Supplemental information

Table S1 – General circulation models included in our CMIP6 model ensemble. Outputs from these models were used to represent future climates. Transient climate response (TCR) (°C) and equilibrium climate sensitivity (ECS) (°C) scores are taken from ref[1].

Model	TCR (°C)	ECS (°C)
INM-CM5-0	-	1.9
CAMS-CSM1-0	1.7	2.3
MIROC6	1.6	2.6
GFDL-ESM4	1.6	2.6
MPI-ESM1-2-HR	1.7	3.0
FGOALS-f3-L	2.1	3.0
BCC-CSM2-MR	1.7	3.0
MRI-ESM2-0	1.6	3.2
IPSL-CM6A-LR	2.3	4.6
ACCESS-CM2	2.1	4.7
CESM2-WACCM	2.0	4.8
CNRM-CM6-1	2.1	4.8

Table S2 – Summary of the logistic regression model which describes the modern climate envelope of palsas/peat plateaus in Europe and Western Siberia. *βs* are standardised coefficients, according to the method of ref[2].

Variable	Coefficient	Standard error	*βs*	*t*	Significance
Constant	7.091×10^{1}	8.719	-	8.133	< 0.001
MAT	-4.616	3.369×10^{-1}	-9.708×10^{-1}	-13.703	< 0.001
*MAT**	3.030×10^{-1}	2.286×10^{-2}	5.251×10^{-1}	13.254	< 0.001
TRANGE	-4.371	3.863×10^{-1}	-1.493	-11.314	< 0.001
$TRANGE^2$	4.221×10^{-2}	3.941×10^{-3}	7.948×10^{-1}	10.709	< 0.001
GDD_5	2.232×10^{-2}	2.871×10^{-3}	6.646×10^{-1}	7.776	< 0.001
GDD_5^2	-7.653×10^{-6}	1.013×10^{-6}	-9.621×10^{-1}	-7.556	< 0.001
RAINFALL	-1.169×10^{-1}	1.930×10^{-2}	-1.290	-6.054	< 0.001
$RAINFALL^2$	1.998×10^{-5}	4.760×10^{-6}	4.394×10^{-1}	4.198	< 0.001
SNOWFALL	-2.291×10^{-2}	4.850×10^{-3}	-9.405×10^{-2}	-4.723	< 0.001
$SNOWFALL^2$	1.925×10^{-5}	6.961×10^{-6}	4.777×10^{-2}	2.765	0.006
RAINFALL × TRANGE	3.804×10^{-3}	5.299×10^{-4}	4.266×10^{-1}	7.179	< 0.001

Table S3 – Summary of the logistic regression model which describes the modern climate envelope of polygon mires in Europe and Western Siberia. *βs* are standardised coefficients, according to the method of ref[2].

Variable	Coefficient	Standard error	*βs*	*t*	Significance
Constant	-3.066×10^{1}	3.372	-	-9.092	< 0.001
MAT	-6.739	5.384×10^{-1}	-9.316×10^{-1}	-12.517	< 0.001
*MAT**	3.865×10^{-1}	3.251×10^{-2}	4.404×10^{-1}	11.888	< 0.001
SNOWFALL	6.271×10^{-2}	2.122×10^{-2}	1.693×10^{-1}	2.955	0.003
$SNOWFALL^2$	-2.153×10^{-4}	4.905×10^{-5}	-3.512×10^{-1}	-4.388	< 0.001

Table S4 – Cross-validated model performance statistics and optimised classification thresholds for our climate envelope models of palsas/peat plateaus and polygon mires for Europe and Western Siberia (from 25°W to 95°E). Mean values (and standard errors) for each evaluation metric were calculated from predictions generated from five validation subsets. We optimised the classification thresholds for each model, because of the imbalance of landform presence and absence in our training datasets (see methods for further details).

Metric	Palsas/peat plateaus	Polygon Mires
Accuracy	94.1 % (± 0.004)	96.1 % (± 0.005)
Informedness	0.886 (± 0.006)	0.936 (± 0.003)
AUC	0.982 (± 0.002)	0.991 (± 0.002)
Optimised classification threshold	0.273	0.130

Table S5 – Predicted climate envelopes for palsas/peat plateaus and polygon mires in Europe and Western Siberia (from 25°W to 95°E), estimated using our logistic regression models (Tables S2–S3) for the modern baseline period (1961–1990). Spatial minima, medians and maxima are presented, calculated from climatically suitable grid cells. Hyphens represent non-significant climate variables.

Climate Envelope		*MAT* (°C)	*TRANGE* (°C)	*GDD$_5$* (°C days)	*RAINFALL* (mm yr^{-1})	*SNOWFALL* (mm yr^{-1})
Palsas/peat plateaus	Min	-9.4	11.6	0	141	130
	Median	-4.7	38.2	1246	283	222
	Max	2.6	43.5	1672	471	751
Polygon Mires	Min	-12.1	-	-	-	108
	Median	-8.3	-	-	-	209
	Max	-5.2	-	-	-	297

Table S6 – Median projected values of regional annual temperature range (*TRANGE*) by 2090–2099; the change from the modern baseline period (1961–1990) (Δ *TRANGE*); and standard deviations of *TRANGE* across our CMIP6 model ensemble (Std. dev). *TRANGE* values were averaged across all grid cells that were classified to be climatically suitable for palsas/peat plateaus and polygon mires during the modern baseline period (Figure 2), for Fennoscandia and Russia. Our Russia region excludes the Kola Peninsula and Karelia, which are included in Fennoscandia.

