Robert Korzeniewicz, Marlena Baranowska, Bartosz Bułaj, Weile Chen, Szymon Czajkowski, Maria Hauke-Kowalska, Anna Ilek, Grzegorz Iszkuło, Wojciech Kowalkowski, Adrian Łukowski, Andrzej Mazur, Joanna Mucha, Radosław Witkowski, Marcin Zadworny

Root morphology, carbohydrate pools, and mycorrhizal associations of silver fir across contrasting canopy conditions

Supplementary Material

Table S1. Meteorological summary from the ATMOS 41 station for April–September 2025. The Total/Average row gives total precipitation and period means for each variable

Month	Precipitation (mm)	Solar radiation (w/m²)	Temperature (°C)	Relative humidity (%)	Wind speed (m/s)	Wind direction (°)
April	40.6	22.1	8.3	78.4	0.5	217.5
May	62.9	27.0	8.2	82.2	0.4	241.9
June	52.3	31.1	15.1	81.1	0.4	228.0
July	82.3	25.7	15.4	86.1	0.4	234.1
August	59.5	22.2	15.0	82.8	0.3	197.6
September	91.3	12.7	11.9	93.7	0.4	196.5
Sum/Mean	389.0	23.5	12.4	84.1	0.4	219.4

Table S2. Soil water reserve and soil temperature in the 0–30 cm soil layer across plots (P1–P10), based on hourly measurements from April to September 2025. CV denotes coefficient of variation. Soil water reserve represents total water storage in the 0–30 cm layer (mm), and soil temperature (°C) represents the depth-averaged temperature (5, 15, and 25 cm)

	Plot	Mean ± SE	Min	Max	CV (%)
Soil water reserve	P1	109.2 ± 0.04	100.5	130.7	2.4
	P2	71.4 ± 0.10	58.1	127.9	9.3
	P3	80.9 ± 0.10	63.4	112.2	8.3
	P4	82.4 ± 0.06	76.4	105.6	4.6
	P5	114.9 ± 0.03	111.8	132.1	1.7
	P6	79.5 ± 0.20	51.7	116.2	16.8
	P7	86.2 ± 0.14	63.4	116.6	10.8
	P8	103.1 ± 0.38	49.9	134.3	25.4
	P9	62.8 ± 0.23	34.3	93.7	24.1
	P10	67.7 ± 0.16	44.9	96.7	15.4
Soil temperature	P1	9.1 ± 0.04	2.7	13.0	29.1
	P2	9.6 ± 0.04	3.4	13.5	26.1
	P3	9.4 ± 0.04	3.3	13.4	27.6
	P4	8.8 ± 0.04	3.3	12.1	26.6
	P5	9.8 ± 0.04	3.4	13.7	27.4
	P6	9.5 ± 0.04	3.7	13.3	26.2
	P7	9.2 ± 0.04	3.1	13.7	27.8
	P8	7.8 ± 0.04	1.5	12.0	33.8
	P9	9.7 ± 0.04	3.1	14.6	27.8
	P10	10.1 ± 0.04	3.2	14.7	26.8

Table S3. Effects of canopy, season, and understory variant on different α-diversity indices calculated for all soil fungi (ALLf) and ectomycorrhizal fungi (ECMf). Comparison of diversity indices for the canopy light treatment (closed canopy vs. canopy gap), season (spring vs. fall), and size class (seedings, low saplings, and high saplings) according to the Kruskal-Wallis test

Diversity indices	Fungal group	Canopy (df = 1)	Season (df = 1)	Size class (df = 2)
Shannon index	ALLf	$\chi2 = 8.14$, P = 0.0022	$\chi2 = 0.57$, P = 0.45	$\chi2 = 1.27$, P = 0.53
	ECMf	$\chi2 = 6.28$, P = 0.01	$\chi2 = 0.52$, P = 0.47	$\chi2 = 0.16$, P = 0.92
Simpson index	ALLf	$\chi2 = 9.73$, P = 0.0009	$\chi2 = 0.81$, P = 0.37	$\chi2 = 1.29$, P = 0.53
	ECMf	$\chi2 = 7.80$, P = 0.01	$\chi2 = 1.39$, P = 0.29	$\chi2 = 0.18$, P = 0.91
Pielou Eveness	ALLf	$\chi2 = 10.97$, P = 0.0005	$\chi2 = 0.42$, P = 0.52	$\chi2 = 1.42$, P = 0.49
	ECMf	$\chi2 = 7.78$, P = 0.01	$\chi2 = 2.78$, P = 0.1	$\chi2 = 0.31$, P = 0.85

Italics indicate significant effect at P≤0.05.

