fens are typically characterized by non-*Sphagnum* peat, whereas late-
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8 503 stage poor fens and bogs are *Sphagnum*-dominated (Figure 6h).
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13 505 *Spatial differences in peat properties*

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15 506 Significant differences in bulk density are found at the regional scale (Table 2). The
16
17 507 densest peat is observed in Alaska (mean = $0.168 \pm 0.087 \text{ g cm}^{-3}$) and western Canada
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19 508 (mean = $0.166 \pm 0.076 \text{ g cm}^{-3}$), whereas the least dense peat is found from the western
20
21 509 European Islands (mean = $0.055 \pm 0.027 \text{ g cm}^{-3}$). Organic matter bulk density values
22
23 510 follow a similar pattern across these regions (Table 2). These differences are strongly
24
25 511 correlated with peat types and sample ages, with the Alaskan and western Canadian
26
27 512 samples largely constituted of herbaceous, humified, and brown moss peat types. OM%
28
29 513 does not vary much between regions (> 90% in all regions), with the notable exception of
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31 514 Alaskan and eastern Russian/Asian peatlands that exhibit mean values of $76.6 \pm 18.8\%$
32
33 515 and $80.3 \pm 16.7\%$, respectively (Table 2). Aeolian dust and tephra ash inputs to some
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35 516 peatlands in Alaska, Kamchatka, and Japan might partly explain such low OM% values.
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43 518 ***Peat inception ages and long-term rates of carbon and nitrogen accumulation***

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45 519 Calibrated ages (mid-point) for peat inception range from 0.6 to 15 ka and the frequency
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47 520 distribution is characterized by a mode at 11-9 ka (Figure 2c). The latter corresponds with
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49 521 peat inception peaks in the West Siberian Lowlands and in Alaska. In general, our
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51 522 samples are in agreement with much larger networks of peat basal ages (Smith et al.,
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3 523 2004; MacDonald et al., 2006; Gorham et al., 2007; Korhola et al., 2010; Ruppel et al.,
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5 524 2013; Yu et al., 2013).
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10 526 The time-weighted long-term rate of C accumulation averages $22.9 \pm 2.0 \text{ g C m}^{-2} \text{ yr}^{-1}$
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12 527 (standard error of mean (S.E.M.); Figure 7b). Values exhibit an increasing trend that
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14 528 initially peaks during the early Holocene between 10 and 7.5 ka at $27.0 \pm 2.6 \text{ g C m}^{-2} \text{ yr}^{-1}$.
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16
17 529 This peak is largely caused by rapid peat accumulation in Alaska, the Western Siberia
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19 530 Lowlands, and southeastern Canada. The remainder of the Holocene is characterized by a
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21 531 decreasing trend in C accumulation rates from 24 to $18 \text{ g C m}^{-2} \text{ yr}^{-1}$ and a time-weighted
22
23 532 mean at $22.0 \pm 1.9 \text{ g C m}^{-2} \text{ yr}^{-1}$ (Figure 7b). There is a notable minimum value between 3
24
25 533 and 1.5 ka at $18\text{-}19 \text{ g C m}^{-2} \text{ yr}^{-1}$. Lack of decomposition probably explains most of the
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27 534 apparent increase in accumulation over the past millennium ($24\text{-}32 \text{ g C m}^{-2} \text{ yr}^{-1}$), as
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29 535 young peat appears to be accumulating more quickly than old peat simply because the
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31 536 former has undergone less decomposition than the latter (Clymo, 1984).
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38 538 The time-weighted long-term rate of N accumulation averages $0.5 \pm 0.04 \text{ g N m}^{-2} \text{ yr}^{-1}$
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40 539 (S.E.M.; Figure 7c). While the mid and late Holocene (6-0 ka) are characterized by the
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42 540 lowest rates of N accumulation at $0.34 \text{ g N m}^{-2} \text{ yr}^{-1}$, the highest rates ($0.61 \text{ g N m}^{-2} \text{ yr}^{-1}$)
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44 541 occur between 12 and 6 ka (Figure 7c). This trend mirrors that of C accumulation (Figure
45
46 542 7b), as C and N sequestration rates are both mainly influenced by peat density and its
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48 543 accumulation rate. The low rates of N accumulation over the past 6 ka might also relate
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50 544 to the increasing presence and persistence of *Sphagnum* (having high C/N ratio and low
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52 545 N concentration) in northern peatlands (Figures 6 and 7).
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6 547 **Discussion**

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8 548 *Representativeness of the database for northern peatlands*

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10 549 The present database contains the most comprehensive compilation of peat properties and
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12 550 C accumulation records for northern peatlands. The previous large-scale synthesis (Yu et
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14
15 551 al., 2009) only contained 33 sites and lacked records from the Hudson Bay lowlands and
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17 552 the Russian Far East, and had limited sites from West Siberia and the western European
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19 553 Islands. The present database fills gaps from these regions.
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24 555 However, European Russia, East Siberia, and the Russian Far East clearly remain poorly
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26 556 studied regions in terms of northern peat C stocks and accumulation histories (Figure 1).
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28 557 A wetland map by Stolbovoi and McCallum (2002) suggests that shallow peaty deposits
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30 558 (<50 cm) interspersed with few deeper peat bogs (>50 cm) dominate the Far East Russian
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32 559 landscape. Most of these deeper peatlands are presumably found in Kamchatka and
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34 560 Sakhalin (Stolbovoi, 2002). This broad portrait is, however, based on fewer than 30 soil
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36 561 profiles from across East Siberia and Far East Russia (Stolbovoi et al., 2001), making it
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38 562 difficult to evaluate the importance of this region in the northern peatland C cycle. In
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40 563 general, peat C stocks in Eastern Russia may not be as massive as those from West
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42 564 Siberia or European Russia (Stolbovoi and McCallum, 2002). Therefore, understanding
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44 565 how these shallow peatlands in East Siberia and the Russian Far East have developed
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46 566 during the Holocene would provide useful end-members of climate controls of peat C
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48 567 accumulation, but these peatlands do not seem to represent a large missing C stock.
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3 569 *Northern peatland soil properties: key findings and uncertainties*

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6 570 Peat-carbon stocks

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8 571 Several studies have quantified the soil C density and total C pool of peatlands using
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10 572 different approaches (e.g., Armentano and Menges, 1986; Gorham, 1991; Yu et al.,
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12 573 2010). These methods have led to total C pool estimates for northern peatlands that vary
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14 574 by at least a factor of two, from 234 to 547 GtC (Lappalainen, 1996; Yu et al., 2010; see
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16 575 Yu, 2012 for a review). Many of these studies have combined mean peat depth, modern
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18 576 peatland area, and a single mean C density value (BD x C% or OMBD x OC%) in their
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20 577 calculations (e.g., Gorham, 1991). Applying Gorham's (1991) mean peat depth and
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22 578 peatland area estimates to the mean BD and C% results from our database yields a C pool
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24 579 estimate of 436 GtC (2.3 m x 3.42 Mkm² x 0.118 g cm⁻³ x 47% C). However, it is well
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26 580 documented that most peatlands undergo a shift from herbaceous to *Sphagnum* peat
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28 581 during their developmental history (Hughes, 2000; Figure 6h) and that different BD, C%,
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30 582 and rates of peat accumulation are associated with fen and bog peats (e.g., Vitt et al.,
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32 583 2000; Figure 6). We also know that peat-C accumulation rates have varied
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34 584 asynchronously between regions throughout the Holocene as a result of regional changes
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36 585 in hydroclimatic conditions (e.g., Yu et al., 2009; Charman et al., 2013). Therefore, we
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38 586 argue that reconstructing Holocene changes in peat C accumulation on the basis of
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40 587 *measured* peat C density and reliable peat-core chronologies constitutes a step forward in
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42 588 providing the best possible peat C stock estimates (see Yu et al., 2010 for an example). It
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44 589 also allows for quantifying spatial and temporal differences in rates of peat C
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46 590 accumulation, as well as the temporal trajectories of peat C fluxes to the atmosphere
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3 591 (MacDonald et al., 2006; Yu et al., 2013). However, better maps of the present peatland
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5 592 area (and its change over time) are still needed to improve current peat C stock estimates.
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10 594 Carbon content in organic matter

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12 595 For each peat layer, peat C density can be estimated by the product of either (1) bulk
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14 596 density and C content in total peat (BD x C%), or (2) ash-free bulk density and C content
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16 597 in organic matter (OMBD x OC%). It could be argued that the first option is preferable
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18 598 when estimating peat C stocks, as it produces values that are directly comparable to
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20 599 routine soil C measurements from other terrestrial ecosystems. However, the present
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22 600 database clearly indicates that the majority of peatland scientists routinely analyze
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24 601 organic matter content (OM%; n = 18,973 samples) rather than C% (n = 3741 samples)
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26 602 along peat cores. To provide a way to estimate OC% from OM%, we developed the
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28 603 following conversion factors: $42.3 \pm 3.0\%$ for *Sphagnum* peat, $51.4 \pm 2.4\%$ for non-
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30 604 *Sphagnum* peat, and $49.2 \pm 2.4\%$ overall (Figure 4, Table 1).
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38 606 While the overall peat and the non-*Sphagnum* peat conversion factors are in line with
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40 607 those from previous studies (e.g., Gorham, 1991; Vitt et al., 2000; Turunen et al., 2002;
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42 608 Beilman et al., 2009), the *Sphagnum* peat factor is lower than other estimates (e.g., Bauer
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44 609 et al., 2006; Beilman et al., 2009; Table 3). Indeed, our mean OC% *Sphagnum* value at
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46 610 42.3% is close to that of surface *Sphagnum* tissues, suggesting that it constitutes a valid
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48 611 estimate for ash-free and poorly decomposed *Sphagnum* peat. As previously mentioned,
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50 612 this bias towards low OC% is due to a large number of *Sphagnum* samples younger than
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52 613 0.5 ka (304 out of 454 *Sphagnum* samples).
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615 Although each one of the three conversion factor slopes was significant ($p < 0.0001$),
616 there is a noticeable scatter in the data (Figure 4) that cannot solely be explained by the ~
617 1% analytical error associated with the loss-on-ignition procedure (Heiri et al., 2001).
618 The progressive accumulation of recalcitrant C in old samples (lignin ~ 60% C vs.
619 cellulose ~ 42% C), assuming it occurs at a greater rate than the loss of OM in the deeper
620 portions of peat profiles, could explain why C% appears higher than our OC% conversion
621 factors (Cagnon et al., 2009). The presence of inorganic C, particularly for the humified
622 and brown moss peat types, could also explain these results.

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624 Oligotrophication and the fen-to-bog transition in northern peatlands

625 *Sphagnum* and non-*Sphagnum* peat types were characterized by very different peat
626 properties, with *Sphagnum* peat having lower BD, OMBD, C%, N%, and C/N ratio than
627 non-*Sphagnum* peat (Figure 6). These differences become important when estimating
628 Holocene peat C fluxes, as the proportion of *Sphagnum*-dominated peat records increases
629 during the late Holocene due to the fen-to-bog transition (Figure 6h). For example, much
630 stronger CH₄ emissions are associated with fens than bogs (e.g., Pelletier et al., 2007). In
631 terms of C sequestration rates, the systematically higher organic C density of non-
632 *Sphagnum* peat suggests that higher accumulation rates are possible in fens than in bogs
633 (Figure 6g), assuming optimal hydroclimatic conditions leading to rapid peat burial. In
634 addition, as non-*Sphagnum* samples contain twice the N mass of *Sphagnum* peat (Figure
635 6e), early-stage fens have the ability to stock more N than late-stage bogs. Overall,
636 further studies on the timing of the fen-to-bog transition across the northern peatland

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3 637 domain are needed to better our understanding of its impact on C sequestration and CH₄
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10 640 ***Holocene pattern of carbon accumulation in northern peatlands***

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12 641 The overall trajectory and shape of our Holocene peat C accumulation curve is similar to
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14 642 the synthesis from a much smaller dataset (n = 33; Yu et al., 2009). As such, an early
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16 643 Holocene peak during the Holocene Thermal Maximum (HTM) and an overall slowdown
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18 644 of C accumulation during the mid- and late-Holocene, particularly after 4 ka during the
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20 645 Neoglacial period and associated permafrost development, were found in both syntheses
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22 646 (Figure 7). However, the mean Holocene value of $22.9 \pm 2.0 \text{ g C m}^{-2} \text{ yr}^{-1}$ (1 S.E.)
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24 647 presented here is approximately 24% higher than the estimate in Yu et al.'s 2009 study
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26 648 ($18.6 \text{ g C m}^{-2} \text{ yr}^{-1}$). Our larger dataset likely better represents the northern peatland C
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28 649 accumulation rates. These results imply that current peat C stocks might be
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30 650 underestimated.

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38 652 While the peak value at $27 \text{ g C m}^{-2} \text{ yr}^{-1}$ is about 23% higher than the time-weighted mean
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40 653 peat-C accumulation rate for the remainder of the Holocene at $22 \text{ g C m}^{-2} \text{ yr}^{-1}$, we only
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42 654 found a 2% difference in organic C density values between young ($0.053 \pm 0.02 \text{ g C cm}^{-3}$)
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44 655 and old ($0.057 \pm 0.03 \text{ g C cm}^{-3}$) peat samples. These results clearly show that the peak
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46 656 value during the early Holocene cannot be mainly attributed to presumably dense peat
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48 657 deposits that would be rich in recalcitrant C due to long-term decomposition and
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50 658 compaction. Instead, factors influencing the rate of peat burial such as peat type
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52 659 (*Sphagnum* vs. non-*Sphagnum* peat; Figure 6), growing season length, and other
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3 660 environmental variables, must have been responsible for such high rates of C
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6 661 sequestration during the early Holocene.
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10 663 The Holocene Thermal Maximum (HTM) is a well-documented period of orbitally-
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12 664 induced warm climate in the northern high-latitude region (Kaufman et al., 2004;
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15 665 Renssen et al., 2012; Marcott et al., 2013) that reaches its maximum around 11 ka
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17 666 (Berger and Loutre, 1991; Figure 7a). The peak in warm climatic conditions shows a
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20 667 transgressional pattern across northern North America that moved eastward with the
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22 668 waning Laurentide Ice Sheet during the early and mid Holocene (Kaufman et al., 2004).
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24 669 This progressive increase in land availability coupled with warming summer conditions
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26 670 have been proposed as the main controls on peatland inception and rapid C accumulation
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28 671 across northern North America (Harden et al., 1992; Gorham et al., 2007, 2012; Yu et al.,
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30 672 2009; Jones and Yu, 2010). In general, our results support the hypothesis that warm
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32 673 summers could promote peat formation and C sequestration (Beilman et al., 2009; Yu et
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34 674 al., 2009; Charman et al., 2013), as the highest rates of C accumulation broadly coincide
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36 675 with the peak in summer insolation from 11 to 7 ka (Figure 7). We acknowledge that
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38 676 sufficient water input was necessary to allow for peatland development. Furthermore, the
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40 677 observed temporal asymmetry in peatland inception age and peaks in C accumulation
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42 678 rates between Alaska, western Canada, and the Hudson Bay Lowlands follows the
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44 679 transgressional pattern of the HTM. For example, peat inception and highest peat C
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46 680 accumulation rates occur at 11-9 ka in Alaska, whereas they are delayed in western
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48 681 Canada with peak values around 9-7 ka. These findings have important implications for
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50 682 projecting the fate of peat-C stocks in a future warmer world.
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5 684 The Neoglacial period is characterized by generally cooler and wetter conditions than the
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8 685 HTM (Figure 7a; Marcott et al., 2013). Particularly low C accumulation rates coincide
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10 686 with this time period across the northern peatland domain (Figure 7; Vitt et al., 2000;
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12 687 Jones and Yu, 2010). Peat accumulation processes might even have stopped in some
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14 688 regions (e.g., Peteet et al., 1998). The onset of permafrost aggradation in many peatlands
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16 689 also occurred during the Neoglacial period (Zoltai, 1971, 1995; Vitt et al., 2000; Oksanen
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18 690 et al., 2003; Sannel and Kuhry, 2008), reducing the peat C-sink capacity. In addition to
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20 691 shorter and cooler growing seasons, lower C accumulation rates in permafrost sites likely
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22 692 relates to a slower peat burial due to (1) more intense peat decomposition in the acrotelm
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24 693 due to drier surface conditions, and (2) a slower rate of peat formation and associated C
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26 694 inputs to soil because many peat plateaus are not *Sphagnum*-dominated. Overall, our
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28 695 results support the notion that climatic changes such as the HTM and the Neoglacial
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30 696 cooling impact C sequestration rates in peatlands.
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39 698 ***Role of northern peatlands in the global nitrogen cycle***

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41 699 As relatively few downcore peat N concentrations have been reported in the literature, it
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43 700 was difficult to compare our mean value of 1.2% to previous estimates. Bragazza et al.
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45 701 (2012) reported N content values of 0.7% for *Sphagnum fuscum* litter and 1.48% for
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47 702 *Eriophorum vaginatum* (herbaceous) litter, in line with our results (Table 1). Similarly,
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49 703 Turunen et al. (2004) documented peat N concentrations ranging from 0.35 to 2.25%
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51 704 (mean value of 0.8%) for the uppermost sections of 23 *Sphagnum* bogs across
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3 705 northeastern Canada. Overall, these values closely match our findings for *Sphagnum*
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5 706 (0.7%) and herbaceous (1.7%) peat types (Table 1).
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10 708 Using our peat C pool estimate of 436 Gt and assuming a mean C/N ratio of 45 yields a
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12 709 peat N pool of 9.7 Gt, roughly equivalent to 10% of the global soil N pool at 95 Gt (Post
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14 710 et al., 1985). This estimate is within the range proposed by Limpens et al. (2006) at 8-15
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16 711 GtN. The Holocene time-weighted peat N accumulation rate of $0.5 \pm 0.04 \text{ g N m}^{-2} \text{ yr}^{-1}$
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18 712 (S.E.; Figure 7) is also in line with a previous estimate of 0.19-0.48 $\text{g N m}^{-2} \text{ yr}^{-1}$ (Limpens
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20 713 et al., 2006). While the mid and late Holocene (6-0 ka) are characterized by the lowest
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22 714 rates of peat-N accumulation at $0.34 \text{ g N m}^{-2} \text{ yr}^{-1}$, the highest rates ($0.61 \text{ g N m}^{-2} \text{ yr}^{-1}$)
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24 715 occur between 12 and 6 ka (Figure 7c). The low rates of N accumulation over the past 6
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26 716 ka might also relate to the increasing presence and persistence of *Sphagnum* peat (having
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28 717 high C/N ratio and low N concentration) across the northern peatlands (Figures 6 and 7).
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30 718 Overall, given the bias toward *Sphagnum*-dominated sites in our database, N pools and N
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32 719 accumulation rates are probably underestimated.
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36 721 Rapid N sequestration in peatlands during the early Holocene might have contributed to
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38 722 the global decline in reactive N availability for terrestrial ecosystems (McLauchlan et al.,
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40 723 2013), pointing to a potentially important and undocumented role of northern peatlands in
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42 724 the global N cycle. These results also raise the important question of N provenance: in the
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44 725 absence of large rates of atmospheric N deposition during the early Holocene, the only
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46 726 process that could account for such a large N pool in peatlands is N fixation, either
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48 727 through symbiotic or asymbiotic processes (Limpens et al., 2006).
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5 729 The fate of these large peat N stocks remains largely unknown under recent and projected
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8 730 warming. Indeed, the importance of peatlands as sources of nitrous oxide (N₂O) is just
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10 731 emerging (e.g., Repo et al., 2009; Marushchak et al., 2011; Palmer et al., 2012), and
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12 732 studies have suggested that reduced surface moisture or increasing temperatures might
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14 733 significantly promote the production, transformation, and transport of dissolved N, and
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16 734 N₂O emissions to the atmosphere through denitrification (e.g., Kane et al., 2010). On the
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18 735 contrary, some authors have speculated that the potential increase in peatland-N₂O
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20 736 emissions from climate change may not be significant relative to the global N₂O budget
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22 737 (e.g., Martikainen et al., 1993; Frohking et al., 2011). Overall, additional peat N cycling
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24 738 studies are needed to address these remaining questions.
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32 740 **Future directions**

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34 741 Peat core analysis has been extensively used over the past 20 years for estimating rates of
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36 742 peat C accumulation at local, regional, and continental scales (e.g., Mäkilä, 1997; Clymo
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38 743 et al., 1998; Vitt et al., 2000; Turunen et al., 2002; Mäkilä and Saarnisto, 2008; Yu et al.,
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40 744 2010; van Bellen et al., 2011; Gorham et al., 2012). The present study analyzed a new
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42 745 database that comprises 268 peat records from 215 northern peatland sites. This
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44 746 systematic analysis of peat properties and Holocene C accumulation rates is essential for
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46 747 accurately addressing the following general research topics in the future: (1) describing
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48 748 and quantifying spatial and temporal patterns of Holocene peatland C and N
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50 749 accumulation; (2) assessing the sensitivity of C and N accumulation to climate change;
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52 750 (3) estimating peatland soil organic carbon (SOC) and soil organic nitrogen (SON) pools
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3 751 at regional and hemispheric scales, (4) furthering our understanding of peatland C cycle –
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5 752 climate linkages, and (5) providing the scientific community with a large dataset for
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8 753 developing and testing earth system and ecological models.
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10 754