Scenario	*TRANGE* (Δ *TRANGE*, Std. dev) (°C)		
	Palsas/peat plateaus in Fennoscandia	Palsas/peat plateaus in Russia	Polygon mires in Russia
SSP1-2.6	27.1 (-0.7, ±1.9)	37.9 (-0.6, ±1.7)	35.5 (-1.4, ±2.1)
SSP2-4.5	26.5 (-1.3, ±1.9)	37.3 (-1.2, ±1.5)	35.1 (-1.7, ±1.7)
SSP3-7.0	25.6 (-2.2, ±2.2)	36.1 (-2.3, ±2.4)	33.1 (-3.7, ±2.4)
SSP5-8.5	26.2 (-1.6, ±2.0)	35.0 (-3.5, ±3.0)	32.6 (-4.2, ±3.6)

Table S7 – Projected regional growing degree days (*GDD_5*) for 2090–2099, with comparisons to the modern baseline period (1961–1990). See Table S6 caption for full details.

Scenario	GDD_5 (Δ GDD_5, Std. dev) (°C days)		
	Palsas/peat plateaus in Fennoscandia	Palsas/peat plateaus in Russia	Polygon mires in Russia
SSP1-2.6	1419 (+496, ±208)	1615 (+322, ±160)	1249 (+428, ±168)
SSP2-4.5	1639 (+716, ±155)	1876 (+583, ±213)	1442 (+621, ±209)
SSP3-7.0	1892 (+968, ±227)	2167 (+874, ±307)	1648 (+827, ±241)
SSP5-8.5	1970 (+1046, ±349)	2591 (+1298, ±425)	2049 (+1227, ±391)

Table S8 – Projected regional rainfall for 2090–2099, with comparisons to the modern baseline period (1961–1990). See Table S6 caption for full details.

Scenario	*RAINFALL* (Δ *RAINFALL*, Std. dev) (mm yr^{-1})		
	Palsas/peat plateaus in Fennoscandia	Palsas/peat plateaus in Russia	Polygon mires in Russia
SSP1-2.6	357 (+69, ±27)	317 (+35, ±29)	230 (+33, ±20)
SSP2-4.5	407 (+118, ±29)	362 (+80, ±34)	250 (+53, ±37)
SSP3-7.0	445 (+156, ±39)	374 (+91, ±39)	308 (+111, ±48)
SSP5-8.5	472 (+183, ±58)	418 (+136, ±52)	328 (+131, ±58)

Table S9 – Projected regional snowfall for 2090–2099, with comparisons to the modern baseline period (1961–1990). See Table S6 caption for full details.

Scenario	*SNOWFALL* (Δ *SNOWFALL*, Std. dev) (mm yr^{-1})		
	Palsas/peat plateaus in Fennoscandia	Palsas/peat plateaus in Russia	Polygon mires in Russia
SSP1-2.6	243 (-29, ±25)	234 (+14, ±25)	224 (+15, ±21)
SSP2-4.5	243 (-30, ±17)	219 (-1, ±22)	233 (+24, ±21)
SSP3-7.0	233 (-40, ±22)	226 (+6, ±22)	225 (+16, ±26)
SSP5-8.5	233 (-39, ±27)	217 (-3, ±33)	215 (+6, ±34)

Table S10 – Description of candidate climate variables.

Variable	Description	Units
Mean annual temperature (*MAT*)	Average annual air temperature	°C
Temperature range (*TRANGE*)	Difference between maximum and minimum monthly air temperatures	°C
Growing degree days (GDD_5)	Annual time integral of monthly air temperatures above 5°C	°C days
Rain precipitation (*RAINFALL*)	Total annual precipitation in months with average air temperatures > 0°C	mm yr^{-1}
Snow precipitation (*SNOWFALL*)	Total annual precipitation in months with average air temperatures < 0°C	mm yr^{-1}

Table S11 – Spearman's Rank correlation matrix for candidate climate variables included in our climate envelope modelling of Europe and Western Siberia. Correlation coefficients, r_s, and significance values, p, are presented. See Table S10 for variable descriptions.

	MAT	*TRANGE*	*GDD5*	*RAINFALL*	*SNOWFALL*
MAT	-	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$
TRANGE	$r_s = -0.783$	-	$p < 0.001$	$p < 0.001$	$p < 0.001$
GDD5	$r_s = 0.897$	$r_s = -0.473$	-	$p < 0.001$	$p < 0.001$
RAINFALL	$r_s = 0.877$	$r_s = -0.773$	$r_s = 0.732$	-	$p < 0.001$
SNOWFALL	$r_s = -0.627$	$r_s = 0.390$	$r_s = -0.707$	$r_s = -0.438$	-

Table S12 – Spearman's Rank correlation matrix for candidate climate variables for grid cells in Europe and Western Siberia where observations of palsas/peat plateaus are present (*n* = 671) and absent (*n* = 3,944). Correlation coefficients, r_s, and significance values, *p*, are presented. See Table S10 for variable descriptions.

