

Tree Growth Submodels for the US Northern Forest

Results and Analysis

Neal Maker & John Foppert

2020-02-21

Table 1: Scaled variable importance measures for predictors in individual submodels. Calculated on out of bag data using 'impurity' measure. The most important predictor for each model is ranked 100 and the least important is ranked 0.

variable	submodel				
	Δdbh	height	Δheight	Δcr	survival
dbh	100	100	100	100	50
cr	26	12	81	88	100
ba	21	8	83	98	34
bal	5	11	89	89	48
lat	2	13	60	66	31
lon	1	15	61	63	31
spp	51	16	35	30	21
elev	1	9	56	53	29
aspect	0	3	34	30	16
slope	0	3	28	26	14
crown class	0	21	8	13	4
forest type	3	5	5	10	2
site class	0	0	7	9	2
stocking	1	0	6	10	0
landscape	0	0	4	6	0
tree class	0	2	0	0	3

Diameter Growth Submodel

Table 2: Accuracy estimates, calculated on out of bag data

RMSE	R ²	MAE
0.008705	0.962	0.005772

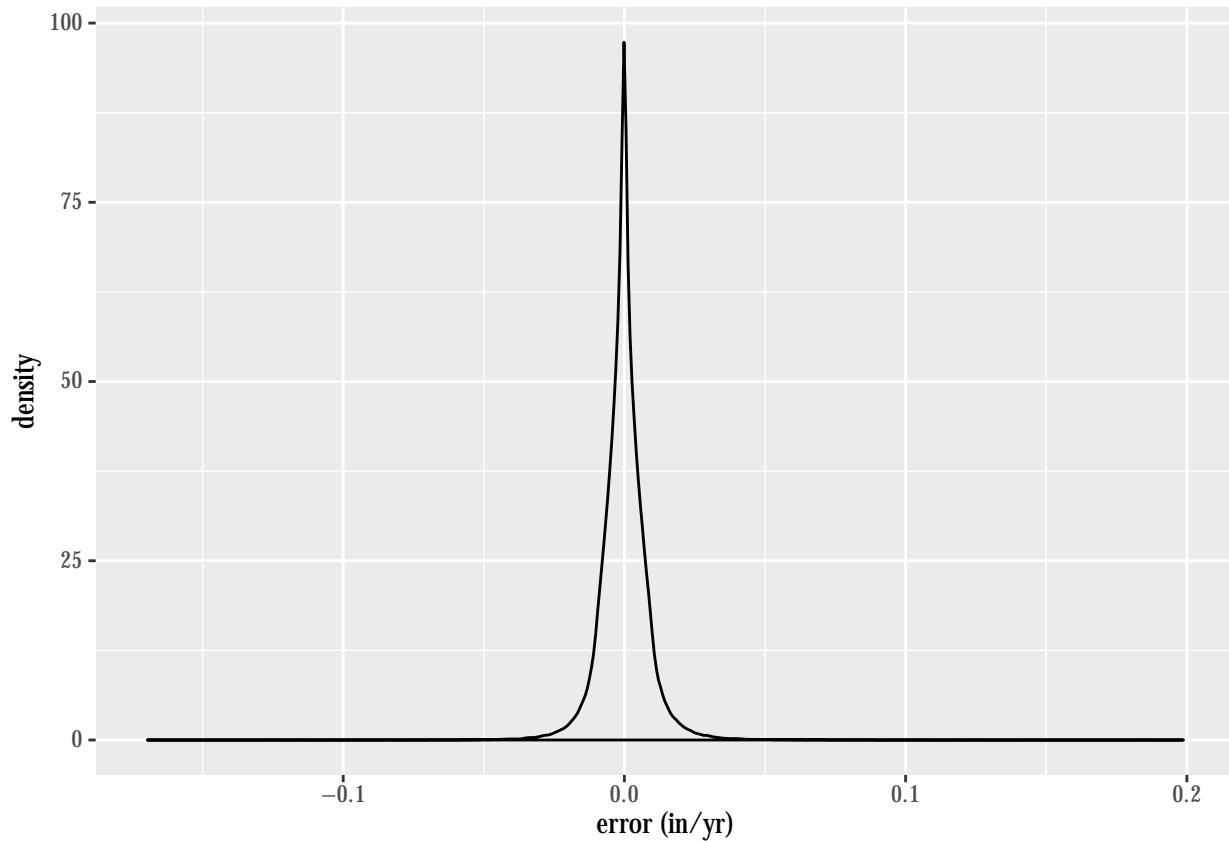


Figure 1: Overall error distribution estimated with kernal density.

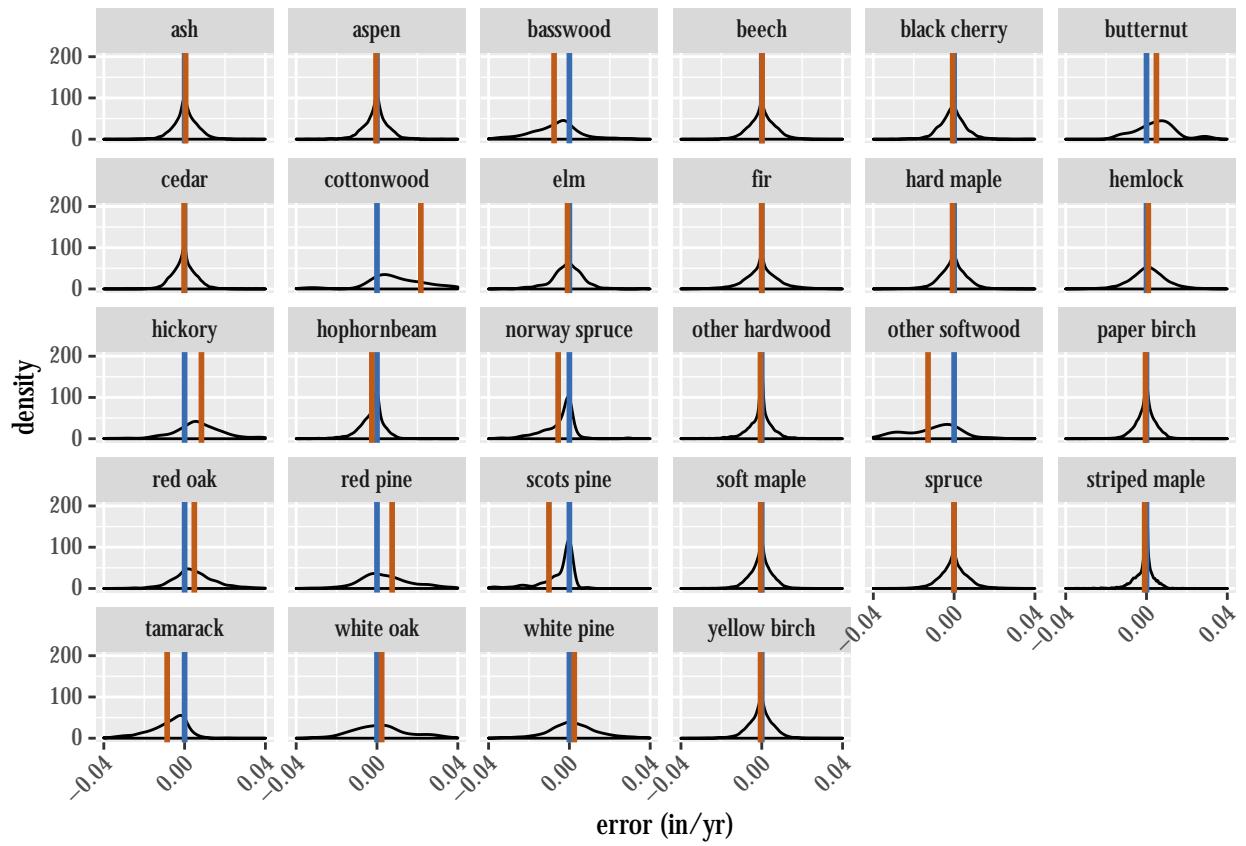
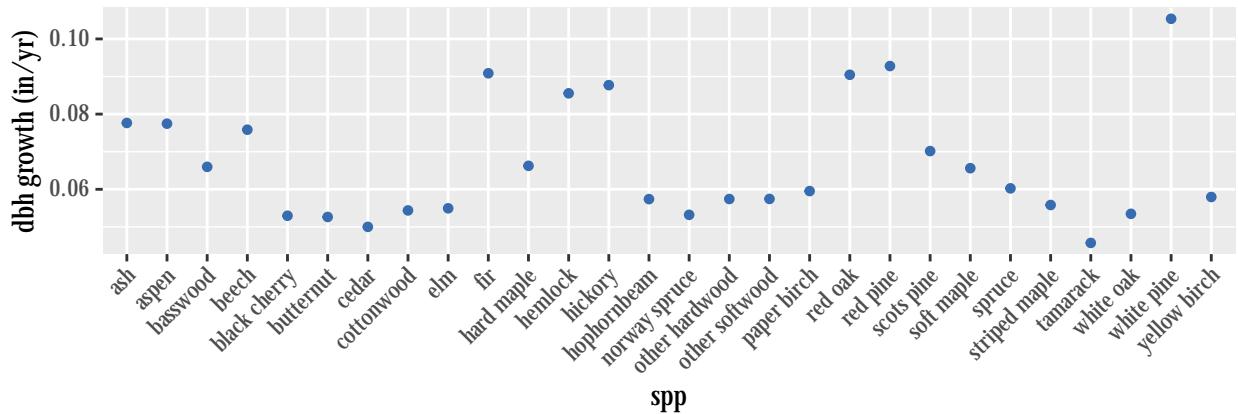


Figure 2: Error distributions for individual species estimated with kernel density. Blue vertical lines indicate 0 (no error). Brown vertical lines indicate mean species errors.

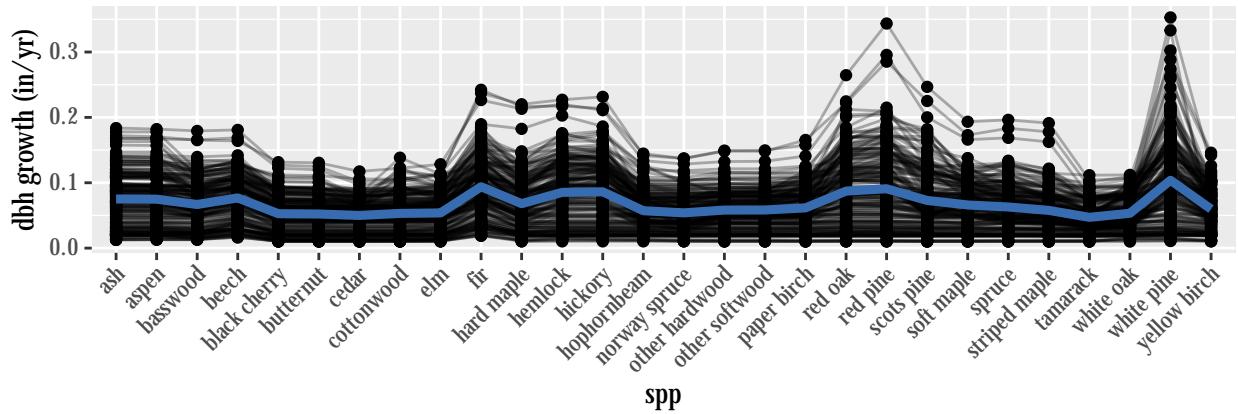
Table 3: Sample sizes and normalized root mean square errors by species

spp	n	nRMSE
fir	62729	0.1198
spruce	42081	0.1220
soft maple	36343	0.0852
hard maple	19627	0.0909
cedar	19144	0.1062
beech	18883	0.0849
yellow birch	16309	0.0993
paper birch	15977	0.0973
hemlock	14024	0.0834
white pine	9480	0.1045
aspen	7875	0.0774
ash	7110	0.0803
other hardwood	5010	0.1815
striped maple	4265	0.2019
red oak	3199	0.0916
black cherry	2192	0.1071
hophornbeam	1824	0.1437
tamarack	1398	0.3012
red pine	1084	0.1400
elm	750	0.1429
norway spruce	533	0.3673
basswood	525	0.2264
hickory	321	0.1408
scots pine	188	0.5137
white oak	170	0.2020
other softwood	71	0.5663
butternut	31	0.1194
cottonwood	26	0.3197