11 12 13 755 **Acknowledgements**

14
15 756 We acknowledge the peatland research community for sharing their datasets. The U.S.
16
17 757 NSF supported the synthesis work through grant ARC-1107981 to Lehigh University.
18
19
20 758 The collection and analysis of unpublished records used in this synthesis were supported
21
22 759 by the following funding agencies and research grants: Alaska (NSF ARC-1107981,
23
24 760 AGS-0628455, and EAR-0819717; USGS Climate Research and Development Program),
25
26
27 761 Canada (NSF ARC-1107981, EAR-0223271, EAR-0843685, and AGS-0628598; NSERC
28
29 762 CRDPJ-305605, CRDPJ-365867; Hydro-Québec), Fennoscandia and Western Siberia
30
31 763 (NSF OPP-9818496; Academy of Finland 201321 and 1133515; University of Helsinki),
32
33
34 764 Kamchatka (NSF ARC-1107981, ARC-1108116), and the United Kingdom (Yorkshire
35
36 765 Peat Partnership). Lehigh University's Library and Technology Services staff is
37
38 766 acknowledged for its support in building the web interface for the peatland database.
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40
41 767 Finally, comments from Paul Glaser and two other journal reviewers improved the
42
43
44 768 overall quality of the manuscript.
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46 769

47 48 770 **References**

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32 33 1072 **Figure and Table Captions**

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35 1073 **Figure 1.** Location of study sites. Map showing the distribution of northern peatlands
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37 1074 (green area from Yu et al., 2010) and peatland sites included in this study (n = 215 sites,
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39 1075 including 268 peat cores). Long-term rate of peat-carbon accumulation was estimated
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41 1076 from 127 sites (151 peat cores; red and blue dots). The yellow dots represent cores for
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43 1077 which only peat properties (bulk density, organic matter content, etc.) were available and
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45 1078 synthesized. Refer to Supplementary Table 1 for details.
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52 1080 **Figure 2.** Overview of data availability for North America (black bars) and Eurasia
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54 1081 (white bars). (A) Number of cores (total = 238) containing information on
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56 1082 carbon/nitrogen ratio (n = 40), nitrogen content (n = 40), carbon content (n = 56), peat
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3 1083 types (n = 83), organic matter bulk density (n = 184), organic matter content (n = 190),
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6 1084 and bulk density (n = 214). (B) Number of cores (total = 151) with a dating quality better
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8 1085 than two dates per 1000 years (n = 35), one to two dates per 1000 years (n = 52), and less
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10 1086 than one date per 1000 years (n = 64). (C) Number of calibrated basal peat ages (median)
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12 1087 in 500-year bins from the database (n = 199) compared to all northern hemisphere basal
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14 1088 peat ages (median) in 200-year bins (n = 2559, MGK data from MacDonald et al., 2006,
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16 1089 Gorham et al., 2007, Korhola et al., 2010).
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22 1091 **Figure 3.** Distribution histograms of peat properties in northern peatlands. (A) Frequency
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24 1092 distribution of bulk density for unidentified peat type samples (white bars) and different
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26 1093 peat types (color bars). (B) Frequency distribution of organic matter content for different
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28 1094 peat types. (C) Frequency distribution of organic matter bulk density for different peat
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30 1095 types. (D) Frequency distribution of carbon content for different peat types. (E)
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32 1096 Frequency distribution of nitrogen content for different peat types. (F) Frequency
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34 1097 distribution of carbon/nitrogen mass ratio for different peat types.
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41 1099 **Figure 4.** Relation between carbon content and organic matter content in northern
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43 1100 peatlands. The slope of each regression line is used as a conversion factor for estimating
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45 1101 carbon content from organic matter content.
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48 1102
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50 1103 **Figure 5.** Temporal patterns of peat properties (mean, standard deviation, and number of
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52 1104 samples). (A) Bulk density. (B) Organic matter content. (C) Organic matter bulk density.
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3 1105 (D) Carbon content. (E) Nitrogen content. (F) Carbon/Nitrogen mass ratio. White bars
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5 1106 represent values that were based on a limited number of samples and peat records.
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10 1108 **Figure 6.** Main differences between *Sphagnum* and non-*Sphagnum* peat samples. (A)
11 Bulk density. (B) Organic matter bulk density. (C) Organic carbon bulk density. (D)
12 1109 Carbon content. (E) Nitrogen content. (F) Carbon/Nitrogen mass ratio. (G) Temporal
13 1110 pattern of organic C bulk density. (H) Proportional change in the number of peat records
14 1111 that are *Sphagnum*-dominated, presented as a percentage of the total number of records.
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18 1115 **Figure 7.** Long-term apparent rate of carbon and nitrogen accumulation from northern
19 1116 peatlands (n = 127 sites). (A) Summer insolation at 60°N (data from Berger and Loutre,
20 1117 1991) and temperature anomaly from an 11,300-year reconstruction for the northern
21 1118 extra-polar region from 30 to 90°N (data from Marcott et al., 2013). Temperature
22 1119 anomaly was calculated based on the 1961-1990 temperature averages. (B) Mean peat-
23 1120 carbon accumulation rates (PCAR) and standard error in 500-year bins. The number of
24 1121 sites per 500-year bins is also presented. (C) Mean peat-nitrogen accumulation rates
25 1122 (PNAR) and standard error in 500-year bins. These values were obtained using different
26 1123 C/N values over time, as indicated by the line.
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30 1127 **Table 1.** Peat properties in northern peatlands. Means and standard deviations are
31 1128 presented, along with the number of samples (n).
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3 1127 **Table 2.** Northern peatland peat properties by regions. Means and standard deviations are
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6 1128 presented, along with the number of samples (n).

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10 1130 **Table 3.** Comparison of northern peatland peat properties estimates with other published
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12 1131 values. Means and standard deviations are presented, along with the number of samples
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15 1132 (n) when available.

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20 1134 **Supplementary Material**

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22 1135 **Table S1.** Summary information for the study sites included in the database.
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1 | A ~~Circum-Arctic~~ database and synthesis of northern peatland soil properties and

2 | Holocene carbon and nitrogen accumulation

4 | Running title

5 | ~~Circum-Arctic-Northern~~ peatland database and synthesis

7 | Authors

8 | Julie Loisel^{1*}, Zicheng Yu^{1*}, David W. Beilman², Philip Camill³, Jukka Alm⁴, Matthew J.

9 | Amesbury⁵, David Anderson⁶, Sofia Andersson⁷, Christopher Bochicchio¹, Keith Barber⁸,

10 | Lisa R. Belyea⁹, Joan Bunbury¹⁰, Frank M. Chambers¹¹, Daniel J. Charman⁵, François De

11 | Vleeschouwer¹², Barbara Fiałkiewicz-Koziel¹³, Sarah A. Finkelstein¹⁴, Mariusz Galka¹³,

12 | Michelle Garneau¹⁵, Dan Hammarlund¹⁶, William Hinchcliffe⁵, James Holmquist¹⁷, Paul

13 | Hughes⁸, Miriam C. Jones¹⁸, Eric S. Klein¹, Ulla Kokfelt¹⁹, Atte Korhola²⁰, Peter Kuhry⁷,

14 | Alexandre Lamarre¹⁵, Mariusz Lamentowicz¹³, David Large²¹, Martin Lavoie²², Glen

15 | MacDonald¹⁷, Gabriel Magnan¹⁵, Markku Mäkilä²³, Gunnar Mallon⁸, Paul Mathijssen²⁰,

16 | Dmitri Mauquoy²⁴, Julia McCarroll¹¹, Tim R. Moore²⁵, Jonathan Nichols²⁶, Benjamin

17 | O'Reilly¹⁴, Pirita Oksanen²⁷, Maara Packalen²⁸, Dorothy Peteet²⁶, Pierre J.H. Richard²⁹,

18 | Stephen Robinson³⁰, Tiina Ronkanen²⁰, Mats Rundgren¹⁶, A. Britta K. Sannel⁷, Charles

19 | Tarnocai³¹, Tim Thom³², Eeva-Stiina Tuittila⁴, Merritt Turetsky³³, Minna Väliranta²⁰,

20 | Marjolein van der Linden³⁴, Bas van Geel³⁵, Simon van Bellen²³, Dale Vitt³⁶, Yan Zhao³⁷,

21 | Weijian Zhou³⁸

22

23 Revised manuscript submitted on 19 December 2013 as a Research Paper for the special
24 issue *Holocene Peatland Carbon Dynamics in the Circum-Arctic Region*.

25
26 Affiliations

27 ¹Department of Earth and Environmental Sciences, Lehigh University, Bethlehem, PA
28 18015, USA

29
30 ²Department of Geography, University of Hawaii – Manoa, Honolulu, HI 96822, USA

31
32 ³Department of Earth and Oceanographic Sciences, Bowdoin College, Brunswick, ME
33 04011, USA

34
35 ⁴School of Forest Sciences, University of Eastern Finland, Joensuu, FI 80101, Finland

36
37 ⁵Department of Geography, University of Exeter, Exeter, EX4 4RJ, UK

38
39 ⁶Department of Geography, Eton College, Windsor, Berkshire SL4 6DW, UK

40
41 ⁷Department of Physical Geography and Quaternary Geology, Stockholm University,
42 Stockholm, 106 91, Sweden

43
44 ⁸Geography and Environment, University of Southampton, Southampton, SO17 1BJ, UK

45
46 ⁹School of Geography, Queen Mary University of London, London, E1 4NS, UK

47
48 ¹⁰Department of Geography and Earth Science, University of Wisconsin – La Crosse, La
49 Crosse, WI 54601, USA

50
51 ¹¹Centre for Environmental Change and Quaternary Research, University of
52 Gloucestershire, Cheltenham, GL50 4AZ, UK

53
54 ¹²CNRS and Université de Toulouse, Castanet Tolosan, 31326, France

55
56 ¹³Department of Biogeography and Paleoecology, Adam Mickiewicz University, Poznan,
57 61-680, Poland

58
59 ¹⁴Department of Earth Sciences, University of Toronto, Toronto, ON M5S 3B1, Canada

60
61 ¹⁵Departement de Géographie and GEOTOP, Université du Québec – Montréal,
62 Montréal, QC H3C 3P8, Canada

63
64 ¹⁶Department of Geology, Lund University, Lund, SE-223 62, Sweden

- 1
2
3
4
5
6
7
8 65
9 66 ¹⁷Department of Geography, University of California – Los Angeles, Los Angeles, CA
10 67 90095, USA
11 68
12 69 ¹⁸U.S. Geological Survey, Reston, VA 20192, USA
13 70
14 71 ¹⁹Department of Geosciences and Natural Resource Management, University of
15 72 Copenhagen, Copenhagen, DK-1350, Denmark
16 73
17 74 ²⁰Department of Environmental Sciences, University of Helsinki, Helsinki, FIN-00014,
18 75 Finland
19 76
20 77 ²¹Department of Chemical and Environmental Engineering, University of Nottingham,
21 78 Nottingham, NG7 2RD, UK
22 79
23 80 ²²Département de Géographie and Centre d'études nordiques, Université Laval, Québec,
24 81 QC G1V 0A6, Canada
25 82
26 83 [²³Geological Survey of Finland, P.O. Box 96, Espoo, 02151, Finland](#)
27 84
28 85 ²⁴School of Geosciences, University of Aberdeen, Aberdeen, AB24 3UF, UK
29 86
30 87 ²⁵Department of Geography and Global Environmental and Climate Change Centre,
31 88 McGill University, Montreal, QC H3A 0B9, Canada
32 89
33 90 ²⁶Lamont-Doherty Earth Observatory, Columbia University, Palisades, NY 10964, USA
34 91
35 92 ²⁷Centre for Economic Development, Transport and the Environment, Vaasa, 65101,
36 93 Finland
37 94
38 95 [²⁸Department of Geography, University of Toronto, Toronto, ON M5S 3G3, Canada](#)
39 96
40 97 ²⁹Département de Géographie, Université de Montréal, Montréal, QC H2V 2B8, Canada
41 98
42 99 ³⁰Champlain College – Dublin Campus, Dublin, Ireland
43 100
44 101 [³¹Agriculture and Agri-Food Canada, Ottawa, ON K1A 0C6, Canada](#)
45 102
46 103 ³²Yorkshire Peat Partnership, Yorkshire Wildlife Trust, York, YO24 1GN, UK
47 104
48 105 ³³Department of Integrative Biology, University of Guelph, Guelph, ON N1G 2W1,
49 106 Canada
50 107
51 108 ³⁴BIAX Consult, Zaandam, 1506 AL, The Netherlands
52 109

- 1
2
3
4
5
6
7
8 110 ³⁵Institute for Biodiversity and Ecosystem Dynamics, University of Amsterdam,
9 111 Amsterdam, 1098 XH, The Netherlands
10 112
11 113 ³⁶Department of Plant Biology, Southern Illinois University, Carbondale, IL 62901, USA
12 114
13 115 ³⁷Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of
14 116 Sciences, Beijing, 100101, China
15 117
16 118 ³⁸Institute of Earth Environment, Chinese Academy of Sciences, Xi'an, 710075 Shaanxi,
17 119 China
18 120

19
20 121 Corresponding authors

- 21
22 122 Julie Loisel email: jul208@lehigh.edu phone: 610-758-3660
23
24 123 Zicheng Yu email: ziy2@lehigh.edu phone: 610-758-6751
25

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27
28 125 Abstract

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30 126 Here we present results from the most comprehensive compilation of Holocene peat soil
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32 127 properties with and associated Holocene carbon and nitrogen accumulation rates for
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34 128 northern peatlands. Our database consists of 268 peat cores from 215 sites located north
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36 129 of 45°N. It encompasses regions within which peat carbon data have only recently
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38 130 become available, such as the West Siberia Lowlands, and the Hudson Bay Lowlands,
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40 131 Kamchatka in Far East Russia, and the Tibetan Plateau. For all northern peatlands, carbon
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42 132 content in organic matter was estimated at $42.3 \pm 3\%$ (S.D.) for *Sphagnum* peat, $51.3 \pm$
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44 133 2% for non-*Sphagnum* peat, and at $49.2 \pm 2\%$ overall. Dry bulk ~~Bulk~~ density averaged
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46 134 $0.12 \pm 0.07 \text{ g cm}^{-3}$, organic matter bulk density averaged $0.11 \pm 0.05 \text{ g cm}^{-3}$, and total
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48 135 carbon content in peat averaged $46.847 \pm 6.4\%$. In general, large differences were found
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50 136 between *Sphagnum* and non-*Sphagnum* peat types in terms of peat properties. Time-
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52 137 weighted peat carbon accumulation rates averaged 232.9 ± 2 (S.E.M.) $\text{g C m}^{-2} \text{ yr}^{-1}$
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8 138 during the Holocene on the basis of 151 peat cores from 127 sites, with the highest rates
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10 139 of carbon accumulation (25-28 g C m⁻² yr⁻¹) recorded during the ~~warmer than today~~ early
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12 140 Holocene when the climate was warmer than the present. Furthermore, Finally, we
13
14 141 ~~provide the first~~ estimate ~~for~~ the northern peatland carbon and nitrogen pools at 436 and
15
16 142 109.7 gigatons, respectively equivalent to 10% of the world's soil nitrogen. The database
17
18 143 is publicly available at <https://www.peatlands.lehigh.edu>.
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20 144

21 145 Keywords

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24 146 Northern peatlands, Data synthesis, Climate change, Soil carbon and nitrogen,
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26 147 Biogeochemical cycles, Long-term ecosystem dynamics
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29 149 **Introduction**

30
31 150 Of all terrestrial ecosystems, peatlands are arguably the most efficient at sequestering
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33 151 carbon (C) over long time scales. Northern peatlands cover approximately 4,000,000 km²
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35 152 or 3% of the global land area (Maltby and Immirzi, 1993) and have accumulated about
36
37 153 500 gigatons of C (GtC) mostly during the Holocene, equivalent to ~ 30% of the present-
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39 154 day the global soil organic carbon (SOC) pool (Gorham, 1991; Bridgham et al., 2006; Yu
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41 155 et al., 2010). These ecosystems have also ~~been playing~~ played a dynamic role in the
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43 156 Holocene global C cycle as important sinks of carbon dioxide (CO₂) and major sources of
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45 157 methane (CH₄) to the atmosphere (Frolking and Roulet, 2007; Korhola et al., 2010; Yu,
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47 158 2011). As climate warming positively affects both plant growth and organic matter
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49 159 decomposition. ~~r~~Recent and projected climate change could shift the balance between
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51 160 peat production and organic matter decomposition, potentially affecting the peatland C-
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9 161 | sink capacity and modifying peat -C fluxes to the atmosphere (Frolking et al., 2011; Yu,
10 162 | 2012). This prediction is particularly the case in holds true for the northern high-latitude
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12 163 | regions, where the intensity of climate change is expected to be greatest (McGuire et al.,
13
14 164 | 2009). The peatland C cycle-carbon climate feedback remains difficult to assess,
15
16 165 | however, because of (1) limited understanding of peatland responses to climate change
17
18 166 | (Frolking et al., 2011), (2) data gaps and large uncertainties in regional peatland C stocks
19
20 167 | (Yu, 2012), and (3) non-linear peatland responses to external forcing (Belyea, 2009).

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24 169 | Very little is known about the nitrogen (N) budget that accompanies C accumulation in
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26 170 | northern peatlands (but see Limpens et al., 2006 for a review). Assuming a net C
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28 171 | sequestration of ~270 GtC (Yu, 2012) and a C/N ratio of 20-30 for fen peat (Bergner et
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30 172 | al., 1990; Rydin and Jeglum, 2013; results therein) during the early Holocene (11-7 ka),
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32 173 | about 10-13 GtN would have been required to build such peat deposits. It is therefore
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34 174 | possible that northern peatlands have been playing an undocumented, dynamic role in the
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36 175 | Holocene global N cycle as important sinks of N, potentially limiting the amount of N
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38 176 | available for other ecosystems at the global scale (McLauchlan et al., 2013).
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40 177 | Alternatively, if the main N input to peatlands was through N_2 fixation by cyanobacteria,
41
42 178 | these microorganisms might have been more important in driving the C cycle in
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44 179 | peatlands than previously thought. Overall, studying the coupling between N and C
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46 180 | cycling in northern peatlands is essential for a better understanding of how key
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48 181 | biogeochemical processes interact in these systems and for predicting the future of peat C
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50 182 | stocks.

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9 184 Here we present the most comprehensive compilation of Holocene C and N data for
10 185 northern peatlands. ~~Our database consists of 268 peat cores from 215 sites located north~~
11 ~~of 45 °N or at high elevations (e.g., Tibetan Plateau).~~ This synthesis encompasses regions
12 186
13 187 within which peat -C and N data have only recently become available, such as the West
14 188 Siberian Lowlands in Asian Russia, ~~a and~~ the Hudson Bay Lowlands in Canada,
15 189 Kamchatka in the Russian Far East, and the Tibetan Plateau. In addition, we present the
16 190 most comprehensive synthesis of peat soil properties (such as bulk density, organic
17 191 matter content, ~~and carbon C~~ and ~~nitrogen N~~ content) from the northern hemisphere.
18 192 Also, this new database and synthesis work represent a major expansion from Yu et al.'s
19 193 (2009) synthesis on Holocene peat C dynamics, which was based on 33 sites (vs. 127
20 194 sites as reported in this paper). Finally, it constitutes a natural continuation of Charman et
21 195 al.'s (2013) recent study on peat C accumulation in northern peatlands during the last
22 196 millennium.
23 197
24 198 In addition to filling regional data and knowledge gaps, The main objectives of this
25 199 paper are to (1) describe a database of peat soil properties and synthesize this information
26 200 for different peat types, time intervals, and geographic regions, and (2) produce a time
27 201 series of Holocene peat -C and N accumulation rates in 500-yr ~~increments bins~~ for
28 202 comparison with climate history. Key differences in Holocene peat properties between
29 203 different regions and peatland types are also discussed in light of their implications for
30 204 long-term peat C stocks. Of particular importance and relevance are the differences
31 205 between *Sphagnum* and non-*Sphagnum* peat types. Finally, we present new estimates for
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9 206 northern peat C and N stocks for northern peatlands on the basis of the expanded
10 207 database.

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14 209 Database and ~~Database and analytical methods~~ analysis

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16 210 *Databasebase*

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18 211 We compiled a dataset of 268 published and unpublished Holocene peat records from
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20 212 215 sites located in North America and Eurasia (Figure 1, Supplementary Table 1). The
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22 213 difference in the number of peat cores and peatland sites is due to the fact that, in a few
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24 214 instances, multiple cores were collected from a single peatland. As these multiple cores
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26 215 were not designed as true replicates in the original publications, each of these cores was
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28 216 considered as an independent record of peat properties in the present study. However,
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30 217 only the oldest core for each site was ~~accounted used~~ for ~~when~~ estimating peat inception
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32 218 age. Finally, when calculating peat ~~-C~~ carbon accumulation rates, ~~estimates, multiple~~
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34 219 cores from a single site were each attributed an equal fraction of the weight for that site.
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36 220 For example, for a site with three cores, the peat ~~-C~~ accumulation history of each core
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38 221 only accounted for 1/3 of ~~a record~~ the site's record.