		MAT	*TRANGE*	*GDD5*	*RAINFALL*	*SNOWFALL*
MAT	*Presence*		$p = 0.213$	$p < 0.001$	$p < 0.001$	$p = 0.036$
	Absence		$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$
TRANGE	*Presence*	$r_s = -0.048$		$p < 0.001$	$p < 0.001$	$p = 0.014$
	Absence	$r_s = -0.787$		$p < 0.001$	$p < 0.001$	$p < 0.001$
GDD5	*Presence*	$r_s = 0.390$	$r_s = 0.825$		$p < 0.001$	$p = 0.011$
	Absence	$r_s = 0.879$	$r_s = -0.455$		$p < 0.001$	$p < 0.001$
RAINFALL	*Presence*	$r_s = 0.712$	$r_s = 0.385$	$r_s = 0.668$		$p = 0.056$
	Absence	$r_s = 0.857$	$r_s = -0.816$	$r_s = 0.670$		$p < 0.001$
SNOWFALL	*Presence*	$r_s = -0.081$	$r_s = 0.095$	$r_s = -0.098$	$r_s = 0.074$	
	Absence	$r_s = -0.636$	$r_s = 0.359$	$r_s = -0.724$	$r_s = -0.413$	

Table S13 – Spearman's Rank correlation matrix for candidate climate variables for grid cells in Europe and Western Siberia where observations of polygon mires are present (n = 339) and absent (n = 4,276). Correlation coefficients, r_s, and significance values, p, are presented. See Table S10 for variable descriptions.

		MAT	*TRANGE*	*GDD5*	*RAINFALL*	*SNOWFALL*
MAT	*Presence*		$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$
	Absence		$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$
TRANGE	*Presence*	$r_s = 0.802$		$p < 0.001$	$p < 0.001$	$p = 0.001$
	Absence	$r_s = -0.810$		$p < 0.001$	$p < 0.001$	$p < 0.001$
GDD5	*Presence*	$r_s = 0.983$	$r_s = 0.864$		$p < 0.001$	$p < 0.001$
	Absence	$r_s = 0.874$	$r_s = -0.473$		$p < 0.001$	$p < 0.001$
RAINFALL	*Presence*	$r_s = 0.797$	$r_s = 0.555$	$r_s = 0.800$		$p < 0.001$
	Absence	$r_s = 0.854$	$r_s = -0.807$	$r_s = 0.676$		$p < 0.001$
SNOWFALL	*Presence*	$r_s = 0.401$	$r_s = 0.181$	$r_s = 0.408$	$r_s = 0.835$	
	Absence	$r_s = -0.696$	$r_s = 0.414$	$r_s = -0.786$	$r_s = -0.488$	

