**Supplementary Materials:**

**Table S1.** Summary of all significant direct paths in the structural equation models (SEM).

| SEM type | Response variable | Predictor variable | Path coefficient (λ) | Significance level | Effect direction |
|---|---|---|---|---|---|
| Bacterial SEM | Soil bacterial diversity | Environmental factors | 0.8 | *** | Positive |
| | Soil bacterial diversity | Chemical factors | −0.74 | ** | Negative |
| | Soil enzyme activity | Physical factors | −0.69 | *** | Negative |
| | Chemical factors | Environmental factors | 0.22 | *** | Positive |
| | Biological factors | Environmental factors | 0.63 | *** | Positive |
| | Physical factors | Biological factors | −0.53 | ** | Negative |
| Fungal SEM | Soil fungal diversity | Environmental factors | 0.64 | *** | Positive |
| | Soil fungal diversity | Biological factors | −0.37 | ** | Negative |
| | Soil enzyme activity | Physical factors | −0.80 | *** | Negative |
| | Chemical factors | Environmental factors | 0.21 | *** | Positive |
| | Biological factors | Environmental factors | 0.58 | *** | Positive |
| | Physical factors | Biological factors | −0.49 | ** | Negative |

**Table S2.** PCA results of SQ indicators in *Picea crassifolia* pure forest.

| Indicator | Principal component (PC) | | Grouping | Norm value |
|---|---|---|---|---|
| | PC1 | PC2 | | |
| TC (g/kg) | 0.76 | 0.65 | 1 | 3.47 |
| TN (g/kg) | 0.80 | 0.60 | 1 | 3.52 |
| TP (g/kg) | 0.99 | 0.15 | 1 | 3.81 |
| TK (g/kg) | 0.11 | −0.98 | 2 | 2.84 |
| SOC (g/kg) | 0.81 | 0.58 | 1 | 3.54 |
| AN (mg/kg) | 0.67 | 0.74 | 2 | 3.34 |
| AP (mg/kg) | 0.65 | 0.76 | 2 | 3.31 |
| AK (mg/kg) | −0.85 | −0.52 | 1 | 3.61 |
| MBC (mg/kg) | 0.98 | 0.19 | 1 | 3.80 |
| MBN (mg/kg) | 0.99 | −0.01 | 1 | 3.82 |
| MBP (mg/kg) | 0.92 | 0.38 | 1 | 3.72 |
| SUC (mg/d/g) | 0.46 | 0.89 | 2 | 3.09 |
| URE (mg/d/g) | 0.98 | −0.14 | 1 | 3.80 |
| ALP (mg/d/g) | 0.86 | 0.50 | 1 | 3.62 |
| CAT (mg/d/g) | 0.10 | −0.98 | 2 | 2.84 |
| SWC (%) | 0.94 | 0.34 | 1 | 3.74 |
| BD (g/cm$^3$) | −0.91 | −0.41 | 1 | 3.70 |
| EC (μS/cm) | 0.49 | 0.87 | 2 | 3.11 |
| pH | −0.58 | −0.81 | 2 | 3.23 |
| Clay (%) | −0.89 | −0.45 | 1 | 3.67 |
| Silt (%) | −0.94 | −0.33 | 1 | 3.75 |
| Sand (%) | 0.92 | 0.40 | 1 | 3.70 |


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| | | | | |
|---|---|---|---|---|
| Bacterial diversity | −0.56 | 0.55 | 1 | 2.66 |
| Fungal diversity | −0.70 | 0.04 | 1 | 2.71 |
| Eigenvalue | 14.81 | 8.18 | | |
| Variance contribution rate (%) | 77.81 | 17.96 | | |
| Cumulative contribution rate (%) | 77.81 | 95.77 | | |

