Geological Research Letters

Supporting Information for

Impact of climate change on hunter-fisher-gatherer cultures in northern Japan over the past 4400 years

Masanobu Yamamoto[1,2], and Osamu Seki[2,3]

[1]Faculty of Environmental Earth Science, Hokkaido University, Sapporo 060-0810, Japan, [2]Graduate School of Environmental Science, Hokkaido University, Sapporo 060-0810, Japan, [3]Institute of Low Temperature Science, Hokkaido University, Sapporo 060-0819, Japan

Content of this file:

Text S1

1.1. History of Hokkaido

Human culture on inland Hokkaido developed through the succession from the Jomon (~8,000–300 BCE), Zoku-Jomon (~300 BCE–700 CE), Satsumon (~700–1200 CE), and Ainu cultures (after ~1200 CE) (*e.g.*, Fujimoto, 1965; Fujio, 2021). Along the northeastern coast of Hokkaido, the Okhotsk culture (marine culture) continued from ~500 to 900 CE. The Jomon culture, distributed through the entire Japanese Archipelago, was gradually replaced by the Yayoi culture with rice farming during the first millennia BCE. Until ~300 BCE, the Yayoi culture spread to Honshu Island except for its northernmost area. The people in Hokkaido and northern Honshu continued to hunt, fish, and gather in the Zoku-Jomon period (Nishimoto, 1985; Minagawa, 2014). The Zoku-Jomon culture expanded to South Sakhalin and the Kuril Islands from ~500 BCE to 1 BCE. After ~200 CE, the people of the Okhotsk culture migrated from Sakhalin Island, settled along the coast of the Okhotsk Sea, and engaged in intense hunting of marine mammals, fishing, terrestrial hunting, gathering, and primitive farming (Nishimoto, 1985; Takahashi, 2002; Minagawa, 2014; Leipe et al., 2017). This culture was modified to the Tobinitai culture characterized by intense salmon fishing and disappeared until ~1200 CE (Yamaura, 1983). The people of the Satsumon culture fished for salmon, hunted animals, gathered food, and engaged in primitive farming (Fujimoto, 1981; Minagawa, 2014). The Ainu culture started around 1200 CE, expanded northward to Sakhalin Island, and then later eastward to the Kuril Islands at 1500 CE.

Text S2

2.1. Radiocarbon dating

The remains of *Sphagnum* in the peats were prepared using the acid–alkali–acid (AAA) treatment (Okuno et al., 2001). The samples were combusted with CuO at 850°C for 3 h in a sealed quartz glass tube to produce CO_2, and the CO_2 was purified in liquid N_2 and EtOH–liquid N_2 traps (Kitagawa et al., 1993). The purified CO_2 was reduced to graphite with an iron powder catalyst. The graphite was then pressed into targets and analyzed at the accelerator mass spectrometry facility at the Museum of the University of Tokyo. Stable carbon isotope compositions were measured using an elemental analyzer mass spectrometer equipped with a continuous flow system (Elementar EA1110 and Thermo Fisher Scientific Delta Plus Advantage). Conventional ages were converted to calendar ages using the OxCal program (ver. 4.4; Bronk Ramsey, 2021) and the IntCal20 dataset (Reimer et al., 2020). Median values were used for the creation of the age–depth model. The sample at 51 cm depth in MHWL-3 shows two different ages (Table S1). We chose the older age for the age-depth model because younger material can be incorporated during coring.

2.2. Purification of cellulose

Cellulose was separated and purified from the tissue fraction according to the following procedure. The sample was ultrasonicated three times in a mixture of methanol and toluene (1:1) solution for 30 min (first) and 5 min (second and third), and the supernatant was discarded each time to remove lipids. The same three-round extraction procedure was repeated with acetone solution. After drying, the sample was heated four times in a 28 g/L sodium chlorite solution in a water–acetone mixture (35: 1) at 70°C for 1 h. The supernatant was discarded each time to remove lignin. The residue was rinsed three times with Milli-Q water at 70–80°C and then rinsed three times at room temperature. The residue was further ultrasonicated four times, with gentle shaking in a 17% sodium hydroxide solution at 80°C for 45 min. The supernatant was discarded to remove the hemicellulose. The residue (purified cellulose) was dried at 60°C.