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41 223 The latitude of most peatland sites ranges ~~ed~~ from 45 to 69 °N. The cutoff at 45 °N
42
43 224 represents the southern limit for defining what is considered to be the area contributing to
44
45 225 the C cycle of the Arctic region (McGuire et al., 2009). ~~with the exception of~~ Four high-
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47 226 elevation ~~three high elevation~~ sites found in China (the Tibetan Plateau) and Japan were
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49 227 also included, as they developed under similar 'northern' climatic conditions. ~~The name~~
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51 228 and coordinates of these four sites are as follows: Zoige (33.5 °N, 102.6 °E), Hongyuan

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8 229 | (32.8 °N, 102.5 °E), Hani (42.2 °N, 126.5 °E), and Utasai (42.4 °N, 140.2 °E). -A total of
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10 230 | 155 cores originate from Eurasia, ~~comprising including~~ 112 cores from Russia. The
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12 231 | remaining 113 cores come from North America, ~~including 12 cores from Alaska~~.
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14 232 | Approximately 40% of all cores were collected ~~from in~~ ombrotrophic bogs (n = 110
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16 233 | ~~cores08~~) and 20% were extracted from minerotrophic fens (n = 50 cores). The remainder
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18 234 | (40%) was collected in ~~permafrost~~ peatlands currently affected by permafrost (n = 108
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20 235 | ~~cores40~~). Note that peatland type was identified independently for each site by the
21
22 236 | original investigators. From an ecosystem functioning perspective, distinguishing bogs
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24 237 | from fens and permafrost peatlands is important, as these peatland types are characterized
25
26 238 | by different hydrological regimes, vegetation communities, and peat-growth trajectories,
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28 239 | all of which impact long-term rates of peat -C sequestration (Rydin and Jeglum,
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30 240 | 20132006). Bogs are ~~nutrient mineral~~-poor, rain-fed peatland ecosystems with relatively
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32 241 | low plant net primary production (NPP) and slow peat decomposition rates. In contrast,
33
34 242 | fens are hydrologically connected to surface or ground water, thereby receiving more
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36 243 | ~~nutrients mineral nutrients from the groundwater~~. Generally speaking, ~~they fens~~ have
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38 244 | greater NPP but also faster peat decay rates than bogs (Blodau, 2002). Finally, in the sub-
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40 245 | ~~A~~arctic and ~~A~~arctic regions, peatland hydrology, structure, and peat -C balance are
41
42 246 | sensitive to the underlying permafrost aggradation and degradation dynamics (Camill,
43
44 247 | 1999; Turetsky et al., 2007). For the analysis, ~~frozen~~ peat plateaus (879 out of 10840
45
46 248 | cores), permafrost bogs (18 out of 10840 cores), and collapse scars (3 out of 10840 cores)
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48 249 | were grouped under the peatland type 'permafrost peatlands'. Original peatland
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50 250 | categories can be found in Supplementary Table 1.
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9 252 | The database was built to include as many peat records as possible. Therefore, we
10 253 | included any peat core that was extracted north of 45 °N (or at high elevation) and for
11 | which bulk density or organic matter bulk density data were available. Information
12 254 | related to peat-core location, peatland type, peat properties, age, and data source can be
13 |
14 255 | related to peat-core location, peatland type, peat properties, age, and data source can be
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16 256 | found in Supplementary Table 1. Additional information related to the type of coring
17 | device used and the year of coring can be found in the original publications. Data ~~and~~
18 257 | age depth relationships used in this synthesis are readily accessible from the Holocene
19 |
20 258 | Peatland Carbon Network website (<https://www.peatlands.lehigh.edu>). The website
21 | includes all published records and will be updated as new records included in this
22 259 | synthesis are eventually published. This database ~~should will~~ be useful in future studies
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24 260 | of ecosystem – carbon-C cycle – climate interactions and for modeling long-term
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26 261 | peatland dynamics.
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33 265 | In the following sub-sections, we present the criteria for site selection and the protocols
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35 266 | used to develop the dataset. In an effort to only analyze and synthesize *peat* samples,
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37 267 | inorganic-rich horizons often found at the base of the peat cores were removed from the
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39 268 | database. When available, stratigraphic information was used to distinguish peat vs. non-
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41 269 | peat material. For example, gyttja (organic-rich lake sediments) was excluded from the
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43 270 | dataset, as well as marshy, clayey, and silty sediments. When stratigraphic information
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45 271 | was not available, a bulk density value of 0.5 g cm^{-3} was used as a cut-off between peat
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47 272 | and non-peat material. This value was chosen on the basis of stratigraphic information
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49 273 | from peatland records where peaty sediments with bulk density values up to 0.5 g cm^{-3}
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51 274 | were identified. We ~~do~~ acknowledge that this cut-off value is arbitrary, and that our
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8 275 dataset likely contains some non-peat samples. Inorganic horizons (e.g., tephra layers)

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10 276 | were also excluded from the [peat records database](#).

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14 278 Peat properties

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16 279 | A [subset-total](#) of 232 peat cores (181 sites) ~~were was~~ used for characterizing peat

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18 280 | properties, though not all cores have all [types of](#) peat properties available (Figure 2a).

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20 281 | This dataset contains 139 cores from Eurasia (including 109 cores from Russia) and 93

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22 282 | cores from North America (Figure 1). While approximately half of these cores ~~were as~~

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24 283 | sampled and analyzed at high resolution (1-5 cm increments), the ~~remainder-wremainder~~

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26 284 | ~~was as~~ sampled at lower resolution, typically at 10 cm increments. ~~Dry b~~Bulk density

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28 285 | (BD; g cm⁻³), organic matter content (OM%; gravimetric %), as well as elemental C and

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30 286 | N concentration values were compiled and synthesized. On the basis of these raw

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32 287 | datasets, [carbon-to-nitrogen ratio](#) (C/N mass ratio) and organic matter bulk density

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34 288 | (OMBD; g OM cm⁻³) were calculated. These peat geochemical values are examined in

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36 289 | light of peat stratigraphy, peat ages, and geographic regions. The following paragraphs

37
38 290 | briefly describe the protocols used to obtain these values.

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42 292 | Peat stratigraphic information was obtained for 83 peat cores ([‘peat types’ in](#) Figure 2a)

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44 293 | for which plant macrofossil analysis or detailed peat description had been performed

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46 294 | following standard techniques (e.g., Troels-Smith, 1955; Mauquoy and van Geel, 2007).

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48 295 | This peat stratigraphic information was condensed into the following five peat types:

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50 296 | *Sphagnum*, herbaceous, woody, brown moss, and humified peat. In a few cases, the

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52 297 | investigators only ascribed a general peat type to the samples (e.g., ‘bog’ vs. ‘fen’ peat, or

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8 298 'Sphagnum' vs. 'herbaceous' peat). In these cases, the uncertainty associated with
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10 299 classifying peat samples mostly relates to the uniformity of naming convention used
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12 300 among the investigators. For example, a peat sample that contains sizable fractions of
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14 301 brown moss and humified peat may be classified by an investigator as 'brown moss peat'
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16 302 and by another one as 'humified peat'. We recognize that, due to their nature, brown
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18 303 moss and humified peat types might be less uniform than *Sphagnum*, ~~or~~ herbaceous, ~~or~~
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20 304 ~~woody~~ peat types. We included as much stratigraphic information as possible in the
21
22 305 database, though ambiguous or imprecise descriptions were left out to avoid further
23
24 306 ~~uncertainties~~ confusions.

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28 308 Dry bulk density and organic matter concentration content were determined following
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30 309 standard procedures; in all cases where these parameters were measured, were
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32 310 determined following standard procedures (Dean, 1974; Chambers et al., 2011). Peat
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34 311 samples of a known fresh volume were either freeze-dried or oven-dried at ca. 100 °C
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36 312 until constant weight was reached and weighed to determine bulk density, then burned at
37
38 313 500-600 °C for one to four hours and weighed again to determine organic matter content.
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40 314 The accuracy of these measurements mostly depends on sample handling (care must be
41
42 315 taken to prevent peat compaction in the field and in the laboratory) and the analytical
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44 316 error associated with weighing. The product of bulk density (BD; g cm⁻³) and organic
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46 317 matter content (OM%) of each peat sample was used to calculate organic matter bulk
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48 318 density (OMBD; g OM cm⁻³), also referred to as ash-free bulk density (AFBD) or organic
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50 319 bulk density (OBD) in the literature (Yu et al., 2003; Björck and Clemmensen, 2004). We
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52 320 compiled a total of 21,220 bulk density measurements ~~from 214 cores~~, 18,973 organic

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9 321 matter content values ~~from 190 cores~~, and computed 18,544 organic matter bulk density
10 322 values ~~from 184 cores~~ (Figure 2a).

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14 324 Total peat carbon-C and nitrogen-N content were directly measured by combustion and
15
16 325 elemental analysis of dry peat samples (Chambers et al., 2011). We compiled 3741 C and
17
18 326 3365 carbon-N measurements ~~from 56 cores and 3365 nitrogen content measurements~~
19
20 327 ~~from 40 cores~~ (Figure 2a). We also computed a total of 3362 carbon to nitrogen ratio
21
22 328 (C/N) mass ratio values ~~from 40 cores~~.

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26 330 Finally, the regression between ~~total~~ peat carbon-C content (C%) and peat organic matter
27
28 331 content (OM%) for each peat type is presented as an estimate for carbon-C content in
29
30 332 organic matter (OC%). A total of 995 samples ~~from 19 cores~~ were used in this analysis.
31
32 333 The slope of each one of these regressions is interpreted as the 'conversion factor' from
33
34 334 OM% to OC%, such that it provides an indirect way for estimating the C% content of
35
36 335 ash-free peat for investigators who do not perform elemental C% measurements directly.

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38
39 337 Peat-core chronology
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41 338 Peat-core chronologies were almost exclusively based on radiocarbon (^{14}C) dates that
42
43 339 were determined mostly by accelerator mass spectrometry (AMS) on terrestrial plant
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45 340 macrofossils or bulk peat (Piotrowska et al., 2011). A few older chronologies were based
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47 341 on conventional ^{14}C dating of bulk samples. Because no systematic offset has been
48
49 342 observed in the ^{14}C age of bulk vs. non-woody plant macrofossils ~~The use of bulk dates is~~
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51 343 ~~justified since the absence of a systematic offset between the ^{14}C dates of bulk peat~~

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9 344 ~~versus those of plant macrofossils it contains~~ (G.M. MacDonald, pers. comm. 2013), the
10 345 use of bulk dates is justifiable. For the purpose of this study, all ^{14}C ~~ages-dates~~ were
11
12 346 calibrated to calendar years before present (cal. BP) using the program CALIB 6.1.0
13
14 347 (Stuiver and Reimer, 1993) with the IntCal09 calibration dataset (Reimer et al., 2009). In
15
16 348 this paper, ages are reported in thousands of calibrated years before present (ka), ~~such~~
17
18 349 ~~that 1 ka = 1000 cal. B.P.~~
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22 351 Age-depth relationships were established for all continuous peat cores for which at least
23
24 352 five ~~radiocarbon dates (^{14}C)~~ age determinations were available (n = 151 cores). Except for
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26 353 a few palynostratigraphic and tephrochronologic markers, nearly all records have
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28 354 chronologies exclusively based on ^{14}C ages (Supplementary Table 1). Chronologies were
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30 355 obtained through linear interpolation of calibrated ages between dated horizons. Single-
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32 356 age estimates were taken from the mid-point of each calibrated 2σ probability
33
34 357 distribution. This parsimonious approach captures general patterns of temporal changes
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36 358 in peat accumulation and allows for analysis of peat $_{\text{C}}$ accumulation trajectories (e.g.,
37
38 359 Telford et al., 2004). Although more sophisticated approaches are possible (e.g.,
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40 360 Charman et al., 2013), we seek to make the fewest or simplest assumptions for this
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42 361 analysis because the temporal resolution target for peat $_{\text{C}}$ accumulation rate calculations
43
44 362 is relatively low (at 500 years). In the cases where the original investigator identified
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46 363 hiatuses (e.g., peat loss caused by erosion or fire) or depositional anomalies (e.g., thick
47
48 364 tephra layers that interrupted peat accumulation) along their peat records, these gaps were
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50 365 taken into consideration when building age-depth relationships (Glaser et al., 2012).
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52 366 Otherwise, peat records were assumed to be continuous.
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368 In an effort to assess the representativeness of our samples in terms of peatland inception
 369 ~~age~~ estimating, peat basal ages were compiled and compared to results from large datasets
 370 (MacDonald et al., 2006; Gorham et al., 2007; Korhola et al., 2010). ~~When multiple cores~~
 371 ~~were collected from a single peatland, only the oldest core was accounted for when~~
 372 ~~estimating peat inception age.~~ Peat inception ages from ~~199~~¹⁶ sites (Supplementary
 373 Table 1) were summed and binned in 500-year intervals.

374

375 Long-term rates of carbon and nitrogen accumulation

376 A ~~subset~~ total of 151 peat cores from 127 sites ~~were~~^{was} used for estimating rates of peat-
 377 C accumulation. This dataset contains 96 cores from 78 North American sites and 55
 378 cores from 49 Eurasian sites (Figure 1). Of the 33 sites presented in Yu et al.'s (2009)
 379 study, 25 were used in the present study (Supplementary Table 1). The remaining 8 sites
 380 did not fulfill our dating quality criterion (presented below). When multiple cores were
 381 collected from a single peatland, each core was attributed a fraction of the weight for that
 382 site such that, for a site with three cores, the peat C accumulation history of each core
 383 only accounted for 1/3. For each core, peat chronology was constrained by at least five
 384 age determinations. The dating ~~resolution quality~~ of ~~these each~~ records was determined
 385 by the quotient of the calibrated peat basal age and the number of age determinations. For
 386 example, a 10,000-year-old peat core with a chronology constrained by 10 ¹⁴C dates was
 387 attributed a dating ~~resolution quality~~ of ~~1000 years per one~~ date per 1000 years. About
 388 58% of ~~these our~~ 151 cores ~~were~~ characterized by an acceptable dating ~~resolution~~
 389 ~~between 10 and~~ quality of one to two, ¹⁴C dates per 1000 years (Figure 2b). These

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390 resolutions are well suited to capture millennial-scale variations in C accumulation.

391 ~~Several peat cores with high resolution (10-500 years) more than two ¹⁴C dates per 1000~~
 392 ~~years per date, (n = 35 cores) were~~ available from North America and Europe. The
 393 ~~coarser lower dating resolution quality~~ cores (~~<1 date per >1000 years per date~~) ~~were~~
 394 unevenly distributed and comprise 44% of the North American records (~~42 out of 96~~
 395 ~~cores~~) and 40% of the Eurasian records (~~22 out of 55 cores~~).

396

397 The long-term rate of peat-C accumulation was calculated for each core following one of
 398 ~~the these following~~ five approaches (Supplementary Table 1): (1) ~~w~~Whenever possible,
 399 peat core chronology was combined with bulk density and ~~C% content values~~ for each
 400 depth increment (n = 47 cores); (2) ~~i~~In the cases where direct C measurements were
 401 lacking, peat core chronology was combined with ~~ash-free organic matter~~ bulk density
 402 measurements and a mean organic ~~matter carbon-C content value~~ of 49% ~~in organic~~
 403 ~~matter~~ (n = 57 cores; ~~see the Results section for details~~); (3) ~~f~~For cores that lacked ~~ash-~~
 404 ~~free organic matter~~ bulk density and direct ~~C-% content measurements~~, peat core
 405 chronology was combined with bulk density measurements and a ~~mean total carbon-C~~
 406 content of 47% ~~in total peat~~ (n = 3 cores; ~~see the Results section for details~~); (4)
 407 ~~w~~Whenever neither bulk density nor ~~C% content~~ was ~~directly~~ available ~~from the cores~~,
 408 long-term rate of peat-C accumulation was calculated for each core by combining time-
 409 dependent bulk densities (0.08 g cm⁻³ at 0-0.5 ka; 0.12 g cm⁻³ at 0.5-6 ka; 0.14 g cm⁻³ at
 410 6-12 ka) with a mean C content of 47% ~~in total peat~~ for each dated interval (n = 32 cores;
 411 ~~see the Results section for details~~), ~~and~~; (5) ~~p~~Peat-C accumulation rates for the remaining
 412 12 cores were directly obtained from published figures and tables. For all the cores, time-

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9 413 weighted peat-C accumulation rates were summed and binned in 500-year intervals. It is
10 414 important to note that such reconstructions are ‘apparent rates’ that are different from true
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12 415 rates of C ~~uptake-accumulation~~ in peatlands, because decomposition processes have been
13
14 416 affecting old peat layers for thousands of years (Turunen et al., 2002). Finally, the long-
15
16 417 term rate of peat N accumulation was calculated by combining our binned peat-C
17
18 418 accumulation rates with time-dependent C/N values (65 at 0-6 ka, and 40 at 6-10 ka).
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419

420 Results

421 Peat Properties

422 ~~, the mean bulk density value for each peat type is reported in Table 1, and regional~~
423 ~~differences are presented in Table 2. Descriptive statistics of dataset~~
424 The frequency distribution of each peat property is shown in Figure 3. Mean values and
425 standard deviations for all peat properties are presented by peat type in The frequency
426 distribution is presented in Figure 3a Table 1, and by region in Table 2.
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428

428 Bulk density values ($n = 21,220$) ranged from 0.003 to 0.498 g cm^{-3} , with a mean value
429 of $0.118 \pm 0.069 \text{ g cm}^{-3}$ (1 standard deviation (S.D.)). A one-way analysis of variance
430 (ANOVA) revealed ~~an significant~~ effect of peat type on bulk density ($F(10709) = 941$,
431 $p < 0.0001$), with all peat types significantly different from each other on the basis of
432 post-hoc Tukey’s LSD tests ($p < 0.0001$). In increasing order, mean bulk density of the
433 peat types is *Sphagnum* < Woody < Herbaceous < Brown Moss < Humified (Table 1).
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8 435 Organic matter content (n = 18,973) has~~d~~ a mean value of $90.7 \pm 13\%$ (1 S.D.) and a
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10 436 median of 95.7%. ~~The frequency distribution is presented in Figure 3b, the mean organic~~
11
12 437 ~~matter content for each peat type is reported in Table 1, and regional differences are~~
13
14 438 ~~presented in Table 2.~~ The ANOVA reveal~~ed~~ ~~an significant~~ effect of peat type on organic
15
16 439 matter content ($F(9512) = 349, p < 0.0001$), with all peat types significantly different
17
18 440 from each other (Tukey's LSD: $p < 0.0001$). In decreasing order, mean organic matter
19
20 441 content of the peat types ~~is are~~ *Sphagnum* > Woody > Herbaceous > Brown Moss >
21
22 442 Humified (Table 1).
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26 444 Organic matter bulk density ~~or ash-free bulk density~~ (n = 18,544) range~~d~~ from 0.003 to
27
28 445 $0.452 \text{ g OM cm}^{-3}$, with a mean value of $0.105 \pm 0.051 \text{ g OM cm}^{-3}$ (1 S.D.). ~~The frequency~~
29
30 446 ~~distribution is presented in Figure 3c, the mean organic matter density for each peat type~~
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32 447 ~~is reported in Table 1, and regional differences are presented in Table 2.~~ The ANOVA
33
34 448 reveal~~ed~~ ~~an significant~~ effect of peat type on organic matter density ($F(9081) = 942, p <$
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36 449 0.0001), with all peat types significantly different from each other (Tukey's LSD: $p <$
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38 450 0.0001). In increasing order, mean organic matter density of the peat types is *Sphagnum*
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40 451 < Herbaceous < Woody < Brown Moss < Humified (Table 1).
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43 453 ~~Total peat carbon C~~ content in total peat (n = 3741) range~~d~~ from 30 to 60%, with a mean
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45 454 value of $46.8 \pm 6.1\%$ (1 S.D.) and a median of 47.8%. While the lowest values (< 35%)
46
47 455 are almost exclusively associated with samples from Alaska, western Canada,
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49 456 Fennoscandia, and eastern Russia, the highest values (> 55%) are characteristic of sites
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51 457 located in the western European Islands and Fennoscandia. Mean C% values for all five
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458 | ~~peat types are reported in Table 1, and regional differences are presented in Table 2.~~ The
459 | ANOVA revealed ~~an insignificant~~ effect of peat type on C% ($F(2,494) = 161, p <$
460 | 0.0001), with *Sphagnum* samples significantly different from other peat types (Tukey's
461 | LSD: $p < 0.0001$). Herbaceous and woody peats ~~were~~ distinct from other types, but
462 | ~~hardly indistinguishable~~ from one another (Tukey's LSD: $p = 0.238$). Likewise,
463 | humified and brown moss peats ~~were~~ distinct from other types, but indistinguishable
464 | from each other (Tukey's LSD: $p = 0.448$). In increasing order, mean C% of the peat
465 | types is *Sphagnum* < Humified = Brown Moss < Herbaceous = Woody (Table 1). The
466 | frequency distribution of C% ~~in peat is also~~ characterized by a second, though minor,
467 | mode at 40% (Figure 3d). The latter is mostly associated with *Sphagnum* peat samples, as
468 | their average ~~C content (C%)~~ is significantly lower than those for other peat types (Table
469 | 1). This difference is likely caused by the high content of complex and recalcitrant
470 | compounds found in *Sphagnum* tissues such as lipids and waxes, which have lower C%
471 | than more labile biopolymers such as cellulose ([Cagnon et al., 2009](#)).
472 |
473 | On the basis of 995 samples for which both OM%~~C~~ and C% were quantified, we
474 | ~~therefore~~ developed conversion factors ([slopes of linear regressions](#)) for several peat
475 | types, ~~providing ways~~ to estimate OC% ~~for investigators who do not perform C%~~
476 | ~~measurements routinely~~ (Figure 4). There ~~was~~ a noticeable difference between the slope
477 | of *Sphagnum* peat (0.423 ± 0.030 ; $n = 454$) and that of non-*Sphagnum* peat ($0.514 \pm$
478 | 0.024 ; $n = 308$). The ~~carbon C~~ content in organic matter (OC%) for *Sphagnum* peat ~~was~~
479 | smaller than expected ~~(at $42.3 \pm 3.0\%$ (e.g., Bauer et al., 2006; Beilman et al., 2009;~~
480 | ~~Table 3)).~~ As the majority of our *Sphagnum* samples for this specific analysis ~~were~~

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8 481 younger than 0.5 ka (304 out of 454 samples) and extracted from raised bogs, it is very
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10 482 likely that our estimated OC% biases towards young and undecomposed *Sphagnum*. This
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12 483 ‘young *Sphagnum* peat effect’ heavily influenced the slope of the overall relation
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14 484 between C% and OM% (0.467 ± 0.045) due to the overrepresentation of *Sphagnum*
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16 485 samples in the dataset (454 out of 995 samples). To minimize this bias when estimating
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18 486 mean OC% in peat, all 304 young *Sphagnum* samples were removed from the dataset,
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20 487 yielding an overall conversion factor of 0.492 ± 0.024 .

