

This is a peer-reviewed, post-print (final draft post-refereeing) version of the following published document and is licensed under All Rights Reserved license:

**Loisel, J. and Yu, Z. and Beilman, D. W. and Camill, P. and Alm, J. and Amesbury, M. J. and Anderson, D. and Andersson, S. and Bochicchio, C. and Barber, K. and Belyea, L. R. and Bunbury, J. and Chambers, Frank M and Charman, D. J. and De Vleeschouwer, F. and Fia kiewicz-Kozie, B. and Finkelstein, S. A. and Ga ka, M. and Garneau, M. and Hammarlund, D. and Hinchcliffe, W. and Holmquist, J. and Hughes, P. and Jones, M. C. and Klein, E. S. and Kokfelt, U. and Korhola, A. and Kuhry, P. and Lamarre, A. and Lamentowicz, M. and Large, D. and Lavoie, M. and MacDonald, G. and Magnan, G. and Makila, M. and Mallon, G. and Mathijssen, P. and Mauquoy, D. and McCarroll, Julia and Moore, T. R. and Nichols, J. and O'Reilly, B. and Oksanen, P. and Packalen, M. and Peteet, D. and Richard, P. J. and Robinson, S. and Ronkainen, T. and Rundgren, M. and Sannel, A. B. K. and Tarnocai, C. and Thom, T. and Tuittila, E.-S. and Turetsky, M. and Valiranta, M. and van der Linden, M. and van Geel, B. and van Bellen, S. and Vitt, D. and 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. ISSN 0959-6836**

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

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

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

#### **Disclaimer**

The University of Gloucestershire has obtained warranties from all depositors as to their title in the material deposited and as to their right to deposit such material.

The University of Gloucestershire makes no representation or warranties of commercial utility, title, or fitness for a particular purpose or any other warranty, express or implied in respect of any material deposited.

The University of Gloucestershire makes no representation that the use of the materials will not infringe any patent, copyright, trademark or other property or proprietary rights.

The University of Gloucestershire accepts no liability for any infringement of intellectual property rights in any material deposited but will remove such material from public view pending investigation in the event of an allegation of any such infringement.

PLEASE SCROLL DOWN FOR TEXT.

This is a for peer-review, pre-print version of the following published document:

**Loisel, J. and Yu, Z. and Beilman, D. W. and Camill, P. and Alm, J. and Amesbury, M. J. and Anderson, D. and Andersson, S. and Bochicchio, C. and Barber, K. and Belyea, L. R. and Bunbury, J. and Chambers, Frank M and Charman, D. J. and De Vleeschouwer, F. and Fia kiewicz-Kozie, B. and Finkelstein, S. A. and Ga ka, M. and Garneau, M. and Hammarlund, D. and Hinchcliffe, W. and Holmquist, J. and Hughes, P. and Jones, M. C. and Klein, E. S. and Kokfelt, U. and Korhola, A. and Kuhry, P. and Lamarre, A. and Lamentowicz, M. and Large, D. and Lavoie, M. and MacDonald, G. and Magnan, G. and Makila, M. and Mallon, G. and Mathijssen, P. and Mauquoy, D. and McCarroll, J. and Moore, T. R. and Nichols, J. and O'Reilly, B. and Oksanen, P. and Packalen, M. and Peteet, D. and Richard, P. J. and Robinson, S. and Ronkainen, T. and Rundgren, M. and Sannel, A. B. K. and Tarnocai, C. and Thom, T. and Tuittila, E.-S. and Turetsky, M. and Valiranta, M. and van der Linden, M. and van Geel, B. and van Bellen, S. and Vitt, D. and Zhao, Y. and Zhou, W. (2014). *A database and synthesis of northern peatland soil properties and Holocene carbon and nitrogen accumulation*. *The Holocene*, 24 (9), 1028-1042. ISSN 0959-6836**

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>

### **Disclaimer**

The University of Gloucestershire has obtained warranties from all depositors as to their title in the material deposited and as to their right to deposit such material.

The University of Gloucestershire makes no representation or warranties of commercial utility, title, or fitness for a particular purpose or any other warranty, express or implied in respect of any material deposited.

The University of Gloucestershire makes no representation that the use of the materials will not infringe any patent, copyright, trademark or other property or proprietary rights.

The University of Gloucestershire accepts no liability for any infringement of intellectual property rights in any material deposited but will remove such material from public view pending investigation in the event of an allegation of any such infringement.

PLEASE SCROLL DOWN FOR TEXT.

### 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 <math>42 \pm 3\%</math> (S.D.) for Sphagnum peat, <math>51 \pm 2\%</math> for non-Sphagnum peat, and at <math>49 \pm 2\%</math> overall. Dry bulk density averaged <math>0.12 \pm 0.07</math> g cm<sup>-3</sup>, organic matter bulk density averaged <math>0.11 \pm 0.05</math> g cm<sup>-3</sup>, and total carbon content in peat averaged <math>47 \pm 6\%</math>. 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 <math>23 \pm 2</math> (S.E.M.) g C m<sup>-2</sup> yr<sup>-1</sup> during the Holocene on the basis of 151 peat cores from 127 sites, with the highest rates of carbon accumulation (<math>25\text{-}28</math> g C m<sup>-2</sup> yr<sup>-1</sup>) 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 <a href="https://peatlands.lehigh.edu">https://peatlands.lehigh.edu</a>.</p>

1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60

SCHOLARONE™  
Manuscripts

For Peer Review

1  
2  
3 1 **A database and synthesis of northern peatland soil properties and Holocene carbon**  
4  
5  
6 2 **and nitrogen accumulation**  
7

8  
9 3

10 4 Running title

11  
12 5 Northern peatland database and synthesis  
13  
14 6

15  
16  
17 7 Authors

18  
19  
20 8 Julie Loisel<sup>1\*</sup>, Zicheng Yu<sup>1\*</sup>, David W. Beilman<sup>2</sup>, Philip Camill<sup>3</sup>, Jukka Alm<sup>4</sup>, Matthew J.  
21  
22 9 Amesbury<sup>5</sup>, David Anderson<sup>6</sup>, Sofia Andersson<sup>7</sup>, Christopher Bochicchio<sup>1</sup>, Keith Barber<sup>8</sup>,  
23  
24 10 Lisa R. Belyea<sup>9</sup>, Joan Bunbury<sup>10</sup>, Frank M. Chambers<sup>11</sup>, Daniel J. Charman<sup>5</sup>, François De  
25  
26 11 Vleeschouwer<sup>12</sup>, Barbara Fiałkiewicz-Kozieł<sup>13</sup>, Sarah A. Finkelstein<sup>14</sup>, Mariusz Gałka<sup>13</sup>,  
27  
28 12 Michelle Garneau<sup>15</sup>, Dan Hammarlund<sup>16</sup>, William Hinchcliffe<sup>5</sup>, James Holmquist<sup>17</sup>, Paul  
29  
30 13 Hughes<sup>8</sup>, Miriam C. Jones<sup>18</sup>, Eric S. Klein<sup>1</sup>, Ulla Kokfelt<sup>19</sup>, Atte Korhola<sup>20</sup>, Peter Kuhry<sup>7</sup>,  
31  
32 14 Alexandre Lamarre<sup>15</sup>, Mariusz Lamentowicz<sup>13</sup>, David Large<sup>21</sup>, Martin Lavoie<sup>22</sup>, Glen  
33  
34 15 MacDonald<sup>17</sup>, Gabriel Magnan<sup>15</sup>, Markku Mäkilä<sup>23</sup>, Gunnar Mallon<sup>8</sup>, Paul Mathijssen<sup>20</sup>,  
35  
36 16 Dmitri Mauquoy<sup>24</sup>, Julia McCarroll<sup>11</sup>, Tim R. Moore<sup>25</sup>, Jonathan Nichols<sup>26</sup>, Benjamin  
37  
38 17 O'Reilly<sup>14</sup>, Pirita Oksanen<sup>27</sup>, Maara Packalen<sup>28</sup>, Dorothy Peteet<sup>26</sup>, Pierre J.H. Richard<sup>29</sup>,  
39  
40 18 Stephen Robinson<sup>30</sup>, Tiina Ronkainen<sup>20</sup>, Mats Rundgren<sup>16</sup>, A. Britta K. Sannel<sup>7</sup>, Charles  
41  
42 19 Tarnocai<sup>31</sup>, Tim Thom<sup>32</sup>, Eeva-Stiina Tuittila<sup>4</sup>, Merritt Turetsky<sup>33</sup>, Minna Väliranta<sup>20</sup>,  
43  
44 20 Marjolein van der Linden<sup>34</sup>, Bas van Geel<sup>35</sup>, Simon van Bellen<sup>23</sup>, Dale Vitt<sup>36</sup>, Yan Zhao<sup>37</sup>,  
45  
46 21 Weijian Zhou<sup>38</sup>  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60

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 <sup>1</sup>Department of Earth and Environmental Sciences, Lehigh University, Bethlehem, PA  
28 18015, USA

29  
30 <sup>2</sup>Department of Geography, University of Hawaii – Manoa, Honolulu, HI 96822, USA

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

34  
35 <sup>4</sup>School of Forest Sciences, University of Eastern Finland, Joensuu, FI 80101, Finland

36  
37 <sup>5</sup>Department of Geography, University of Exeter, Exeter, EX4 4RJ, UK

38  
39 <sup>6</sup>Department of Geography, Eton College, Windsor, Berkshire SL4 6DW, UK

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

43  
44 <sup>8</sup>Geography and Environment, University of Southampton, Southampton, SO17 1BJ, UK

45  
46 <sup>9</sup>School of Geography, Queen Mary University of London, London, E1 4NS, UK

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

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

53  
54 <sup>12</sup>CNRS and Université de Toulouse, Castanet Tolosan, 31326, France

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

58  
59 <sup>14</sup>Department of Earth Sciences, University of Toronto, Toronto, ON M5S 3B1, Canada

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

63  
64 <sup>16</sup>Department of Geology, Lund University, Lund, SE-223 62, Sweden

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

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

17 121 Corresponding authors

19 122 Julie Loisel email: [jul208@lehigh.edu](mailto:jul208@lehigh.edu) phone: 610-758-3660

21 123 Zicheng Yu email: [ziy2@lehigh.edu](mailto:ziy2@lehigh.edu) phone: 610-758-6751

23 124

25 125 Abstract

27 126 Here we present results from the most comprehensive compilation of Holocene peat soil  
28 127 properties with associated carbon and nitrogen accumulation rates for northern peatlands.  
29 128 Our database consists of 268 peat cores from 215 sites located north of 45°N. It  
30 129 encompasses regions within which peat carbon data have only recently become available,  
31 130 such as the West Siberia Lowlands, the Hudson Bay Lowlands, Kamchatka in Far East  
32 131 Russia, and the Tibetan Plateau. For all northern peatlands, carbon content in organic  
33 132 matter was estimated at  $42 \pm 3\%$  (S.D.) for *Sphagnum* peat,  $51 \pm 2\%$  for non-*Sphagnum*  
34 133 peat, and at  $49 \pm 2\%$  overall. Dry bulk density averaged  $0.12 \pm 0.07 \text{ g cm}^{-3}$ , organic  
35 134 matter bulk density averaged  $0.11 \pm 0.05 \text{ g cm}^{-3}$ , and total carbon content in peat  
36 135 averaged  $47 \pm 6\%$ . In general, large differences were found between *Sphagnum* and non-  
37 136 *Sphagnum* peat types in terms of peat properties. Time-weighted peat carbon  
38 137 accumulation rates averaged  $23 \pm 2 \text{ (S.E.M.) g C m}^{-2} \text{ yr}^{-1}$  during the Holocene on the



1  
2  
3 138 basis of 151 peat cores from 127 sites, with the highest rates of carbon accumulation (25-  
4  
5 139 28 g C m<sup>-2</sup> yr<sup>-1</sup>) recorded during the early Holocene when the climate was warmer than  
6  
7  
8 140 the present. Furthermore, we estimate the northern peatland carbon and nitrogen pools at  
9  
10 141 436 and 10 gigatons, respectively. The database is publicly available at  
11  
12 142 <https://peatlands.lehigh.edu>.  
13  
14  
15 143

#### 17 144 Keywords

18  
19  
20 145 Northern peatlands, Data synthesis, Climate change, Soil carbon and nitrogen,  
21  
22 146 Biogeochemical cycles, Long-term ecosystem dynamics  
23  
24  
25 147

#### 26 27 148 **Introduction**

28  
29 149 Of all terrestrial ecosystems, peatlands are arguably the most efficient at sequestering  
30  
31 150 carbon (C) over long time scales. Northern peatlands cover approximately 4,000,000 km<sup>2</sup>  
32  
33 151 or 3% of the global land area (Maltby and Immirzi, 1993) and have accumulated about  
34  
35 152 500 gigatons of C (GtC) mostly during the Holocene, equivalent to ~ 30% of the present-  
36  
37 153 day global soil organic carbon (SOC) pool (Gorham, 1991; Bridgham et al., 2006; Yu et  
38  
39 154 al., 2010). These ecosystems have also played a dynamic role in the Holocene global C  
40  
41 155 cycle as important sinks of carbon dioxide (CO<sub>2</sub>) and major sources of methane (CH<sub>4</sub>) to  
42  
43 156 the atmosphere (Frolking and Roulet, 2007; Korhola et al., 2010; Yu, 2011). As climate  
44  
45 157 warming positively affects both plant growth and organic matter decomposition, recent  
46  
47 158 and projected climate change could shift the balance between peat production and organic  
48  
49 159 matter decomposition, potentially affecting the peatland C-sink capacity and modifying  
50  
51 160 peat C fluxes to the atmosphere (Frolking et al., 2011; Yu, 2012). This prediction  
52  
53  
54  
55  
56  
57  
58  
59  
60

1  
2  
3 161 particularly holds true for the northern high-latitude regions, where the intensity of  
4  
5 162 climate change is expected to be greatest (McGuire et al., 2009). The peatland C cycle –  
6  
7  
8 163 climate feedback remains difficult to assess, however, because of (1) limited  
9  
10 164 understanding of peatland responses to climate change (Frolking et al., 2011), (2) data  
11  
12 165 gaps and large uncertainties in regional peatland C stocks (Yu, 2012), and (3) non-linear  
13  
14  
15 166 peatland responses to external forcing (Belyea, 2009).  
16

17  
18  
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  
23  
24 170 sequestration of ~270 GtC (Yu, 2012) and a C/N ratio of 20-30 for fen peat (Bergner et  
25  
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  
30  
31 173 possible that northern peatlands have been playing an undocumented, dynamic role in the  
32  
33  
34 174 Holocene global N cycle as important sinks of N, potentially limiting the amount of N  
35  
36 175 available for other ecosystems at the global scale (McLauchlan et al., 2013).  
37  
38  
39 176 Alternatively, if the main N input to peatlands was through N<sub>2</sub> fixation by cyanobacteria,  
40  
41 177 these microorganisms might have been more important in driving the C cycle in  
42  
43 178 peatlands than previously thought. Overall, studying the coupling between N and C  
44  
45  
46 179 cycling in northern peatlands is essential for a better understanding of how key  
47  
48 180 biogeochemical processes interact in these systems and for predicting the future of peat C  
49  
50  
51 181 stocks.  
52

53 182  
54  
55  
56  
57  
58  
59  
60

1  
2  
3 183 Here we present the most comprehensive compilation of Holocene C and N data for  
4  
5 184 northern peatlands. This synthesis encompasses regions within which peat C and N data  
6  
7  
8 185 have only recently become available, such as the West Siberian Lowlands in Asian  
9  
10 186 Russia, the Hudson Bay Lowlands in Canada, Kamchatka in the Russian Far East, and  
11  
12 187 the Tibetan Plateau. In addition, we present the most comprehensive synthesis of peat soil  
13  
14 188 properties (such as bulk density, organic matter content, C and N content) from the  
15  
16 189 northern hemisphere. Also, this new database and synthesis work represent a major  
17  
18 190 expansion from Yu et al.'s (2009) synthesis on Holocene peat C dynamics, which was  
19  
20 191 based on 33 sites (vs. 127 sites as reported in this paper). Finally, it constitutes a natural  
21  
22 192 continuation of Charman et al.'s (2013) recent study on peat C accumulation in northern  
23  
24 193 peatlands during the last millennium.  
25  
26  
27  
28

29 194  
30  
31 195 In addition to filling regional data and knowledge gaps, the main objectives of this paper  
32  
33 196 are to (1) describe a database of peat soil properties and synthesize this information for  
34  
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  
38  
39 199 history. Key differences in Holocene peat properties between different regions and  
40  
41 200 peatland types are also discussed in light of their implications for long-term peat C  
42  
43 201 stocks. Of particular importance and relevance are the differences between *Sphagnum*  
44  
45 202 and non-*Sphagnum* peat types. Finally, we present new estimates for northern peat C and  
46  
47 203 N stocks for northern peatlands on the basis of the expanded database.  
48  
49  
50  
51  
52

53 204

54  
55 205 **Database and analysis**  
56  
57  
58  
59  
60

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 Utsai (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%)

1  
2  
3 229 was collected in peatlands currently affected by permafrost (n = 108 cores). Note that  
4  
5  
6 230 peatland type was identified independently for each site by the original investigators.  
7  
8 231 From an ecosystem functioning perspective, distinguishing bogs from fens and  
9  
10 232 permafrost peatlands is important, as these peatland types are characterized by different  
11  
12 233 hydrological regimes, vegetation communities, and peat-growth trajectories, all of which  
13  
14 234 impact long-term rates of peat C sequestration (Rydin and Jeglum, 2013). Bogs are  
15  
16 235 mineral-poor, rain-fed peatland ecosystems with relatively low plant net primary  
17  
18 236 production (NPP) and slow peat decomposition rates. In contrast, fens are hydrologically  
19  
20 237 connected to surface or ground water, thereby receiving more mineral nutrients.  
21  
22 238 Generally speaking, fens have greater NPP but also faster peat decay rates than bogs  
23  
24 239 (Blodau, 2002). Finally, in the sub-Arctic and Arctic regions, peatland hydrology,  
25  
26 240 structure, and peat C balance are sensitive to the underlying permafrost aggradation and  
27  
28 241 degradation dynamics (Camill, 1999; Turetsky et al., 2007). For the analysis, peat  
29  
30 242 plateaus (87 out of 108 cores), permafrost bogs (18 out of 108 cores), and collapse scars  
31  
32 243 (3 out of 108 cores) were grouped under the peatland type ‘permafrost peatlands’.  
33  
34 244 Original peatland categories can be found in Supplementary Table 1.  
35  
36 245  
37  
38  
39  
40  
41  
42  
43 246 The database was built to include as many peat records as possible. Therefore, we  
44  
45 247 included any peat core that was extracted north of 45 °N (or at high elevation) and for  
46  
47 248 which bulk density or organic matter bulk density data were available. Information  
48  
49 249 related to peat-core location, peatland type, peat properties, age, and data source can be  
50  
51 250 found in Supplementary Table 1. Additional information related to the type of coring  
52  
53 251 device used and the year of coring can be found in the original publications. Data used in  
54  
55  
56  
57  
58  
59  
60

1  
2  
3 252 this synthesis are readily accessible from the Holocene Peatland Carbon Network website  
4  
5 253 (<https://peatlands.lehigh.edu>). This database will be useful in future studies of ecosystem  
6  
7  
8 254 – C cycle – climate interactions and for modeling long-term peatland dynamics.  
9

10 255

11  
12 256 In the following sub-sections, we present the criteria for site selection and the protocols  
13  
14 257 used to develop the database. In an effort to only analyze and synthesize *peat* samples,  
15  
16 258 inorganic-rich horizons often found at the base of the peat cores were removed from the  
17  
18 259 database. When available, stratigraphic information was used to distinguish peat vs. non-  
19  
20 260 peat material. For example, gyttja (organic-rich lake sediments) was excluded from the  
21  
22 261 dataset, as well as marshy, clayey, and silty sediments. When stratigraphic information  
23  
24 262 was not available, a bulk density value of  $0.5 \text{ g cm}^{-3}$  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  
27  
28 264 from peatland records where peaty sediments with bulk density values up to  $0.5 \text{ g cm}^{-3}$   
29  
30 265 were identified. We acknowledge that this cut-off value is arbitrary, and that our dataset  
31  
32 266 likely contains some non-peat samples. Inorganic horizons (e.g., tephra layers) were also  
33  
34 267 excluded from the database.  
35  
36  
37  
38  
39

40 268

#### 41 269 Peat properties

42  
43 270 A total of 232 peat cores (181 sites) were used for characterizing peat properties, though  
44  
45 271 not all cores have all types of peat properties available (Figure 2a). This dataset contains  
46  
47 272 139 cores from Eurasia (including 109 cores from Russia) and 93 cores from North  
48  
49 273 America (Figure 1). While approximately half of these cores were sampled and analyzed  
50  
51 274 at high resolution (1-5 cm increments), the remainder was sampled at lower resolution,  
52  
53  
54  
55  
56  
57  
58  
59  
60

1  
2  
3 275 typically at 10 cm increments. Dry bulk density (BD; g cm<sup>-3</sup>), organic matter content  
4  
5 276 (OM%; gravimetric %), as well as elemental C and N concentration values were  
6  
7  
8 277 compiled and synthesized. On the basis of these raw datasets, C/N mass ratio and organic  
9  
10 278 matter bulk density (OMBD; g OM cm<sup>-3</sup>) were calculated. These peat geochemical values  
11  
12 279 are examined in light of peat stratigraphy, peat ages, and geographic regions. The  
13  
14 280 following paragraphs briefly describe the protocols used to obtain these values.  
15  
16  
17  
18 281

19  
20 282 Peat stratigraphic information was obtained for 83 peat cores ('peat types' in Figure 2a)  
21  
22 283 for which plant macrofossil analysis or detailed peat description had been performed  
23  
24 284 following standard techniques (e.g., Troels-Smith, 1955; Mauquoy and van Geel, 2007).  
25  
26  
27 285 This peat stratigraphic information was condensed into the following five peat types:  
28  
29 286 *Sphagnum*, herbaceous, woody, brown moss, and humified peat. In a few cases, the  
30  
31 287 investigators only ascribed a general peat type to the samples (e.g., 'bog' vs. 'fen' peat, or  
32  
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  
36  
37 290 among the investigators. For example, a peat sample that contains sizable fractions of  
38  
39 291 brown moss and humified peat may be classified by an investigator as 'brown moss peat'  
40  
41 292 and by another one as 'humified peat'. We recognize that, due to their nature, brown  
42  
43 293 moss and humified peat types might be less uniform than *Sphagnum* or herbaceous peat  
44  
45 294 types. We included as much stratigraphic information as possible in the database, though  
46  
47 295 ambiguous or imprecise descriptions were left out to avoid further confusions.  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60

1  
2  
3 297 Dry bulk density and organic matter content were determined following standard  
4  
5 298 procedures (Dean, 1974; Chambers et al., 2011). Peat samples of a known fresh volume  
6  
7 299 were either freeze-dried or oven-dried at ca. 100 °C until constant weight was reached  
8  
9 300 and weighed to determine bulk density, then burned at 500-600 °C for one to four hours  
10  
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  
14  
15 303 compaction in the field and in the laboratory) and the analytical error associated with  
16  
17 304 weighing. The product of bulk density (BD; g cm<sup>-3</sup>) and organic matter content (OM%)  
18  
19 305 of each peat sample was used to calculate organic matter bulk density (OMBD; g OM  
20  
21 306 cm<sup>-3</sup>), 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  
24  
25 308 21,220 bulk density measurements, 18,973 organic matter content values, and computed  
26  
27 309 18,544 organic matter bulk density values (Figure 2a).  
28  
29 310  
30  
31 311 Total peat C and N content were directly measured by combustion and elemental analysis  
32  
33 312 of dry peat samples (Chambers et al., 2011). We compiled 3741 C and 3365 N  
34  
35 313 measurements (Figure 2a). We also computed a total of 3362 C/N mass ratio values.  
36  
37 314  
38  
39 315 Finally, the regression between peat C content (C%) and peat organic matter content  
40  
41 316 (OM%) for each peat type is presented as an estimate for C content in organic matter  
42  
43 317 (OC%). A total of 995 samples were used in this analysis. The slope of each one of these  
44  
45 318 regressions is interpreted as the 'conversion factor' from OM% to OC%, such that it  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60



1  
2  
3 319 provides an indirect way for estimating the C% content of ash-free peat for investigators  
4  
5  
6 320 who do not perform elemental C measurements directly.  
7

8 321

9  
10 322 Peat-core chronology

11  
12 323 Peat-core chronologies were almost exclusively based on radiocarbon ( $^{14}\text{C}$ ) dates that  
13  
14 324 were determined mostly by accelerator mass spectrometry (AMS) on terrestrial plant  
15  
16 325 macrofossils or bulk peat (Piotrowska et al., 2011). A few older chronologies were based  
17  
18 326 on conventional  $^{14}\text{C}$  dating of bulk samples. Because no systematic offset has been  
19  
20 327 observed in the  $^{14}\text{C}$  age of bulk vs. non-woody plant macrofossils (G.M. MacDonald,  
21  
22 328 pers. comm. 2013), the use of bulk dates is justifiable. For the purpose of this study, all  
23  
24 329  $^{14}\text{C}$  dates were calibrated to calendar years before present (cal. BP) using the program  
25  
26 330 CALIB 6.1.0 (Stuiver and Reimer, 1993) with the IntCal09 calibration dataset (Reimer et  
27  
28 331 al., 2009). In this paper, ages are reported in thousands of calibrated years before present  
29  
30 332 (ka).  
31  
32  
33  
34  
35  
36  
37  
38

39 334 Age-depth relationships were established for all continuous peat cores for which at least  
40  
41 335 five age determinations were available ( $n = 151$  cores). Except for a few  
42  
43 336 palynostratigraphic and tephrochronologic markers, nearly all records have chronologies  
44  
45 337 exclusively based on  $^{14}\text{C}$  ages (Supplementary Table 1). Chronologies were obtained  
46  
47 338 through linear interpolation of calibrated ages between dated horizons. Single-age  
48  
49 339 estimates were taken from the mid-point of each calibrated  $2\sigma$  probability distribution.  
50  
51 340 This parsimonious approach captures general patterns of temporal changes in peat  
52  
53 341 accumulation and allows for analysis of peat C accumulation trajectories (e.g., Telford et  
54  
55  
56  
57  
58  
59  
60

1  
2  
3 342 al., 2004). Although more sophisticated approaches are possible (e.g., Charman et al.,  
4  
5 343 2013), we seek to make the fewest or simplest assumptions for this analysis because the  
6  
7 344 temporal resolution target for peat C accumulation rate calculations is relatively low (at  
8  
9 345 500 years). In the cases where the original investigator identified hiatuses (e.g., peat loss  
10  
11 346 caused by erosion or fire) or depositional anomalies (e.g., thick tephra layers that  
12  
13 347 interrupted peat accumulation) along their peat records, these gaps were taken into  
14  
15 348 consideration when building age-depth relationships (Glaser et al., 2012). Otherwise, peat  
16  
17 349 records were assumed to be continuous.