2.3. Cellulose isotopes

Analysis of cellulose oxygen isotopes was conducted using a continuous flow pyrolysis elemental analyzer/isotope mass spectrometer (TCEA/Delta plus XL) (Sharp et al., 2001). The cellulose (150 μg) was wrapped in a silver foil and decomposed in a furnace at 1375°C. The cellulose yielded CO from the degradation of its unexchangeable oxygen and carbon, and the $\delta^{18}O$ of this CO was analyzed by mass spectrometry. A cellulose standard (Merck), with known $\delta^{18}O$ (27.4 ‰) relative to VSMOW, was simultaneously measured and used for calibration of $\delta^{18}O$. The accuracy of the analysis of $\delta^{18}O$ was ±0.3 ‰. The average value of duplicate analyses was used for discussion.

References

Bronk Ramsey, C. (2021), OxCal Program ver. 4.4. Oxford: Radiocarbon Accelerator Unit, University of Oxford, https://c14.arch.ox.ac.uk/oxcal.html.

Fujimoto, T. (1965), On the Okhotsk Pottery. *Journal of the Archaeological Society of Nippon*, 51, 4, 28–44 (in Japanese).

Fujimoto, T. (1981), The Satsumon culture -Pre-Ainu culture of Hokkaido-. *Journal of Geography*, 90, 72–86 (in Japanese).

Fijio, S. (2021) *Prehistoric period of Japan*. Chuokouronshinsha, Tokyo, 299p (in Japanese).

Kitagawa, H., Masuzawa, T., Nakamura, T., & Matsumoto, E. (1993), A batch preparation method for graphite targets with low background for AMS ^{14}C measurements. *Radiocarbon*, 35, 295–300.

Leipe, C., Sergusheva E. A., Müller. S., Spengler, R. N., III, Goslar, T., Kato, H., et al. (2017), Barley (Hordeum vulgare) in the Okhotsk culture (5th±10th century AD) of northern Japan and the role of cultivated plants in hunter-gatherer economies. *PLoS ONE*, 12, e0174397.

Minagawa, M. (2014), *Dietetic Behavior of the Japanese: The Quest for the Japanese through Dietetic Analysis.* Keibunsha, Tokyo, 319p (in Japanese).

Nishimoto, T. (1985) The Transition of Hunting and Fishing Activities in Hokkaido. *Bulletin of the National Museum of Japanese History*, 6, 53–74 (in Japanese).

Okuno, M., Nakamura, T., Kamata, H., & Kobayashi, T. (2001), Radiocarbon dating of paleosol intercalated with tephra layers in Japan. *In* Juvigné, E, & Raynal, J. P., eds. *Tephras, Chronology and Archaeology*. Les Dossiers de l'Archeo-Logis Volume 1. Clermont-Ferrand: CRDP. 67–71.

Reimer, P., Austin, W. E. N., Bard, E., Bayliss, A., Blackwell, P. G., Bronk Ramsey, C., Butzin, M., Edwards, R. L., et al. (2020), The IntCal20 Northern Hemisphere radiocarbon age calibration curve (0-55 cal kB). *Radiocarbon*, 62. doi: 10.1017/RDC.2020.41.

Sharp, Z. D., Atudorei, V., & Durakiewicz, T. (2001), A rapid method for determination of hydrogen and oxygen isotope ratios from water and hydrous minerals. *Chemical Geology*, 178, 197–210.

Takahashi, T. (2002), Okhotskians who lived on the sea. In Nishiaki, Y., & Udagawa, H. eds., *The Otherworld of the North-Ancient Okhotsk and Ice Peoples Culture*. University of Tokyo Collection, Chapter 2. (in Japanese).

Yamaura, K. (1983), The last stage of the Okhotsk culture and the Satsumon culture. *Bulletin of the Faculty of Letters, the University of Tokyo*, 2, 157–179 (in Japanese).

