2 Table S1: Number of occurrence records (aggregated to 200 m resolution) and UEL for the 16

3 principal tree species across Switzerland and within the study area. Species with observed UEL >=

41800 m a.s.l. were considered "treeline" species and are highlighted in bold.

|  | Nb of occurrence records |  |  | UEL observed |
| :--- | :---: | :---: | :---: | :---: |
| Species | nationwide | study area |  | in study area (m) |
| Abies alba Mill. | 6276 | 1625 |  | $\mathbf{1 8 5 0}$ |
| Acer campestre L. | 781 | 234 |  | 1250 |
| Acer platanoides L. | 564 | 233 |  | 1250 |
| Acer pseudoplatanus L. | 4057 | 1705 | 1900 |  |
| Carpinus betulus L. | 1049 | 78 | 1000 |  |
| Fagus sylvatica L. | 9196 | 1320 |  | 1600 |
| Fraxinus excelsior L. | 3938 | 1096 | 1500 |  |
| Picea abies (L.) H. Karst. | 12088 | 2349 | 2000 |  |
| Quercus pubescens Willd. | 380 | 7 | 550 |  |
| Quercus petraea Liebl. | 1838 | 124 | 1350 |  |
| Quercus robur L. | 1096 | 65 | 1050 |  |
| Sorbus aria (L.) Crantz | 1406 | 732 | 1800 |  |
| Sorbus aucuparia L. | 629 | 1470 | 2000 |  |
| Tilia cordata Mill. | 692 | 111 | 1100 |  |
| Tilia platyphyllos Scop. | 742 | 264 | 1200 |  |
| Ulmus glabra Huds | 1143 | 365 | 1450 |  |
| All species | 45875 | 11778 |  |  |

5

6

## 7 Table S2

8 Table S2: Parameter values for all the tree and shrub species used in the dynamic forest simulations with TreeMig.

| Name | Abbrv | sType/B | sType/N | $\mathrm{D}_{\text {Max }}$ | $\mathrm{H}_{\text {Max }}$ | $\mathbf{A}_{\text {max }}$ | G | $\mathrm{DD}_{\text {Min }}$ | d75 | WiT | DrT | NTol | brow | Ls | La |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Abies alba | Aa | C | 5 | 187 | 60 | 700 | 284 | 590 | 900 | -6 | 0.19 | 2 | 3 | 3 | 1 |
| Acer campestre | Ac | D | 2 | 55 | 23 | 170 | 177 | 1000 | 500 | -999 | 0.1 | 2 | 1 | 5 | 5 |
| Acer platanoides | Ap | D | 3 | 99 | 32 | 380 | 220 | 1000 | 200 | -17 | 0.15 | 2 | 1 | 2 | 4 |
| Acer pseudoplatanus | As | D | 3 | 121 | 37 | 550 | 240 | 700 | 250 | -999 | 0.2 | 2 | 3 | 3 | 4 |
| Alnus glutinosa | Ag | D | 2 | 110 | 31 | 240 | 227 | 900 | 400 | -16 | 0.05 | 2 | 2 | 5 | 5 |
| Alnus incana | Ai | D | 2 | 110 | 22 | 150 | 188 | 675 | 200 | -999 | 0.2 | 2 | 2 | 6 | 7 |
| Alnus viridis | Av | D | 2 | 11 | 4 | 100 | 60 | 272 | 250 | -999 | 0.05 | 2 | 2 | 7 | 7 |