22 350

24 351 In an effort to assess the representativeness of our samples in terms of peatland inception  
25  
26 352 timing, peat basal ages were compiled and compared to results from large datasets  
27  
28 353 (MacDonald et al., 2006; Gorham et al., 2007; Korhola et al., 2010). Peat inception ages  
29  
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  
39  
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  
43  
44 360 were used in the present study (Supplementary Table 1). The remaining 8 sites did not  
45  
46 361 fulfill our dating quality criterion (presented below). The dating quality of each record  
47  
48 362 was determined by the quotient of the calibrated peat basal age and the number of age  
49  
50 363 determinations. For example, a 10,000-year-old peat core with a chronology constrained  
51  
52 364 by 10 <sup>14</sup>C dates was attributed a dating quality of one date per 1000 years. About 58% of  
53  
54  
55  
56  
57  
58  
59  
60

1  
2  
3 365 our 151 cores were characterized by an acceptable dating quality of one to two  $^{14}\text{C}$  dates  
4  
5 366 per 1000 years (Figure 2b). These resolutions are well suited to capture millennial-scale  
6  
7 367 variations in C accumulation. Several peat cores with more than two  $^{14}\text{C}$  dates per 1000  
8  
9 368 years ( $n = 35$  cores) were available from North America and Europe. The lower dating  
10  
11 369 quality cores ( $<1$  date per 1000 years,) were unevenly distributed and comprise 44% of  
12  
13 370 the North American records and 40% of the Eurasian records.  
14  
15  
16

17 371

18  
19  
20 372 The long-term rate of peat C accumulation was calculated for each core following one of  
21  
22 373 the following five approaches (Supplementary Table 1): (1) whenever possible, peat core  
23  
24 374 chronology was combined with bulk density and C% for each depth increment ( $n = 47$   
25  
26 375 cores); (2) in the cases where direct C measurements were lacking, peat core chronology  
27  
28 376 was combined with organic matter bulk density measurements and a mean organic C  
29  
30 377 value of 49% in organic matter ( $n = 57$  cores); (3) for cores that lacked organic matter  
31  
32 378 bulk density and direct C%, peat core chronology was combined with bulk density  
33  
34 379 measurements and a mean C content of 47% in total peat ( $n = 3$  cores); (4) whenever  
35  
36 380 neither bulk density nor C% was directly available from the cores, long-term rate of peat  
37  
38 381 C accumulation was calculated for each core by combining time-dependent bulk densities  
39  
40 382 ( $0.08 \text{ g cm}^{-3}$  at 0-0.5 ka;  $0.12 \text{ g cm}^{-3}$  at 0.5-6 ka;  $0.14 \text{ g cm}^{-3}$  at 6-12 ka) with a mean C  
41  
42 383 content of 47% in total peat for each dated interval ( $n = 32$  cores), and (5) peat C  
43  
44 384 accumulation rates for the remaining 12 cores were directly obtained from published  
45  
46 385 figures and tables. For all the cores, time-weighted peat C accumulation rates were  
47  
48 386 summed and binned in 500-year intervals. It is important to note that such reconstructions  
49  
50 387 are ‘apparent rates’ that are different from true rates of C accumulation in peatlands,  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60

1  
2  
3 388 because decomposition processes have been affecting old peat layers for thousands of  
4  
5 389 years (Turunen et al., 2002). Finally, the long-term rate of peat N accumulation was  
6  
7 390 calculated by combining our binned peat-C accumulation rates with time-dependent C/N  
8  
9 391 values (65 at 0-6 ka, and 40 at 6-10 ka).  
10  
11  
12  
13  
14

## 15 393 **Results**

### 17 394 *Peat Properties*

#### 19 395 Descriptive statistics of dataset

20 396 The frequency distribution of each peat property is shown in Figure 3. Mean values and  
21  
22 397 standard deviations for all peat properties are presented by peat type in Table 1, and by  
23  
24 398 region in Table 2.  
25  
26  
27  
28

29 399  
30  
31 400 Bulk density values (n = 21,220) ranges from 0.003 to 0.498 g cm<sup>-3</sup>, with a mean value of  
32  
33 401 0.118 ± 0.069 g cm<sup>-3</sup> (1 standard deviation (S.D.)). A one-way analysis of variance  
34  
35 402 (ANOVA) reveals an effect of peat type on bulk density ( $F(10709) = 941, p < 0.0001$ ),  
36  
37 403 with all peat types significantly different from each other on the basis of post-hoc  
38  
39 404 Tukey's LSD tests ( $p < 0.0001$ ). In increasing order, mean bulk density of the peat types  
40  
41 405 is *Sphagnum* < Woody < Herbaceous < Brown Moss < Humified (Table 1).  
42  
43  
44  
45

46 406  
47  
48 407 Organic matter content (n = 18,973) has a mean value of 90.7 ± 13% (1 S.D.) and a  
49  
50 408 median of 95.7%. The ANOVA reveals an effect of peat type on organic matter content  
51  
52 409 ( $F(9512) = 349, p < 0.0001$ ), with all peat types significantly different from each other  
53  
54  
55  
56  
57  
58  
59  
60

1  
2  
3 410 (Tukey's LSD:  $p < 0.0001$ ). In decreasing order, mean organic matter content of the peat  
4  
5 411 types is *Sphagnum* > Woody > Herbaceous > Brown Moss > Humified (Table 1).  
6  
7

8 412

9  
10 413 Organic matter bulk density ( $n = 18,544$ ) ranges from 0.003 to 0.452 g OM cm<sup>-3</sup>, with a  
11  
12 414 mean value of  $0.105 \pm 0.051$  g OM cm<sup>-3</sup> (1 S.D.). The ANOVA reveals an effect of peat  
13  
14 415 type on organic matter density ( $F(9081) = 942$ ,  $p < 0.0001$ ), with all peat types  
15  
16 416 significantly different from each other (Tukey's LSD:  $p < 0.0001$ ). In increasing order,  
17  
18 417 mean organic matter density of the peat types is *Sphagnum* < Herbaceous < Woody <  
19  
20 418 Brown Moss < Humified (Table 1).  
21  
22  
23

24 419

25  
26  
27 420 C content in total peat ( $n = 3741$ ) ranges from 30 to 60%, with a mean value of  $46.8 \pm$   
28  
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  
32  
33 423 eastern Russia, the highest values (> 55%) are characteristic of sites located in the  
34  
35 424 western European Islands and Fennoscandia. The ANOVA reveals an effect of peat type  
36  
37 425 on C% ( $F(2494) = 161$ ,  $p < 0.0001$ ), with *Sphagnum* samples significantly different from  
38  
39 426 other peat types (Tukey's LSD:  $p < 0.0001$ ). Herbaceous and woody peats are distinct  
40  
41 427 from other types, but indistinguishable from one another (Tukey's LSD:  $p = 0.238$ ).  
42  
43 428 Likewise, humified and brown moss peats are distinct from other types, but  
44  
45 429 indistinguishable from each other (Tukey's LSD:  $p = 0.448$ ). In increasing order, mean  
46  
47 430 C% of the peat types is *Sphagnum* < Humified = Brown Moss < Herbaceous = Woody  
48  
49 431 (Table 1). The frequency distribution of C% in peat is also characterized by a second,  
50  
51 432 though minor, mode at 40% (Figure 3d). The latter is mostly associated with *Sphagnum*  
52  
53  
54  
55  
56  
57  
58  
59  
60

1  
2  
3 433 peat samples, as their average C% is significantly lower than those for other peat types  
4  
5 434 (Table 1). This difference is likely caused by the high content of complex and recalcitrant  
6  
7  
8 435 compounds found in *Sphagnum* tissues such as lipids and waxes, which have lower C%  
9  
10 436 than more labile biopolymers such as cellulose (Cagnon et al., 2009).

11  
12  
13 437

14  
15 438 On the basis of 995 samples for which both OM% and C% were quantified, we  
16  
17 439 developed conversion factors (slopes of linear regressions) for several peat types to  
18  
19 440 estimate OC% (Figure 4). There is a noticeable difference between the slope of  
20  
21 441 *Sphagnum* peat ( $0.423 \pm 0.030$ ;  $n = 454$ ) and that of non-*Sphagnum* peat ( $0.514 \pm 0.024$ ;  
22  
23 442  $n = 308$ ). The C content in organic matter (OC%) for *Sphagnum* peat is smaller than  
24  
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  
28  
29 445 out of 454 samples) and extracted from raised bogs, it is very likely that our estimated  
30  
31 446 OC% biases towards young and undecomposed *Sphagnum*. This ‘young *Sphagnum* peat  
32  
33 447 effect’ heavily influenced the slope of the overall relation between C% and OM% ( $0.467$   
34  
35 448  $\pm 0.045$ ) due to the overrepresentation of *Sphagnum* samples in the dataset (454 out of  
36  
37 449 995 samples). To minimize this bias when estimating mean OC% in peat, all 304 young  
38  
39 450 *Sphagnum* samples were removed from the dataset, yielding an overall conversion factor  
40  
41 451 of  $0.492 \pm 0.024$ .

42  
43  
44  
45  
46  
47  
48 452

49  
50 453 N content in peat ( $n = 3365$ ) ranges from 0.04 to 3.39%, with a mean value of  $1.2 \pm 0.7\%$   
51  
52 454 (1 S.D.). The frequency distribution is asymmetric and characterized by a mode at 0.65%  
53  
54 455 (Figure 3e). The latter is largely due to the overrepresentation of *Sphagnum* peat samples  
55  
56  
57  
58  
59  
60

1  
2  
3 456 (having low N content) in our database. The ANOVA reveals an effect of peat type on N  
4  
5 457 content ( $F(2504) = 666, p < 0.0001$ ) with *Sphagnum* and herbaceous peat types  
6  
7 458 significantly different from each other and from all other types (Tukey's LSD:  $p <$   
8  
9 459 0.0001). Humified and brown moss peats are distinct from other types, but  
10  
11 460 indistinguishable from each other (Tukey's LSD:  $p = 0.113$ ). Likewise, woody and brown  
12  
13 461 moss peats are indistinguishable from one another (Tukey's LSD:  $p = 0.240$ ). In  
14  
15 462 increasing order, mean N% of the peat types is *Sphagnum* < Woody = Brown Moss =  
16  
17 463 Humified < Herbaceous (Table 1).  
18  
19  
20  
21  
22 464  
23  
24 465 C/N mass ratio ( $n = 3362$ ) ranges from 12 to 217, with a mean value of  $55 \pm 33$  (1 S.D.).  
25  
26 466 The frequency distribution is asymmetric and characterized by a mode at 25 (Figure 3f).  
27  
28 467 While the distribution mode (25) is associated with non-*Sphagnum* peat types, the  
29  
30 468 distribution mean (55) is skewed towards *Sphagnum* peat samples owing to their  
31  
32 469 overrepresentation in our database (Figures 3f). The ANOVA reveals an effect of peat  
33  
34 470 type on C/N ratio ( $F(2501) = 174, p < 0.0001$ ) with *Sphagnum* peat significantly  
35  
36 471 different from all other types (Tukey's LSD:  $p < 0.0001$ ). Woody peat is distinguishable  
37  
38 472 from all peat types except for brown moss peat (Tukey's LSD:  $p = 0.665$ ). Herbaceous  
39  
40 473 and humified peat types are indistinguishable from one another (Tukey's LSD:  $p =$   
41  
42 474 0.721). In decreasing order, the mean C/N ratio of peat types is *Sphagnum* > Woody =  
43  
44 475 Brown Moss > Humified = Herbaceous (Table 1).  
45  
46  
47  
48  
49  
50  
51  
52

53 477 Temporal changes in peat properties  
54  
55  
56  
57  
58  
59  
60

1  
2  
3 478 We find a decreasing trend in bulk density over the Holocene (Figure 5a), with the  
4  
5 479 densest peat characterizing the oldest samples (8-10 ka) and the least-dense peat  
6  
7 480 characterizing the youngest samples (0-2 ka). This trend is most likely attributable to the  
8  
9 481 progressive decomposition and subsequent compaction of peat over time, as well as to  
10  
11 482 higher ash content in early-stage peat (likely from fens). Conversely, a clear increasing  
12  
13 483 trend in organic matter content (OM%) is found over the Holocene (Figure 5b), with the  
14  
15 484 greatest OM% characterizing the youngest samples (0-2 ka) and the least OM%  
16  
17 485 characterizing the oldest samples (8-10 ka). This trend is most likely attributable to  
18  
19 486 higher inorganic material inputs during early-stage peatland development as well as to a  
20  
21 487 greater loss of OM in the deeper portions of peat profiles. Organic matter bulk density  
22  
23 488 (OMBD) remains relatively constant over the Holocene (Figure 5c) because of the  
24  
25 489 opposite trends exhibited by BD and OM% (Figures 5a, 5b). The only exceptions are the  
26  
27 490 low OMBD values characterizing the youngest samples (< 0.5 ka), probably due to the  
28  
29 491 large proportion of young, undecomposed *Sphagnum* peat samples.  
30  
31 492  
32  
33  
34  
35  
36  
37  
38  
39 493 C content in peat remains uniform over the Holocene (Figure 5d), except for slightly  
40  
41 494 lower C% during the late Holocene. We find a decreasing trend in N% over the  
42  
43 495 Holocene, such that young peat deposits are associated with low N% (Figure 5e). Peat  
44  
45 496 deposits older than 6 ka are mostly associated with low C/N ratios, whereas peat samples  
46  
47 497 younger than 6 ka are characterized by high C/N values (Figure 5f).  
48  
49  
50  
51 498  
52  
53 499 In general, *Sphagnum* peat is characterized by lower BD, OMBD, C%, N%, and C/N  
54  
55 500 ratio than samples composed of non-*Sphagnum* peat (Figure 6). Therefore, peatland  
56  
57  
58  
59  
60



1  
2  
3 501 development could explain much of the aforementioned temporal trends (Figure 5), as  
4  
5 502 early-stage rich fens are typically characterized by non-*Sphagnum* peat, whereas late-  
6  
7  
8 503 stage poor fens and bogs are *Sphagnum*-dominated (Figure 6h).  
9

10 504

11  
12  
13 505 *Spatial differences in peat properties*

14  
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  
18  
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  
30  
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  
34  
35 516 peatlands in Alaska, Kamchatka, and Japan might partly explain such low OM% values.  
36  
37  
38  
39  
40

41 517

42  
43 518 ***Peat inception ages and long-term rates of carbon and nitrogen accumulation***

44  
45 519 Calibrated ages (mid-point) for peat inception range from 0.6 to 15 ka and the frequency  
46  
47 520 distribution is characterized by a mode at 11-9 ka (Figure 2c). The latter corresponds with  
48  
49 521 peat inception peaks in the West Siberian Lowlands and in Alaska. In general, our  
50  
51 522 samples are in agreement with much larger networks of peat basal ages (Smith et al.,  
52  
53  
54  
55  
56  
57  
58  
59  
60

1  
2  
3 523 2004; MacDonald et al., 2006; Gorham et al., 2007; Korhola et al., 2010; Ruppel et al.,  
4  
5 524 2013; Yu et al., 2013).  
6  
7  
8 525  
9  
10 526 The time-weighted long-term rate of C accumulation averages  $22.9 \pm 2.0 \text{ g C m}^{-2} \text{ yr}^{-1}$   
11  
12 527 (standard error of mean (S.E.M.); Figure 7b). Values exhibit an increasing trend that  
13  
14 528 initially peaks during the early Holocene between 10 and 7.5 ka at  $27.0 \pm 2.6 \text{ g C m}^{-2} \text{ yr}^{-1}$ .  
15  
16  
17 529 This peak is largely caused by rapid peat accumulation in Alaska, the Western Siberia  
18  
19 530 Lowlands, and southeastern Canada. The remainder of the Holocene is characterized by a  
20  
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  
26  
27 534 apparent increase in accumulation over the past millennium ( $24\text{-}32 \text{ g C m}^{-2} \text{ yr}^{-1}$ ), as  
28  
29 535 young peat appears to be accumulating more quickly than old peat simply because the  
30  
31 536 former has undergone less decomposition than the latter (Clymo, 1984).  
32  
33  
34 537  
35  
36  
37  
38 538 The time-weighted long-term rate of N accumulation averages  $0.5 \pm 0.04 \text{ g N m}^{-2} \text{ yr}^{-1}$   
39  
40 539 (S.E.M.; Figure 7c). While the mid and late Holocene (6-0 ka) are characterized by the  
41  
42 540 lowest rates of N accumulation at  $0.34 \text{ g N m}^{-2} \text{ yr}^{-1}$ , the highest rates ( $0.61 \text{ g N m}^{-2} \text{ yr}^{-1}$ )  
43  
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  
47  
48 543 accumulation rate. The low rates of N accumulation over the past 6 ka might also relate  
49  
50 544 to the increasing presence and persistence of *Sphagnum* (having high C/N ratio and low  
51  
52 545 N concentration) in northern peatlands (Figures 6 and 7).  
53  
54  
55  
56  
57  
58  
59  
60

1  
2  
3 546  
4  
5

6 547 **Discussion**

7  
8 548 *Representativeness of the database for northern peatlands*

9  
10 549 The present database contains the most comprehensive compilation of peat properties and  
11  
12 550 C accumulation records for northern peatlands. The previous large-scale synthesis (Yu et  
13  
14  
15 551 al., 2009) only contained 33 sites and lacked records from the Hudson Bay lowlands and  
16  
17 552 the Russian Far East, and had limited sites from West Siberia and the western European  
18  
19  
20 553 Islands. The present database fills gaps from these regions.

21  
22 554

23  
24 555 However, European Russia, East Siberia, and the Russian Far East clearly remain poorly  
25  
26  
27 556 studied regions in terms of northern peat C stocks and accumulation histories (Figure 1).  
28  
29 557 A wetland map by Stolbovoi and McCallum (2002) suggests that shallow peaty deposits  
30  
31 558 (<50 cm) interspersed with few deeper peat bogs (>50 cm) dominate the Far East Russian  
32  
33  
34 559 landscape. Most of these deeper peatlands are presumably found in Kamchatka and  
35  
36 560 Sakhalin (Stolbovoi, 2002). This broad portrait is, however, based on fewer than 30 soil  
37  
38  
39 561 profiles from across East Siberia and Far East Russia (Stolbovoi et al., 2001), making it  
40  
41 562 difficult to evaluate the importance of this region in the northern peatland C cycle. In  
42  
43  
44 563 general, peat C stocks in Eastern Russia may not be as massive as those from West  
45  
46 564 Siberia or European Russia (Stolbovoi and McCallum, 2002). Therefore, understanding  
47  
48 565 how these shallow peatlands in East Siberia and the Russian Far East have developed  
49  
50 566 during the Holocene would provide useful end-members of climate controls of peat C  
51  
52  
53 567 accumulation, but these peatlands do not seem to represent a large missing C stock.

54  
55 568  
56  
57  
58  
59  
60

1  
2  
3 569 *Northern peatland soil properties: key findings and uncertainties*

4  
5  
6 570 Peat-carbon stocks

7  
8 571 Several studies have quantified the soil C density and total C pool of peatlands using  
9  
10 572 different approaches (e.g., Armentano and Menges, 1986; Gorham, 1991; Yu et al.,  
11  
12 573 2010). These methods have led to total C pool estimates for northern peatlands that vary  
13  
14 574 by at least a factor of two, from 234 to 547 GtC (Lappalainen, 1996; Yu et al., 2010; see  
15  
16 575 Yu, 2012 for a review). Many of these studies have combined mean peat depth, modern  
17  
18 576 peatland area, and a single mean C density value (BD x C% or OMBD x OC%) in their  
19  
20 577 calculations (e.g., Gorham, 1991). Applying Gorham's (1991) mean peat depth and  
21  
22 578 peatland area estimates to the mean BD and C% results from our database yields a C pool  
23  
24 579 estimate of 436 GtC (2.3 m x 3.42 Mkm<sup>2</sup> x 0.118 g cm<sup>-3</sup> x 47% C). However, it is well  
25  
26 580 documented that most peatlands undergo a shift from herbaceous to *Sphagnum* peat  
27  
28 581 during their developmental history (Hughes, 2000; Figure 6h) and that different BD, C%,  
29  
30 582 and rates of peat accumulation are associated with fen and bog peats (e.g., Vitt et al.,  
31  
32 583 2000; Figure 6). We also know that peat-C accumulation rates have varied  
33  
34 584 asynchronously between regions throughout the Holocene as a result of regional changes  
35  
36 585 in hydroclimatic conditions (e.g., Yu et al., 2009; Charman et al., 2013). Therefore, we  
37  
38 586 argue that reconstructing Holocene changes in peat C accumulation on the basis of  
39  
40 587 *measured* peat C density and reliable peat-core chronologies constitutes a step forward in  
41  
42 588 providing the best possible peat C stock estimates (see Yu et al., 2010 for an example). It  
43  
44 589 also allows for quantifying spatial and temporal differences in rates of peat C  
45  
46 590 accumulation, as well as the temporal trajectories of peat C fluxes to the atmosphere  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60

1  
2  
3 591 (MacDonald et al., 2006; Yu et al., 2013). However, better maps of the present peatland  
4  
5 592 area (and its change over time) are still needed to improve current peat C stock estimates.  
6  
7

8 593

9  
10 594 Carbon content in organic matter

11  
12 595 For each peat layer, peat C density can be estimated by the product of either (1) bulk  
13  
14 596 density and C content in total peat (BD x C%), or (2) ash-free bulk density and C content  
15  
16 597 in organic matter (OMBD x OC%). It could be argued that the first option is preferable  
17  
18 598 when estimating peat C stocks, as it produces values that are directly comparable to  
19  
20 599 routine soil C measurements from other terrestrial ecosystems. However, the present  
21  
22 600 database clearly indicates that the majority of peatland scientists routinely analyze  
23  
24 601 organic matter content (OM%; n = 18,973 samples) rather than C% (n = 3741 samples)  
25  
26 602 along peat cores. To provide a way to estimate OC% from OM%, we developed the  
27  
28 603 following conversion factors:  $42.3 \pm 3.0\%$  for *Sphagnum* peat,  $51.4 \pm 2.4\%$  for non-  
29  
30 604 *Sphagnum* peat, and  $49.2 \pm 2.4\%$  overall (Figure 4, Table 1).  
31  
32  
33  
34  
35

36 605

37  
38 606 While the overall peat and the non-*Sphagnum* peat conversion factors are in line with  
39  
40 607 those from previous studies (e.g., Gorham, 1991; Vitt et al., 2000; Turunen et al., 2002;  
41  
42 608 Beilman et al., 2009), the *Sphagnum* peat factor is lower than other estimates (e.g., Bauer  
43  
44 609 et al., 2006; Beilman et al., 2009; Table 3). Indeed, our mean OC% *Sphagnum* value at  
45  
46 610 42.3% is close to that of surface *Sphagnum* tissues, suggesting that it constitutes a valid  
47  
48 611 estimate for ash-free and poorly decomposed *Sphagnum* peat. As previously mentioned,  
49  
50 612 this bias towards low OC% is due to a large number of *Sphagnum* samples younger than  
51  
52 613 0.5 ka (304 out of 454 *Sphagnum* samples).  
53  
54  
55  
56  
57  
58  
59  
60

614

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.

623

#### 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 CH<sub>4</sub> 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

1  
2  
3 637 domain are needed to better our understanding of its impact on C sequestration and CH<sub>4</sub>  
4  
5 638 emissions.  
6

7  
8 639

9  
10 640 ***Holocene pattern of carbon accumulation in northern peatlands***

11  
12 641 The overall trajectory and shape of our Holocene peat C accumulation curve is similar to  
13  
14 642 the synthesis from a much smaller dataset (n = 33; Yu et al., 2009). As such, an early  
15  
16 643 Holocene peak during the Holocene Thermal Maximum (HTM) and an overall slowdown  
17  
18 644 of C accumulation during the mid- and late-Holocene, particularly after 4 ka during the  
19  
20 645 Neoglacial period and associated permafrost development, were found in both syntheses  
21  
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.)  
23  
24 647 presented here is approximately 24% higher than the estimate in Yu et al.'s 2009 study  
25  
26 648 ( $18.6 \text{ g C m}^{-2} \text{ yr}^{-1}$ ). Our larger dataset likely better represents the northern peatland C  
27  
28 649 accumulation rates. These results imply that current peat C stocks might be  
29  
30 650 underestimated.  
31  
32  
33  
34  
35

36 651

37  
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  
39  
40 653 peat-C accumulation rate for the remainder of the Holocene at  $22 \text{ g C m}^{-2} \text{ yr}^{-1}$ , we only  
41  
42 654 found a 2% difference in organic C density values between young ( $0.053 \pm 0.02 \text{ g C cm}^{-3}$ )  
43  
44 655 and old ( $0.057 \pm 0.03 \text{ g C cm}^{-3}$ ) peat samples. These results clearly show that the peak  
45  
46 656 value during the early Holocene cannot be mainly attributed to presumably dense peat  
47  
48 657 deposits that would be rich in recalcitrant C due to long-term decomposition and  
49  
50 658 compaction. Instead, factors influencing the rate of peat burial such as peat type  
51  
52 659 (*Sphagnum* vs. non-*Sphagnum* peat; Figure 6), growing season length, and other  
53  
54  
55  
56  
57  
58  
59  
60

1  
2  
3 660 environmental variables, must have been responsible for such high rates of C  
4  
5  
6 661 sequestration during the early Holocene.  
7  
8 662  
9  
10 663 The Holocene Thermal Maximum (HTM) is a well-documented period of orbitally-  
11  
12 664 induced warm climate in the northern high-latitude region (Kaufman et al., 2004;  
13  
14  
15 665 Renssen et al., 2012; Marcott et al., 2013) that reaches its maximum around 11 ka  
16  
17 666 (Berger and Loutre, 1991; Figure 7a). The peak in warm climatic conditions shows a  
18  
19  
20 667 transgressional pattern across northern North America that moved eastward with the  
21  
22 668 waning Laurentide Ice Sheet during the early and mid Holocene (Kaufman et al., 2004).  
23  
24  
25 669 This progressive increase in land availability coupled with warming summer conditions  
26  
27 670 have been proposed as the main controls on peatland inception and rapid C accumulation  
28  
29 671 across northern North America (Harden et al., 1992; Gorham et al., 2007, 2012; Yu et al.,  
30  
31 672 2009; Jones and Yu, 2010). In general, our results support the hypothesis that warm  
32  
33  
34 673 summers could promote peat formation and C sequestration (Beilman et al., 2009; Yu et  
35  
36 674 al., 2009; Charman et al., 2013), as the highest rates of C accumulation broadly coincide  
37  
38 675 with the peak in summer insolation from 11 to 7 ka (Figure 7). We acknowledge that  
39  
40 676 sufficient water input was necessary to allow for peatland development. Furthermore, the  
41  
42  
43 677 observed temporal asymmetry in peatland inception age and peaks in C accumulation  
44  
45  
46 678 rates between Alaska, western Canada, and the Hudson Bay Lowlands follows the  
47  
48 679 transgressional pattern of the HTM. For example, peat inception and highest peat C  
49  
50 680 accumulation rates occur at 11-9 ka in Alaska, whereas they are delayed in western  
51  
52  
53 681 Canada with peak values around 9-7 ka. These findings have important implications for  
54  
55 682 projecting the fate of peat-C stocks in a future warmer world.  
56  
57  
58  
59  
60



1  
2  
3 683  
4  
5  
6

684 The Neoglacial period is characterized by generally cooler and wetter conditions than the  
685 HTM (Figure 7a; Marcott et al., 2013). Particularly low C accumulation rates coincide  
686 with this time period across the northern peatland domain (Figure 7; Vitt et al., 2000;  
687 Jones and Yu, 2010). Peat accumulation processes might even have stopped in some  
688 regions (e.g., Peteet et al., 1998). The onset of permafrost aggradation in many peatlands  
689 also occurred during the Neoglacial period (Zoltai, 1971, 1995; Vitt et al., 2000; Oksanen  
690 et al., 2003; Sannel and Kuhry, 2008), reducing the peat C-sink capacity. In addition to  
691 shorter and cooler growing seasons, lower C accumulation rates in permafrost sites likely  
692 relates to a slower peat burial due to (1) more intense peat decomposition in the acrotelm  
693 due to drier surface conditions, and (2) a slower rate of peat formation and associated C  
694 inputs to soil because many peat plateaus are not *Sphagnum*-dominated. Overall, our  
695 results support the notion that climatic changes such as the HTM and the Neoglacial  
696 cooling impact C sequestration rates in peatlands.