**Table S3.** PCA results of SQ indicators in the *Betula* pure forest

| Indicator | Principal component (PC) | | | Grouping | Norm value |
|---|---|---|---|---|---|
| | PC1 | PC2 | PC3 | | |
| TC (g/kg) | 0.58 | 0.80 | 0.14 | 2 | 3.22 |
| TN (g/kg) | 0.66 | 0.74 | 0.14 | 2 | 3.26 |
| TP (g/kg) | −1.00 | 0.06 | 0.00 | 1 | 3.48 |
| TK (g/kg) | 0.77 | 0.63 | 0.12 | 1 | 3.32 |
| SOC (g/kg) | 0.57 | 0.81 | 0.15 | 2 | 3.21 |
| AN (mg/kg) | 0.81 | 0.57 | 0.11 | 1 | 3.35 |
| AP (mg/kg) | 0.55 | 0.82 | 0.15 | 2 | 3.20 |
| AK (mg/kg) | −0.76 | 0.64 | 0.10 | 1 | 3.32 |
| MBC (mg/kg) | 0.92 | 0.38 | 0.08 | 1 | 3.42 |
| MBN (mg/kg) | 0.99 | 0.12 | 0.03 | 1 | 3.47 |
| MBP (mg/kg) | 0.93 | 0.35 | 0.07 | 1 | 3.43 |
| SUC (mg/d/g) | 0.96 | 0.28 | 0.06 | 1 | 3.45 |
| URE (mg/d/g) | −0.82 | 0.57 | 0.09 | 1 | 3.35 |
| ALP (mg/d/g) | −0.08 | 0.98 | 0.17 | 2 | 3.08 |
| CAT (mg/d/g) | 0.43 | 0.89 | 0.16 | 2 | 3.16 |
| SWC (%) | 0.40 | 0.90 | 0.16 | 2 | 3.15 |
| BD (g/cm$^3$) | −0.21 | −0.96 | −0.17 | 2 | 3.09 |
| EC (μS/cm) | −0.34 | 0.93 | 0.16 | 2 | 3.13 |
| pH | −0.59 | −0.79 | −0.14 | 2 | 3.22 |
| Clay (%) | −0.93 | −0.37 | −0.08 | 1 | 3.43 |
| Silt (%) | −0.97 | −0.22 | −0.05 | 1 | 3.46 |
| Sand (%) | 0.96 | 0.29 | 0.06 | 1 | 3.45 |
| Bacterial diversity | 0.12 | 0.16 | 0.89 | 3 | 1.35 |
| Fungal diversity | 0.02 | −0.30 | −0.84 | 3 | 1.47 |
| Eigenvalue | 12.12 | 9.70 | 1.80 | | |
| Variance contribution rate (%) | 67.15 | 25.95 | 5.34 | | |
| Cumulative contribution rate (%) | 67.15 | 93.10 | 98.44 | | |

**Table S4.** PCA results of SQ indicators in *Juniperus przewalskii* pure forest

| Indicator | Principal component (PC) | | Grouping | Norm value |
|---|---|---|---|---|
| | PC1 | PC2 | | |
| TC (g/kg) | 1.00 | 0.08 | 1 | 3.53 |
| TN (g/kg) | 0.98 | −0.21 | 1 | 3.51 |
| TP (g/kg) | 0.86 | −0.50 | 1 | 3.45 |
| TK (g/kg) | −0.55 | −0.84 | 2 | 3.33 |
| SOC (g/kg) | 1.00 | 0.07 | 1 | 3.52 |
| AN (mg/kg) | 0.90 | −0.44 | 1 | 3.47 |
| AP (mg/kg) | 0.34 | −0.94 | 2 | 3.27 |
| AK (mg/kg) | 0.87 | −0.49 | 1 | 3.45 |
| MBC (mg/kg) | 0.39 | 0.92 | 2 | 3.28 |
| MBN (mg/kg) | −0.12 | 0.99 | 2 | 3.24 |
| MBP (mg/kg) | −0.22 | 0.97 | 2 | 3.25 |
| SUC (mg/d/g) | 0.78 | 0.63 | 1 | 3.42 |
| URE (mg/d/g) | 0.81 | −0.58 | 1 | 3.43 |
| ALP (mg/d/g) | −0.35 | 0.93 | 2 | 3.27 |
| CAT (mg/d/g) | 0.65 | −0.76 | 2 | 3.36 |
| SWC (%) | 0.03 | −1.00 | 2 | 3.24 |
| BD (g/cm$^3$) | 0.95 | 0.31 | 1 | 3.50 |

| | | | | |
|---|---|---|---|---|
| EC (μS/cm) | −0.05 | 1.00 | 2 | 3.24 |
| pH | 0.68 | 0.74 | 2 | 3.37 |
| Clay (%) | −0.99 | −0.16 | 1 | 3.52 |
| Silt (%) | −0.93 | 0.37 | 1 | 3.49 |
| Sand (%) | 1.00 | 0.08 | 1 | 3.53 |
| Bacterial diversity | 0.76 | −0.28 | 1 | 2.81 |
| Fungal diversity | 0.14 | −0.59 | 2 | 1.97 |
| Eigenvalue | 12.45 | 10.51 | | |
| Variance contribution rate (%) | 55.78 | 39.90 | | |
| Cumulative contribution rate (%) | 55.78 | 95.68 | | |

