

Supplementary Material

Analysis at pixel level

Variance Inflation Factor (VIF) for the Full Model

Predictor	GVIF	GVIF ^{1/(2×df)}
rao	1.490661	1.220926
h_mean	2.665003	1.632484
density	2.866775	1.693155
aspect	1.290380	1.018377
slope	1.236771	1.021478
altitude	1.682591	1.044315

Table 1: Variance Inflation Factor (VIF) for the fixed effects in the initial model at pixel level

Full Model (GLMM)

Variable	Estimate	Std. Error	z value	Pr(> z)
(Intercept)	-15.566746	498.764775	-0.031	0.9751
rao	0.046945	0.022191	2.115	0.0344 *
h_mean	0.083291	0.015021	5.545	2.94e-08 ***
density	0.006620	0.006416	1.032	0.3021
aspectNorth	-1.503614	0.317765	-4.732	2.22e-06 ***
aspectNorth-East	-0.822408	0.186802	-4.403	1.07e-05 ***
aspectNorth-West	-1.369682	0.188391	-7.270	3.58e-13 ***
aspectSouth	-0.289353	0.214653	-1.348	0.1777
aspectSouth-East	1.064369	0.194313	5.478	4.31e-08 ***
aspectSouth-West	-0.151246	0.190101	-0.796	0.4263
aspectWest	-0.941145	0.179930	-5.231	1.69e-07 ***
slopeHilly	11.104908	498.764818	0.022	0.9822
slopeModerately sloping	11.457112	498.764838	0.023	0.9817
slopeModerately steep	10.856868	498.764815	0.022	0.9826
slopeSteep	10.252172	498.765059	0.021	0.9836
slopeUndulating	10.916287	498.765033	0.022	0.9825
altitude1000-1250m	2.434947	0.550814	4.421	9.84e-06 ***
altitude1250-1500m	2.237379	0.545208	4.104	4.07e-05 ***
altitude1500-1750m	2.753749	0.546107	5.043	4.59e-07 ***
altitude1750-2000m	2.342411	0.557957	4.198	2.69e-05 ***
altitude2000-2250m	1.438608	0.753806	1.908	0.0563 .
altitude2250-2500m	-7.892565	754.757474	-0.010	0.9917

Table 2: Full GLMM results for the analysis at pixel level

Reduced Model

Variable	Estimate	Std. Error	z value	Pr(> z)
(Intercept)	-15.566746	498.764775	-0.031	0.9751
rao	0.046945	0.022191	2.115	0.0344 *
h_mean	0.083291	0.015021	5.545	2.94e-08 ***
density	0.006620	0.006416	1.032	0.3021
aspectNorth	-1.503614	0.317765	-4.732	2.22e-06 ***
aspectNorth-East	-0.822408	0.186802	-4.403	1.07e-05 ***
aspectNorth-West	-1.369682	0.188391	-7.270	3.58e-13 ***
aspectSouth	-0.289353	0.214653	-1.348	0.1777
aspectSouth-East	1.064369	0.194313	5.478	4.31e-08 ***
aspectSouth-West	-0.151246	0.190101	-0.796	0.4263
aspectWest	-0.941145	0.179930	-5.231	1.69e-07 ***
slopeHilly	11.104908	498.764818	0.022	0.9822
slopeModerately sloping	11.457112	498.764838	0.023	0.9817
slopeModerately steep	10.856868	498.764815	0.022	0.9826
slopeSteep	10.252172	498.765059	0.021	0.9836
slopeUndulating	10.916287	498.765033	0.022	0.9825
altitude1000-1250m	2.434947	0.550814	4.421	9.84e-06 ***
altitude1250-1500m	2.237379	0.545208	4.104	4.07e-05 ***
altitude1500-1750m	2.753749	0.546107	5.043	4.59e-07 ***
altitude1750-2000m	2.342411	0.557957	4.198	2.69e-05 ***
altitude2000-2250m	1.438608	0.753806	1.908	0.0563 .
altitude2250-2500m	-7.892565	754.757474	-0.010	0.9917

Table 3: Reduced GLMM results for the pixel level analysis

Model with Interactions

Table 4: GLMM results with interactions between aspect, slope, and altitude at pixel level