| Betula pendula | Bp | D | 1 | 121 | 29 | 220 | 195 | 541 | 250 | -999 | 0.3 | 1 | 1 | 7 | 9 |
| Carpinus betulus | Cb | D | 3 | 99 | 27 | 220 | 202 | 1460 | 350 | -9 | 0.1 | 2 | 3 | 4 | 3 |
| Castanea sativa | Cs | D | 3 | 198 | 33 | 1510 | 146 | 1200 | 250 | -999 | 0.21 | 1 | 3 | 5 | 5 |
| Corylus avellana | Ca | D | 3 | 22 | 10 | 70 | 95 | 900 | 250 | -16 | 0.2 | 2 | 3 | 6 | 6 |
| Fagus sylvatica | Fs | D | 3 | 154 | 45 | 430 | 279 | 620 | 800 | -4 | 0.23 | 1 | 2 | 3 | 1 |
| Fraxinus excelsior | Fe | D | 2 | 154 | 42 | 350 | 273 | 820 | 350 | -10 | 0.23 | 2 | 3 | 4 | 6 |
| Larix decidua | Ld | D | 2 | 100 | 44 | 850 | 215 | 325 | 390 | -11 | 0.4 | 1 | 2 | 8 | 9 |
| Picea abies | Pe | C | 5 | 180 | 50 | 930 | 215 | 380 | 500 | -7 | 0.29 | 2 | 1 | 5 | 5 |
| Pinus cembra | Pc | C | 5 | 165 | 26 | 1050 | 131 | 325 | 300 | -11 | 0.28 | 1 | 3 | 8 | 5 |
| Pinus mugo | Pm | C | 5 | 88 | 23 | 300 | 100 | 340 | 150 | -999 | 0.25 | 1 | 2 | 8 | 9 |
| Pinus sylvestris | Ps | C | 4 | 99 | 45 | 760 | 243 | 450 | 700 | -999 | 0.4 | 1 | 1 | 7 | 9 |
| Populus nigra | Pn | D | 2 | 220 | 36 | 280 | 258 | 1700 | 200 | -999 | 0.1 | 3 | 3 | 5 | 5 |
| Populus tremula | Pt | D | 2 | 110 | 30 | 140 | 199 | 850 | 200 | -999 | 0.23 | 1 | 3 | 6 | 7 |
| Quercus petraea | Qp | D | 3 | 110 | 45 | 860 | 281 | 900 | 600 | -5 | 0.2 | 1 | 2 | 6 | 7 |
| Quercus pubescens | Qu | D | 3 | 66 | 25 | 500 | 142 | 1200 | 100 | -999 | 0.4 | 2 | 2 | 7 | 7 |
| Quercus robur | Qr | D | 3 | 143 | 52 | 1060 | 355 | 1100 | 600 | -17 | 0.15 | 1 | 2 | 7 | 9 |
| Salix alba | Sa | D | 1 | 220 | 27 | 170 | 121 | 657 | 300 | -999 | 0.15 | 3 | 1 | 5 | 5 |
| Sorbus aria | So | D | 2 | 66 | 22 | 180 | 171 | 650 | 300 | -999 | 0.15 | 2 | 2 | 6 | 7 |
| Sorbus aucuparia | Sr | D | 1 | 66 | 19 | 110 | 177 | 500 | 250 | -999 | 0.15 | 1 | 2 | 6 | 7 |
| Taxus baccata | Tb | C | 5 | 55 | 22 | 2110 | 171 | 1000 | 250 | -5 | 0.05 | 2 | 3 | 4 | 3 |
| Tilia cordata | Tc | D | 3 | 110 | 30 | 940 | 199 | 950 | 500 | -19 | 0.25 | 2 | 2 | 5 | 5 |
| Tilia platyphyllos | Tp | D | 3 | 110 | 39 | 960 | 235 | 850 | 700 | -999 | 0.2 | 2 | 2 | 4 | 3 |
| Ulmus glabra | Us | D | 3 | 143 | 43 | 480 | 277 | 957 | 400 | -16 | 0.15 | 3 | 1 | 4 | 3 |
| Grasses/Dwarf shrubs | Ds | D | 5 | 20 | 2 | 100 | 2000 | 200 | 6000 | -60 | 0.5 | 1 | 1 | 1 | 1 |