Table S4. Spearman correlation (ρ) for Shannon indices of all fungi and the ectomycorrhizal community with morphological, chemical traits of *Abies alba* and stand characteristic

	Shannon index ALLf	Shannon index ECMf
Shannon index ECMf	*ρ = 0.54, P < 0.0001*	
density	ρ = −0.02 P = 0.8754	ρ = −0.08, P = 0.5602
TNC in needles	ρ = −0.24, P = 0.0623	ρ = 0.14, P = 0.2712
TNC in fine roots	ρ = −0.10, P = 0.4575	ρ = 0.17, P = 0.1838
Starch in needles	*ρ = −0.26, P = 0.0455*	ρ = 0.11, P = 0.4096
Starch in fine roots	ρ = −0.03, P = 0.8209	ρ = 0.23, P = 0.0757
N in needles	ρ = 0.08, P = 0.5374	ρ = 0.08, P = 0.5262
N in fine roots	ρ = 0.20, P = 0.1242	ρ = −0.04, P = 0.7821
C:N in needles	ρ = −0.8, P = 0.5614	ρ = −0.05, P = 0.6967
C:N in fine roots	ρ = −0.18, P = 0.1681	ρ = −0.01, P = 0.9431
SRL	ρ = 0.09, P = 0.4788	ρ = 0.19, P = 0.1421
RTD	ρ = −0.05, P = 0.7122	ρ = −0.15, P = 0.2412
Tips	ρ = 018, P = 0.1634	ρ = 0.03, P = 0.7969
PPFD	*ρ = 0.43, P = 0.0007*	ρ = −0.11, P = 0.3946

Italics indicate significant effect at $P \leq 0.05$.

Table S5. Spearman correlation (ρ) for *Boletus* relative abundance. Shannon indices of all fungi and the ectomycorrhizal community with morphological and chemical traits of *Abies alba* and stand characteristics

	Boletus abundance
Shannon index ALLf	ρ = −0.05, P = 0.7070
Shannon index ECMf	ρ = 0.15, P = 0.2535
density	ρ = −0.09, P = 0.5021
TNC in needles	ρ = 0.25, P = 0.0537
TNC in fine roots	ρ = 0.16, P = 0.2254
Starch in needles	ρ = 0.24, P = 0.0655
Starch in fine roots	ρ = 0.19, P = 0.1523
N in needles	ρ = −0.13, P = 0.3311
N in fine roots	ρ = −0.15, P = 0.2512
C:N in needles	ρ = 0.11, P = 0.3956
C:N in fine roots	ρ = 0.15, P = 0.2614
SRL	*ρ = −0.29, P = 0.0249*
RTD	ρ = 0.06, P = 0.6787
Tips	ρ = −0.20, P = 0.1184
PPFD	*ρ = −0.26, P = 0.0412*

Italics indicate significant effect at $P \leq 0.05$.

Fig. S1. Drill & Drop Bluetooth probe (Sentek Technologies) installed on one of the study plots to record soil moisture and temperature up to 30 cm depth

