Supplement of

Environmental spaces for palsas and peat plateaus are disappearing at a circumpolar scale

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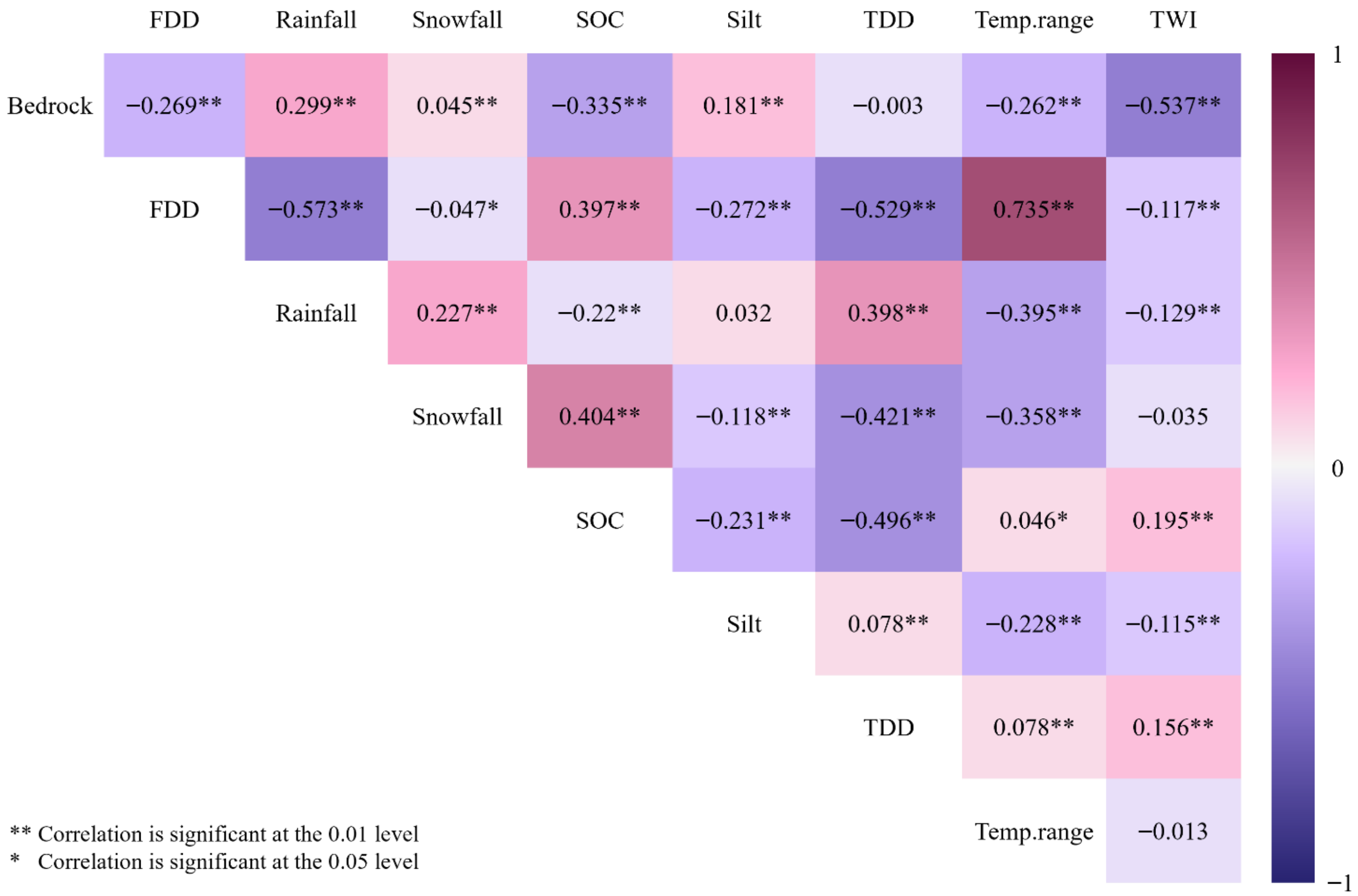

Figure S1: Bivariate correlations between used environmental variables. Spearman two-tailed correlations are color-graded (positive purple, and negative violet) according to their strength. Abbreviated variables are thawing- and freezing degree-days (TDD and FDD, °C-days), annual air temperature range (Temp.range, °C), topographic wetness index (TWI), soil organic carbon content (SOC, g kg^{-1}), silt content (Silt, g kg^{-1}) and bedrock probability within two meters (Bedrock, %). Statistical significancy of the correlation is illustrated with ** p ≤ 0.01 level) and * p ≤ 0.05.

Table S1: Average True Skill Statistic (TSS) cut-off values and ±1 standard deviations for used modelling methods (generalized linear model (GLM), generalized additive model (GAM), generalized boosting method (GBM), random forest (RF), and ensemble of the former methods). Calculations were based on 100 modelling runs of each method. Cut-off values were used in the binary classification.

	GLM	GAM	GBM	RF	Ensemble
Cut-off value	0.42 ± 0.081	0.48 ± 0.115	0.44 ± 0.166	0.45 ± 0. 087	0.52 ± 0.088