697

### 698 ***Role of northern peatlands in the global nitrogen cycle***

699 As relatively few downcore peat N concentrations have been reported in the literature, it  
700 was difficult to compare our mean value of 1.2% to previous estimates. Bragazza et al.  
701 (2012) reported N content values of 0.7% for *Sphagnum fuscum* litter and 1.48% for  
702 *Eriophorum vaginatum* (herbaceous) litter, in line with our results (Table 1). Similarly,  
703 Turunen et al. (2004) documented peat N concentrations ranging from 0.35 to 2.25%  
704 (mean value of 0.8%) for the uppermost sections of 23 *Sphagnum* bogs across

1  
2  
3 705 northeastern Canada. Overall, these values closely match our findings for *Sphagnum*  
4  
5 706 (0.7%) and herbaceous (1.7%) peat types (Table 1).  
6  
7  
8 707  
9  
10 708 Using our peat C pool estimate of 436 Gt and assuming a mean C/N ratio of 45 yields a  
11  
12 709 peat N pool of 9.7 Gt, roughly equivalent to 10% of the global soil N pool at 95 Gt (Post  
13  
14 710 et al., 1985). This estimate is within the range proposed by Limpens et al. (2006) at 8-15  
15  
16 711 GtN. The Holocene time-weighted peat N accumulation rate of  $0.5 \pm 0.04 \text{ g N m}^{-2} \text{ yr}^{-1}$   
17  
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  
19  
20 713 et al., 2006). While the mid and late Holocene (6-0 ka) are characterized by the lowest  
21  
22 714 rates of peat-N accumulation at  $0.34 \text{ g N m}^{-2} \text{ yr}^{-1}$ , the highest rates ( $0.61 \text{ g N m}^{-2} \text{ yr}^{-1}$ )  
23  
24 715 occur between 12 and 6 ka (Figure 7c). The low rates of N accumulation over the past 6  
25  
26 716 ka might also relate to the increasing presence and persistence of *Sphagnum* peat (having  
27  
28 717 high C/N ratio and low N concentration) across the northern peatlands (Figures 6 and 7).  
29  
30 718 Overall, given the bias toward *Sphagnum*-dominated sites in our database, N pools and N  
31  
32 719 accumulation rates are probably underestimated.  
33  
34 720  
35  
36 721 Rapid N sequestration in peatlands during the early Holocene might have contributed to  
37  
38 722 the global decline in reactive N availability for terrestrial ecosystems (McLauchlan et al.,  
39  
40 723 2013), pointing to a potentially important and undocumented role of northern peatlands in  
41  
42 724 the global N cycle. These results also raise the important question of N provenance: in the  
43  
44 725 absence of large rates of atmospheric N deposition during the early Holocene, the only  
45  
46 726 process that could account for such a large N pool in peatlands is N fixation, either  
47  
48 727 through symbiotic or asymbiotic processes (Limpens et al., 2006).  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60

1  
2  
3 728

4  
5 729 The fate of these large peat N stocks remains largely unknown under recent and projected  
6  
7  
8 730 warming. Indeed, the importance of peatlands as sources of nitrous oxide (N<sub>2</sub>O) is just  
9  
10 731 emerging (e.g., Repo et al., 2009; Marushchak et al., 2011; Palmer et al., 2012), and  
11  
12 732 studies have suggested that reduced surface moisture or increasing temperatures might  
13  
14 733 significantly promote the production, transformation, and transport of dissolved N, and  
15  
16 734 N<sub>2</sub>O emissions to the atmosphere through denitrification (e.g., Kane et al., 2010). On the  
17  
18 735 contrary, some authors have speculated that the potential increase in peatland-N<sub>2</sub>O  
19  
20 736 emissions from climate change may not be significant relative to the global N<sub>2</sub>O budget  
21  
22 737 (e.g., Martikainen et al., 1993; Frohking et al., 2011). Overall, additional peat N cycling  
23  
24 738 studies are needed to address these remaining questions.  
25  
26  
27  
28  
29

30 739

31  
32 740 **Future directions**

33  
34 741 Peat core analysis has been extensively used over the past 20 years for estimating rates of  
35  
36 742 peat C accumulation at local, regional, and continental scales (e.g., Mäkilä, 1997; Clymo  
37  
38 743 et al., 1998; Vitt et al., 2000; Turunen et al., 2002; Mäkilä and Saarnisto, 2008; Yu et al.,  
39  
40 744 2010; van Bellen et al., 2011; Gorham et al., 2012). The present study analyzed a new  
41  
42 745 database that comprises 268 peat records from 215 northern peatland sites. This  
43  
44 746 systematic analysis of peat properties and Holocene C accumulation rates is essential for  
45  
46 747 accurately addressing the following general research topics in the future: (1) describing  
47  
48 748 and quantifying spatial and temporal patterns of Holocene peatland C and N  
49  
50 749 accumulation; (2) assessing the sensitivity of C and N accumulation to climate change;  
51  
52 750 (3) estimating peatland soil organic carbon (SOC) and soil organic nitrogen (SON) pools  
53  
54  
55  
56  
57  
58  
59  
60

1  
2  
3 751 at regional and hemispheric scales, (4) furthering our understanding of peatland C cycle –  
4  
5 752 climate linkages, and (5) providing the scientific community with a large dataset for  
6  
7  
8 753 developing and testing earth system and ecological models.  
9

10 754

### 11 12 755 **Acknowledgements**

13  
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  
33 764 Kamchatka (NSF ARC-1107981, ARC-1108116), and the United Kingdom (Yorkshire  
34  
35 765 Peat Partnership). Lehigh University's Library and Technology Services staff is  
36  
37 766 acknowledged for its support in building the web interface for the peatland database.  
38  
39 767 Finally, comments from Paul Glaser and two other journal reviewers improved the  
40  
41 768 overall quality of the manuscript.  
42  
43  
44  
45

46 769

### 47 48 770 **References**

49  
50 771 Armentano TV and Menges ES (1986) Patterns of change in the carbon balance of  
51 772 organic soil-wetlands of the temperate zone. *Journal of Ecology* 74: 755-774.  
52 773  
53 774 Bauer IE, Bhatti JS, Cash KJ, Tarnocai, C and Robinson SD (2006) Developing statistical  
54 775 models to estimate the carbon density of organic soils. *Canadian Journal of Soil Science*  
55 776 86: 295-304.  
56  
57  
58  
59  
60

- 1  
2  
3 777  
4 778 Beilman DW, MacDonald GM, Smith LC and Reimer PJ (2009) Carbon accumulation in  
5 779 peatlands of West Siberia over the last 2000 years. *Global Biogeochemical cycles* 23,  
6 780 GB1012. doi: 10.1029/2007GB003112.  
7 781  
8 782 Belyea LR (2009) Non-linear dynamics of peatlands and potential feedbacks on the  
9 783 climate system. In: Baird A, Belyea L, Comas X, Reeve A. and Slater L (Eds.), *Northern*  
10 784 *peatlands and carbon cycling*, American Geophysical Union Monograph Series,  
11 785 Washington D.C., USA, pp. 5-18.  
12 786  
13 787 Berger A and Loutre M-F (1991) Insolation values for the climate of the last 10 million  
14 788 years. *Quaternary Science Reviews* 10: 297-317.  
15 789  
16 790 Bergner K, Albano Å and Bohlin E (1990) The content of peat: a compilation of  
17 791 botanical, physical and chemical data of peat. Department of Agricultural Research,  
18 792 Northern Sweden, Swedish University of Agricultural Sciences.  
19 793  
20 794 Björck S and Clemmensen LB (2004) Aeolian sediment in raised bog deposits, Halland,  
21 795 SW Sweden: a new proxy record of Holocene winter storminess in southern Scandinavia?  
22 796 *The Holocene* 14: 677-688.  
23 797  
24 798 Blodau C (2002) Carbon cycling in peatlands - A review of processes and controls,  
25 799 *Environmental Reviews* 10: 111-134.  
26 800  
27 801 Bragazza L, Buttler A, Habermacher J, Brancaloni L, Gerdol R, Fritze H, Hanajik P,  
28 802 Laiho R and Johnson D (2012) High nitrogen deposition alters the decomposition of bog  
29 803 plant litter and reduces carbon accumulation. *Global Change Biology* 18: 1163-1172.  
30 804  
31 805 Bridgham SC, Megonigal JP, Keller JK, Bliss, NB and Trettin C (2006) The carbon  
32 806 balance of North American wetlands. *Wetlands* 26: 889-916.  
33 807  
34 808 Buffam I, Carpenter SR, Yeck W, Hanson PC and Turner MG (2010) Filling holes in  
35 809 regional carbon budgets: Predicting peat depth in a north temperate lake district. *Journal*  
36 810 *of Geophysical Research – Biogeosciences* 115, G01005, doi:10.1029/ 2009JG001034.  
37 811  
38 812 Cagnon B, Py X, Guillot A, Stoekli F and Chambat G (2009) Contributions of  
39 813 hemicellulose, cellulose and lignin to the mass and the porous properties of chars and  
40 814 steam activated carbons from various lignocellulosic precursors. *Bioresource Technology*  
41 815 100: 292-298.  
42 816  
43 817 Camill P (1999) Peat accumulation and succession following permafrost thaw in the  
44 818 boreal peatlands of Manitoba, Canada. *Ecoscience* 6: 592-602.  
45 819  
46 820 Chambers FM, Beilman DW and Yu Z (2011) Methods for determining peat  
47 821 humification and for quantifying peat bulk density, organic matter and carbon content for  
48 822 palaeostudies of climate and peatland carbon dynamics. *Mires and Peat* 7, article 7, 10 p.

- 1  
2  
3 823  
4 824 Charman D, Beilman D, Blaauw M, Booth RK, Brewer S, Chambers F, Christen JA,  
5 825 Gallego-Sala AV, Harrison SP, Hughes PDM, Jackson S, Korhola A, Mauquoy D,  
6 826 Mitchell F, Prentice IC, van der Linden M, De Vleeschouwer F, Yu Z, Alm J, Bauer IE,  
7 827 McCorish Y, Garneau M, Hohl V, Huang Y, Karofeld E, Le Roux G, Loisel J, Moschen  
8 828 R, Nichols JE, Nieminen TM, MacDonald GM, Phadtare NR, Rausch N, Sillasoo Ü,  
9 829 Swindles GT, Tuittila E-S, Ukonmaanaho L, Väiliranta M, van Bellen S, van Geel B, Vitt  
10 830 D and Zhao Y (2013) Climate-related changes in peatland carbon accumulation during  
11 831 the last millennium. *Biogeosciences* 10: 929-944. doi: 10.5194/bg-10-929-2013.  
12 832  
13 833 Clymo RS (1984) The limits to peat growth. *Philosophical Transactions of the Royal*  
14 834 *Society of London, Series B, Biological Sciences* 303: 605-654.  
15 835  
16 836 Clymo RS, Turunen J and Tolonen K (1998) Carbon accumulation in peatlands. *Oikos*  
17 837 81: 368-388.  
18 838  
19 839 Dean Jr WE (1974) Determination of carbonate and organic matter in calcareous  
20 840 sediments and sedimentary rocks by loss on ignition: comparison with other methods.  
21 841 *Journal of Sedimentary Petrology* 44: 242-248.  
22 842  
23 843 Frohking S and Roulet NT (2007) Holocene radiative forcing impact of northern peatland  
24 844 carbon accumulation and methane emissions. *Global Change Biology* 13: 1-10.  
25 845  
26 846 Frohking S, Talbot J, Jones MC, Treat CC, Kauffman JB, Tuittila E-S and Roulet N  
27 847 (2011) Peatlands in the Earth's 21<sup>st</sup> century coupled climate-carbon system.  
28 848 *Environmental Reviews* 19: 371-396.  
29 849  
30 850 Glaser PH, Volin JC, Givnish TJ, Hansen BCS and Stricker CA (2012) Carbon and  
31 851 sediment accumulation in the Everglades (USA) during the past 4000 years: rates,  
32 852 drivers, and sources of error. *Journal of Geophysical Research-Biogeosciences* 117,  
33 853 G03026. doi:10.1029/2011JG001821.  
34 854  
35 855 Gorham E (1990) Biotic impoverishment in northern peatlands. In: Woodwell GM (Ed.),  
36 856 *The Earth in transition: Patterns and processes of biotic impoverishment*. Cambridge  
37 857 University Press, New York, USA, pp. 65-98.  
38 858  
39 859 Gorham E (1991) Northern peatlands: role in the carbon cycle and probable responses to  
40 860 climatic warming. *Ecological Applications* 1: 182-195.  
41 861  
42 862 Gorham E, Lehman C, Dyke A, Janssens J and Dyke L (2007) Temporal and spatial  
43 863 aspects of peatland initiation following deglaciation in North America. *Quaternary*  
44 864 *Science Reviews* 26: 300-311.  
45 865  
46 866 Gorham E, Lehman C, Dyke A, Clymo D and Janssens J. (2012) Long-term carbon  
47 867 sequestration in North American peatlands. *Quaternary Science Reviews* 58: 77-82.  
48 868  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60

- 1  
2  
3 869 Harden JW, Sundquist ET, Stallard RF and Mark RK (1992) Dynamics of soil carbon  
4 870 during deglaciation of the Laurentide ice sheet. *Science* 258: 1921-1924.  
5 871  
6  
7 872 Heiri O, Lotter AF and Lemcke G (2001) Loss on ignition as a method for estimating  
8 873 organic and carbonate content in sediments: reproducibility and comparability of results.  
9 874 *Journal of Paleolimnology* 25: 101-110.  
10 875  
11 876 Hughes PDM (2000) A reappraisal of the mechanisms leading to ombrotrophy in British  
12 877 raised mires. *Ecology Letters* 3: 7-9.  
13 878  
14 879 Ireland AW, Booth RK, Hotchkiss SC and Schmitz JE (2013) A comparative study of  
15 880 within-basin and regional peatland development: implications for peatland carbon  
16 881 dynamics. *Quaternary Science Reviews* 61: 85-95.  
17 882  
18 883 Jones MC and Yu Z (2010) Rapid deglacial and early Holocene expansion of peatlands in  
19 884 Alaska. *Proceedings of the National Academy of Sciences* 107: 7347-7352.  
20 885  
21 886 Kane ES, Turetsky MR, Harden JW, McGuire AD and Waddington JM (2010) Seasonal  
22 887 ice and hydrologic controls on dissolved organic carbon and nitrogen concentrations in a  
23 888 boreal-rich fen. *Journal of Geophysical Research – Biogeosciences* 115, G04012. doi:  
24 889 10.1029/2010JG001366.  
25 890  
26 891 Kaufman DS, Ager TA, Anderson NJ, Anderson PM, Andrews JT, Bartlein PJ, Brubaker  
27 892 LB, Coats LL, Cwynar LC, Duvall ML, Dyke AS, Edwards ME, Eisner WR, Gajewski  
28 893 K, Geirsdottir A, Hu FS, Jennings AE, Kaplan MR, Kerwin MW, Lozhkin AV,  
29 894 MacDonald GM, Miller GH, Mock CJ, Oswald WW, Otto-Bliesner BL, Porinchu DF,  
30 895 Ruhland KR, Smol JP, Steig EJ, Wolfey BB (2004) Holocene thermal maximum in the  
31 896 western Arctic (0-180 °W). *Quaternary Science Reviews* 23: 529-560.  
32 897  
33 898 Korhola A, Ruppel M, Seppä H, Välranta M, Virtanen T and Weckström J (2010) The  
34 899 importance of northern peatland expansion to the late-Holocene rise of atmospheric  
35 900 methane. *Quaternary Science Reviews* 29: 611-617.  
36 901  
37 902 Lappalainen E (1996) General review on world peatlands and peat resources. In:  
38 903 Lappalainen E (Ed.), *Global Peat Resources*. International Peat Society, Jyska, pp. 53-56.  
39 904  
40 905 Limpens J, Heijmans MPD and Berendse F (2006) The nitrogen cycle in boreal  
41 906 peatlands. In: Wieder RK and Vitt DH (Eds.), *Boreal Peatland Ecosystems*. Ecological  
42 907 Studies Vol. 188, Springer-Verlag, Berlin Heidelberg, Germany, pp. 195-230.  
43 908  
44 909 MacDonald GM, Beilman DW, Kremenetski KV, Sheng Y, Smith LC and Valichko AA  
45 910 (2006) Rapid early development of circum-arctic peatlands and atmospheric CH<sub>4</sub> and  
46 911 CO<sub>2</sub> variations. *Science* 314: 285-288.  
47 912  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60

- 1  
2  
3 913 Mäkilä M (1997) Holocene lateral expansion, peat growth and carbon accumulation on  
4 914 Haukkasuo, a raised bog in southeastern Finland. *Boreas* 26: 1-14. doi:10.1111/j.1502-  
5 915 3885.1997.tb00647.x.  
6  
7 916  
8 917 Mäkilä M and Saarnisto M (2008) Carbon accumulation in boreal peatlands during the  
9 918 Holocene – impacts of climate variations. In: Strack, M. (Ed.), *Peatlands and climate*  
10 919 *change*. International Peat Society, Jyväskylä, Finland, pp. 24-43.  
11 920  
12 921 Maltby E and Immirzi P (1993) Carbon dynamics in peatlands and other wetland soils,  
13 922 regional and global perspectives. *Chemosphere* 27: 999-1023.  
14 923  
15 924 Marcott SA, Shakun JD, Clark PU and Mix AC (2013) A reconstruction of regional and  
16 925 global temperature for the past 11,300 years. *Science* 339: 1198-1201.  
17 926  
18 927 Martikainen PJ, Nykänen H, Crill P and Silvola J (1993) Effect of a lowered water-table  
19 928 on nitrous-oxide fluxes from northern peatlands. *Nature* 366: 51-53.  
20 929  
21 930 Marushchak ME, Pitkämäki A, Koponen H, Biasi C, Seppälä M and Martikainen PJ  
22 931 (2011) Hot spots for nitrous oxide emissions found in different types of permafrost  
23 932 peatlands. *Global Change Biology* 17: 2601-2614.  
24 933  
25 934 Mauquoy D and van Geel B (2007) Mire and Peat Macros. In: Elias S.A. (Ed.),  
26 935 *Encyclopedia of Quaternary Science*. vol. 3. Elsevier, Amsterdam, The Netherlands, pp.  
27 936 2315-2336.  
28 937  
29 938 McGuire AD, Anderson LG, Christensen TR, Dallimore S, Guo L, Hayes DJ, Heimann  
30 939 M, Lorenson TD, MacDonald RW and Roulet N (2009) Sensitivity of the carbon cycle in  
31 940 the Arctic to climate change. *Ecological Monographs* 79: 523-555.  
32 941  
33 942 McLaughlan KK, Williams JJ, Craine JM and Jeffers ES (2013) Changes in global  
34 943 nitrogen cycling during the Holocene epoch. *Nature* 495: 352-357.  
35 944  
36 945 Oksanen PO, Kuhry P and Alekseeva RN (2003) Holocene development and permafrost  
37 946 history of the Usinsk Mire, northeast European Russia. *Géographie Physique et*  
38 947 *Quaternaire* 57: 169-187.  
39 948  
40 949 Palmer K, Biasi C and Horn MA (2012) Contrasting denitrifier communities relate to  
41 950 contrasting N<sub>2</sub>O emission patterns from acidic peat soils in arctic tundra. *The ISME*  
42 951 *Journal* 6: 1058-1077.  
43 952  
44 953 Pelletier L, Moore TR, Roulet NT, Garneau M and Beaulieu-Audy V (2007) Methane  
45 954 fluxes from three peatlands in the La Grande Rivière watershed, James Bay lowland,  
46 955 Canada. *Journal of Geophysical Research – Biogeosciences* 112, G01018. doi:  
47 956 10.1029/2006JG000216.  
48 957  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60



- 1  
2  
3 958 Peteet D, Andreev A, Bardeen W and Mistretta F (1998) Long-term Arctic peatland  
4 959 dynamics, vegetation and climate history of the Pur-Taz region, Western Siberia. *Boreas*  
5 960 27: 115-126.  
6 961
- 7  
8 962 Piotrowska N, Blaauw M, Mauquoy D and Chambers FM (2011) Constructing deposition  
9 963 chronologies for peat deposits using radiocarbon dating. *Mires and Peat* 7, article 10, 14  
10 964 p.  
11 965
- 12  
13 966 Post WM, Pastor J, Zinke PJ and Stangenberger AG (1985) Global patterns of soil  
14 967 nitrogen storage. *Nature* 317: 613-616.  
15 968
- 16  
17 969 Reimer PJ, Baillie MGL, Bard E, Bayliss A, Beck JW, Bertrand C, Blackwell PG, Buck  
18 970 CE, Burr G, Cutler KB, Damon PE, Edwards RL, Fairbanks RG, Friedrich M, Guilderson  
19 971 TM, Hughen KA, Kromer B, McCormac FG, Manning S, Bronk Ramsey C, Reimer RW,  
20 972 Remmele S, Southon JR, Stuiver M, Talamo S, Taylor FW, van der Plicht J,  
21 973 Weyhenmeyer CE (2009) IntCal09 and Marine09 radiocarbon age calibration curves, 0–  
22 974 50,000 years cal BP. *Radiocarbon* 51: 1111-1150.  
23 975
- 24  
25 976 Renssen H, Seppä H, Crosta X, Goose H and Roche DM (2012) Global characterization  
26 977 of the Holocene Thermal Maximum. *Quaternary Science Reviews* 48: 7-19.  
27 978
- 28  
29 979 Repo ME, Susiluoto S, Lind SE, Jokinen S, Elsakov V, Biasi C, Virtanen T, Martikainen  
30 980 PJ (2009) Large N<sub>2</sub>O emissions from cryoturbated peat soil in tundra. *Nature Geoscience*  
31 981 2: 189-192.  
32 982
- 33  
34 983 Ruppel M, Väiliranta M, Virtanen T and Korhola A (2013) Postglacial spatiotemporal  
35 984 peatland initiation and lateral expansion dynamics in North America and northern  
36 985 Europe. *The Holocene*. doi:10.1177/0959683613499053.  
37 986
- 38  
39 987 Rydin H and Jeglum J (2013). *The biology of peatlands*. 2<sup>nd</sup> edition, Oxford University  
40 988 Press, Oxford, UK, 382 p.  
41 989
- 42  
43 990 Sannel ABK and Kuhry P (2008) Long-term stability of permafrost in subarctic peat  
44 991 plateaus, west-central Canada. *The Holocene* 18: 589-601.  
45 992
- 46  
47 993 Sheng Y, Smith LC, MacDonald GM, Kremenetski KV, Frey KE, Velichko AA, Lee M,  
48 994 Beilman DW and Dubinin P (2004) A high-resolution GIS-based inventory of the West  
49 995 Siberian peat carbon pool. *Global Biogeochemical Cycles* 18, GB3004. doi:  
50 996 10.1029/2003GB002190.  
51 997
- 52  
53 998 Smith, L.C., MacDonald, G.M., Velichko, A.A., Beilman, D.W., Borisova, O.K., Frey,  
54 999 K.E., Kremenetski, K.V., Sheng, Y. 2004. Siberian peatlands a net carbon sink and global  
55 1000 methane source since the Early Holocene. *Science*, 303, 353–356.  
56 1001
- 57  
58 1002 Stolbovoi V (2002) Carbon in Russian soils. *Climatic Change* 55: 131-156.  
59 1003  
60

- 1  
2  
3 1004 Stolbovoi V and McCallum I (2002) *Land resources of Russia*. International Institute for  
4 1005 Applied Systems Analysis. [www.iiasa.ac.at/Research/FOR/russia\\_cd/download.htm](http://www.iiasa.ac.at/Research/FOR/russia_cd/download.htm).  
5 1006  
6  
7 1007 Stolbovoi V, Montanarella L, Medvedev V, Smeyan N, Shishov L, Ungureanu V,  
8 1008 Dobrovolski G, Jamagne M, King D, Rozhkov V and Savin I (2001) Integration of data  
9 1009 on the soils of Russia, Byelorussia, Moldova and Ukraine into the Soil Geographic Database  
10 1010 of the European Community. *Eurasian Soil Science* 34: 687-703.  
11 1011  
12 1012 Stuiver M and Reimer PJ (1993) Extended <sup>14</sup>C database and revised CALIB radiocarbon  
13 1013 calibration program. *Radiocarbon* 35: 215-230.  
14 1014  
15 1015 Telford RJ, Heegaard E and Birks HJB (2004) All age-depth models are wrong: but how  
16 1016 badly? *Quaternary Science Reviews* 23: 1-5.  
17 1017  
18 1018 Troels-Smith J (1955) Characterization of unconsolidated sediments. Danmarks  
19 1019 Geologiske *Undersøgelse Series* 4: 1-73.  
20 1020  
21 1021 Turetsky MR, Wieder RK, Vitt DH, Evans RJ and Scott KD (2007) The disappearance of  
22 1022 relict permafrost in boreal North America: effects on peatland carbon storage and fluxes.  
23 1023 *Global Change Biology* 13: 1922-1934.  
24 1024  
25 1025 Turunen J, Tomppo E, Tolonen K and Reinikainen A (2002) Estimating carbon  
26 1026 accumulation rates of undrained mires in Finland – application to boreal and subarctic  
27 1027 regions. *The Holocene* 12: 69-80.  
28 1028  
29 1029 Turunen J, Roulet NT, Moore TR and Richard PJH (2004) Nitrogen deposition and  
30 1030 increased carbon accumulation in ombrotrophic peatlands in eastern Canada. *Global*  
31 1031 *Biogeochemical Cycles*, 18, GB3002. doi: 10.1029/2003GB002154.  
32 1032  
33 1033 van Bellen S, Dallaire P-L, Garneau M and Bergeron Y (2011) Quantifying spatial and  
34 1034 temporal Holocene carbon accumulation in ombrotrophic peatlands of the Eastmain  
35 1035 region, Quebec, Canada. *Global Biogeochemical Cycles* 25, GB2016.  
36 1036 doi:10.1029/2010GB003877.  
37 1037  
38 1038 Vitt DH, Halsey LA, Bauer IE and Campbell C (2000) Spatial and temporal trends in  
39 1039 carbon storage of peatlands of continental western Canada through the Holocene.  
40 1040 *Canadian Journal of Earth Sciences* 37: 683-693.  
41 1041  
42 1042 Yu Z (2011) Holocene carbon flux histories of the world's peatlands: global carbon-cycle  
43 1043 implications. *The Holocene* 21: 761-774.  
44 1044  
45 1045 Yu Z (2012) Northern peatland carbon stocks and dynamics: a review. *Biogeosciences* 9:  
46 1046 4071-4085.  
47 1047  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60

- 1  
2  
3 1048 Yu Z, Campbell ID, Campbell C, Vitt DH, Bond GC and Apps MJ (2003) Carbon  
4 1049 sequestration in western Canadian peat highly sensitive to Holocene wet-dry climate  
5 1050 cycles at millennial timescales. *The Holocene* 13: 801-808.  
6 1051  
7  
8 1052 Yu Z, Beilman DW and Jones MC (2009) Sensitivity of northern peatland carbon  
9 1053 dynamics to Holocene climate change. In: Baird A, Belyea L, Comas X, Reeve A, Slater  
10 1054 L (Eds.), *Northern peatlands and carbon cycling*. American Geophysical Union  
11 1055 Monograph Series, Washington D.C., USA, pp. 55-69.  
12 1056  
13  
14 1057 Yu Z, Loisel J, Brosseau DP, Beilman DW and Hunt SJ (2010) Global peatland dynamics  
15 1058 since the Last Glacial Maximum. *Geophysical Research Letters* 37, L13402. doi:10.1029/  
16 1059 2010GL043584.  
17 1060  
18  
19 1061 Yu Z, Loisel J, Turetsky MR, Cai S, Zhao Y, Frolking S, MacDonald GM and Bubier JL  
20 1062 (2013) Evidence for elevated emissions from high-latitude wetlands contributing to high  
21 1063 atmospheric CH<sub>4</sub> concentration in the early Holocene. *Global Biogeochemical Cycles* 27:  
22 1064 131-140. doi:10.1002/GBC.20025.  
23 1065  
24  
25 1066 Zoltai SC (1971) Southern limit of permafrost features in peat landforms, Manitoba and  
26 1067 Saskatchewan. *Geological Association of Canada*, Special Paper 9, 305-310.  
27 1068  
28  
29 1069 Zoltai SC (1995) Permafrost distribution in peatlands of west-central Canada during the  
30 1070 Holocene warm period 6000 years B.P. *Géographie Physique et Quaternaire* 49: 45-54.  
31 1071

## 1072 **Figure and Table Captions**

1073 **Figure 1.** Location of study sites. Map showing the distribution of northern peatlands  
1074 (green area from Yu et al., 2010) and peatland sites included in this study (n = 215 sites,  
1075 including 268 peat cores). Long-term rate of peat-carbon accumulation was estimated  
1076 from 127 sites (151 peat cores; red and blue dots). The yellow dots represent cores for  
1077 which only peat properties (bulk density, organic matter content, etc.) were available and  
1078 synthesized. Refer to Supplementary Table 1 for details.