**Table S5.** PCA results of SQ indicators in *Pinus tabuliformis* pure forest

| Indicator | Principal component (PC) | | | Grouping | Norm value |
|---|---|---|---|---|---|
| | PC1 | PC2 | PC3 | | |
| TC (g/kg) | 0.73 | 0.67 | −0.11 | 1 | 3.30 |
| TN (g/kg) | 0.72 | 0.68 | −0.12 | 1 | 3.30 |
| TP (g/kg) | 0.82 | 0.56 | −0.11 | 1 | 3.34 |
| TK (g/kg) | −0.48 | −0.87 | 0.12 | 2 | 3.23 |
| SOC (g/kg) | 0.73 | 0.67 | −0.11 | 1 | 3.30 |
| AN (mg/kg) | 0.77 | 0.63 | −0.11 | 1 | 3.32 |
| AP (mg/kg) | 0.69 | 0.72 | −0.12 | 2 | 3.29 |
| AK (mg/kg) | 0.96 | 0.27 | −0.09 | 1 | 3.39 |
| MBC (mg/kg) | 0.62 | 0.78 | −0.12 | 2 | 3.27 |
| MBN (mg/kg) | 0.61 | 0.79 | −0.12 | 2 | 3.26 |
| MBP (mg/kg) | 0.55 | 0.83 | −0.12 | 2 | 3.25 |
| SUC (mg/d/g) | 0.94 | 0.32 | −0.09 | 1 | 3.39 |
| URE (mg/d/g) | −0.50 | 0.86 | −0.05 | 2 | 3.25 |
| ALP (mg/d/g) | 0.73 | 0.68 | −0.11 | 1 | 3.30 |
| CAT (mg/d/g) | −0.18 | −0.98 | 0.11 | 2 | 3.19 |
| SWC (%) | 0.78 | 0.62 | −0.11 | 1 | 3.32 |
| BD (g/cm$^3$) | −0.99 | −0.10 | 0.08 | 1 | 3.41 |
| EC (μS/cm) | 0.14 | 0.98 | −0.11 | 2 | 3.18 |
| pH | 0.96 | 0.27 | −0.09 | 1 | 3.40 |
| Clay (%) | −0.58 | −0.81 | 0.12 | 2 | 3.26 |
| Silt (%) | −1.00 | -0.03 | 0.07 | 1 | 3.42 |
| Sand (%) | 0.73 | 0.68 | −0.11 | 1 | 3.30 |
| Bacterial diversity | −0.33 | −0.02 | 0.90 | 3 | 1.68 |
| Fungal diversity | 0.07 | −0.25 | 0.92 | 3 | 1.53 |
| Eigenvalue | 11.72 | 10.21 | 1.91 | | |
| Variance contribution rate (%) | 78.51 | 14.37 | 6.45 | | |
| Cumulative contribution rate (%) | 78.51 | 92.88 | 99.32 | | |

**Table S6.** PCA results of SQ indicators in mixed coniferous-broadleaved forest

| Indicator | Principal component (PC) | | | Grouping | Norm value |
|---|---|---|---|---|---|
| | PC1 | PC2 | PC3 | | |
| TC (g/kg) | 0.87 | 0.50 | −0.06 | 1 | 3.41 |
| TN (g/kg) | 0.85 | 0.53 | −0.07 | 1 | 3.40 |
| TP (g/kg) | 0.36 | 0.93 | −0.06 | 2 | 3.22 |
| TK (g/kg) | −0.38 | −0.92 | 0.06 | 2 | 3.23 |
| SOC (g/kg) | 0.89 | 0.45 | −0.06 | 1 | 3.43 |
| AN (mg/kg) | 0.94 | −0.35 | −0.03 | 1 | 3.45 |
| AP (mg/kg) | 0.92 | 0.38 | −0.06 | 1 | 3.45 |
| AK (mg/kg) | −0.38 | 0.92 | −0.02 | 2 | 3.23 |
| MBC (mg/kg) | 0.70 | 0.71 | −0.07 | 2 | 3.34 |
| MBN (mg/kg) | 0.84 | 0.54 | −0.07 | 1 | 3.40 |
| MBP (mg/kg) | 0.98 | −0.21 | −0.04 | 1 | 3.48 |
| SUC (mg/d/g) | 0.37 | −0.93 | 0.02 | 2 | 3.23 |