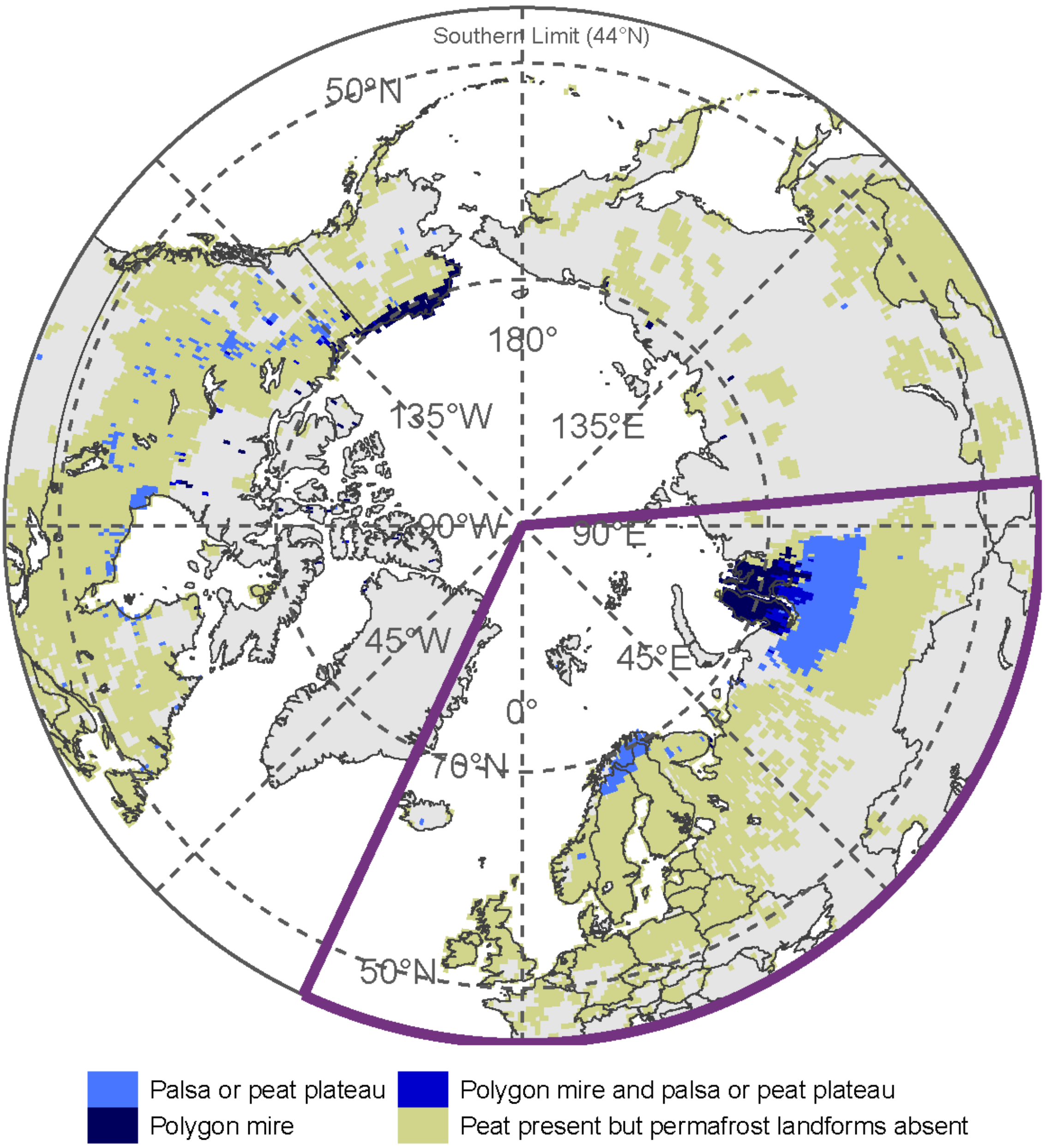


Figure S1 – Distribution of observed permafrost peatland landforms in our catalogue of published records (Dataset S1). Dark purple box indicates our study domain (north of 44°N and between 25°W and 95°E). Map outlines are from ref[4].

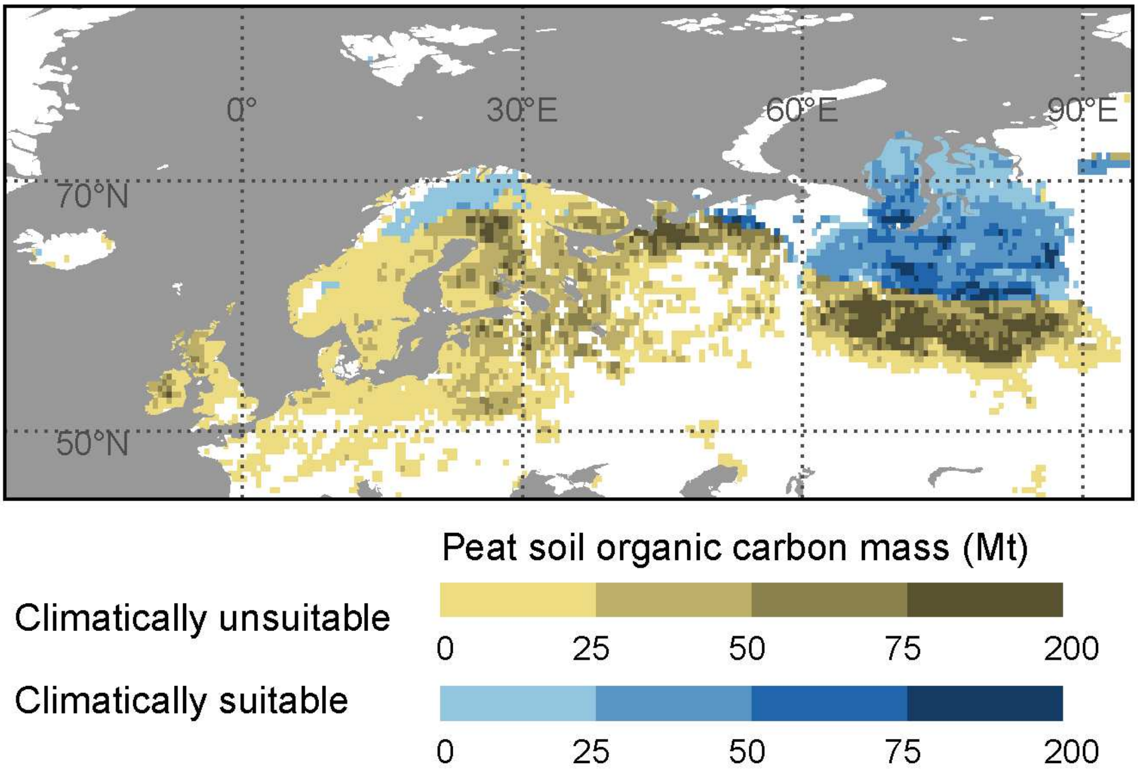
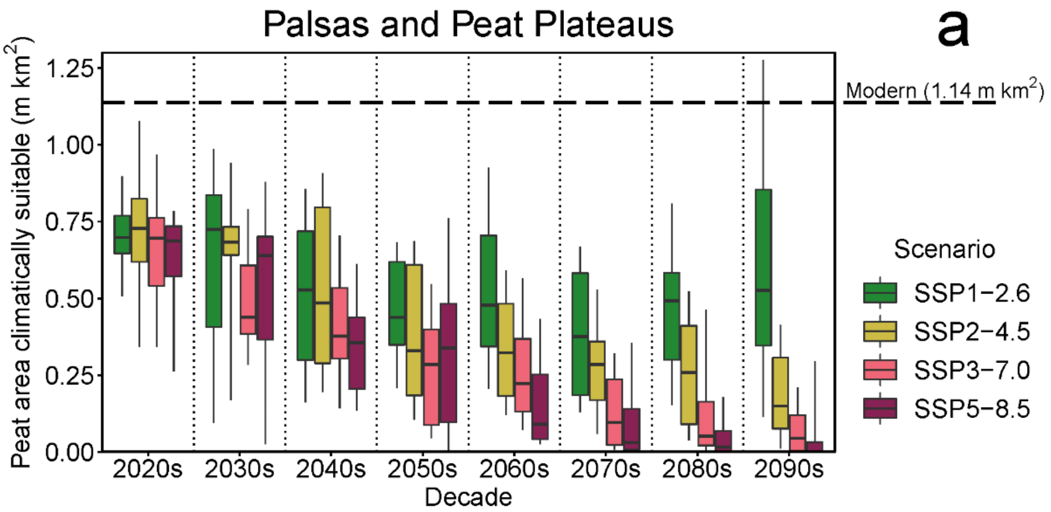