Max. age (years), $\boldsymbol{G}=$ Max. growth rate (cm/y), $\boldsymbol{D} \boldsymbol{D}_{\text {Min }}=$ Min. yearly degree-day sum above 5:5 ${ }^{\circ} \mathrm{C}, \mathbf{d 7 5}=$ Degree-day sum at $75 \%$ of maximum growth modifier, WiT $=$ Min. mean temperature of

11 winter months (Dec, Jan, Feb; ${ }^{\circ}$ C), DrT = Drought tolerance: prop. of evapotranspiration deficit tolerated, NTol = Low nitrogen concentration tolerance: tolerant [1] to intolerant [3], brow =
12 Susceptibility to browsing: high [3] to low [1], Ls = Sapling light parameter: shade-tolerant [1] to shade-intolerant [9], La = Adult light parameter: shade-tolerant [1] to shade-intolerant [9]

Table S3: Parameter values for all the tree and shrub species used in the dynamic forest stimulations with TreeMig.

| Name | Mtmin | seedGerm | seedLoss | seedMaxAge | period | SD ${ }_{\text {max }}$ | dispFac | alfa1 | alfa2 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Abies alba | 7 | 0.46 | 0.8 | 7.7 | 4.3 | 50000 | 1 | 100 | 0 |
| Acer campestre | 4.1 | 0.8 | 0.8 | 7.7 | 3.5 | 193000 | 1 | 100 | 0 |
| Acer platanoides | 3.1 | 0.55 | 0.8 | 7.7 | 3.4 | 510000 | 1 | 100 | 0 |
| Acer pseudoplatanus | 2.6 | 0.6 | 0.8 | 7.7 | 4 | 551500 | 1 | 100 | 0 |
| Alnus glutinosa | 4.5 | 0.4 | 0.8 | 7.7 | 2.3 | 218500 | 0.99 | 25 | 200 |
| Alnus incana | 2.6 | 0.33 | 0.8 | 7.7 | 2 | 400000 | 0.99 | 25 | 200 |
| Alnus viridis | 2.3 | 0.15 | 0.8 | 7.7 | 2 | 400000 | 1 | 200 | 0 |
| Betula pendula | 4.5 | 0.19 | 0.8 | 7.7 | 2 | 11775000 | 1 | 200 | 0 |
| Carpinus betulus | 3.4 | 0.67 | 0.8 | 7.7 | 2 | 154000 | 1 | 100 | 0 |
| Castanea sativa | 2.2 | 0.58 | 0.8 | 7.7 | 1 | 4000 | 0.99 | 25 | 200 |
| Corylus avellana | 0.7 | 0.3 | 0.8 | 7.7 | 1.5 | 6000 | 0.99 | 25 | 200 |
| Fagus sylvatica | 14.7 | 0.71 | 0.8 | 7.7 | 8 | 29000 | 0.99 | 25 | 200 |
| Fraxinus excelsior | 5 | 0.6 | 0.8 | 7.7 | 3.2 | 42000 | 1 | 100 | 0 |
| Larix decidua | 4.4 | 0.39 | 0.8 | 7.7 | 5.7 | 133000 | 1 | 100 | 0 |
| Picea abies | 10.1 | 0.76 | 0.8 | 7.7 | 5.4 | 96500 | 1 | 100 | 0 |
| Pinus cembra | 2.4 | 0.64 | 0.8 | 7.7 | 8 | 1000 | 0.99 | 25 | 200 |
| Pinus mugo | 1.6 | 0.54 | 0.8 | 7.7 | 4 | 11000 | 1 | 100 | 0 |
| Pinus sylvestris | 2.6 | 0.91 | 0.8 | 7.7 | 2.8 | 22000 | 1 | 100 | 0 |
| Populus nigra | 2.7 | 0.2 | 0.8 | 7.7 | 1 | 1890000 | 1 | 200 | 0 |
| Populus tremula | 4.8 | 0.4 | 0.8 | 7.7 | 1 | 1680000 | 1 | 200 | 0 |
| Quercus petraea | 10.2 | 0.69 | 0.8 | 7.7 | 5.5 | 47000 | 0.99 | 25 | 200 |
| Quercus pubescens | 8.7 | 0.7 | 0.8 | 7.7 | 5 | 18000 | 0.99 | 25 | 200 |
| Quercus robur | 11.6 | 0.75 | 0.8 | 7.7 | 4.9 | 27500 | 0.99 | 25 | 200 |
| Salix alba | 15.6 | 0.2 | 0.8 | 7.7 | 2 | 1512000 | 1 | 200 | 0 |
| Sorbus aria | 2.6 | 0.6 | 0.8 | 7.7 | 1 | 80500 | 0.99 | 25 | 200 |
| Sorbus aucuparia | 3.6 | 0.7 | 0.8 | 7.7 | 1 | 375000 | 0.99 | 25 | 200 |
| Taxus baccata | 0.6 | 0.6 | 0.8 | 7.7 | 1 | 23000 | 0.99 | 25 | 200 |
| Tilia cordata | 2.2 | 0.45 | 0.8 | 7.7 | 2 | 720000 | 1 | 100 | 0 |
| Tilia platyphyllos | 1.6 | 0.48 | 0.8 | 7.7 | 3 | 380500 | 1 | 100 | 0 |
| Ulmus glabra | 6.4 | 0.35 | 0.8 | 7.7 | 2.1 | 372000 | 1 | 100 | 0 |
| Grasses/Dwarf shrubs | 0.3 | 0.48 | 0.8 | 7.7 | 1 | 50000 | 0.99 | 25 | 200 |


number of seeds, dispFac = Fraction of long-distance dispersal, alfa1 = Mean short-distance dispersal distance (m), alfa2 = Mean long-distance dispersal distance

| Model setup | Abbr. | Explanation |
| :--- | :--- | :--- |
| TreeMig - Normal | TM_Normal | TreeMig with all 29 species (competition) and species- <br> specific seed production and dispersal |
| TreeMig- Unlimited <br> dispersal | TM_UD | TreeMig with all 29 species (competition) and a constant <br> seed rain eliminating dispersal limitations |
| TreeMig - No <br> competition | TM_NC | TreeMig separately for each species limiting the <br> competition to intra-specific only. Seed production and <br> dispersal is species-specific |
| TreeMig - Unlimited <br> dispersal \& no <br> competition | TM_UD_NC | TreeMig separately for each species limiting the <br> competition to intra-specific only and a constant seed <br> rain eliminating dispersal limitations |
| TreeMig - <br> Competition with $P$. <br> abies only | TM_PA | TreeMig separately for each species with $P$. abies as sole <br> competitor. |
| TreeMig - Unlimited <br>  <br> Competition with $P$. <br> $a b i e s ~ o n l y ~$ | T_UD_PA | TreeMig separately for each species with $P$. abies as sole <br> competitor and a constant seed rain eliminating dispersal <br> limitations |

Table S4: Short explanation of the six different model setups with varying amounts of dispersal limitation and competition.