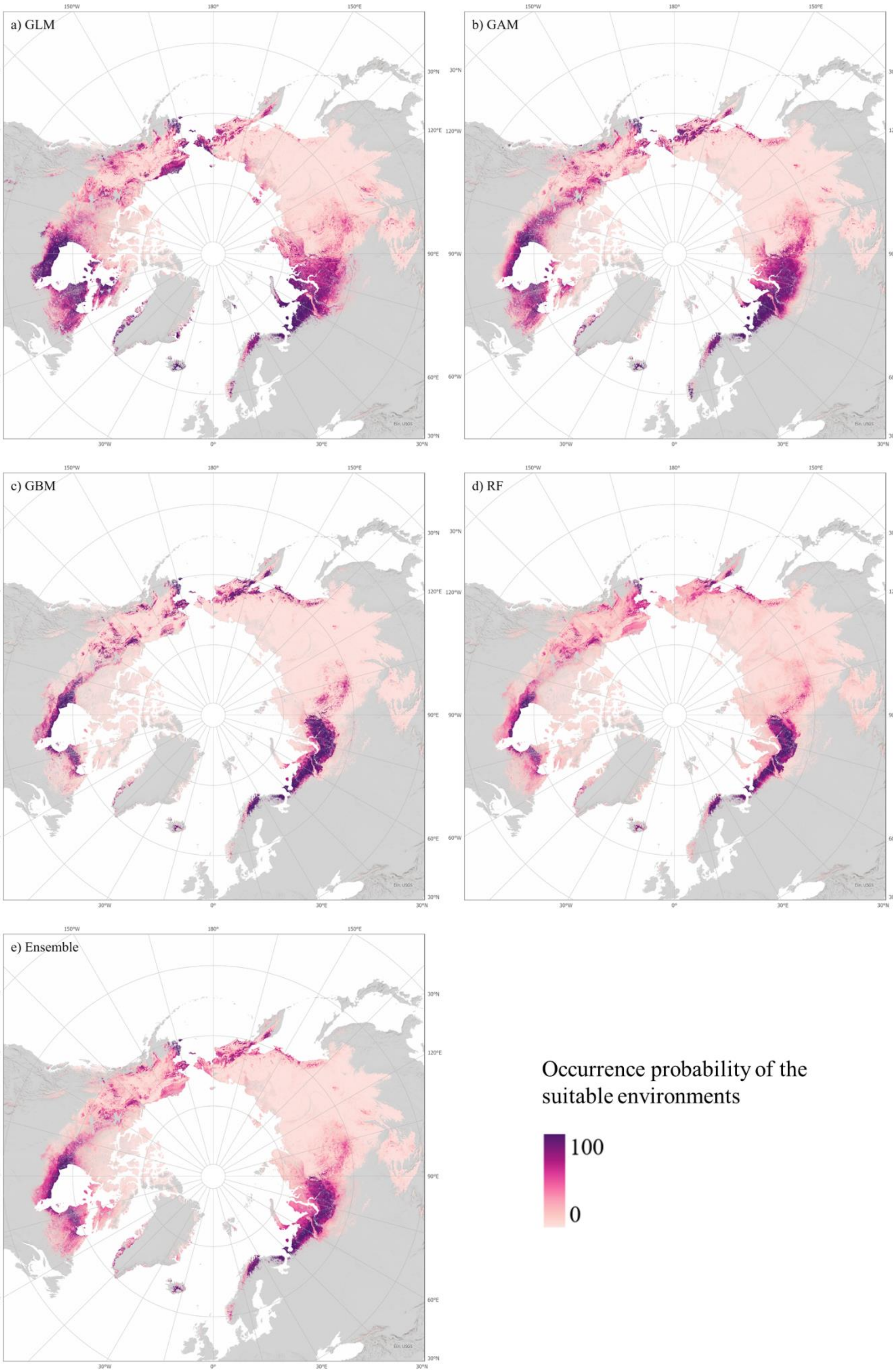

Figure S2: Occurrence probabilities of the suitable environments for the used modelling methods (a) generalized linear model (GLM), b) generalized additive model (GAM), c) generalized boosting method (GBM) and d) random forest (RF), and e) ensemble of the former methods. Model predictions are extracted for the permafrost region (Ran et al. 2022).

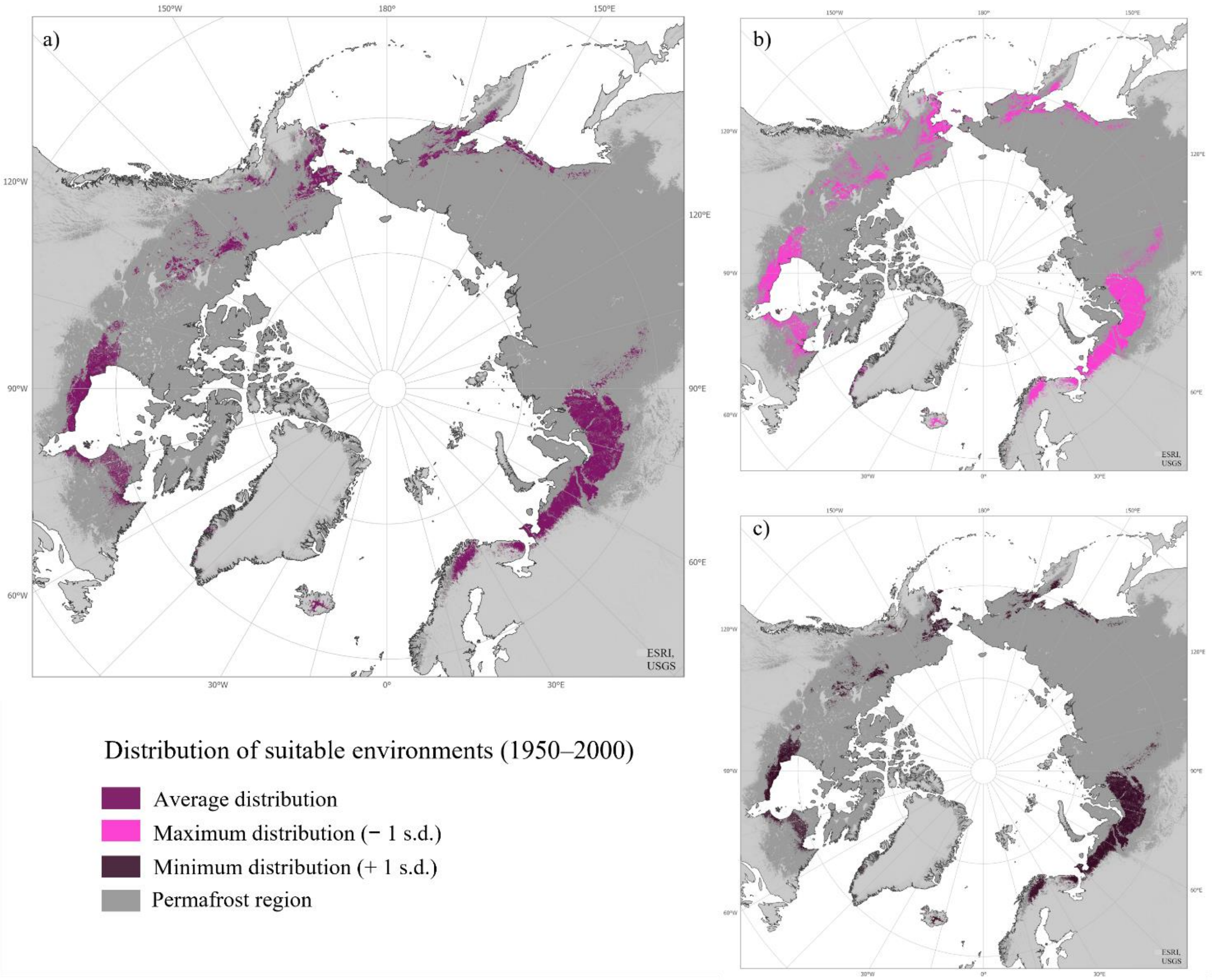

Figure S3: Comparison between binary classifications of the suitable environments (for period 1950–2000) for palsas and peat plateaus, based on different True Skill Statistic (TSS) cutoff values calculated from 100 model iterations: (a) average, (b) -1 standard deviation and (c) +1 standard deviation. On the background the permafrost region on dark grey (Ran et al. 2022).