1079

1080 **Figure 2.** Overview of data availability for North America (black bars) and Eurasia  
1081 (white bars). (A) Number of cores (total = 238) containing information on  
1082 carbon/nitrogen ratio (n = 40), nitrogen content (n = 40), carbon content (n = 56), peat

1  
2  
3 1083 types (n = 83), organic matter bulk density (n = 184), organic matter content (n = 190),  
4  
5 1084 and bulk density (n = 214). (B) Number of cores (total = 151) with a dating quality better  
6  
7 1085 than two dates per 1000 years (n = 35), one to two dates per 1000 years (n = 52), and less  
8  
9 1086 than one date per 1000 years (n = 64). (C) Number of calibrated basal peat ages (median)  
10  
11 1087 in 500-year bins from the database (n = 199) compared to all northern hemisphere basal  
12  
13 1088 peat ages (median) in 200-year bins (n = 2559, MGK data from MacDonald et al., 2006,  
14  
15 1089 Gorham et al., 2007, Korhola et al., 2010).

16  
17 1090  
18  
19  
20  
21  
22 1091 **Figure 3.** Distribution histograms of peat properties in northern peatlands. (A) Frequency  
23  
24 1092 distribution of bulk density for unidentified peat type samples (white bars) and different  
25  
26 1093 peat types (color bars). (B) Frequency distribution of organic matter content for different  
27  
28 1094 peat types. (C) Frequency distribution of organic matter bulk density for different peat  
29  
30 1095 types. (D) Frequency distribution of carbon content for different peat types. (E)  
31  
32 1096 Frequency distribution of nitrogen content for different peat types. (F) Frequency  
33  
34 1097 distribution of carbon/nitrogen mass ratio for different peat types.

35  
36 1098  
37  
38  
39  
40  
41 1099 **Figure 4.** Relation between carbon content and organic matter content in northern  
42  
43 1100 peatlands. The slope of each regression line is used as a conversion factor for estimating  
44  
45 1101 carbon content from organic matter content.

46  
47 1102  
48  
49  
50 1103 **Figure 5.** Temporal patterns of peat properties (mean, standard deviation, and number of  
51  
52 1104 samples). (A) Bulk density. (B) Organic matter content. (C) Organic matter bulk density.

1  
2  
3 1105 (D) Carbon content. (E) Nitrogen content. (F) Carbon/Nitrogen mass ratio. White bars  
4  
5 1106 represent values that were based on a limited number of samples and peat records.  
6  
7

8 1107

9  
10 1108 **Figure 6.** Main differences between *Sphagnum* and non-*Sphagnum* peat samples. (A)  
11  
12 1109 Bulk density. (B) Organic matter bulk density. (C) Organic carbon bulk density. (D)  
13  
14 1110 Carbon content. (E) Nitrogen content. (F) Carbon/Nitrogen mass ratio. (G) Temporal  
15  
16 1111 pattern of organic C bulk density. (H) Proportional change in the number of peat records  
17  
18 1112 that are *Sphagnum*-dominated, presented as a percentage of the total number of records.  
19  
20 1113

21  
22 1114

23  
24 1115 **Figure 7.** Long-term apparent rate of carbon and nitrogen accumulation from northern  
25  
26 1116 peatlands (n = 127 sites). (A) Summer insolation at 60°N (data from Berger and Loutre,  
27  
28 1117 1991) and temperature anomaly from an 11,300-year reconstruction for the northern  
29  
30 1118 extra-polar region from 30 to 90°N (data from Marcott et al., 2013). Temperature  
31  
32 1119 anomaly was calculated based on the 1961-1990 temperature averages. (B) Mean peat-  
33  
34 1120 carbon accumulation rates (PCAR) and standard error in 500-year bins. The number of  
35  
36 1121 sites per 500-year bins is also presented. (C) Mean peat-nitrogen accumulation rates  
37  
38 1122 (PNAR) and standard error in 500-year bins. These values were obtained using different  
39  
40 1123 C/N values over time, as indicated by the line.  
41  
42  
43  
44  
45

46 1124

47  
48 1125 **Table 1.** Peat properties in northern peatlands. Means and standard deviations are  
49  
50 1126 presented, along with the number of samples (n).  
51  
52

53  
54  
55  
56  
57  
58  
59  
60

1  
2  
3 1127 **Table 2.** Northern peatland peat properties by regions. Means and standard deviations are  
4  
5  
6 1128 presented, along with the number of samples (n).

7  
8 1129

9  
10 1130 **Table 3.** Comparison of northern peatland peat properties estimates with other published  
11  
12 1131 values. Means and standard deviations are presented, along with the number of samples  
13  
14  
15 1132 (n) when available.

16  
17 1133

18  
19  
20 1134 **Supplementary Material**

21  
22 1135 **Table S1.** Summary information for the study sites included in the database.  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60

1 | A ~~Circum-Arctic~~ database and synthesis of northern peatland soil properties and

2 | Holocene carbon and nitrogen accumulation

3 |

4 | Running title

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

6 |

7 | Authors

8 | Julie Loisel<sup>1\*</sup>, Zicheng Yu<sup>1\*</sup>, David W. Beilman<sup>2</sup>, Philip Camill<sup>3</sup>, Jukka Alm<sup>4</sup>, Matthew J.

9 | Amesbury<sup>5</sup>, David Anderson<sup>6</sup>, Sofia Andersson<sup>7</sup>, Christopher Bochicchio<sup>1</sup>, Keith Barber<sup>8</sup>,

10 | Lisa R. Belyea<sup>9</sup>, Joan Bunbury<sup>10</sup>, Frank M. Chambers<sup>11</sup>, Daniel J. Charman<sup>5</sup>, François De

11 | Vleeschouwer<sup>12</sup>, Barbara Fiałkiewicz-Koziel<sup>13</sup>, Sarah A. Finkelstein<sup>14</sup>, Mariusz Galka<sup>13</sup>,

12 | Michelle Garneau<sup>15</sup>, Dan Hammarlund<sup>16</sup>, William Hinchcliffe<sup>5</sup>, James Holmquist<sup>17</sup>, Paul

13 | Hughes<sup>8</sup>, Miriam C. Jones<sup>18</sup>, Eric S. Klein<sup>1</sup>, Ulla Kokfelt<sup>19</sup>, Atte Korhola<sup>20</sup>, Peter Kuhry<sup>7</sup>,

14 | Alexandre Lamarre<sup>15</sup>, Mariusz Lamentowicz<sup>13</sup>, David Large<sup>21</sup>, Martin Lavoie<sup>22</sup>, Glen

15 | MacDonald<sup>17</sup>, Gabriel Magnan<sup>15</sup>, Markku Mäkilä<sup>23</sup>, Gunnar Mallon<sup>8</sup>, Paul Mathijssen<sup>20</sup>,

16 | Dmitri Mauquoy<sup>24</sup>, Julia McCarroll<sup>11</sup>, Tim R. Moore<sup>25</sup>, Jonathan Nichols<sup>26</sup>, Benjamin

17 | O'Reilly<sup>14</sup>, Pirita Oksanen<sup>27</sup>, Maara Packalen<sup>28</sup>, Dorothy Peteet<sup>26</sup>, Pierre J.H. Richard<sup>29</sup>,

18 | Stephen Robinson<sup>30</sup>, Tiina Ronkanen<sup>20</sup>, Mats Rundgren<sup>16</sup>, A. Britta K. Sannel<sup>7</sup>, Charles

19 | Tarnocai<sup>31</sup>, Tim Thom<sup>32</sup>, Eeva-Stiina Tuittila<sup>4</sup>, Merritt Turetsky<sup>33</sup>, Minna Väliranta<sup>20</sup>,

20 | Marjolein van der Linden<sup>34</sup>, Bas van Geel<sup>35</sup>, Simon van Bellen<sup>23</sup>, Dale Vitt<sup>36</sup>, Yan Zhao<sup>37</sup>,

21 | Weijian Zhou<sup>38</sup>

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 <sup>1</sup>Department of Earth and Environmental Sciences, Lehigh University, Bethlehem, PA  
28 18015, USA

29  
30 <sup>2</sup>Department of Geography, University of Hawaii – Manoa, Honolulu, HI 96822, USA

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

34  
35 <sup>4</sup>School of Forest Sciences, University of Eastern Finland, Joensuu, FI 80101, Finland

36  
37 <sup>5</sup>Department of Geography, University of Exeter, Exeter, EX4 4RJ, UK

38  
39 <sup>6</sup>Department of Geography, Eton College, Windsor, Berkshire SL4 6DW, UK

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

43  
44 <sup>8</sup>Geography and Environment, University of Southampton, Southampton, SO17 1BJ, UK

45  
46 <sup>9</sup>School of Geography, Queen Mary University of London, London, E1 4NS, UK

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

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

53  
54 <sup>12</sup>CNRS and Université de Toulouse, Castanet Tolosan, 31326, France

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

58  
59 <sup>14</sup>Department of Earth Sciences, University of Toronto, Toronto, ON M5S 3B1, Canada

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

63  
64 <sup>16</sup>Department of Geology, Lund University, Lund, SE-223 62, Sweden



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

- 1  
2  
3  
4  
5  
6  
7  
8 110 <sup>35</sup>Institute for Biodiversity and Ecosystem Dynamics, University of Amsterdam,  
9 111 Amsterdam, 1098 XH, The Netherlands  
10 112  
11 113 <sup>36</sup>Department of Plant Biology, Southern Illinois University, Carbondale, IL 62901, USA  
12 114  
13 115 <sup>37</sup>Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of  
14 116 Sciences, Beijing, 100101, China  
15 117  
16 118 <sup>38</sup>Institute 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](mailto:jul208@lehigh.edu) phone: 610-758-3660  
23  
24 123 Zicheng Yu email: [ziy2@lehigh.edu](mailto:ziy2@lehigh.edu) phone: 610-758-6751  
25

26 124

27  
28 125 Abstract

29  
30 126 Here we present results from the most comprehensive compilation of Holocene peat soil  
31  
32 127 properties with and associated Holocene carbon and nitrogen accumulation rates for  
33  
34 128 northern peatlands. Our database consists of 268 peat cores from 215 sites located north  
35  
36 129 of 45°N. It encompasses regions within which peat carbon data have only recently  
37  
38 130 become available, such as the West Siberia Lowlands, and the Hudson Bay Lowlands,  
39  
40 131 Kamchatka in Far East Russia, and the Tibetan Plateau. For all northern peatlands, carbon  
41  
42 132 content in organic matter was estimated at  $42.3 \pm 3\%$  (S.D.) for *Sphagnum* peat,  $51.3 \pm$   
43  
44 133  $2\%$  for non-*Sphagnum* peat, and at  $49.2 \pm 2\%$  overall. Dry bulk ~~Bulk~~ density averaged  
45  
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  
47  
48 135 carbon content in peat averaged  $46.847 \pm 6.4\%$ . In general, large differences were found  
49  
50 136 between *Sphagnum* and non-*Sphagnum* peat types in terms of peat properties. Time-  
51  
52 137 weighted peat carbon accumulation rates averaged  $232.9 \pm 2$  (S.E.M.)  $\text{g C m}^{-2} \text{ yr}^{-1}$   
53  
54  
55  
56  
57  
58  
59  
60

1  
2  
3  
4  
5  
6  
7  
8 138 during the Holocene on the basis of 151 peat cores from 127 sites, with the highest rates  
9  
10 139 of carbon accumulation (25-28 g C m<sup>-2</sup> yr<sup>-1</sup>) recorded during the ~~warmer than today~~ early  
11  
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>.  
19  
20 144

#### 21 145 Keywords

22  
23  
24 146 Northern peatlands, Data synthesis, Climate change, Soil carbon and nitrogen,  
25  
26 147 Biogeochemical cycles, Long-term ecosystem dynamics  
27  
28 148

#### 29 149 **Introduction**

30  
31 150 Of all terrestrial ecosystems, peatlands are arguably the most efficient at sequestering  
32  
33 151 carbon (C) over long time scales. Northern peatlands cover approximately 4,000,000 km<sup>2</sup>  
34  
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-  
38  
39 154 day the global soil organic carbon (SOC) pool (Gorham, 1991; Bridgham et al., 2006; Yu  
40  
41 155 et al., 2010). These ecosystems have also ~~been playing~~ played a dynamic role in the  
42  
43 156 Holocene global C cycle as important sinks of carbon dioxide (CO<sub>2</sub>) and major sources of  
44  
45 157 methane (CH<sub>4</sub>) to the atmosphere (Frolking and Roulet, 2007; Korhola et al., 2010; Yu,  
46  
47 158 2011). As climate warming positively affects both plant growth and organic matter  
48  
49 159 decomposition. ~~r~~Recent and projected climate change could shift the balance between  
50  
51 160 peat production and organic matter decomposition, potentially affecting the peatland C-  
52  
53  
54  
55  
56  
57  
58  
59  
60

1  
2  
3  
4  
5  
6  
7  
8  
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  
11  
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).

21  
22 168  
23  
24 169 | Very little is known about the nitrogen (N) budget that accompanies C accumulation in  
25  
26 170 | northern peatlands (but see Limpens et al., 2006 for a review). Assuming a net C  
27  
28 171 | sequestration of ~270 GtC (Yu, 2012) and a C/N ratio of 20-30 for fen peat (Bergner et  
29  
30 172 | al., 1990; Rydin and Jeglum, 2013; results therein) during the early Holocene (11-7 ka),  
31  
32 173 | about 10-13 GtN would have been required to build such peat deposits. It is therefore  
33  
34 174 | possible that northern peatlands have been playing an undocumented, dynamic role in the  
35  
36 175 | Holocene global N cycle as important sinks of N, potentially limiting the amount of N  
37  
38 176 | available for other ecosystems at the global scale (McLauchlan et al., 2013).  
39  
40 177 | Alternatively, if the main N input to peatlands was through N<sub>2</sub> fixation by cyanobacteria,  
41  
42 178 | these microorganisms might have been more important in driving the C cycle in  
43  
44 179 | peatlands than previously thought. Overall, studying the coupling between N and C  
45  
46 180 | cycling in northern peatlands is essential for a better understanding of how key  
47  
48 181 | biogeochemical processes interact in these systems and for predicting the future of peat C  
49  
50 182 | stocks.

51 183

1  
2  
3  
4  
5  
6  
7  
8  
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 ~~of 45 °N or at high elevations (e.g., Tibetan Plateau).~~ This synthesis encompasses regions  
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  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60

1  
2  
3  
4  
5  
6  
7  
8  
9 206 northern peat C and N stocks for northern peatlands on the basis of the expanded  
10 207 database.  
11  
12 208  
13  
14 209 Database and ~~Database and analytical methods~~ analysis  
15  
16 210 *Databasebase*  
17  
18 211 We compiled a dataset of 268 published and unpublished Holocene peat records from  
19  
20 212 215 sites located in North America and Eurasia (Figure 1, Supplementary Table 1). The  
21  
22 213 difference in the number of peat cores and peatland sites is due to the fact that, in a few  
23  
24 214 instances, multiple cores were collected from a single peatland. As these multiple cores  
25  
26 215 were not designed as true replicates in the original publications, each of these cores was  
27  
28 216 considered as an independent record of peat properties in the present study. However,  
29  
30 217 only the oldest core for each site was ~~accounted used~~ for ~~when~~ estimating peat inception  
31  
32 218 age. Finally, when calculating peat ~~-C~~ carbon accumulation rates, ~~estimates, multiple~~  
33  
34 219 cores from a single site were each attributed an equal fraction of the weight for that site.  
35  
36 220 For example, for a site with three cores, the peat ~~-C~~ accumulation history of each core  
37  
38 221 only accounted for 1/3 of ~~a record~~ the site's record.  
39  
40 222  
41  
42 223 The latitude of most peatland sites ranges ~~ed~~ from 45 to 69 °N. The cutoff at 45 °N  
43  
44 224 represents the southern limit for defining what is considered to be the area contributing to  
45  
46 225 the C cycle of the Arctic region (McGuire et al., 2009). ~~with the exception of~~ Four high-  
47  
48 226 elevation ~~three high elevation~~ sites found in China (the Tibetan Plateau) and Japan were  
49  
50 227 also included, as they developed under similar 'northern' climatic conditions. The name  
51  
52 228 and coordinates of these four sites are as follows: Zoige (33.5 °N, 102.6 °E), Hongyuan  
53  
54  
55  
56  
57  
58  
59  
60

1  
2  
3  
4  
5  
6  
7  
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  
9  
10 230 | 155 cores originate from Eurasia, ~~comprising including~~ 112 cores from Russia. The  
11  
12 231 | remaining 113 cores come from North America, ~~including 12 cores from Alaska~~.  
13  
14 232 | Approximately 40% of all cores were collected ~~from in~~ ombrotrophic bogs (n = [110](#)  
15  
16 233 | ~~cores08~~) and 20% were extracted from minerotrophic fens (n = [50 cores](#)). The remainder  
17  
18 234 | (40%) was collected in ~~permafrost~~ peatlands ~~currently affected by permafrost~~ (n = [108](#)  
19  
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  
23  
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,  
27  
28 239 | all of which impact long-term rates of peat ~~-~~C sequestration (Rydin and Jeglum,  
29  
30 240 | [20132006](#)). Bogs are ~~nutrient mineral~~-poor, rain-fed peatland ecosystems with relatively  
31  
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~~  
35  
36 243 | ~~nutrients mineral nutrients from the groundwater~~. Generally speaking, ~~they fens~~ have  
37  
38 244 | greater NPP but also faster peat decay rates than bogs (Blodau, 2002). Finally, in the sub-  
39  
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)  
47  
48 249 | were grouped under the peatland type ‘permafrost peatlands’. Original peatland  
49  
50 250 | categories can be found in Supplementary Table 1.  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60

1  
2  
3  
4  
5  
6  
7  
8  
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  
12 254 | which bulk density or organic matter bulk density data were available. Information  
13  
14 255 | related to peat-core location, peatland type, peat properties, age, and data source can be  
15  
16 256 | found in Supplementary Table 1. Additional information related to the type of coring  
17  
18 257 | device used and the year of coring can be found in the original publications. Data ~~and~~  
19  
20 258 | ~~age depth relationships~~ used in this synthesis are readily accessible from the Holocene  
21  
22 259 | Peatland Carbon Network website (<https://www.peatlands.lehigh.edu>). ~~The website~~  
23  
24 260 | ~~includes all published records and will be updated as new records included in this~~  
25  
26 261 | ~~synthesis are eventually published.~~ This database ~~should will~~ be useful in future studies  
27  
28 262 | of ecosystem – ~~earbon~~-C cycle – climate interactions and for modeling long-term  
29  
30 263 | peatland dynamics.  
31  
32 264

33 265 | In the following sub-sections, we present the criteria for site selection and the protocols  
34  
35 266 | used to develop the ~~data~~dataset. In an effort to only analyze and synthesise *peat* samples,  
36  
37 267 | inorganic-rich horizons often found at the base of the peat cores were removed from the  
38  
39 268 | database. When available, stratigraphic information was used to distinguish peat vs. non-  
40  
41 269 | peat material. For example, gyttja (organic-rich lake sediments) was excluded from the  
42  
43 270 | dataset, as well as marshy, clayey, and silty sediments. When stratigraphic information  
44  
45 271 | was not available, a bulk density value of  $0.5 \text{ g cm}^{-3}$  was used as a cut-off between peat  
46  
47 272 | and non-peat material. This value was chosen on the basis of stratigraphic information  
48  
49 273 | from peatland records where peaty sediments with bulk density values up to  $0.5 \text{ g cm}^{-3}$   
50  
51 274 | were identified. We ~~do~~ acknowledge that this cut-off value is arbitrary, and that our  
52  
53  
54  
55  
56  
57  
58  
59  
60



1  
2  
3  
4  
5  
6  
7  
8 275 dataset likely contains some non-peat samples. Inorganic horizons (e.g., tephra layers)

9  
10 276 | were also excluded from the [peat records database](#).

11  
12 277

13  
14 278 Peat properties

15  
16 279 | A [subset-total](#) of 232 peat cores (181 sites) ~~were was~~ used for characterizing peat

17  
18 280 | properties, though not all cores have all [types of](#) peat properties available (Figure 2a).

19  
20 281 | This dataset contains 139 cores from Eurasia (including 109 cores from Russia) and 93

21  
22 282 | cores from North America (Figure 1). While approximately half of these cores ~~were as~~

23  
24 283 | sampled and analyzed at high resolution (1-5 cm increments), the ~~remainder-wremainder~~

25  
26 284 | ~~was as~~ sampled at lower resolution, typically at 10 cm increments. ~~Dry b~~Bulk density

27  
28 285 | (BD; g cm<sup>-3</sup>), organic matter content (OM%; gravimetric %), as well as elemental C and

29  
30 286 | N concentration values were compiled and synthesized. On the basis of these raw

31  
32 287 | datasets, [carbon-to-nitrogen-ratio](#) (C/N mass ratio) and organic matter bulk density

33  
34 288 | (OMBD; g OM cm<sup>-3</sup>) were calculated. These peat geochemical values are examined in

35  
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.

39  
40 291

41  
42 292 | Peat stratigraphic information was obtained for 83 peat cores ([‘peat types’ in](#) Figure 2a)

43  
44 293 | for which plant macrofossil analysis or detailed peat description had been performed

45  
46 294 | following standard techniques (e.g., Troels-Smith, 1955; Mauquoy and van Geel, 2007).

47  
48 295 | This peat stratigraphic information was condensed into the following five peat types:

49  
50 296 | *Sphagnum*, herbaceous, woody, brown moss, and humified peat. In a few cases, the

51  
52 297 | investigators only ascribed a general peat type to the samples (e.g., ‘bog’ vs. ‘fen’ peat, or

1  
2  
3  
4  
5  
6  
7  
8 298 ‘*Sphagnum*’ vs. ‘herbaceous’ peat). In these cases, the uncertainty associated with  
9  
10 299 classifying peat samples mostly relates to the uniformity of naming convention used  
11  
12 300 among the investigators. For example, a peat sample that contains sizable fractions of  
13  
14 301 brown moss and humified peat may be classified by an investigator as ‘brown moss peat’  
15  
16 302 and by another one as ‘humified peat’. We recognize that, due to their nature, brown  
17  
18 303 moss and humified peat types might be less uniform than *Sphagnum*, ~~or~~, herbaceous, ~~or~~  
19  
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.

25  
26 307

27  
28 308 Dry bulk density and organic matter concentration content were determined following  
29  
30 309 standard procedures; in all cases where these parameters were measured, were  
31  
32 310 determined following standard procedures (Dean, 1974; Chambers et al., 2011). Peat  
33  
34 311 samples of a known fresh volume were either freeze-dried or oven-dried at ca. 100 °C  
35  
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.  
39  
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  
43  
44 316 error associated with weighing. The product of bulk density (BD; g cm<sup>-3</sup>) and organic  
45  
46 317 matter content (OM%) of each peat sample was used to calculate organic matter bulk  
47  
48 318 density (OMBD; g OM cm<sup>-3</sup>), also referred to as ash-free bulk density (AFBD) or organic  
49  
50 319 bulk density (OBD) in the literature (Yu et al., 2003; Björck and Clemmensen, 2004). We  
51  
52 320 compiled a total of 21,220 bulk density measurements ~~from 214 cores~~, 18,973 organic

1  
2  
3  
4  
5  
6  
7  
8  
9 321 matter content values ~~from 190 cores~~, and computed 18,544 organic matter bulk density  
10 322 values ~~from 184 cores~~ (Figure 2a).

11  
12 323

13  
14 324 Total peat ~~carbon-C~~ and ~~nitrogen-N~~ content were directly measured by combustion and  
15 325 elemental analysis of dry peat samples (Chambers et al., 2011). We compiled 3741 C and  
16 326 3365 carbon-N measurements ~~from 56 cores and 3365 nitrogen content measurements~~  
17 327 ~~from 40 cores~~ (Figure 2a). We also computed a total of 3362 carbon to nitrogen ratio  
18 328 (C/N) mass ratio values ~~from 40 cores~~.

19  
20 329

21 330 Finally, the regression between ~~total~~ peat carbon-C content (C%) and peat organic matter  
22 331 content (OM%) for each peat type is presented as an estimate for carbon-C content in  
23 332 organic matter (OC%). A total of 995 samples ~~from 19 cores~~ were used in this analysis.  
24 333 The slope of each one of these regressions is interpreted as the 'conversion factor' from  
25 334 OM% to OC%, such that it provides an indirect way for estimating the C% content of  
26 335 ash-free peat for investigators who do not perform elemental C% measurements directly.