| Type of | Climate change | $v$ UEL 2000-2085 (m/y) |  |  |
| :--- | :--- | :---: | :---: | :---: |
| Model | scenario | All species | Treeline species | Non-treeline specias |
| SDM | A1B | $11.2 \pm 1.1$ | $10.8 \pm 0.7$ | $11.4 \pm 1.3$ |
|  | A2 | $13.6 \pm 1.3$ | $13.0 \pm 1.0$ | $13.9 \pm 1.5$ |
|  | RCP3PD | $4.7 \pm 0.6$ | $4.9 \pm 0.7$ | $4.6 \pm 0.6$ |
| TM_Normal | A1B | $5.3 \pm 1.4$ | $7.1 \pm 1.0$ | $4.5 \pm 1.5$ |
|  | A2 | $5.4 \pm 1.5$ | $7.2 \pm 1.0$ | $4.6 \pm 1.5$ |
|  | RCP3PD | $2.5 \pm 0.7$ | $3.2 \pm 0.5$ | $2.1 \pm 0.7$ |
| TM_UD | A1B | $5.6 \pm 1.5$ | $7.3 \pm 1.1$ | $4.8 \pm 1.6$ |
|  | A2 | $5.6 \pm 1.6$ | $7.3 \pm 1.1$ | $4.8 \pm 1.6$ |
|  | RCP3PD | $2.5 \pm 0.8$ | $3.5 \pm 0.6$ | $2.1 \pm 0.9$ |
| TM_NC | A1B | $7.5 \pm 0.7$ | $7.6 \pm 0.5$ | $7.4 \pm 0.7$ |
|  | A2 | $7.8 \pm 0.7$ | $7.8 \pm 0.7$ | $7.8 \pm 0.8$ |
|  | RCP3PD | $3.5 \pm 0.5$ | $3.6 \pm 0.5$ | $3.5 \pm 0.5$ |
| TM_UD_NC | A1B | $7.7 \pm 0.7$ | $7.5 \pm 0.5$ | $7.8 \pm 0.8$ |
|  | A2 | $8.0 \pm 0.8$ | $7.6 \pm 0.5$ | $8.2 \pm 0.9$ |
|  | RCP3PD | $3.6 \pm 0.4$ | $3.5 \pm 0.5$ | $3.6 \pm 0.4$ |
| TM_PA | A1B | $5.5 \pm 1.2$ | $7.5 \pm 0.8$ | $4.7 \pm 1.2$ |
|  | A2 | $5.7 \pm 1.3$ | $7.9 \pm 0.9$ | $4.7 \pm 1.2$ |
|  | RCP3PD | $2.6 \pm 0.5$ | $2.9 \pm 0.5$ | $2.5 \pm 0.5$ |
| TM_UD_PA | A1B | $6.0 \pm 1.2$ | $7.9 \pm 0.9$ | $5.2 \pm 1.2$ |
|  | A2 | $6.2 \pm 1.3$ | $8.0 \pm 1.0$ | $5.3 \pm 1.2$ |
|  | RCP3PD | $3.0 \pm 0.4$ | $3.1 \pm 0.5$ | $2.9 \pm 0.4$ |

SDM = Species distribution model, TM_Normal = TreeMig with all species and explicit dispersal, TM_UD $=$ TreeMig with unlimited dispersal, TM_NC = TreeMig without intraspecific competition, TM_UD_NC = TreeMig with unlimited dispersal and no intraspecific competition, TM_PA = TreeMig with only P. abies as competing species, TM_UD_PA = TreeMig with unlimited dispersal and only P. abies as competing species.

Table S6: The expected species-specific upslope migration velocity ( $V U E L$ ) of the bioclimatic envelope (SDMs) and the dynamic forest (TreeMig) based on

33 different climate change scenarios. The difference between the bioclimatic envelope and expected upslope migration velocity of the forest was partitioned into
different processes hindering the upslope advancement of tree species.

| Climate <br> Scenario | Species | vUEL (m/y) |  |  | Contribution to difference in vUEL ( $\mathbf{m} / \mathrm{y}$ ) |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | Climate suitability | Dynamic forest | Difference | Dispersal limitation | Competition Suppression | Demography |
| A1B | Abies alba | 9.4 | 4 | 5.4 | 0 (0\%) | 4 (74\%) | 1.4 (26\%) |
|  | Acer campestre | 11.2 | 8 | 3.2 | 0.7 (22\%) | 0 (0\%) | 2.5 (78\%) |
|  | Acer platanoides | 11.8 | 7.3 | 4.5 | 0.7 (16\%) | 1.3 (29\%) | 2.5 (55\%) |
|  | Acer pseudoplatanus | 12.9 | 7.3 | 5.6 | 0.7 (12\%) | 0.1 (2\%) | 4.8 (86\%) |
|  | Carpinus betulus | 8.2 | 5.3 | 2.9 | 0 (0\%) | 0 (0\%) | 2.9 (100\%) |
|  | Fagus sylvatica | 11.2 | 3.4 | 7.8 | -0.7 (0\%) | 4.7 (60\%) | 3.8 (40\%) |
|  | Fraxinus excelsior | 17 | 5.3 | 11.7 | 0 (0\%) | 2.7 (23\%) | 9 (77\%) |
|  | Picea abies | 11.7 | 10 | 1.7 | 0 (0\%) | -0.7 (0\%) | 2.4 (100\%) |
|  | Quercus petraea | 13.5 | 2 | 11.5 | 0.7 (6\%) | 6 (52\%) | 4.8 (42\%) |
|  | Quercus pubescens | 11.8 | -1.3 | 13.1 | -1.4 (0\%) | 5.3 (40\%) | 9.2 (60\%) |
|  | Quercus robur | 7.6 | 0.7 | 6.9 | 2 (29\%) | 6 (87\%) | 0 (0\%) |
|  | Sorbus aria | 10.6 | 7.4 | 3.2 | 0 (0\%) | -0.7 (0\%) | 3.9 (100\%) |
|  | Sorbus aucuparia | 9.4 | 6.7 | 2.7 | 0.6 (22\%) | 0 (0\%) | 2.1 (78\%) |
|  | Tilia cordata | 9.4 | 6.6 | 2.8 | 0 (0\%) | 2 (71\%) | 0.8 (29\%) |
|  | Tilia platyphyllos | 11.7 | 7.3 | 4.4 | 0 (0\%) | 1.4 (32\%) | 3 (68\%) |
|  | Ulmus glabra | 12.4 | 5.4 | 7 | 0.6 (9\%) | 2.6 (37\%) | 3.8 (54\%) |
| A2 | Abies alba | 14.7 | 4 | 10.7 | 0 (0\%) | 4 (37\%) | 6.7 (63\%) |
|  | Acer campestre | 12.9 | 8.7 | 4.2 | 0 (0\%) | 0.6 (14\%) | 3.6 (86\%) |