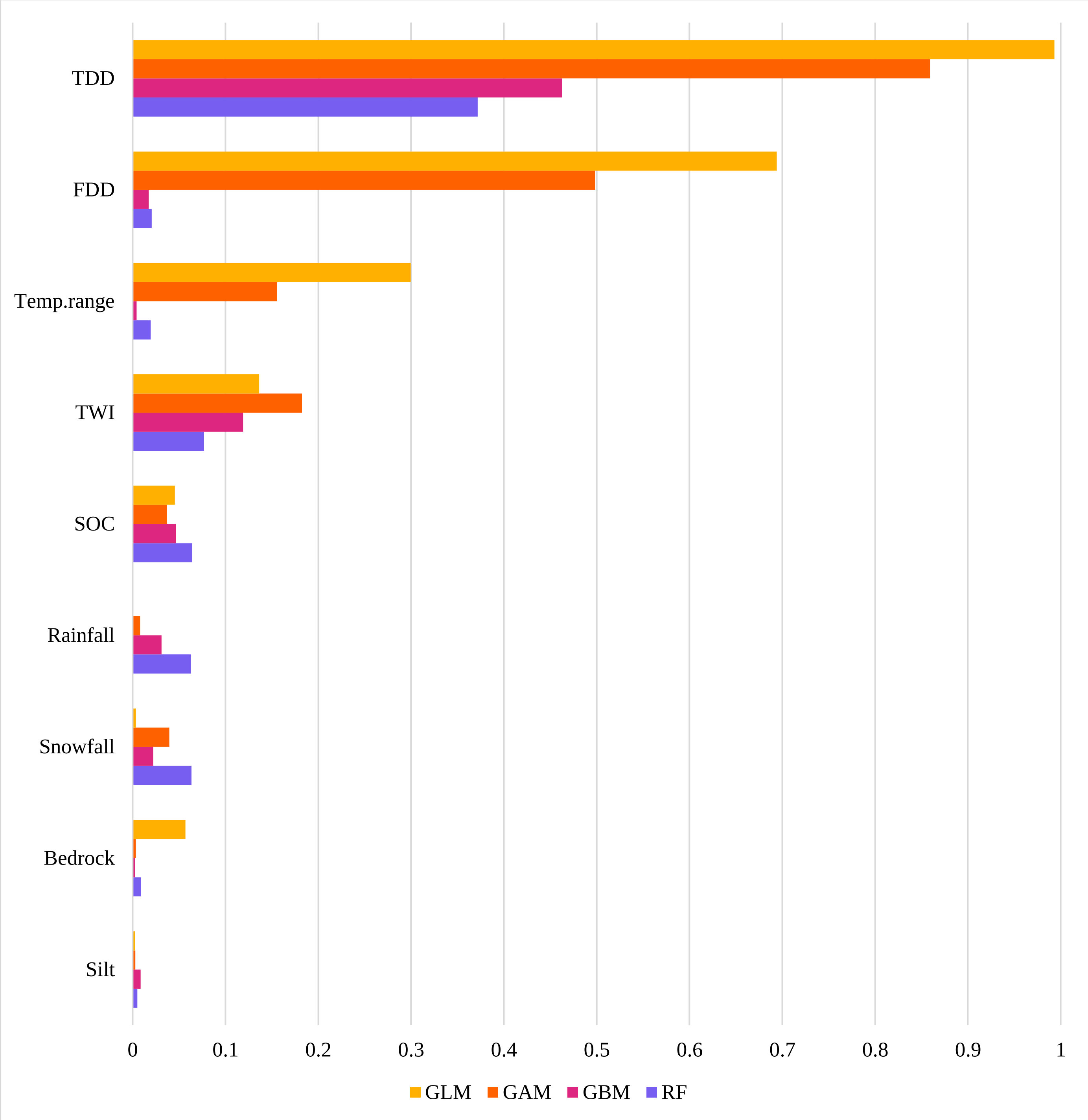

Figure S4: Variable importance of the environmental factors in different models (generalized linear model (GLM), generalized additive model (GAM), generalized boosting method (GBM) and random forest (RF Abbreviated variables are thawing- and freezing degree-days (TDD and FDD, °C-days), annual air temperature range (Temp.range, °C), topographic wetness index (TWI), soil organic carbon content (SOC, g kg^{-1}), silt content (Silt, g kg^{-1}) and bedrock probability within two meters from the ground surface (Bedrock, %).

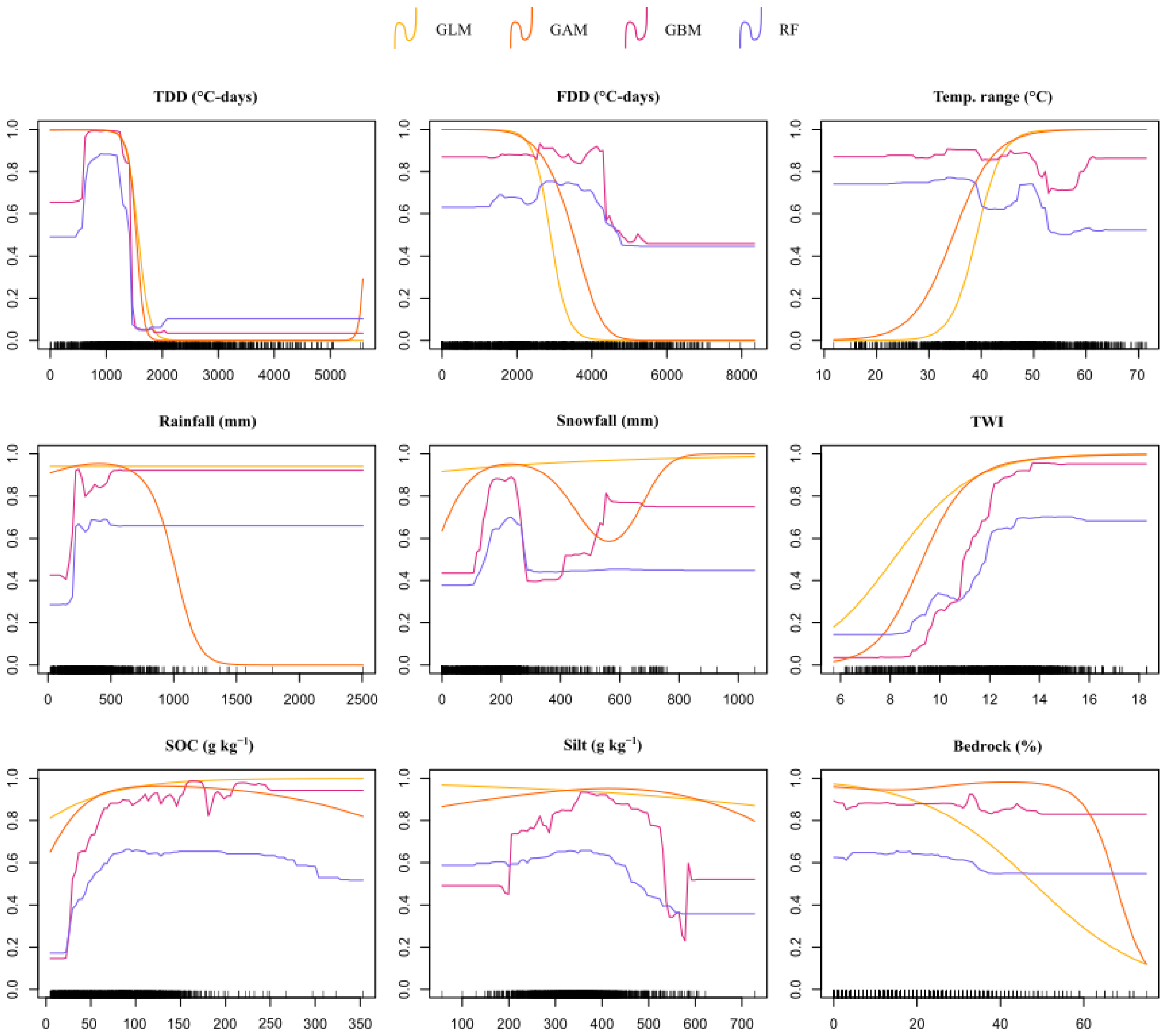

Figure S5: Response curves of the environmental factors. Results from four used models (generalized linear model (GLM), generalized additive model (GAM), generalized boosting method (GBM) and random forest (RF)). Abbreviated variables are thawing- and freezing degree-days (TDD and FDD, °C-days), annual air temperature range (Temp.range, °C), topographic wetness index (TWI), soil organic carbon content (SOC, g kg^{-1}), silt content (Silt, g kg^{-1}) and bedrock probability within two meters from the ground surface (Bedrock, %).

Table S2: Suitable environmental environments (in km²) for palsas and peat plateaus at different time periods and representative concentration pathway (RCP) climate change scenarios for used modelling methods (generalized linear model (GLM), generalized additive model (GAM), generalized boosting method (GBM), random forest (RF), and ensemble of the former methods). Areal percentage changes are given in relation to the modelled area of period 1950–2000.

