## Appendix S1

# Growth and quality of Fagus sylvatica saplings depend on seed source, site, and browsing intensity 

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Ecosphere

## Appendix S1: Detailed trait descriptions

## Growth traits

We measured sapling height $(\mathrm{H})$ as the vertical distance from the ground surface to the base of the uppermost terminal bud. Total sapling length (LTot) was also quantified as the distance from the ground surface to the base of the uppermost terminal bud, but was measured along the stem axis. Further, we measured total terminal leader shoot length (LLead) along the stem axis, which included the second and any additional flushes as well as the length of the second and any additional flushes (LSecFlush). Measurements of stem diameter (D) were taken at fixed positions 2 cm above the ground using electronic calipers (M-150, MBFZ toolcraft GmbH, Georgensgmünd, Germany). Derived traits included relative annual growth (RelGr), which was calculated as LLead/LTot (resp. LLead14/H14), and sapling biomass (Biom, see main text Biomass modeling).

## Morphological traits

The number of stems per sapling in 2014 (MultiStem14) and 2016 (MultiStem16) was determined by counting the number of vertically growing stems that reached $2 / 3$ of the terminal leader length. Sapling growth form (Form) was assessed as "vertical", "bent" (inclined more than $25^{\circ}$, but less than $65^{\circ}$ ), or "horizontal". In 2014, growth form was assessed separately for the first terminal flush (FormLead14), for additional terminal flushes (FormSecFlush14), for proleptic shoots on the terminal shoot(s) (FormProl14) and on lateral shoots (FormLat14). In 2016, growth form was only assessed for total terminal shoot(s) (FormLead16), as there were considerably fewer differences in the bending pattern of theses shoots. We classified sapling stem form (StemForm16) as "straight" (deviation from vertical line $\leq 22.5^{\circ}$ ), "bent" (deviation from vertical line $22.5-45^{\circ}$ ), or "heavily bent" (deviation from vertical line $>45^{\circ}$ ) (Fig. 1). Dominance was judged by comparing each sapling to its adjacent neighbors: "dominant" trees tended to overgrow their neighbors, "intermediate" trees grew comparably to their neighbors, and "suppressed" trees were overgrown by their neighbors. Finally, we assessed the saplings' apical dominance. We did so by checking for the occurrence of proleptic lateral shoots of at least 0.5 cm length in the uppermost parts of the dominant terminal shoot (ApiDomOcc14, ApiDomOcc16). We also noted the number of meristems along the 2016 terminal shoot until proleptic sprouting, counting from the tree top down to the point where the first proleptic shoot of $\geq 0.5 \mathrm{~cm}$ length occurred on the 2016 leader shoot (ApiDomNum16). Furthermore, we calculated the ratio of terminal leader length to apical bud count, i.e., LLead16/ApiDomNum16 (ApiDomRatio16).

## Appendix S1: Figure S1



Figure S1. Study design. a) Random distribution of three clipping treatments across plots at the two study sites Birmensdorf and Matzendorf. White bars: 5 control plots per site with no clipping; light gray bars: 6 plots per site with light clipping; dark gray bars: 5 plots per site with heavy clipping. The original experimental design of the previous study ADAPT contained 16 plots per site. For analysis of variance, plots were summarized to 2 blocks per site (block 1: blocks surrounded by black frame; block 2: blocks surrounded by dashed frame (also the two dashed areas in Birmensdorf were treated as a single block). For details see section "Data analysis" in the main text. b) Each plot contained 3 seedlings per mother tree planted in 6 rows, with a spacing of $30 \mathrm{~cm} \times 40 \mathrm{~cm}$ between seedlings. c) Explanation of simulated browsing treatment. Scissors and red lines indicate cutting positions for light and heavy clipping. The images are adapted from drawings by A. Schwyzer, WSL.