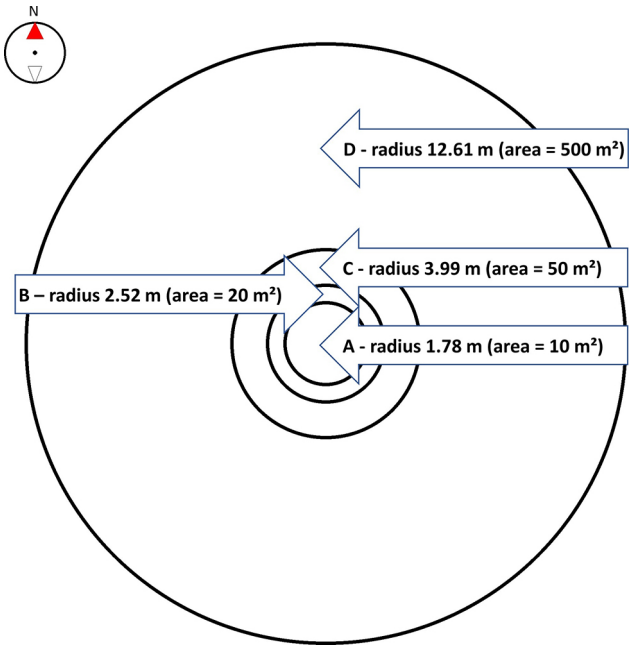

Fig. S2. Map of inventoried tree locations within a 500 m² circular sample plot, recorded using FieldMap technology. Layout of a circular sample plot with three internal concentric subplots used for measuring trees, advance regeneration, and seedlings: A) Within a plot of radius 1.78 m (area = 10 m²), all tree species except current-year seedlings were inventoried, recorded, and measured; B) Within a subplot of radius 2.52 m (area = 20 m²), all trees with a height (h) ≥ 0.5 m were inventoried, recorded, and measured; C) Within a subplot of radius 3.99 m (area = 50 m²), all trees with a diameter at breast height (DBH) ≥ 2 cm were inventoried and measured; D) Within a plot of radius 12.61 m (area = 500 m²), all trees with a diameter at breast height (DBH) ≥ 12 cm were inventoried and measured

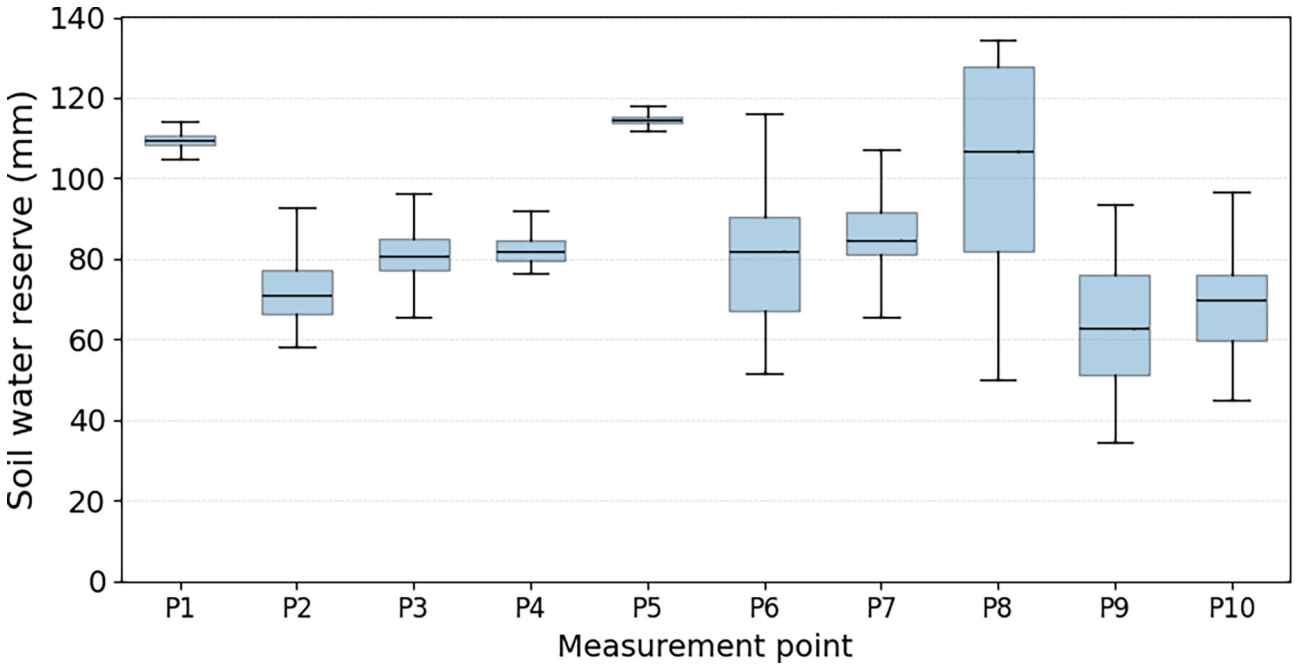

Fig. S3. Daily averages of soil water reserve and depth-averaged soil temperature (0–30 cm), together with air temperature and precipitation, from April (IV) to September (IX) 2025. Soil values represent means across plots P1–P10