122

123 **Table S1.** Raw radiocarbon dates of *Sphagnum* in cores MHWL-1 and MHWL-3

Core	Depth (cm)	Age (years BP) ± 1σ			Note
MHWL-1	91	1137	±	20	
MHWL-1	221	2178	±	21	
MHWL-1	461	3908	±	23	
MHWL-3	51	212	±	32	not used
MHWL-3	51	290	±	21	
MHWL-3	131	1200	±	19	
MHWL-3	181	1625	±	21	
MHWL-3	271	1971	±	21	
MHWL-3	351	2430	±	27	

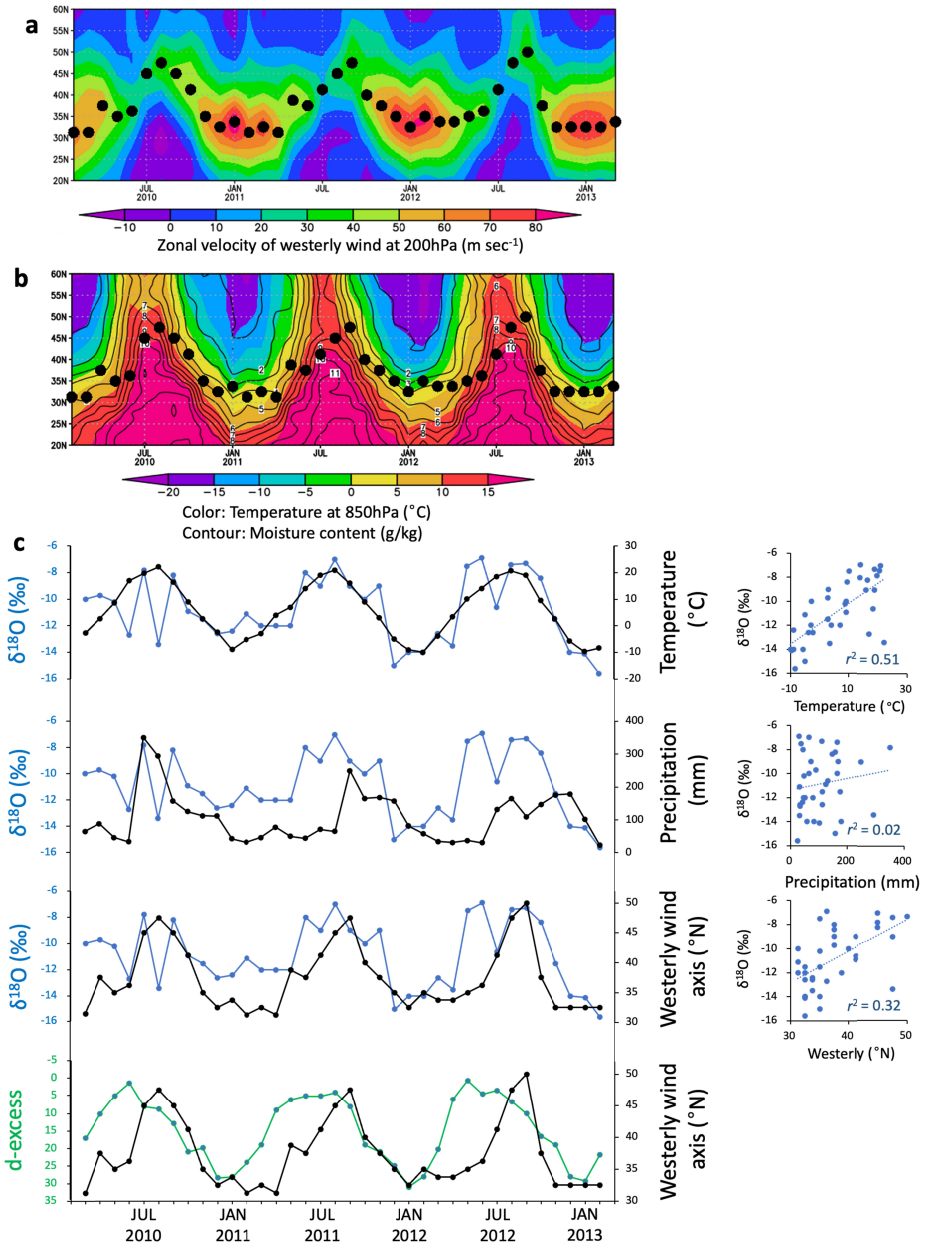

Figure S1. (a) Zonal wind velocity at 200 hPa (positive westward) along 145 °E, **(b)** temperature and moisture content at 850 hPa along 145°E (Sakurai et al., 2021), **(c)** precipitated water $\delta^{18}O$, d-excess, temperature and precipitation at the town of Teshio (2010–2013; Li et al., 2017) ~40 km southeast of the study site, and the position of the westerly jet. Black solid dots indicate the positions of the westerly jet.