## Appendix S1: Figure S2



Figure S2. Timeline of growth measurements and morphology assessments of Fagus sylvatica saplings between 2013 (age one) and 2016 (age four). Derived traits are italicized. Trait codes are provided in Table 1 and descriptions of ReactType, ReactPlace, Quality, CrownForm, and Biomass are provided in the main text.

## Appendix S1: Figure S3



Figure S3. Crown form, after Ott et al. (2003): 1) fine branches, 2) rough branches, 3) steep branches, 4) forked branches, and 5) bushy crown form. For the analysis, we combined classes 1 and 2, resulting in a total of 4 crown form classes. Drawings by A. Schwyzer, WSL.

## Appendix S1: Figure S4



Figure S4. Relationship between elevation at seed sources (provenance elevation classes) and growth performance of Fagus sylvatica saplings at the two planting sites Birmensdorf (light gray) and Matzendorf (dark gray): a) Sapling height after the 2015 growing season (H15), b) length of terminal shoot from the 2015 growing season (LLead15). Boxplots were drawn using the ggplot2 package in R. They represent the median (thick line), first and third quartiles (bottom and top of the boxes), quartiles $\pm 1.5 *$ interquartile range (whiskers), and individual points exceeding this range (circles).

## Appendix S1: Figure S5



Figure S5. Length of terminal shoots from the growing seasons 2015 (a; LLead15) and 2016 (b; LLead16) for different growth forms of the first flush on the 2014 terminal shoot (FormLead14). Light gray bars represent Fagus sylvatica saplings with no clipping treatment applied, gray bars saplings with light treatment, and dark gray saplings with heavy clipping. Numbers above boxes indicate the numbers of saplings included in each box.

## Appendix S1: Figure S6



Figure S6. Boxplots for sapling height of Fagus sylvatica per population (provenance numbers), displayed for all measurement years (2014 to 2016) and for both study sites. Populations are ordered by 2014 mean values.

## Appendix S1: Figure S7



Figure S7. Boxplots for relative growth of Fagus sylvatica saplings per population (provenance numbers), displayed for all measurement years (2014 to 2016) and for both study sites. Populations are sorted by 2014 mean values.

## Appendix S1: Table S1

Table S1. Trait-environment relations for Fagus sylvatica saplings displayed using Pearson correlation coefficients ( $r$ ) between sapling trait population effects and environmental variables at the 77 seed sources. Significant correlations $(P<0.05)$ are displayed in italics, and highly significant correlations ( $p<0.001$ ) in bold italics. Increasing blue shading represents increasingly positive $r$ values, and increasing red shading represents increasingly negative $r$ values. See Table 1 in the main text for sapling trait descriptions.