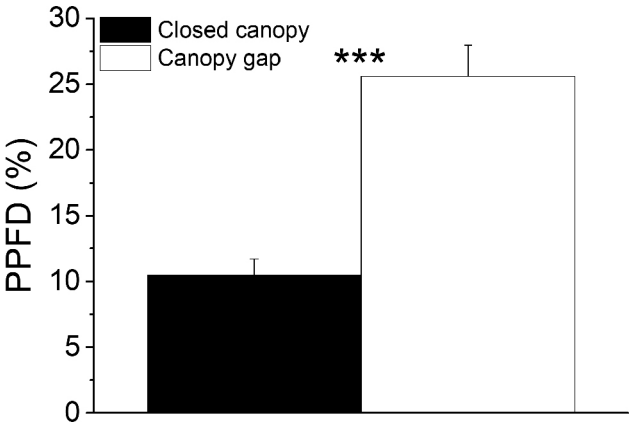

Fig. S4. Photosynthetically active photon flux density (PPFD) measured within understory patches in closed canopy and canopy gap plots. Values are presented as mean PPFD across season and along the vertical profile (0.5–2 m height) ± SE. Values were transformed but chart shows non-transformed data for clarity. Asterisks indicate significantly different means between closed and canopy gaps at P <0.05 (*), at P < 0.01 (**), and at P < 0.001 (***) according to Student's t-test

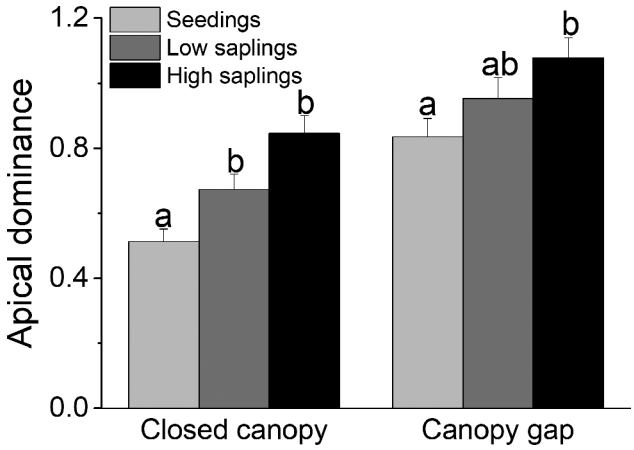

Fig. S5. Apical dominance ratios for seedings (light grey color), low saplings (heavy grey color), and high saplings (black color) in closed canopy understories and canopy gap plots. Values are shown as means ± SE by size classes. Values were transformed but chart shows non-transformed data for clarity. Different letters indicate significantly different means within closed canopy and canopy gap plots at P<0.05 (Tuckey HSD test)