27 336

### 28 337 Peat-core chronology

29 338 Peat-core chronologies were almost exclusively based on radiocarbon ( $^{14}\text{C}$ ) dates that  
30 339 were determined mostly by accelerator mass spectrometry (AMS) on terrestrial plant  
31 340 macrofossils or bulk peat (Piotrowska et al., 2011). A few older chronologies were based  
32 341 on conventional  $^{14}\text{C}$  dating of bulk samples. Because no systematic offset has been  
33 342 observed in the  $^{14}\text{C}$  age of bulk vs. non-woody plant macrofossils ~~The use of bulk dates is~~  
34 343 ~~justified since the absence of a systematic offset between the  $^{14}\text{C}$  dates of bulk peat~~

1  
2  
3  
4  
5  
6  
7  
8  
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  $^{14}\text{C}$  ~~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.~~  
19  
20 350  
21  
22 351 Age-depth relationships were established for all continuous peat cores for which at least  
23  
24 352 five ~~radiocarbon dates ( $^{14}\text{C}$ )~~ age determinations were available (n = 151 cores). Except for  
25  
26 353 a few palynostratigraphic and tephrochronologic markers, nearly all records have  
27  
28 354 chronologies exclusively based on  $^{14}\text{C}$  ages (Supplementary Table 1). Chronologies were  
29  
30 355 obtained through linear interpolation of calibrated ages between dated horizons. Single-  
31  
32 356 age estimates were taken from the mid-point of each calibrated  $2\sigma$  probability  
33  
34 357 distribution. This parsimonious approach captures general patterns of temporal changes  
35  
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.,  
39  
40 360 Charman et al., 2013), we seek to make the fewest or simplest assumptions for this  
41  
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  
45  
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  
49  
50 365 taken into consideration when building age-depth relationships (Glaser et al., 2012).  
51  
52 366 Otherwise, peat records were assumed to be continuous.  
53  
54  
55  
56  
57  
58  
59  
60

367  
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 <sup>14</sup>C 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, <sup>14</sup>C dates per 1000 years (Figure 2b). These

Formatted: Superscript

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

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

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

Formatted: Superscript

1  
2  
3  
4  
5  
6  
7  
8  
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  
11  
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).  
19

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.  
427

428

428 Bulk density values ( $n = 21,220$ ) ranged from  $0.003$  to  $0.498 \text{ g cm}^{-3}$ , 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).  
434

435

1  
2  
3  
4  
5  
6  
7  
8  
9 435 Organic matter content (n = 18,973) has a mean value of  $90.7 \pm 13\%$  (1 S.D.) and a  
10 436 median of 95.7%. ~~The frequency distribution is presented in Figure 3b, the mean organic~~  
11 ~~matter content for each peat type is reported in Table 1, and regional differences are~~  
12 437 ~~presented in Table 2.~~ The ANOVA revealed an ~~significant~~ effect of peat type on organic  
13 438 matter content ( $F(9512) = 349, p < 0.0001$ ), with all peat types significantly different  
14 439 from each other (Tukey's LSD:  $p < 0.0001$ ). In decreasing order, mean organic matter  
15 440 content of the peat types ~~is~~ *Sphagnum* > Woody > Herbaceous > Brown Moss >  
16 441 Humified (Table 1).  
17  
18  
19  
20  
21  
22  
23  
24  
25

26 444 Organic matter bulk density ~~or ash-free bulk density~~ (n = 18,544) ranges from 0.003 to  
27 445  $0.452 \text{ g OM cm}^{-3}$ , with a mean value of  $0.105 \pm 0.051 \text{ g OM cm}^{-3}$  (1 S.D.). ~~The frequency~~  
28 446 ~~distribution is presented in Figure 3c, the mean organic matter density for each peat type~~  
29 447 ~~is reported in Table 1, and regional differences are presented in Table 2.~~ The ANOVA  
30 448 revealed an ~~significant~~ effect of peat type on organic matter density ( $F(9081) = 942, p <$   
31 449  $0.0001$ ), with all peat types significantly different from each other (Tukey's LSD:  $p <$   
32 450  $0.0001$ ). In increasing order, mean organic matter density of the peat types is *Sphagnum*  
33 451 < Herbaceous < Woody < Brown Moss < Humified (Table 1).  
34  
35  
36  
37  
38  
39  
40  
41  
42

43 453 ~~Total peat carbon C~~ content in total peat (n = 3741) ranges from 30 to 60%, with a mean  
44 454 value of  $46.8 \pm 6.1\%$  (1 S.D.) and a median of 47.8%. While the lowest values (< 35%)  
45 455 are almost exclusively associated with samples from Alaska, western Canada,  
46 456 Fennoscandia, and eastern Russia, the highest values (> 55%) are characteristic of sites  
47 457 located in the western European Islands and Fennoscandia. Mean C% values for all five  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60



1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60

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 ( $0.423 \pm 0.030$ ;  $n = 454$ ) 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~~

1  
2  
3  
4  
5  
6  
7  
8  
9 481 younger than 0.5 ka (304 out of 454 samples) and extracted from raised bogs, it is very  
10 482 likely that our estimated OC% biases towards young and undecomposed *Sphagnum*. This  
11  
12 483 ‘young *Sphagnum* peat effect’ heavily influenced the slope of the overall relation  
13  
14 484 between C% and OM% ( $0.467 \pm 0.045$ ) due to the overrepresentation of *Sphagnum*  
15  
16 485 samples in the dataset (454 out of 995 samples). To minimize this bias when estimating  
17  
18 486 mean OC% in peat, all 304 young *Sphagnum* samples were removed from the dataset,  
19  
20 487 yielding an overall conversion factor of  $0.492 \pm 0.024$ .  
21  
22 488  
23  
24 489 ~~Total peat nitrogen-N~~ content in peat (n = 3365) ~~range~~ from 0.04 to 3.39%, with a mean  
25  
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  
33  
34 494 ( $F(2504) = 666, p < 0.0001$ ) with *Sphagnum* and herbaceous peat types significantly  
35  
36 495 different from each other and from all other types (Tukey’s LSD:  $p < 0.0001$ ). Humified  
37  
38 496 and brown moss peats ~~are~~ distinct from other types, but indistinguishable from each  
39  
40 497 other (Tukey’s LSD:  $p = 0.113$ ). Likewise, woody and brown moss peats ~~are~~  
41  
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 <  
45  
46 500 Herbaceous (Table 1).  
47  
48 501  
49 502 C/N mass ratio (n = 3362) ~~range~~ from 12 to 217, with a mean value of  $55 \pm 33$  (1 S.D.).  
50  
51 503 The frequency distribution ~~is~~ asymmetric and characterized by, ~~with~~ a mode at 25  
52  
53  
54  
55  
56  
57  
58  
59  
60

1  
2  
3  
4  
5  
6  
7  
8 504 | (Figure 3f). While the distribution mode (25) ~~is~~ associated with non-*Sphagnum* peat  
9 |  
10 505 | types, the distribution mean (55) is skewed towards *Sphagnum* peat samples owing to  
11 |  
12 506 | their overrepresentation in our ~~samples database~~ (Figures 3f). The ANOVA revealed ~~an~~  
13 |  
14 507 | ~~significant~~ effect of peat type on C/N ratio ( $F(2501) = 174, p < 0.0001$ ) with *Sphagnum*  
15 |  
16 508 | peat significantly different from all other types (Tukey's LSD:  $p < 0.0001$ ). Woody peat  
17 |  
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  
23 |  
24 512 | *Sphagnum* > Woody = Brown Moss > Humified = Herbaceous (Table 1).  
25 |

513

514 | *Temporal changes in peat properties*515 | The frequency distribution is presented in Figure 3a

516

517 | We find a decreasing trend in bulk density over the Holocene (Figure 5a), with the518 | densest peat characterizing the oldest samples (8-10 ka) and the least-dense peat519 | characterizing the youngest samples (0-2 ka). This trend is most likely attributable to the520 | progressive decomposition and subsequent compaction of peat over time, as well as to521 | higher ash content in early-stage peat (likely from fens). Conversely, a clear increasing522 | trend in organic matter content (OM%) is found over the Holocene (Figure 5b), with the523 | greatest OM% characterizing the youngest samples (0-2 ka) and the least OM%524 | characterizing the oldest samples (8-10 ka). This trend is most likely attributable to525 | higher inorganic material inputs during early-stage peatland development as well as to a526 | greater loss of OM in the deeper portions of peat profiles. Organic matter bulk density

1  
2  
3  
4  
5  
6  
7  
8 527 (OMBD) remains relatively constant over the Holocene (Figure 5c) because of the  
9  
10 528 opposite trends exhibited by BD and OM% (Figures 5a, 5b). The only exceptions ~~except~~  
11  
12 529 ~~for~~are the low OMBD values characterizing the youngest samples (< 0.5 ka), probably  
13  
14 530 due to the large proportion of young, undecomposed *Sphagnum* peat samples.  
15  
16 531  
17  
18 532  
19  
20 533 While OMBD values closely tracked changes in bulk density during the mid and late  
21  
22 534 Holocene (0–8 ka), their trajectory diverged between 8 and 10 ka (Figure 4a and 4e)  
23  
24 535 because of decreasing organic matter content in early Holocene peat samples (Figure 4b).  
25  
26 536 C content in peat remains uniform over the Holocene (Figure 5d), except for slightly  
27  
28 537 lower C% during the late Holocene. However, as C values for early Holocene samples  
29  
30 538 are based on a very limited number of samples and peat records (white bars in Fig. 4d),  
31  
32 539 we caution against analysis or interpretation of the documented trend in our data. We also  
33  
34 540 find a decreasing trend in N% ~~content~~ over the Holocene, such that young peat deposits  
35  
36 541 are associated with low N% ~~content~~ (Figure 5e). This trend could be explained by a  
37  
38 542 progressive retention of N ~~downcore~~ as a result of long-term peat decomposition  
39  
40 543 processes and associated C loss (e.g., Kuhry and Vitt, 1996). Peat deposits older than 6 ka  
41  
42 544 are mostly associated with lower C/N ratios, whereas peat samples younger than 6 ka are  
43  
44 545 characterized by high C/N values (Figure 5f).  
45  
46 546  
47 547 In general, *Sphagnum* peat is characterized by lower BD, OMBD, C%, N%, and C/N  
48  
49 548 ratio than samples composed of non-*Sphagnum* peat (Figure 6). Therefore, peatland  
50  
51 549 development could explain much of the aforementioned temporal trends (Figure 5), as  
52  
53  
54  
55  
56  
57  
58  
59  
60

1  
2  
3  
4  
5  
6  
7  
8  
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

559

560

561

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.

1  
2  
3  
4  
5  
6  
7  
8 573  
9  
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  $\text{cm}^{-3}$ ). 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.  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40

582  
583  
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  
596  
597  
598  
599  
600

1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60

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).~~

603  
604 The time-weighted long-term rate of C accumulation averages ~~sd~~  $22.9 \pm 2.0$  g C m<sup>-2</sup> yr<sup>-1</sup>  
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~~ $27.0 \pm 2.6$  g C  
607 m<sup>-2</sup> yr<sup>-1</sup>. 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<sup>-2</sup> yr<sup>-1</sup>  
610 ~~and a time-weighted mean at  $22.0 \pm 1.9$  g C m<sup>-2</sup> yr<sup>-1</sup>, 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<sup>-2</sup>  
612 yr<sup>-1</sup>. Lack of decomposition probably explains most of the apparent increase in  
613 accumulation over the past millennium (24-32 g C m<sup>-2</sup> yr<sup>-1</sup>), 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).

616  
617 The time-weighted long-term rate of N accumulation averages  $0.5 \pm 0.04$  g N m<sup>-2</sup> yr<sup>-1</sup>  
618 (S.E.M.; Figure 7c). While the mid and late Holocene (6-0 ka) are characterized by the

1  
2  
3  
4  
5  
6  
7  
8 619 lowest rates of N accumulation at 0.34 g N m<sup>-2</sup> yr<sup>-1</sup>, the highest rates (0.61 g N m<sup>-2</sup> yr<sup>-1</sup>)  
9  
10 620 occur between 12 and 6 ka (Figure 7c). This trend mirrors that of C accumulation (Figure  
11  
12 621 7b), as C and N sequestration rates are both mainly influenced by peat density and its  
13  
14 622 accumulation rate. The low rates of N accumulation over the past 6 ka might also relate  
15  
16 623 to the increasing presence and persistence of *Sphagnum* (having high C/N ratio and low  
17  
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

Formatted: Comment Text



1  
2  
3  
4  
5  
6  
7  
8 642 stock, the high proportion of sites from large peatland complexes seems justified. On  
9  
10 643 another note, further studies of small depressional peatlands could potentially lead to a  
11  
12 644 better understanding of peat C accumulation processes and peatland sensitivity to climate  
13  
14 645 change (e.g., Buffam et al., 2010; Ireland et al., 2013). East Siberia, and the Russian Far  
15  
16 646 East clearly remain poorly studied regions in terms of northern peat C stocks and  
17  
18 647 accumulation histories (Figure 1). A wetland map by Stolbovoi and McCallum (2002)  
19  
20 648 suggests that shallow peaty deposits (<50 cm) interspersed with few deeper peat bogs  
21  
22 649 (>50 cm) dominate the Far East Russian landscape. Most of these deeper peatlands are  
23  
24 650 presumably found in Kamchatka and Sakhalin (Stolbovoi, 2002). This broad portrait is,  
25  
26 651 however, based on fewer than 30 soil profiles from across East Siberia and Far East  
27  
28 652 Russia (Stolbovoi et al., 2001), making it difficult to evaluate the importance of this  
29  
30 653 region in the northern peatland C cycle. In general, peat C stocks in Eastern Russia may  
31  
32 654 not be as massive as those from West Siberia or European Russia (Stolbovoi and  
33  
34 655 McCallum, 2002). Therefore, understanding how these shallow peatlands in East Siberia  
35  
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  
39  
40 658 represent a large missing C stock.

41 659

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

##### 45 661 Peat-carbon stocks and density

46  
47 662 Several studies have quantified the soil C density and total C pool of peatlands using  
48  
49 663 different approaches (e.g., Armentano and Menges, 1986; Gorham, 1991; Yu et al.,  
50  
51 664 2010). These ~~different~~ methods have led to total C pool estimates for northern peatlands

1  
2  
3  
4  
5  
6  
7  
8  
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,  
11  
12 667 modern peatland area, and a single mean ~~peat-C bulk~~-density value (BD x C% or OMBD  
13  
14 668 x OC%) in their calculations (e.g., Gorham, 1991). Applying Gorham's (1991) mean peat  
15  
16 669 depth and peatland area estimates to the mean BD and C% results ~~presented in this from~~  
17  
18 670 our database yields a ~~peat-C~~ pool estimate of 436 GtC (2.3 m x 3.42 Mkm<sup>2</sup> x 0.118 g cm<sup>-</sup>  
19  
20 671 <sup>3</sup> x 47% C). However, it is well documented that most peatlands undergo a shift from  
21  
22 672 herbaceous ~~fen~~-to *Sphagnum* ~~peatbog~~ during their developmental history (Hughes, 2000;  
23  
24 673 Figure 6h) and that different BD, C%, and rates of peat accumulation are associated with  
25  
26 674 fen and bog peats (e.g., Vitt et al., 2000; Figure 6). We also know that peat-C  
27  
28 675 accumulation rates have varied asynchronously between regions throughout the Holocene  
29  
30 676 as a result of regional changes in hydroclimatic conditions (e.g., Yu et al., 2009; Charman  
31  
32 677 et al., 2013). Therefore, we argue that reconstructing Holocene changes in peat-C  
33  
34 678 accumulation on the basis of *measured* peat C density ~~peat-C bulk density values~~ and  
35  
36 679 reliable peat-core chronologies constitutes a step forward in providing the best possible  
37  
38 680 peat-C stock estimates (see Yu et al., 2010 for an example). It also allows for  
39  
40 681 quantifying spatial and temporal differences in rates of peat-C accumulation, as well as  
41  
42 682 the temporal trajectories of peat-C fluxes to the atmosphere (MacDonald et al., 2006; Yu  
43  
44 683 et al., 2013). However, better maps of the present peatland area (and its change over  
45  
46 684 time) are still needed to improve current peat C stock estimates. Therefore, our database  
47  
48 685 should be of great use for updating current peat C stock estimates, as it contains the most  
49  
50 686 extensive set of peat-C bulk density measurements.  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60

1  
2  
3  
4  
5  
6  
7  
8 688 Carbon content in organic matter

9  
10 689 For each peat layer, peat ~~C~~carbon bulk density can be estimated by the product of either  
11  
12 690 (1) bulk density and ~~total peat C~~carbon content in total peat (BD x C%), or (2) ash-free  
13  
14 691 bulk density and ~~carbon C~~content in organic matter (OMBD x OC%). ~~It is important to~~  
15  
16 692 ~~mention that peat C stocks estimated using BD x C% or OMBD x OC% yield the same~~  
17  
18 693 ~~value. Whenever BD and C% measurements were available along peat cores, we used the~~  
19  
20 694 ~~former formula. However, when only OMBD was available, the second formula was~~  
21  
22 695 ~~used.~~ It could be argued that the first option is preferable when estimating peat ~~C~~C stocks,  
23  
24 696 as it produces values that are directly comparable to routine soil ~~C~~C measurements from  
25  
26 697 other terrestrial ecosystems. However, the present database clearly indicates that the  
27  
28 698 majority of peatland scientists routinely analyze organic matter content (OM%; n =  
29  
30 699 18,973 samples) rather than C% (n = 3741 samples) along peat cores. To provide a way  
31  
32 700 to estimate OC% from OM%, we developed the following conversion factors:  $42.3 \pm$   
33  
34 701  $3.0\%$  for *Sphagnum* peat,  $51.4 \pm 2.4\%$  for non-*Sphagnum* peat, and  $49.2 \pm 2.4\%$  overall  
35  
36 702 (Figure 4, Table 1).

37 703  
38  
39 704 While the overall peat and the non-*Sphagnum* peat conversion factors are in line with  
40  
41 705 those from previous studies (e.g., Gorham, 1991; Vitt et al., 2000; Turunen et al., 2002;  
42  
43 706 Beilman et al., 2009), the *Sphagnum* peat factor is lower than other estimates (e.g., Bauer  
44  
45 707 et al., 2006; Beilman et al., 2009; Table 3). Indeed, our mean OC% *Sphagnum* value at  
46  
47 708 42.3% is close to that of surface *Sphagnum* tissues, suggesting that it constitutes a valid  
48  
49 709 estimate for ash-free and poorly decomposed *Sphagnum* peat. As previously mentioned,

1  
2  
3  
4  
5  
6  
7  
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).

12 712 |

14 713 | Although each one of the three conversion factor slopes was significant ( $p < 0.0001$ ),  
15  
16 714 | there is a noticeable scatter in the data (Figure 4) that cannot solely be explained by the ~  
17  
18 715 | 1% analytical error associated with the loss-on-ignition procedure (Heiri et al., 2001).  
19  
20 716 | The progressive accumulation of recalcitrant C in old samples (lignin ~ 60% C vs.  
21  
22 717 | cellulose ~ 42% C), assuming it occurs at a greater rate than the loss of OM in the deeper  
23  
24 718 | portions of peat profiles, could explain why C% appears higher than our OC% conversion  
25  
26 719 | factors (Cagnon et al., 2009). The presence of inorganic C, particularly for the humified  
27  
28 720 | and brown moss peat types, could also explain these results. While the overall peat and  
29  
30 721 | the non-*Sphagnum* peat conversion factors are in line with those from previous studies  
31  
32 722 | (e.g., Gorham, 1991; Vitt et al., 2000; Turunen et al., 2002; Beilman et al., 2009), the  
33  
34 723 | *Sphagnum* peat factor is lower than other estimates. Indeed, our mean OC% *Sphagnum*  
35  
36 724 | value at 42% is close to that of surface *Sphagnum* tissues, suggesting that it constitutes a  
37  
38 725 | valid estimate for ash-free and poorly decomposed *Sphagnum* peat. As previously  
39  
40 726 | mentioned, this bias toward low OC% is due to a large number of *Sphagnum* samples  
41  
42 727 | younger than 0.5 ka (304 samples out of 454).

43 728 |

45 729 |

47 730 | Oligotrophication and the fen-to-bog transition in northern peatlands  
48  
49 731 | *Carbon content in organic matter*

Formatted: Font: Font color: Black

1  
2  
3  
4  
5  
6  
7  
8 732 The relation between total peat carbon content (C%) and peat organic matter content  
9 (OM%) is presented in Figure 4 (n = 995).  
10 733  
11 734  
12  
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,  
15 736  
16 1984; Yu et al., 2010; Table 3).  
17 737  
18 738  
19  
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 CH<sub>4</sub> 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 CH<sub>4</sub>  
33 751 emissions.  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60

Formatted: Subscript

Formatted: Subscript

1  
2  
3  
4  
5  
6  
7  
8 755 *Holocene pattern of ~~eireum-Arctic peatland~~ carbon accumulation in northern*  
9 *peatlands*  
10  
11 756  
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  
15  
16 759 shows an early Holocene peak during the Holocene Thermal Maximum (HTM) as well  
17  
18 760 as and an overall slowdown of carbon-C accumulation during the mid- and late-Holocene,  
19  
20 761 particularly after 4 ka during the Neoglacial period and associated permafrost  
21  
22 762 development. were found in both syntheses (Vitt et al., 2000; Figure 76). However, the  
23  
24 763 mean Holocene value of  $22.9 \pm 2.0$  g C m<sup>-2</sup> yr<sup>-1</sup> (1 S.E.) presented here is approximately  
25  
26 764 24% higher than the estimate in Yu et al.'s 2009 study (18.6 g C m<sup>-2</sup> yr<sup>-1</sup>). Our larger  
27  
28 765 dataset likely better represents the northern peatland -C accumulation rates ~~stock~~. These  
29  
30 766 results imply that current peat -C stocks might be underestimated.  
31  
32 767  
33 768 While the peak value at 27 g C m<sup>-2</sup> yr<sup>-1</sup> is about 23% higher than the time-weighted mean  
34  
35 769 peat-C accumulation rate for the remainder of the Holocene at 22 g C m<sup>-2</sup> yr<sup>-1</sup>, we only  
36  
37 770 found a 2% difference in organic C density values between young (0.053 ± 0.02 g C cm<sup>-3</sup>  
38  
39 771 ) and old (0.057 ± 0.03 g C cm<sup>-3</sup>) peat samples. These results clearly show that the peak  
40  
41 772 value during the early Holocene cannot be mainly attributed to presumably dense peat  
42  
43 773 deposits that would be rich in recalcitrant C due to long-term decomposition and  
44  
45 774 compaction. Instead, factors influencing the rate of peat burial such as peat type  
46  
47 775 (Sphagnum vs. non-Sphagnum peat; Figure 6), growing season length, and other  
48  
49 776 environmental variables, must have been responsible for such high rates of C  
50  
51 777 sequestration during the early Holocene.  
52  
53  
54  
55  
56  
57  
58  
59  
60

1  
2  
3  
4  
5  
6  
7  
8 778  
9  
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.  
31 799

1  
2  
3  
4  
5  
6  
7  
8 800 These findings have important implications for projecting the fate of peat-C stocks in a  
9 future warmer world.  
10 801  
11  
12 802  
13  
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.  
27 815  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40

#### 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



1  
2  
3  
4  
5  
6  
7  
8 823 | *Eriophorum vaginatum* (herbaceous) litter, ~~also~~ in line with our results (Table 1).  
9  
10 824 | Similarly, Turunen et al. (2004) documented peat N concentrations ranging from 0.35 to  
11  
12 825 | 2.25% (mean value of 0.8%) for the uppermost sections of 23 *Sphagnum* bogs across  
13  
14 826 | northeastern Canada. Overall, these values closely match our findings for *Sphagnum*  
15  
16 827 | (0.7%) and herbaceous (1.7%) peat types (Table 1).  
17  
18 828 |  
19  
20 829 | Using our peat C pool estimate of 436 Gt and assuming a mean C/N ratio of 45 yields a  
21  
22 830 | peat-N pool of 9.7 Gt, roughly equivalent to 10% of the global soil N pool at 95 Gt (Post  
23  
24 831 | et al., 1985). ~~This estimate is within the range proposed by Limpens et al. (2006) at 8-15~~  
25  
26 832 | ~~GtN. We also calculated 500-year bin N accumulation rates for the past 10,000 years by~~  
27  
28 833 | ~~combining our binned peat C accumulation rates with time-dependent C/N values.~~  
29  
30 834 | ~~Results indicate a~~The Holocene time-weighted peat-N accumulation rate ~~of~~  $0.5 \pm 0.04$   
31  
32 835 | ~~g N m<sup>-2</sup> yr<sup>-1</sup> (S.E.; Figure 76) is also in line with a previous estimate of 0.19-0.48 g N m<sup>-2</sup>~~  
33  
34 836 | ~~yr<sup>-1</sup> (Limpens et al., 2006).~~ While the mid and late Holocene (6-0-6 ka) ~~were~~  
35  
36 837 | characterized by the lowest rates of peat-N accumulation at  $0.34 \text{ g N m}^{-2} \text{ yr}^{-1}$ , the highest  
37  
38 838 | rates ( $0.61 \text{ g N m}^{-2} \text{ yr}^{-1}$ ) occurred ~~ed~~ between 126 and 642 ka (Figure 7c6). ~~This trend~~  
39  
40 839 | ~~mirrors that of C accumulation (Figure 6), as C and N sequestration rates are both~~  
41  
42 840 | ~~influenced by bulk density and peat accumulation rates.~~The low rates of N accumulation  
43  
44 841 | over the past 6 ka might also relate to the increasing presence and persistence of  
45  
46 842 | *Sphagnum* peat (having high C/N ratio and low N concentration) across the northern  
47  
48 843 | peatlands ~~as a result of the fen to bog transition~~ (Figures 6 and 76). Overall, given the  
49  
50 844 | ~~bias toward Sphagnum-dominated sites in our database, N pools and N accumulation~~  
51  
52 845 | ~~rates are probably underestimated.~~

1  
2  
3  
4  
5  
6  
7  
8 846  
9  
10 847 Rapid N sequestration in peatlands during the early Holocene might have contributed to  
11  
12 848 the global decline in reactive N availability for terrestrial ecosystems (McLaughlan et  
13  
14 849 al., 2013), pointing to a potentially important and undocumented role of northern  
15  
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  
19  
20 852 Holocene, the only process that could account for such a large N pool in peatlands is N  
21  
22 853 fixation, either through symbiotic or asymbiotic processes (Limpens et al., 2006).

23 854  
24  
25 855 The fate of these large peat-N stocks remains largely unknown under recent and  
26  
27 856 projected warming. Indeed, the importance of peatlands as sources of nitrous oxide (N<sub>2</sub>O)  
28  
29 857 is just emerging (e.g., Repo et al., 2009; Marushchak et al., 2011; Palmer et al., 2012),  
30  
31 858 and studies have suggested that reduced surface moisture or increasing temperatures  
32  
33 859 might significantly promote the production, transformation, and transport of dissolved N,  
34  
35 860 and N<sub>2</sub>O emissions to the atmosphere through denitrification (e.g., Kane et al., 2010). On  
36  
37 861 the contrary, some authors have speculated that the potential increase in peatland-N<sub>2</sub>O  
38  
39 862 emissions from climate change may not be significant relative to the global N<sub>2</sub>O budget  
40  
41 863 (e.g., Martikainen et al., 1993; Frohking et al., 2011). Overall, additional peat N cycling  
42  
43 864 studies are needed to address these remaining questions.

44  
45 865

#### 46 47 866 **Conclusions and future directions**

48  
49 867 Peat core analysis has been extensively used over the past 20 years for estimating rates of  
50  
51 868 peat-Carbon accumulation at local, regional, and continental scales (e.g., Mäkilä, 1997;  
52

1  
2  
3  
4  
5  
6  
7  
8 869 | Clymo et al., 1998; Vitt et al., 2000; Turunen et al., 2002; [Mäkilä and Saarnisto, 2008](#);  
9  
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  
17  
18 874 | general research topics in the future: (1) describing and quantifying spatial and temporal  
19  
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~~ --  
27  
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.