|  |  | Pearson correlation coefficient (r) ${ }^{\dagger \text { ¢, }}$ |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | MAT | MTSp | MTSu | PREC | PRSu | PRWi | Elevation |
| 年 | H14 | 0.01 | 0.01 | 0.00 | 0.00 | 0.03 | -0.04 | 0.04 |
|  | HaT14 | 0.00 | -0.01 | -0.01 | 0.01 | 0.03 | -0.02 | 0.06 |
|  | H15 | -0.19 | -0.19 | -0.20 | 0.10 | 0.12 | 0.10 | 0.23 |
|  | H16 | -0.10 | -0.10 | -0.12 | -0.02 | 0.02 | 0.00 | 0.16 |
|  | LTot15 | -0.10 | -0.09 | -0.10 | 0.04 | 0.08 | 0.03 | 0.14 |
|  | LTot16 | -0.09 | -0.09 | -0.11 | -0.03 | 0.01 | 0.00 | 0.15 |
|  | LLead14 | 0.22 | 0.21 | 0.21 | -0.15 | -0.11 | -0.20 | -0.14 |
|  | LLead 15 | -0.37 | -0.35 | -0.36 | 0.28 | 0.30 | 0.26 | 0.36 |
|  | LLead 16 | -0.07 | -0.06 | -0.09 | -0.10 | -0.05 | -0.05 | 0.12 |
|  | SecFlush14 | 0.44 | 0.44 | 0.44 | -0.26 | -0.20 | -0.39 | -0.43 |
|  | SecFlush16 | 0.05 | 0.04 | 0.03 | -0.21 | -0.25 | -0.09 | -0.01 |
|  | LSecFlush14 | 0.20 | 0.20 | 0.19 | -0.14 | -0.07 | -0.19 | -0.16 |
|  | LSecFlush16 | 0.42 | 0.41 | 0.40 | -0.30 | -0.19 | -0.42 | -0.40 |
|  | RelGr 14 | 0.24 | 0.23 | 0.23 | -0.17 | -0.13 | -0.22 | -0.15 |
|  | RelGr15 | -0.56 | -0.53 | -0.54 | 0.40 | 0.36 | 0.44 | 0.50 |
|  | RelGr16 | -0.05 | -0.05 | -0.07 | -0.17 | -0.13 | -0.09 | 0.08 |
|  | D14 | -0.33 | -0.32 | -0.32 | 0.23 | 0.21 | 0.24 | 0.37 |
|  | D15 | -0.32 | -0.32 | -0.32 | 0.18 | 0.15 | 0.23 | 0.38 |
|  | D16 | -0.32 | -0.32 | -0.33 | 0.14 | 0.10 | 0.21 | 0.38 |
|  | Biom14 | -0.21 | -0.20 | -0.21 | 0.14 | 0.14 | 0.13 | 0.26 |
|  | Biom16 | -0.28 | -0.28 | -0.29 | 0.09 | 0.07 | 0.15 | 0.34 |
| $\begin{aligned} & \frac{30}{30} \\ & \frac{0}{0} \\ & \frac{0}{2} \\ & \frac{0}{2} \end{aligned}$ | ReactType | na | na | na | na | na | na | na |
|  | ReactPlace | na | na | na | na | na | na | na |
|  | MultiStem14 | 0.13 | 0.12 | 0.13 | -0.04 | -0.02 | -0.09 | -0.11 |
|  | MultiStem16 | 0.02 | 0.03 | 0.04 | 0.23 | 0.22 | 0.15 | -0.02 |
|  | FormLead14 | 0.34 | 0.33 | 0.33 | -0.31 | -0.28 | -0.26 | -0.37 |
|  | FormSecFlush14 | 0.03 | 0.01 | 0.03 | -0.02 | -0.06 | 0.03 | -0.02 |
|  | FormLat14 | -0.25 | -0.26 | -0.27 | 0.01 | -0.04 | 0.17 | 0.26 |
|  | FormProl14 | -0.22 | -0.21 | -0.21 | 0.04 | 0.01 | 0.10 | 0.19 |
|  | FormLead16 | 0.45 | 0.45 | 0.47 | -0.33 | -0.28 | -0.34 | -0.44 |
|  | Quality 14 | 0.25 | 0.24 | 0.23 | -0.15 | -0.19 | -0.15 | -0.25 |
|  | Quality 16 | 0.24 | 0.25 | 0.25 | 0.04 | 0.05 | -0.07 | -0.26 |
|  | StemForm16 | 0.40 | 0.39 | 0.41 | -0.20 | -0.19 | -0.24 | -0.41 |
|  | CrownForm16 | 0.22 | 0.23 | 0.23 | 0.08 | 0.10 | -0.07 | -0.24 |
|  | Dominance16 | 0.11 | 0.09 | 0.11 | -0.07 | -0.12 | -0.02 | -0.15 |
|  | ApiDomOcc14 | 0.22 | 0.20 | 0.20 | -0.04 | -0.03 | -0.09 | -0.17 |
|  | ApiDomOcc16 | na | na | na | na | na | na | na |
|  | ApiDomNum16 | -0.40 | -0.40 | -0.38 | 0.25 | 0.16 | 0.34 | 0.42 |
|  | ApiDomRatio16 | 0.14 | 0.14 | 0.11 | -0.21 | -0.13 | -0.20 | -0.11 |