|  | Acer platanoides | 15.3 | 8 | 7.3 | 0 (0\%) | 0.6 (8\%) | 6.7 (92\%) |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Acer pseudoplatanus | 14.7 | 7.3 | 7.4 | 0.7 (9\%) | 0.1 (1\%) | 6.6 (90\%) |
|  | Carpinus betulus | 7 | 5.3 | 1.7 | 0 (0\%) | 0 (0\%) | 1.7 (100\%) |
|  | Fagus sylvatica | 15.9 | 3.4 | 12.5 | -0.7 (0\%) | 4.7 (38\%) | 8.5 (62\%) |
|  | Fraxinus excelsior | 18.8 | 5.3 | 13.5 | 0 (0\%) | 2.7 (20\%) | 10.8 (80\%) |
|  | Picea abies | 13.5 | 10 | 3.5 | 0 (0\%) | -0.7 (0\%) | 4.2 (100\%) |
|  | Quercus petraea | 13.5 | 2 | 11.5 | 0 (0\%) | 7.3 (63\%) | 4.2 (37\%) |
|  | Quercus pubescens | 11.8 | -1.3 | 13.1 | -1.4 (0\%) | 5.3 (40\%) | 9.2 (60\%) |
|  | Quercus robur | 14.1 | 0.7 | 13.4 | 2 (15\%) | 7.3 (54\%) | 4.1 (31\%) |
|  | Sorbus aria | 12.3 | 7.4 | 4.9 | 0 (0\%) | -0.7 (0\%) | 5.6 (100\%) |
|  | Sorbus aucuparia | 10 | 7.3 | 2.7 | 0 (0\%) | 0 (0\%) | 2.7 (100\%) |
|  | Tilia cordata | 13.5 | 6.6 | 6.9 | 0 (0\%) | 2 (29\%) | 4.9 (71\%) |
|  | Tilia platyphyllos | 13 | 7.3 | 5.7 | 0.7 (12\%) | 1.4 (25\%) | 3.6 (63\%) |
|  | Ulmus glabra | 17 | 4.7 | 12.3 | 1.3 (11\%) | 3.3 (27\%) | 7.7 (62\%) |
| RCP3PD | Abies alba | 5.9 | 3.3 | 2.6 | 0 (0\%) | 0.7 (27\%) | 1.9 (73\%) |
|  | Acer campestre | 3.5 | 3.3 | 0.2 | 0 (0\%) | 0.7 (350\%) | 0 (0\%) |
|  | Acer platanoides | 5.9 | 2.7 | 3.2 | 0 (0\%) | 1.3 (41\%) | 1.9 (59\%) |
|  | Acer pseudoplatanus | 5.9 | 4 | 1.9 | 0 (0\%) | 0.7 (37\%) | 1.2 (63\%) |
|  | Carpinus betulus | 4.1 | 3.3 | 0.8 | 0 (0\%) | -0.7 (0\%) | 1.5 (100\%) |
|  | Fagus sylvatica | 6.4 | 2 | 4.4 | 0 (0\%) | 3.3 (75\%) | 1.1 (25\%) |
|  | Fraxinus excelsior | 6.5 | 2.7 | 3.8 | 0.7 (18\%) | 0.6 (16\%) | 2.5 (66\%) |
|  | Picea abies | 5.3 | 4 | 1.3 | 0 (0\%) | -0.6 (0\%) | 1.9 (100\%) |
|  | Quercus petraea | 3.5 | 2 | 1.5 | 0 (0\%) | 2 (133\%) | 0 (0\%) |
|  | Quercus pubescens | 3 | -1.3 | 4.3 | -1.4 (0\%) | 2.6 (60\%) | 3.1 (40\%) |
|  | Quercus robur | 4.1 | 0.7 | 3.4 | 0.6 (18\%) | 2 (59\%) | 0.8 (23\%) |
|  | Sorbus aria | 5.3 | 3.3 | 2 | 1.4 (70\%) | 0.7 (35\%) | 0 (0\%) |
|  | Sorbus aucuparia | 2.4 | 1.3 | 1.1 | 0 (0\%) | 0.7 (64\%) | 0.4 (36\%) |
|  | Tilia cordata | 3.5 | 2 | 1.5 | 0 (0\%) | 2 (133\%) | 0 (0\%) |
|  | Tilia platyphyllos | 4.1 | 3.3 | 0.8 | 0 (0\%) | 0.7 (88\%) | 0.1 (12\%) |
|  | Ulmus glabra | 5.9 | 2.7 | 3.2 | 0 (0\%) | 0.6 (19\%) | 2.6 (81\%) |