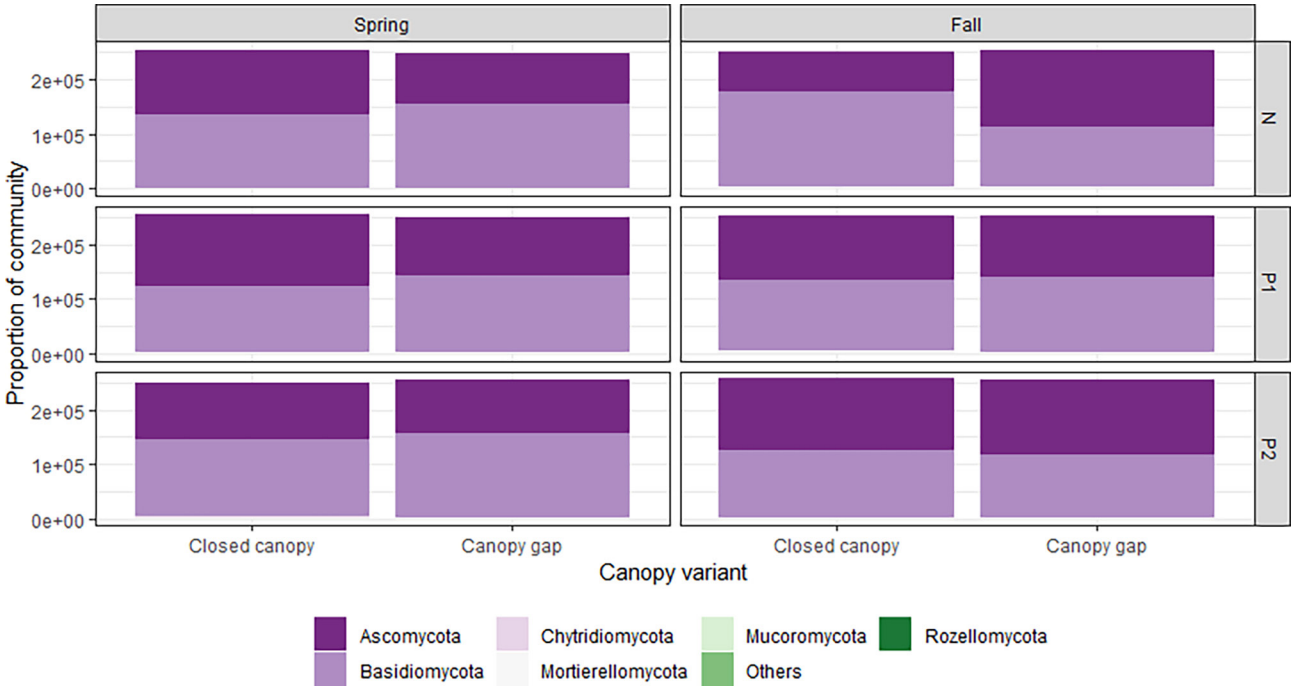

Fig. S6. Absolute abundance of fungal phyla between closed canopy and canopy gaps in two seasons (spring and fall) including three size classes (N – seedings, P1 – low saplings, and P2 – high saplings)

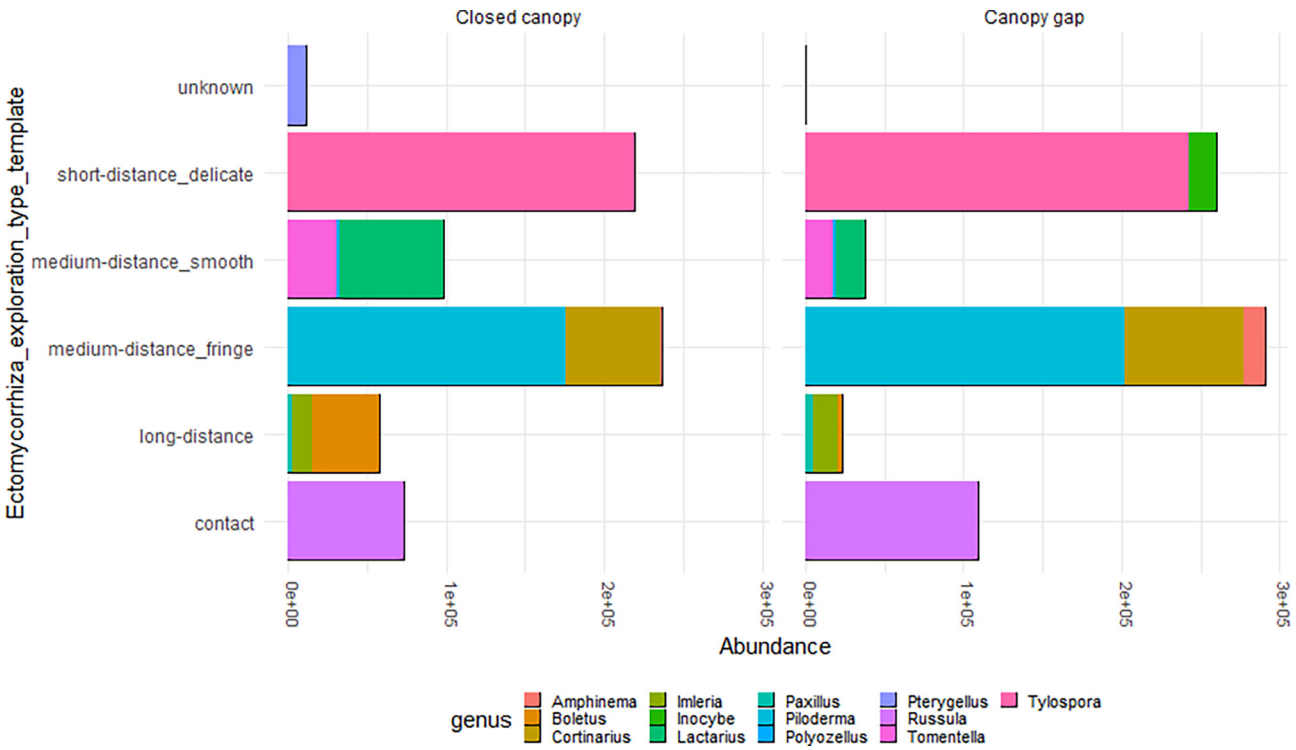

Fig. S7. Distribution of ectomycorrhizal (ECM) exploration types and dominant fungal genera in *Abies alba* roots. The stacked bar plots represent the total abundance of fungal sequences assigned to specific exploration type templates under closed canopy and canopy gap conditions. The color-coded segments indicate the contribution of major genera (e.g., *Tylospora*, *Piloderma*, *Russula*, and *Tomentella*) within each functional category. Functional classification reveals a high prevalence of short-distance delicate and medium-distance fringe strategies across both canopy variants