Figure S2 – The distribution of gridded peat soil organic carbon mass (Mt), based on recent soil maps[3,5] (see methods for details) and coloured according to the predicted presence and absence of suitable climatic conditions for permafrost peatlands. Map outlines are from ref[4].



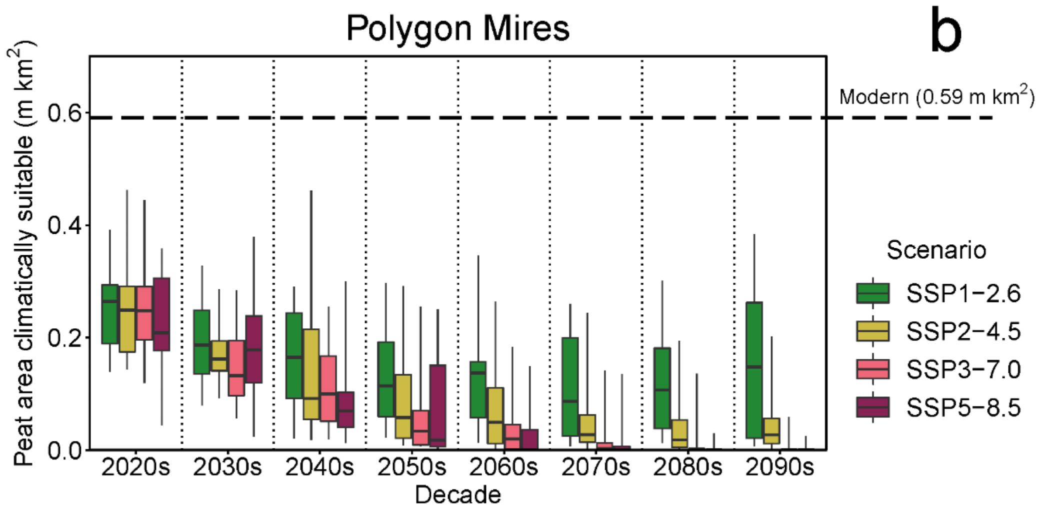


Figure S3 – Comparisons of the total peatland area (m km^2) that is within the suitable climate envelopes for peatland permafrost in Europe and Western Siberia under four CMIP6 emission scenarios. Decadal time series showing for SSP1-2.6, SSP2-4.5, SSP3-7.0 and SSP5-8.5 the total peatland area in Europe and Western Siberia that is: a) within the suitable climate envelope for palsas/peat plateaus; and b) within the suitable climate envelope for polygon mires. Whiskers indicate the full range of values from the 12 CMIP6 models in our ensemble, lower hinges indicate the 25th percentiles, upper hinges indicate the 75th percentiles, and centre lines indicate median values. Dashed lines represent the total peatland area that is within the respective suitable climate envelopes during the modern baseline period (1961–1990).