Table S7

Table S7: The expected average upslope migration velocity of the bioclimatic envelope ( $v$ UELSDM) and the dynamic forest $\left(v \mathrm{UEL}_{T M}\right)$ based on different climate change scenarios. The difference between the bioclimatic envelope and expected upslope migration velocity of the forest was partitioned into different processes hindering the upslope advancement of tree species. The numbers in the bracket (\%) indicate the proportional distribution to the observed difference between bioclimatic envelope and dynamic forest model. Values represent mean $\pm 95 \%$ C.I.

|  | vUEL (m/y) |  |  | Contribution to difference in vUEL (m/y) |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Climate Scenario | Bioclimatic envelope | Dynamic forest | Difference | Dispersal limitation | Competition Suppression | Demography |
| A1B | $11.2 \pm 1.1$ | $5.3 \pm 1.4$ | $5.9 \pm 1.7$ | $\begin{gathered} 0.3 \pm 0.4 \\ (8.2 \pm 5.9 \%) \end{gathered}$ | $\begin{gathered} 2.2 \pm 1.2 \\ (33.0 \pm 14.3 \%) \end{gathered}$ | $\begin{gathered} 3.5 \pm 1.3 \\ (59.8 \pm 14.4 \%) \end{gathered}$ |
| A2 | $13.6 \pm 1.3$ | $5.4 \pm 1.5$ | $8.2 \pm 2.0$ | $\begin{gathered} 0.2 \pm 0.4 \\ (5.2 \pm 6.1 \%) \end{gathered}$ | $\begin{gathered} 2.4 \pm 1.3 \\ (22.2 \pm 10.0 \%) \end{gathered}$ | $\begin{gathered} 5.6 \pm 1.3 \\ (72.6 \pm 10.6 \%) \end{gathered}$ |
| RCP3PD | $4.7 \pm 0.6$ | $2.5 \pm 0.7$ | $2.2 \pm 0.7$ | $\begin{gathered} 0.1 \pm 0.3 \\ (7.6 \pm 8.8 \%) \\ \hline \end{gathered}$ | $\begin{gathered} 1.1 \pm 0.5 \\ (71.1 \pm 41.4 \%) \\ \hline \end{gathered}$ | $\begin{gathered} 1.1 \pm 0.5 \\ (41.4 \pm 17.9 \%) \\ \hline \end{gathered}$ |

Table S8
Table S8: Tables of the two-way ANOVA and TukeyHSD posthoc-test for scenario A1B (a), A2 (b) and RCP3PD (c). The test analyses the effect of Processes (demography, competition, dispersal limitation) and Tree_Type ("treeline", "non-treeline") on the upslope migration speed (vUEL).
(a) Climate change scenario A1B: aov(vUEL ~ Process + Treetype)

|  | Df | Sum Sq | Mean Sq | F value $\operatorname{Pr}(>F)$ |  |
| :--- | :--- | :--- | :--- | :--- | :--- |
| Process | 3 | 128.0 | 42.66 | 5.950 | 0.00129 ** |
| TreeType | 1 | 35.7 | 35.72 | 4.982 | 0.02942 * |
| Residuals | 59 | 423.0 | 7.17 |  |  |

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| \$Process |  |  |  |  |
| :--- | :--- | :--- | :--- | :--- |
|  | diff | lwr | upr | p adj |
| Demography-Competition | 1.25625 | -1.246625 | 3.7591248 | 0.5497172 |
| Dispersal-Competition | -1.88125 | -4.384125 | 0.6216248 | 0.2044564 |
| Dynamic_Forest-Competition | -2.21250 | -4.715375 | 0.2903748 | 0.1012390 |
| Dispersal-Demography | -3.13750 | -5.640375 | -0.6346252 | 0.0083422 |
| Dynamic_Forest-Demography | -3.46875 | -5.971625 | -0.9658752 | 0.0029221 |
| Dynamic_Forest-Dispersal | -0.33125 | -2.834125 | 2.1716248 | 0.9851484 |
|  |  |  |  |  |
| \$TreeType |  |  |  | padj |
|  | diff | lwr | upr | adi |
| TL-Non_TL | 1.611818 | 0.1668729 | 3.056763 | 0.0294195 |

(b) Climate change scenario A2: aov(vUEL ~ Process + Treetype)

|  | Df | Sum Sq | Mean Sq | F value | $\operatorname{Pr}(>\mathrm{F})$ |
| :--- | :--- | :--- | :--- | :--- | :--- |
| Process | 3 | 1306.3 | 435.4 | 30.324 | $5.45 \mathrm{e}-12$ *** |
| TreeType | 1 | 107.1 | 107.1 | 7.459 | $0.00831^{* *}$ |
| Residuals | 59 | 847.2 | 14.4 |  |  |


| \$Process |  |  |  |  |
| :--- | :--- | :--- | :--- | :--- |
|  | diff | lwr | upr | p adj |
| Demography-Competition | 3.22500 | 0.6608728 | 5.7891272 | 0.0080792 |
| Dispersal-Competition | -2.12500 | -4.6891272 | 0.4391272 | 0.1376511 |
| Dynamic_Forest-Competition | -2.36875 | -4.9328772 | 0.1953772 | 0.0801808 |
| Dispersal-Demography | -5.35000 | -7.9141272 | -2.7858728 | 0.0000048 |
| Dynamic_Forest-Demography | -5.59375 | -8.1578772 | -3.0296228 | 0.0000019 |
| Dynamic_Forest-Dispersal | -0.24375 | -2.8078772 | 2.3203772 | 0.9943677 |
|  |  |  |  |  |
| \$TreeType |  |  | upr | p adj |
|  | diff | lwr |  |  |
| TL-Non_TL | 1.730455 | 0.2501474 | 3.210762 | 0.0227347 |