Model	Scenario	Suitable environments (km²)	Percentage change (%)
GLM	1950–2000	3 787 750	
	RCP2.6 2041–2060	2 538 710	-33.0
	RCP2.6 2061–2080	2 465 660	-34.9
	RCP4.5 2041–2060	2 410 500	-36.4
	RCP4.5 2061–2080	2 002 450	-47.1
	RCP8.5 2041–2060	1 970 290	-48.0
	RCP8.5 2061–2080	1 257 860	-66.8
GAM	1950–2000	2 926 920	
	RCP2.6 2041–2060	1 343 190	-54.1
	RCP2.6 2061–2080	1 256 910	-57.1
	RCP4.5 2041–2060	1 151 210	-60.7
	RCP4.5 2061–2080	819 280	-72.0
	RCP8.5 2041–2060	782 370	-73.3
	RCP8.5 2061–2080	338 800	-88.4
GBM	1950–2000	2 039 920	
	RCP2.6 2041–2060	672 490	-67.0
	RCP2.6 2061–2080	637 110	-68.8
	RCP4.5 2041–2060	549 850	-73.1
	RCP4.5 2061–2080	352 040	-82.7
	RCP8.5 2041–2060	329 310	-83.9
	RCP8.5 2061–2080	103 820	-94.9
RF	1950–2000	1 587 360	
	RCP2.6 2041–2060	416 910	-73.7
	RCP2.6 2061–2080	376 650	-76.3
	RCP4.5 2041–2060	296 110	-81.4
	RCP4.5 2061–2080	169 460	-89.3
	RCP8.5 2041–2060	151 990	-90.4
	RCP8.5 2061–2080	28 590	-98.2
Ensemble	1950–2000	1 860 830	
	RCP2.6 2041–2060	622 230	-66.6
	RCP2.6 2061–2080	573 570	-69.2
	RCP4.5 2041–2060	499 720	-73.2
	RCP4.5 2061–2080	291 550	-84.3
	RCP8.5 2041–2060	268 030	-85.6
	RCP8.5 2061–2080	65 360	-96.5

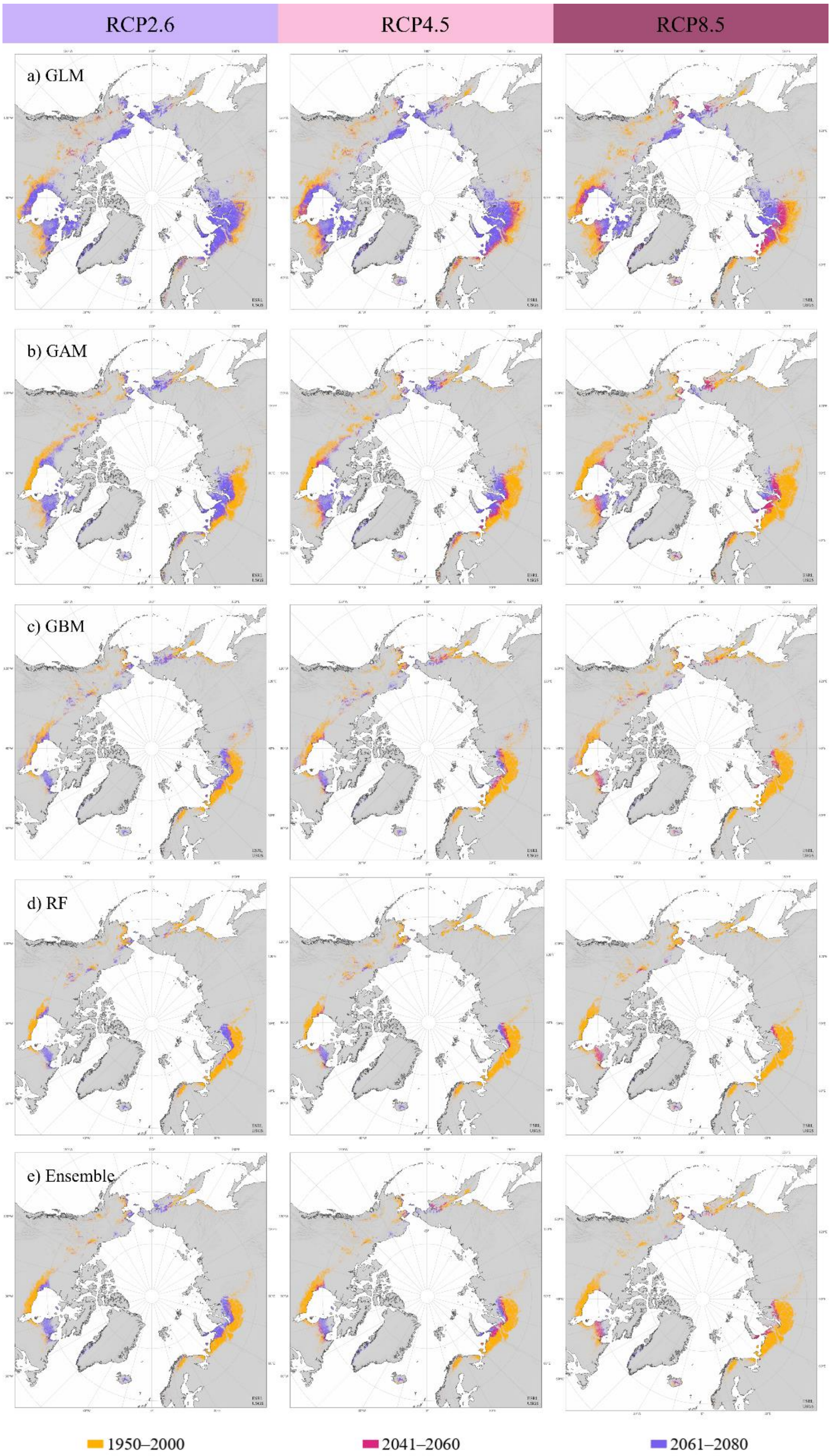

Figure S6: Predicted changes in distribution of suitable environmental spaces for palsas and peat plateaus for time periods 1950–2000, 2041–2060 and 2061–2080 under low (RCP2.6), moderate (RCP4.5), and high emissions (RCP8.5) representative concentration pathway climate change scenarios (RCP). Modelling results are presented for used modelling methods, generalized linear model (GLM; a), generalized additive model (GAM; b), generalized boosting method (GBM; c), random forest (RF; d), and ensemble (e) of the former methods. Results are provided for the permafrost region (Ran et al. 2022) and for the future periods for the extent of the period 1950–2000.