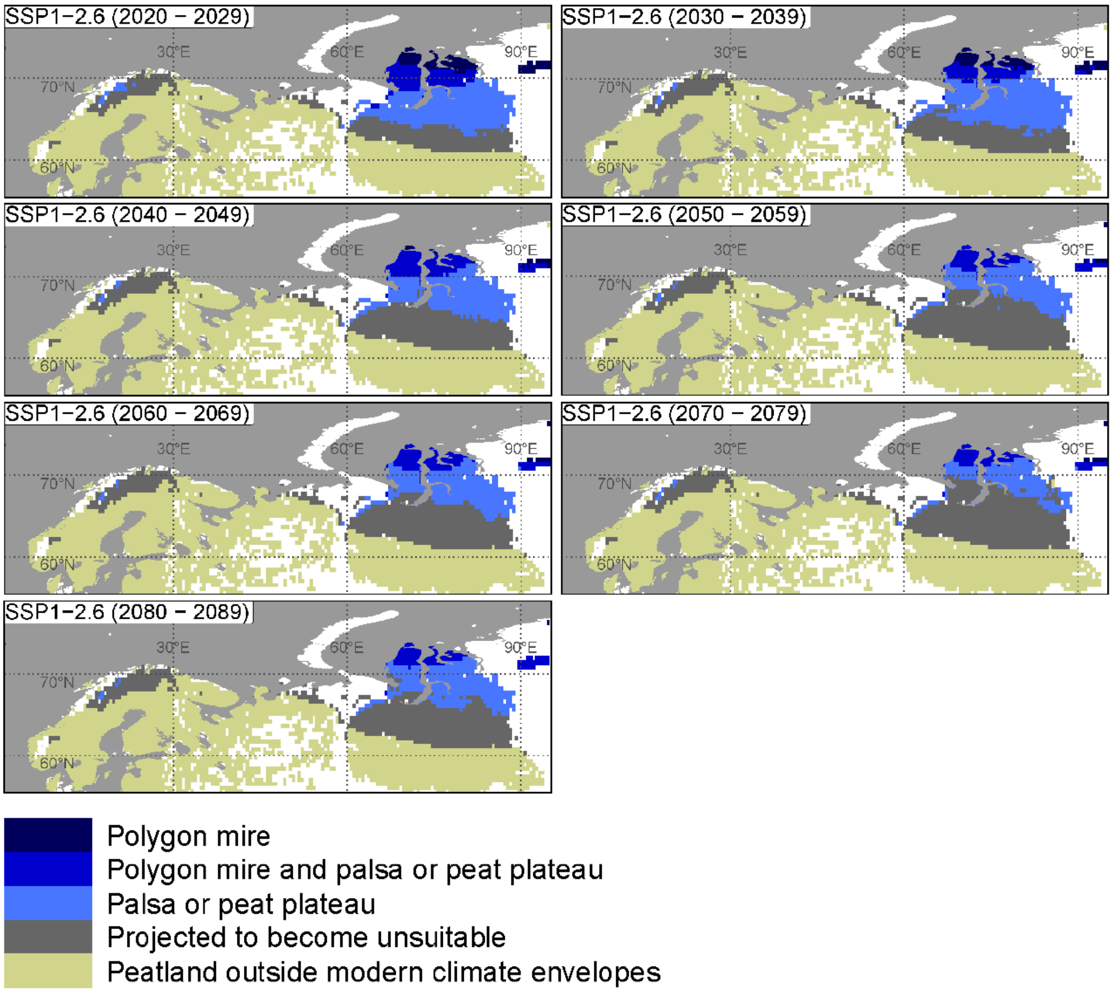


Figure S4 – Projected decadal distributions of the suitable climate envelopes for palsas/peat plateaus and polygon mires in Europe and Western Siberia under SSP1-2.6 (strong climate change mitigation) from 2020–2029 to 2080–2089. Map outlines are from ref[4].