${ }^{\dagger}$ MAT: mean annual temperature ( ${ }^{\circ} \mathrm{C}$ ); MTSp: mean spring temperature ( ${ }^{\circ} \mathrm{C}$, March-May); MTSu: mean summer temperature ( ${ }^{\circ} \mathrm{C}$, June-Aug); PREC: annual precipitation sum ( mm ); PRSu: summer precipitation sum ( mm , JuneAug); PRWi: winter precipitation sum (mm, Dec. of previous year through Feb. of current year); Elevation: elevation at seed source (m a.s.l.). Climate variables refer to the time period 1931-1960 (see Appendix S2 in Frank et al., 2017).
${ }^{\ddagger} P$ values of correlations were corrected for multiple comparisons after Bonferroni, using $\mathrm{n}=$ number of environmental variables $\times$ number of traits per group $=7 \times 21$ for the growth traits, and $7 \times 18$ for the morphology traits.

## Appendix S1: Table S2

Table S2. Interactive effect of treatment and site $(T \times S)$ for all growth and morphological traits of Fagus sylvatica saplings, measured after the simulated browsing treatment in 2015. Significance effects are indicated by asterisks ( $p T \times S$ ). Trait codes and descriptions are provided in Table 1 of the main text. Traits in gray were not tested, as they were measured before clipping.

|  | Trait | Year | $\boldsymbol{p}^{\dagger} \boldsymbol{T} \times \boldsymbol{S}$ |
| :---: | :---: | :---: | :---: |
| $\begin{aligned} & \text { J } \\ & \substack{0 \\ 0} \\ & \hline \end{aligned}$ | H14 | 2014 |  |
|  | HaT14 | 2014 | * |
|  | H15 | 2015 | * |
|  | H16 | 2016 | * |
|  | LTot15 | 2015 | * |
|  | LTot16 | 2016 | * |
|  | LLead14 | 2014 |  |
|  | LLead15 | 2015 | * |
|  | LLead16 | 2016 | * |
|  | SecFlush14 | 2014 |  |
|  | SecFlush16 | 2016 | ** |
|  | LSecFlush14 | 2014 |  |
|  | LSecFlush16 | 2016 | * |
|  | RelGr 14 | 2014 |  |
|  | RelGr 15 | 2015 | * |
|  | RelGr 16 | 2016 | * |
|  | D14 | 2014 |  |
|  | D15 | 2015 | n.s. |
|  | D16 | 2016 | , |
|  | Biom14 | 2014 |  |
|  | Biom16 | 2016 | * |
| $\begin{aligned} & \text { bo } \\ & \frac{0}{0} \\ & 0 \\ & 0.0 \\ & 0.0 \end{aligned}$ | ReactType | 2015 | n.s. |
|  | ReactPlace | 2015 | n.s. |
|  | MultiStem14 | 2014 |  |
|  | MultiStem16 | 2016 | n.s. |
|  | FormLead14 | 2014 |  |
|  | FormSecFlush14 | 2014 |  |
|  | FormLat14 | 2014 |  |
|  | FormProl14 | 2014 |  |
|  | FormLead16 | 2016 | n.s. |
|  | Quality14 | 2014 |  |
|  | Quality 16 | 2016 | n.s. |
|  | StemForm16 | 2016 | *** |
|  | CrownForm16 | 2016 | n.s. |
|  | Dominance16 | 2016 | n.s. |
|  | ApiDomNum16Occ14 | 2014 |  |
|  | ApiDomNum16Occ16 | 2016 | * |
|  | ApiDomNum16 | 2016 | n.s. |
|  | ApiDomRatio16 | 2016 | * |

## Literature cited in Appendix S1

Frank, A., C. Sperisen, G. T. Howe, P. Brang, L. Walthert, J. B. St.Clair, and C. Heiri. 2017. Distinct genecological patterns in seedlings of Norway spruce and silver fir from a mountainous landscape. Ecology 98:211-227.

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