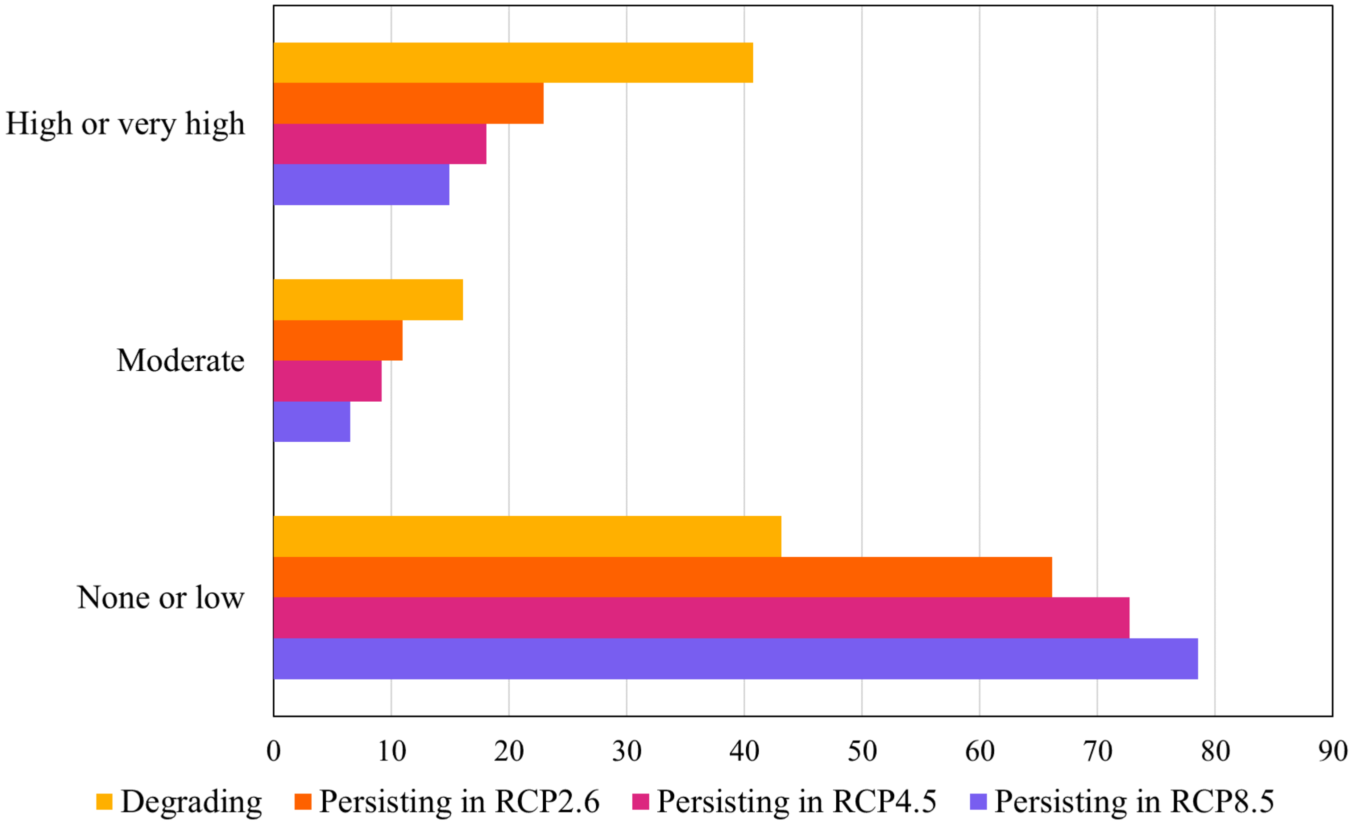

Figure S7: Classified wetland thermokarst likelihoods (%, Olefeldt et al., 2016) of the regions that our models predicted to be lost (under RCP2.6) and persist as suitable palsa and peat plateau environments during the period 2040–2061 in RCP2.6, RCP4.5, and RCP8.5 climate change scenarios.

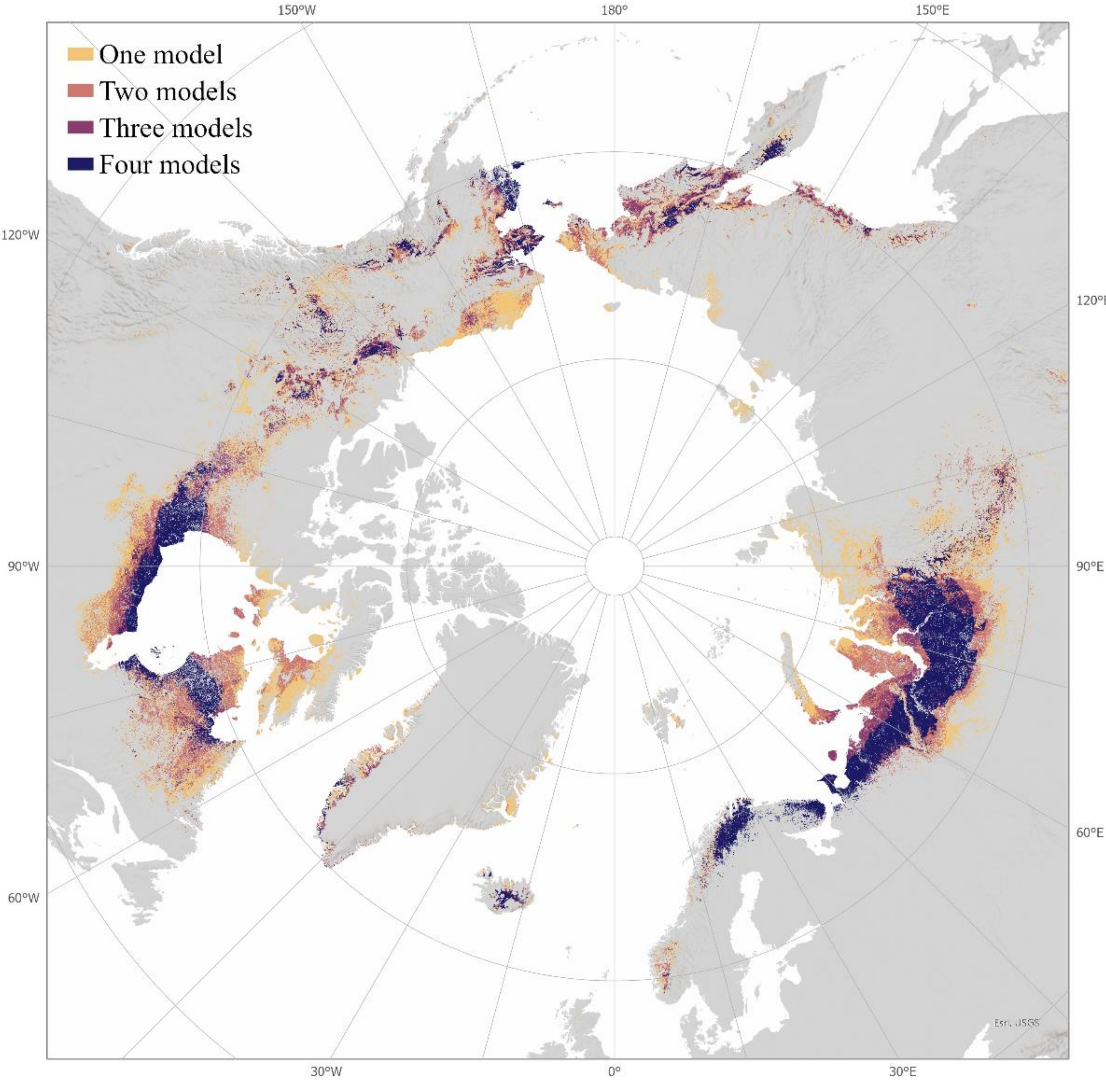

Figure S8: Inter-model variability in predicted suitable environmental spaces for palsa mires in 1950–2000. The model agreement from low (one model predicts palsa occurrence) to high (all four models predict palsa occurrence) is illustrated with graded colors from yellow to dark blue. Results are provided for the permafrost region (Ran et al., 2022).

List of references used in the compilation of palsa and peat plateau data.

Allards, M., and Seguin, M. K.: The Holocene evolution of permafrost near the tree line, on the eastern coast of Hudson Bay (northern Québec), Can. J. Earth Sci., 24, 2206–2222, https://doi.org/10.1139/e87-209, 1987.

An, W., and Allard, M.: A mathematical approach to modelling palsa formation: Insights on processes and growth conditions, Cold Reg. Sci. Tech., 23, 231–244, https://doi.org/10.1016/0165-232X(94)00015-P, 1995.

Arlen-Pouliot, Y., and Bhiry, N.: Palaeoecology of a palsa and a filled thermokarst pond in a permafrost peatland, subarctic Québec, Canada, Holocene 15:3, 408–419, https://doi.org/10.1191%2F0959683605hl818rp, 2005.

Backe, S.: Kartering av Sveriges palsmyrar, Länsstyrelsen, Luleå, 72 pp., urn:nbn:se:naturvardsverket:diva-2318, 2014.

Beilman, D. W., and Robinson, S. D.: Peatland permafrost thaw and landform type along a climatic gradient, in: Permafrost, edited by Philips, M., Springman S. M., and Arenson L. U., Swets & Zeitlinger, Lisse, 61–65, ISBN 90 5809 582 7, 2003.

Bhiry, N., and Robert, É.: Reconstruction of changes in vegetation and trofic conditions of a palsa in a permafrost peatland, subarctic Québec, Canada, Ecoscience, 13, 56–65, http://dx.doi.org/10.2980/1195-6860(2006)13[56:ROCIVA]2.0.CO;2, 2006.