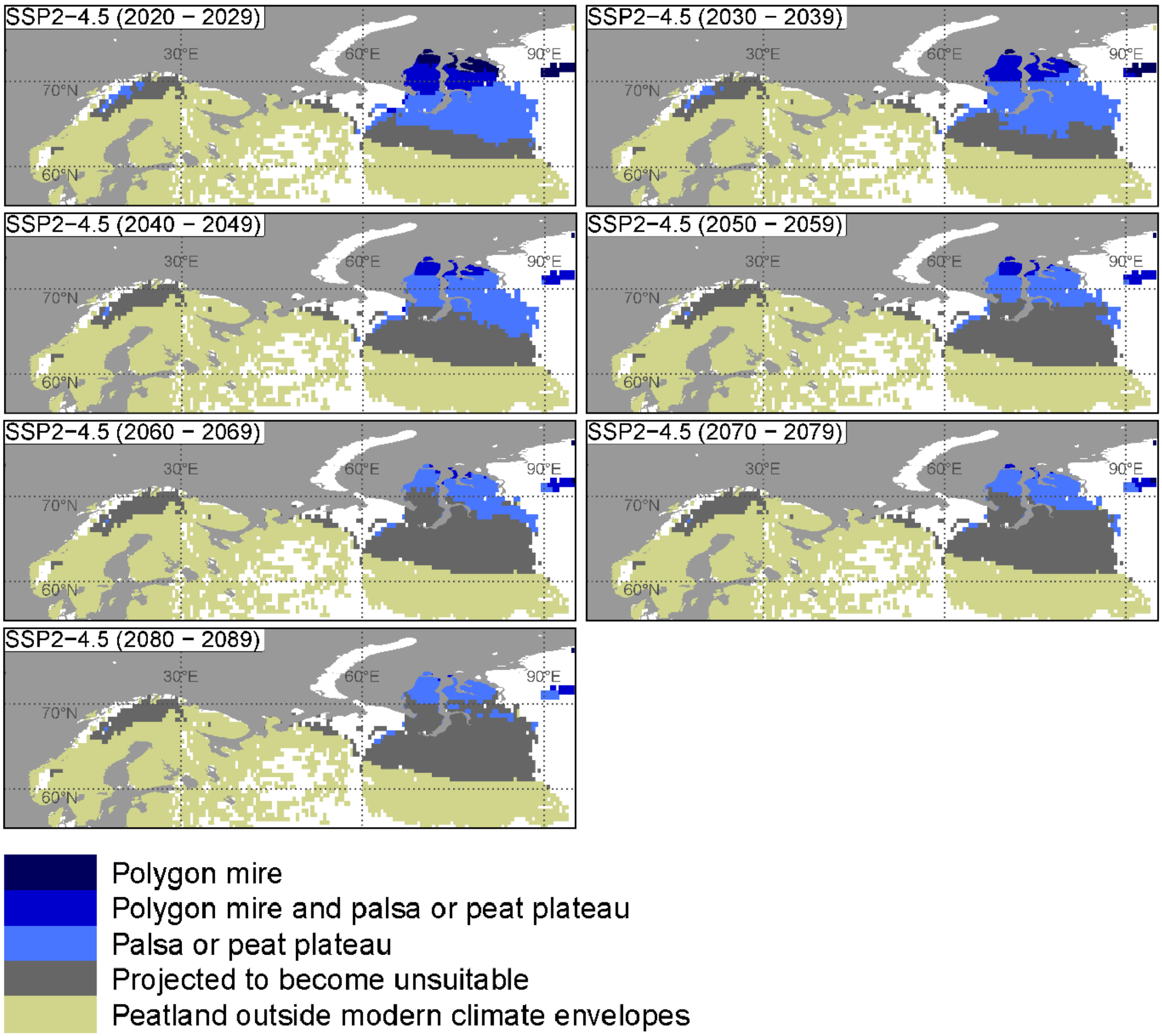


Figure S5 – Projected decadal distributions of the suitable climate envelopes for palsas/peat plateaus and polygon mires in Europe and Western Siberia under SSP2-4.5 (moderate mitigation) from 2020–2029 to 2080–2089. Map outlines are from ref[4].