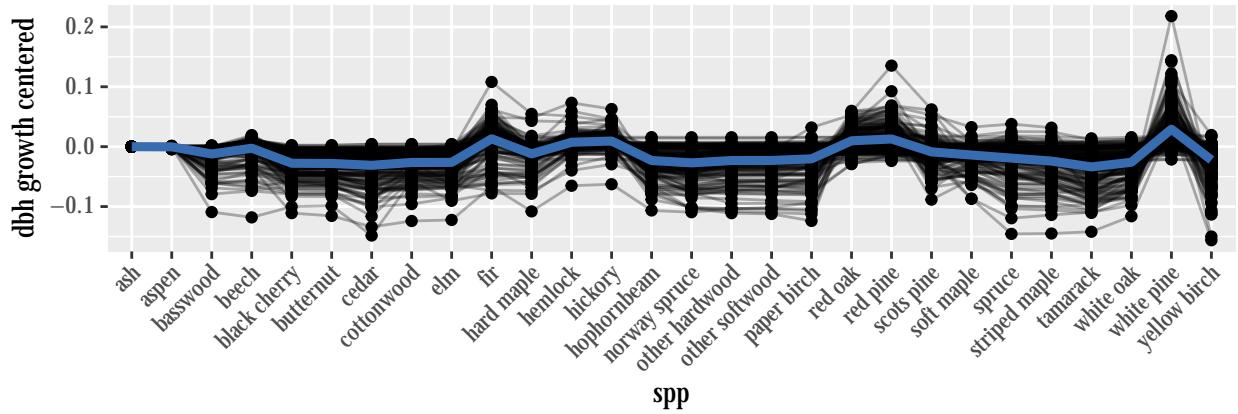
PDP for spp



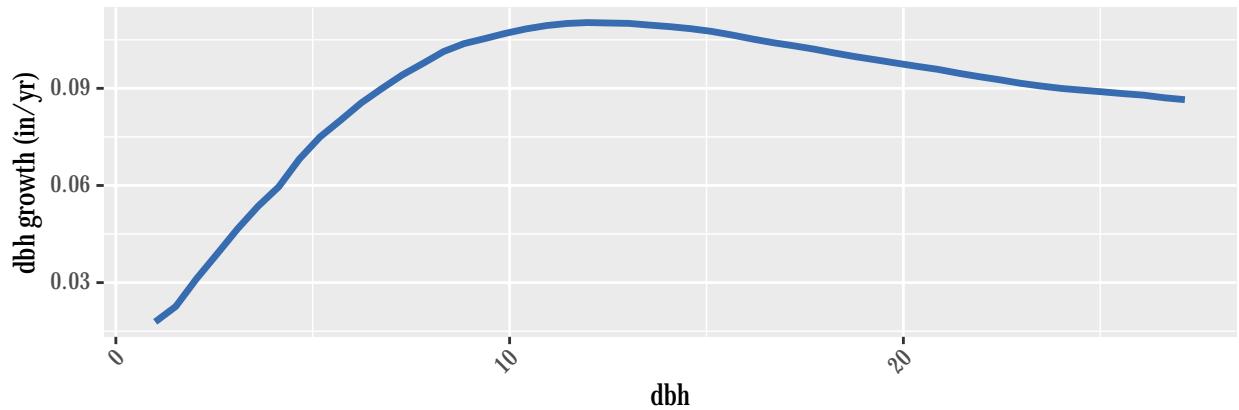
ICE plot for spp



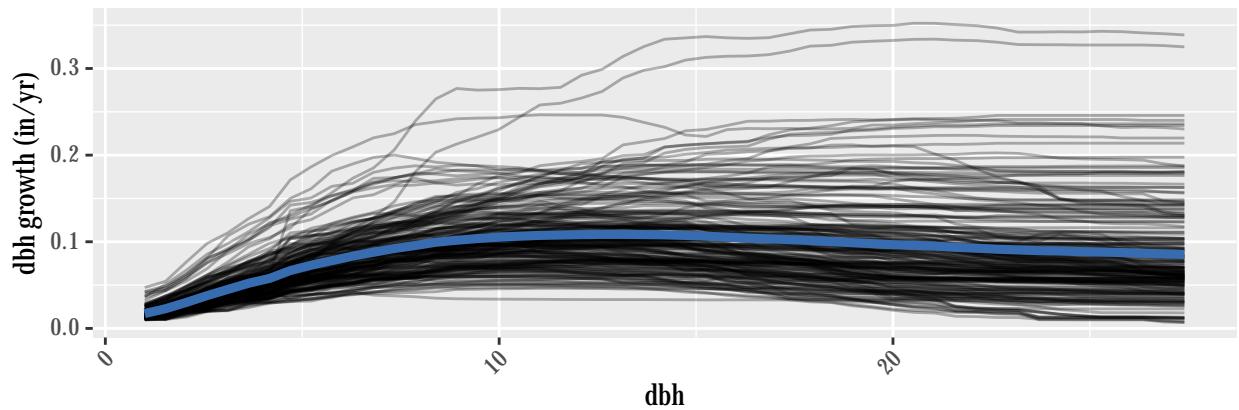
Centered ICE plot for spp



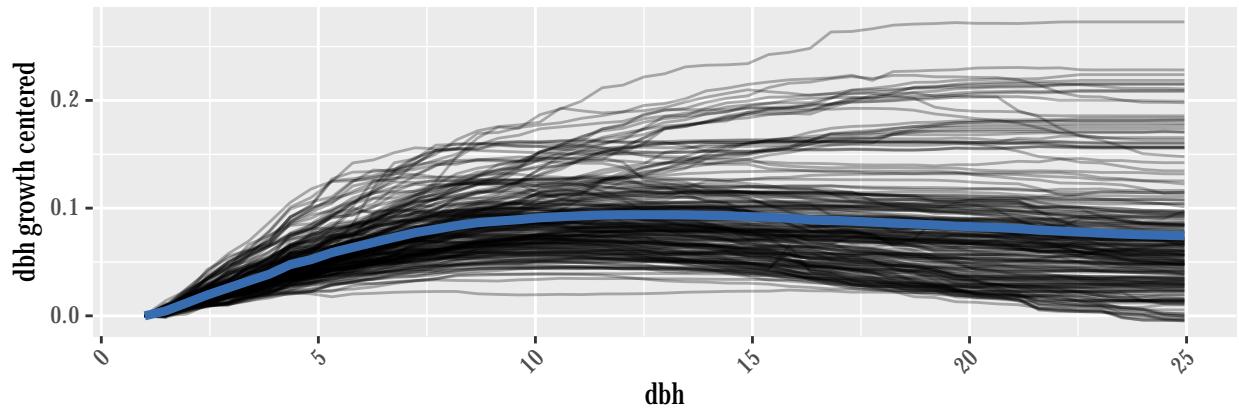
PDP for dbh



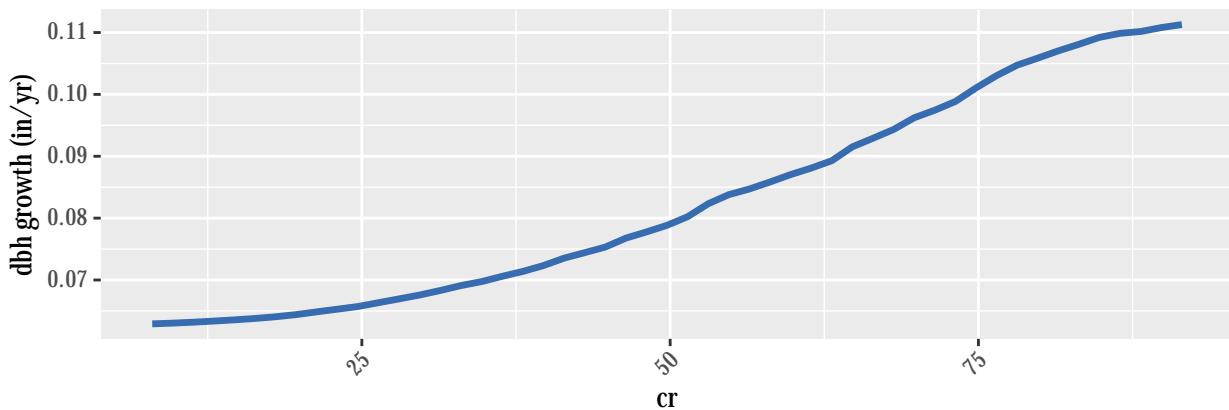
ICE plot for dbh



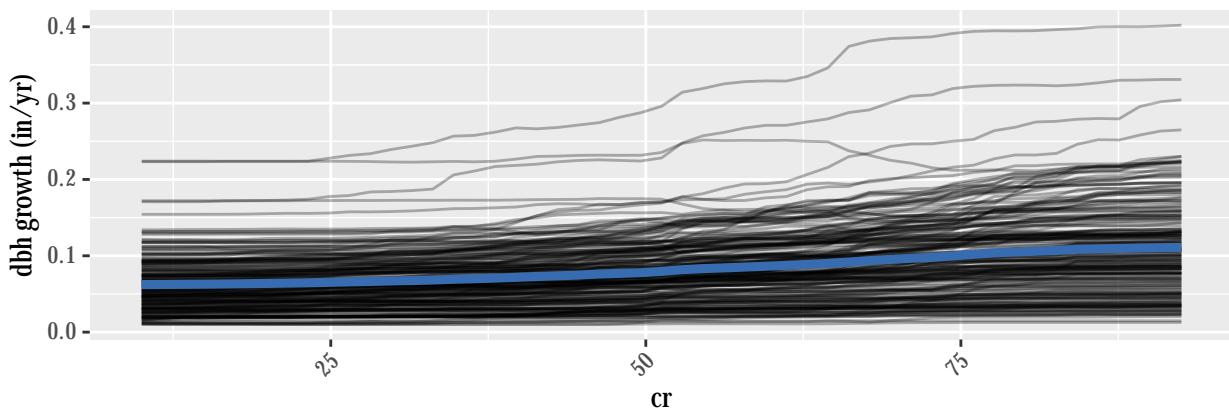
Centered ICE plot for dbh



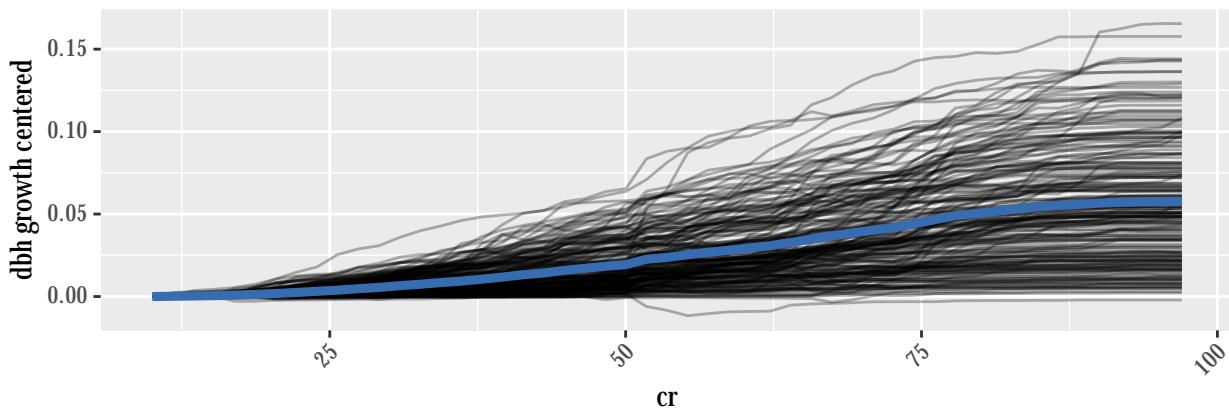
PDP for cr



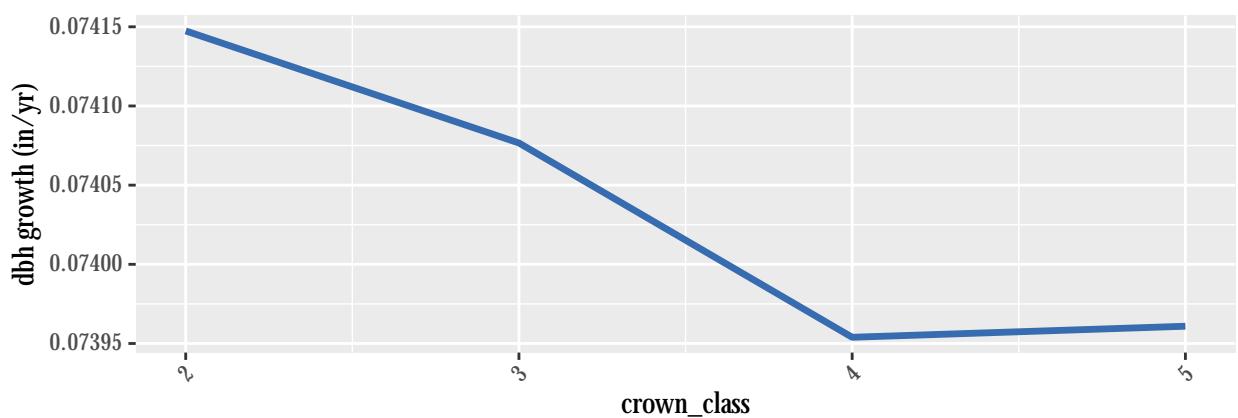
ICE plot for cr



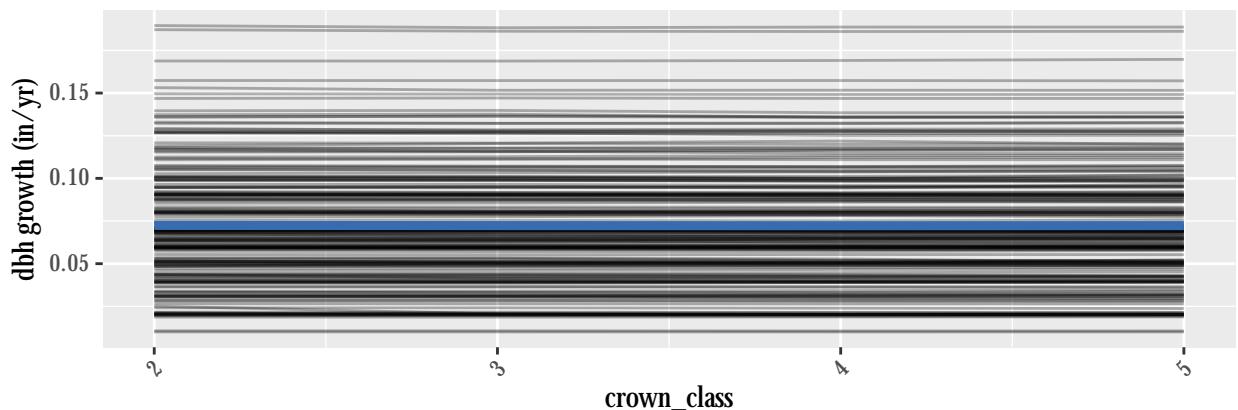
Centered ICE plot for cr



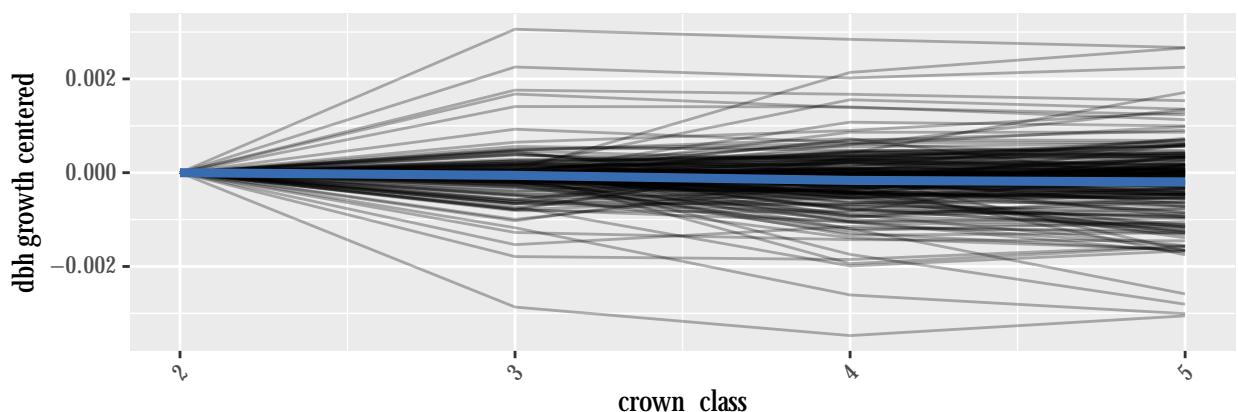
