1 The productivity vs climate regression model

We disentangled the influence of climatological variables (TSUM and precipitation) on productivities of spruce and pine forests using ANCOVA (Analysis of Covariance). All possible combinations of single continuous variables and their interactions with species were alternatively included in data-driven regression models to finally select the one with the lowest mean square of prediction error according to 10-fold cross-validation (package DAAG - Maindonald and Braun, 2015). In addition, potential non-linearities were detected with a generalized additive model from the mgcv package (Wood, 2006) and histograms of the variables. Assumptions of linearity, normality of residuals, homoscedasticity, outliers and non-collinearity were tested with the methods mentioned in the main text.

$$MAI\ [m^3\ ha^{-1}\ yr^{-1}] = a \times TSUM^2\ [°C\ days] + b \times TSUM\ [°C\ days] + c \times MAP\ [mm] + d\ , \quad (S1)$$

Table S1. Overall mean squared error (ms) after 10-fold cross-validation for the most relevant (i.e. TSUM and spp clearly had to be included) candidate model structures that explain variation in productivity (mean annual increment - MAI - $m^3\ ha^{-1}\ yr^{-1}$) by climate (TSUM and MAP) and species across Swedish spruce and pine forests. The selected model is marked in gray. Abbreviations: TSUM = growing season temperature sum [°C days]; MAP = mean annual precipitation [mm]; spp = species.

Variables in model	Overall ms	Variables in model	Overall ms
$TSUM^2$:spp, TSUM:spp, $TSUM^2$, TSUM, MAP, spp	*1.48*	TSUM:spp, MAP, TSUM, spp	1.63
$TSUM^2$:spp, TSUM:spp, MAP:spp, $TSUM^2$, TSUM, MAP, spp	1.48	TSUM:spp, TSUM, spp	1.64
$TSUM^2$:spp, TSUM:spp, TSUM, spp	1.49	$TSUM^2$, TSUM, MAP, spp	2.23
$TSUM^2$, TSUM:spp, MAP:spp, TSUM, MAP, spp	1.58	$TSUM^2$, TSUM, spp	2.24
TSUM:spp, $TSUM^2$, TSUM, MAP, spp	1.59	MAP:spp, TSUM, MAP, spp	2.24
TSUM:spp, $TSUM^2$, TSUM, spp	1.60	TSUM, MAP, spp	2.27
TSUM:spp, MAP:spp, TSUM, MAP, spp	1.61	TSUM, spp	2.28

Table S2. Species specific estimates, statistics (t and partial R^2) and significance (P values) for the parameters in Eq. (S1) and F statistics and significance for species differences in these estimates. (Partial) R^2 values were approximated based on comparing fitted values with actual productivities.

Parameter	Species difference	Spruce			Pine		
		Estimate	Statistics		Estimate	Statistics	
a	$F_{1,2475} = 175.3$ $P < 0.01$	$(9.0 \pm 0.6) \times 10^{-6}$	$t_{1071} = 14.15$ $P < 0.01$	$R^2 \approx 0.854$	$(-3.0 \pm 0.6) \times 10^{-6}$	$t_{1403} = -4.64$ $P < 0.01$	$R^2 \approx 0.480$
b	$F_{1,2475} = 1112.2$ $P < 0.01$	-0.008 ± 0.001	$t_{1071} = -5.76$ $P < 0.01$		0.011 ± 0.001	$t_{1403} = 7.80$ $P < 0.01$	
c	N/A[a]	$(0.3 \pm 0.3) \times 10^{-3}$	$t_{1071} = 0.97$ $P = 0.33$	$R^2 \approx 0.001$	$(0.3 \pm 0.3) \times 10^{-3}$	$t_{1403} = 0.97$ $P = 0.33$	$R^2 \approx 0$
d	$F_{1,2475} = 1731.1$ $P < 0.01$	3.5 ± 0.8	$t_{1071} = 4.59$ $P < 0.01$		-4.1 ± 0.7	$t_{1403} = -5.24$ $P < 0.01$	
Total				$R^2 \approx 0.856$			$R^2 \approx 0.480$
					$R^2 = 0.805$		

[a]A regression model without MAP * species interaction was selected by the cross-validation procedure (Table S1).

Table S3. Overall mean squared error (ms) after 10-fold cross-validation for the most relevant candidate model structures that explain variation in normalized productivity according to method 1 (residual mean annual increment - MAI) by soil variables (0-20 cm depth or mineral soil only) for Swedish spruce and pine forests. The selected model is marked in gray. Abbreviations: C:N = soil carbon to nitrogen ratio; pH = pH_{KCl}; SOC = soil organic carbon concentration; $CLAY_{min.soil}$ = clay fraction in the mineral soil; TEB = total exchangeable bases. REGION is a factor with north, middle and south as levels.