Variable	Estimate	Std. Error	z value	Pr(> z)
(Intercept)	-19.12	3690.00	-0.005	0.9959
rao	0.0316	0.0237	1.336	0.1815
h_mean	0.1027	0.0162	6.332	2.41e-10 ***
density	-0.00055	0.0068	-0.081	0.9352
aspectNorth	-0.3317	0.9588	-0.346	0.7294
aspectNorth-East	-35.07	6366.00	-0.006	0.9956
aspectNorth-West	-34.22	4852.00	-0.007	0.9944
aspectSouth	-33.60	5823.00	-0.006	0.9954
aspectSouth-East	-17.75	4529.00	-0.004	0.9969
aspectSouth-West	-34.76	5546.00	-0.006	0.9950
aspectWest	-34.38	4846.00	-0.007	0.9943
slopeHilly	16.24	3690.00	0.004	0.9965
slopeModerately sloping	16.50	3690.00	0.004	0.9964
slopeModerately steep	15.99	3690.00	0.004	0.9965
slopeSteep	16.69	3690.00	0.005	0.9964
slopeUndulating	33.82	5842.00	0.006	0.9954
altitude1000-1250m	0.8676	0.7415	1.170	0.2420
altitude1250-1500m	1.1600	0.7023	1.651	0.0987 .
altitude1500-1750m	1.5190	0.7047	2.156	0.0311 *
altitude1750-2000m	1.1580	0.7433	1.557	0.1194
altitude2000-2250m	0.0860	1.2990	0.066	0.9472
altitude2250-2500m	2.3450	5333.00	0.000	0.9996

Table 4: (continued)

Variable	Estimate	Std. Error	z value	Pr(> z)
aspectNorth:slopeHilly	-0.6996	0.7869	-0.889	0.3739
aspectNorth-East:slopeHilly	17.85	4529.00	0.004	0.9969
aspectNorth-West:slopeHilly	17.42	4529.00	0.004	0.9969
aspectSouth:slopeHilly	18.04	4529.00	0.004	0.9968
aspectSouth-East:slopeHilly	17.75	4529.00	0.004	0.9969
aspectSouth-West:slopeHilly	18.78	4529.00	0.004	0.9967
aspectWest:slopeHilly	17.41	4529.00	0.004	0.9969
aspectNorth:slopeModerately sloping	0.8793	1.2490	0.704	0.4813
aspectNorth-East:slopeModerately sloping	17.13	4529.00	0.004	0.9970
aspectNorth-West:slopeModerately sloping	18.19	4529.00	0.004	0.9968
aspectSouth:slopeModerately sloping	16.54	4529.00	0.004	0.9971
aspectSouth-East:slopeModerately sloping	16.19	4529.00	0.004	0.9971
aspectSouth-West:slopeModerately sloping	19.72	4529.00	0.004	0.9965
aspectWest:slopeModerately sloping	18.19	4529.00	0.004	0.9968
aspectNorth-East:slopeModerately steep	16.61	4529.00	0.004	0.9971
aspectNorth-West:slopeModerately steep	17.24	4529.00	0.004	0.9970
aspectSouth:slopeModerately steep	18.65	4529.00	0.004	0.9967
aspectSouth-East:slopeModerately steep	17.90	4529.00	0.004	0.9968