31 881

32  
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  
52  
53  
54  
55  
56  
57  
58  
59  
60

- 1  
2  
3  
4  
5  
6  
7  
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.](#)  
15  
16 896  
17  
18 897 **References**  
19  
20 898 Armentano TV and Menges ES (1986) Patterns of change in the carbon balance of  
21 899 organic soil-wetlands of the temperate zone. *Journal of Ecology* 74: 755-774.  
22 900  
23 901 Bauer IE, Bhatti JS, Cash KJ, Tarnocai, C and Robinson SD (2006) Developing statistical  
24 902 models to estimate the carbon density of organic soils. *Canadian Journal of Soil Science*  
25 903 86: 295-304.  
26 904  
27 905 Beilman DW, MacDonald GM, Smith LC and Reimer PJ (2009) Carbon accumulation in  
28 906 peatlands of West Siberia over the last 2000 years. *Global Biogeochemical cycles* 23,  
29 907 GB1012. doi: 10.1029/2007GB003112.  
30 908  
31 909 Belyea LR (2009) Non-linear dynamics of peatlands and potential feedbacks on the  
32 910 climate system. In: Baird A, Belyea L, Comas X, Reeve A. and Slater L (Eds.), *Northern*  
33 911 *peatlands and carbon cycling*, American Geophysical Union Monograph Series,  
34 912 Washington D.C., USA, pp. 5-18.  
35 913  
36 914 Berger A and Loutre M-F (1991) Insolation values for the climate of the last 10 million  
37 915 years. *Quaternary Science Reviews* 10: 297-317.  
38 916  
39 917 [Bergner K, Albano Å and Bohlin E \(1990\) The content of peat: a compilation of](#)  
40 918 [botanical, physical and chemical data of peat. Department of Agricultural Research,](#)  
41 919 [Northern Sweden, Swedish University of Agricultural Sciences.](#)  
42 920  
43 921 Björck S and Clemmensen LB (2004) Aeolian sediment in raised bog deposits, Halland,  
44 922 SW Sweden: a new proxy record of Holocene winter storminess in southern Scandinavia?  
45 923 *The Holocene* 14: 677-688.  
46 924  
47 925 Blodau C (2002) Carbon cycling in peatlands - A review of processes and controls,  
48 926 *Environmental Reviews* 10: 111-134.  
49 927  
50 928 Bragazza L, Buttler A, Habermacher J, Brancaleoni L, Gerdol R, Fritze H, Hanajik P,  
51 929 Laiho R and Johnson D (2012) High nitrogen deposition alters the decomposition of bog  
52 930 plant litter and reduces carbon accumulation. *Global Change Biology* 18: 1163-1172.  
53 931

- 1  
2  
3  
4  
5  
6  
7  
8 932 Bridgham SC, Megonigal JP, Keller JK, Bliss, NB and Trettin C (2006) The carbon  
9 933 balance of North American wetlands. *Wetlands* 26: 889-916.  
10 934
- 11 935 Buffam I, Carpenter SR, Yeck W, Hanson PC and Turner MG (2010) Filling holes in  
12 936 regional carbon budgets: Predicting peat depth in a north temperate lake district. *Journal*  
13 937 *of Geophysical Research – Biogeosciences* 115, G01005, doi:10.1029/2009JG001034.  
14 938
- 15 939 [Cagnon B, Py X, Guillot A, Stoeckli F and Chablat G \(2009\) Contributions of](#)  
16 940 [hemicellulose, cellulose and lignin to the mass and the porous properties of chars and](#)  
17 941 [steam activated carbons from various lignocellulosic precursors. \*Bioresource Technology\*](#)  
18 942 [100: 292-298.](#)  
19 943
- 20 944 Camill P (1999) Peat accumulation and succession following permafrost thaw in the  
21 945 boreal peatlands of Manitoba, Canada. *Ecoscience* 6: 592-602.  
22 946
- 23 947 Chambers FM, Beilman DW and Yu Z (2011) Methods for determining peat  
24 948 humification and for quantifying peat bulk density, organic matter and carbon content for  
25 949 palaeostudies of climate and peatland carbon dynamics. *Mires and Peat* 7, article 7, 10 p.  
26 950
- 27 951 Charman D, Beilman D, Blaauw M, Booth RK, Brewer S, Chambers F, Christen JA,  
28 952 Gallego-Sala AV, Harrison SP, Hughes PDM, Jackson S, Korhola A, Mauquoy D,  
29 953 Mitchell F, Prentice IC, van der Linden M, De Vleeschouwer F, Yu Z, Alm J, Bauer IE,  
30 954 McCorish Y, Garneau M, Hohl V, Huang Y, Karofeld E, Le Roux G, Loisel J, Moschen  
31 955 R, Nichols JE, Nieminen TM, MacDonald GM, Phadtare NR, Rausch N, Sillasoo Ü,  
32 956 Swindles GT, Tuittila E-S, Ukonmaanaho L, Väliranta M, van Bellen S, van Geel B, Vitt  
33 957 D and Zhao Y (2013) Climate-related changes in peatland carbon accumulation during  
34 958 the last millennium. *Biogeosciences* 10: 929-944. doi: 10.5194/bg-10-929-2013.  
35 959
- 36 960 Clymo RS (1984) The limits to peat growth. *Philosophical Transactions of the Royal*  
37 961 *Society of London, Series B, Biological Sciences* 303: 605-654.  
38 962
- 39 963 Clymo RS, Turunen J and Tolonen K (1998) Carbon accumulation in peatlands. *Oikos*  
40 964 81: 368-388.  
41 965
- 42 966 Dean Jr WE (1974) Determination of carbonate and organic matter in calcareous  
43 967 sediments and sedimentary rocks by loss on ignition: comparison with other methods.  
44 968 *Journal of Sedimentary Petrology* 44: 242-248.  
45 969
- 46 970 Frohling S and Roulet NT (2007) Holocene radiative forcing impact of northern peatland  
47 971 carbon accumulation and methane emissions. *Global Change Biology* 13: 1-10.  
48 972
- 49 973 Frohling S, Talbot J, Jones MC, Treat CC, Kauffman JB, Tuittila E-S and Roulet N  
50 974 (2011) Peatlands in the Earth's 21<sup>st</sup> century coupled climate-carbon system.  
51 975 *Environmental Reviews* 19: 371-396.  
52 976

- 1  
2  
3  
4  
5  
6  
7  
8 977 | [Glaser PH, Volin JC, Givnish TJ, Hansen BCS and Stricker CA \(2012\) Carbon and](#)  
9 978 | [sediment accumulation in the Everglades \(USA\) during the past 4000 years: rates,](#)  
10 979 | [drivers, and sources of error. \*Journal of Geophysical Research-Biogeosciences\* 117,](#)  
11 980 | [G03026. doi:10.1029/2011JG001821.](#)  
12 981 |  
13 982 | Gorham E (1990) Biotic impoverishment in northern peatlands. In: Woodwell GM (Ed.),  
14 983 | *The Earth in transition: Patterns and processes of biotic impoverishment*. Cambridge  
15 984 | University Press, New York, USA, pp. 65-98.  
16 985 |  
17 986 | Gorham E (1991) Northern peatlands: role in the carbon cycle and probable responses to  
18 987 | climatic warming. *Ecological Applications* 1: 182-195.  
19 988 |  
20 989 | Gorham E, Lehman C, Dyke A, Janssens J and Dyke L (2007) Temporal and spatial  
21 990 | aspects of peatland initiation following deglaciation in North America. *Quaternary*  
22 991 | *Science Reviews* 26: 300-311.  
23 992 |  
24 993 | Gorham E, Lehman C, Dyke A, Clymo D and Janssens J. (2012) Long-term carbon  
25 994 | sequestration in North American peatlands. *Quaternary Science Reviews* 58: 77-82.  
26 995 |  
27 996 | Harden JW, Sundquist ET, Stallard RF and Mark RK (1992) Dynamics of soil carbon  
28 997 | during deglaciation of the Laurentide ice sheet. *Science* 258: 1921-1924.  
29 998 |  
30 999 | [Heiri O, Lotter AF and Lemcke G \(2001\) Loss on ignition as a method for estimating](#)  
31 1000 | [organic and carbonate content in sediments: reproducibility and comparability of results.](#)  
32 1001 | [\*Journal of Paleolimnology\* 25: 101-110.](#)  
33 1002 |  
34 1003 | [Huguenes PDM \(2000\) A reappraisal of the mechanisms leading to ombrotrophy in](#)  
35 1004 | [British raised mires. \*Ecology Letters\* 3: 7-9.](#)  
36 1005 |  
37 1006 | Ireland AW, Booth RK, Hotchkiss SC and Schmitz JE (2013) A comparative study of  
38 1007 | within-basin and regional peatland development: implications for peatland carbon  
39 1008 | dynamics. *Quaternary Science Reviews* 61: 85-95.  
40 1009 |  
41 1010 | [Jones MC and Yu Z \(2010\) Rapid deglacial and early Holocene expansion of peatlands in](#)  
42 1011 | [Alaska. \*Proceedings of the National Academy of Sciences\* 107: 7347-7352.](#)  
43 1012 |  
44 1013 | Kane ES, Turetsky MR, Harden JW, McGuire AD and Waddington JM (2010) Seasonal  
45 1014 | ice and hydrologic controls on dissolved organic carbon and nitrogen concentrations in a  
46 1015 | boreal-rich fen. *Journal of Geophysical Research – Biogeosciences* 115, G04012. doi:  
47 1016 | 10.1029/2010JG001366.  
48 1017 |  
49 1018 | Kaufman DS, Ager TA, Anderson NJ, Anderson PM, Andrews JT, Bartlein PJ, Brubaker  
50 1019 | LB, Coats LL, Cwynar LC, Duvall ML, Dyke AS, Edwards ME, Eisner WR, Gajewski  
51 1020 | K, Geirsdottir A, Hu FS, Jennings AE, Kaplan MR, Kerwin MW, Lozhkin AV,  
52 1021 | MacDonald GM, Miller GH, Mock CJ, Oswald WW, Otto-Bliesner BL, Porinchu DF,

- 1  
2  
3  
4  
5  
6  
7  
8 1022 Ruhland KR, Smol JP, Steig EJ, Wolfey BB (2004) Holocene thermal maximum in the  
9 1023 western Arctic (0-180 °W). *Quaternary Science Reviews* 23: 529-560.  
10 1024
- 11 1025 | Korhola A, Ruppel M, Seppä H, [Väliranta M](#), Virtanen T and Weckström J (2010) The  
12 1026 importance of northern peatland expansion to the late-Holocene rise of atmospheric  
13 1027 methane. *Quaternary Science Reviews* 29: 611-617.  
14 1028
- 15 1029 Lappalainen E (1996) General review on world peatlands and peat resources. In:  
16 1030 Lappalainen E (Ed.), *Global Peat Resources*. International Peat Society, Jyska, pp. 53-56.  
17 1031
- 18 1032 Limpens J, Heijmans MPD and Berendse F (2006) The nitrogen cycle in boreal  
19 1033 peatlands. In: Wieder RK and Vitt DH (Eds.), *Boreal Peatland Ecosystems*. Ecological  
20 1034 Studies Vol. 188, Springer-Verlag, Berlin Heidelberg, Germany, pp. 195-230.  
21 1035
- 22 1036 MacDonald GM, Beilman DW, Kremenetski KV, Sheng Y, Smith LC and Valichko AA  
23 1037 (2006) Rapid early development of circum-arctic peatlands and atmospheric CH<sub>4</sub> and  
24 1038 CO<sub>2</sub> variations. *Science* 314: 285-288.  
25 1039
- 26 1040 Mäkilä M (1997) Holocene lateral expansion, peat growth and carbon accumulation on  
27 1041 Haukkasuo, a raised bog in southeastern Finland. *Boreas* 26: 1-14. doi:10.1111/j.1502-  
28 1042 3885.1997.tb00647.x.  
29 1043
- 30 1044 [Mäkilä M and Saarnisto M \(2008\) Carbon accumulation in boreal peatlands during the  
31 1045 Holocene – impacts of climate variations. In: Strack, M. \(Ed.\), \*Peatlands and climate  
32 1046 change. International Peat Society, Jyväskylä, Finland, pp. 24-43.\*](#)  
33 1047
- 34 1048 Maltby E and Immirzi P (1993) Carbon dynamics in peatlands and other wetland soils,  
35 1049 regional and global perspectives. *Chemosphere* 27: 999-1023.  
36 1050
- 37 1051 Marcott SA, Shakun JD, Clark PU and Mix AC (2013) A reconstruction of regional and  
38 1052 global temperature for the past 11,300 years. *Science* 339: 1198-1201.  
39 1053
- 40 1054 Martikainen PJ, Nykänen H, Crill P and Silvola J (1993) Effect of a lowered water-table  
41 1055 on nitrous-oxide fluxes from northern peatlands. *Nature* 366: 51-53.  
42 1056
- 43 1057 Marushchak ME, Pitkämäki A, Koponen H, Biasi C, Seppälä M and Martikainen PJ  
44 1058 (2011) Hot spots for nitrous oxide emissions found in different types of permafrost  
45 1059 peatlands. *Global Change Biology* 17: 2601-2614.  
46 1060
- 47 1061 Mauquoy D and van Geel B (2007) Mire and Peat Macros. In: Elias S.A. (Ed.),  
48 1062 *Encyclopedia of Quaternary Science*. vol. 3. Elsevier, Amsterdam, The Netherlands, pp.  
49 1063 2315-2336.  
50 1064
- 51 1065 McGuire AD, Anderson LG, Christensen TR, Dallimore S, Guo L, Hayes DJ, Heimann  
52 1066 M, Lorenson TD, MacDonald RW and Roulet N (2009) Sensitivity of the carbon cycle in  
53 1067 the Arctic to climate change. *Ecological Monographs* 79: 523-555.

- 1  
2  
3  
4  
5  
6  
7  
8 1068  
9 1069 McLaughlan KK, Williams JJ, Craine JM and Jeffers ES (2013) Changes in global  
10 1070 nitrogen cycling during the Holocene epoch. *Nature* 495: 352-357.  
11 1071  
12 1072 [Oksanen PO, Kuhry P and Alekseeva RN \(2003\) Holocene development and permafrost](#)  
13 1073 [history of the Usinsk Mire, northeast European Russia. \*Géographie Physique et\*](#)  
14 1074 [Quaternaire 57: 169-187.](#)  
15 1075  
16 1076 Palmer K, Biasi C and Horn MA (2012) Contrasting denitrifier communities relate to  
17 1077 contrasting N<sub>2</sub>O emission patterns from acidic peat soils in arctic tundra. *The ISME*  
18 1078 *Journal* 6: 1058-1077.  
19 1079  
20 1080 [Pelletier L, Moore TR, Roulet NT, Garneau M and Beaulieu-Audy V \(2007\) Methane](#)  
21 1081 [fluxes from three peatlands in the La Grande Rivière watershed, James Bay lowland,](#)  
22 1082 [Canada. \*Journal of Geophysical Research – Biogeosciences\* 112, G01018. doi:](#)  
23 1083 [10.1029/2006JG000216.](#)  
24 1084  
25 1085 [Peteet D, Andreev A, Bardeen W and Mistretta F \(1998\) Long-term Arctic peatland](#)  
26 1086 [dynamics, vegetation and climate history of the Pur-Taz region, Western Siberia. \*Boreas\*](#)  
27 1087 [27: 115-126.](#)  
28 1088  
29 1089 Piotrowska N, Blaauw M, Mauquoy D and Chambers FM (2011) Constructing deposition  
30 1090 chronologies for peat deposits using radiocarbon dating. *Mires and Peat* 7, article 10, 14  
31 1091 p.  
32 1092  
33 1093 Post WM, Pastor J, Zinke PJ and Stangenberger AG (1985) Global patterns of soil  
34 1094 nitrogen storage. *Nature* 317: 613-616.  
35 1095  
36 1096 Reimer PJ, Baillie MGL, Bard E, Bayliss A, Beck JW, Bertrand C, Blackwell PG, Buck  
37 1097 CE, Burr G, Cutler KB, Damon PE, Edwards RL, Fairbanks RG, Friedrich M, Guilderson  
38 1098 TM, Hughen KA, Kromer B, McCormac FG, Manning S, Bronk Ramsey C, Reimer RW,  
39 1099 Remmele S, Southon JR, Stuiver M, Talamo S, Taylor FW, van der Plicht J,  
40 1100 Weyhenmeyer CE (2009) IntCal09 and Marine09 radiocarbon age calibration curves, 0–  
41 1101 50,000 years cal BP. *Radiocarbon* 51: 1111-1150.  
42 1102  
43 1103 [Renssen H, Seppä H, Crosta X, Goose H and Roche DM \(2012\) Global characterization](#)  
44 1104 [of the Holocene Thermal Maximum. \*Quaternary Science Reviews\* 48: 7-19.](#)  
45 1105  
46 1106 Repo ME, Susiluoto S, Lind SE, Jokinen S, Elsakov V, Biasi C, Virtanen T, Martikainen  
47 1107 PJ (2009) Large N<sub>2</sub>O emissions from cryoturbated peat soil in tundra. *Nature Geoscience*  
48 1108 2: 189-192.  
49 1109  
50 1110 Ruppel M, Väiliranta M, Virtanen T and Korhola A (2013) Postglacial spatiotemporal  
51 1111 peatland initiation and lateral expansion dynamics in North America and northern  
52 1112 Europe. *The Holocene*. doi:10.1177/0959683613499053.  
53 1113

Formatted: Font: Italic



- 1  
2  
3  
4  
5  
6  
7  
8 1114 Rydin H and Jeglum J (2013). *The biology of peatlands*. 2<sup>nd</sup> edition. Oxford University  
9 1115 Press, Oxford, UK, 382 p.  
10 1116  
11 1117 [Sannel ABK and Kuhry P \(2008\) Long-term stability of permafrost in subarctic peat](#)  
12 1118 [plateaus, west-central Canada. \*The Holocene\* 18: 589-601.](#)  
13 1119  
14 1120 Sheng Y, Smith LC, MacDonald GM, Kremenetski KV, Frey KE, Velichko AA, Lee M,  
15 1121 Beilman DW and Dubinin P (2004) A high-resolution GIS-based inventory of the West  
16 1122 Siberian peat carbon pool. *Global Biogeochemical Cycles* 18, GB3004. doi:  
17 1123 10.1029/2003GB002190.  
18 1124  
19 1125 Smith, L.C., MacDonald, G.M., Velichko, A.A., Beilman, D.W., Borisova, O.K., Frey,  
20 1126 K.E., Kremenetski, K.V., Sheng, Y. 2004. Siberian peatlands a net carbon sink and global  
21 1127 methane source since the Early Holocene. *Science*, 303, 353–356.  
22 1128  
23 1129 [Stolbovoi V \(2002\) Carbon in Russian soils. \*Climatic Change\* 55: 131-156.](#)  
24 1130  
25 1131 [Stolbovoi V and McCallum I \(2002\) \*Land resources of Russia\*. International Institute for](#)  
26 1132 [Applied Systems Analysis. \[www.iiasa.ac.at/Research/FOR/russia\\\_cd/download.htm\]\(http://www.iiasa.ac.at/Research/FOR/russia\_cd/download.htm\).](#)  
27 1133  
28 1134 [Stolbovoi V, Montanarella L, Medvedev V, Smeyan N, Shishov L, Ungureanu V,](#)  
29 1135 [Dobrovolski G, Jamagne M, King D, Rozhkov V and Savin I \(2001\) Integration of data](#)  
30 1136 [on the soils of Russia, Byelorussia, Moldova and Ukraine into the Soil Geographic Database](#)  
31 1137 [of the European Community. \*Eurasian Soil Science\* 34: 687-703.](#)  
32 1138  
33 1139 Stuiver M and Reimer PJ (1993) Extended <sup>14</sup>C database and revised CALIB radiocarbon  
34 1140 calibration program. *Radiocarbon* 35: 215-230.  
35 1141  
36 1142 Telford RJ, Heegaard E and Birks HJB (2004) All age-depth models are wrong: but how  
37 1143 badly? *Quaternary Science Reviews* 23: 1-5.  
38 1144  
39 1145 Troels-Smith J (1955) Characterization of unconsolidated sediments. Danmarks  
40 1146 Geologiske *Undersøgelse Series* 4: 1-73.  
41 1147  
42 1148 Turetsky MR, Wieder RK, Vitt DH, Evans RJ and Scott KD (2007) The disappearance of  
43 1149 relict permafrost in boreal North America: effects on peatland carbon storage and fluxes.  
44 1150 *Global Change Biology* 13: 1922-1934.  
45 1151  
46 1152 Turunen J, Tomppo E, Tolonen K and Reinikainen A (2002) Estimating carbon  
47 1153 accumulation rates of undrained mires in Finland – application to boreal and subarctic  
48 1154 regions. *The Holocene* 12: 69-80.  
49 1155  
50 1156 Turunen J, Roulet NT, Moore TR and Richard PJH (2004) Nitrogen deposition and  
51 1157 increased carbon accumulation in ombrotrophic peatlands in eastern Canada. *Global*  
52 1158 *Biogeochemical Cycles*, 18, GB3002. doi: 10.1029/2003GB002154.  
53  
54  
55  
56  
57  
58  
59  
60

Formatted: Superscript

- 1  
2  
3  
4  
5  
6  
7  
8 1160 van Bellen S, Dallaire P-L, Garneau M and Bergeron Y (2011) Quantifying spatial and  
9 1161 temporal Holocene carbon accumulation in ombrotrophic peatlands of the Eastmain  
10 1162 region, Quebec, Canada. *Global Biogeochemical Cycles* 25, GB2016.  
11 1163 doi:10.1029/2010GB003877.  
12 1164
- 13 1165 Vitt DH, Halsey LA, Bauer IE and Campbell C (2000) Spatial and temporal trends in  
14 1166 carbon storage of peatlands of continental western Canada through the Holocene.  
15 1167 *Canadian Journal of Earth Sciences* 37: 683-693.  
16 1168
- 17 1169 Yu Z (2011) Holocene carbon flux histories of the world's peatlands: global carbon-cycle  
18 1170 implications. *The Holocene* 21: 761-774.  
19 1171
- 20 1172 Yu Z (2012) Northern peatland carbon stocks and dynamics: a review. *Biogeosciences* 9:  
21 1173 4071-4085.  
22 1174
- 23 1175 Yu Z, Campbell ID, Campbell C, Vitt DH, Bond GC and Apps MJ (2003) Carbon  
24 1176 sequestration in western Canadian peat highly sensitive to Holocene wet-dry climate  
25 1177 cycles at millennial timescales. *The Holocene* 13: 801-808.  
26 1178
- 27 1179 Yu Z, Beilman DW and Jones MC (2009) Sensitivity of northern peatland carbon  
28 1180 dynamics to Holocene climate change. In: Baird A, Belyea L, Comas X, Reeve A, Slater  
29 1181 L (Eds.), *Northern peatlands and carbon cycling*. American Geophysical Union  
30 1182 Monograph Series, Washington D.C., USA, pp. 55-69.  
31 1183
- 32 1184 Yu Z, Loisel J, Brosseau DP, Beilman DW and Hunt SJ (2010) Global peatland dynamics  
33 1185 since the Last Glacial Maximum. *Geophysical Research Letters* 37, L13402. doi:10.1029/  
34 1186 2010GL043584.  
35 1187
- 36 1188 Yu Z, Loisel J, Turetsky MR, Cai S, Zhao Y, Frolking S, MacDonald GM and Bubier JL  
37 1189 (2013) Evidence for elevated emissions from high-latitude wetlands contributing to high  
38 1190 atmospheric CH<sub>4</sub> concentration in the early Holocene. *Global Biogeochemical Cycles* 27:  
39 1191 131-140. doi:10.1002/GBC.20025.  
40 1192
- 41 1193 [Zoltai SC \(1971\) Southern limit of permafrost features in peat landforms, Manitoba and](#)  
42 1194 [Saskatchewan. \*Geological Association of Canada, Special Paper\* 9, 305-310.](#)
- 43 1196 [Zoltai SC \(1995\) Permafrost distribution in peatlands of west-central Canada during the](#)  
44 1197 [Holocene warm period 6000 years B.P. \*Géographie Physique et Quaternaire\* 49: 45-54.](#)  
45 1198
- 46
- 47 1199 **Figure and Table Captions**
- 48
- 49 1200 **Figure 1.** Location of study sites. Map showing the distribution of northern peatlands  
50  
51 1201 (green area from Yu et al., 2010) and peatland sites included in this study (n = 215 sites,  
52  
53  
54  
55  
56  
57  
58  
59  
60

1  
2  
3  
4  
5  
6  
7  
8 1202 including 268 peat cores). Long-term rate of peat-carbon accumulation was estimated  
9  
10 1203 from 127 sites (151 peat cores; red and blue dots). The yellow dots represent cores for  
11  
12 1204 which only peat properties (bulk density, organic matter content, etc.) were available and  
13  
14 1205 synthesized. Refer to Supplementary Table 1 for details.  
15

16 1206

17  
18 1207 **Figure 2.** Overview of data availability for North America (black bars) and Eurasia  
19  
20 1208 (white bars). (A) Number of cores (total = 238) containing information on  
21  
22 1209 carbon/nitrogen ratio (n = 40), nitrogen content (n = 40), carbon content (n = 56), peat  
23  
24 1210 types (n = 83), organic matter bulk density (n = 184), organic matter content (n = 190),  
25  
26 1211 and bulk density (n = 214). (B) Number of cores (total = 151) with a temporal-dating  
27  
28 1212 resolution-quality better than 500-yearstwo dates per 1000 years (n = 35), 500-1000one to  
29  
30 1213 two dates per 1000 years (n = 52), and less than one date per > 1000 years (n = 64). (C)  
31  
32 1214 Number of calibrated basal peat ages (median) in 500-year bins from the database (~~black~~  
33  
34 1215 ~~bars~~, n = 199) compared to all northern hemisphere basal peat ages (median) in 200-year  
35  
36 1216 bins (~~grey bars~~, n = 2559, MGK data from MacDonald et al., 2006, Gorham et al., 2007,  
37  
38 1217 Korhola et al., 2010).  
39

40 1218

41 1219 **Figure 3.** Distribution histograms of peat properties in northern peatlands. (A) Frequency  
42  
43 1220 distribution of bulk density for unidentified peat type samples (white bars) and different  
44  
45 1221 peat types (color bars). (B) Frequency distribution of organic matter content for different  
46  
47 1222 peat types. (C) Frequency distribution of organic matter bulk density for different peat  
48  
49 1223 types. (D) Frequency distribution of carbon content for different peat types. (E)  
50

1  
2  
3  
4  
5  
6  
7  
8 1224 Frequency distribution of nitrogen content for different peat types. (F) Frequency  
9  
10 1225 distribution of carbon/nitrogen mass ratio for different peat types.

11 1226  
12  
13  
14 1227 **Figure 4.** Relation between carbon content and organic matter content in northern  
15  
16 1228 peatlands. The slope of each regression line is used as a conversion factor for estimating  
17  
18 1229 carbon content from organic matter content.

19  
20 1230  
21  
22 1231 **Figure 5.** Temporal patterns of peat properties (mean, standard deviation, and number of  
23  
24 1232 samples). (A) Bulk density. (B) Organic matter content. (C) Organic matter bulk density.  
25  
26 1233 (D) Carbon content. (E) Nitrogen content. (F) Carbon/Nitrogen mass ratio. White bars  
27  
28 1234 represent values that were based on a limited number of samples and peat records.