Variables in model	Overall ms	Variables in model	Overall ms
LN^2(SOC), LN(SOC), C:N, $CLAY_{min.soil}$, LN(TEB), pH^2, pH, REGION, all interactions with REGION	1.24	*LN^2(SOC), LN(SOC), C:N, LN(TEB), pH^2, pH, REGION, all interactions with REGION except LN^2(SOC):REGION, LN(SOC):REGION, LN(TEB):REGION*	*1.23*
LN^2(SOC), LN(SOC), C:N, $CLAY_{min.soil}$, LN(TEB), pH^2, pH, REGION, all interactions with REGION except LN^2(SOC):REGION	1.24		
LN^2(SOC), LN(SOC), C:N, $CLAY_{min.soil}$, LN(TEB), pH^2, pH, REGION, all interactions with REGION except LN^2(SOC):REGION, LN(TEB): REGION	1.24	LN^2(SOC), LN(SOC), C:N, pH^2, pH, REGION, all interactions with REGION except LN^2(SOC):REGION, LN(SOC):REGION, LN(TEB):REGION	1.24
LN^2(SOC), LN(SOC), C:N, $CLAY_{min.soil}$, LN(TEB), pH^2, pH, REGION, all interactions with REGION except LN^2(SOC):REGION, LN(TEB):REGION, $CLAY_{min.soil}$:REGION	1.24	LN^2(SOC), LN(SOC), C:N, LN(TEB), pH^2, pH, REGION, all interactions with REGION except LN^2(SOC):REGION, LN(SOC):REGION, LN(TEB):REGION, pH^2:REGION	1.24
LN^2(SOC), LN(SOC), C:N, LN(TEB), pH^2, pH, REGION, all interactions with REGION except LN^2(SOC):REGION, LN(TEB):REGION	1.23	LN^2(SOC), LN(SOC), C:N, LN(TEB), pH^2, pH, REGION, all interactions with REGION except LN^2(SOC):REGION, LN(SOC):REGION, LN(TEB):REGION, C:N:REGION	1.25
LN^2(SOC), LN(SOC), C:N, LN(TEB), pH^2, pH, REGION, all interactions with REGION except LN^2(SOC):REGION, LN(TEB):REGION, pH^2:REGION	1.24	LN(SOC), C:N, LN(TEB), pH^2, pH, REGION, all interactions with REGION except LN^2(SOC):REGION, LN(SOC):REGION, LN(TEB):REGION	1.26
LN^2(SOC), LN(SOC), C:N, pH^2, pH, REGION, all interactions with REGION except LN^2(SOC):REGION, pH^2:REGION	1.24		
		all models including LN(N stock)	≥ 1.24

Table S4. Overall mean squared error (ms) after 10-fold cross-validation for the most relevant candidate model structures that explain variation in normalized productivity according to method 2 (actual/attainable mean annual increment - MAI) by soil variables (0-20 cm or mineral soil only) for Swedish spruce and pine forests. The selected model is marked in gray. Abbreviations: C:N = soil carbon to nitrogen ratio; TEB = total exchangeable bases; pH = pH_{KCl}; $CLAY_{min.soil}$ = clay fraction in the mineral soil; SOC = soil organic carbon concentration. For soil C:N, data of depth 0-10 cm were used instead of 0-20 cm as the mean squared error of the single regression model was lowest in the former case (Table 2).

Variables in model	Overall ms
LN^2(SOC), LN(SOC), LN(N stock), LN(C:N), $SAND_{min.soil}$, $CLAY_{min.soil}$, LN(TEB), pH	138
LN^2(SOC), LN(SOC), LN(N stock), LN(C:N), $SAND_{min.soil}$, LN(TEB), pH	138
LN^2(SOC), LN(SOC), LN(N stock), LN(C:N), $SAND_{min.soil}$, pH	*138*
LN^2(SOC), LN(SOC), LN(N stock), LN(C:N), pH	139
LN^2(SOC), LN(SOC), LN(N stock), LN(C:N), $SAND_{min.soil}$	143

Table S5. Associations between single key soil variables and normalized productivity (method 1) for spruce and pine forests in southern Sweden. Significance (*P*-values) of single soil variable effects on residual productivity (mean annual increment - MAI [m^3 ha^{-1} yr^{-1}]) are given. For (near) significant variables (i.e. $P < 0.10$), parameter estimates ± s.e.m. and the proportion of variation explained (R^2) are shown as well. Note that the results presented here deviate slightly from the data presented in Table 2, as separate regression analyses were performed for southern Sweden here instead of ANCOVA analyses with region as the factor. Moreover, pH_w was used instead of pH_{KCl} to keep the same variable for soil pH as in the original nutrient availability metric. Abbreviations: S = south; SOC = soil organic carbon concentration; C:N = soil carbon to nitrogen ratio; quad = parameter estimate for quadratic term; lin = parameter estimate for linear term of a quadratic function.