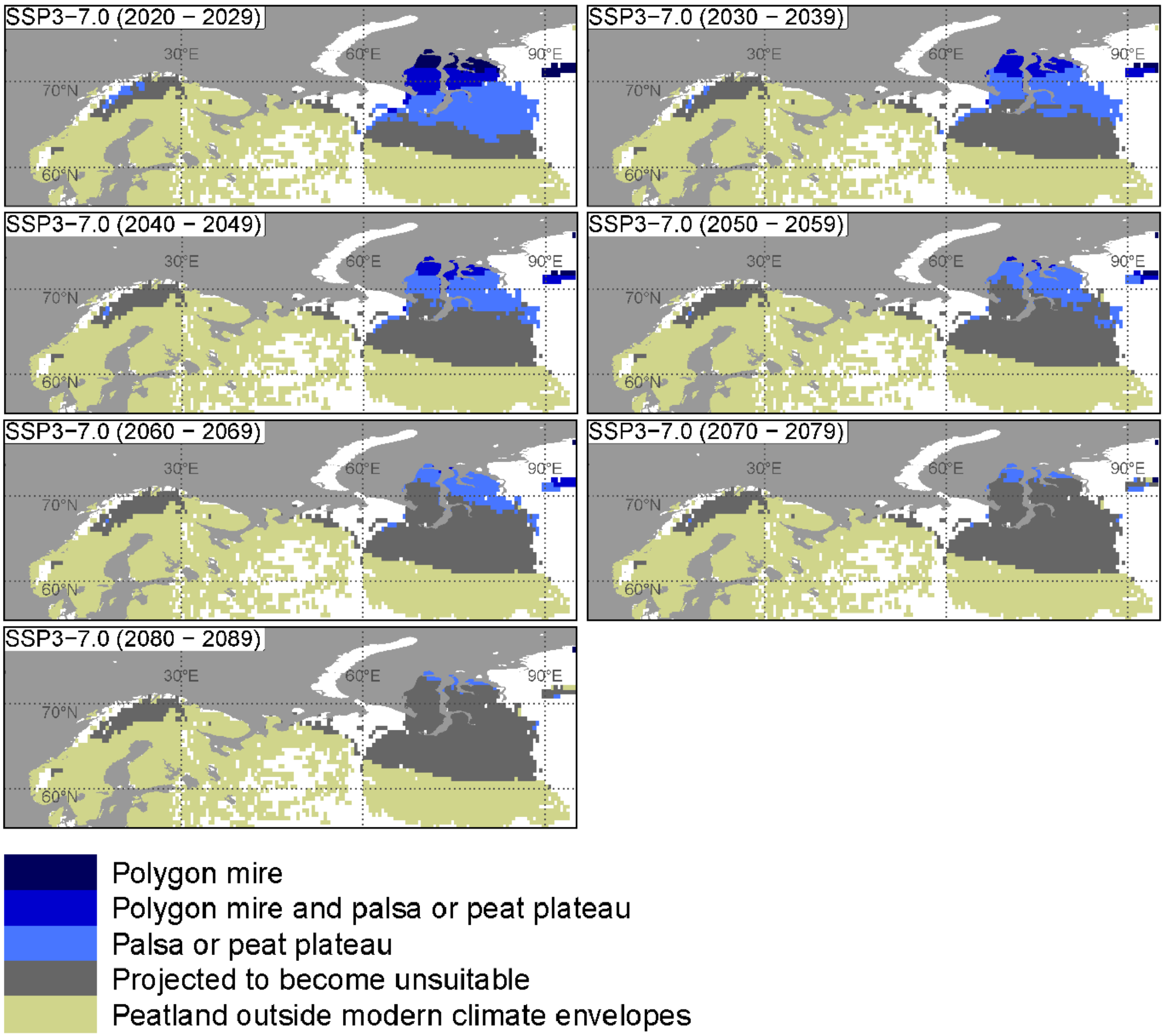


Figure S6 – Projected decadal distributions of the suitable climate envelopes for palsas/peat plateaus and polygon mires in Europe and Western Siberia under SSP3-7.0 (no mitigation baseline) from 2020–2029 to 2080–2089. Map outlines are from ref[4].

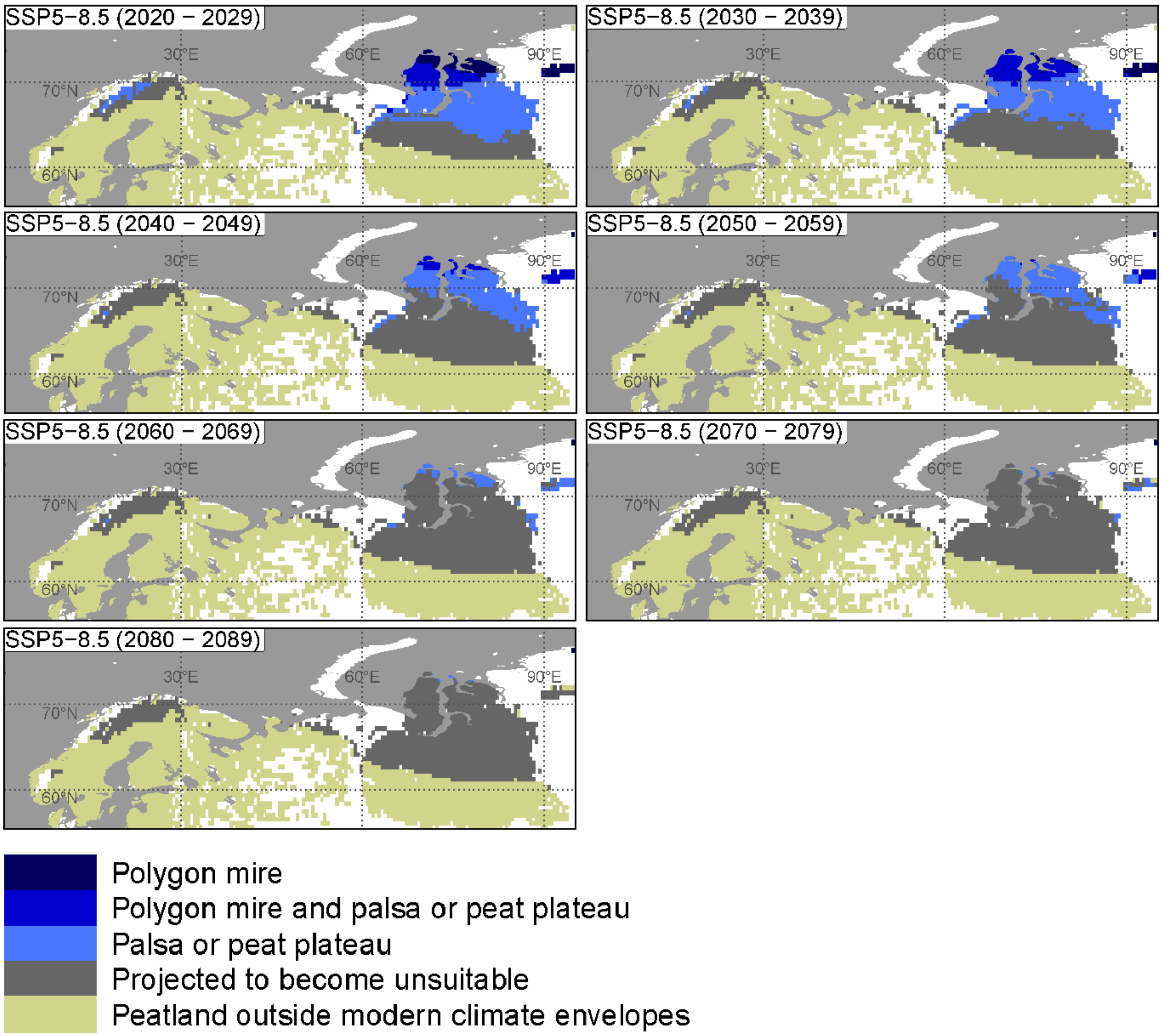


Figure S7 – Projected decadal distributions of the suitable climate envelopes for palsas/peat plateaus and polygon mires in Europe and Western Siberia under SSP5-8.5 (no mitigation, worst-case) from 2020–2029 to 2080–2089. Map outlines are from ref[4].

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