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24 489 ~~Total peat nitrogen-N~~ content in peat (n = 3365) ~~range~~ from 0.04 to 3.39%, with a mean
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26 490 value of $1.2 \pm 0.7\%$ (1 S.D.). ~~The~~ frequency distribution ~~is~~ asymmetric and
27
28 491 characterized by, ~~with~~ a mode at 0.65% (Figure 3e). The latter is largely due to the
29
30 492 overrepresentation of *Sphagnum* peat samples (having low N content) in our
31
32 493 samplesdatabase. The ANOVA revealed ~~an~~ ~~significant~~ effect of peat type on N content
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34 494 ($F(2504) = 666, p < 0.0001$) with *Sphagnum* and herbaceous peat types significantly
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36 495 different from each other and from all other types (Tukey’s LSD: $p < 0.0001$). Humified
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38 496 and brown moss peats ~~are~~ distinct from other types, but indistinguishable from each
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40 497 other (Tukey’s LSD: $p = 0.113$). Likewise, woody and brown moss peats ~~are~~
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42 498 indistinguishable from one another (Tukey’s LSD: $p = 0.240$). In increasing order, mean
43
44 499 ~~N content~~ N% of the peat types is *Sphagnum* < Woody = Brown Moss = Humified <
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46 500 Herbaceous (Table 1).

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49 502 C/N mass ratio (n = 3362) ~~range~~ from 12 to 217, with a mean value of 55 ± 33 (1 S.D.).
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51 503 The frequency distribution ~~is~~ asymmetric and characterized by, ~~with~~ a mode at 25
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8 504 | (Figure 3f). While the distribution mode (25) ~~is~~ associated with non-*Sphagnum* peat
9 | types, the distribution mean (55) is skewed towards *Sphagnum* peat samples owing to
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12 506 | their overrepresentation in our ~~samples database~~ (Figures 3f). The ANOVA revealed ~~an~~
13 | ~~significant~~ effect of peat type on C/N ratio ($F(2501) = 174, p < 0.0001$) with *Sphagnum*
14 507 |
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16 508 | peat significantly different from all other types (Tukey's LSD: $p < 0.0001$). Woody peat
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18 509 | ~~was~~ distinguishable from all peat types except for brown moss peat (Tukey's LSD: $p =$
19 |
20 510 | 0.665). Herbaceous and humified peat types ~~are~~ indistinguishable from one another
21 |
22 511 | (Tukey's LSD: $p = 0.721$). In decreasing order, the mean C/N ratio of peat types is
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24 512 | *Sphagnum* > Woody = Brown Moss > Humified = Herbaceous (Table 1).
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28 514 | *Temporal changes in peat properties*

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30 515 | The frequency distribution is presented in Figure 3a

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33 517 | We find a decreasing trend in bulk density over the Holocene (Figure 5a), with the
34 | densest peat characterizing the oldest samples (8-10 ka) and the least-dense peat
35 518 | characterizing the youngest samples (0-2 ka). This trend is most likely attributable to the
36 | progressive decomposition and subsequent compaction of peat over time, as well as to
37 519 | higher ash content in early-stage peat (likely from fens). Conversely, a clear increasing
38 | trend in organic matter content (OM%) is found over the Holocene (Figure 5b), with the
39 520 | greatest OM% characterizing the youngest samples (0-2 ka) and the least OM%
40 | characterizing the oldest samples (8-10 ka). This trend is most likely attributable to
41 521 | higher inorganic material inputs during early-stage peatland development as well as to a
42 | greater loss of OM in the deeper portions of peat profiles. ~~Organic matter bulk density~~
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9 527 (OMBD) remains relatively constant over the Holocene (Figure 5c) because of the
10 528 opposite trends exhibited by BD and OM% (Figures 5a, 5b). The only exceptions ~~except~~
11 ~~for~~are the low OMBD values characterizing the youngest samples (< 0.5 ka), probably
12 due to the large proportion of young, undecomposed *Sphagnum* peat samples.
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14 530
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18 533 While OMBD values closely tracked changes in bulk density during the mid and late
19 534 Holocene (0–8 ka), their trajectory diverged between 8 and 10 ka (Figure 4a and 4e)
20 because of decreasing organic matter content in early Holocene peat samples (Figure 4b).
21
22 535
23 536 C content in peat remains uniform over the Holocene (Figure 5d), except for slightly
24 537 lower C% during the late Holocene. However, as C values for early Holocene samples
25 538 are based on a very limited number of samples and peat records (white bars in Fig. 4d),
26 539 we caution against analysis or interpretation of the documented trend in our data. We also
27 540 find a decreasing trend in N% ~~content~~ over the Holocene, such that young peat deposits
28 541 are associated with low N% ~~content~~ (Figure 5e). This trend could be explained by a
29 542 progressive retention of N ~~downcore~~ as a result of long-term peat decomposition
30 543 processes and associated C loss (e.g., Kuhry and Vitt, 1996). Peat deposits older than 6 ka
31 544 are mostly associated with lower C/N ratios, whereas peat samples younger than 6 ka are
32 545 characterized by high C/N values (Figure 5f).
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34 546
35 547 In general, *Sphagnum* peat is characterized by lower BD, OMBD, C%, N%, and C/N
36 548 ratio than samples composed of non-*Sphagnum* peat (Figure 6). Therefore, peatland
37 549 development could explain much of the aforementioned temporal trends (Figure 5), as
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9 550 edense peat (herbaceous, brown moss, and humified types) typically characterarly-stage
10 551 rich fens are typically characterized by non-*Sphagnum* peat, whereas and late-stage poor
11 552 fens and bogs are *Sphagnum*-dominated (Figure 6h). -AlternativeThis effect may be
12 553 partly explained by peat type differences between young and old samples, with young
13 554 samples mostly composed of *Sphagnum* peat (having low N content) and old samples
14 555 composed of non-*Sphagnum* peat (having high N content). peat type differences between
15 556 young and old samples, with young samples mostly composed of *Sphagnum* peat (having
16 557 low N content) and old samples composed of non-*Sphagnum* peat (having high N
17 558 content). This 'peat type effect' may also be combined with

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562 *Spatial differences in peat properties*563 Significant differences in bulk density are found at the regional scale (Table 2). The564 densest peat is observed in Alaska (mean = $0.168 \pm 0.087 \text{ g cm}^{-3}$) and western Canada565 (mean = $0.166 \pm 0.076 \text{ g cm}^{-3}$), whereas the least dense peat is found from the western566 European Islands (mean = $0.055 \pm 0.027 \text{ g cm}^{-3}$). Organic matter bulk density values567 follow a similar pattern across these regions (Table 2). These differences are strongly568 correlated with peat types and sample ages, with the Alaskan and western Canadian569 samples largely constituted of herbaceous, humified, and brown moss peat types. These570 regional differences were strongly correlated with peat types and sample ages, with the571 United Kingdom samples mostly composed of young *Sphagnum* peat and the Alaskan572 samples largely constituted of old herbaceous, humified, and brown moss peat types.

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10 574 Significant differences in bulk density were found at the regional scale (Table 2 and
11 Figure 6a). The densest peat was found at permafrost sites (), whereas the least dense peat
12 575 was reported from non-permafrost peatlands (). There was also a marked difference
13 576 between Alaskan (mean = $0.168 \pm 0.087 \text{ g cm}^{-3}$) and western Canadian sites (mean =
14 577 $0.166 \pm 0.076 \text{ g cm}^{-3}$) versus the Western European Island sites (mean = $0.055 \pm 0.027 \text{ g}$
15 578 cm^{-3}). These regional differences were strongly correlated with peat types and sample
16 579 ages, with the United Kingdom samples mostly composed of young *Sphagnum* peat and
17 580 the Alaskan samples largely constituted of old herbaceous, humified, and brown moss
18 581 peat types.
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584 OM% does not vary much between regions (> 90% in all regions), with the notable
585 exception of Alaskan and eastern Russian/Asian peatlands that exhibit a mean values of
586 76.6 ± 18.8% and 80.3 ± 16.7%, respectively (Table 2). Aeolian dust and tephra ash
587 inputs to some peatlands in Alaska, Kamchatka, and Japan might partly explain such low
588 OM% values.
589

590 ***Peat inception ages and long-term rates of carbon and nitrogen accumulation***

591 Calibrated ages (mid-point) for peat inception ranged from 04.6 to 15 ka and the
592 frequency distribution followed a bimodal distribution with characterized by a modes at
593 11-9 ka and at 8-6 ka (Figure 2c). The early Holocene model latter corresponds with peat
594 inception peaks in the West Siberian Lowlands and, in Alaska, and Fennoscandia. The
595 mid-Holocene peak is linked with peatland inception across western Canada and the
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596 ~~Hudson Bay Lowlands. While the majority of sites older than 11 ka are found in Alaska~~
597 ~~and Siberia, most sites younger than 6 ka are located in northeastern Canada. Generally~~
598 ~~speaking~~In general, our samples are in agreement with much larger networks of peat
599 basal ages (Smith et al., 2004; MacDonald et al., 2006; Gorham et al., 2007; Korhola et
600 al., 2010; Ruppel et al., 2013; Yu et al., 2013), ~~except for our underrepresentation of~~
601 ~~peatlands with inception ages between 10 and 8 ka (Figure 2b). This discrepancy may be~~
602 ~~attributable to an underrepresentation of Siberian sites in our dataset (Smith et al., 2004).~~

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604 The time-weighted long-term rate of C accumulation averages ~~sd~~ 22.9 ± 2.0 g C m⁻² yr⁻¹
605 (standard error of mean (S.E.M.); Figure ~~7b6~~). Values exhibit an increasing trend that
606 initially peaks during the early Holocene between 10 and 7.5 ka at ~~25-28~~ 27.0 ± 2.6 g C
607 m⁻² yr⁻¹. This peak is largely caused by rapid peat accumulation in Alaska, the Western
608 Siberia Lowlands, and ~~s~~southeastern Canada. The remainder of the Holocene is
609 characterized by a decreasing trend in C accumulation rates from 24 to 18 g C m⁻² yr⁻¹
610 ~~and a time-weighted mean at~~ 22.0 ± 1.9 g C m⁻² yr⁻¹, ~~and millennial scale variations~~
611 (Figure ~~7b6~~). There is a notable minimum value between 3 and 1.5 ka at 18-19 g C m⁻²
612 yr⁻¹. Lack of decomposition probably explains most of the apparent increase in
613 accumulation over the past millennium (24-32 g C m⁻² yr⁻¹), as young peat appears to be
614 accumulating more quickly than old peat simply because the former has undergone less
615 decomposition than the latter (Clymo, 1984).

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617 The time-weighted long-term rate of N accumulation averages 0.5 ± 0.04 g N m⁻² yr⁻¹
618 (S.E.M.; Figure 7c). While the mid and late Holocene (6-0 ka) are characterized by the

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8 619 lowest rates of N accumulation at 0.34 g N m⁻² yr⁻¹, the highest rates (0.61 g N m⁻² yr⁻¹)
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10 620 occur between 12 and 6 ka (Figure 7c). This trend mirrors that of C accumulation (Figure
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12 621 7b), as C and N sequestration rates are both mainly influenced by peat density and its
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14 622 accumulation rate. The low rates of N accumulation over the past 6 ka might also relate
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16 623 to the increasing presence and persistence of *Sphagnum* (having high C/N ratio and low
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18 624 N concentration) in northern peatlands (Figures 6 and 7).

625

626 Discussion

627 ~~R~~Data representativeness of the database for northern peatlands

628 The present database contains the most comprehensive compilation of peat properties and
629 C accumulation records for northern peatlands. The previous large-scale synthesis (Yu et
630 al., 2009) only contained 33 sites and lacked records from the Hudson Bay lowlands and
631 the Russian Far East, and had limited sites from West Siberia and the western European
632 Islands. The present database fills gaps from these regions.

633

634 However, European Russia. The database comprises 268 peat cores from 215 sites
635 located between 45 and 69 °N, throughout the circum-Arctic peatland domain. These
636 sites were found across broad gradients of continentality, temperature, growing season
637 length, and precipitation (Yu et al., 2009). The majority of our study sites were found in
638 large peatland complexes such as the Hudson Bay Lowlands or in peatland-rich regions
639 such as the northwestern European Islands and Fennoscandia. Conversely, smaller
640 peatland systems such as kettle bogs and other isolated features were sparsely
641 represented. As the main objective of our dataset was to estimate the northern peatland C

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8 642 stock, the high proportion of sites from large peatland complexes seems justified. On
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10 643 another note, further studies of small depressional peatlands could potentially lead to a
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12 644 better understanding of peat C accumulation processes and peatland sensitivity to climate
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14 645 change (e.g., Buffam et al., 2010; Ireland et al., 2013). East Siberia, and the Russian Far
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16 646 East clearly remain poorly studied regions in terms of northern peat C stocks and
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18 647 accumulation histories (Figure 1). A wetland map by Stolbovoi and McCallum (2002)
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20 648 suggests that shallow peaty deposits (<50 cm) interspersed with few deeper peat bogs
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22 649 (>50 cm) dominate the Far East Russian landscape. Most of these deeper peatlands are
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24 650 presumably found in Kamchatka and Sakhalin (Stolbovoi, 2002). This broad portrait is,
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26 651 however, based on fewer than 30 soil profiles from across East Siberia and Far East
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28 652 Russia (Stolbovoi et al., 2001), making it difficult to evaluate the importance of this
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30 653 region in the northern peatland C cycle. In general, peat C stocks in Eastern Russia may
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32 654 not be as massive as those from West Siberia or European Russia (Stolbovoi and
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34 655 McCallum, 2002). Therefore, understanding how these shallow peatlands in East Siberia
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36 656 and the Russian Far East have developed during the Holocene would provide useful end-
37
38 657 members of climate controls of peat C accumulation, but these peatlands do not seem to
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40 658 represent a large missing C stock.

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43 660 *Northern peatland soil properties: key findings and uncertainties*

45 661 Peat-carbon stocks and density

47 662 Several studies have quantified the soil C density and total C pool of peatlands using
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49 663 different approaches (e.g., Armentano and Menges, 1986; Gorham, 1991; Yu et al.,
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51 664 2010). These ~~different~~ methods have led to total C pool estimates for northern peatlands

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9 665 that vary by at least a factor of two, from 234 to 547 GtC (Lappalainen, 1996; Yu et al.,
10 666 2010; see Yu, 2012 for a review). Many of these studies have combined mean peat depth,
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12 667 modern peatland area, and a single mean ~~peat-C bulk~~-density value (BD x C% or OMBD
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14 668 x OC%) in their calculations (e.g., Gorham, 1991). Applying Gorham's (1991) mean peat
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16 669 depth and peatland area estimates to the mean BD and C% results ~~presented in this from~~
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18 670 our database yields a ~~peat-C~~ pool estimate of 436 GtC (2.3 m x 3.42 Mkm² x 0.118 g cm⁻
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20 671 ³ x 47% C). However, it is well documented that most peatlands undergo a shift from
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22 672 herbaceous ~~fen~~-to *Sphagnum* ~~peatbog~~ during their developmental history (Hughes, 2000;
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24 673 Figure 6h) and that different BD, C%, and rates of peat accumulation are associated with
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26 674 fen and bog peats (e.g., Vitt et al., 2000; Figure 6). We also know that peat-C
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28 675 accumulation rates have varied asynchronously between regions throughout the Holocene
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30 676 as a result of regional changes in hydroclimatic conditions (e.g., Yu et al., 2009; Charman
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32 677 et al., 2013). Therefore, we argue that reconstructing Holocene changes in peat-C
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34 678 accumulation on the basis of *measured* peat C density ~~peat-C bulk density values~~ and
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36 679 reliable peat-core chronologies constitutes a step forward in providing the best possible
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38 680 peat-C stock estimates (see Yu et al., 2010~~09~~ for an example). It also allows for
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40 681 quantifying spatial and temporal differences in rates of peat-C accumulation, as well as
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42 682 the temporal trajectories of peat-C fluxes to the atmosphere (MacDonald et al., 2006; Yu
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44 683 et al., 2013). However, better maps of the present peatland area (and its change over
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46 684 time) are still needed to improve current peat C stock estimates. ~~Therefore, our database~~
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48 685 ~~should be of great use for updating current peat C stock estimates, as it contains the most~~
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50 686 ~~extensive set of peat-C bulk density measurements.~~

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8 688 Carbon content in organic matter

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10 689 For each peat layer, peat ~~_C~~carbon bulk density can be estimated by the product of either
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12 690 (1) bulk density and ~~total peat~~C-carbon content in total peat (BD x C%), or (2) ash-free
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14 691 bulk density and ~~carbon~~C content in organic matter (OMBD x OC%). ~~It is important to~~
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16 692 ~~mention that peat C stocks estimated using BD x C% or OMBD x OC% yield the same~~
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18 693 ~~value. Whenever BD and C% measurements were available along peat cores, we used the~~
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20 694 ~~former formula. However, when only OMBD was available, the second formula was~~
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22 695 ~~used.~~ It could be argued that the first option is preferable when estimating peat ~~_C~~C stocks,
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24 696 as it produces values that are directly comparable to routine soil ~~_C~~C measurements from
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26 697 other terrestrial ecosystems. However, the present database clearly indicates that the
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28 698 majority of peatland scientists routinely analyze organic matter content (OM%; n =
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30 699 18,973 samples) rather than C% (n = 3741 samples) along peat cores. To provide a way
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32 700 to estimate OC% from OM%, we developed the following conversion factors: $42.3 \pm$
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34 701 3.0% for *Sphagnum* peat, $51.4 \pm 2.4\%$ for non-*Sphagnum* peat, and $49.2 \pm 2.4\%$ overall
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36 702 (Figure 4, Table 1).

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39 704 While the overall peat and the non-*Sphagnum* peat conversion factors are in line with
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41 705 those from previous studies (e.g., Gorham, 1991; Vitt et al., 2000; Turunen et al., 2002;
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43 706 Beilman et al., 2009), the *Sphagnum* peat factor is lower than other estimates (e.g., Bauer
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45 707 et al., 2006; Beilman et al., 2009; Table 3). Indeed, our mean OC% *Sphagnum* value at
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47 708 42.3% is close to that of surface *Sphagnum* tissues, suggesting that it constitutes a valid
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49 709 estimate for ash-free and poorly decomposed *Sphagnum* peat. As previously mentioned,
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8 710 | this bias towards low OC% is due to a large number of *Sphagnum* samples younger than
9 711 | 0.5 ka (304 out of 454 *Sphagnum* samples).

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14 713 | Although each one of the three conversion factor slopes was significant ($p < 0.0001$),
16 714 | there is a noticeable scatter in the data (Figure 4) that cannot solely be explained by the ~
18 715 | 1% analytical error associated with the loss-on-ignition procedure (Heiri et al., 2001).
20 716 | The progressive accumulation of recalcitrant C in old samples (lignin ~ 60% C vs.
22 717 | cellulose ~ 42% C), assuming it occurs at a greater rate than the loss of OM in the deeper
24 718 | portions of peat profiles, could explain why C% appears higher than our OC% conversion
26 719 | factors (Cagnon et al., 2009). The presence of inorganic C, particularly for the humified
28 720 | and brown moss peat types, could also explain these results. While the overall peat and
30 721 | the non-*Sphagnum* peat conversion factors are in line with those from previous studies
32 722 | (e.g., Gorham, 1991; Vitt et al., 2000; Turunen et al., 2002; Beilman et al., 2009), the
34 723 | *Sphagnum* peat factor is lower than other estimates. Indeed, our mean OC% *Sphagnum*
36 724 | value at 42% is close to that of surface *Sphagnum* tissues, suggesting that it constitutes a
38 725 | valid estimate for ash-free and poorly decomposed *Sphagnum* peat. As previously
40 726 | mentioned, this bias toward low OC% is due to a large number of *Sphagnum* samples
42 727 | younger than 0.5 ka (304 samples out of 454).