Normalized productivity response	**Region**	**ln SOC [%]**	**C:N**	**pH_w**
Residual MAI	S	quad = -0.18 ± 0.06 $P < 0.01$ lin = 0.3 ± 0.3 $P = 0.22$ intercept = 0.4 ± 0.3 $P = 0.19$ $R^2_{tot} = 0.134$	slope = -0.082 ± 0.009 $P < 0.01$ intercept = 2.0 ± 0.2 $P < 0.01$ $R^2 = 0.134$	quad = -0.9 ± 0.1 $P < 0.01$ lin = 8.4 ± 0.9 $P < 0.01$ intercept = -19 ± 2 $P < 0.01$ $R^2_{tot} = 0.172$

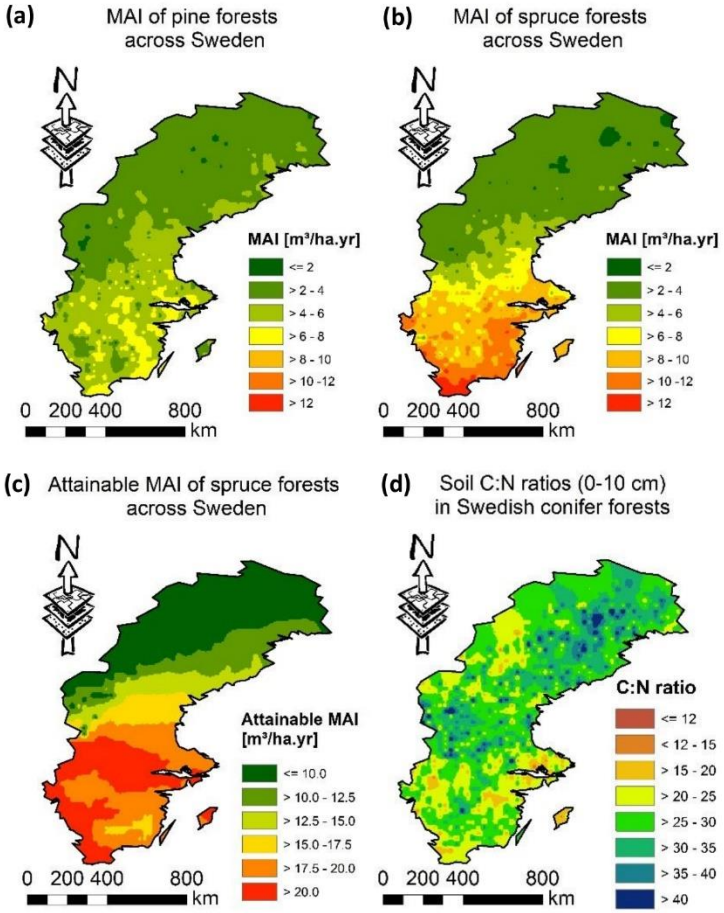

Figure S1. Productivities (mean annual increment - MAI) of (a) pine and (b) spruce, (c) attainable productivity for spruce (Bergh et al., 2005) and (d) soil carbon to nitrogen (C:N) ratio of conifer forests in Sweden.