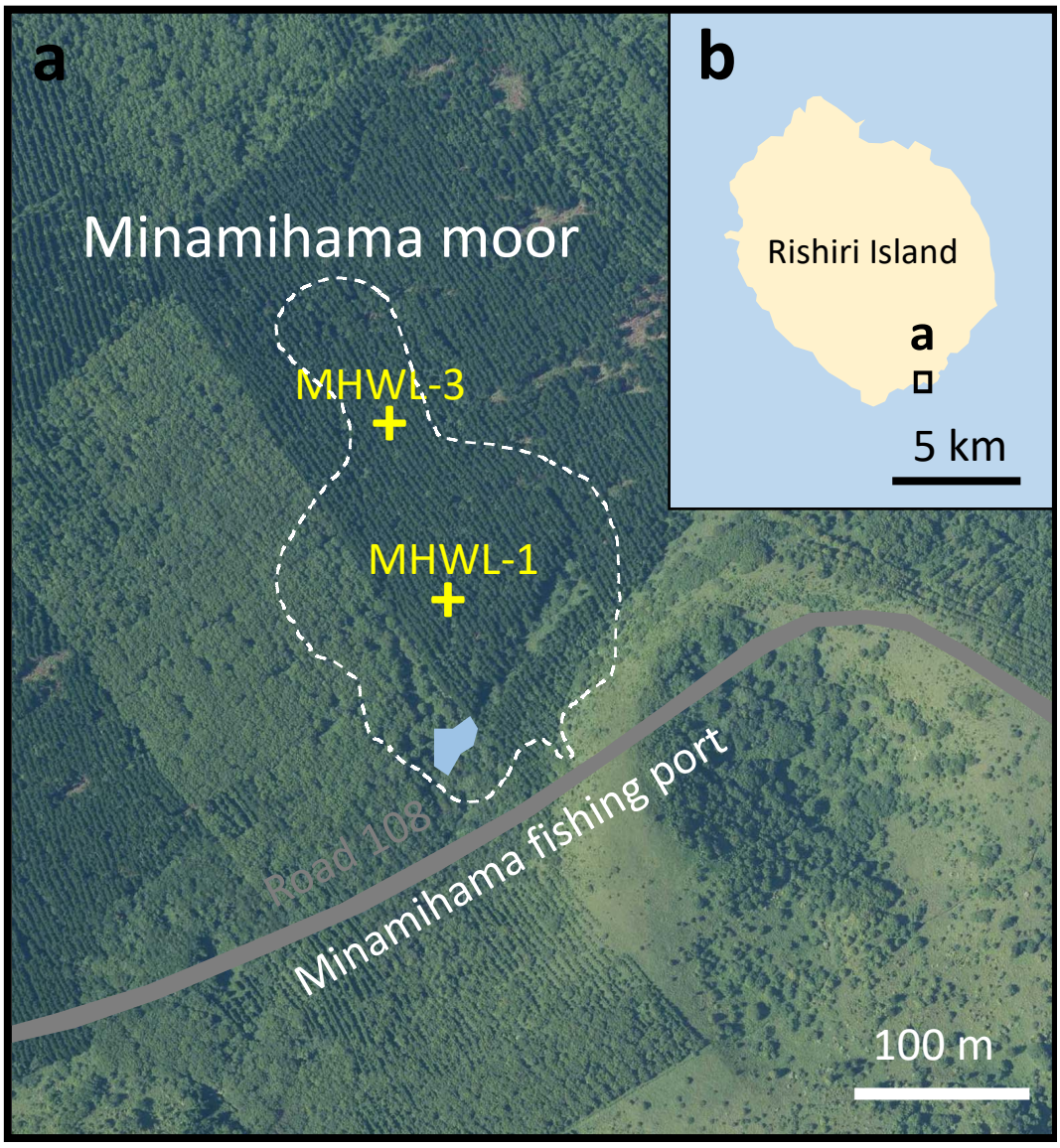

Figure S2. Locations of coring sites in (**a**) the Minamihama moor and at **(b)** Rishiri Island.