PDP for crown_class



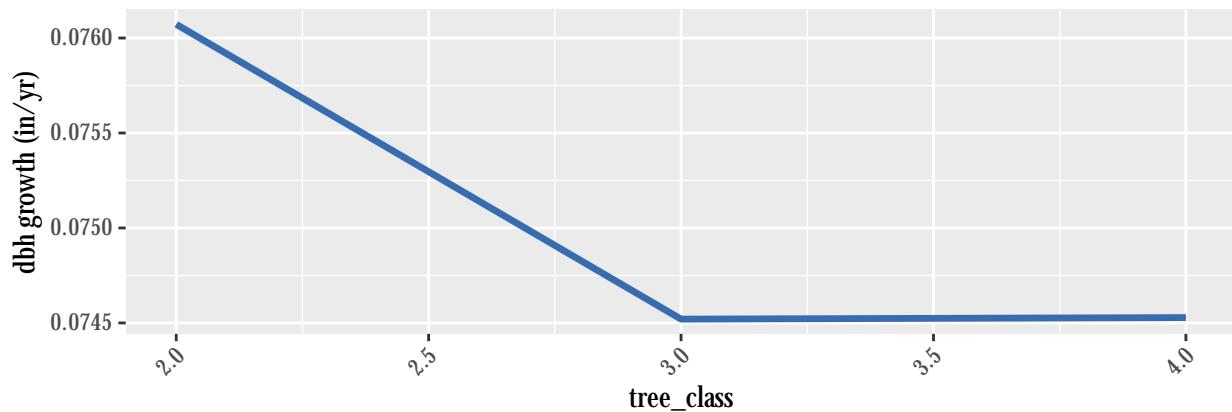
ICE plot for crown_class



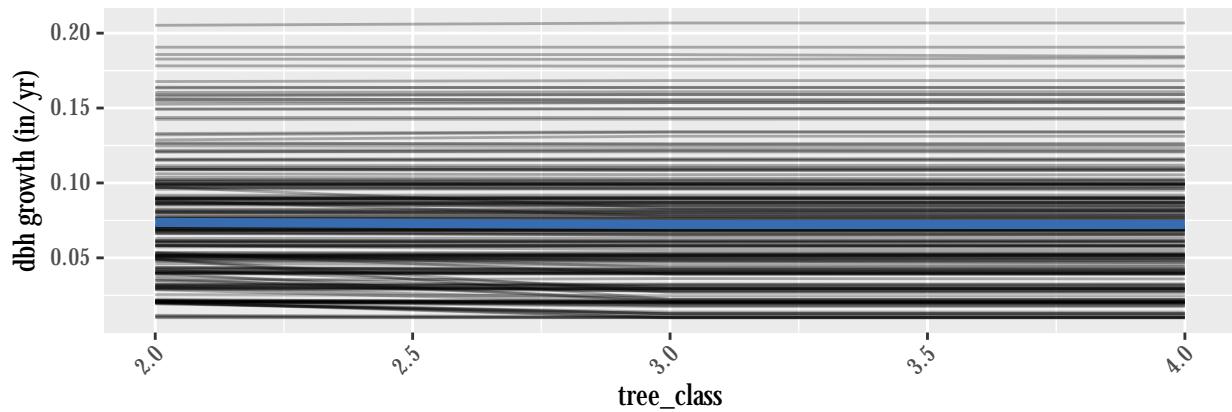
Centered ICE plot for crown_class



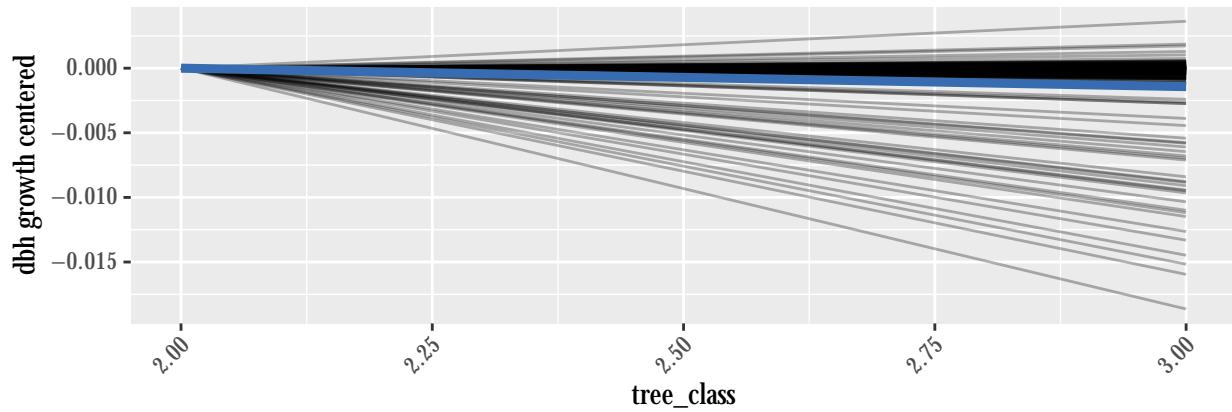
PDP for tree_class



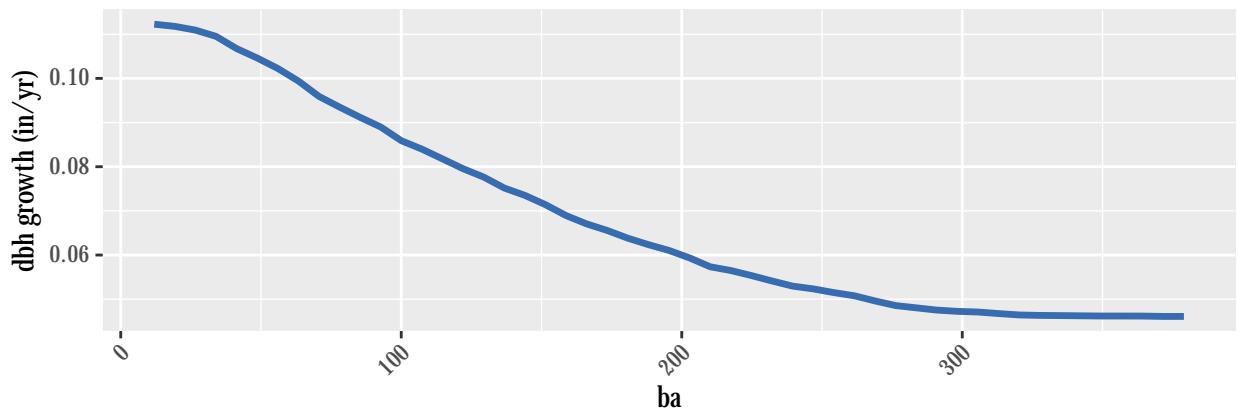
ICE plot for tree_class



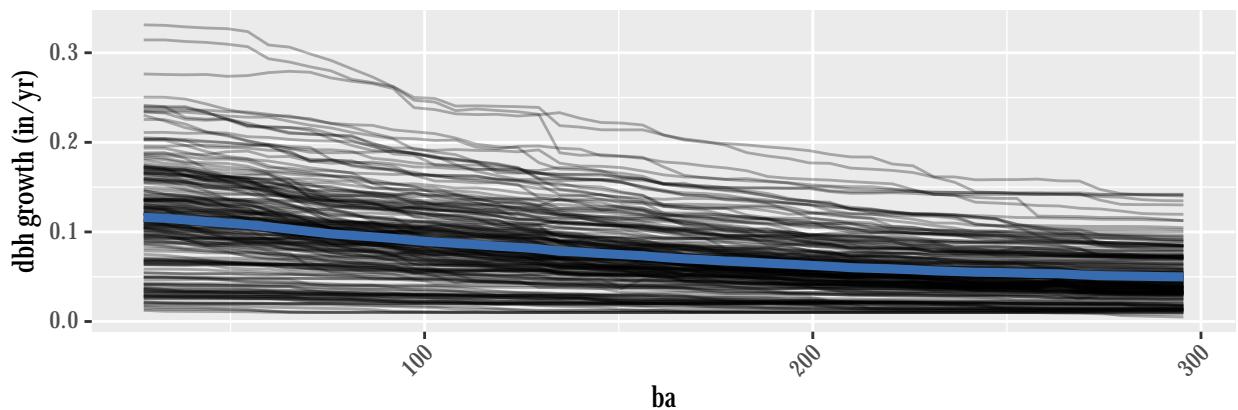
Centered ICE plot for tree_class



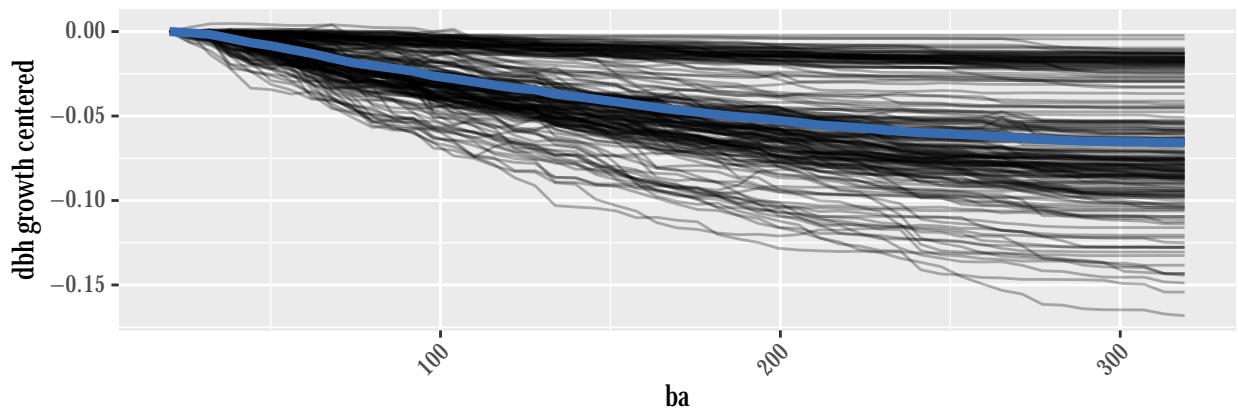
PDP for ba



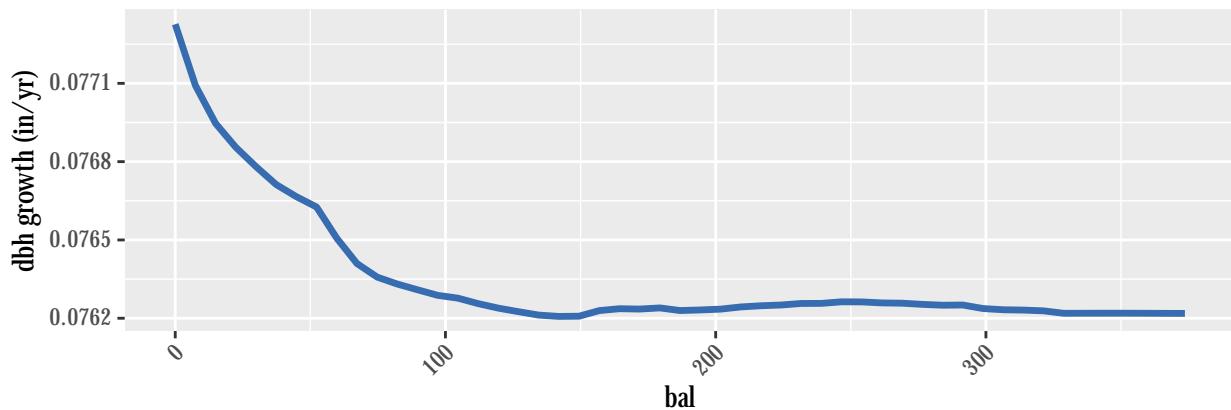
ICE plot for ba



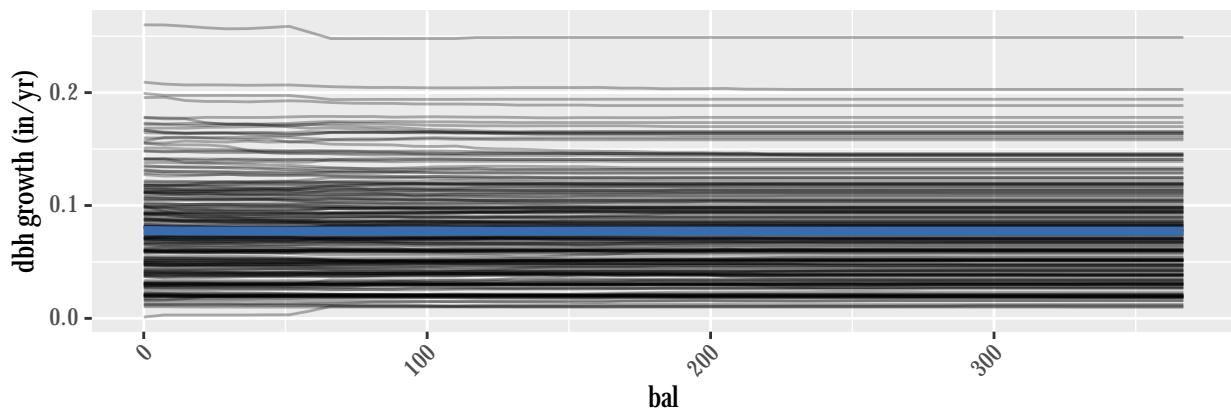
Centered ICE plot for ba