29  
30 1235  
31  
32 1236 **Figure 6.** Main differences between *Sphagnum* and non-*Sphagnum* peat samples. (A)  
33  
34 1237 Bulk density. (B) Organic matter bulk density. (C) Organic carbon bulk density. (D)  
35  
36 1238 Carbon content. (E) Nitrogen content. (F) Carbon/Nitrogen mass ratio. (G) Temporal  
37  
38 1239 pattern of organic C bulk density. (H) Proportional change in the number of peat records  
39  
40 1240 that are *Sphagnum*-dominated, presented as a percentage of the total number of records.

41 1241  
42  
43 1242 **Figure 7.** Long-term apparent rate of carbon and nitrogen accumulation from northern  
44  
45 1243 peatlands (n = 127 sites). (A) Summer insolation at 60°N (data from Berger and Loutre,  
46  
47 1244 1991) and temperature anomaly from an 11,300-year reconstruction for the northern  
48  
49 1245 extra-polar region from 30 to 90°N (data from Marcott et al., 2013). Temperature  
50  
51 1246 anomaly was calculated based on the 1961-1990 temperature averages. (B) Mean peat-

1  
2  
3  
4  
5  
6  
7  
8 1247 carbon accumulation rates (PCAR) and standard error in 500-year bins. The number of  
9  
10 1248 sites per 500-year bins is also presented. (C) Mean peat-nitrogen accumulation rates  
11  
12 1249 (PNAR) and standard error in 500-year bins. These values were obtained using different  
13  
14 1250 C/N values over time, as indicated by the line. ~~PCAR: peat carbon accumulation rate;~~  
15  
16 1251 ~~PNAR: peat N accumulation rate.~~  
17  
18 1252

19  
20 1253 **Table 1.** Peat properties in northern peatlands. Means and standard deviations are  
21  
22 1254 presented, along with the number of samples (n).  
23

24 1255

25  
26 1256 **Table 2.** Northern peatland peat properties by regions. Means and standard deviations are  
27  
28 1257 presented, along with the number of samples (n).  
29

30 1258

31 1259 **Table 3.** Comparison of northern peatland peat properties estimates with other published  
32  
33 1260 values. Means and standard deviations are presented, along with the number of samples  
34  
35 1261 (n) when available.  
36

37 1262

38  
39 1263 **Supplementary Material**

40  
41 1264 **Table S1.** Summary information for the study sites included in the database.  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54

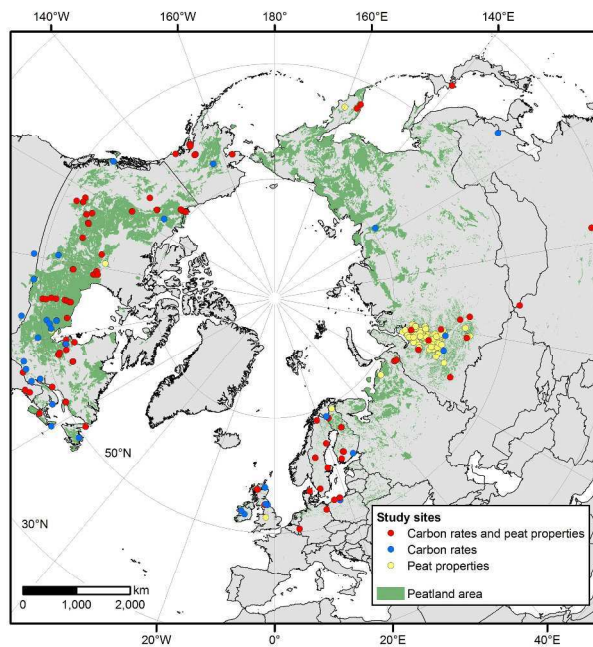


Figure 1. Location of study sites. Map showing the distribution of northern peatlands (green area from Yu et al., 2010) and peatland sites included in this study ( $n = 215$  sites, including 268 peat cores). Long-term rate of peat-carbon accumulation was estimated from 127 sites (151 peat cores; red 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.

279x361mm (300 x 300 DPI)

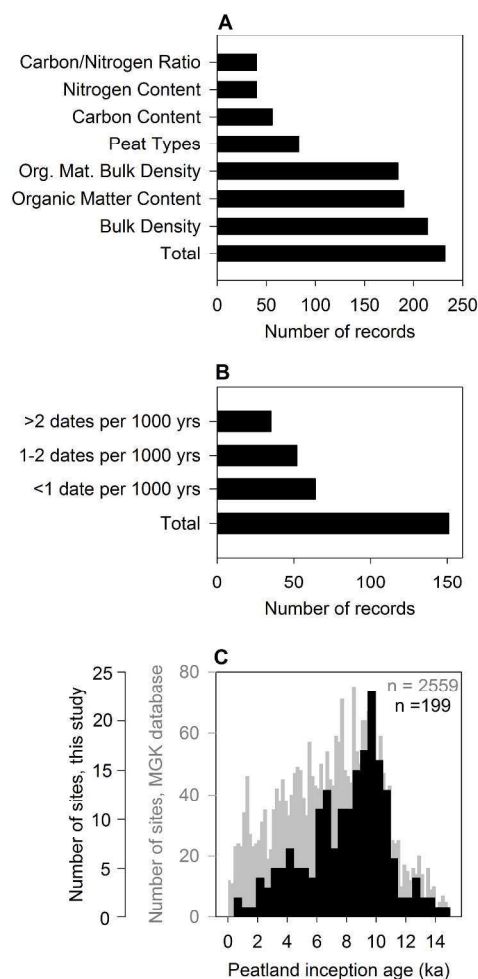


Figure 2. Overview of data availability for North America (black bars) and Eurasia (white bars). (A) Number of cores (total = 238) containing information on carbon/nitrogen ratio ( $n = 40$ ), nitrogen content ( $n = 40$ ), carbon content ( $n = 56$ ), peat types ( $n = 83$ ), organic matter bulk density ( $n = 184$ ), 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).  
279x361mm (300 x 300 DPI)

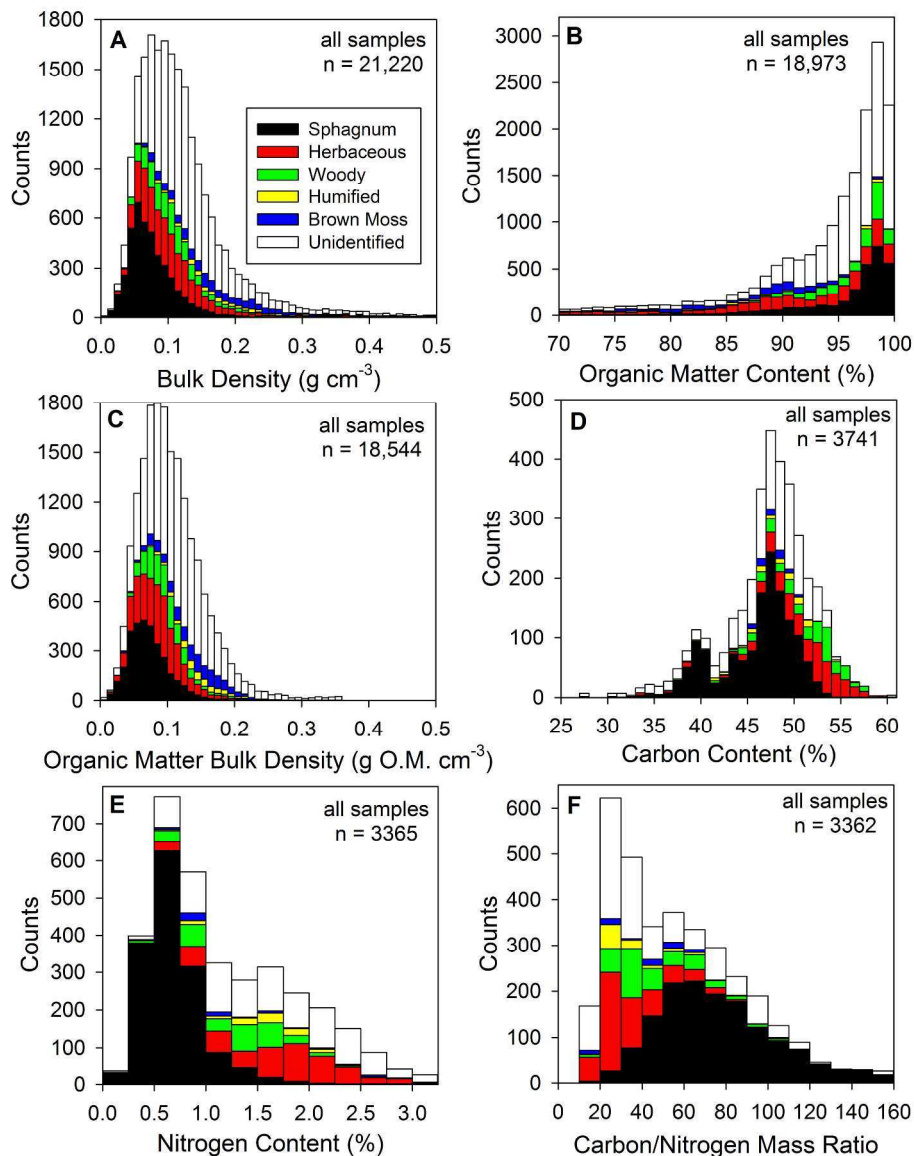


Figure 3. Distribution histograms of peat properties in northern peatlands. (A) Frequency distribution of bulk density for unidentified peat type samples (white bars) and different peat types (color bars). (B) Frequency distribution of organic matter content for different peat types. (C) Frequency distribution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

279x361mm (300 x 300 DPI)



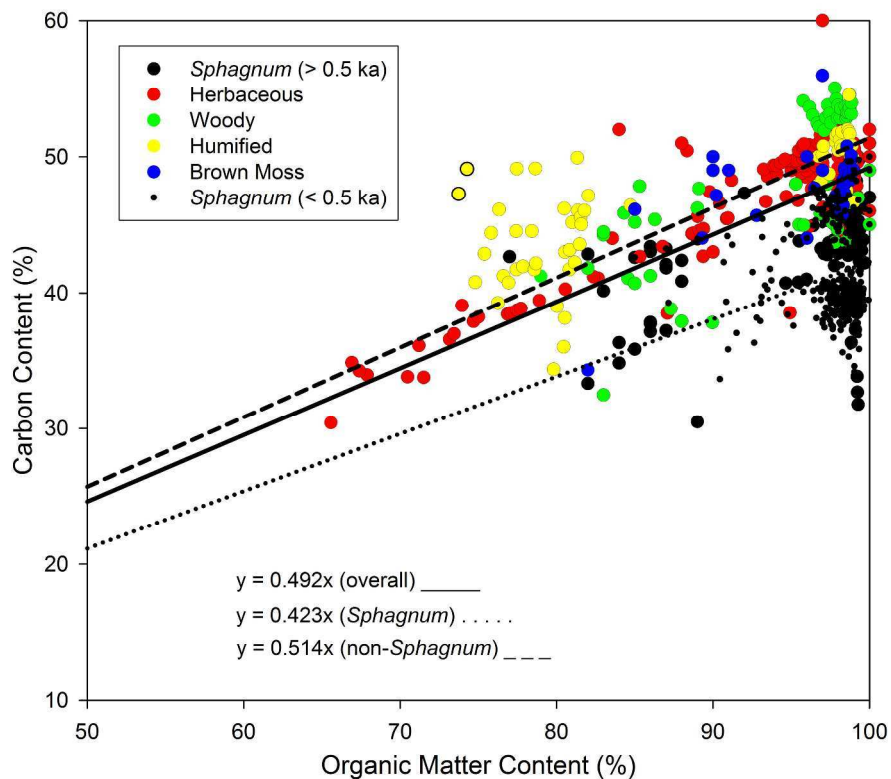


Figure 4. Relation between carbon content and organic matter content in northern peatlands. The slope of each regression line is used as a conversion factor for estimating carbon content from organic matter content.

279x361mm (300 x 300 DPI)

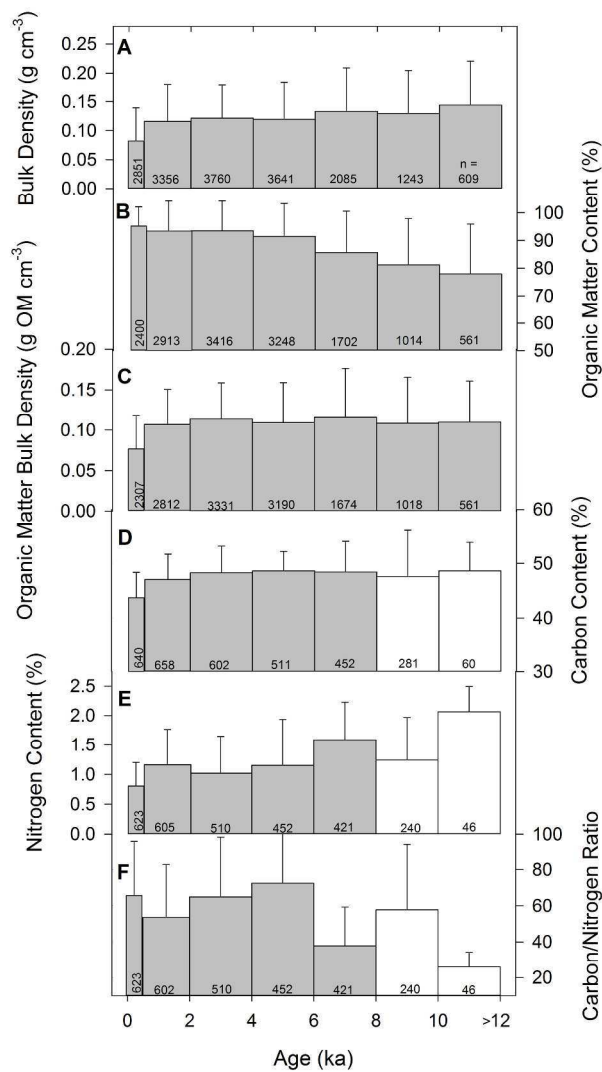


Figure 5. Temporal patterns of peat properties (mean, standard deviation, and number of samples). (A) Bulk density. (B) Organic matter content. (C) Organic matter bulk density. (D) Carbon content. (E) Nitrogen content. (F) Carbon/Nitrogen mass ratio. White bars represent values that were based on a limited number of samples and peat records.  
279x361mm (300 x 300 DPI)

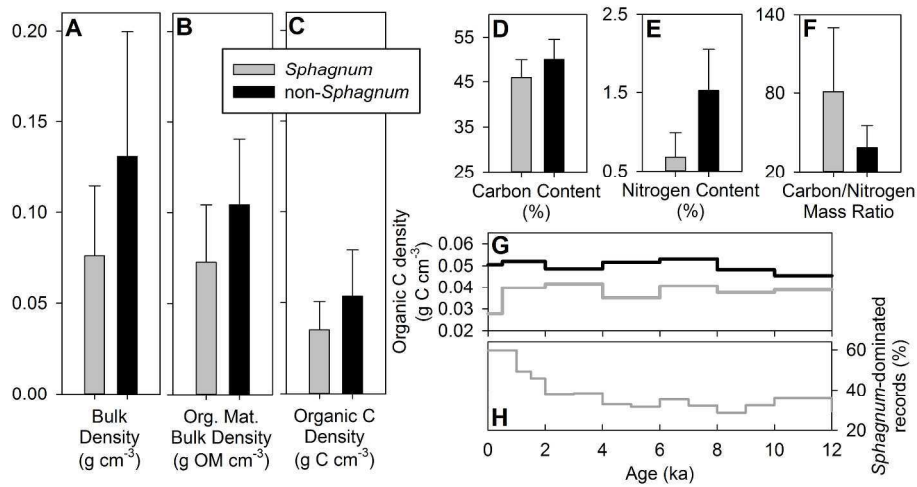


Figure 6. Main differences between Sphagnum and non-Sphagnum peat samples. (A) Bulk density. (B) Organic matter bulk density. (C) Organic carbon bulk density. (D) Carbon content. (E) Nitrogen content. (F) Carbon/Nitrogen mass ratio. (G) Temporal pattern of organic C bulk density. (H) Proportional change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

279x361mm (300 x 300 DPI)

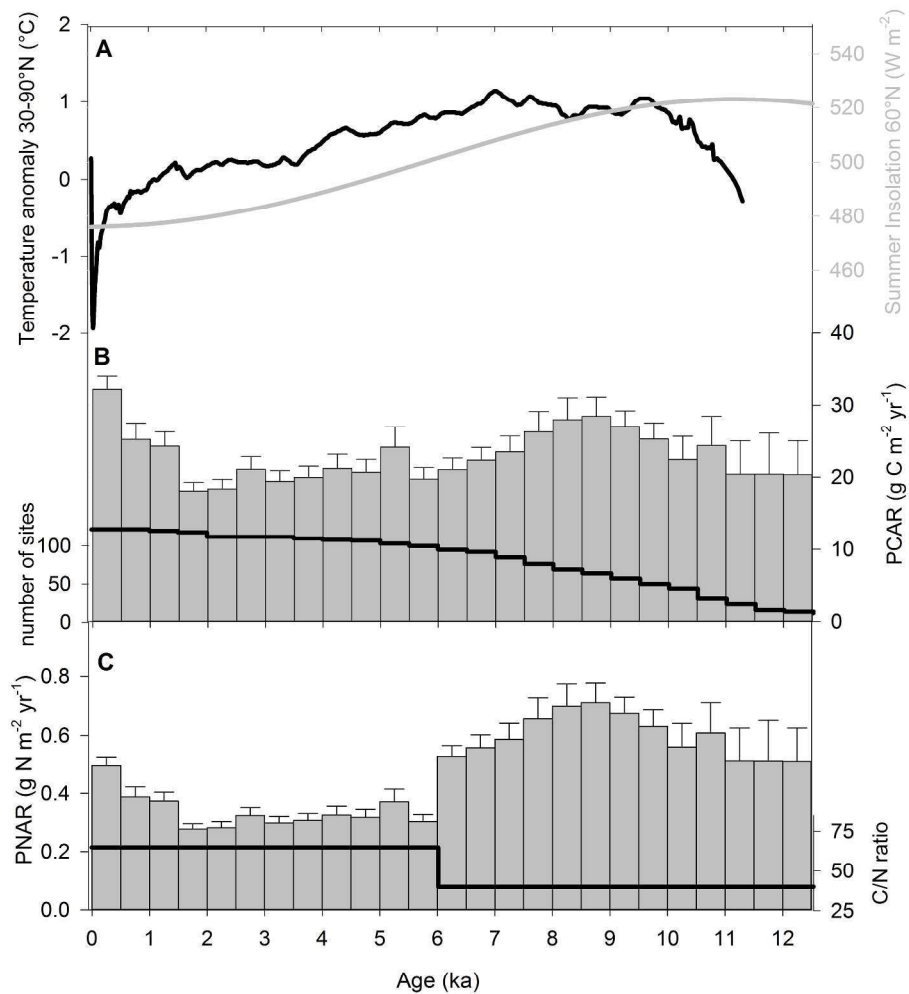


Figure 7. Long-term apparent rate of carbon and nitrogen accumulation from northern peatlands ( $n = 127$  sites). (A) Summer insolation at 60°N (data from Berger and Loutre, 1991) and temperature anomaly from an 11,300-year reconstruction for the northern extra-polar region from 30 to 90°N (data from 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.

279x361mm (300 x 300 DPI)

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***
<b>Bulk density (g cm<sup>-3</sup>)</b>	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)
<b>Organic matter content (%)</b>	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)
<b>Organic matter bulk density (g OM cm<sup>-3</sup>)</b>	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)
<b>Carbon content in total peat (%)</b>	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)
<b>Carbon content in organic matter (%)</b>	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)
<b>Nitrogen content in peat (%)</b>	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)
<b>Carbon/Nitrogen mass ratio</b>	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
<b>Bulk density (g cm<sup>-3</sup>)</b>	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)
<b>Organic matter content (%)</b>	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)
<b>Organic matter bulk density (g OM cm<sup>-3</sup>)</b>	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)
<b>Carbon content in total peat (%)</b>	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)
<b>Nitrogen content in peat (%)</b>	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)
<b>Carbon/Nitrogen mass ratio</b>	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.

1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49

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



1  
2  
3  
4

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

41  
42  
43  
44  
45  
46  
47  
48  
49

1  
2  
3  
4

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

41  
42  
43  
44  
45  
46  
47  
48  
49

1  
2  
3  
4

	Abbreviated reference <sup>a</sup>	Site name	Peatland type	Country	Latitude	Longitude	<sup>14</sup> 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 <sup>2</sup>	Y
9	C. Tarnocai, 2010	NW-BG-8	Polyg. peat plateau	Canada	65.21	-127.01	5	10,818	Y	N	Y <sup>2</sup>	Y
10	C. Tarnocai, 2010	NW-BG-10	Polyg. peat plateau	Canada	65.21	-127.00	5	10,480	Y	N	Y <sup>2</sup>	Y
11	C. Tarnocai, unpubl	T1	Polygon bog	Canada	68.32	-133.42	7	8623	Y	N	Y <sup>2</sup>	Y
12	C. Tarnocai, unpubl	T6	Polygon bog	Canada	69.12	-134.18	5	3014	Y	N	Y <sup>2</sup>	Y
13	C. Tarnocai, unpubl	IN-BG-2B	Polyg. peat plateau	Canada	68.32	-133.43	6	5828	Y	N	Y <sup>2</sup>	Y
14	C. Tarnocai, unpubl	NW-BG-2	Polyg. peat plateau	Canada	65.21	-127.01	5	10,932	Y	N	Y <sup>2</sup>	Y
15	C. Tarnocai, unpubl	NW-BG-3	Polyg. peat plateau	Canada	65.21	-127.01	6	11,010	Y	N	Y <sup>2</sup>	Y
16	C. Tarnocai, unpubl	NW-BG-3	Polyg. peat plateau	Canada	65.21	-127.01	6	11,010	Y	N	Y <sup>2</sup>	Y
17	Turunen, 2003 <sup>a</sup>	Diana Lake bog	Slope bog	Canada	54.15	-130.25	5	8500	Y	N	Y <sup>6</sup>	N
18	van Bellen, 2011	Mosaik	Bog	Canada	51.98	-75.4	10	7120	Y	N	Y <sup>3</sup>	Y
19	van Bellen, 2011	Sterne	Bog	Canada	52.05	-75.17	11	7134	Y	N	Y <sup>3</sup>	Y
20	van Bellen, 2011	Lac Le Caron	Bog	Canada	52.28	-75.83	12	7510	Y	N	Y <sup>3</sup>	Y
21	van Bellen, 2011	Lac Le Caron	Bog	Canada	52.28	-75.83	12	7510	Y	N	Y <sup>3</sup>	Y
22	Yu, 2003 <sup>a</sup>	Upper Pinto Fen	Rich fen	Canada	53.58	-118.02	20	7599	Y	N	Y <sup>3</sup>	Y
23	Yu, 2006 <sup>a</sup>	Goldeye Lake Fen	Rich fen	Canada	52.45	-116.2	6	9207	Y	tephra (2)	Y <sup>3</sup>	Y
24	Z. Yu, unpubl	Sundance Fen 03-2	Rich fen	Canada	53.58	-116.75	5	6719	Y <sup>1</sup>	N	Y <sup>3</sup>	Y
25	Z. Yu, unpubl	Sundance Fen 03-3	Rich fen	Canada	53.58	-116.75	13	10,973	Y	N	Y <sup>3</sup>	Y
26	Z. Yu, unpubl	Utikuma	Poor Fen	Canada	55.84	-115.09	18	5079	Y	N	Y <sup>3</sup>	Y
27	Z. Yu, unpubl	Mariana Lake 03-1	Poor Fen	Canada	55.9	-112.09	14	7222	Y	N	Y <sup>3</sup>	Y
28	Z. Yu, unpubl	Mariana Lake 03-2	Poor Fen	Canada	55.9	-112.09	11	6105	Y <sup>1</sup>	N	Y <sup>3</sup>	Y
29	Z. Yu, unpubl	Mariana Lake 03-3	Poor Fen	Canada	56.02	-111.93	18	5872	Y <sup>1</sup>	N	Y <sup>3</sup>	Y
30	Z. Yu, unpubl <sup>a</sup>	Patuanak	Internal lawn	Canada	55.85	-107.68	11	9017	Y	N	Y <sup>3</sup>	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 <sup>1</sup>	pollen (3)	N	Y
36	Lamarre, 2012	KUJU-BF2	Permafrost bog	Canada	55.23	-77.7	4	3914	Y	N	N	Y

41  
42  
43  
44  
45  
46  
47  
48  
49

1  
2  
3  
4

	Abbreviated reference <sup>a</sup>	Site name	Peatland type	Country	Latitude	Longitude	<sup>14</sup> 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	<b>EURASIA</b>											
21	Anderson, 1998 <sup>a</sup>	Glen Torridon	Olig. topogen. bog	UK	57.56	-5.37	7	9568	Y	N	Y <sup>2</sup>	Y
22	Anderson, 1998 <sup>a</sup>	Glen Carron	Olig. topogen. bog	UK	57.53	-5.15	6	10,431	Y	N	Y <sup>2</sup>	Y
23	Andersson, 2010	Lilla Backsjömyren 1	Mixed mire	Sweden	62.41	14.32	5	8527	Y	tephra (2)	Y <sup>5</sup>	Y
24	Andersson, 2010	Lilla Backsjömyren 2	Mixed mire	Sweden	62.41	14.32	13	3804	Y <sup>1</sup>	tephra (2)	Y <sup>5</sup>	Y
25	Barber, 2003	Bolton Fell Moss J,L	Bog	UK	55	-2	28	10,476	Y	N	Y <sup>5</sup>	N
26	Barber, 2003	Mongan Bog	Bog	Ireland	53	-8	13	4607	N	N	Y <sup>5</sup>	N
27	Barber, 2003	Abbeyknockmoy Bog	Bog	Ireland	53.5	-9	10	6707	N	N	Y <sup>5</sup>	N
28	C. Bocchicchio, unpubl.	KAM12-C4	Bog	Russia (Far-E)	54.01	156.08	10	12,891	Y	N	Y <sup>3</sup>	Y
29	Borren, 2004 <sup>a</sup>	Vasyugan (V21)	Bog	Russia (Siberia)	56.83	78.42	11	9709	Y	N	Y <sup>3</sup>	Y
30	Borren, 2004 <sup>a</sup>	86-Kvartal (Zh0)	Fen	Russia (Siberia)	56.83	84.58	9	8711	Y	N	Y <sup>3</sup>	Y
31	Charman, 1994	East Southerland	Fen	UK	58	-3	6	10,084	Y	N	Y <sup>5</sup>	N
32	D. Vleeschouwer, 2009	Słowińskie Błota	Raised bog	Poland	54.36	16.49	8	1165	N	N	Y <sup>2</sup>	Y
33	D. Vleeschouwer, 2012	Misten	Raised bog	Belgium	50.56	6.16	15	1434	N	N	Y <sup>2</sup>	Y