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47 730 | Oligotrophication and the fen-to-bog transition in northern peatlands
49 731 | *Carbon content in organic matter*

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8 732 The relation between total peat carbon content (C%) and peat organic matter content
9 (OM%) is presented in Figure 4 (n = 995).
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13 735 Our averaged bulk density ($0.12 \pm 0.07 \text{ g cm}^{-3}$) and organic matter bulk density ($0.11 \pm$
14 $0.05 \text{ g OM cm}^{-3}$) values are within the range of most widely used estimates (e.g., Clymo,
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16 1984; Yu et al., 2010; Table 3).
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20 739 *Sphagnum* and non-*Sphagnum* peat types were characterized by very different peat
21 properties, with *Sphagnum* peat having lower BD, OMBD, C%, N%, and C/N ratio than
22 740 non-*Sphagnum* peat (Figure 6). These differences become important when estimating
23 741 Holocene peat C fluxes, as the proportion of *Sphagnum*-dominated peat records increases
24 742 during the late Holocene due to the fen-to-bog transition (Figure 6h). For example, much
25 743 stronger CH₄ emissions are associated with fens than bogs (e.g., Pelletier et al., 2007). In
26 744 terms of C sequestration rates, the systematically higher organic C density of non-
27 745 *Sphagnum* peat suggests that higher accumulation rates are possible in fens than in bogs
28 746 (Figure 6g), assuming optimal hydroclimatic conditions leading to rapid peat burial. In
29 747 addition, as non-*Sphagnum* samples contain twice the N mass of *Sphagnum* peat (Figure
30 748 6e), early-stage fens have the ability to stock more N than late-stage bogs. Overall,
31 749 further studies on the timing of the fen-to-bog transition across the northern peatland
32 750 domain are needed to better our understanding of its impact on C sequestration and CH₄
33 751 emissions.
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8 755 *Holocene pattern of ~~eireum-Aretic peatland~~ carbon accumulation in northern*
9 *peatlands*
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12 757 The overall trajectory and shape of our Holocene peat -C accumulation curve is similar to
13
14 758 the synthesis ~~from~~ a much smaller -dataset (n = 33; Yu et al., 2009). As such, an that
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16 759 shows an early Holocene peak during the Holocene Thermal Maximum (HTM) as well
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18 760 as and an overall slowdown of carbon-C accumulation during the mid- and late-Holocene,
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20 761 particularly after 4 ka during the Neoglacial period and associated permafrost
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22 762 development, were found in both syntheses (Vitt et al., 2000; Figure 76). However, the
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24 763 mean Holocene value of 22.9 ± 2.0 g C m⁻² yr⁻¹ (1 S.E.) presented here is approximately
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26 764 24% higher than the estimate in Yu et al.'s 2009 study (18.6 g C m⁻² yr⁻¹). Our larger
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28 765 dataset likely better represents the northern peatland -C accumulation rates ~~stock~~. These
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30 766 results imply that current peat -C stocks might be underestimated.
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32 767
33 768 While the peak value at 27 g C m⁻² yr⁻¹ is about 23% higher than the time-weighted mean
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35 769 peat-C accumulation rate for the remainder of the Holocene at 22 g C m⁻² yr⁻¹, we only
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37 770 found a 2% difference in organic C density values between young (0.053 ± 0.02 g C cm⁻³
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39 771) and old (0.057 ± 0.03 g C cm⁻³) peat samples. These results clearly show that the peak
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41 772 value during the early Holocene cannot be mainly attributed to presumably dense peat
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43 773 deposits that would be rich in recalcitrant C due to long-term decomposition and
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45 774 compaction. Instead, factors influencing the rate of peat burial such as peat type
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47 775 (*Sphagnum* vs. non-*Sphagnum* peat; Figure 6), growing season length, and other
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49 776 environmental variables, must have been responsible for such high rates of C
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51 777 sequestration during the early Holocene.
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10 779 The Holocene Thermal Maximum (HTM) is a well-documented period of orbitally-
11 induced warm climate in the northern high-latitude region (Kaufman et al., 2004;
12 780 Renssen et al., 2012; Marcott et al., 2013) that reaches its maximum around 11 ka
13 781 (Berger and Loutre, 1991; Figure 7a). The peak in warm climatic conditions shows a
14 782 transgressional pattern across northern North America that moved eastward with the
15 783 waning Laurentide Ice Sheet during the early and mid Holocene (Kaufman et al., 2004).
16 784 This progressive increase in land availability coupled with warming summer conditions
17 785 have been proposed as the main controls on peatland inception and rapid C accumulation
18 786 across northern North America (Harden et al., 1992; Gorham et al., 2007, 2012; Yu et al.,
19 787 2009; Jones and Yu, 2010). As such, the highest rates of C accumulation have been
20 788 recorded between 11 and 8.5 ka in Alaska, but only around 7 ka in western Canada
21 789 (Figure 6; Vitt et al., 2000; Yu et al., 2009; Jones and Yu, 2010). In general, our results
22 790 confirm this trend and support the hypothesis that warm summers could promote peat
23 791 formation and C sequestration (Beilman et al., 2009; Yu et al., 2009; Charman et al.,
24 792 2013), as the highest rates of C accumulation broadly coincide with the peak in summer
25 793 insolation from 11 to 7 ka (Figure 7). We acknowledge that water input was necessary to
26 794 allow for peatland development. Furthermore, the observed temporal asymmetry in
27 795 peatland inception age and peaks in C accumulation rates between Alaska, western
28 796 Canada, and the Hudson Bay Lowlands follows the transgressional pattern of the HTM.
29 797 For example, peat inception and highest peat C accumulation rates occur at 11-9 ka in
30 798 Alaska, whereas they are delayed in western Canada with peak values around 9-7 ka.
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8 800 These findings have important implications for projecting the fate of peat-C stocks in a
9 future warmer world.
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14 803 The Neoglacial period is characterized by generally cooler and wetter conditions than the
15 HTM (Figure 7a; Marcott et al., 2013). Particularly low C accumulation rates coincide
16 804 with this time period across the northern peatland domain (Figure 7; Vitt et al., 2000;
17 805 Jones and Yu, 2010). Peat accumulation processes might even have stopped in some
18 806 regions (e.g., Peteet et al., 1998). The onset of permafrost aggradation in many peatlands
19 807 also occurred during the Neoglacial period (Zoltai, 1971, 1995; Vitt et al., 2000; Oksanen
20 808 et al., 2003; Sannel and Kuhry, 2008), reducing the peat C-sink capacity. In addition to
21 809 shorter and cooler growing seasons, lower C accumulation rates in permafrost sites likely
22 810 relates to a slower peat burial due to (1) more intense peat decomposition in the acrotelm
23 811 due to drier surface conditions, and (2) a slower rate of peat formation and associated C
24 812 inputs to soil because many peat plateaus are not *Sphagnum*-dominated. Overall, our
25 813 results support the notion that climatic changes such as the HTM and the Neoglacial
26 814 cooling impact C sequestration rates in peatlands.
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817 ***Role of northern peatlands in the global nitrogen cycle***

818 As relatively few downcore peat N concentrations have been reported in the literature, it
819 was difficult to compare our mean value of 1.2% to previous estimates. ~~Percent N in new~~
820 ~~foliage of vascular species growing in subarctic peatlands average 1.8% (Schuur et al.,~~
821 ~~2007), similar to our mean value for non-*Sphagnum* peat types (1.5%).~~ Bragazza et al.
822 (2012) reported N content values of 0.7% for *Sphagnum fuscum* litter and 1.48% for

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8 823 | *Eriophorum vaginatum* (herbaceous) litter, ~~also~~ in line with our results (Table 1).
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10 824 | Similarly, Turunen et al. (2004) documented peat N concentrations ranging from 0.35 to
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12 825 | 2.25% (mean value of 0.8%) for the uppermost sections of 23 *Sphagnum* bogs across
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14 826 | northeastern Canada. Overall, these values closely match our findings for *Sphagnum*
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16 827 | (0.7%) and herbaceous (1.7%) peat types (Table 1).
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18 828 |
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20 829 | Using our peat C pool estimate of 436 Gt and assuming a mean C/N ratio of 45 yields a
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22 830 | peat-N pool of 9.7 Gt, roughly equivalent to 10% of the global soil N pool at 95 Gt (Post
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24 831 | et al., 1985). ~~This estimate is within the range proposed by Limpens et al. (2006) at 8-15~~
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26 832 | ~~GtN. We also calculated 500-year bin N accumulation rates for the past 10,000 years by~~
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28 833 | ~~combining our binned peat C accumulation rates with time-dependent C/N values.~~
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30 834 | ~~Results indicate a~~The Holocene time-weighted peat-N accumulation rate ~~of~~ 0.5 ± 0.04
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32 835 | ~~g N m⁻² yr⁻¹ (S.E.; Figure 76) is also in line with a previous estimate of 0.19-0.48 g N m⁻²~~
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34 836 | ~~yr⁻¹ (Limpens et al., 2006). While the mid and late Holocene (6-0-6 ka) were~~
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36 837 | characterized by the lowest rates of peat-N accumulation at $0.34 \text{ g N m}^{-2} \text{ yr}^{-1}$, the highest
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38 838 | rates ($0.61 \text{ g N m}^{-2} \text{ yr}^{-1}$) occurred between ~~126~~ and ~~642~~ ka (Figure ~~7c6~~). ~~This trend~~
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40 839 | ~~mirrors that of C accumulation (Figure 6), as C and N sequestration rates are both~~
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42 840 | ~~influenced by bulk density and peat accumulation rates.~~The low rates of N accumulation
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44 841 | over the past 6 ka might also relate to the increasing presence and persistence of
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46 842 | *Sphagnum* peat (having high C/N ratio and low N concentration) across the northern
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48 843 | peatlands ~~as a result of the fen to bog transition~~ (Figures 6 and 76). Overall, given the
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50 844 | ~~bias toward Sphagnum-dominated sites in our database, N pools and N accumulation~~
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52 845 | ~~rates are probably underestimated.~~

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10 847 Rapid N sequestration in peatlands during the early Holocene might have contributed to
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12 848 the global decline in reactive N availability for terrestrial ecosystems (McLaughlan et
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14 849 al., 2013), pointing to a potentially important and undocumented role of northern
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16 850 peatlands in the global N cycle. These results also raise the important question of N
17
18 851 provenance: in the absence of large rates of atmospheric N deposition during the early
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20 852 Holocene, the only process that could account for such a large N pool in peatlands is N
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22 853 fixation, either through symbiotic or asymbiotic processes (Limpens et al., 2006).
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26 855 The fate of these large peat-N stocks remains largely unknown under recent and
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28 856 projected warming. Indeed, the importance of peatlands as sources of nitrous oxide (N₂O)
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30 857 is just emerging (e.g., Repo et al., 2009; Marushchak et al., 2011; Palmer et al., 2012),
31
32 858 and studies have suggested that reduced surface moisture or increasing temperatures
33
34 859 might significantly promote the production, transformation, and transport of dissolved N,
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36 860 and N₂O emissions to the atmosphere through denitrification (e.g., Kane et al., 2010). On
37
38 861 the contrary, some authors have speculated that the potential increase in peatland-N₂O
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40 862 emissions from climate change may not be significant relative to the global N₂O budget
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42 863 (e.g., Martikainen et al., 1993; Frohking et al., 2011). Overall, additional peat N cycling
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44 864 studies are needed to address these remaining questions.
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47 **Conclusions and future directions**

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49 867 Peat core analysis has been extensively used over the past 20 years for estimating rates of
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51 868 peat-Carbon accumulation at local, regional, and continental scales (e.g., Mäkilä, 1997;
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8 869 | Clymo et al., 1998; Vitt et al., 2000; Turunen et al., 2002; [Mäkilä and Saarnisto, 2008](#);
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10 870 | Yu et al., 2010; van Bellen et al., 2011; Gorham et al., 2012). The present study analyzed
11
12 871 | a new database that comprises 268 peat records from 215 [northern peatland](#) sites ~~located~~
13
14 872 | ~~throughout the circum-Arctic peatlands~~. This systematic analysis of peat properties and
15
16 873 | Holocene C accumulation rates is essential for accurately addressing the following
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18 874 | general research topics in the future: (1) describing and quantifying spatial and temporal
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20 875 | patterns of Holocene peatland C and N accumulation; (2) assessing the sensitivity of C
21
22 876 | and N accumulation to climate ~~forcing~~[change](#); (3) estimating peatland ~~soil organic matter~~
23
24 877 | ~~(SOM)~~, soil organic carbon (SOC), and soil organic nitrogen (SON) pools at regional and
25
26 878 | hemispheric scales, (4) furthering our understanding of peatland ~~C cycle-carbon~~ --
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28 879 | climate linkages, and (5) providing the scientific community with a large dataset for
29
30 880 | developing and testing earth system and ecological models.

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33 **Acknowledgements**

34
35 883 | ~~The authors would like to~~[We](#) acknowledge the peatland research community for sharing
36
37 884 | their datasets. The U.S. NSF supported the synthesis work through grant ARC-1107981
38
39 885 | [to Lehigh University](#). The collection and analysis of unpublished records used in this
40
41 886 | synthesis were supported by the following funding agencies and research grants: Alaska
42
43 887 | (NSF ARC-1107981, AGS-0628455, and EAR-0819717; [USGS Climate Research and](#)
44
45 888 | [Development Program](#)), Canada (NSF ARC-1107981, EAR-0223271, EAR-0843685,
46
47 889 | and AGS-0628598; NSERC CRDPJ-305605, CRDPJ-365867; Hydro-Québec),
48
49 890 | Fennoscandia and Western Siberia ([NSF OPP-9818496](#); Academy of Finland 201321 and
50
51 891 | 1133515; University of Helsinki), [Kamchatka \(NSF ARC-1107981, ARC-1108116\)](#), and
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8 892 the United Kingdom (Yorkshire Peat Partnership). Lehigh University's Library and
9
10 893 Technology Services staff is acknowledged for its support in building the web interface
11
12 894 for the peatland database. [Finally, comments from Paul Glaser and two other journal](#)
13
14 895 [reviewers improved the overall quality of the manuscript.](#)
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45 1198
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- 47 1199 **Figure and Table Captions**
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- 49 1200 **Figure 1.** Location of study sites. Map showing the distribution of northern peatlands
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51 1201 (green area from Yu et al., 2010) and peatland sites included in this study (n = 215 sites,
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8 1202 including 268 peat cores). Long-term rate of peat-carbon accumulation was estimated
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10 1203 from 127 sites (151 peat cores; red and blue dots). The yellow dots represent cores for
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12 1204 which only peat properties (bulk density, organic matter content, etc.) were available and
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14 1205 synthesized. Refer to Supplementary Table 1 for details.
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18 1207 **Figure 2.** Overview of data availability for North America (black bars) and Eurasia
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20 1208 (white bars). (A) Number of cores (total = 238) containing information on
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22 1209 carbon/nitrogen ratio (n = 40), nitrogen content (n = 40), carbon content (n = 56), peat
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24 1210 types (n = 83), organic matter bulk density (n = 184), organic matter content (n = 190),
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26 1211 and bulk density (n = 214). (B) Number of cores (total = 151) with a temporal-dating
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28 1212 resolution-quality better than 500-yearstwo dates per 1000 years (n = 35), 500-1000one to
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30 1213 two dates per 1000 years (n = 52), and less than one date per > 1000 years (n = 64). (C)
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32 1214 Number of calibrated basal peat ages (median) in 500-year bins from the database (~~black~~
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34 1215 ~~bars~~, n = 199) compared to all northern hemisphere basal peat ages (median) in 200-year
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36 1216 bins (~~grey bars~~, n = 2559, MGK data from MacDonald et al., 2006, Gorham et al., 2007,
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38 1217 Korhola et al., 2010).
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41 1219 **Figure 3.** Distribution histograms of peat properties in northern peatlands. (A) Frequency
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43 1220 distribution of bulk density for unidentified peat type samples (white bars) and different
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45 1221 peat types (color bars). (B) Frequency distribution of organic matter content for different
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47 1222 peat types. (C) Frequency distribution of organic matter bulk density for different peat
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49 1223 types. (D) Frequency distribution of carbon content for different peat types. (E)
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8 1224 Frequency distribution of nitrogen content for different peat types. (F) Frequency
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10 1225 distribution of carbon/nitrogen mass ratio for different peat types.

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14 1227 **Figure 4.** Relation between carbon content and organic matter content in northern
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16 1228 peatlands. The slope of each regression line is used as a conversion factor for estimating
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18 1229 carbon content from organic matter content.

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22 1231 **Figure 5.** Temporal patterns of peat properties (mean, standard deviation, and number of
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24 1232 samples). (A) Bulk density. (B) Organic matter content. (C) Organic matter bulk density.
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26 1233 (D) Carbon content. (E) Nitrogen content. (F) Carbon/Nitrogen mass ratio. White bars
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28 1234 represent values that were based on a limited number of samples and peat records.

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32 1236 **Figure 6.** Main differences between *Sphagnum* and non-*Sphagnum* peat samples. (A)
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34 1237 Bulk density. (B) Organic matter bulk density. (C) Organic carbon bulk density. (D)
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36 1238 Carbon content. (E) Nitrogen content. (F) Carbon/Nitrogen mass ratio. (G) Temporal
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38 1239 pattern of organic C bulk density. (H) Proportional change in the number of peat records
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40 1240 that are *Sphagnum*-dominated, presented as a percentage of the total number of records.

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43 1242 **Figure 7.** Long-term apparent rate of carbon and nitrogen accumulation from northern
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45 1243 peatlands (n = 127 sites). (A) Summer insolation at 60°N (data from Berger and Loutre,
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47 1244 1991) and temperature anomaly from an 11,300-year reconstruction for the northern
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49 1245 extra-polar region from 30 to 90°N (data from Marcott et al., 2013). Temperature
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51 1246 anomaly was calculated based on the 1961-1990 temperature averages. (B) Mean peat-

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8 1247 carbon accumulation rates (PCAR) and standard error in 500-year bins. The number of
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10 1248 sites per 500-year bins is also presented. (C) Mean peat-nitrogen accumulation rates
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12 1249 (PNAR) and standard error in 500-year bins. These values were obtained using different
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14 1250 C/N values over time, as indicated by the line. ~~PCAR: peat carbon accumulation rate;~~
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16 1251 ~~PNAR: peat N accumulation rate.~~
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20 1253 **Table 1.** Peat properties in northern peatlands. Means and standard deviations are
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22 1254 presented, along with the number of samples (n).
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26 1256 **Table 2.** Northern peatland peat properties by regions. Means and standard deviations are
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28 1257 presented, along with the number of samples (n).
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31 1259 **Table 3.** Comparison of northern peatland peat properties estimates with other published
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33 1260 values. Means and standard deviations are presented, along with the number of samples
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35 1261 (n) when available.
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39 1263 **Supplementary Material**

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41 1264 **Table S1.** Summary information for the study sites included in the database.
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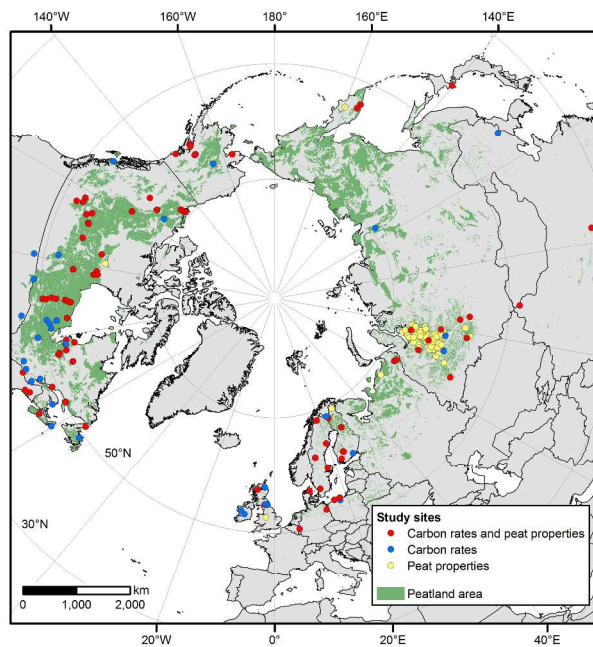


Figure 1. Location of study sites. Map showing the distribution of northern peatlands (green area from Yu et al., 2010) and peatland sites included in this study ($n = 215$ sites, including 268 peat cores). Long-term rate of peat-carbon accumulation was estimated from 127 sites (151 peat cores; red and blue dots). The yellow dots represent cores for which only peat properties (bulk density, organic matter content, etc.) were available and synthesized. Refer to Supplementary Table 1 for details.
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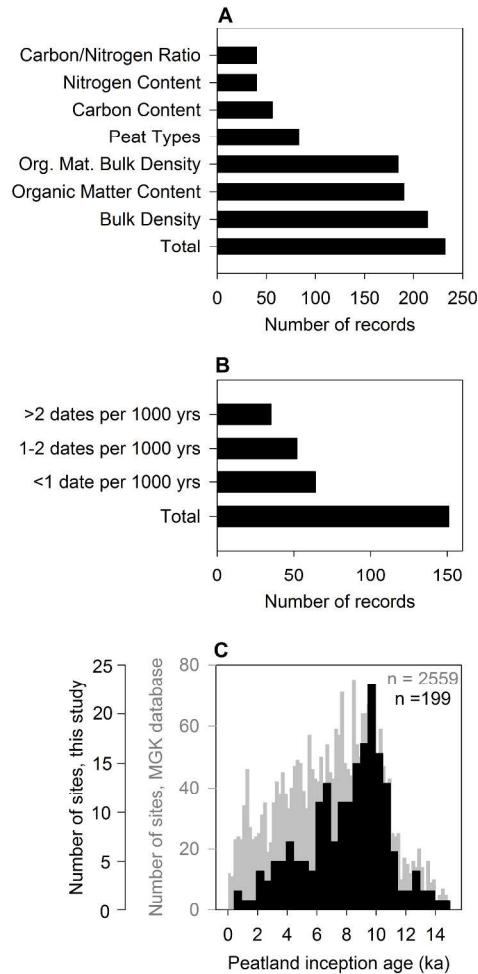


Figure 2. Overview of data availability for North America (black bars) and Eurasia (white bars). (A) Number of cores (total = 238) containing information on carbon/nitrogen ratio ($n = 40$), nitrogen content ($n = 40$), carbon content ($n = 56$), peat types ($n = 83$), organic matter bulk density ($n = 184$), organic matter content ($n = 190$), and bulk density ($n = 214$). (B) Number of cores (total = 151) with a dating quality better than two dates per 1000 years ($n = 35$), one to two dates per 1000 years ($n = 52$), and less than one date per 1000 years ($n = 64$). (C) Number of calibrated basal peat ages (median) in 500-year bins from the database ($n = 199$) compared to all northern hemisphere basal peat ages (median) in 200-year bins ($n = 2559$, MGK data from MacDonald et al., 2006, Gorham et al., 2007, Korhola et al., 2010).