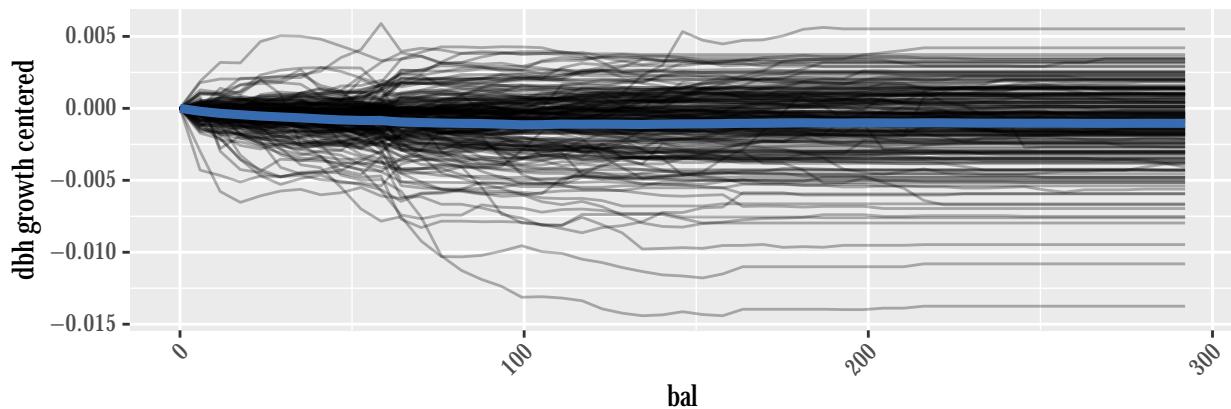
PDP for bal



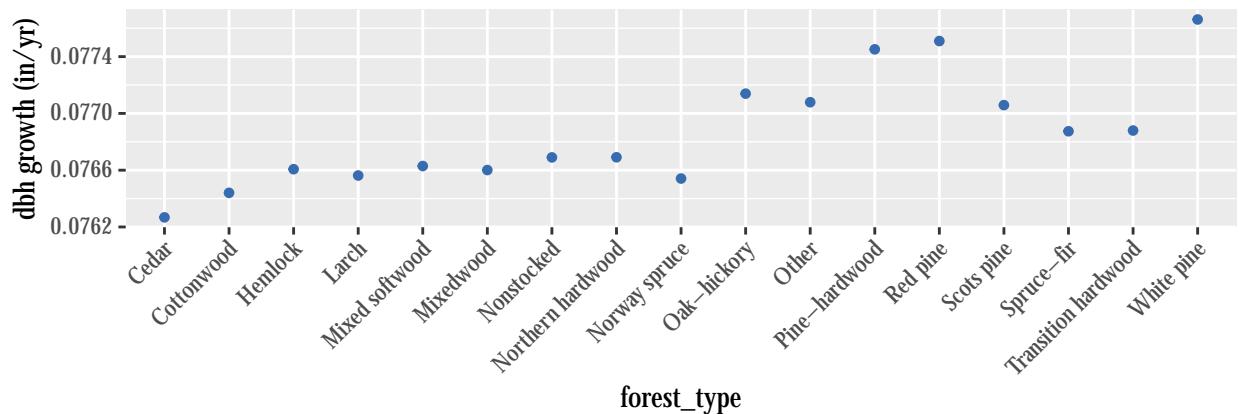
ICE plot for bal



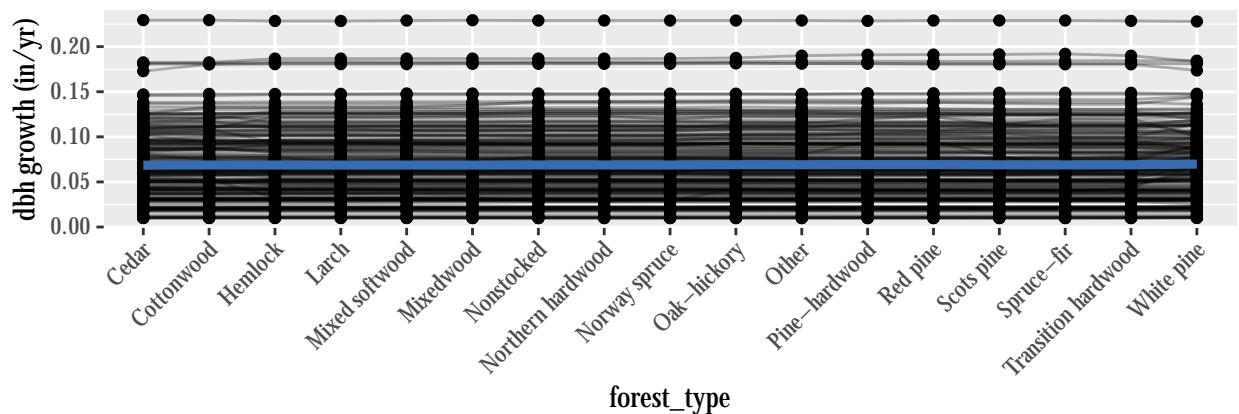
Centered ICE plot for bal



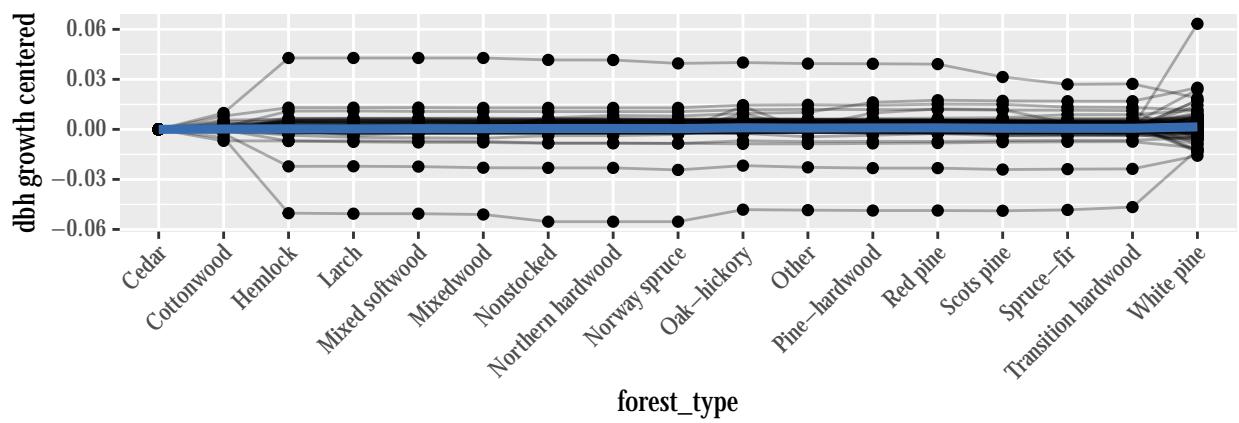
PDP for forest_type



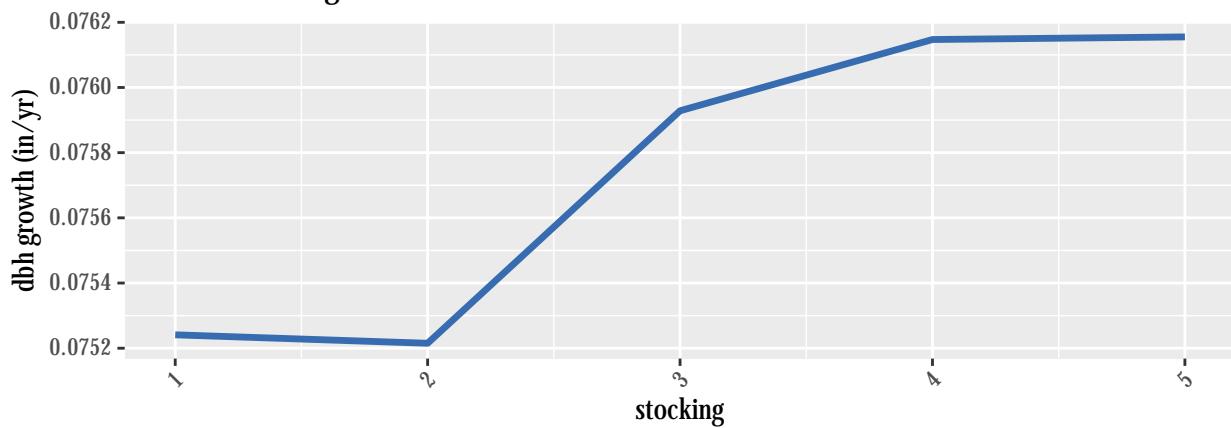
ICE plot for forest_type



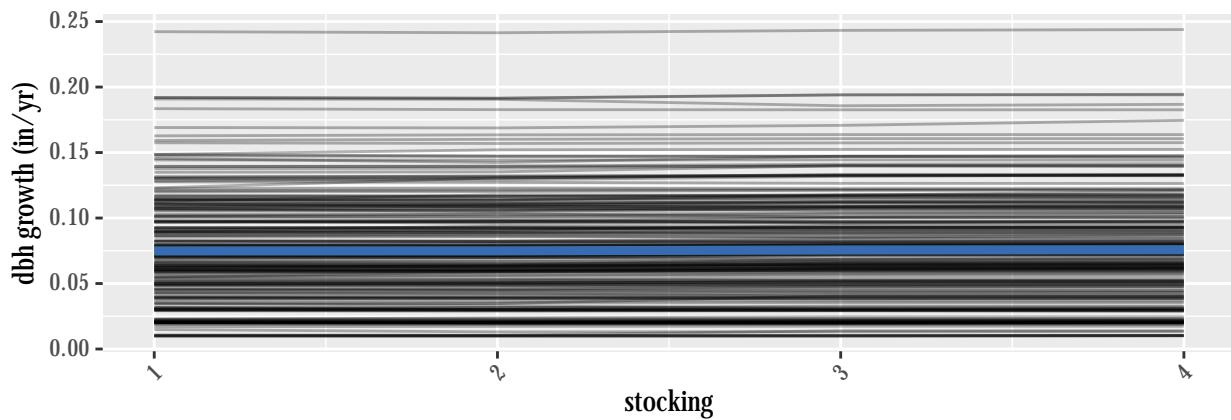
Centered ICE plot for forest_type



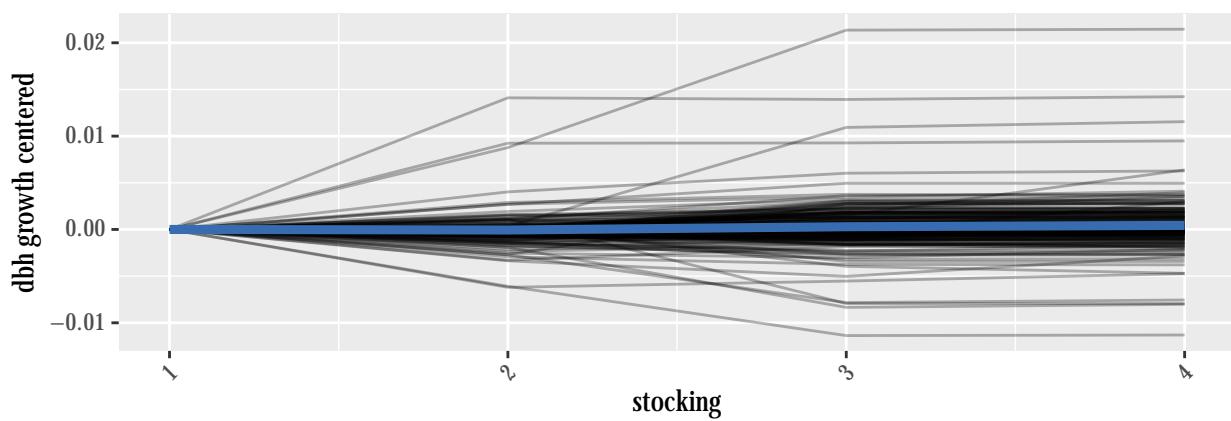
PDP for stocking

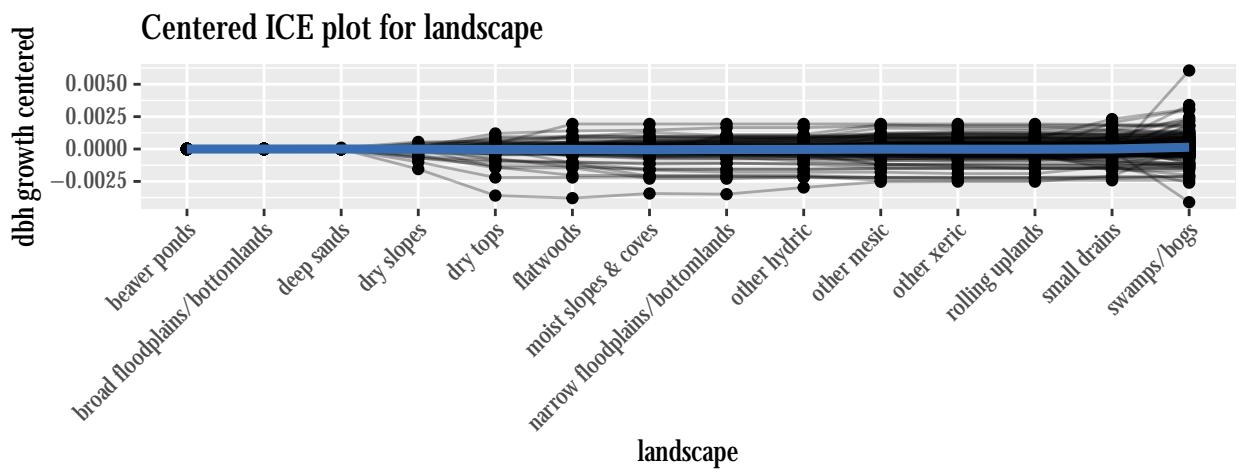
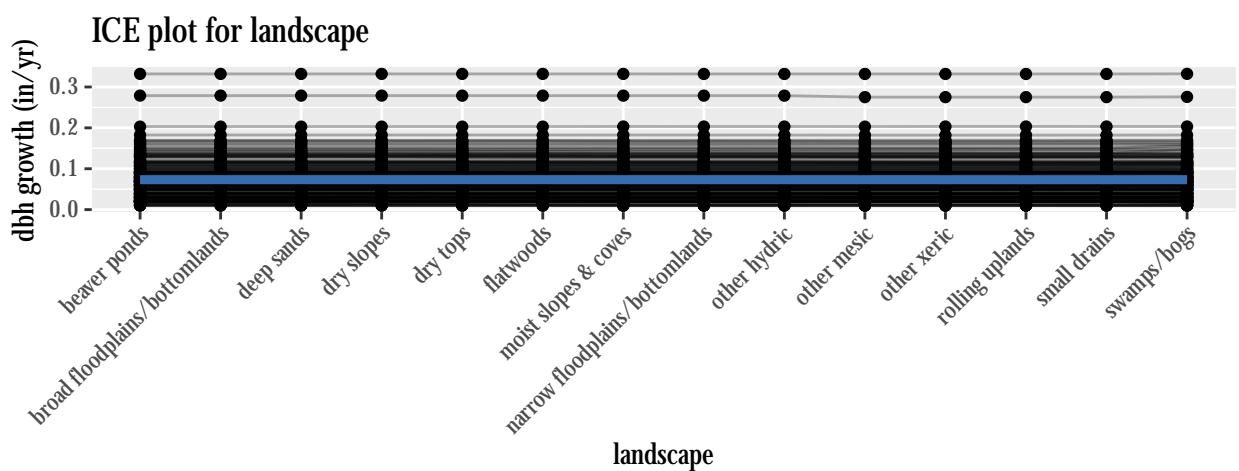
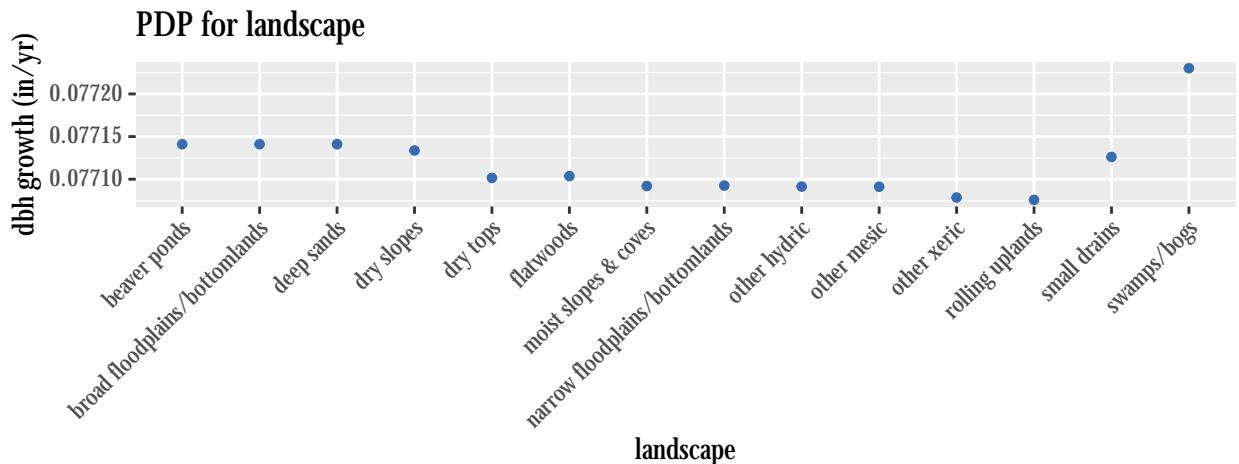