41  
42  
43  
44  
45  
46  
47  
48  
49

1  
2  
3  
4

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

41  
42  
43  
44  
45  
46  
47  
48  
49

1  
2  
3  
4

	Abbreviated reference <sup>*</sup>	Site name	Peatland type	Country	Latitude	Longitude	<sup>14</sup> 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 <sup>1</sup>	N	Y <sup>2</sup>	Y
9	Oksanen, 2001	Rogovaya River 3	Peat plateau	Russia (E Eur.)	67.25	62.07	6	10,641	Y	N	Y <sup>3</sup>	Y
10	Oksanen, 2003	Usinsk Mire 1	Peat plateau	Russia (E. Eur.)	57.42	65.67	6	13,236	Y	N	Y <sup>2</sup>	Y
11	Ronkainen, unpubl	Seida	Peat plateau	Russia (E. Eur.)	67.05	62.92	6	8469	Y	N	Y <sup>4</sup>	Y
12	Ruhland, 2000	Lena River Valley	Wet fen	Russia (E Sib)	69.38	125.13	6	8022	Y	N	Y <sup>5</sup>	N
14	Tuittila, 2007	Lakkasuo (hummock)	Bog	Finland	61.78	24.3	12	6567	Y <sup>1</sup>	N	Y <sup>5</sup>	Y
15	Tuittila, 2007	Lakkasuo (lawn)	Bog	Finland	61.78	24.3	7	6803	Y	N	Y <sup>5</sup>	Y
16	Turunen, 2001 <sup>a</sup>	Salym-Gyugan Mire 3	Bog	Russia (W Sib)	60.17	72.83	6	10,500	Y	N	Y <sup>6</sup>	N
18	Väliranta, 2007	Kontolanrahka	Bog	Finland	60.78	22.78	40	4937	Y	<sup>137</sup> Cs	Y <sup>2</sup>	Y
19	van der Linden, 2006	Saxnäs Mosse	Raised bog	Sweden	56.86	13.46	36	1068	N	N	Y <sup>2</sup>	Y
20	van der Linden, 2007	Barschpfohl	Kettle hole	Germany	53.05	13.83	32	134	N	N	Y <sup>2</sup>	Y
21	van der Linden, 2008	Lappmyran	String & flark mire	Sweden	64.16	19.58	40	1712	N	N	Y <sup>2</sup>	Y
22	van der Linden, 2008	Åkerlänna Römosse	Raised bog	Sweden	60.02	17.36	36	392	N	N	Y <sup>2</sup>	Y
23	Y. Zhao, unpubl.	Altay	Sedge-dom rich fen	China	48.12	88.35	18	11,308	Y	N	Y <sup>3</sup>	Y
24	Zhao, 2011	Zoige	Sedge-dom rich fen	China	33.45	102.63	7	9996	Y	N	Y <sup>3</sup>	Y
25	Zhou, 2010	Hani Peat Bog	Bog	China	42.22	126.52	6	15,014	Y	N	Y <sup>5</sup>	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 <sup>1</sup>	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

41  
42  
43  
44  
45  
46  
47  
48  
49

1  
2  
3  
4

5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40							
Abbreviated reference <sup>a</sup>	Site name	Peatland type	Country	Latitude	Longitude	<sup>14</sup> C dates (number)	Oldest age (cal BP)	Basal age (cal BP)	Other dates	Carbon rate site	Peat properties site																															
Smith, 2004, 2012	S-8	Pine-domin. bog	Russia (W Sib)	61.75	73.39	1	9860	Y	N	N	Y																															
Smith, 2004, 2012	S-9	Non-permafrost	Russia (W Sib)	62.12	73.84	2	8725	Y	N	N	Y																															
Smith, 2004, 2012	N-10	Peat plateau	Russia (W Sib)	63.14	76.54	1	4720	Y	N	N	Y																															
Smith, 2004, 2012	N-11	Non-permafrost	Russia (W Sib)	62.66	76.77	1	5090	Y	N	N	Y																															
Smith, 2004, 2012	N-12	Peat plateau	Russia (W Sib)	63.50	76.82	1	10,080	Y	N	N	Y																															
Smith, 2004, 2012	N-13	Peat plateau	Russia (W Sib)	63.77	76.64	1	9465	Y	N	N	Y																															
Smith, 2004, 2012	N-14	Peat plateau	Russia (W Sib)	63.77	75.51	1	9035	Y	N	N	Y																															
Smith, 2004, 2012	N-15	Peat plateau	Russia (W Sib)	63.65	74.27	2	9630	Y	N	N	Y																															
Smith, 2004, 2012	N-16	Peat plateau	Russia (W Sib)	64.50	75.53	1	3540	Y	N	N	Y																															
Smith, 2004, 2012	N-17	Peat plateau	Russia (W Sib)	64.07	74.99	1	11,330	Y	N	N	Y																															
Smith, 2004, 2012	N-18	Peat plateau	Russia (W Sib)	62.85	75.22	1	1005	Y	N	N	Y																															
Smith, 2004, 2012	N-19	Peat plateau	Russia (W Sib)	62.96	74.26	1	8290	Y <sup>1</sup>	N	N	Y																															
Smith, 2004, 2012	N-19-1	Peat plateau	Russia (W Sib)	62.96	74.26	1	8675	Y	N	N	Y																															
Smith, 2004, 2012	S-20	Pine-domin. bog	Russia (W Sib)	62.55	71.72	1	3395	Y	N	N	Y																															
Smith, 2004, 2012	S-21	Pine-domin. bog	Russia (W Sib)	62.40	72.87	1	9905	Y	N	N	Y																															
Smith, 2004, 2012	S-22	Pine-domin. bog	Russia (W Sib)	60.84	71.26	2	7125	Y	N	N	Y																															
Smith, 2004, 2012	S-23	Pine-domin. bog	Russia (W Sib)	60.65	73.08	1	6665	Y	N	N	Y																															
Smith, 2004, 2012	S-24	Open raised bog	Russia (W Sib)	61.32	73.24	1	2305	Y	N	N	Y																															
Smith, 2004, 2012	S-25	Pine-domin. bog	Russia (W Sib)	62.25	74.78	1	9910	Y	N	N	Y																															
Smith, 2004, 2012	V-26	Open raised bog	Russia (W Sib)	61.03	76.47	2	9700	Y	N	N	Y																															
Smith, 2004, 2012	V-27	Open raised bog	Russia (W Sib)	61.32	76.73	1	4540	Y	N	N	Y																															
Smith, 2004, 2012	V-28	Open raised bog	Russia (W Sib)	61.81	77.50	1	7750	Y	N	N	Y																															
Smith, 2004, 2012	V-29	Open raised bog	Russia (W Sib)	61.23	75.31	1	9750	Y	N	N	Y																															
Smith, 2004, 2012	V-30	Open raised bog	Russia (W Sib)	61.74	75.20	1	5455	Y	N	N	Y																															
Smith, 2004, 2012	V-31	Open raised bog	Russia (W Sib)	62.37	75.79	1	5600	Y	N	N	Y																															
Smith, 2004, 2012	V-32	Open raised bog	Russia (W Sib)	62.36	77.48	1	2140	Y	N	N	Y																															

41  
42  
43  
44  
45  
46  
47  
48  
49

1  
2  
3  
4

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

41  
42  
43  
44  
45  
46  
47  
48  
49



1  
2  
3  
4

5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40					
Abbreviated reference	Site name	Peatland type	Country	Latitude	Longitude	<sup>14</sup> 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																													

41  
42  
43  
44  
45  
46  
47  
48  
49

1  
2  
3  
4

Abbreviated reference <sup>a</sup>	Site name	Peatland type	Country	Latitude	Longitude	<sup>14</sup> 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 <sup>1</sup>	N	N	Y

<sup>a</sup>A list of detailed references is presented below the table.

<sup>a</sup>Site used in Yu et al.'s (2009) synthesis.

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

<sup>2</sup>Measured bulk density was multiplied by measured C content (elemental analyzer) for each layer to estimate C bulk density (g C cm<sup>-3</sup>).

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

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

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

<sup>6</sup>Peat-C accumulation rates directly obtained from published figures and tables.

31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49

**References:**

- 1  
2  
3  
4  
5  
6 Anderson, D.E. 1998. A reconstruction of Holocene climatic changes from peat bogs in  
7 north-west Scotland. *Boreas*, 27, 208-224.  
8
- 9  
10 Andersson, S., Schoning, K. 2010. Surface wetness and mire development during the late  
11 Holocene in central Sweden. *Boreas*, 39, 749-760.  
12
- 13  
14 Barber, K.E., Chambers, F.M., Maddy, D. 2003. Holocene palaeoclimates from peat  
15 stratigraphy: macrofossil proxy climate records from three oceanic raised bogs in  
16 England and Ireland. *Quaternary Science Reviews*, 22, 521-539.  
17
- 18  
19 Beaulieu-Audy, V., Garneau, M., Richard, P.J.H., Asnong, H. 2009. Holocene  
20 palaeoecological reconstruction of three boreal peatlands in the La Grande Rivière  
21 region, Québec, Canada. *The Holocene*, 19(3), 459-476.  
22
- 23  
24 Belyea, L.R., Warner, B.G. 1996. Temporal scale and the accumulation of peat in a  
25 *Sphagnum* bog. *Canadian Journal of Botany*, 74, 366-377.  
26
- 27  
28 Bender, M.M., Bryson, R.A., Baerreis, D.A. 1969. University of Wisconsin radiocarbon  
29 dates VI. *Radiocarbon*, 11(1), 228-235.  
30
- 31  
32 Booth, R.K., Jackson, S.T., Gray, C.E.D. 2004. Paleoecology and high-resolution  
33 paleohydrology of a kettle peatland in upper Michigan. *Quaternary Research*, 61, 1-13.  
34
- 35  
36 Borren, W., Bleuten, W., Lapshina, E.D. 2004. Holocene peat and carbon accumulation  
37 rates in the southern taiga of western Siberia. *Quaternary Research*, 61, 42-51.  
38
- 39  
40 Bunbury, J., Finkelstein, S.A., Bollman, J. 2012. Holocene hydro-climatic change and  
41 effects on carbon accumulation inferred from a peat bog in the Attawapiskat River  
42 watershed, Hudson Bay Lowlands, Canada. *Quaternary Research*, 78, 275-284.  
43
- 44  
45 Camill, P., Barry, A., Williams, E., Andreassi, C., Limmer, J., Solick, D. 2009. Climate-  
46 vegetation-fire interactions and their impact on long-term carbon dynamics in a boreal  
47 peatland landscape in northern Manitoba, Canada. *Journal of Geophysical Research*, 114,  
48 G04017, doi:10.1029/2009JG001071.  
49
- 50  
51 Charman, D.J. 1994. Patterned fen development in northern Scotland: developing a  
52 hypothesis from palaeoecological data. *Journal of Quaternary Science*, 9(3), 285-297.  
53
- 54  
55 Charman, D.J., Aravena, R., Warner, B.G. 1995. Carbon dynamics in a forested peatland  
56 in North-Eastern Ontario, Canada. *Journal of Ecology*, 82(1), 55-62.  
57
- 58  
59 De Vleeschouwer, F., Piotrowska, N., Sikorski, J., Pawlyta, J., Cheburkin, A., Le Roux,  
60 G., Lamentowicz, M., Fagel, N., Mauquoy, D. 2009. Multiproxy evidence of 'Little Ice

1  
2  
3 Age' palaeoenvironmental changes in a peat bog from northern Poland. *The Holocene*,  
4 19(4), 625-637.  
5

6  
7 De Vleeschouwer, F., Pazdur, A., Luthers, C., Streeel, M., Mauquoy, D., Wastiaux, C., Le  
8 Roux, G., Moschen, R., Blaauw, M., Pawlyta, J., Sikorski, J., Piotrowska, N. 2012. A  
9 millennial record of environmental change in peat deposits from the Misten bog (East  
10 Belgium). *Quaternary International*, 268, 44-57.  
11

12  
13 Elliott, S.M., Roe, H.M., Patterson, T. 2011. Testate amoebae as indicators of hydroseral  
14 change: An 8500 years record from Mer Bleue Bog, eastern Ontario, Canada. *Quaternary*  
15 *International*, 268, 128-144.  
16

17  
18 Gałka, M., Miotk-Szpiganowicz, G., Goslar, T., Ješko, M., van der Knaap, W.,  
19 Lamentowicz, M. 2013a. Paleohydrology, fires and vegetation succession in the southern  
20 Baltic during the last 7500 years reconstructed from a raised bog based on multi-proxy  
21 data. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 370, 209-221.  
22

23  
24 Gałka, M., Tobolski, K., Górska, A., Milecka, K., Fiałkiewicz-Kozieł, B., Lamentowicz,  
25 M. 2013b. Disentangling the drivers of a Baltic bog development during the Little Ice  
26 Age in northern Poland. *Quaternary International*, doi.org/10.1016/j.quaint.2013.02.026.  
27

28  
29 Glaser, P.H., Hansen, B.C.S., Siegel, D.I., Reeve, A.S., Morin, P.J. 2004. Rates,  
30 pathways and drivers for peatland development in the Hudson Bay Lowlands, northern  
31 Ontario, Canada. *Journal of Ecology*, 92, 1036-1053.  
32

33  
34 Glebov, F.Z., Karpenko, L.V., Dashkovskaya, I.S. 2002. Climatic changes, successions  
35 of peatlands and zonal vegetation, and peat accumulation dynamics in the Holocene (the  
36 West-Siberia peat profile 'Vodorasdel'). *Climatic Change*, 55, 175-181.  
37

38  
39 Gorham, E., Janssens, J.A., Glaser, P.H. 2003. Rates of peat accumulation during the  
40 postglacial period in 32 sites from Alaska to Newfoundland, with special emphasis on  
41 northern Minnesota. *Canadian Journal of Botany*, 81, 429-438.  
42

43  
44 Hendon, D., Charman, D.J., Kent, M. 2001. Palaeohydrological records derived from  
45 testate amoebae analysis from peatlands in northern England: within-site variability,  
46 between-site comparability and palaeoclimatic implications. *The Holocene*, 11(2), 127-  
47 148.

48  
49 Hu, F.S., Davis, R.B. 1994. Postglacial development of a Maine bog and  
50 paleoenvironmental implications. *Canadian Journal of Botany*, 73, 638-649.  
51

52  
53 Hughes, P.D.M., Blundell, A., Charman, D.J., Bartlett, S., Daniell, J.R.G., Wojatschke,  
54 A., Chambers, F.M. 2006. An 8500 cal. year multi-proxy climate record from a bog in  
55 eastern Newfoundland: contributions of meltwater discharge and solar forcing.  
56 *Quaternary Science Reviews*, 25, 1208-1227.  
57  
58  
59  
60

1  
2  
3 Hughes, P.D.M., Mallon, G., Brown, A., Esssex, H.J., Stanford, J.D., Hotes, S. 2013. The  
4 impact of high tephra loading on late-Holocene carbon accumulation and vegetation  
5 succession in peatland communities. *Quaternary Science Reviews*, 67, 160-175.  
6  
7

8 Hunt, S., Yu, Z., Jones, M. 2013. Lateglacial and Holocene climate, disturbance and  
9 permafrost peatland dynamics on the Seward Peninsula, western Alaska. *Quaternary  
10 Science Reviews*, 63, 42-58.  
11

12 Jones, M.C., Yu, Z. 2010. Rapid deglacial and early Holocene expansion of peatlands in  
13 Alaska. *Proceedings of the National Academy of Sciences*, 107(15), 7347-7352.  
14  
15

16 Juutinen, S., Väiliranta, M., Kuutti, V., Laine, A.M., Virtanen, T., Seppä, H., Weckström,  
17 Tuittila, E.-S. 2013. Short-term and long-term carbon dynamics in a northern peatland-  
18 stream-lake continuum: A catchment approach. *Journal of Geophysical Research*, 118, 1-  
19 13, doi:10.1002/JGRG20028.  
20  
21

22 Klein, E.S., Booth, R.K., Yu, Z., Mark, B.G., Stansell, N.D. 2013. Hydrology-mediated  
23 differential response of carbon accumulation to late Holocene climate change at two  
24 peatlands in Southcentral Alaska. *Quaternary Science Reviews*, 64, 61-75.  
25  
26

27 Kokfelt, U., Reuss, N., Struyf, E., Sonesson, M., Rundgren, M., Skog, G., Rosén, P.,  
28 Hammarlund, D. 2010. Wetland development, permafrost history and nutrient cycling  
29 inferred from late Holocene peat and lake sediment records in subarctic Sweden. *Journal  
30 of Paleolimnology*, 44, 327-342.  
31  
32

33 Kuhry, P., Vitt, D.H. 1996. Fossil carbon/nitrogen ratios as a measure of peat  
34 decomposition, *Ecology*, 77(1), 271-275.  
35  
36

37 Lamentowicz, M., Gałka, M., Milecka, K., Tobolski, K., Lamentowicz, L., Fiałkiewicz-  
38 Kozieł, B., Blaauw, M. 2013. A 1300-year multi-proxy, high-resolution record from a  
39 rich fen in northern Poland: reconstructing hydrology, land use and climate change.  
40 *Journal of Quaternary Science*, 28(6): 582-594.  
41  
42

43 Lamarre, A., Garneau, M., Asnong, H. 2012. Holocene paleohydrological reconstruction  
44 and carbon accumulation of a permafrost peatland using testate amoeba and macrofossil  
45 analyses, Kuujjuarapik, subarctic Québec, Canada. *Review of Palaeobotany and  
46 Palynology*, 186, 131-141.  
47

48 Large, D.J., Spiro, B., Ferrat, M., Shopland, M., Kylander, M., Gallagher, K., Li, X.,  
49 Shen, C., Possnert, G., Zhang, G., Darling, W.G., Weiss, D. 2009. The influence of  
50 climate, hydrology and permafrost on Holocene peat accumulation at 3500 m on the  
51 eastern Qinghai-Tibetan Plateau. *Quaternary Science Reviews*, 3303-3314.  
52  
53

54 Lavoie, M., Richard, P.J.H. 2000. The role of climate on the developmental history of  
55 Frontenac Peatland, southern Quebec. *Canadian Journal of Botany*, 78, 668-684.  
56  
57  
58  
59  
60

1  
2  
3 Lavoie, M., Richard, P.J.H. 2000. Paléoécologie de la tourbière du lac Malbaie, dans le  
4 massif des Laurentides (Québec): évaluation du rôle du climat sur l'accumulation de la  
5 tourbe. *Géographie Physique et Quaternaire*, 54(2), 169-185.

7  
8 Lavoie, M., Pellerin, S., Larocque, M. 2013. Examining the role of allogenuous and  
9 autogenous factors in the long-term dynamics of a temperate headwater peatland  
10 (southern Québec, Canada). *Palaeogeography, Palaeoclimatology, Palaeoecology*, 386,  
11 336-348.

13  
14 Loisel, J., Garneau, M. 2010. Late Holocene paleoecohydrology and carbon accumulation  
15 estimates from two boreal peat bogs in eastern Canada: Potential and limits of multi-  
16 proxy archives. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 291, 493-533.

18  
19 Loisel, J., Yu, Z. 2013. Recent acceleration of carbon accumulation in a boreal peatland,  
20 south central Alaska. *Journal of Geophysical Research*, 118, 1-13,  
21 doi:10.1029/2012JG001978.

23  
24 MacDonald, G.M. 1983. Holocene vegetation history of the Upper Natla River Area,  
25 Northwest Territories, Canada. *Arctic and Alpine Research*, 15(2), 169-180.

27  
28 Magnan, G., Lavoie, M., Payette, S. 2012. Impact of fire on long-term vegetation  
29 dynamics of ombrotrophic peatlands in northwestern Québec, Canada. *Quaternary*  
30 *Research*, 77, 110-121.

31  
32 Mäkilä, M. 1997. Holocene lateral expansion, peat growth and carbon accumulation on  
33 Haukkasuo, a raised bog in southeastern Finland, *Boreas*, 26 (1), 1-14,  
34 doi:10.1111/j.1502-3885.1997.tb00647.x.

36  
37 Mäkilä, M., Saarnisto, M., Kankainen, T. 2001. Aapa mires as a carbon sink and source  
38 during the Holocene. *Journal of Ecology*, 89(4), 589-599.

39  
40 Mäkilä, M., Moisanen, M. 2007. Holocene lateral expansion and carbon accumulation of  
41 Luovuoma, a northern fen in Finnish Lapland. *Boreas*, 36(2), 198-210.

43  
44 Mauquoy, D., Engelkes, T., Groot, M.H.M., Markesteijn, F., Oudejans, M.G., van der  
45 Plicht, J., van Geel, B. 2002. High-resolution records of late-Holocene climate change  
46 and carbon accumulation in two north-west European ombrotrophic peat bogs.  
47 *Palaeogeography, Palaeoclimatology, Palaeoecology*, 186, 275-310.

49  
50 Muller, S.D., Richard, P.J.H., Larouche, A.C. 2003. Holocene development of a peatland  
51 (southern Québec): a spatio-temporal reconstruction based on pachymetry,  
52 sedimentology, microfossils and macrofossils. *The Holocene*, 13(5), 649-664.

53  
54 O'Donnell, J.A., Jorgenson, M.T., Harden, J.W., McGuire, A.D., Kanevskiy, M.Z.,  
55 Wickland, K.P. 2012. The effects of permafrost thaw on soil hydrologic, thermal, and  
56 carbon dynamics in an Alaskan peatland. *Ecosystems*, 15, 213-229.

1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60

O'Reilly, B.C. 2011. Paleoeological and carbon accumulation dynamics of a peatland in the Hudson Bay Lowlands, Northern Ontario, from the mid-Holocene to present. M.Sc thesis, University of Toronto, Canada.

Oksanen, P.O., Kuhry, P., Alekseeva, R.N. 2001. Holocene development of the Rogovaya River peat plateau, European Russian Arctic. *The Holocene*, 11(1): 25-40.

Oksanen, P.O., Kuhry, P., Alekseeva, R.N. 2003. Holocene development and permafrost history of the Usinsk Mire, Northeast European Russia. *Géographie Physique et Quaternaire*, 57(2-3), 169-187.

Robinson, S.D. 2000. Carbon accumulation in discontinuously frozen peatlands, Southwestern Northwest Territories, Canada. Ph.D. thesis, McGill University, Canada.

Robinson, S.D. 2006. Carbon accumulation in peatlands, southwestern Northwest Territories, Canada. *Canadian Journal of Soil Science*, 86, 305-319.

Ruhland, K., Smol, J.P., Jasinski, J.P.P., Warner, B.G. 2000. Response of diatoms and other siliceous indicators to the developmental history of a peatland in the Tiksi Forest, Siberia, Russia. *Arctic, Antarctic, and Alpine Research*, 32(2), 167-178.

Sannel, A.B.K., Kuhry, P. 2009. Holocene peat growth and decay dynamics in sub-arctic peat plateaus, west-central Canada. *Boreas*, 38: 13-24.

Smith, L.C., Beilman, D.W., Kremenetski, K.V., Sheng, Y., MacDonald, G.M., Lammers, R.B., Shiklomanov, A.I., Lapshina, E.D. 2012. Influence of permafrost on water storage in West Siberian peatlands revealed from a new database of soil properties. *Permafrost and Periglacial Processes*, 23, 69-79.

Smith, L.C., MacDonald, G.M., Velichko, A.A., Beilman, D.W., Borisova, O.K., Frey, K.E., Kremenetski, K.V., Sheng, Y. 2004. Siberian peatlands a net carbon sink and global methane source since the early Holocene. *Science*, 303(5656), 353-356.

Tarnocai, C. 2010. Carbon sequestration dynamics and climate change in Subarctic and Low Arctic organic cryosols in Canada. *Proceedings of the 19th World Congress of Soil Science*, p. 5-8.

Tuittila, E.-S., Väliiranta, M., Laine, J., Korhola, A. 2007. Quantifying patterns and controls of mire vegetation succession in a southern boreal bog in Finland using partial ordinations. *Journal of Vegetation Science*, 18, 891-902.

Turunen, J., Tahvanainen, T., Tolonen, K. 2001. Carbon accumulation in West Siberian mires, Russia. *Global Biogeochemical Cycles*, 15(2), 285-296.

1  
2  
3 Turunen, C., Turunen, J. 2003. Development history and carbon accumulation of a slope  
4 bog in oceanic British Columbia, Canada. *The Holocene*, 13(2), 225-238.

5  
6  
7 Väiliranta, M., Kaakinen, A., Kuhry, P. 2003. Holocene climate and landscape evolution  
8 East of the Pechora delta, East-European Russian Arctic. *Quaternary Research*, 59, 335-  
9 344.

10  
11 Väiliranta, M., Korhola, A., Seppä, H., Tuittila, E.-S., Sarmaja-Korjonen, K., Laine, J.,  
12 Alm, J. 2007. High-resolution reconstruction of wetness dynamics in a southern boreal  
13 raised bog, Finland, during the late Holocene: a quantitative approach. *The Holocene*,  
14 17(8), 1093-1107.

15  
16  
17 van der Linden, M. 2007. Effects of climate change and human impact on late-Holocene  
18 species composition and carbon accumulation in bog ecosystems. Ph.D. thesis,  
19 Universiteit van Amsterdam, The Netherlands.

20  
21  
22 van der Linden, M., van Geel, B. 2006. Late-Holocene climate change and human  
23 impact recorded in a South Swedish ombrotrophic peat bog. *Palaeogeography*,  
24 *Palaeoclimatology*, *Palaeoecology*, 240(3-4), 649-667.

25  
26  
27 van der Linden, M., Vickery, E., Charman, D.J., Broekens, P., van Geel, B. 2008.  
28 Vegetation history and human impact during the last 300 years recorded in a German peat  
29 deposit. *Review of Palaeobotany and Palynology*, 152, 158-175.

30  
31  
32 van Bellen, S., Dallaire, P.-L., Garneau, M., Bergeron, Y. 2011. Quantifying spatial and  
33 temporal Holocene carbon accumulation in ombrotrophic peatlands of the Eastmain  
34 region, Quebec, Canada, *Global Biogeochemical Cycles*, 25, GB2016,  
35 doi:10.1029/2010GB003877.

36  
37  
38 Yu, Z., Campbell, I.D., Campbell, C., Vitt, D.H., Bond, G.C., Apps, M.J. 2003. Carbon  
39 sequestration in western Canadian peat highly sensitive to Holocene wet-dry climate  
40 cycles at millennial timescales. *The Holocene*, 13(6), 801-808.

41  
42  
43 Yu, Z., Beilman, D.W., Jones, M.C. 2009. Sensitivity of northern peatland carbon  
44 dynamics to Holocene climate change. In: Baird, A., Belyea, L., Comas, X., Reeve, A.,  
45 Slater, L. (Eds.), *Northern peatlands and carbon cycling*, American Geophysical Union  
46 Monograph Series, Washington D.C., USA, pp. 55-69.

47  
48  
49 Yu, Z. 2006. Holocene carbon accumulation of fen peatlands in boreal Western Canada:  
50 A complex ecosystem response to climate variation and disturbance. *Ecosystems*, 9(8),  
51 1278-1288.

52  
53  
54 Zhao, Y., Yu, Z., Zhao, W. 2011. Holocene vegetation and climate histories in the eastern  
55 Tibetan Plateau: controls by insolation-driven temperature or monsoon-derived  
56 precipitation changes? *Quaternary Science Reviews*, 30, 1173-1184.



1  
2  
3 Zhou, W., Zheng, Y., Meyers, P.A., Jull, A.J.T., Xie, S. 2010. Postglacial climate-  
4 change record in biomarker lipid compositions of the Hani peat sequence, Northeastern  
5 China. Earth and Planetary Science Letters, 294, 37-46.  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60

For Peer Review