Borge, A. F., Westermann, S., Solheim, I., and Etzelmüller, B.: Strong degradation of palsas and peat plateaus in northern Norway during the last 60 years, The Cryosphere, 11, 1–16, https://doi.org/10.5194/tc-11-1-2017, 2017.

Calmels, F., and Allard M.: Segregated Ice Structures in Various Heaved Permafrost Landforms Through CT scan, Earth Surf. Proc. Land., 33, 209–225, https://doi.org/10.1002/esp.1538, 2008.

Camill, P., Barry, A., Williams, E., Andreassi, C., Limmer J., and Solick, D.: Climate-vegetation-fire interactions and their impact on long-term carbon dynamics in a boreal peatland landscape in northern Manitoba, Canada, J. Geophy. Res., 114, G04017, https://doi.org/10.1029/2009JG001071, 2009.

Christiansen, H. H., Etzelmüller, B., Isaksen, K., Juliussen, H., Farbrot, H., Humlum, O., Johansson, M., Ingeman-Nielsen, T., Kristensen, L., Hjort, J., Holmlund, P., Sannel, A. B. K., Sigsgaard, C., Foged, N., Blikra, L. H., Pernosky, M. A., Ødegård, R. S., and Åkerman, H. J.: The Thermal State of Permafrost in the Nordic Area during the International Polar Year 2007–2009, Permafrost Periglac., 21, 156–181, https://doi.org/10.1002/ppp.687, 2010.

Cyr, S., and Payette S.: The origin and structure of wooded permafrost mounds at the treeline in eastern Canada, Plant Ecol. Div., 3, 35–46, https://doi.org/10.1080/17550871003777176, 2010.

Dionne, J. C.: Formes et phénomènes périglaciaires en Jamésie, Québec subarctique, Géogr. Phys. Quartr., 32, 187–247, https://doi.org/10.7202/1000303ar, 1978.

Dionne, J. C., and Richard, P. J. H.: Origine, Age et taux d'accrétion verticale de la tourbiere palses de Blanc-Sablon, basse Cote-Nord, Golfe du Saint-Laurent, Québec, Géogr. Phys. Quartr., 60, 199–205, https://doi.org/10.7202/016829ar, 2006.

Dredge, L., and Mott J.: Holocone Pollen Records and Peatland Development, Northeastern Manitoba, Géogr. Phys. Quartr., 57, 7–19, https://doi.org/10.7202/010328ar, 2003.

Eisner, W. R., Hinkel, K. M., Nelson, F. E., and Bockheim, J. G.: Late-Quaternary paleoenvironmental record from a palsa-scale frost mound in northern Alaska, in: Permafrost, edited by Philips, M., Springman S. M., and Arenson L. U., Swets & Zeitlinger, Lisse, 299–234, ISBN 90 5809 582 7, 2003.

Ferbar, M.: Palsa development in Dovrefjell, southern Norwegian Mountains Breakdown in a warming climate, Master's Thesis, Department of Geosciences, University of Oslo, Norway, 2009.

Fewster, R. E., Morris, P. J., Swindles, G. T., Gregoire, L. J., Ivanovic, R. F., Valdes, P. J., and Mullan, D.: Drivers of Holocene palsa distribution in North America, Quaternary Sci. Rev., 240, 106337, https://doi.org/10.1016/j.quascirev.2020.106337, 2020.

Fillion, M. E., Bihry, N., and Touazi, M.: Differential Development of Two Palsa Fields in a Peatland Located near Whapmagoostui-Kuujjuarapik, Northern Québec, Canada, Arct. Antarct. Alp. Res., 46, 40–5, https://doi.org/10.1657/1938-4246-46.1.40, 2014.

Glagolev, M., Kleptsova, I., Filippov, I., Maksyutov, S., and Machida, T.: Regional methane emission from West Siberia mire landscape. Environ. Res. Lett., 6, 045214, http://dx.doi.org/10.1088/1748-9326/6/4/045214, 2011.

Goncharova, O. Y., Matyshak Y. V., Bobrik, A. A., Moskalenko, N. G., and Ponomareva, O. E.: Temperature Regimes of Northern Taiga Soils in the Isolated Permafrost Zone of Western Siberia, Eurasian Soil Sci., 48, 1329–1340, https://doi.org/10.1134/S1064229315100038, 2015.

Göttlich, K., Hornburg, P., Köning, D., Schwaar, J., and Vorren, K.-D.: An examination of a palsa with layers of diatomite at Kautokeino, North Norway. Norsk. Geogr. Tidsskr., 37, 1–31, https://doi.org/10.1080/00291958308552086, 1983.

Holmquist, J. R., MacDonald, G. M., and Gallego-Sala, A.: Peatland initiation, carbon accumulation, and 2 ka depth in the James Bay Lowland and adjacent regions, Arct. Antarct. Alp. Res., 46, 19–39, https://doi.org/10.1657/1938-4246-46.1.19, 2014.

Hunt, S., Yu, Z., and Jones, M.: Lateglacial and Holocene climate, disturbance, and permafrost peatland dynamics on the Seward Peninsula, western Alaska, Quatr. Sci. Rev., 63, 42–58, https://doi.org/10.1016/j.quascirev.2012.11.019, 2013.

Jean, M., and Payette, S.: Effect of Vegetation Cover on the Ground Thermal Regime of Wooded and Non-Wooded Palsas, Permafrost Periglac., 25, 281–294, https://doi.org/10.1002/ppp.1817, 2014.

Jones, M. C., Harden, J., O'donnel, J., Manies, K., Jorgenson, T., Treat, C., and Ewing, S.: Rapid carbon loss and slow recovery following permafrost thaw in boreal peatlands, Glob. Change Biol., 23, 1109–1127, https://doi.org/10.1111/gcb.13403, 2017.

Kanevskiy, M., Jorgenson, T., Shur, Y., O'Donnell, J. A., Harden, J. W., Zhuang, Q., and Fortier, D.: Cryostarigraphy and permafrost pvolution in the lacustrine lowlands of West-Central Alaska. Permafrost Periglac., 25, 14–34, https://doi.org/10.1002/ppp.1800, 2014.

Kaverin, D. A., Pastukhov, A. V., and Novakovsky, A. B.: Specifity of the present-day soil temperature regime in a peat plateau (southern part of Bolshezemelskaya tundra) at locations crossed by regional highway, Earth`s Cryosphere 24, 20–28, 2020.

Kirpotin, S., Polishchuk, Y., Bryksina, N., Sugaipova, A., Kouraev, A., Zakharova, E., Pokrovsky, O. S., Shirokova, L., Kolmakova, M., Manassypov, R., and Dupre, B.: West Siberian palsa peatlands: distribution, typology, cyclic development, present day climate-driven changes, seasonal hydrology, and impact on CO2 cycle, Int. J. Environ. Stud., 68, 603–623, https://doi.org/10.1080/00207233.2011.593901, 2011

Kirpotin, S. N., Kvasnikova, Z. N., Potapova, S. A., Volkova, I. I., Volkov, I. V., Pyak, A. I., Byzaakay, A. A., Kolesnichenko, L. G., Lushchaeva, I. V., Khovalyg, A. O., Kuzhevskaia I. V. Chursin, V. V., and Peregon, A. M.: Pilot studies of the unique highland palsa mire in Western Sayan (Tuva Republic, Russian Federation), Atmosphere, 13, https://doi.org/10.3390/atmos13010032, 2022.

Koronatova, N. G., Mironycheva-Tokareva, N. P., & Solomin, Y. R.: Thermal Regime of Peat Deposits of Palsas and Hollows of Peat Plateaus in Western Siberia, Earth's Cryosphere 24, 15–23, https://doi.org/10.21782/EC2541-9994-2018-6(15-23), 2018.