ICE plot for stocking

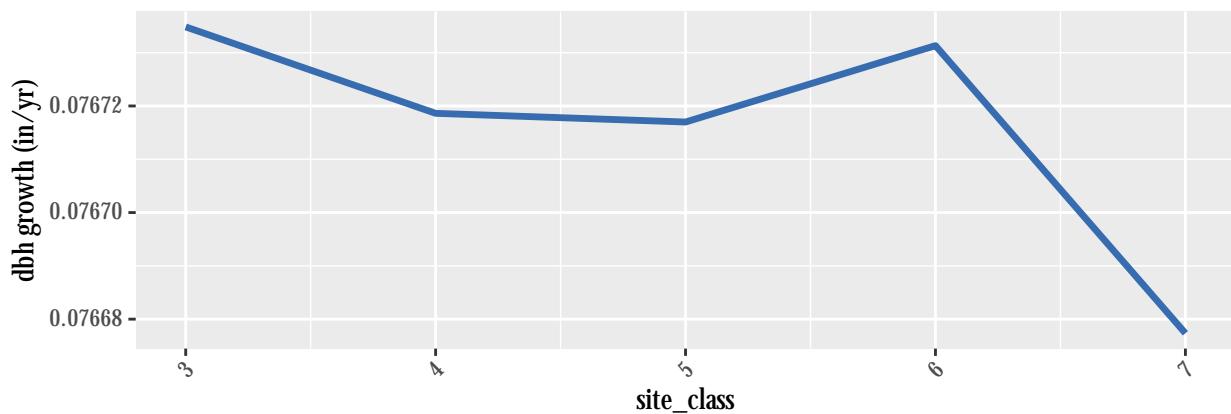


Centered ICE plot for stocking

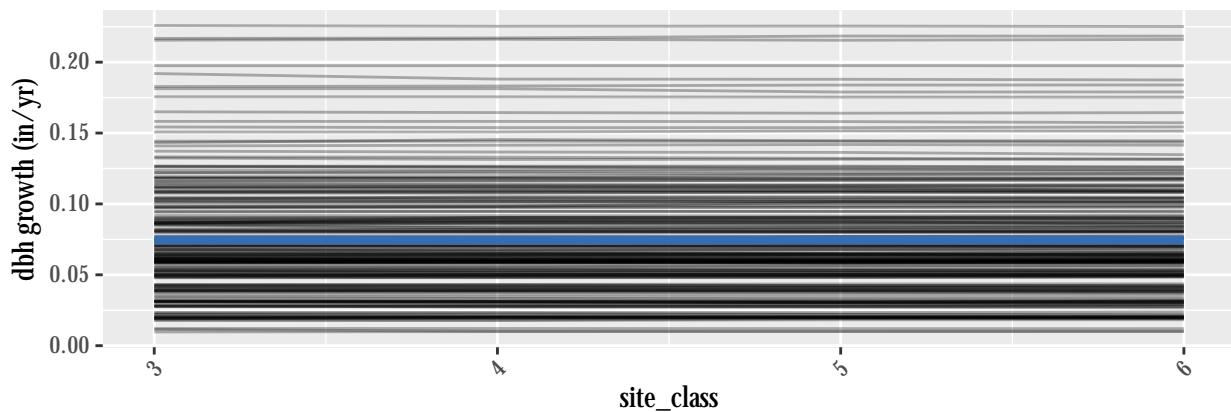




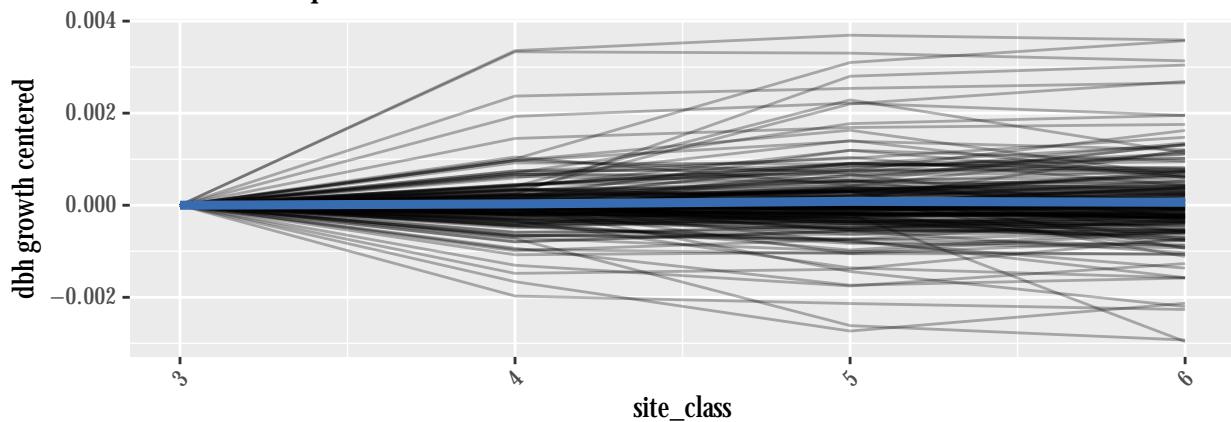
PDP for site_class



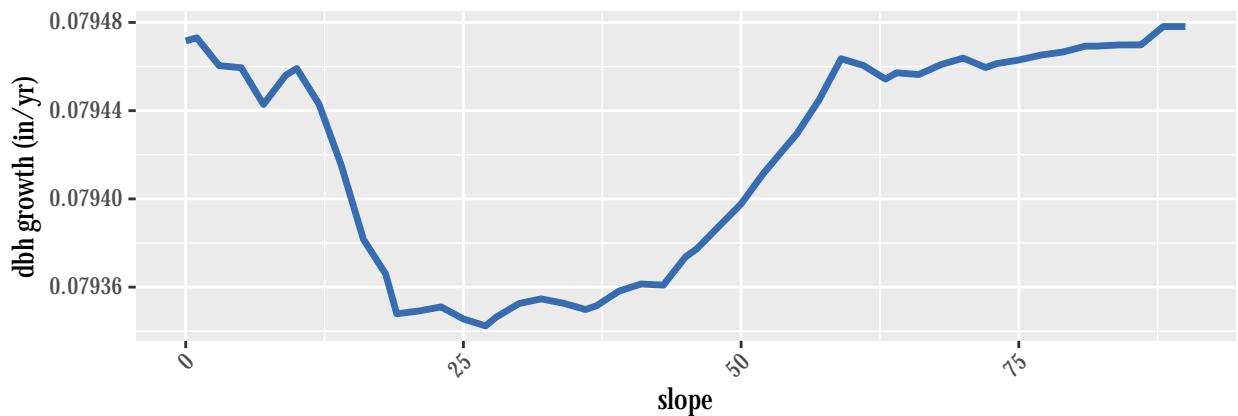
ICE plot for site_class



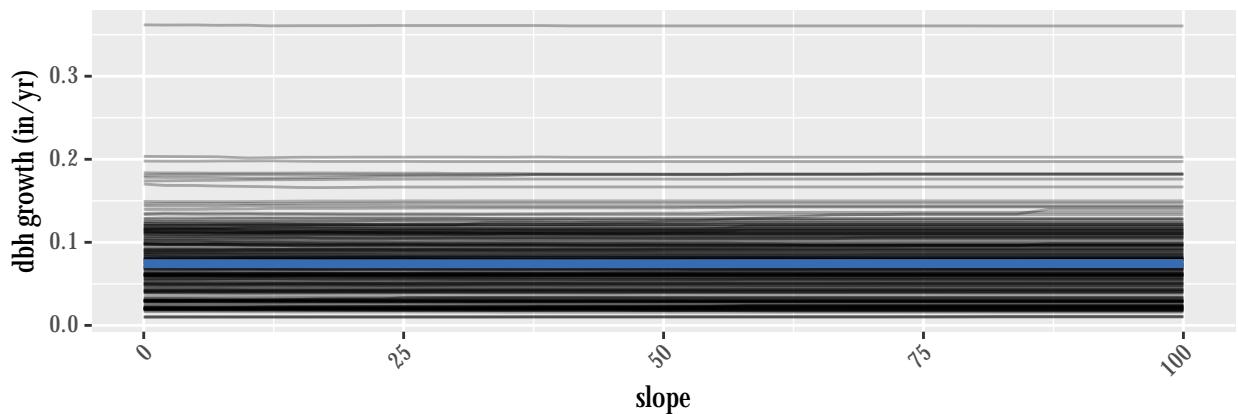
Centered ICE plot for site_class



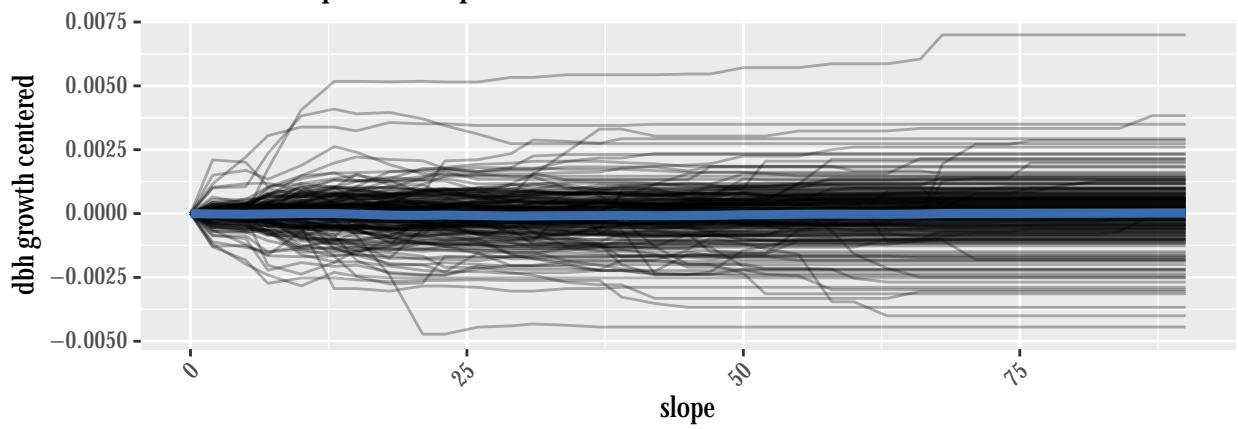
PDP for slope



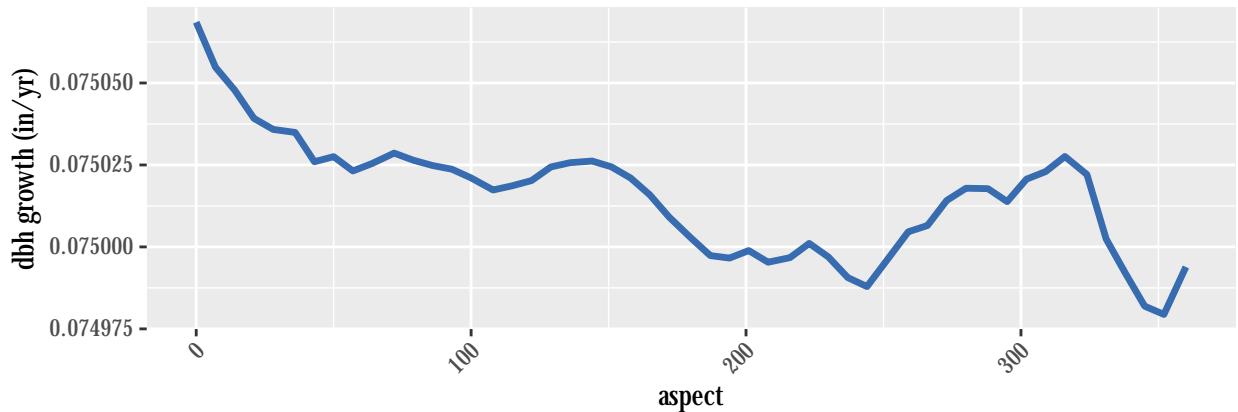
ICE plot for slope



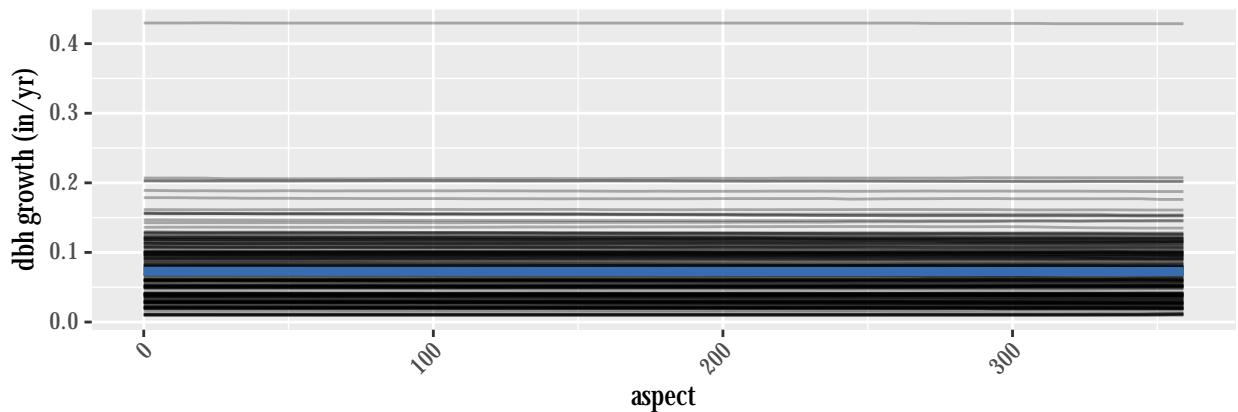
Centered ICE plot for slope



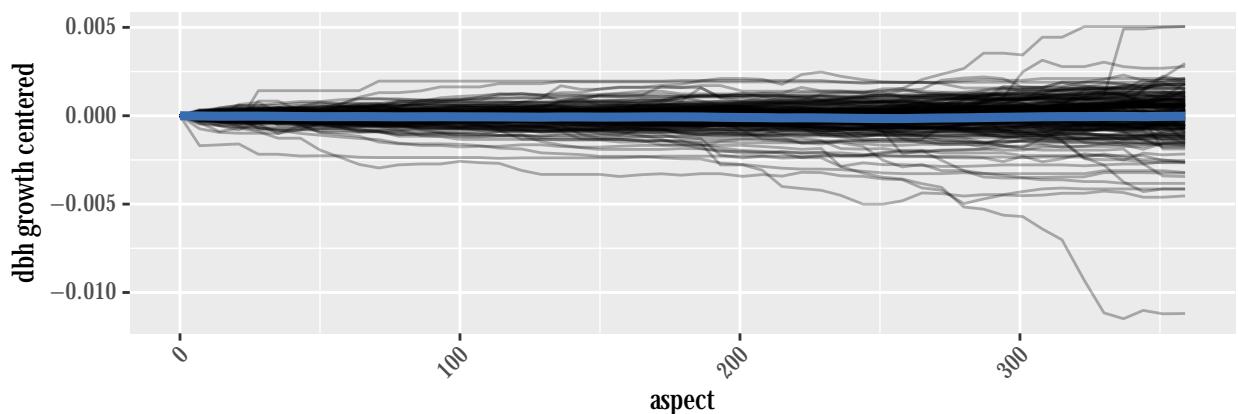
PDP for aspect



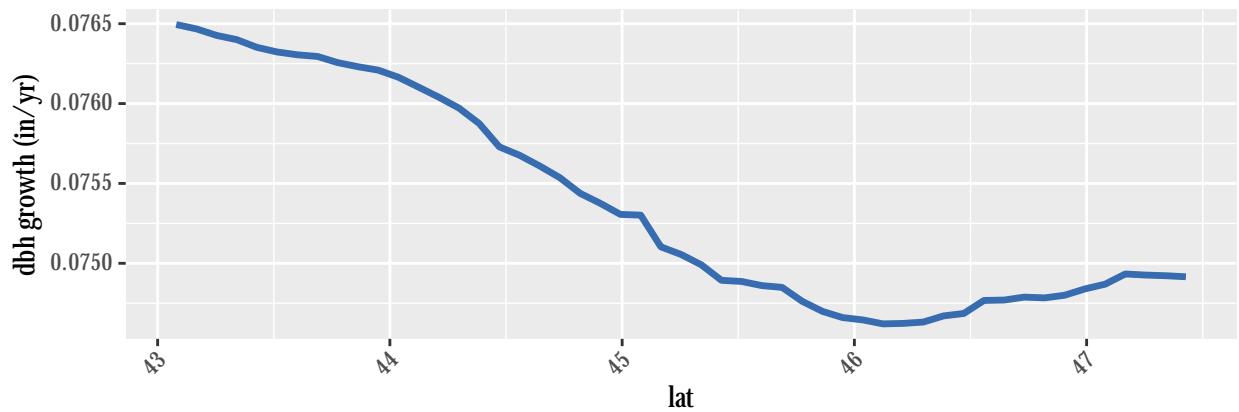
ICE plot for aspect



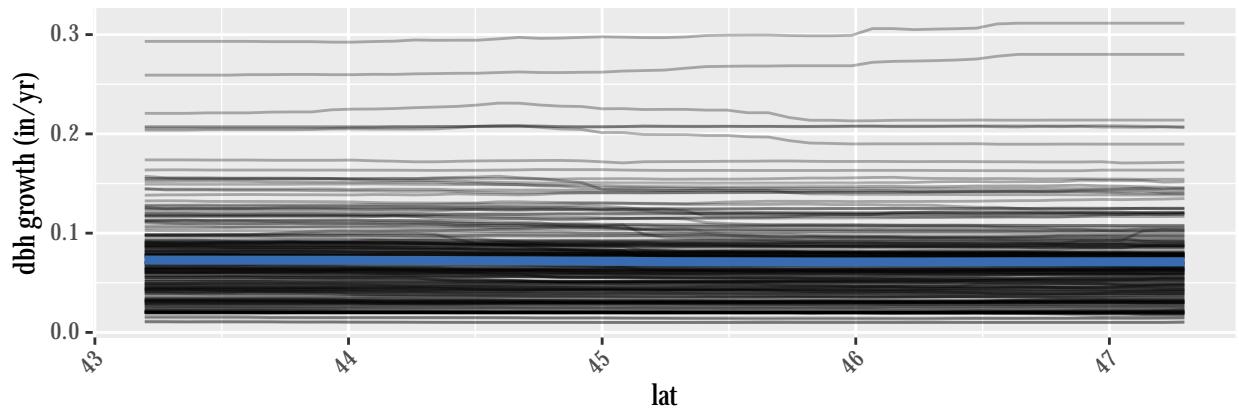