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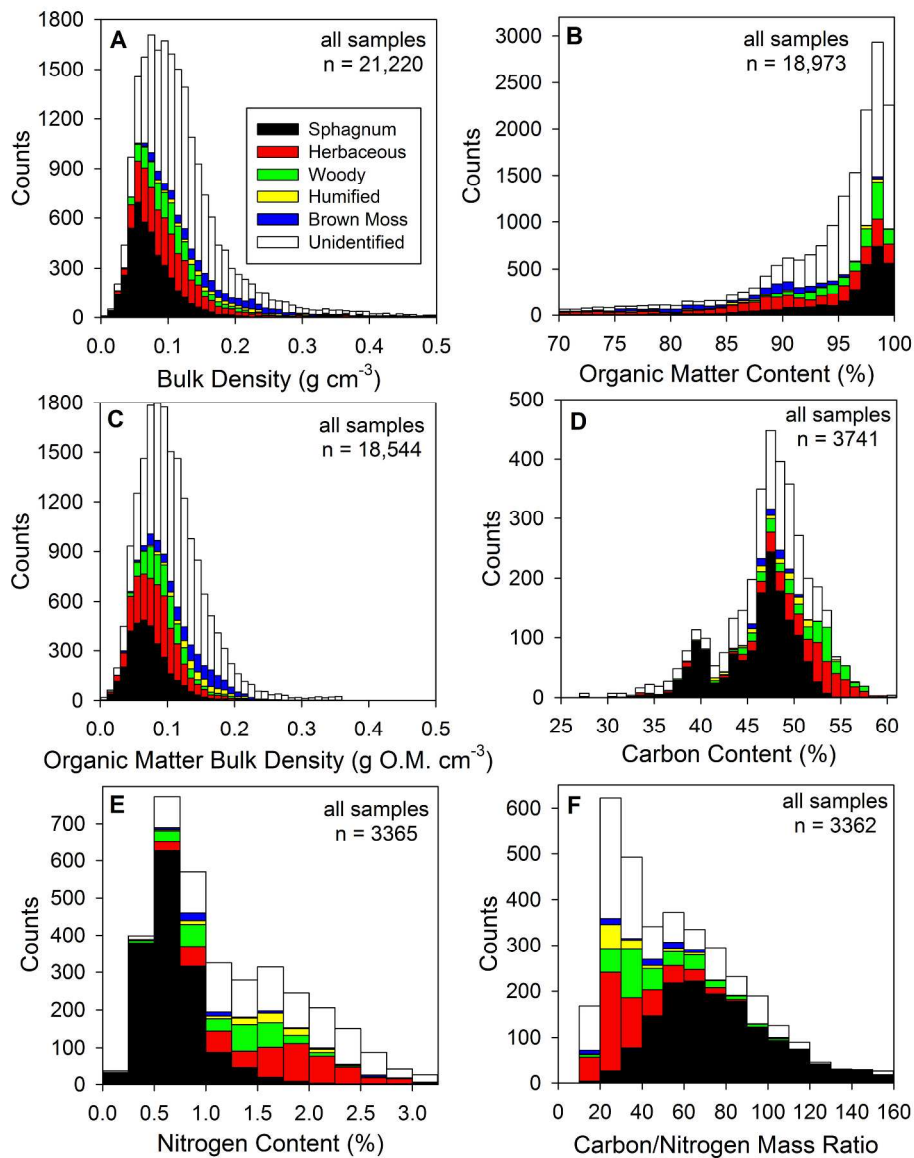


Figure 3. Distribution histograms of peat properties in northern peatlands. (A) Frequency distribution of bulk density for unidentified peat type samples (white bars) and different peat types (color bars). (B) Frequency distribution of organic matter content for different peat types. (C) Frequency distribution of organic matter bulk density for different peat types. (D) Frequency distribution of carbon content for different peat types. (E) Frequency distribution of nitrogen content for different peat types. (F) Frequency distribution of carbon/nitrogen mass ratio for different peat types.

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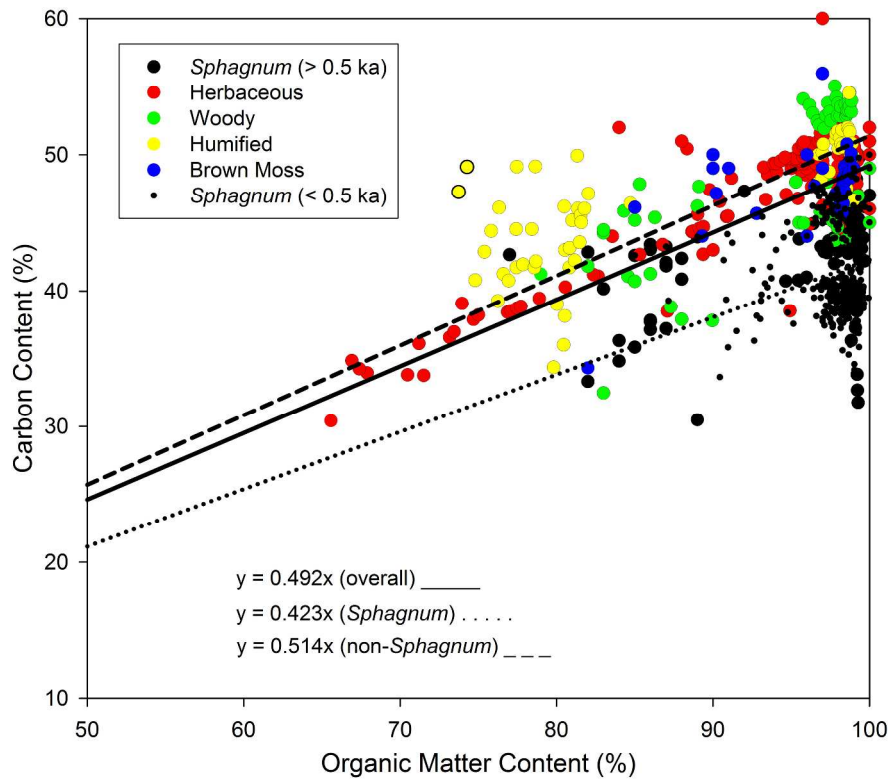


Figure 4. Relation between carbon content and organic matter content in northern peatlands. The slope of each regression line is used as a conversion factor for estimating carbon content from organic matter content.

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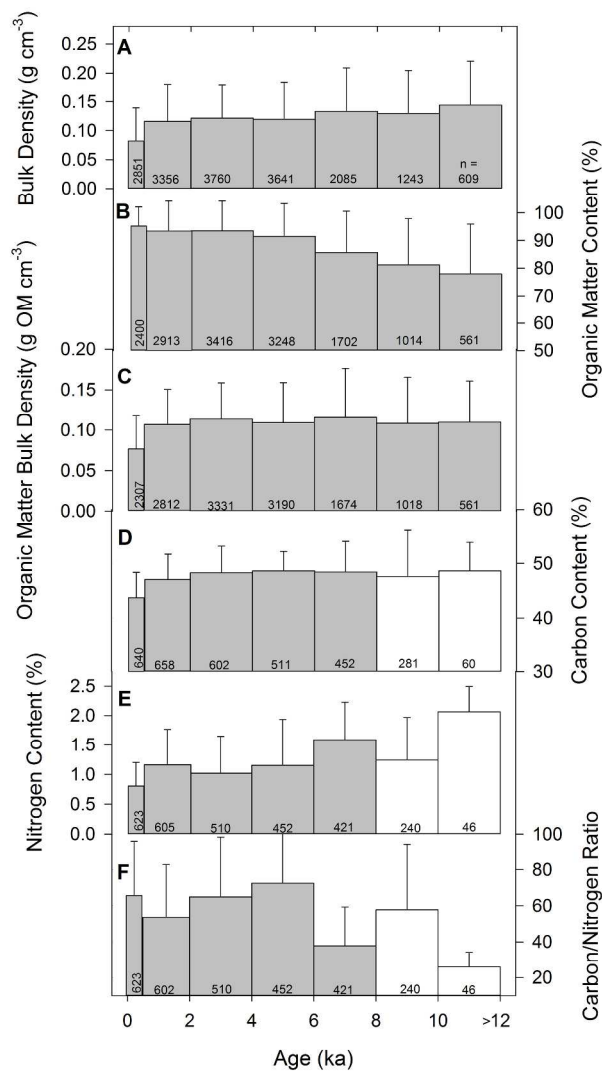


Figure 5. Temporal patterns of peat properties (mean, standard deviation, and number of samples). (A) Bulk density. (B) Organic matter content. (C) Organic matter bulk density. (D) Carbon content. (E) Nitrogen content. (F) Carbon/Nitrogen mass ratio. White bars represent values that were based on a limited number of samples and peat records.
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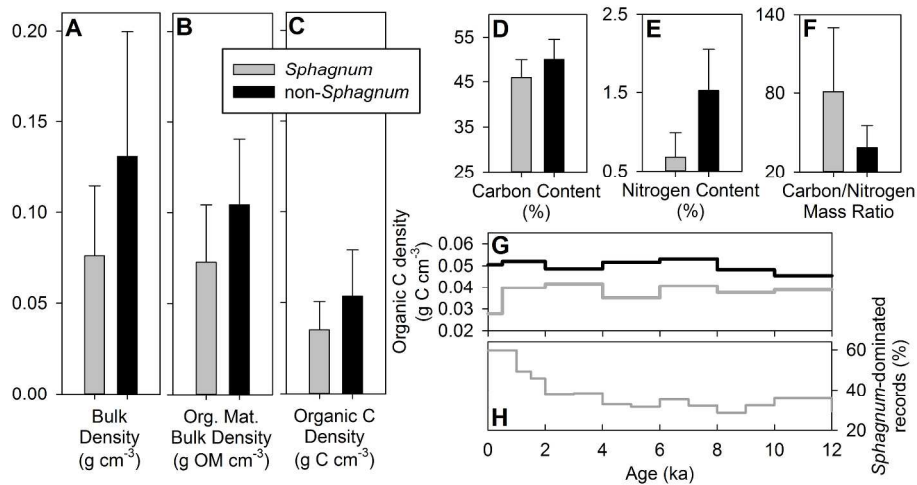


Figure 6. Main differences between Sphagnum and non-Sphagnum peat samples. (A) Bulk density. (B) Organic matter bulk density. (C) Organic carbon bulk density. (D) Carbon content. (E) Nitrogen content. (F) Carbon/Nitrogen mass ratio. (G) Temporal pattern of organic C bulk density. (H) Proportional change in the number of peat records that are Sphagnum-dominated, presented as a percentage of the total number of records.

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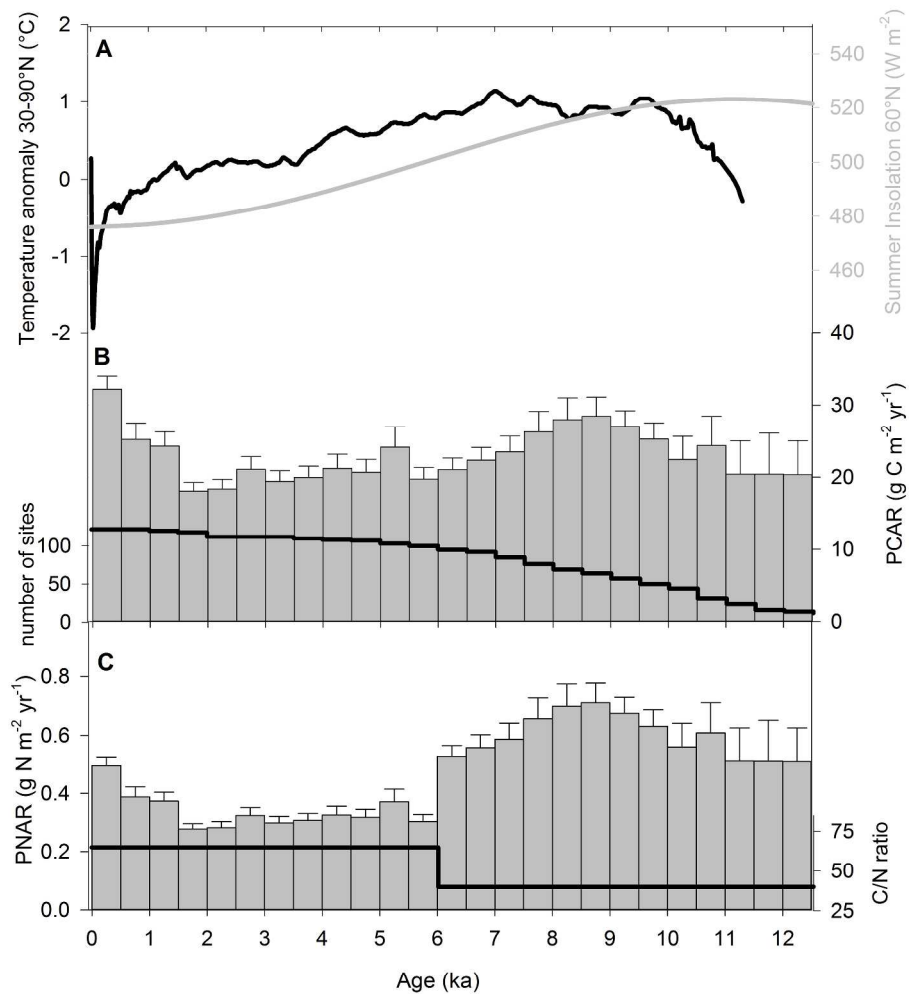


Figure 7. Long-term apparent rate of carbon and nitrogen accumulation from northern peatlands ($n = 127$ sites). (A) Summer insolation at 60°N (data from Berger and Loutre, 1991) and temperature anomaly from an 11,300-year reconstruction for the northern extra-polar region from 30 to 90°N (data from Marcott et al., 2013). Temperature anomaly was calculated based on the 1961-1990 temperature averages. (B) Mean peat-carbon accumulation rates (PCAR) and standard error in 500-year bins. The number of sites per 500-year bins is also presented. (C) Mean peat-nitrogen accumulation rates (PNAR) and standard error in 500-year bins. These values were obtained using different C/N values over time, as indicated by the line.

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Table 1. Peat properties in northern peatlands. Means and standard deviations are presented, along with the number of samples (*n*).

	<i>Sphagnum</i>	Herbaceous	Woody	Humified	Brown Moss	Overall***
Bulk density (g cm⁻³)	0.076 ± 0.038 (<i>n</i> = 4372)	0.118 ± 0.075 (3188)	0.108 ± 0.047 (1584)	0.192 ± 0.082 (452)	0.177 ± 0.076 (1114)	0.118 ± 0.069 (21,220)
Organic matter content (%)	94.3 ± 9.3 (3297)	85.6 ± 15.4 (3121)	92.0 ± 13.5 (1587)	78.4 ± 17.8 (418)	81.4 ± 15.5 (1090)	90.7 ± 13.0 (18,973)
Organic matter bulk density (g OM cm⁻³)	0.073 ± 0.031 (3332)	0.089 ± 0.036 (2854)	0.098 ± 0.032 (1388)	0.144 ± 0.036 (418)	0.136 ± 0.043 (1090)	0.105 ± 0.051 (18,544)
Carbon content in total peat (%)	46.0 ± 4.1 (1520)	50.5 ± 4.9 (519)	50.9 ± 4.0 (308)	47.4 ± 4.1 (96)	47.9 ± 2.8 (72)	46.8 ± 6.1 (3741)
Carbon content in organic matter (%)	42.3 ± 3.0* (454)	51.1 ± 1.7* (147)	51.4 ± 3.4* (59)	53.2 ± 2.6* (58)	50.0 ± 2.0* (44)	49.2 ± 2.4** (458)
Nitrogen content in peat (%)	0.7 ± 0.3 (1523)	1.7 ± 0.6 (518)	1.3 ± 0.5 (308)	1.5 ± 0.4 (96)	1.4 ± 0.7 (60)	1.2 ± 0.7 (3365)
Carbon/Nitrogen mass ratio	81.0 ± 49.2 (1520)	34.4 ± 15.0 (518)	45.3 ± 19.1 (308)	36.0 ± 17.6 (96)	42.9 ± 18.8 (60)	55 ± 33 (3362)

*Obtained from regression between carbon content and organic matter content (see the Database and analysis section).

**Includes all herbaceous, woody, humified and brown moss samples, as well as *Sphagnum* samples older than 0.5 ka (see Results section).

***Includes samples for which peat type was not ascribed.

Table 2. **Northern peatland peat properties by regions.** Means and standard deviations are presented, along with the number of samples in parentheses (n).

	Alaska	Western Canada	Hudson & James Bays	Eastern Canada/USA	Western European Islands	Continental Europe	Fennoscandia	Western Russia	Eastern Russia & Asia
Bulk density (g cm⁻³)	0.168 ± 0.087 (n = 1659)	0.166 ± 0.076 (3635)	0.097 ± 0.038 (6002)	0.100 ± 0.039 (2834)	0.055 ± 0.027 (656)	0.120 ± 0.139 (410)	0.075 ± 0.043 (562)	0.118 ± 0.070 (2701)	0.116 ± 0.063 (2761)
Organic matter content (%)	76.6 ± 18.8 (1659)	91.6 ± 8.1 (3442)	94.8 ± 8.2 (5129)	97.8 ± 6.5 (1835)	97.5 ± 1.8 (227)	97.4 ± 5.43 (305)	95.6 ± 8.7 (789)	94.6 ± 10.3 (2666)	80.3 ± 16.7 (2700)
Organic matter bulk density (g OM cm⁻³)	0.119 ± 0.049 (1659)	0.151 ± 0.062 (3441)	0.088 ± 0.029 (5129)	0.107 ± 0.028 (1750)	0.055 ± 0.035 (227)	0.056 ± 0.028 (222)	0.073 ± 0.034 (422)	0.106 ± 0.058 (2773)	0.088 ± 0.034 (2700)
Carbon content in total peat (%)	42.4 ± 3.7 (64)	45.0 ± 4.3 (382)	47.9 ± 4.5 (1026)	48.9 ± 3.7 (1084)	54.0 ± 2.5 (242)	38.9 ± 1.3 (60)	44.4 ± 5.7 (580)	49.2 ± 3.2 (74)	36.0 ± 9.2 (229)
Nitrogen content in peat (%)	1.3 ± 0.6 (64)	1.1 ± 0.8 (265)	1.6 ± 0.7 (910)	0.9 ± 0.5 (1084)	1.6 ± 0.4 (242)	0.7 ± 0.1 (60)	1.0 ± 0.5 (565)	1.6 ± 0.9 (44)	1.4 ± 0.6 (131)
Carbon/Nitrogen mass ratio	43.9 ± 32.8 (64)	62.4 ± 37.5 (265)	39.5 ± 23.7 (910)	77.2 ± 56.1 (1084)	35.7 ± 10.8 (242)	54.2 ± 7.6 (60)	57.9 ± 31.4 (562)	40.8 ± 21.7 (44)	34.2 ± 21.9 (131)

Table 3. Northern peatland peat properties estimates from published studies. Means and standard deviations are presented, along with the number of samples in parentheses (*n*) when available.

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Bulk density (g cm ⁻³)	Organic matter content (%)	Organic matter bulk density (g OM cm ⁻³)	Carbon content in organic matter (%)	Carbon/Nitrogen mass ratio	Region	Reference
-	-	0.094 open fens & bogs 0.105 wooded & shrubby fens	51.8 ± 4.7 (<i>n</i> = 253)	-	Western Canada	Vitt et al., 2000
0.073 ± 0.029 <i>Sphagnum</i> 0.091 ± 0.025 brown moss 0.110 ± 0.037 sedge-moss 0.211 ± 0.061 humified 0.138 ± 0.036 wood	95.5 ± 2.6 <i>Sphagnum</i> 90.3 ± 6.6 brown moss 91.4 ± 4.4 sedge-moss 73.6 ± 13.0 humified 87.8 ± 6.3 wood	0.069 ± 0.028 <i>Sphagnum</i> 0.082 ± 0.023 brown moss 0.100 ± 0.032 sedge-moss 0.149 ± 0.023 humified 0.120 ± 0.029 wood	50.7 ± 5.0 <i>Sphagnum</i> 51.9 ± 3.4 brown moss 53.4 ± 2.9 sedge-moss 54.0 ± 3.8 humified 52.1 ± 3.5 wood	-	Western Canada	Bauer et al., 2006
-	-	0.0784 bogs	52.8 (<i>n</i> = 276)	-	Eastern Canada and USA	Gorham, 1990
-	-	0.112	51.7	-	Eastern Canada and USA	Gorham, 1991
0.128 ± 0.065	96.26 ± 3.16	0.123*	52	-	West Siberia Lowlands	Sheng et al., 2004
-	-	-	51 ± 5 <i>Sphagnum</i> ** 55 ± 3 non- <i>Sphagnum</i> ** 52 ± 3 overall**	-	West Siberia Lowlands	Beilman et al., 2009
-	-	0.074 bogs 0.081 fens	50	-	Finland	Turunen et al., 2002
0.118 ± 0.069 (<i>n</i> = 21,220)	90.7 ± 13.0 (<i>n</i> = 18,973)	0.105 ± 0.051 (<i>n</i> = 18,544)	49.2 ± 2.4 (<i>n</i> = 458)	55 ± 33 (<i>n</i> = 3362)	circum-Arctic	This study

*This value was obtained by multiplying bulk density (0.128 g cm⁻³) by organic matter content (96.26%).