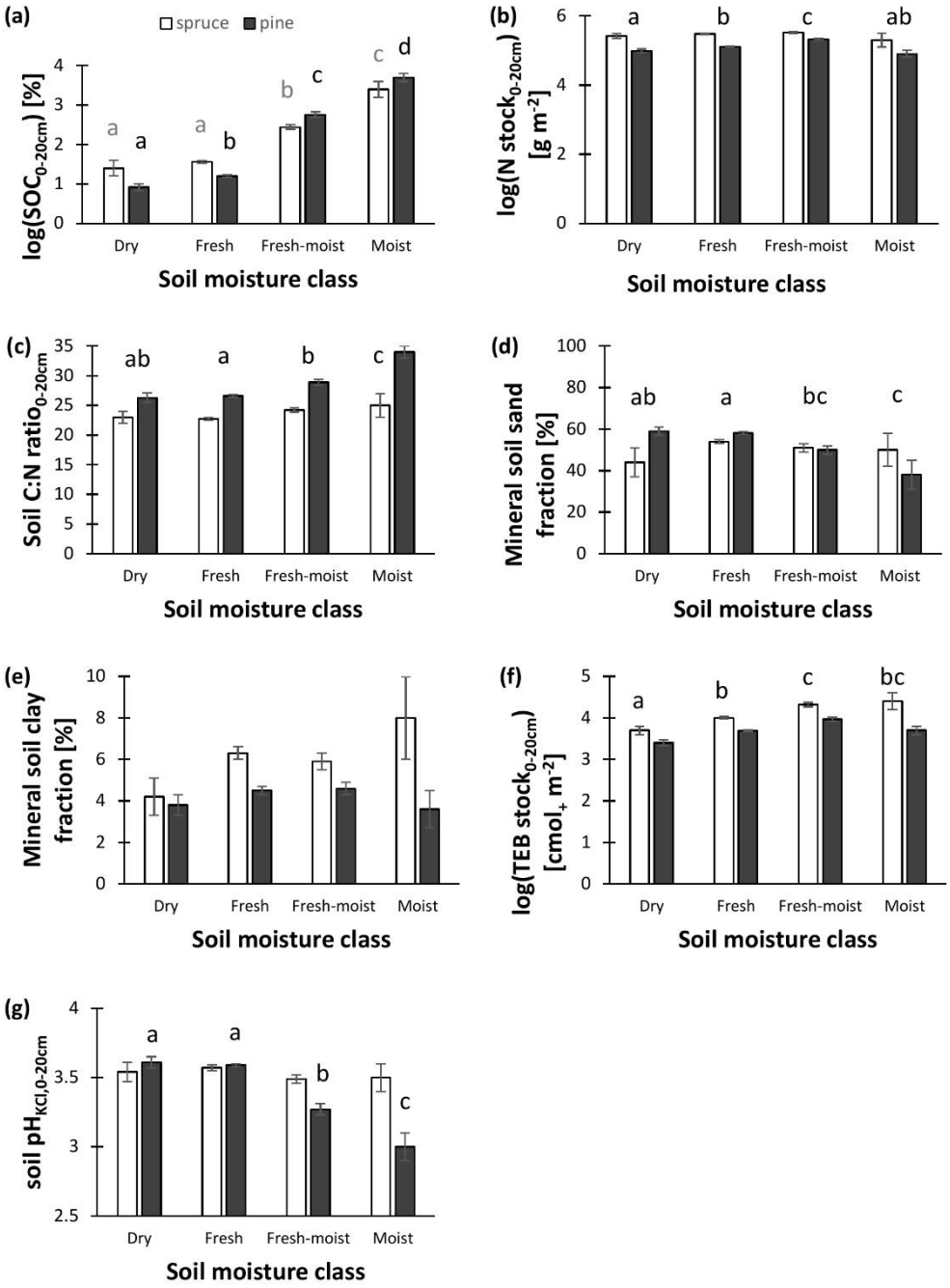

Figure S2. Soil conditions in spruce and pine forests with varying soil moisture. Abbreviations: SOC = soil organic carbon concentration; TEB = total exchangeable bases. Letters indicate statistical differences among moisture classes, either within spruce and pine forests (if the moisture x species interaction was included in the model after cross-validation) or for spruce and pine forests combined (if the moisture x species interaction was not included in the final model). Error bars represent the s.e.m.

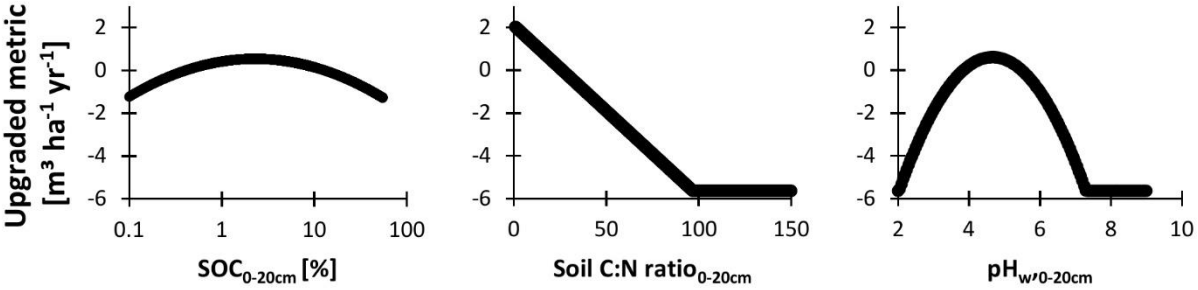

Figure S3. Updated soil scores for soil organic carbon concentration (SOC), soil carbon to nitrogen (C:N) ratio and pH measured in water (pH_w). Curves were drawn based on regression equations from Table S5. Minimum constraints were added to avoid artefacts if applied to other databases.