(c) Climate change scenario RCP3PD: $\operatorname{aov}(v U E L$ ~ Process + Treetype)

|  | Df | Sum Sq | Mean Sq | F value | $\operatorname{Pr}(>F)$ |
| :--- | :--- | :--- | :--- | :--- | :--- |
| Process | 3 | 17.8 | 5.932 | 3.120 | $0.0327^{*}$ |
| TreeType | 1 | 10.0 | 9.998 | 5.258 | $0.0254^{*}$ |
| Residuals | 59 | 112.2 | 1.901 |  |  |

## \$Process

Demography-Competition

| diff | lwr | upr | p adj |
| :--- | :--- | :--- | :--- |
| 0.06250 | -1.226402 | 1.3514024 | 0.9992386 |
| -0.95625 | -2.245152 | 0.3326524 | 0.2143048 |
| -1.08125 | -2.370152 | 0.2076524 | 0.1302850 |
| -1.01875 | -2.307652 | 0.2701524 | 0.1684116 |
| -1.14375 | -2.432652 | 0.1451524 | 0.0992809 |
| -0.12500 | -1.413902 | 1.1639024 | 0.9940255 |
|  |  |  |  |
|  |  |  |  |
| diff | Iwr | upr | padj |
| 0.8527273 | 0.1086256 | 1.596829 | 0.0254227 |

Figure S1


Figure S1: Performance of the species distribution models (SDMs) as measured by area under curve (AUC) of the receiver operator characteristic (ROC) and the True Skill Statistic (TSS) across the 16 principal species.

Figure S2


Figure S2: Variable importance of SDMs across the 16 principal species and modelling techniques.

Tyear = mean annual temperature, Tmin = minimum temperature of the coldest month, Tsummer = mean temperature of the driest quarter, Pyear = annual sum of precipitation, Psummer = sum of precipitation of the direst quarter

Figure S3


Figure S3: Variable importance of SDMs for the 16 principal tree species. Tyear = mean annual temperature, Tmin = minimum temperature of the coldest month, Tsummer = mean temperature of the driest quarter, Pyear = annual sum of precipitation, Psummer = sum of precipitation of the direst quarter

Figure S4


Figure S4: Relative contribution of the 16 principal tree species to the average biomass per ha in four different elevation bands based on either observations in the national forest inventory ( $\mathrm{N}=315$ ) or as simulated by the dynamic forest model ( $\mathrm{N}=21^{\prime} 971$ ). The whiskers indicate the standard error of the mean.

Figure S5


Figure S5: Biomass per ha ( $\mathrm{m}^{3} / \mathrm{ha}$ ) of the 16 principal tree species in four different elevation bands and depending on the different model setups used for the dynamic forest model. The whiskers indicate the standard error of the mean values.

Figure S6


Figure S6: Correlation of the species-specific UEL based on TreeMig predictions for the year 2000 and field observations (1981-2015) within the study area for all six TreeMig setups. The dotted lines represent perfect agreement, the blue lines a simple linear regression with the $95 \%$ confidence interval as shaded areas.

Figure S7


Year of SDM
$\rightarrow 2000$
$\rightarrow 2060$
$\rightarrow 2085$

Figure S7: The mean elevation difference between the SDM and TreeMig predictions across the 16 principal tree species for the year 2000, 2060 and 2085 based on the climate change scenario A2. The lines represent the difference between the upper limit estimated by the dynamic forest model (TreeMig) and the bioclimatic envelope (SDM prediction) of a given year (colours) across time. The numbers indicated the average elevation difference at a given point in time and the years the TreeMig models are ahead or behind the SDM predictions (time lag).

Figure S8


Figure S8: The mean elevation difference between the SDM and TreeMig predictions across all 16 tree species for the year 2000, 2060 and 2085 based on the climate change scenario RCP3PD. The lines represent the difference between the upper limit estimated by the dynamic forest model (TreeMig) and the bioclimatic envelope (SDM prediction) of a given year (colours) across time. The numbers indicated the average elevation difference at a given point in time and the years the TreeMig models are ahead or behind the SDM predictions (time lag).

Figure S9


Figure S9: Correlation of the species-specific UEL (dots) based on predictions of the dynamic forest model (TreeMig) and the bioclimatic envelope (SDM prediction) for the different TreeMig setups and time steps based on the climate change scenario A2. Normal = TreeMig - Normal, UD = TreeMig Unlimited dispersal, NC = TreeMig - No competition, UD \& NC = TreeMig - Unlimited dispersal \& no competition, PA = Competition with P. abies only, UD \& PA = Unlimited dispersal \& competition with P. abies only.