**Standard errors

Supplementary Material: Table S1. Summary information for the study sites included in the circum-Arctic peatland database.

Abbreviated reference*	Core name and ID	Peatland type	Country	Latitude	Longitude	Number of ¹⁴ C dates	Oldest age (cal BP)	Basal age (cal BP)	Other dates	Carbon date site	Peat properties site
<u>NORTH AMERICA</u>											
Beaulieu-Audy, 2009	La Grande 3	Bog	Canada	53.57	-76.13	7	6816	Y	N	Y ³	Y
Beaulieu-Audy, 2009	La Grande 2	Bog	Canada	53.65	-77.73	6	6543	Y	N	Y ³	Y
Beaulieu-Audy, 2009	La Grande 1	Intermediate fen	Canada	53.9	-78.77	8	1612	Y	N	Y ³	Y
Belyea, 1996	Rainy River Bog	Bog	Canada	48.78	-94.55	9	5310	N	N	Y ⁵	N
Bender, 1969	Porcupine	Bog	Canada	52.52	-101.25	7	7624	Y	N	Y ⁵	N
Bender, 1969	Colville Lake	Bog	Canada	67.1	-125.78	7	7650	Y	N	Y ⁵	N
Booth, 2004	South Rhody	Kettle bog	USA	46.55	-86.07	9	10,562	Y	N	Y ⁵	N
Bunbury, 2012	VC04-06	Shrub bog	Canada	52.71	-84.18	6	6599	Y	N	Y ²	Y
Camill, 2009	Joey Lake 5	Permafrost bog	Canada	55.46	-98.16	8	8100	Y ¹	N	Y ²	Y
Camill, 2009	Joey Lake 7	Permafrost bog	Canada	55.46	-98.16	10	8256	Y	N	Y ²	Y
Camill, 2009	Joey Lake 2	Permafrost bog	Canada	55.47	-98.16	11	7980	Y ¹	N	Y ²	Y
Camill, 2009	Joey Lake 12	Permafrost bog	Canada	55.47	-98.15	8	6564	Y ¹	N	Y ²	Y
Camill, 2009	Joey Lake 15	Permafrost bog	Canada	55.47	-98.15	10	7882	Y ¹	N	Y ²	Y
Camill, 2009	Joey Lake 17	Permafrost bog	Canada	55.47	-98.16	7	7632	Y ¹	N	Y ²	Y
P. Camill, unpubl	Lake 785 core 4	Permafrost bog	Canada	59.11	-97.4	9	6833	Y	N	Y ²	Y
P. Camill, unpubl	Unit Lake core 4	Permafrost bog	Canada	59.42	-97.48	9	7053	Y	N	Y ²	Y
P. Camill, unpubl	Lake 396 core 3	Permafrost bog	Canada	59.58	-98.57	6	6077	Y	N	Y ²	Y
P. Camill, unpubl	Shuttle Lake core 2	Permafrost bog	Canada	59.86	-97.64	6	6242	Y	N	Y ²	Y
Charman, 1995	Wally Creek Area	Bog	Canada	49.07	-80.6	10	6672	Y	N	Y ⁵	N
P. Charman, unpubl	Burnt Village	Raised bog	Canada	51.13	-55.93	26	8526	Y	N	Y ²	Y
P. Charman, unpubl	Petite Bog	Raised bog	Canada	45.14	-63.94	32	13,474	Y	N	Y ²	Y
P. Charman, unpubl	Sidney Bog	Raised bog	USA	44.39	-69.79	31	9311	Y	N	Y ²	Y
Elliott, 2011	Mer Bleue	Bog	Canada	45.68	-75.8	11	8463	Y	N	Y ⁵	N

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	Abbreviated reference ^a	Site name	Peatland type	Country	Latitude	Longitude	¹⁴ C dates (number)	Oldest age (cal BP)	Basal age (cal BP)	Other dates	Carbon rate site	Peat properties site
8	M. Garneau, unpubl	Ours 1	Fen	Canada	54.05	-72.45	6	5491	N	N	Y ³	Y
9	M. Garneau, unpubl	Ours 3	Fen	Canada	54.05	-72.46	5	3899	N	N	Y ³	Y
10	M. Garneau, unpubl	Ours 4	Fen	Canada	54.05	-72.46	6	4774	N	N	Y ³	Y
11	M. Garneau, unpubl	Aero 1	Fen	Canada	54.1	-72.52	6	5485	N	N	Y ³	Y
12	M. Garneau, unpubl	Aero 5	Fen	Canada	54.1	-72.52	6	4252	N	N	Y ³	Y
14	Glaser, 2004	Oldman Bog	Bog	Canada	51.02	-84.57	13	6728	Y	N	Y ⁵	N
15	Glaser, 2004	Albany River Bog	Bog	Canada	51.43	-83.62	6	5492	Y	N	Y ⁵	N
17	Glaser, 2004	Belec Lake Bog	Bog	Canada	51.62	-82.28	7	4480	Y	N	Y ⁵	N
18	Gorham, 2003 ^a	Miscou	Bog	Canada	47.93	-64.5	7	9000	Y	N	Y ⁶	N
19	Gorham, 2003 ^a	Fourchou	Bog	Canada	45.93	-60.27	8	11,200	Y	N	Y ⁶	N
20	Gorham, 2003	Denbigh	Fen	USA	48.22	-100.5	8	12,500	Y	N	Y ⁶	N
22	Holmquist, unpubl	JBL8	Sphagnum bog	Canada	50.47	-89.93	11	4481	Y	N	Y ³	Y
23	Holmquist, unpubl	JBL1	Sphagnum bog	Canada	51.07	-89.8	11	6034	Y	N	Y ³	Y
24	Holmquist, unpubl	JBL2	Sphagnum bog	Canada	52.02	-90.13	13	6742	Y	N	Y ³	Y
25	Holmquist, unpubl	JBL3	Sphagnum bog	Canada	52.87	-89.93	10	7708	Y	N	Y ³	Y
27	Holmquist, unpubl	JBL7	Sphagnum bog	Canada	54.4	-89.52	12	7607	Y	N	Y ³	Y
28	Holmquist, unpubl	JBL6	Permafrost bog	Canada	54.77	-89.32	8	3248	Y	N	Y ³	Y
29	Holmquist, unpubl	JBL4	Sphagnum bog	Canada	55.27	-88.93	11	6051	Y	N	Y ³	Y
30	Holmquist, unpubl	JBL5	Peat plateau	Canada	55.42	-88.95	12	5826	Y	N	Y ³	Y
32	Hu, 1994	Caribou Bog RC-2	Bog	USA	45	-69	6	9707	Y	pollen (1)	Y ⁵	Y
33	Hughes, 2006	Nordan's Pond Bog	Bog	Canada	53.6	-49.17	10	8827	N	N	Y ⁵	N
34	Hunt, 2013	Nuikluk 10-1	Peat plateau	USA (Alaska)	64.83	-163.45	5	6392	Y ¹	N	Y ³	Y
35	Hunt, 2013	Nuikluk 10-2	Collapse Scar	USA (Alaska)	64.83	-163.45	9	13,545	Y	N	Y ³	Y
37	Jones, 2010 ^a	Horse Trail Fen	Poor fen	USA (Alaska)	60.42	-150.9	11	12,695	Y	N	Y ³	Y
38	Jones, 2010 ^a	Kenai Gasfield 07-2	Poor Fen	USA (Alaska)	60.45	-151.25	17	11,448	Y	N	Y ³	Y
39	Jones, 2010 ^a	No Name Creek 07-1	Poor Fen	USA (Alaska)	60.63	-151.08	10	10,993	Y	N	Y ³	Y

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	Abbreviated reference ^a	Site name	Peatland type	Country	Latitude	Longitude	¹⁴ C dates (number)	Oldest age (cal BP)	Basal age (cal BP)	Other dates	Carbon rate site	Peat properties site
8	Jones, 2010 ^a	Swanson Fen	Poor fen	USA (Alaska)	60.79	-150.83	10	14,065	Y	N	Y ³	Y
9	Klein, 2013	Kahiltna Valley Mor.	Bog	USA (Alaska)	62.37	-151.09	5	1949	N	N	Y ³	Y
10	E. Klein, unpubl	HERC 09-3	Bog	USA (Alaska)	62.37	-151.07	8	11,768	Y	N	Y ³	Y
11	Kuhry, 1996 ^a	Slave Lake Bog	Bog	Canada	55.01	-114.09	6	10,516	Y	N	Y ²	Y
12	Lamarre, 2012	KUJU-PD2	Permafrost bog	Canada	55.23	-77.7	8	5084	Y	N	Y ³	Y
14	Lavoie, 2000	Lac Malbaie MAL-2	Bog	Canada	47.6	-70.97	5	10,654	Y	N	Y ⁵	N
15	Lavoie, 2000	Frontenac FRON-2	Bog	Canada	45.97	-71.13	7	12,851	Y	N	Y ⁵	N
17	Lavoie, 2013	Covey Hill	Bog	Canada	45.00	-73.49	12	12,720	Y	N	Y ³	Y
18	Loisel, 2010	Lac Le Caron RiP2	Bog	Canada	52.28	-75.83	6	2731	N	N	Y ²	Y
19	Loisel, 2013	Petersville 08-S	Bog	USA (Alaska)	62.42	-150.68	6	2825	N	tephra (1)	Y ²	Y
20	J. Loisel, unpubl	Petersville 09-MC	Bog	USA (Alaska)	62.42	-150.68	12	13,881	Y	tephra (4)	Y ³	Y
21	MacDonald, 1983	Natla River Bog	Bog	Canada	63.02	-128.8	6	9747	Y	tephra (1)	Y ⁵	Y
23	Magnan, 2012	Radisson	Semi-forested bog	Canada	53.73	-77.7	6	6154	Y	N	Y ⁵	N
24	G. Magnan, unpubl	Lebel	Raised bog	Canada	49.1	-68.25	12	5831	Y	N	Y ³	Y
25	G. Magnan, unpubl	Baie	Raised bog	Canada	49.1	-68.22	9	4221	Y	N	Y ³	Y
26	G. Magnan, unpubl	Morts	Peat plateau	Canada	50.26	-63.67	10	3246	Y	N	Y ³	Y
27	G. Magnan, unpubl	Plaine	Peat plateau	Canada	50.27	-63.54	12	7451	Y	N	Y ³	Y
28	G. Magnan, unpubl											
29	Muller, 2003 ^a	Mirabel bog (7 cores)	Bog	Canada	45.68	-74.03	2 to 7	10,000	Y	N	Y ⁶	N
30	J. Nichols, unpubl	Bear Bog	Bog	USA (Alaska)	60.53	-145.45	13	10357	Y	N	Y ³	Y
31	O'Donnell, 2012	Koyukuk Flats PP2	Peat plateau	USA (Alaska)	65.19	-155.36	7	12,329	Y	N	Y ⁵	N
32	O'Reilly, 2011	Victor Fen	Fen	Canada	52.71	-84.17	6	6405	Y	N	Y ⁵	N
33	H. Paakalen, unpubl	HL-02	Patterned bog	Canada	54.61	-84.61	5	4494	Y	N	Y ²	Y
34	Robinson, 2006 ^a	Martin River	Bog	Canada	61.8	-121.4	6	7552	Y	N	Y ⁴	Y
35	Sannel, 2009 ^a	Selwyn Lake 1	Peat plateau	Canada	59.88	-104.2	14	6573	Y	N	Y ²	Y
36	C. Tarnocai, 2010	T5	Polygon bog	Canada	68.57	-133.50	6	8805	Y	N	Y ²	Y
37	C. Tarnocai, 2010	IN-BG-1	Polyg. peat plateau	Canada	68.32	-133.42	9	9121	Y	N	Y ²	Y

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	Abbreviated reference ^a	Site name	Peatland type	Country	Latitude	Longitude	¹⁴ C dates (number)	Oldest age (cal BP)	Basal age (cal BP)	Other dates	Carbon rate site	Peat properties site
8	C. Tarnocai, 2010	IN-BG-3	Polyg. peat plateau	Canada	68.32	-133.43	6	6293	Y	N	Y ²	Y
9	C. Tarnocai, 2010	NW-BG-8	Polyg. peat plateau	Canada	65.21	-127.01	5	10,818	Y	N	Y ²	Y
10	C. Tarnocai, 2010	NW-BG-10	Polyg. peat plateau	Canada	65.21	-127.00	5	10,480	Y	N	Y ²	Y
11	C. Tarnocai, unpubl	T1	Polygon bog	Canada	68.32	-133.42	7	8623	Y	N	Y ²	Y
12	C. Tarnocai, unpubl	T6	Polygon bog	Canada	69.12	-134.18	5	3014	Y	N	Y ²	Y
13	C. Tarnocai, unpubl	IN-BG-2B	Polyg. peat plateau	Canada	68.32	-133.43	6	5828	Y	N	Y ²	Y
14	C. Tarnocai, unpubl	NW-BG-2	Polyg. peat plateau	Canada	65.21	-127.01	5	10,932	Y	N	Y ²	Y
15	C. Tarnocai, unpubl	NW-BG-3	Polyg. peat plateau	Canada	65.21	-127.01	6	11,010	Y	N	Y ²	Y
16	C. Tarnocai, unpubl	NW-BG-3	Polyg. peat plateau	Canada	65.21	-127.01	6	11,010	Y	N	Y ²	Y
17	Turunen, 2003 ^a	Diana Lake bog	Slope bog	Canada	54.15	-130.25	5	8500	Y	N	Y ⁶	N
18	van Bellen, 2011	Mosaik	Bog	Canada	51.98	-75.4	10	7120	Y	N	Y ³	Y
19	van Bellen, 2011	Sterne	Bog	Canada	52.05	-75.17	11	7134	Y	N	Y ³	Y
20	van Bellen, 2011	Lac Le Caron	Bog	Canada	52.28	-75.83	12	7510	Y	N	Y ³	Y
21	van Bellen, 2011	Lac Le Caron	Bog	Canada	52.28	-75.83	12	7510	Y	N	Y ³	Y
22	Yu, 2003 ^a	Upper Pinto Fen	Rich fen	Canada	53.58	-118.02	20	7599	Y	N	Y ³	Y
23	Yu, 2006 ^a	Goldeye Lake Fen	Rich fen	Canada	52.45	-116.2	6	9207	Y	tephra (2)	Y ³	Y
24	Z. Yu, unpubl	Sundance Fen 03-2	Rich fen	Canada	53.58	-116.75	5	6719	Y ¹	N	Y ³	Y
25	Z. Yu, unpubl	Sundance Fen 03-3	Rich fen	Canada	53.58	-116.75	13	10,973	Y	N	Y ³	Y
26	Z. Yu, unpubl	Utikuma	Poor Fen	Canada	55.84	-115.09	18	5079	Y	N	Y ³	Y
27	Z. Yu, unpubl	Mariana Lake 03-1	Poor Fen	Canada	55.9	-112.09	14	7222	Y	N	Y ³	Y
28	Z. Yu, unpubl	Mariana Lake 03-2	Poor Fen	Canada	55.9	-112.09	11	6105	Y ¹	N	Y ³	Y
29	Z. Yu, unpubl	Mariana Lake 03-3	Poor Fen	Canada	56.02	-111.93	18	5872	Y ¹	N	Y ³	Y
30	Z. Yu, unpubl ^a	Patuanak	Internal lawn	Canada	55.85	-107.68	11	9017	Y	N	Y ³	Y
31	M. Garneau, unpubl	Ours 5	Fen	Canada	54.05	-72.46	3	5958	N	N	N	Y
32	M. Garneau, unpubl	Ours 2	Fen	Canada	54.05	-72.46	2	3496	N	N	N	Y
33	M. Garneau, unpubl	Aero 3	Fen	Canada	54.1	-72.52	2	3387	N	N	N	Y
34	M. Garneau, unpubl	Aero 3	Fen	Canada	54.1	-72.52	2	3387	N	N	N	Y
35	Hu, 1994	Caribou Bog RC-1	Bog	USA	45	-69	2	9547	Y ¹	pollen (3)	N	Y
36	Lamarre, 2012	KUJU-BF2	Permafrost bog	Canada	55.23	-77.7	4	3914	Y	N	N	Y

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	Abbreviated reference ^a	Site name	Peatland type	Country	Latitude	Longitude	¹⁴ C dates (number)	Oldest age (cal BP)	Basal age (cal BP)	Other dates	Carbon rate site	Peat properties site
8	Loisel, 2010	Mosaik RiP2	Bog	Canada	51.97	-75.4	4	2433	N	N	N	Y
9	M. Paackalen, unpubl	KJ2-3	Poor fen	Canada	51.59	-81.76	4	4677	Y	N	N	Y
10	Robinson, 2000	Peat Plateau LC	Peat Plateau	Canada	61.8	-121.4	0		N	tephra (1)	N	Y
11	Robinson, 2000	Peat Plateau 13	Peat Plateau	Canada	61.8	-121.4	0		N	tephra (1)	N	Y
12	Robinson, 2000	Poor Fen 11	Poor Fen	Canada	61.8	-121.4	0		N	tephra (1)	N	Y
13	Robinson, 2000	Rich Fen 12	Rich fen	Canada	61.8	-121.4	0		N	tephra (1)	N	Y
14	Robinson, 2000	Unfrozen Bog 10	Permafrost bog	Canada	61.8	-121.4	0		N	tephra (1)	N	Y
15	Robinson, 2000	Collapse Scar Fen 06	Collapse Scar	Canada	61.8	-121.4	0		N	tephra (1)	N	Y
16	Sannel, 2009	Ennadai Lake 1	Peat plateau	Canada	60.83	-101.55	4	5792	Y	N	N	Y
17	C. Tarnocai, unpubl	NW-BG-4	Polyg. peat plateau	Canada	65.21	-127.01	3	9916	Y	N	N	Y
18	C. Tarnocai, unpubl	NW-BG-9	Polyg. peat plateau	Canada	65.23	-127.00	3	9575	Y	N	N	Y
19	Z. Yu, unpubl	Hondo	Rich fen	Canada	55.08	-114.14	4	10,012	Y	N	N	Y
20	EURASIA											
21	Anderson, 1998 ^a	Glen Torridon	Olig. topogen. bog	UK	57.56	-5.37	7	9568	Y	N	Y ²	Y
22	Anderson, 1998 ^a	Glen Carron	Olig. topogen. bog	UK	57.53	-5.15	6	10,431	Y	N	Y ²	Y
23	Andersson, 2010	Lilla Backsjömyren 1	Mixed mire	Sweden	62.41	14.32	5	8527	Y	tephra (2)	Y ⁵	Y
24	Andersson, 2010	Lilla Backsjömyren 2	Mixed mire	Sweden	62.41	14.32	13	3804	Y ¹	tephra (2)	Y ⁵	Y
25	Barber, 2003	Bolton Fell Moss J,L	Bog	UK	55	-2	28	10,476	Y	N	Y ⁵	N
26	Barber, 2003	Mongan Bog	Bog	Ireland	53	-8	13	4607	N	N	Y ⁵	N
27	Barber, 2003	Abbeyknockmoy Bog	Bog	Ireland	53.5	-9	10	6707	N	N	Y ⁵	N
28	C. Bocchicchio, unpubl.	KAM12-C4	Bog	Russia (Far-E)	54.01	156.08	10	12,891	Y	N	Y ³	Y
29	Borren, 2004 ^a	Vasyugan (V21)	Bog	Russia (Siberia)	56.83	78.42	11	9709	Y	N	Y ³	Y
30	Borren, 2004 ^a	86-Kvartal (Zh0)	Fen	Russia (Siberia)	56.83	84.58	9	8711	Y	N	Y ³	Y
31	Charman, 1994	East Southerland	Fen	UK	58	-3	6	10,084	Y	N	Y ⁵	N
32	D. Vleeschouwer, 2009	Słowińskie Błota	Raised bog	Poland	54.36	16.49	8	1165	N	N	Y ²	Y
33	D. Vleeschouwer, 2012	Misten	Raised bog	Belgium	50.56	6.16	15	1434	N	N	Y ²	Y