aspectSouth-West:slopeModerately steep	18.99	4529.00	0.004	0.9967
aspectWest:slopeModerately steep	17.90	4529.00	0.004	0.9968
aspectNorth-East:slopeSteep	0.4312	4994.00	0.000	0.9999
aspectNorth-West:slopeSteep	0.0629	5806.00	0.000	1.0000
aspectSouth:slopeSteep	16.41	4529.00	0.004	0.9971
aspectSouth-East:slopeSteep	33.99	9833.00	0.003	0.9972
aspectSouth-West:slopeSteep	3.0880	7617.00	0.000	0.9997
aspectWest:slopeSteep	16.89	4529.00	0.004	0.9970
aspectNorth:altitude1000-1250m	-0.3994	1.1740	-0.340	0.7336
aspectNorth-East:altitude1000-1250m	16.15	4474.00	0.004	0.9971
aspectNorth-West:altitude1000-1250m	16.01	1740.00	0.009	0.9927
aspectSouth:altitude1000-1250m	15.49	3661.00	0.004	0.9966
aspectSouth-East:altitude1000-1250m	1.9870	1.3870	1.432	0.1520
aspectSouth-West:altitude1000-1250m	15.45	3201.00	0.005	0.9961
aspectWest:altitude1000-1250m	16.49	1724.00	0.010	0.9924
aspectNorth:altitude1250-1500m	-1.7160	1.0080	-1.702	0.0887
aspectNorth-East:altitude1250-1500m	16.61	4474.00	0.004	0.9970
aspectNorth-West:altitude1250-1500m	15.11	1740.00	0.009	0.9931
aspectSouth:altitude1250-1500m	14.93	3661.00	0.004	0.9967
aspectSouth-East:altitude1250-1500m	1.6240	1.3670	1.188	0.2349
aspectSouth-West:altitude1250-1500m	15.91	3201.00	0.005	0.9960
aspectWest:altitude1250-1500m	15.23	1724.00	0.009	0.9929
aspectNorth:altitude1500-1750m	-1.2250	0.9085	-1.348	0.1776
aspectNorth-East:altitude1500-1750m	17.10	4474.00	0.004	0.9969
aspectNorth-West:altitude1500-1750m	15.72	1740.00	0.009	0.9928
aspectSouth:altitude1500-1750m	15.27	3661.00	0.004	0.9967
aspectSouth-East:altitude1500-1750m	0.6473	1.3570	0.477	0.6335
aspectSouth-West:altitude1500-1750m	15.96	3201.00	0.005	0.9960
aspectWest:altitude1500-1750m	15.80	1724.00	0.009	0.9927
aspectNorth-East:altitude1750-2000m	17.77	4474.00	0.004	0.9968
aspectNorth-West:altitude1750-2000m	14.78	1740.00	0.008	0.9932
aspectSouth:altitude1750-2000m	15.11	3661.00	0.004	0.9967
aspectSouth-East:altitude1750-2000m	-0.0668	1.4300	-0.047	0.9628
aspectSouth-West:altitude1750-2000m	15.12	3201.00	0.005	0.9962
aspectWest:altitude1750-2000m	16.03	1724.00	0.009	0.9926
aspectNorth-East:altitude2000-2250m	2.8630	5068.00	0.001	0.9995