Kosykh, N., Koronatova, N. G., Naumova, N. B., and Titlyanova, A. A.: Above- and below-ground phytomass and net primary production in boreal mire ecosystems of Western Siberia, Wetlands Ecological Management, 16, 139–153, https://doi.org/10.1007/s11273-007-9061-7, 2008.

Kultti, S., Oksanen, P., and Väliranta, M.: Holocene tree line, permafrost, and climate dynamics in the Nenets Region, East European Arctic, Can. J. Earth Sci., 41, 1141–1158, https://doi.org/10.1139/e04-058, 2004.

Kettles, I. M., Robinson, S. D., Bastien, D.-F., Garneau, M., and Hall, G. E. M.: Physical, geochemical, macrofossil and ground penetrating radar information on fourteen permafrost-affected peatlands in the Mackenzie Valley, Northwest Territories, Natural Resources Canada, Geological Survey of Canada, Ottawa, https://doi.org/10.4095/214221, 2003.

Kuhry, P.: Palsa and peat plateau development in the Hudson Bay Lowlands, Canada: timing, pathways and causes, Boreas, 37, 316–327, https://doi.org/10.1111/j.1502-3885.2007.00022.x, 2008.

Lamarre, A., Garneau, M., and Asnong, H.: Holocene paleohydrological reconstruction and carbon accumulation of a permafrost peatland using testate amoeba and macrofossil analyses, Kuujjuarapik, subarctic Quebec, Canada, Rev. Palaeobot. Palyno., 186, 131–141, https://doi.org/10.1016/j.revpalbo.2012.04.009, 2012.

Langlais, K.: Dynamique holocéne d'une tourbiére á palses de la region du lac á l'Eau-Claire (Nunavik), Master's thesis, University of Laval, Quebec, Canasa, 68 p, 2016.

Lavoie, C., and Payette, S.: Analyse macrofossile d'une palse subarctique (Québec nordique), Can. J. Bot., 73, 527–537, https://doi.org/10.1139/b95-054, 1995.

Lewkowicz, A. G., and Coultish, T. L.: Beaver Damming and Palsa Dynamics in a Subarctic Mountainous Environment, Wolf Creek, Yukon Territory, Canada, Arct. Antarct. Alp. Res., 36, 208–218, http://dx.doi.org/10.1657/1523-0430(2004)036[0208:BDAPDI]2.0.CO;2, 2004.

Loiko, S. V., Pokrovsky, O. S., Raudina, T. V., Lim, A., Kolesnichenko, L. G., Shirokova, L. S., Vorobyev S. N., and Kirpotin, S. N.: Abrupt permafrost collapse enhances organic carbon, CO2, nutrient, and metal release into surface waters, Chem. Geol., 47, 153–165, https://doi.org/10.1016/j.chemgeo.2017.10.002, 2017.

Lundqvist, G.: En palsmyr sydost om Kebnekaise. Geol. Forenings. Stock. For., 73, 209–225, https://doi.org/10.1080/11035895109453338, 1951.

Mamet, S. D., Chun, K. P., Kershaw, G. G. L., Loranty, M. M., and Peter Kershaw, G.: Recent Increases in Permafrost Thaw Rates and Areal Loss of Palsas in the Western Northwest Territories, Canada, Permafrost Periglac., 28, 619–633, https://doi.org/10.1002/ppp.1951, 2017.

Martin, L. C. P., Nitzbon, J., Aas, K. S., Etzelmüller, B., Kristiansen, H., and Westermann, S.: Stability Conditions of Peat Plateaus and Palsas in Northern Norway, J. Geophy. Res. Earth Sur., 124, 705–719, https://doi.org/10.1029/2018JF004945, 2019.

Matthews, J. A., Dahl, S.-O. O., Berrisford, M. S., and Nesje, A.: Cyclic development and thermokarstic degradation of palsas in the mid-alpine zone at Leirpullan, Dovrefjell, Southern Norway, Permafrost Periglac., 8, 107–122, https://doi.org/10.1002/(sici)1099-1530(199701)8:1<107::aid-ppp237>3.0.co;2-z, 1997.

Metsähallitus: Valtion suojelualueiden biotooppikuviot (Finnish dataset of biotopes), Metsähallitus, luontopalvelut, e3aa7b2a-e6e2-45dc-a29a-b64bcf2aba9f, 2019.

Nelson, F., Outcalt, S., Goodwin, C., and Hinkel, K.: Diurnal Thermal Regime in a Peat-Covered Palsa, Toolik Lake, Alaska, Arctic, 38, 310–315, 1985.

Oksanen, P. O., Kuhry, P., and Alekseeva, R. N.: Quaternaire Holocene Development and Permafrost History of the Usinsk Mire, Geogr. Phys. Quatr., 57, 169–187, https://doi.org/10.7202/011312ar, 2003.

Olvmo, M., Holmer, B., Thorsson, S., Reese, H., and Lindberg, F.: Sub-arctic palsa degradation and the role of climatic drivers in the largest coherent palsa mire complex in Sweden (Vissátvuopmi), 1955–2016, Sci. Rep.–UK., 10, 8937, https://doi.org/10.1038/s41598-020-65719-1, 2020.

Ottósson, J. G., Sveinsdóttir, A., and Harðardóttir, M.: Vistgerðirá Íslandi, Fjölrit Náttúrufræðistofnunar 54. Garðabær: NáttúrufræðistofnunÍslands (Habitat types in Iceland, Icelandic Institute of Natural History), ISBN 978-9979-9335-8-8, 2016.

Ou, C., Leblon, B., Zhang, Y., LaRocque, A., Webster, K., and McLaughlin, J.: Modelling and mapping permafrost at high spatial resolution using Landsat and Radarsat images in northern Ontario, Canada: part 1 – model calibration. Int. J. Remote Sens., 37, 2727–2750, https://doi.org/10.1080/01431161.2016.1157642, 2016.

Outcalt, S., and Nelson, F.: Computer simulations of buoyancy and snow-cover effects in palsa dynamics, Arct. Alp. Res., 16, 259–263, https://doi.org/10.1080/00040851.1984.12004413, 1984.

Patzner, M. S., Mueller, C. W., Malusova, M., Baur, M., Nikeleit, V., Scholten, T., Hoeschen, C., Byrne, J. M., Borch, T., Kappler, A., and Bryce, C.: Iron mineral dissolution releases iron and associated organic carbon during permafrost thaw, Nat. Commun., 11, 6329, https://doi.org/10.1038/s41467-020-20102-6, 2020.

Payette, S., Delwaide, A., Caccianiga, M., and Beauchemin, M.: Accelerated thawing of subarctic peatland permafrost over the last 50 years, Geophys. Res. Lett., 31, L18208, https://doi.org/10.1029/2004GL020358, 2004.

Pironkova, Z.: Mapping Palsa and Peat Plateau Changes in the Hudson Bay Lowlands, Canada, Using Historical Aerial Photography and High-Resolution Satellite Imagery, Can. J. Remote Sens., 43, 455–467, https://doi.org/10.1080/07038992.2017.1370366, 2017.

Plug, L. (2003). Ground-ice features and depth of peat across a mire chronosequence, NW Alaska, in: Permafrost, edited by Philips, M., Springman S. M., and Arenson L. U., Swets & Zeitlinger, Lisse, 901–906, ISBN 90 5809 582 7, 2003.

Points of Interest – Palsa MP 41, Alaska.org, https://www.alaska.org/detail/palsa-mp-41, last access: 08 May 2021.

Prater, J. L., Chanton, J. P., and Whiting, G. J.: Variation in methane production pathways associated with permafrost decomposition in collapse scar bogs of Alberta, Canada. Global Biogeo. Cyc., 21, GB4004, https://doi.org/10.1029/2006GB002866, 2007.