Centered ICE plot for aspect



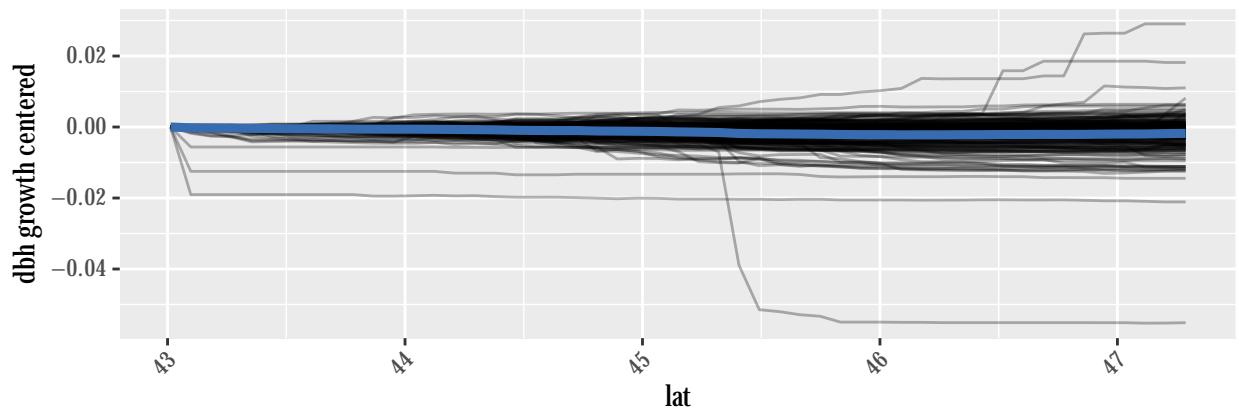
PDP for lat



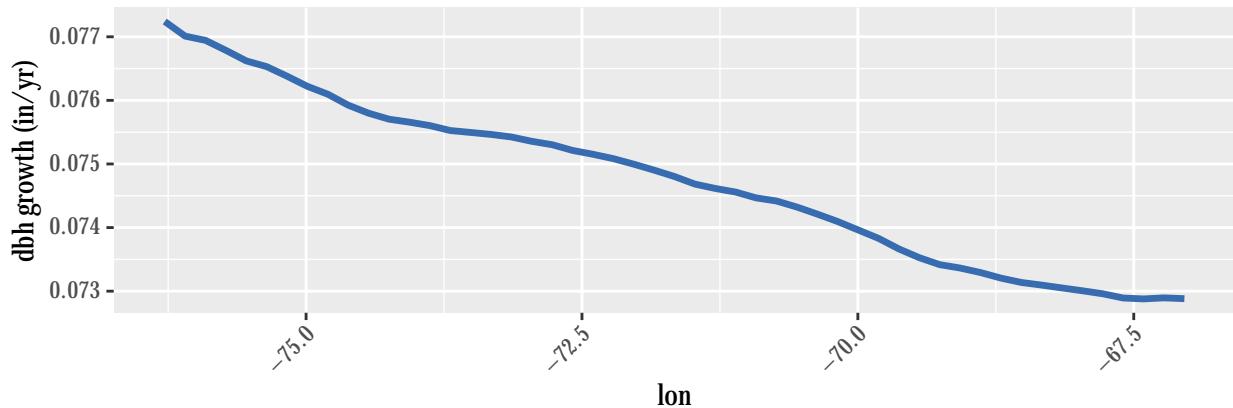
ICE plot for lat



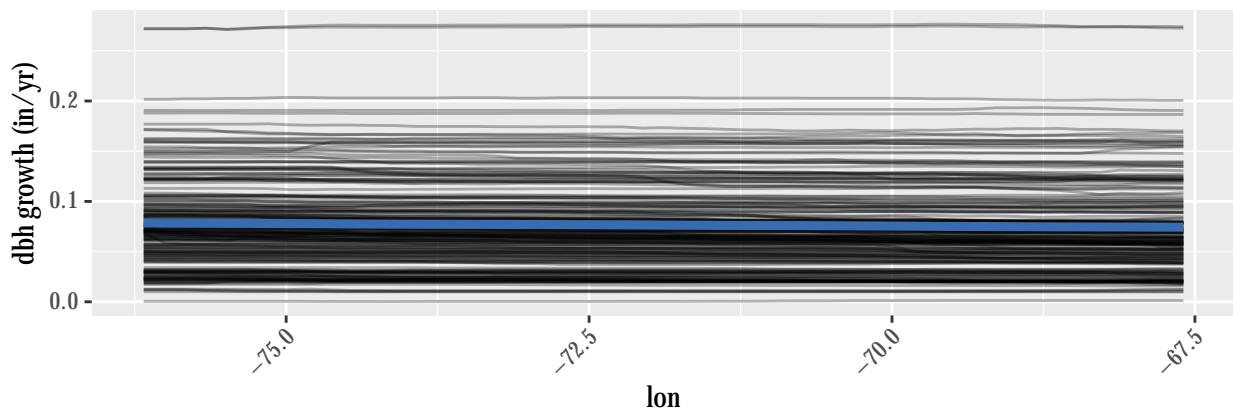
Centered ICE plot for lat



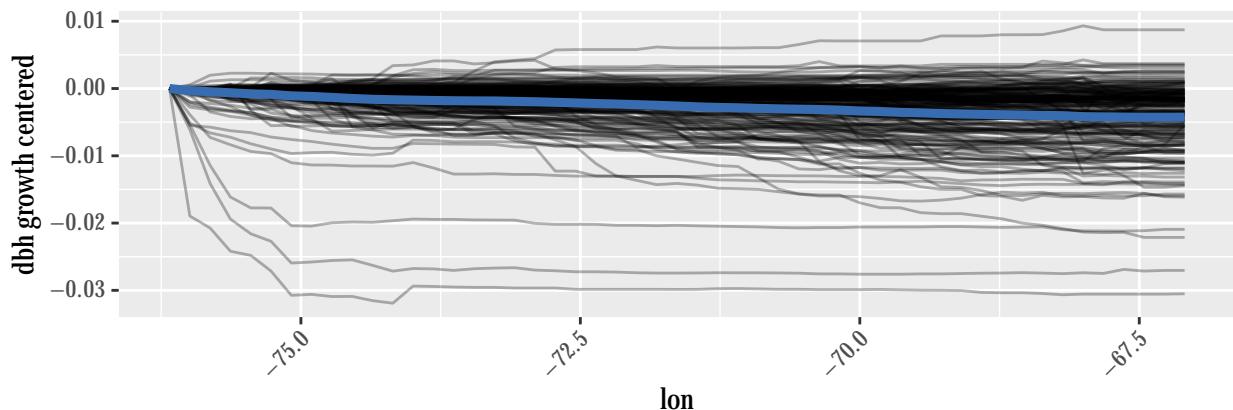
PDP for lon



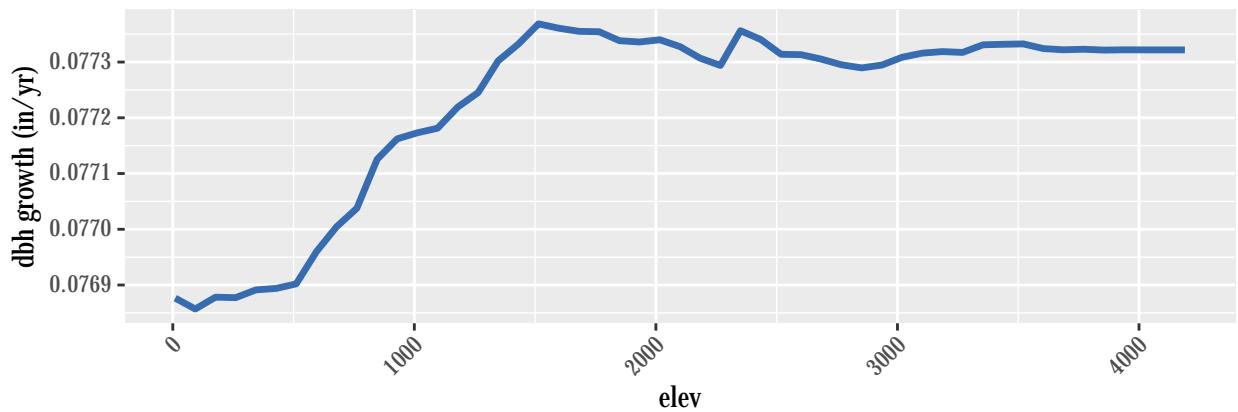
ICE plot for lon



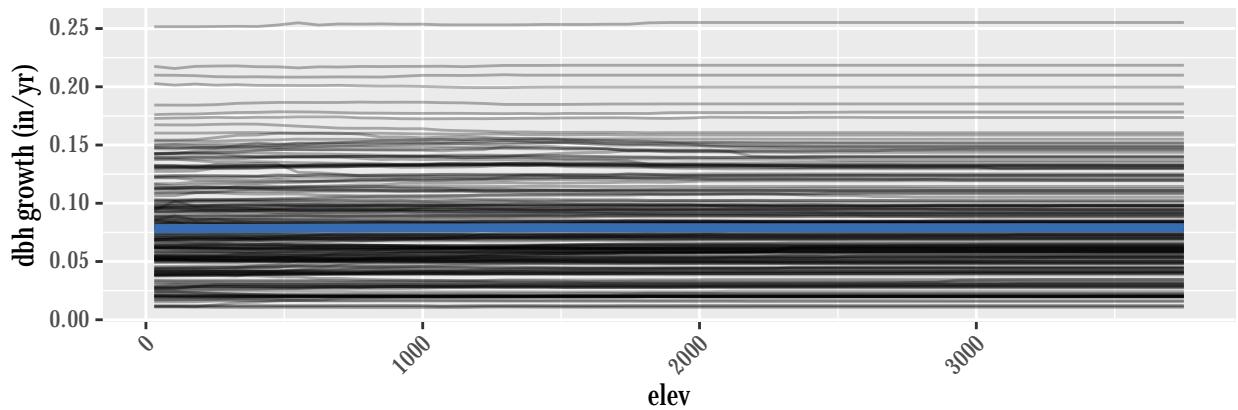
Centered ICE plot for lon



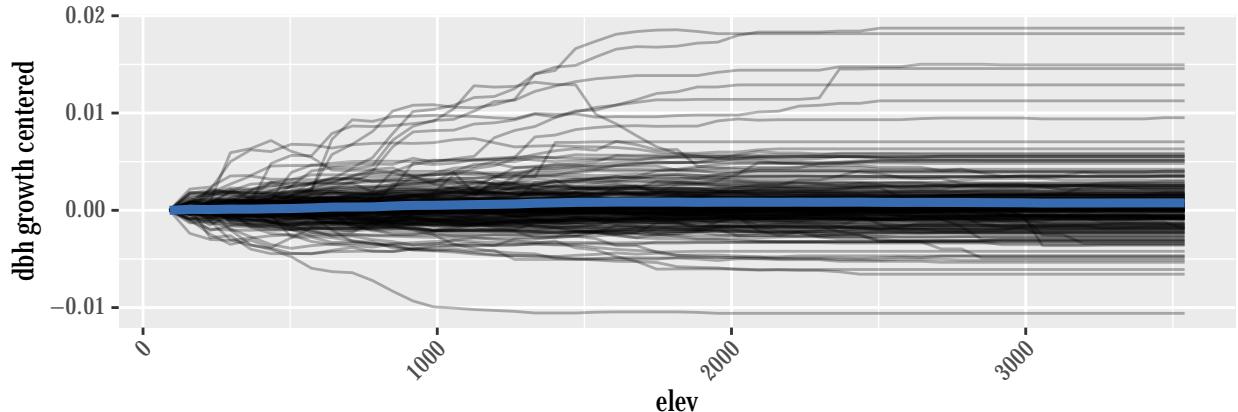
PDP for elev



ICE plot for elev



Centered ICE plot for elev



Height Submodel

Table 4: Accuracy estimates, calculated on out of bag data

RMSE	R ²	MAE
6.41	0.809	4.93

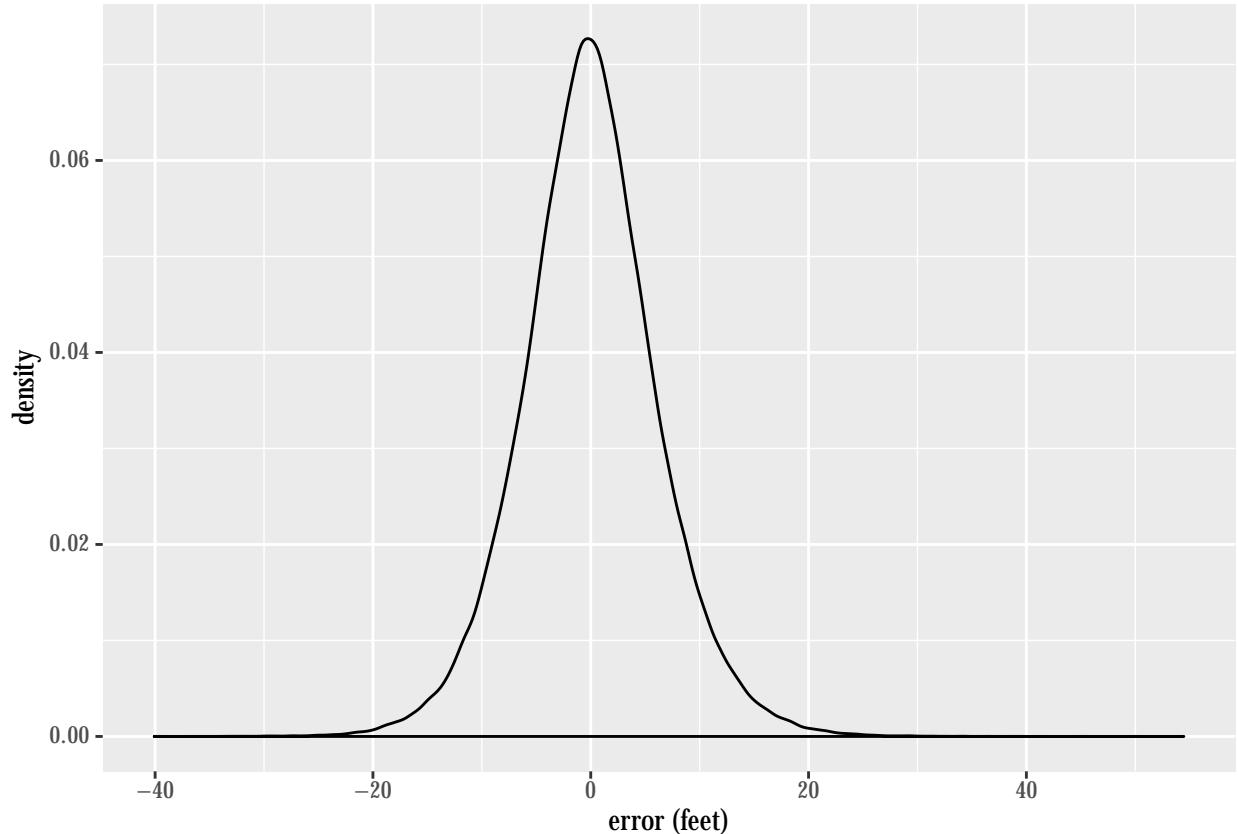


Figure 3: Overall error distribution estimated with kernel density.