Figure S10


Figure S10: Correlation of the species-specific UEL (dots) based on predictions of the dynamic forest model (TreeMig) and the bioclimatic envelope (SDM prediction) for the different TreeMig setups and time steps based on the climate change scenario RCP3PD. Normal = TreeMig - Normal, UD = TreeMig - Unlimited dispersal, NC = TreeMig - No competition, UD \& NC = TreeMig - Unlimited dispersal \& no competition, PA = Competition with P. abies only, UD \& PA = Unlimited dispersal \& competition with P. abies only.

Figure S11


Figure S11: Species-specific UELs across time based on observations (2000), SDM predictions (2000, 2060, 2085) and TreeMig simulations (1950 to 2300, 25 year intervals). For the future climate, the scenario A2 was used. Observation = Highest observation within study area, SDM = Correlative species distribution model, TM_Normal = TreeMig simulation, TM_UD = TreeMig simulation with unlimited dispersal, TM_NC = TreeMig simulation without competition, TM_UD_NC = TreeMig simulation with unlimited dispersal and no competition, TM_PA = TreeMig simulation with $P$. abies as sole competitor, TM_PA_UD = TreeMig simulation with P. abies as sole competitor and unlimited dispersal.

Figure S12


Figure S12: Species-specific UELs across time based on observations (2000), SDM predictions (2000, 2060, 2085) and TreeMig simulations (1950 to 2300, 25 year intervals). For the future climate, the scenario RCP3PD was used. Observation = Highest observation within study area, SDM = Correlative species distribution model, TM_Normal = TreeMig simulation, TM_UD = TreeMig simulation with unlimited dispersal, TM_NC = TreeMig simulation without competition, TM_UD_NC = TreeMig simulation with unlimited dispersal and no competition, TM_PA = TreeMig simulation with $P$. abies as sole competitor, TM_PA_UD = TreeMig simulation with P. abies as sole competitor and unlimited dispersal.

Figure S13


Figure S13: Correlation of the species-specific UEL based on the dynamic forest model (TreeMig) and the bioclimatic envelope (based on SDM predictions) for the year 2000 for all six TreeMig setups. The dotted lines represent perfect agreement, the blue lines a simple linear regression with the $95 \%$ confidence interval as shaded areas.

Figure S14


Figure S14: Correlation of the species-specific UEL based on the dynamic forest model (TreeMig) and the bioclimatic envelope (based on SDM predictions) for the year 2060 based on climate change scenario A1B for all six TreeMig setups. The dotted lines represent perfect agreement, the blue lines a simple linear regression with the 95\% confidence interval as shaded areas.

Figure S15


Figure S15: Correlation of the species-specific UEL based on the dynamic forest model (TreeMig) and the bioclimatic envelope (based on SDM predictions) for the year 2060 based on climate change scenario A2 for all six TreeMig setups. The dotted lines represent perfect agreement, the blue lines a simple linear regression with the 95\% confidence interval as shaded areas.

Figure S16


Figure S16: Correlation of the species-specific UEL based on the dynamic forest model (TreeMig) and the bioclimatic envelope (based on SDM predictions) for the year 2060 based on climate change scenario RCP3PD for all six TreeMig setups. The dotted lines represent perfect agreement, the blue lines a simple linear regression with the $95 \%$ confidence interval as shaded areas.

Figure S17


Figure S17: Correlation of the species-specific UEL based on the dynamic forest model (TreeMig) and the bioclimatic envelope (based on SDM predictions) for the year 2085 based on climate change scenario A1B for all six TreeMig setups. The dotted lines represent perfect agreement, the blue lines a simple linear regression with the 95\% confidence interval as shaded areas.

Figure S18


Figure S18: Correlation of the species-specific UEL based on the dynamic forest model (TreeMig) and the bioclimatic envelope (based on SDM predictions) for the year 2085 based on climate change scenario A2 for all six TreeMig setups. The dotted lines represent perfect agreement, the blue lines a simple linear regression with the 95\% confidence interval as shaded areas.

Figure S19


Figure S19: Correlation of the species-specific UEL based on the dynamic forest model (TreeMig) and the bioclimatic envelope (based on SDM predictions) for the year 2085 based on climate change scenario RCP3PD for all six TreeMig setups. The dotted lines represent perfect agreement, the blue lines a simple linear regression with the $95 \%$ confidence interval as shaded areas.

Figure S20


Figure S20: Correlation the species-specific UEL based on the dynamic forest model (TreeMig, year 2500) and the bioclimatic envelope (based on SDM predictions, year 2085) based on climate change scenario A1B for all six TreeMig setups. The dotted lines represent perfect agreement, the blue lines a simple linear regression with the $95 \%$ confidence interval as shaded areas.

Figure S21


Figure S21: Correlation of the species-specific UEL based on the dynamic forest model (TreeMig, year 2500) and the bioclimatic envelope (based on SDM predictions, year 2085) based on climate change scenario A2 for all six TreeMig setups. The dotted lines represent perfect agreement, the blue lines a simple linear regression with the 95\% confidence interval as shaded areas.

Figure S22


Figure S22: Correlation of the species-specific UEL based on the dynamic forest model (TreeMig, year 2500) and the bioclimatic envelope (based on SDM predictions, year 2085) based on climate change scenario RCP3PD for all six TreeMig setups. The dotted lines represent perfect agreement, the blue lines a simple linear regression with the $95 \%$ confidence interval as shaded areas.