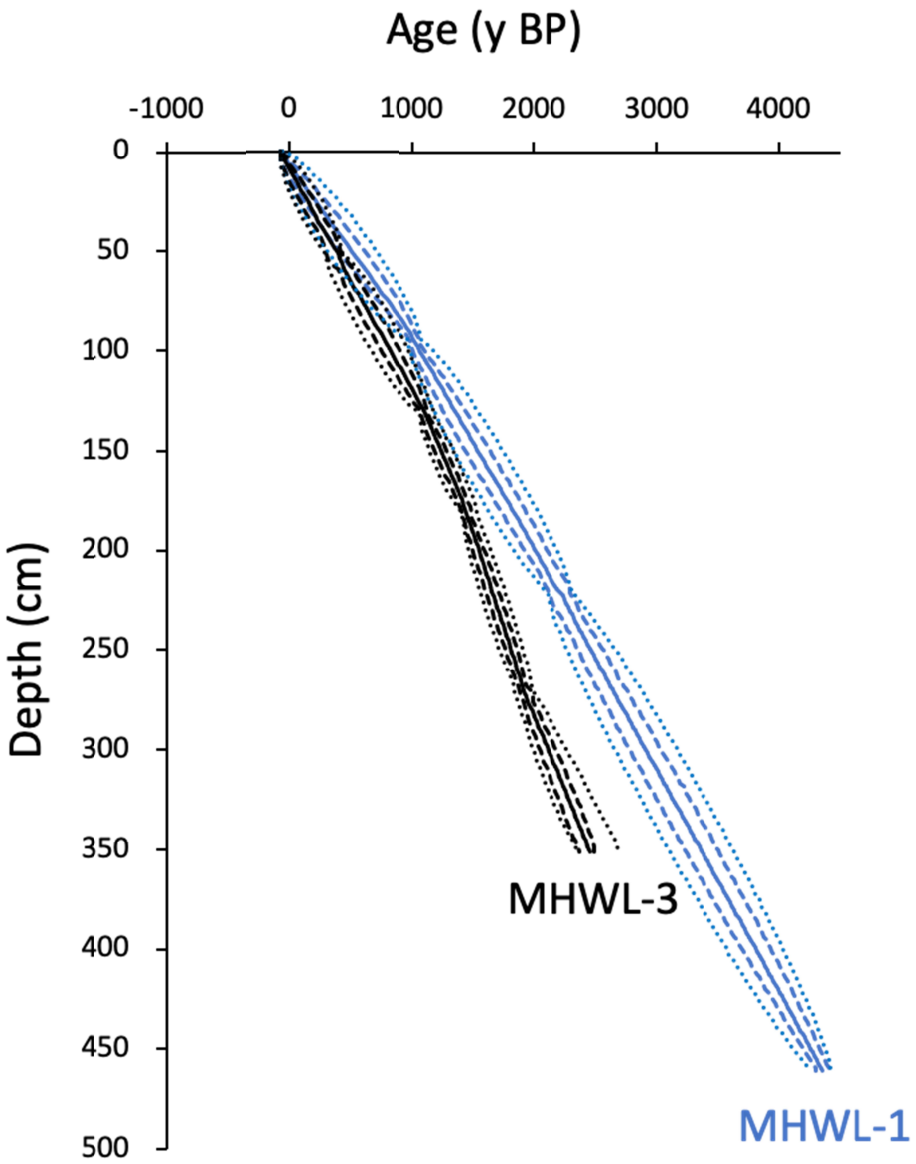

Figure S3. The age-depth model for cores MHWL-1 and MHWL-2. Solid, broken and dotted lines in the age–depth plot indicate the median and the 1σ and 2σ range of the modeled age, respectively.