Table 4: (continued)

Variable	Estimate	Std. Error	z value	Pr(> z)
aspectNorth-West:altitude2000-2250m	16.90	1740.00	0.010	0.9922
aspectSouth:altitude2000-2250m	15.64	3661.00	0.004	0.9966
aspectSouth-East:altitude2000-2250m	-15.85	3074.00	-0.005	0.9959
aspectSouth-West:altitude2000-2250m	16.69	3201.00	0.005	0.9958
aspectWest:altitude2000-2250m	15.92	1724.00	0.009	0.9926

Simplified Model with Interactions

Variable	Estimate	Std. Error	z value	Pr(> z)
(Intercept)	-2.9750	0.8591	-3.463	0.000535 ***
rao	0.0266	0.0225	1.178	0.2387
h_mean	0.1003	0.0156	6.433	1.25e-10 ***
density	-0.0020	0.0065	-0.306	0.7594
aspectNorth	-0.4070	0.6193	-0.657	0.5110
aspectNorth-East	-15.5800	1673.000	-0.009	0.9926
aspectNorth-West	-14.7400	637.400	-0.023	0.9815
aspectSouth	-13.1400	1376.000	-0.010	0.9924
aspectSouth-East	0.0507	1.2820	0.040	0.9685
aspectSouth-West	-13.6800	1179.000	-0.012	0.9907
aspectWest	-14.2900	636.000	-0.022	0.9821
altitude1000-1250m	1.0730	0.7228	1.484	0.1377
altitude1250-1500m	1.3790	0.6840	2.017	0.0437 *
altitude1500-1750m	1.7390	0.6860	2.535	0.0112 *
altitude1750-2000m	1.4220	0.7240	1.964	0.0495 *
altitude2000-2250m	0.1976	1.2740	0.155	0.8768
altitude2250-2500m	2.0750	1699.000	0.001	0.9990
aspectNorth:altitude1000-1250m	-0.5535	1.0150	-0.546	0.5854
aspectNorth-East:altitude1000-1250m	13.9400	1673.000	0.008	0.9933
aspectNorth-West:altitude1000-1250m	13.9100	637.400	0.022	0.9826
aspectSouth:altitude1000-1250m	13.3500	1376.000	0.010	0.9923
aspectSouth-East:altitude1000-1250m	1.9620	1.3540	1.449	0.1473
aspectSouth-West:altitude1000-1250m	13.3300	1179.000	0.011	0.9910
aspectWest:altitude1000-1250m	14.1800	636.000	0.022	0.9822
aspectNorth:altitude1250-1500m	-1.8380	0.8751	-2.101	0.0356 *
aspectNorth-East:altitude1250-1500m	14.3400	1673.000	0.009	0.9932
aspectNorth-West:altitude1250-1500m	13.0700	637.400	0.021	0.9836
aspectSouth:altitude1250-1500m	12.7200	1376.000	0.009	0.9926
aspectSouth-East:altitude1250-1500m	1.6020	1.3330	1.201	0.2296
aspectSouth-West:altitude1250-1500m	13.7200	1179.000	0.012	0.9907
aspectWest:altitude1250-1500m	12.8500	636.000	0.020	0.9839
aspectNorth:altitude1500-1750m	-1.5030	0.8386	-1.792	0.0732 .
aspectNorth-East:altitude1500-1750m	14.9700	1673.000	0.009	0.9929
aspectNorth-West:altitude1500-1750m	13.8100	637.400	0.022	0.9827
aspectSouth:altitude1500-1750m	12.8700	1376.000	0.009	0.9925
aspectSouth-East:altitude1500-1750m	0.4740	1.3240	0.358	0.7203
aspectSouth-West:altitude1500-1750m	13.7500	1179.000	0.012	0.9907
aspectWest:altitude1500-1750m	13.4300	636.000	0.021	0.9832
aspectNorth-East:altitude1750-2000m	15.5100	1673.000	0.009	0.9926
aspectNorth-West:altitude1750-2000m	12.7700	637.400	0.020	0.9840
aspectSouth:altitude1750-2000m	12.7300	1376.000	0.009	0.9926
aspectSouth-East:altitude1750-2000m	-0.2723	1.3960	-0.195	0.8454
aspectSouth-West:altitude1750-2000m	12.8800	1179.000	0.011	0.9913
aspectWest:altitude1750-2000m	13.6300	636.000	0.021	0.9829
aspectNorth-East:altitude2000-2250m	2.5860	1947.000	0.001	0.9989
aspectNorth-West:altitude2000-2250m	14.9000	637.400	0.023	0.9813
aspectSouth:altitude2000-2250m	13.6600	1376.000	0.010	0.9921
aspectSouth-East:altitude2000-2250m	-13.9600	1208.000	-0.012	0.9908
aspectSouth-West:altitude2000-2250m	14.4700	1179.000	0.012	0.9902
aspectWest:altitude2000-2250m	13.5900	636.000	0.021	0.9829

Table 5: Simplified GLMM results with reduced interaction terms at pixel level

Analysis at Tree Level

Variance Inflation Factor (VIF) for the Full Model

Predictor	GVIF	GVIF ^{1/(2×df)}
rao	1.226764	1.107594
h_mean	1.278120	1.130540
density	1.234484	1.111073
aspect	1.313978	1.019696
slope	1.241639	1.021879
altitude	1.563968	1.037972

Table 6: Variance Inflation Factor (VIF) for the fixed effects in the initial model at tree level

Full Model (GLMM)