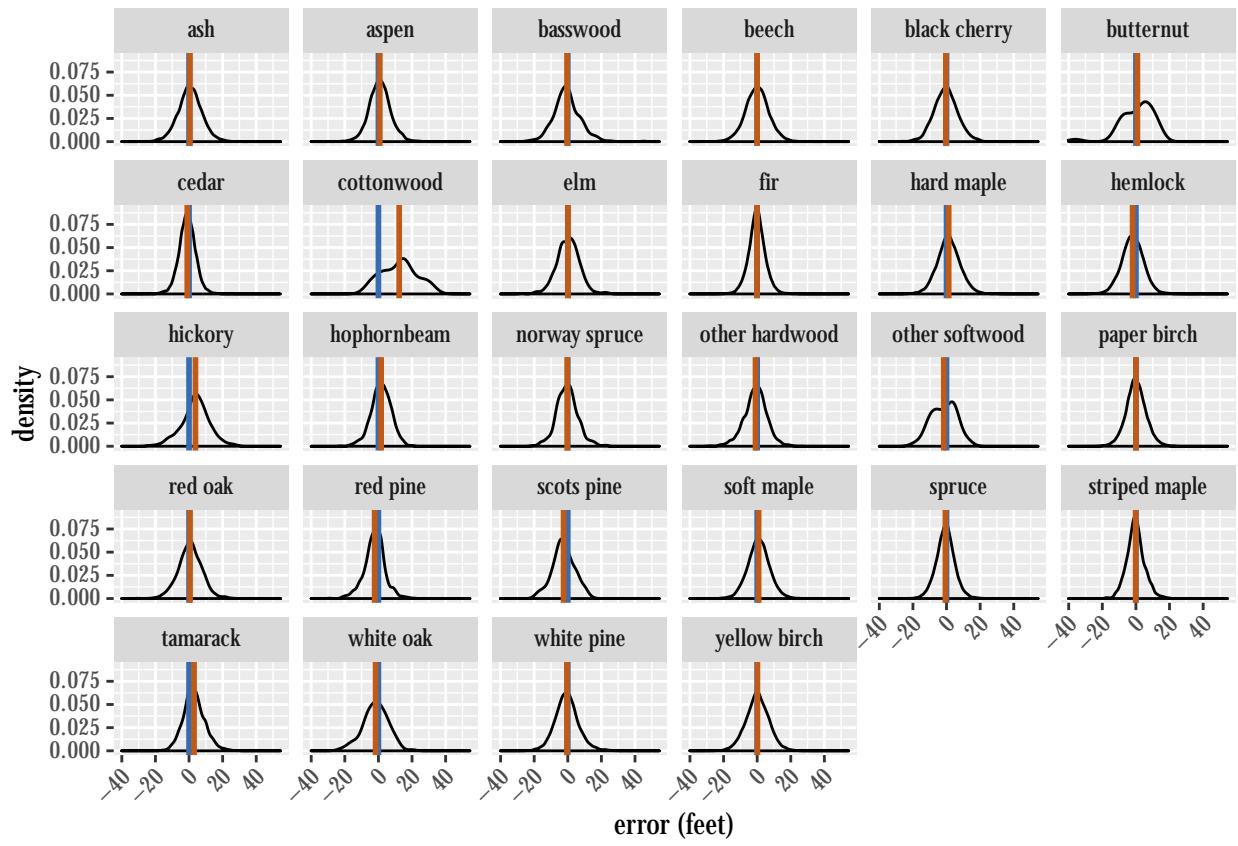
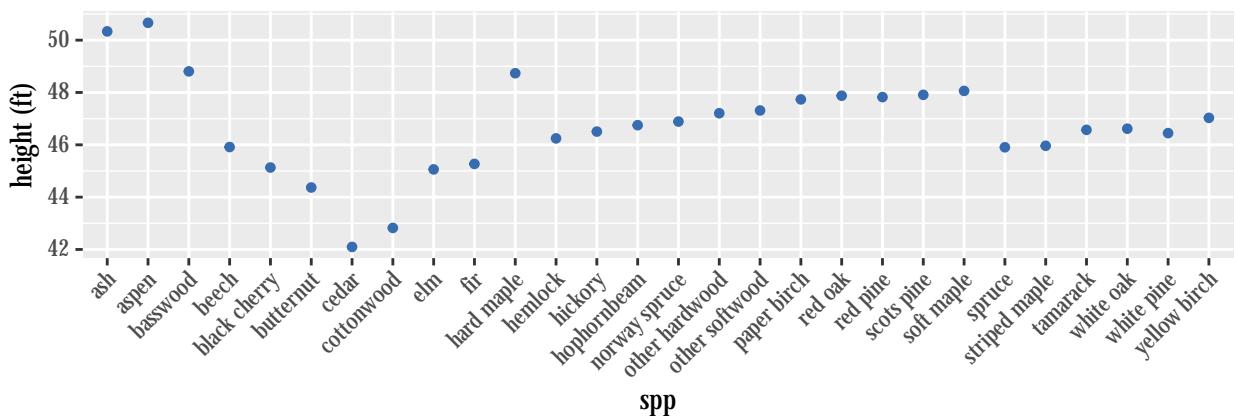


Figure 4: Error distributions for individual species estimated with kernel density. Blue vertical lines indicate 0 (no error). Brown vertical lines indicate mean species errors.

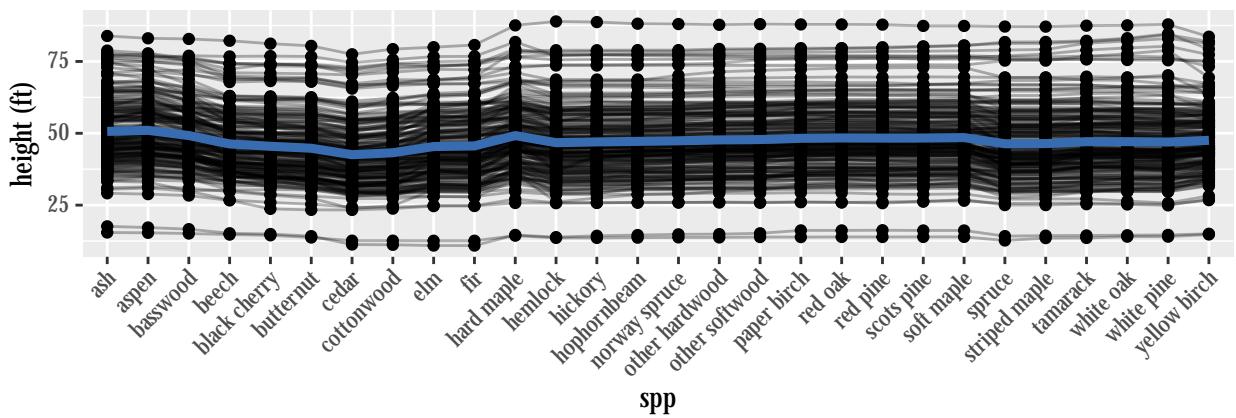
Table 5: Sample sizes and normalized root mean square errors by species

spp	n	nRMSE
fir	33208	0.1329
spruce	32049	0.1297
soft maple	28353	0.1273
cedar	17620	0.1367
hard maple	17457	0.1227
beech	13794	0.1538
yellow birch	13091	0.1375
paper birch	13045	0.1291
hemlock	12356	0.1551
white pine	8947	0.1335
aspen	6381	0.1145
ash	5552	0.1328
red oak	2977	0.1260
other hardwood	2176	0.1757
black cherry	1908	0.1382
tamarack	1344	0.1355
hophornbeam	1160	0.1462
striped maple	943	0.1589
red pine	853	0.1383
elm	729	0.1550
norway spruce	620	0.1292
basswood	501	0.1449
hickory	279	0.1604
scots pine	156	0.1366
white oak	133	0.1533
other softwood	55	0.1574
butternut	39	0.1651
cottonwood	17	0.2134