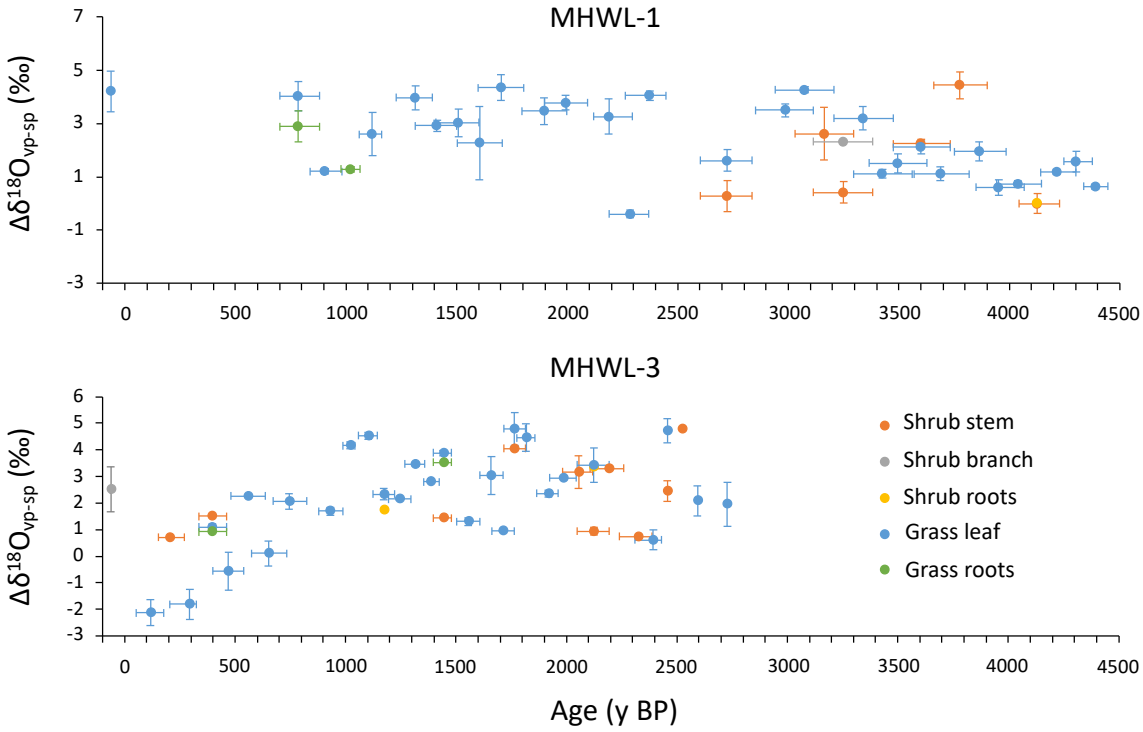

Figure S4. Changes in the difference of $\delta^{18}O$ between vascular plants and *Sphagnum* ($\Delta\delta^{18}O_{vp-sp}$) in cores MHWL-1 and MHWL-3. The vertical and horizontal bars of the sample value indicate the 1σ interval ranges.

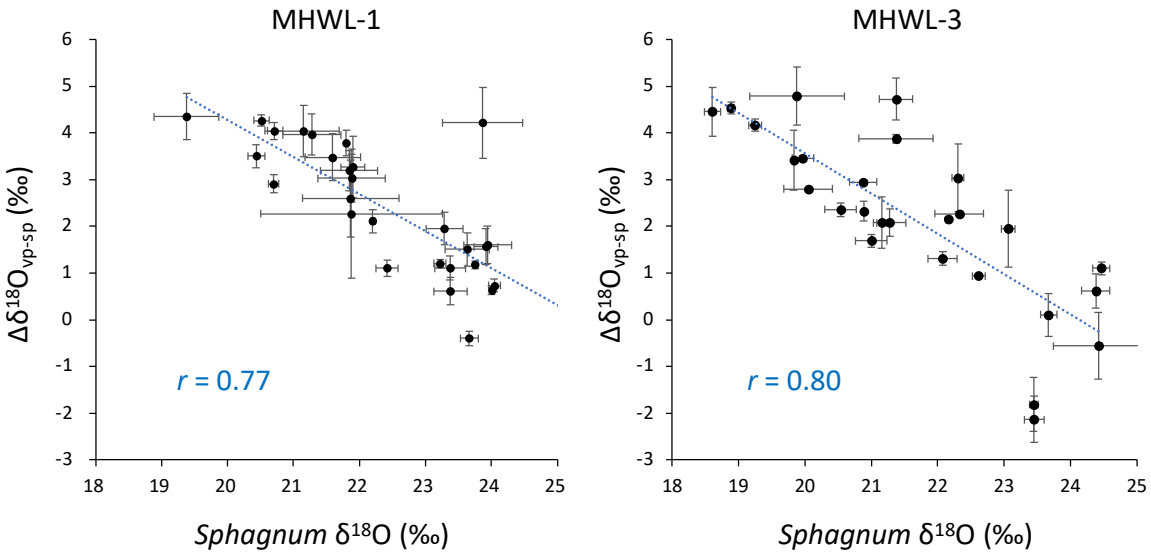

Figure S5. Cellulose $\delta^{18}O$ values of *Sphagnum* and the difference of $\delta^{18}O$ between grass leaf and *Sphagnum* in cores MHWL-1 and MHWL-3. Bars indicate 1σ intervals.