Railton, J. B., and Sparling, J. H.: Preliminary studies on the ecology of palsa mounds in northern Ontario, Can. J. Bot., 51, 1037–1044, https://doi.org/10.1139/b73-128, 1973.

Reger, R., Bundtzen, T., and Smith, T.: Geology of the Healy A-3 quadrangle, Alaska, Alaska Division of Geological & Geophysical Surveys Public-Data File 90-1, Fairbanks, Alaska, 13 p, 1990.

Robinson, S. D., and Moore, T. R.: The influence of permafrost and fire upon carbon accumulation in high boreal peatlands, Northwest Territories, Canada, Arct. Antarct. Alp. Res., 32, 155–166, https://doi.org/10.1080/15230430.2000.12003351, 2000.

Saemundsson, T., Arnalds, O., Kneisel, C., Jonsson, H. P., and Decaulne, A.: The Orravatnsrustir palsa site in Central Iceland-Palsas in an aeolian sedimentation environment, Geomorphology, 167–168, 13–20, https://doi.org/10.1016/j.geomorph.2012.03.014, 2012.

Sannel, B. K., and Kuhry, P.: Long-term stability of permafrost in subarctic peat plateaus, west-central Canada, The Holocene, 18, 589–601, https://doi.org/10.1177/0959683608089658, 2008.

Sannel, B. K., and Brown, I. A.: High-resolution remote sensing identification of thermokarst lake dynamics in a subarctic peat plateau complex, Can. J. Remote Sens., 36, S26–S40, https://doi.org/10.5589/m10-010, 2010.

Tam, A.: Permafrost in Canada's Subarctic Region of Northern Ontario, Master's thesis, Department of Geography, University of Toronto, Scarborough, Ontario, Canada, 2009.

Tam, A., Gough, W. A., Kowal, S., and Xie, C. (2014). The Fate of Hudson Bay Lowlands Palsas in a Changing Climate, Arct., Antarct. Alp. Res., 46, 114–120, https://doi.org/10.1657/1938-4246-46.1.114, 2014.

Tarnocai, C., and Bockheim, J. G.: Cryosolic soils of Canada: Genesis, distribution, and classification, Can. J. Soil Sci., 91, 749–762, https://doi.org/10.4141/cjss10020, 2011.

Terentieva, I. E., Glagolev, M. V., Lapshina, E. D., Faritovich Sabrekov, A., and Maksyutov, S.: Mapping of West Siberian taiga wetland complexes using Landsat imagery: implications for methane emissions, Biogeosciences, 13, 4615–462, https://doi.org/10.5194/bg-13-4615-2016, 2016.

Thibault, S., and Payette, S.: Recent Permafrost Degradation in Bogs of the James Bay Area Northern Quebec, Canada, Permafrost Periglac., 20, 383–389, https://doi.org/10.1002/ppp.660, 2009.

Throop, J., Lewkowicz, A. G., and Smith, S. L.: Climate and ground temperature relations at sites across the continuous and discontinuous permafrost zones, northern Canada, Can. J. Earth Sci., 49, 865–876, https://doi.org/10.1139/e11-075, 2012.

Treat, C. C., Wollheim, W. M., Varner, R. K., Grandy, A. S., Talbot, J., and Frolking, S.: Temperature and peat type control CO_2 and CH_4 production in Alaskan permafrost peats, Global Change Biol., 20, 2674–2686, https://doi.org/10.1111/gcb.12572, 2014.

Tsuyuzaki, S., Sawada, Y., Kushida, K., and Fukuda, M.: A preliminary report on the vegetation zonation of palsas in the Arctic National Wildlife Refuge, northern Alaska, USA, Ecol. Res., 23, 787–793, https://doi.org/10.1007/s11284-007-0437-1, 2008.

Vallée, S., and Payette, S.: Collapse of permafrost mounds along a subarctic river over the last 100 years (Northern Québec), Geomorphology, 90, 162–170, https://doi.org/10.1016/j.geomorph.2007.01.019, 2007.

Vasil'chuk Y. K., Vasil'chuk, A. C., Budantseva, N. A., Volkova, Y. M., Sulerzhitsky, L. D., Chizhova, J. N., and Jungner, H.: Radiocarbon age and Holocene dynamics of palsa in the Usa River valley, Doclady Earth Sciences, 384, 442–447, 2002.

Vasil'chuk, Y., Vasil'chuk, A. C., Sulerzhitskiim L. D., Budantseva N. A., Volkova, E. M., and Chizhova, J. N.: Radiocarbon chronology of palsen in the Bol'shaya Zemlya Tundra, Doklady Earth Sciences, 396, 1160–1164, 2003.

Vasil'chuk Y. K., Vasil'chuk, A. C., Budantseva, N. A., and Chizhova, J. N.: Palsas in the north of Western Siberia: the southern and northern limits of the areal and the modern dynamics, Eng. Geol., 3, 62–78, 2012.

Vasil'chuk, Y., Vasil'chuk, A. C., Jungner, H., Budantseva, N. A., Chizhova, J. N.: Radiocarbon chronology of Holocene palsa of Bol'shemel'skaya tundra in Russian North, Geography, Environment, Sustainability, 6, 38–59, https://doi.org/10.24057/2071-9388-2013-6-3-38-59, 2013.

Vasil'chuk, Y. K., Vasil'chuk, A. C., and Repkina, T. Y.: Palsas in the polar part of the Middle Siberia permafrost zone, Eng. Geol. 2, 28–45, 2013a.

Vasil'chuk, Y. K., Vasil'chuk, A. C., Budantseva, N. A., Yoshikawa, K., Chizhova, J. N., and Stanilovskaya, J. V.: Palsas in the southern part of the Middle Siberia permafrost zone, Eng. Geol. 3, 13–34, 2013b

Vasil'chuk, Y. K., Budantseva, N. A., Vasil'chuk, A. C., and Chizhova, J. N.: Palsas in the Eastern Siberia and Far East permafrost zone, Eng. Geol., 1, 40–64, 2014.

Wang, Z., and Roulet, N.: Comparison of plant litter and peat decomposition changes with permafrost thaw in a subarctic peatland, Plant Soil 417, 197–216, https://doi.org/10.1007/s11104-017-3252-7, 2017.

Way, R. G., and Lewkowicz, A. G.: Environmental controls on ground temperature and permafrost in Labrador, northeast Canada, Permafrost Periglac., 29, 73–85, https://doi.org/10.1002/ppp.1972, 2018.

Way, R. G., Lewkowicz, A. G., and Zhang, Y.: Characteristics and fate of isolated permafrost patches in coastal Labrador, Canada, The Cryosphere 12, 2667–2688, https://doi.org/10.5194/tc-12-2667-2018, 2018.

White, S., Clark, G., and Rapp, A.: Palsa Localities in Padjelanta National Park, Swedish Lapland, Geogr. Ann., 51, 97–103, https://doi.org/10.1080/04353676.1969.11879793, 1969.

Yukon Geological Survey, Yukon Landform Atlas: https://open.yukon.ca/data/datasets/yukon-landform atlas, last access: 28 May 2021

Zhang, H., Amesbury, M. J., Ronkainen, T., Charman, D. J., Gallego-Sala, A. V., and Väliranta, M.: Testate amoeba as palaeohydrological indicators in the permafrost peatlands of north-east European Russia and Finnish Lapland, J. Quatr. Sci., 32, 976–988, https://doi.org/10.1002/jqs.2970, 2017.

Zoltai, S. C., R. M. Siltanen & J. D. Johnson: A wetland environmental data base, NOR-X Report, Northern Forestry Centre, Canadian Forest Service, Edmonton, Alberta, Canda, ISSN 0704-7673, 2000.