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	Abbreviated reference [*]	Site name	Peatland type	Country	Latitude	Longitude	¹⁴ C dates (number)	Oldest age (cal BP)	Basal age (cal BP)	Other dates	Carbon rate site	Peat properties site
8	Galka, 2013a	Stażki-B	Bog	Poland	54.43	18.09	9	7352	Y	N	Y ⁵	Y
9	Galka, 2013b	Kusowo	Raised bog	Poland	54	18	8	578	N	N	Y ⁵	N
10	Glebov, 2002	Ob-Vasygan	Bog	Russia (Siberia)	60.52	77.68	17	10,817	Y	N	Y ⁵	N
11	Hendon, 2001	Butternburn Flow 1	Intermed. ombrotr	UK	55.08	-2.5	7	9,213	Y	N	Y ⁵	N
12	Hughes, 2013	Utasai Bog	Oligotrophic bog	Japan	42.38	140.18	7	2954	N	tephra (4)	Y ²	Y
13	Kokfelt, 2010	Stordalen	Permafrost bog	Sweden	68.35	19.05	11	4717	Y	N	Y ²	Y
14	Lamentowicz, 2013	Stażki-F	Rich fen	Poland	54.43	18.09	8	1225	Y ¹	N	Y ⁵	Y
15	Large, 2009	Hongyuan HYLK1	Bog	China	32.77	102.52	14	10,827	Y	N	Y ²	Y
16	J. Loisel, unpubl.	KAM12-C1	Bog	Russia (Far-E)	54.9	156.6	13	11,914	Y	N	Y ³	Y
17	G. MacDonald, unpubl	N-1	Peat plateau	Russia (W Sib)	63.16	74.82	8	10,072	Y	N	Y ³	Y
18	MacDonald, unpubl	V-34	Open raised bog	Russia (W Sib)	61.47	79.46	8	8824	Y	N	Y ³	Y
19	MacDonald, unpubl	E-110	Peat plateau	Russia (W Sib)	66.47	76.99	6	9496	Y	N	Y ³	Y
20	MacDonald, unpubl	D-127	Peat plateau	Russia (W Sib)	64.31	70.29	6	10,034	Y	N	Y ³	Y
21	MacDonald, unpubl	SIB06	Pine-domin. bog	Russia (W Sib)	58.44	83.43	17	8680	Y	N	Y ³	Y
22	Mäkilä, 2007 ^a	Hanhijänkä	Palsa	Finland	68.4	23.55	7	9800	Y	N	Y ⁶	N
23	Mäkilä, 2007 ^a	Luovuoma (3 cores)	Fen	Finland	68.4	23.55	6	9800	Y	N	Y ⁶	N
24	Mäkilä, 2001 ^a	Ruosuo (P8)	Aapa	Finland	65.65	27.32	7	9500	Y	N	Y ²	Y
25	Mäkilä, 2001 ^a	Ruosuo (P20)	Aapa	Finland	65.65	27.32	9	9500	Y ¹	N	Y ²	Y
26	Mäkilä, 2001 ^a	Saarisuo (B800)	Fen	Finland	65.65	27.32	11	9600	Y	N	Y ²	Y
27	Mäkilä, 1997 ^a	Haukkasuo (3 cores)	Bog	Finland	60.82	26.95	13	9500	Y	N	Y ⁶	N
28	Mathijssen, unpubl	Lompolojänkkä	Fen	Finland	68	24.22	10	9969	Y	N	Y ³	Y
29	Mathijssen, unpubl	Siikaneva	Bog	Finland	61.84	24.17	6	9622	Y	N	Y ⁴	Y
30	Mauquoy, 2002	Walton Moss 21	Raised bog	UK	54.98	-2.77	21	1120	N	N	Y ²	Y
31	Mauquoy, 2002	Walton Moss 20	Raised bog	UK	54.98	-2.77	23	1048	N	N	Y ²	Y
32	Mauquoy, 2002	Walton Moss 19	Raised bog	UK	54.98	-2.77	30	925	N	N	Y ²	Y
33	Mauquoy, 2002	Lille Vildmose	Raised bog	Denmark	56.83	10.25	19	609	N	N	Y ²	Y

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	Abbreviated reference [*]	Site name	Peatland type	Country	Latitude	Longitude	¹⁴ C dates (number)	Oldest age (cal BP)	Basal age (cal BP)	Other dates	Carbon rate site	Peat properties site
8	Oksanen, 2001	Rogovaya River 2	Peat plateau	Russia (E Eur.)	67.27	62.14	5	10,413	Y ¹	N	Y ²	Y
9	Oksanen, 2001	Rogovaya River 3	Peat plateau	Russia (E Eur.)	67.25	62.07	6	10,641	Y	N	Y ³	Y
10	Oksanen, 2003	Usinsk Mire 1	Peat plateau	Russia (E. Eur.)	57.42	65.67	6	13,236	Y	N	Y ²	Y
11	Ronkainen, unpubl	Seida	Peat plateau	Russia (E. Eur.)	67.05	62.92	6	8469	Y	N	Y ⁴	Y
12	Ruhland, 2000	Lena River Valley	Wet fen	Russia (E Sib)	69.38	125.13	6	8022	Y	N	Y ⁵	N
14	Tuittila, 2007	Lakkasuo (hummock)	Bog	Finland	61.78	24.3	12	6567	Y ¹	N	Y ⁵	Y
15	Tuittila, 2007	Lakkasuo (lawn)	Bog	Finland	61.78	24.3	7	6803	Y	N	Y ⁵	Y
16	Turunen, 2001 ^a	Salym-Gyugan Mire 3	Bog	Russia (W Sib)	60.17	72.83	6	10,500	Y	N	Y ⁶	N
18	Väliranta, 2007	Kontolanrahka	Bog	Finland	60.78	22.78	40	4937	Y	¹³⁷ Cs	Y ²	Y
19	van der Linden, 2006	Saxnäs Mosse	Raised bog	Sweden	56.86	13.46	36	1068	N	N	Y ²	Y
20	van der Linden, 2007	Barschpfohl	Kettle hole	Germany	53.05	13.83	32	134	N	N	Y ²	Y
21	van der Linden, 2008	Lappmyran	String & flark mire	Sweden	64.16	19.58	40	1712	N	N	Y ²	Y
22	van der Linden, 2008	Åkerlänna Römosse	Raised bog	Sweden	60.02	17.36	36	392	N	N	Y ²	Y
23	Y. Zhao, unpubl.	Altay	Sedge-dom rich fen	China	48.12	88.35	18	11,308	Y	N	Y ³	Y
24	Zhao, 2011	Zoige	Sedge-dom rich fen	China	33.45	102.63	7	9996	Y	N	Y ³	Y
25	Zhou, 2010	Hani Peat Bog	Bog	China	42.22	126.52	6	15,014	Y	N	Y ⁵	N
26	Anderson, 1998	Eilean Subhainn	Olig. topogen. bog	UK	57.69	-5.48	4	8700	Y	N	N	Y
27	Beilman, unpubl.	KAM12-C10	Fen	Russia (Far-E)	55.5	159.87	1	7500	Y	N	N	Y
28	Juutinen, 2013	Kiposuo III	Fen	Finland	69.18	27.28	3	9510	Y	pollen (1)	N	Y
29	Juutinen, 2013	Kiposuo IV	Fen	Finland	69.18	27.28	2	8574	Y ¹	N	N	Y
30	McCarroll, unpubl	Mossdale Moor 2	Blanket bog	UK	49.85	-7.46	3	1429	N	N	N	Y
31	Smith, 2004, 2012	N-2	Peat plateau	Russia (W Sib)	63.88	75.02	1	3600	Y	N	N	Y
32	Smith, 2004, 2012	S-4	Non-permafrost	Russia (W Sib)	61.55	72.71	1	6285	Y	N	N	Y
33	Smith, 2004, 2012	S-5	Non-permafrost	Russia (W Sib)	61.98	72.18	1	3885	Y	N	N	Y
34	Smith, 2004, 2012	S-6	Non-permafrost	Russia (W Sib)	61.62	73.98	1	11,120	Y	N	N	Y
35	Smith, 2004, 2012	S-7	Non-permafrost	Russia (W Sib)	61.49	74.32	1	8675	Y	N	N	Y

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	Abbreviated reference ^a	Site name	Peatland type	Country	Latitude	Longitude	¹⁴ C dates (number)	Oldest age (cal BP)	Basal age (cal BP)	Other dates	Carbon rate site	Peat properties site
8	Smith, 2004, 2012	S-8	Pine-domin. bog	Russia (W Sib)	61.75	73.39	1	9860	Y	N	N	Y
9	Smith, 2004, 2012	S-9	Non-permafrost	Russia (W Sib)	62.12	73.84	2	8725	Y	N	N	Y
10	Smith, 2004, 2012	N-10	Peat plateau	Russia (W Sib)	63.14	76.54	1	4720	Y	N	N	Y
11	Smith, 2004, 2012	N-11	Non-permafrost	Russia (W Sib)	62.66	76.77	1	5090	Y	N	N	Y
12	Smith, 2004, 2012	N-12	Peat plateau	Russia (W Sib)	63.50	76.82	1	10,080	Y	N	N	Y
13	Smith, 2004, 2012	N-13	Peat plateau	Russia (W Sib)	63.77	76.64	1	9465	Y	N	N	Y
14	Smith, 2004, 2012	N-14	Peat plateau	Russia (W Sib)	63.77	75.51	1	9035	Y	N	N	Y
15	Smith, 2004, 2012	N-15	Peat plateau	Russia (W Sib)	63.65	74.27	2	9630	Y	N	N	Y
16	Smith, 2004, 2012	N-16	Peat plateau	Russia (W Sib)	64.50	75.53	1	3540	Y	N	N	Y
17	Smith, 2004, 2012	N-17	Peat plateau	Russia (W Sib)	64.07	74.99	1	11,330	Y	N	N	Y
18	Smith, 2004, 2012	N-18	Peat plateau	Russia (W Sib)	62.85	75.22	1	1005	Y	N	N	Y
19	Smith, 2004, 2012	N-19	Peat plateau	Russia (W Sib)	62.96	74.26	1	8290	Y ¹	N	N	Y
20	Smith, 2004, 2012	N-19-1	Peat plateau	Russia (W Sib)	62.96	74.26	1	8675	Y	N	N	Y
21	Smith, 2004, 2012	S-20	Pine-domin. bog	Russia (W Sib)	62.55	71.72	1	3395	Y	N	N	Y
22	Smith, 2004, 2012	S-21	Pine-domin. bog	Russia (W Sib)	62.40	72.87	1	9905	Y	N	N	Y
23	Smith, 2004, 2012	S-22	Pine-domin. bog	Russia (W Sib)	60.84	71.26	2	7125	Y	N	N	Y
24	Smith, 2004, 2012	S-23	Pine-domin. bog	Russia (W Sib)	60.65	73.08	1	6665	Y	N	N	Y
25	Smith, 2004, 2012	S-24	Open raised bog	Russia (W Sib)	61.32	73.24	1	2305	Y	N	N	Y
26	Smith, 2004, 2012	S-25	Pine-domin. bog	Russia (W Sib)	62.25	74.78	1	9910	Y	N	N	Y
27	Smith, 2004, 2012	V-26	Open raised bog	Russia (W Sib)	61.03	76.47	2	9700	Y	N	N	Y
28	Smith, 2004, 2012	V-27	Open raised bog	Russia (W Sib)	61.32	76.73	1	4540	Y	N	N	Y
29	Smith, 2004, 2012	V-28	Open raised bog	Russia (W Sib)	61.81	77.50	1	7750	Y	N	N	Y
30	Smith, 2004, 2012	V-29	Open raised bog	Russia (W Sib)	61.23	75.31	1	9750	Y	N	N	Y
31	Smith, 2004, 2012	V-30	Open raised bog	Russia (W Sib)	61.74	75.20	1	5455	Y	N	N	Y
32	Smith, 2004, 2012	V-31	Open raised bog	Russia (W Sib)	62.37	75.79	1	5600	Y	N	N	Y
33	Smith, 2004, 2012	V-32	Open raised bog	Russia (W Sib)	62.36	77.48	1	2140	Y	N	N	Y

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	Abbreviated reference ^a	Site name	Peatland type	Country	Latitude	Longitude	¹⁴ C dates (number)	Oldest age (cal BP)	Basal age (cal BP)	Other dates	Carbon rate site	Peat properties site
8	Smith, 2004, 2012	V-33	Open raised bog	Russia (W Sib)	62.00	76.71	1	10,975	Y	N	N	Y
9	Smith, 2004, 2012	V-35	Open raised bog	Russia (W Sib)	60.80	77.62	1	10,350	Y	N	N	Y
10	Smith, 2004, 2012	V-36	Open raised bog	Russia (W Sib)	60.81	78.58	1	4400	Y	N	N	Y
11	Smith, 2004, 2012	V-37	Betula & Salix fen	Russia (W Sib)	61.25	74.73	1	2425	Y	N	N	Y
12	Smith, 2004, 2012	V-38	Open raised bog	Russia (W Sib)	60.80	74.54	2	7525	Y	N	N	Y
13	Smith, 2004, 2012	V-39	Open raised bog	Russia (W Sib)	61.09	79.38	2	10,925	Y	N	N	Y
14	Smith, 2004, 2012	V-40	Open raised bog	Russia (W Sib)	61.20	77.84	1	7850	Y	N	N	Y
15	Smith, 2004, 2012	E-101	Peat plateau	Russia (W Sib)	66.46	76.68	1	10,970	Y	N	N	Y
16	Smith, 2004, 2012	E-102	Peat plateau	Russia (W Sib)	66.04	76.59	1	8065	Y	N	N	Y
17	Smith, 2004, 2012	E-103	Peat plateau	Russia (W Sib)	66.74	76.48	1	10,395	Y	N	N	Y
18	Smith, 2004, 2012	E-104	Peat plateau	Russia (W Sib)	65.97	77.99	1	4240	Y	N	N	Y
19	Smith, 2004, 2012	E-105	Peat plateau	Russia (W Sib)	65.98	77.61	1	735	Y	N	N	Y
20	Smith, 2004, 2012	E-106	Peat plateau	Russia (W Sib)	66.00	77.35	1	9175	Y	N	N	Y
21	Smith, 2004, 2012	E-107	Peat plateau	Russia (W Sib)	66.01	75.86	1	6650	Y	N	N	Y
22	Smith, 2004, 2012	E-108	Peat plateau	Russia (W Sib)	65.86	75.29	1	10,685	Y	N	N	Y
23	Smith, 2004, 2012	E-111	Peat plateau	Russia (W Sib)	66.20	79.14	1	8630	Y	N	N	Y
24	Smith, 2004, 2012	E-112	Peat plateau	Russia (W Sib)	66.20	79.14	1	8765	Y	N	N	Y
25	Smith, 2004, 2012	E-113	Peat plateau	Russia (W Sib)	66.45	79.32	4	8305	Y	N	N	Y
26	Smith, 2004, 2012	E-114	Peat plateau	Russia (W Sib)	66.44	76.32	1	605	Y	N	N	Y
27	Smith, 2004, 2012	E-115	Peat plateau	Russia (W Sib)	67.81	75.43	2	9120	Y	N	N	Y
28	Smith, 2004, 2012	E-116	Peat plateau	Russia (W Sib)	67.46	76.42	1	3050	Y	N	N	Y
29	Smith, 2004, 2012	E-118	Peat plateau	Russia (W Sib)	66.60	77.41	1	2540	Y	N	N	Y
30	Smith, 2004, 2012	E-118M	Peat plateau	Russia (W Sib)	66.60	77.41	0		N	N	N	Y
31	Smith, 2004, 2012	E-119	Peat plateau	Russia (W Sib)	65.50	75.50	2	9750	Y	N	N	Y
32	Smith, 2004, 2012	E-120	Peat plateau	Russia (W Sib)	65.61	77.96	1	2585	Y	N	N	Y
33	Smith, 2004, 2012	E-120M	Peat plateau	Russia (W Sib)	65.61	77.96	0		N	N	N	Y

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Abbreviated reference ^a	Site name	Peatland type	Country	Latitude	Longitude	¹⁴ C dates (number)	Oldest age (cal BP)	Basal age (cal BP)	Other dates	Carbon rate site	Peat properties site																												
Smith, 2004, 2012	E-121	Peat plateau	Russia (W Sib)	65.87	78.81	1	2190	Y	N	N	Y																												
Smith, 2004, 2012	E-121M	Peat plateau	Russia (W Sib)	65.87	78.81	0		N	N	N	Y																												
Smith, 2004, 2012	D-122	Peat plateau	Russia (W Sib)	65.58	73.01	2	8495	Y	N	N	Y																												
Smith, 2004, 2012	D-123	Peat plateau	Russia (W Sib)	64.42	71.03	1	10,080	Y	N	N	Y																												
Smith, 2004, 2012	D-123M	Peat plateau	Russia (W Sib)	64.42	71.03	0		N	N	N	Y																												
Smith, 2004, 2012	D-124	Peat plateau	Russia (W Sib)	65.08	72.97	1	6475	Y	N	N	Y																												
Smith, 2004, 2012	D-124M	Peat plateau	Russia (W Sib)	65.08	72.97	0		N	N	N	Y																												
Smith, 2004, 2012	D-125	Peat plateau	Russia (W Sib)	64.52	72.16	1	9600	Y	N	N	Y																												
Smith, 2004, 2012	D-125M	Peat plateau	Russia (W Sib)	64.52	72.16	1	9735	Y	N	N	Y																												
Smith, 2004, 2012	D-126	Peat plateau	Russia (W Sib)	64.33	71.20	1	9140	Y	N	N	Y																												
Smith, 2004, 2012	D-126M	Peat plateau	Russia (W Sib)	64.33	71.20	0		N	N	N	Y																												
Smith, 2004, 2012	D-127M	Peat plateau	Russia (W Sib)	64.31	70.29	1	10,420	Y	N	N	Y																												
Smith, 2004, 2012	D-128	Peat plateau	Russia (W Sib)	65.55	72.46	1	9180	Y	N	N	Y																												
Smith, 2004, 2012	P-129	Peat plateau	Russia (W Sib)	66.61	73.75	1	9635	Y	N	N	Y																												
Smith, 2004, 2012	P-130	Peat plateau	Russia (W Sib)	66.87	74.53	1	8815	Y	N	N	Y																												
Smith, 2004, 2012	P-131	Peat plateau	Russia (W Sib)	66.17	73.99	2	9940	Y	N	N	Y																												
Smith, 2004, 2012	P-132	Peat plateau	Russia (W Sib)	66.50	73.95	1	10,065	Y	N	N	Y																												
Smith, 2004, 2012	P-133	Peat plateau	Russia (W Sib)	65.79	74.35	1	6515	Y	N	N	Y																												
Smith, 2004, 2012	G-134	Peat plateau	Russia (W Sib)	64.43	77.18	1	8285	Y	N	N	Y																												
Smith, 2004, 2012	G-135	Peat plateau	Russia (W Sib)	64.83	77.67	1	9450	Y	N	N	Y																												
Smith, 2004, 2012	G-136	Peat plateau	Russia (W Sib)	64.15	75.36	2	7820	Y	N	N	Y																												
Smith, 2004, 2012	G-136M	Peat plateau	Russia (W Sib)	64.15	75.36	1	6385	Y	N	N	Y																												
Smith, 2004, 2012	G-137	Peat plateau	Russia (W Sib)	63.75	75.77	4	9360	Y	N	N	Y																												
Smith, 2004, 2012	G-138	Peat plateau	Russia (W Sib)	64.52	76.67	1	9915	Y	N	N	Y																												
Smith, 2004, 2012	G-139	Peat plateau	Russia (W Sib)	64.89	76.73	1	6240	Y	N	N	Y																												
Smith, 2004, 2012	G-139M	Peat plateau	Russia (W Sib)	64.89	76.73	0		N	N	N	Y																												

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Abbreviated reference ^a	Site name	Peatland type	Country	Latitude	Longitude	¹⁴ C dates (number)	Oldest age (cal BP)	Basal age (cal BP)	Other dates	Carbon rate site	Peat properties site
Smith, 2004, 2012	G-140	Peat plateau	Russia (W Sib)	64.27	79.55	1	10,365	Y	N	N	Y
Smith, 2004, 2012	G-140M	Peat plateau	Russia (W Sib)	64.27	79.55	0		N	N	N	Y
Smith, 2004, 2012	G-141	Peat plateau	Russia (W Sib)	64.69	75.40	1	10,410	Y	N	N	Y
Smith, 2004, 2012	G-142	Peat plateau	Russia (W Sib)	64.09	78.60	0		N	N	N	Y
Smith, 2004, 2012	G-142M	Peat plateau	Russia (W Sib)	64.09	78.60	1	8675	Y	N	N	Y
Smith, 2004, 2012	SIB01	Pine-domin. bog	Russia (W Sib)	59.36	68.98	3	6970	Y	N	N	Y
Smith, 2004, 2012	SIB02	Pine-domin. bog	Russia (W Sib)	61.06	70.06	2	8500	Y	N	N	Y
Smith, 2004, 2012	SIB03	Pine-domin. bog	Russia (W Sib)	56.36	79.07	3	2770	Y	N	N	Y
Smith, 2004, 2012	SIB04	Pine-domin. bog	Russia (W Sib)	56.80	78.74	3	3770	Y	N	N	Y
Smith, 2004, 2012	SIB05	Pine-domin. bog	Russia (W Sib)	57.35	81.16	3	4240	Y	N	N	Y
Väliranta, 2003	Ortino 1	Peat plateau	Russia (E. Eur.)	68	54	4	10,374	Y	N	N	Y
Väliranta, 2003	Ortino 2	Peat plateau	Russia (E. Eur.)	68	54	3	8786	Y ¹	N	N	Y

^aA list of detailed references is presented below the table.

^aSite used in Yu et al.'s (2009) synthesis.

¹Basal age not considered in the peatland inception age database because older cores were collected from the same site.

²Measured bulk density was multiplied by measured C content (elemental analyzer) for each layer to estimate C bulk density (g C cm⁻³).

³Measured ash-free bulk density was multiplied by inferred C content (ash-free bulk density x 49%) for each layer to estimate C bulk density.

⁴Measured bulk density was multiplied by assumed C content (47%) for each layer to estimate C bulk density.

⁵Assumed time-dependent bulk density was multiplied by assumed C content (47%) for each dated interval to estimate peat-C density.

⁶Peat-C accumulation rates directly obtained from published figures and tables.

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