Variable	Estimate	Std. Error	z value	Pr(> z)
(Intercept)	-16.396688	14.577284	-1.125	0.2607
rao	0.010048	0.019120	0.526	0.5992
h_mean	0.091848	0.010127	9.069	< 2e-16 ***
density	0.004718	0.000870	5.423	5.84e-08 ***
aspectNorth	-1.644762	0.319324	-5.151	2.59e-07 ***
aspectNorth-East	-0.853053	0.189393	-4.504	6.66e-06 ***
aspectNorth-West	-1.420954	0.190036	-7.477	7.59e-14 ***
aspectSouth	-0.244078	0.216684	-1.126	0.2600
aspectSouth-East	1.085933	0.197543	5.497	3.86e-08 ***
aspectSouth-West	-0.126481	0.190802	-0.663	0.5074
aspectWest	-0.934253	0.181239	-5.155	2.54e-07 ***
slopeHilly	11.026010	14.567136	0.757	0.4491
slopeModerately sloping	11.381522	14.567628	0.781	0.4346
slopeModerately steep	10.829616	14.567269	0.743	0.4572
slopeSteep	10.232667	14.573532	0.702	0.4826
slopeUndulating	10.687768	14.572589	0.733	0.4633
altitude1000-1250m	2.443376	0.551628	4.429	9.45e-06 ***
altitude1250-1500m	2.212634	0.545909	4.053	5.05e-05 ***
altitude1500-1750m	2.666657	0.546622	4.878	1.07e-06 ***
altitude1750-2000m	2.331268	0.558845	4.172	3.02e-05 ***
altitude2000-2250m	1.503278	0.752308	1.998	0.0457 *
altitude2250-2500m	-10.005649	117.615686	-0.085	0.9322

Table 7: Full GLMM results for the analysis at tree level

Reduced Model

Variable	Estimate	Std. Error	z value	Pr(> z)
(Intercept)	-16.396688	14.577284	-1.125	0.2607
rao	0.010048	0.019120	0.526	0.5992
h_mean	0.091848	0.010127	9.069	< 2e-16 ***
density	0.004718	0.000870	5.423	5.84e-08 ***
aspectNorth	-1.644762	0.319324	-5.151	2.59e-07 ***
aspectNorth-East	-0.853053	0.189393	-4.504	6.66e-06 ***
aspectNorth-West	-1.420954	0.190036	-7.477	7.59e-14 ***
aspectSouth	-0.244078	0.216684	-1.126	0.2600
aspectSouth-East	1.085933	0.197543	5.497	3.86e-08 ***
aspectSouth-West	-0.126481	0.190802	-0.663	0.5074
aspectWest	-0.934253	0.181239	-5.155	2.54e-07 ***
slopeHilly	11.026010	14.567136	0.757	0.4491
slopeModerately sloping	11.381522	14.567628	0.781	0.4346
slopeModerately steep	10.829616	14.567269	0.743	0.4572
slopeSteep	10.232667	14.573532	0.702	0.4826
slopeUndulating	10.687768	14.572589	0.733	0.4633
altitude1000-1250m	2.443376	0.551628	4.429	9.45e-06 ***
altitude1250-1500m	2.212634	0.545909	4.053	5.05e-05 ***
altitude1500-1750m	2.666657	0.546622	4.878	1.07e-06 ***
altitude1750-2000m	2.331268	0.558845	4.172	3.02e-05 ***
altitude2000-2250m	1.503278	0.752308	1.998	0.0457 *
altitude2250-2500m	-10.005649	117.615686	-0.085	0.9322