| | | | | | |
|---|---|---|---|---|---|
| URE (mg/d/g) | 0.43 | −0.90 | 0.02 | 2 | 3.24 |
| ALP (mg/d/g) | 0.40 | 0.91 | −0.06 | 2 | 3.23 |
| CAT (mg/d/g) | −0.93 | 0.37 | 0.03 | 1 | 3.45 |
| SWC (%) | 0.85 | 0.53 | −0.07 | 1 | 3.41 |
| BD (g/cm$^3$) | −0.16 | −0.99 | 0.05 | 2 | 3.19 |
| EC (μS/cm) | 0.61 | 0.79 | −0.07 | 2 | 3.30 |
| pH | −0.04 | 1.00 | −0.04 | 2 | 3.18 |
| Clay (%) | −0.99 | 0.14 | 0.04 | 1 | 3.48 |
| Silt (%) | −1.00 | −0.04 | 0.05 | 1 | 3.49 |
| Sand (%) | 1.00 | −0.07 | −0.05 | 1 | 3.49 |
| Bacterial diversity | −0.46 | 0.22 | 0.74 | 3 | 1.92 |
| Fungal diversity | 0.14 | −0.39 | 0.81 | 3 | 1.62 |
| Eigenvalue | 12.21 | 10.14 | 1.26 | | |
| Variance contribution rate (%) | 57.92 | 35.67 | 4.81 | | |
| Cumulative contribution rate (%) | 57.92 | 93.59 | 98.40 | | |

**Table S7.** PCA results of SQ indicators in mixed broadleaved forest

| Indicator | Principal component (PC) | | | Grouping | Norm value |
|---|---|---|---|---|---|
| | PC1 | PC2 | PC3 | | |
| TC (g/kg) | −0.22 | 0.97 | 0.04 | 2 | 3.17 |
| TN (g/kg) | 0.02 | 1.00 | 0.05 | 2 | 3.15 |
| TP (g/kg) | −0.84 | 0.54 | 0.02 | 1 | 3.40 |
| TK (g/kg) | −0.85 | −0.52 | −0.03 | 1 | 3.41 |
| SOC (g/kg) | −0.19 | 0.98 | 0.04 | 2 | 3.16 |
| AN (mg/kg) | 0.99 | 0.14 | 0.01 | 1 | 3.49 |
| AP (mg/kg) | 0.91 | 0.42 | 0.02 | 1 | 3.44 |
| AK (mg/kg) | −0.09 | 0.99 | 0.05 | 2 | 3.15 |
| MBC (mg/kg) | 0.96 | 0.28 | 0.02 | 1 | 3.47 |
| MBN (mg/kg) | 1.00 | 0.03 | 0.01 | 1 | 3.50 |
| MBP (mg/kg) | 0.98 | −0.18 | 0.00 | 1 | 3.49 |
| SUC (mg/d/g) | −0.94 | 0.33 | 0.01 | 1 | 3.46 |
| URE (mg/d/g) | 0.99 | 0.15 | 0.01 | 1 | 3.49 |
| ALP (mg/d/g) | −0.26 | 0.96 | 0.04 | 2 | 3.18 |
| CAT (mg/d/g) | −0.15 | −0.99 | −0.05 | 2 | 3.16 |
| SWC (%) | −0.08 | 1.00 | 0.05 | 2 | 3.15 |
| BD (g/cm$^3$) | −0.11 | −0.99 | −0.05 | 2 | 3.15 |
| EC (μS/cm) | 0.52 | 0.85 | 0.04 | 2 | 3.25 |
| pH | −0.89 | 0.46 | 0.02 | 1 | 3.43 |
| Clay (%) | −0.94 | 0.34 | 0.01 | 1 | 3.46 |
| Silt (%) | −1.00 | 0.06 | 0.00 | 1 | 3.50 |
| Sand (%) | 0.98 | −0.21 | −0.01 | 1 | 3.48 |
| Bacterial diversity | −0.29 | 0.26 | 0.65 | 3 | 1.47 |
| Fungal diversity | −0.26 | 0.04 | −0.82 | 3 | 1.26 |
| Eigenvalue | 12.24 | 9.95 | 1.11 | | |
| Variance contribution rate (%) | 51.80 | 40.81 | 4.47 | | |
| Cumulative contribution rate (%) | 51.80 | 92.61 | 97.08 | | |