Table 8: Reduced GLMM results for the tree level analysis

Model with Interactions

Variable	Estimate	Std. Error	z value	Pr(> z)
(Intercept)	-19.510	4576.000	-0.004	0.9966
rao	0.004524	0.02016	0.224	0.8225
h_mean	0.099240	0.01077	9.215	< 2e-16 ***
density	0.004488	0.000914	4.908	9.22e-07 ***
aspectNorth	-0.442600	0.9626	-0.460	0.6456
aspectNorth-East	-34.82000	6395.000	-0.005	0.9957
aspectNorth-West	-34.24000	4932.000	-0.007	0.9945
aspectSouth	-33.51000	5847.000	-0.006	0.9954
aspectSouth-East	-18.53000	4606.000	-0.004	0.9968
aspectSouth-West	-34.73000	5629.000	-0.006	0.9951
aspectWest	-34.23000	4923.000	-0.007	0.9945
slopeHilly	15.17000	4576.000	0.003	0.9974
slopeModerately sloping	15.42000	4576.000	0.003	0.9973
slopeModerately steep	14.98000	4576.000	0.003	0.9974
slopeSteep	15.48000	4576.000	0.003	0.9973
slopeUndulating	32.68000	6493.000	0.005	0.9960
altitude1000-1250m	0.877500	0.7434	1.180	0.2379
altitude1250-1500m	1.215000	0.7042	1.726	0.0844 .
altitude1500-1750m	1.462000	0.7071	2.068	0.0387 *
altitude1750-2000m	1.243000	0.7477	1.662	0.0965 .
altitude2000-2250m	0.261700	1.2990	0.201	0.8403
altitude2250-2500m	2.746000	4370.000	0.001	0.9995
aspectNorth:slopeHilly	-0.744200	0.7985	-0.932	0.3514
aspectNorth-East:slopeHilly	17.73000	4606.000	0.004	0.9969
aspectNorth-West:slopeHilly	17.65000	4606.000	0.004	0.9969
aspectSouth:slopeHilly	17.87000	4606.000	0.004	0.9969
aspectSouth-East:slopeHilly	18.54000	4606.000	0.004	0.9968
aspectSouth-West:slopeHilly	18.69000	4606.000	0.004	0.9968
aspectWest:slopeHilly	17.42000	4606.000	0.004	0.9970
aspectNorth:altitude1000-1250m	-0.475800	1.1870	-0.401	0.6885
aspectNorth-East:altitude1000-1250m	16.07000	4436.000	0.004	0.9971
aspectNorth-West:altitude1000-1250m	15.83000	1762.000	0.009	0.9928
aspectSouth:altitude1000-1250m	15.66000	3602.000	0.004	0.9965
aspectSouth-East:altitude1000-1250m	2.023000	1.3900	1.456	0.1455
aspectSouth-West:altitude1000-1250m	15.63000	3235.000	0.005	0.9961
aspectWest:altitude1000-1250m	16.51000	1738.000	0.009	0.9924

Table 9: GLMM results with interactions between aspect, slope, and altitude at tree level

Simplified Model with Interactions

Variable	Estimate	Std. Error	z value	Pr(> z)
(Intercept)	-4.255	0.7892	-5.392	6.98e-08 ***
rao	-0.004556	0.01922	-0.237	0.8127
h_mean	0.096010	0.01032	9.308	< 2e-16 ***
density	0.004270	0.000874	4.882	1.05e-06 ***
aspectNorth	-0.541100	0.6199	-0.873	0.3827
aspectNorth-East	-16.600	2771.000	-0.006	0.9952
aspectNorth-West	-15.650	1065.000	-0.015	0.9883
aspectSouth	-14.370	2249.000	-0.006	0.9949
aspectSouth-East	-0.124100	1.2860	-0.097	0.9231
aspectSouth-West	-14.890	1965.000	-0.008	0.9940
aspectWest	-15.300	1055.000	-0.015	0.9884
altitude1000-1250m	0.915600	0.7312	1.252	0.2105
altitude1250-1500m	1.274000	0.6927	1.840	0.0658 .
altitude1500-1750m	1.525000	0.6948	2.195	0.0282 *
altitude1750-2000m	1.330000	0.7343	1.812	0.0700 .
altitude2000-2250m	0.214800	1.2800	0.168	0.8667
altitude2250-2500m	2.462000	2328.000	0.001	0.9992
aspectNorth:altitude1000-1250m	-0.577000	1.0210	-0.565	0.5718
aspectNorth-East:altitude1000-1250m	14.98000	2771.000	0.005	0.9957
aspectNorth-West:altitude1000-1250m	14.84000	1065.000	0.014	0.9889
aspectSouth:altitude1000-1250m	14.70000	2249.000	0.007	0.9948
aspectSouth-East:altitude1000-1250m	2.173000	1.3580	1.600	0.1096
aspectSouth-West:altitude1000-1250m	14.67000	1965.000	0.007	0.9940
aspectWest:altitude1000-1250m	15.34000	1055.000	0.015	0.9884

Table 10: Simplified GLMM results with reduced interaction terms at tree level.