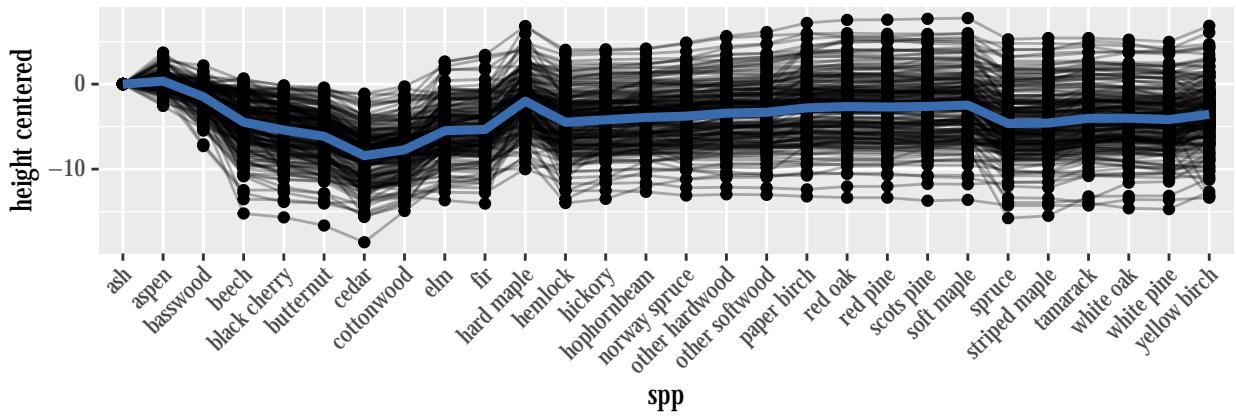
PDP for spp



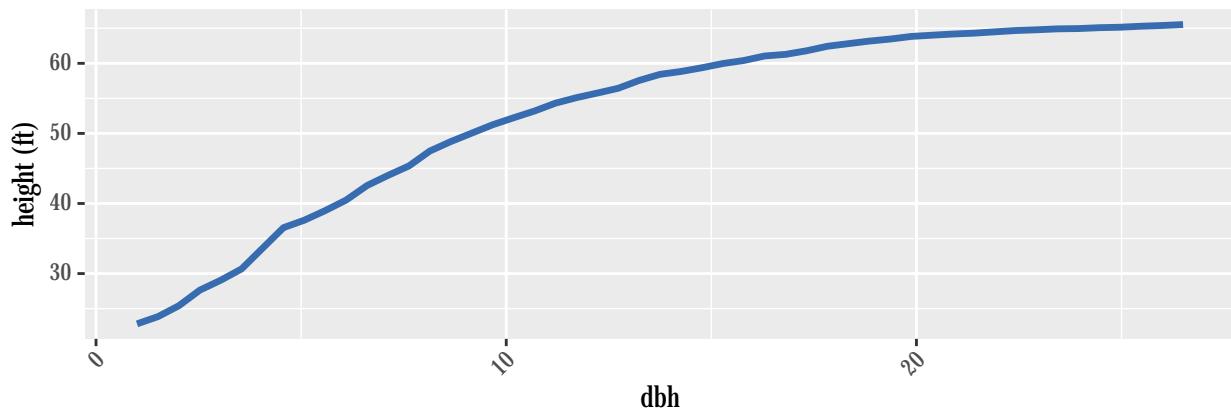
ICE plot for spp



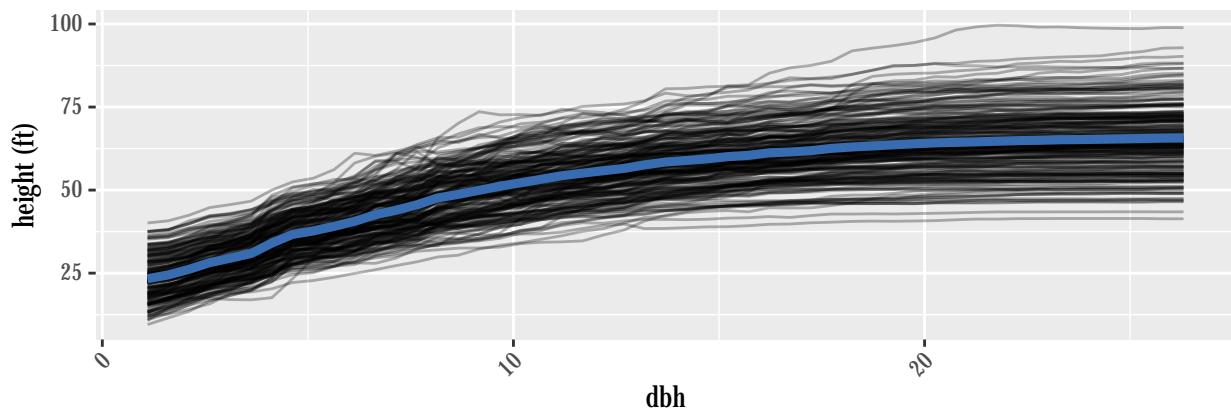
Centered ICE plot for spp



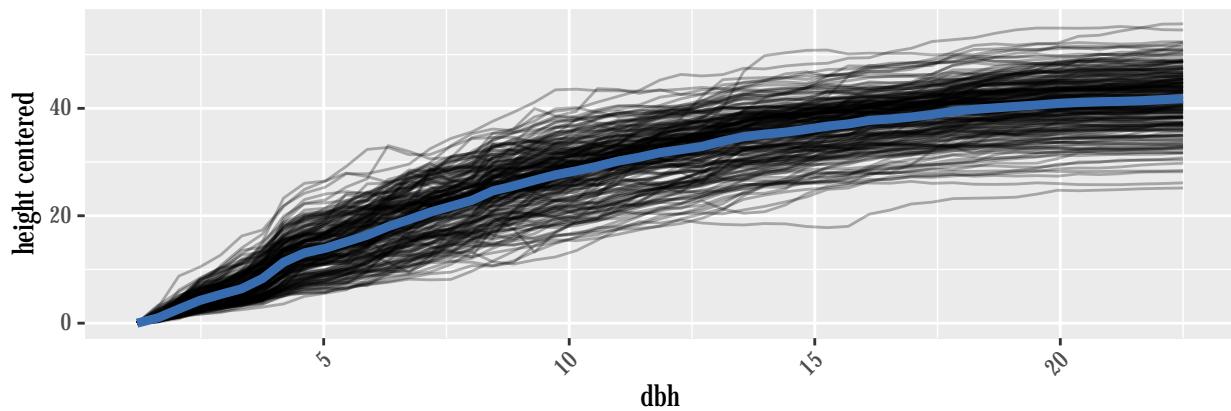
PDP for dbh



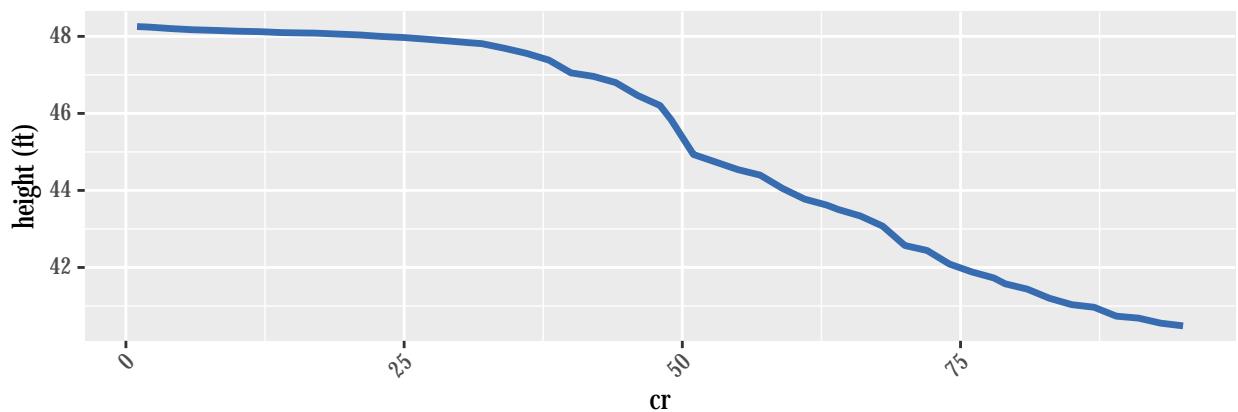
ICE plot for dbh



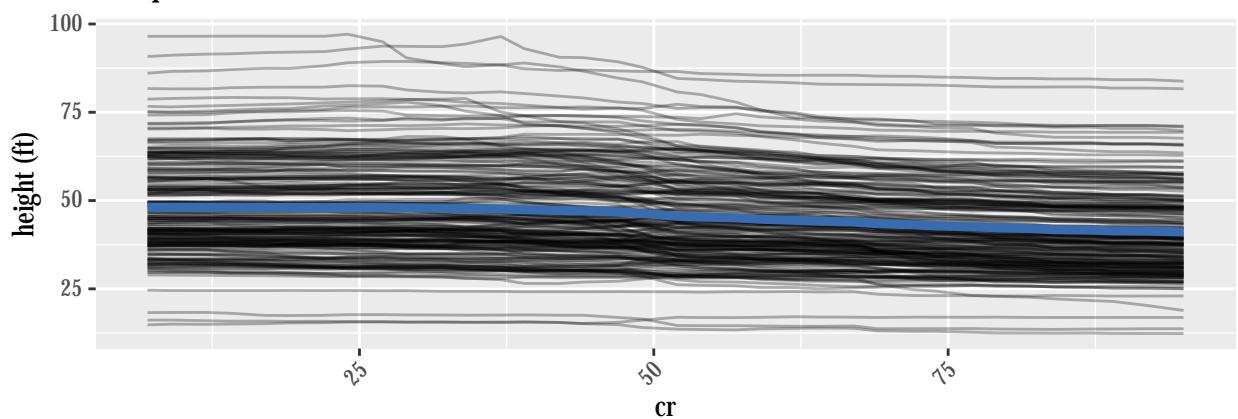
Centered ICE plot for dbh



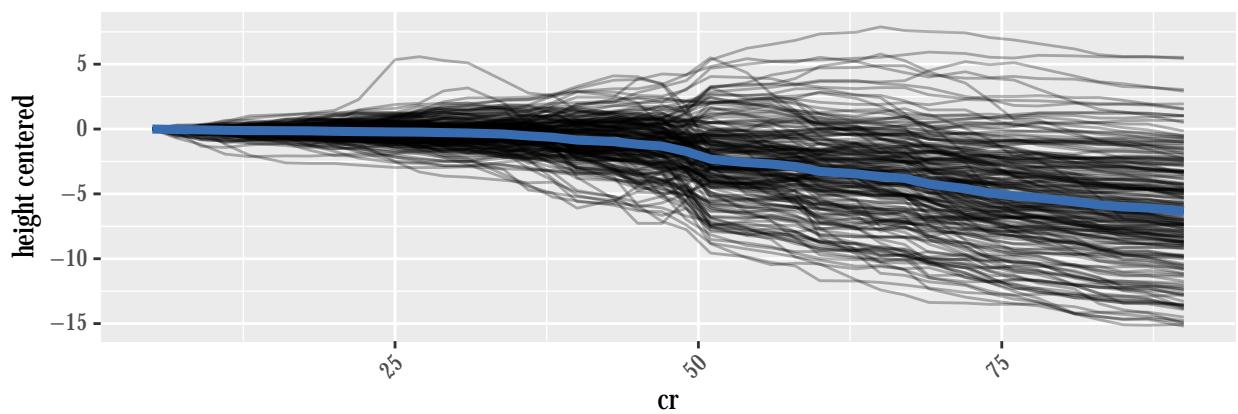
PDP for cr



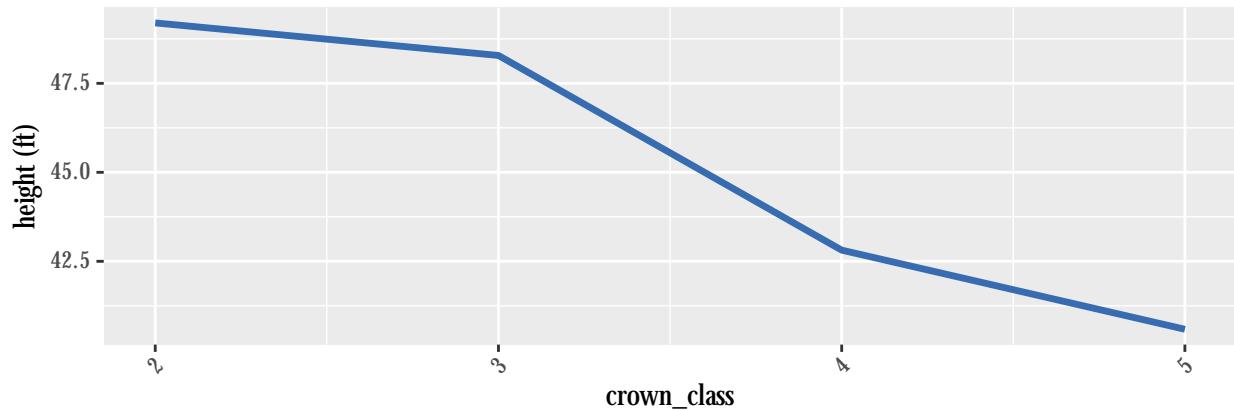
ICE plot for cr



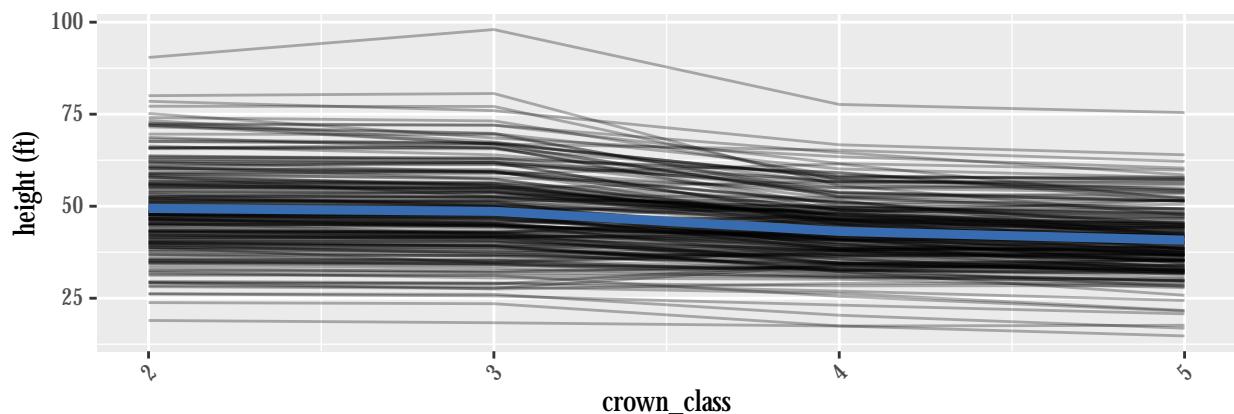
Centered ICE plot for cr



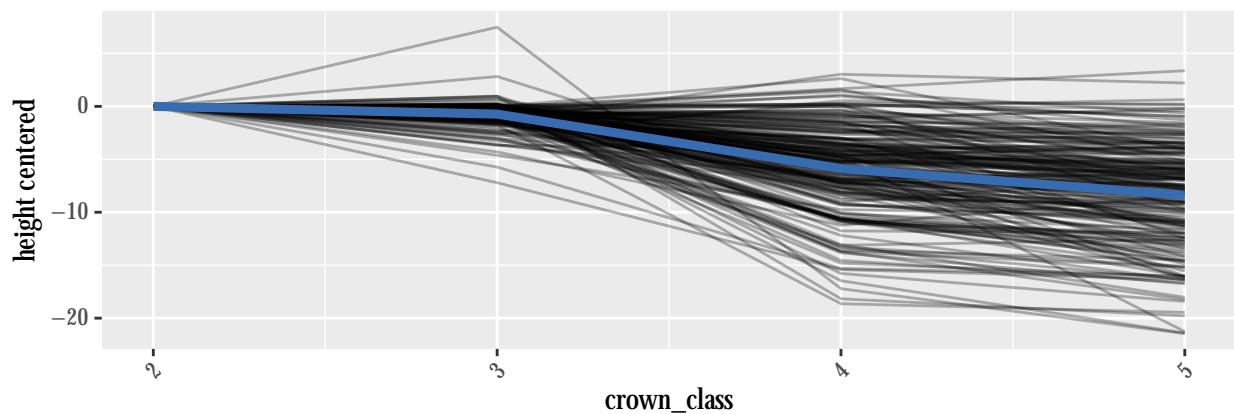
PDP for crown_class



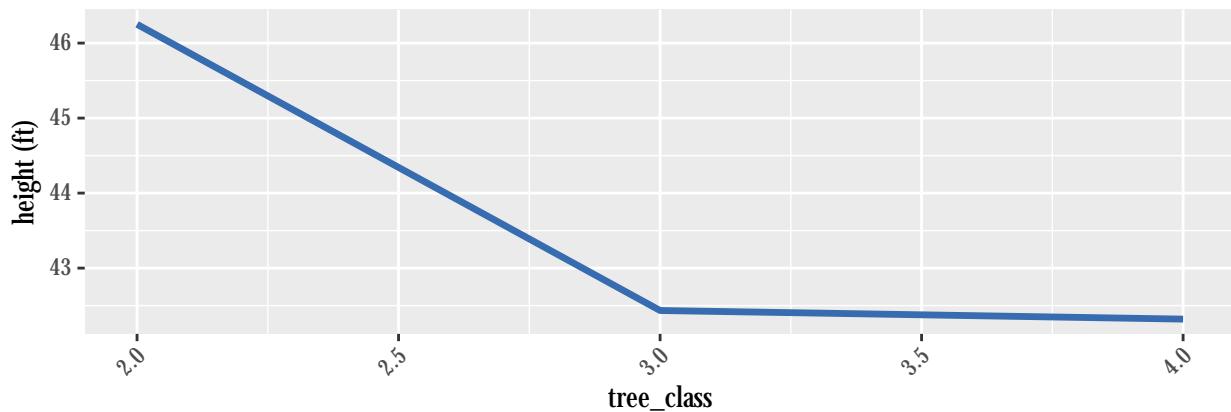
ICE plot for crown_class



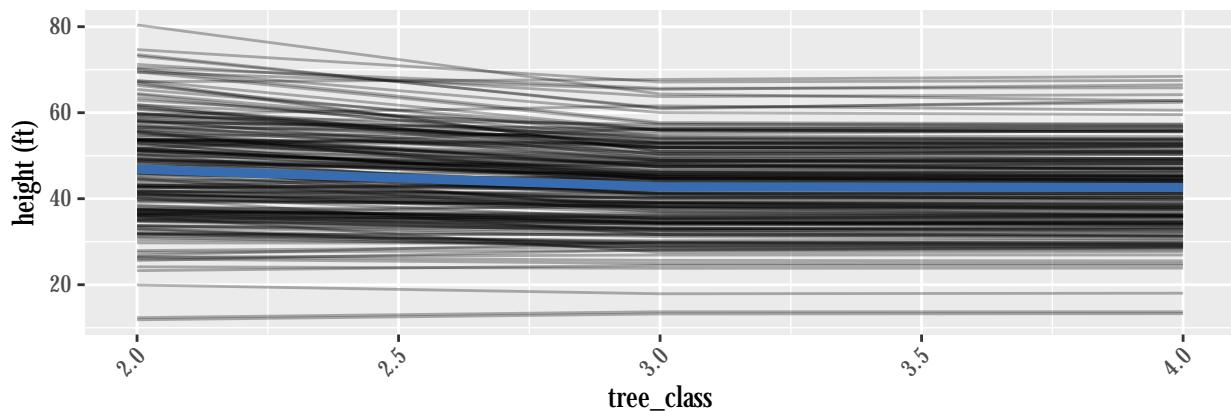
Centered ICE plot for crown_class



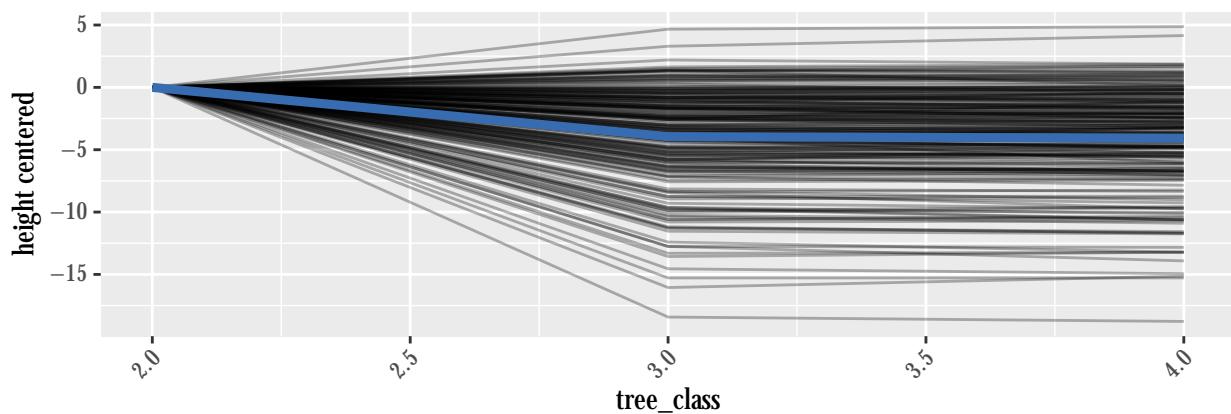
PDP for tree_class



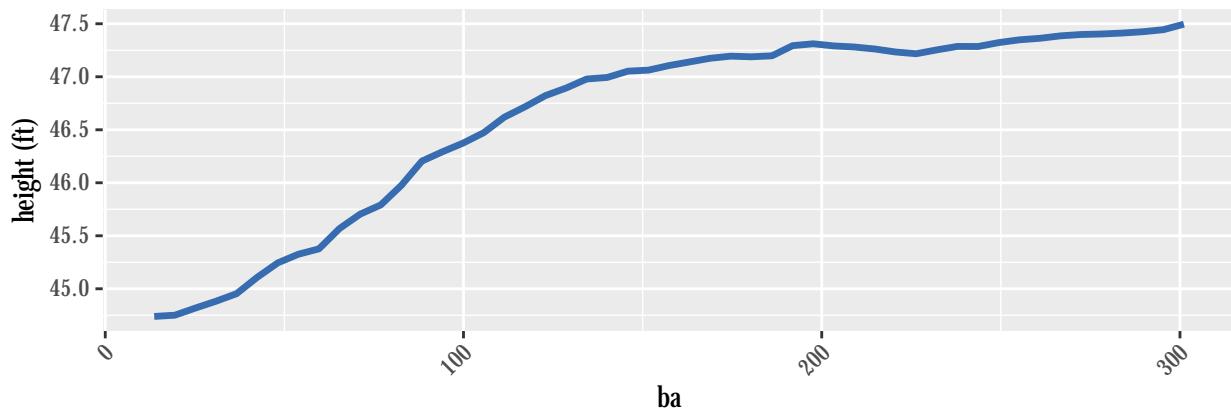
ICE plot for tree_class



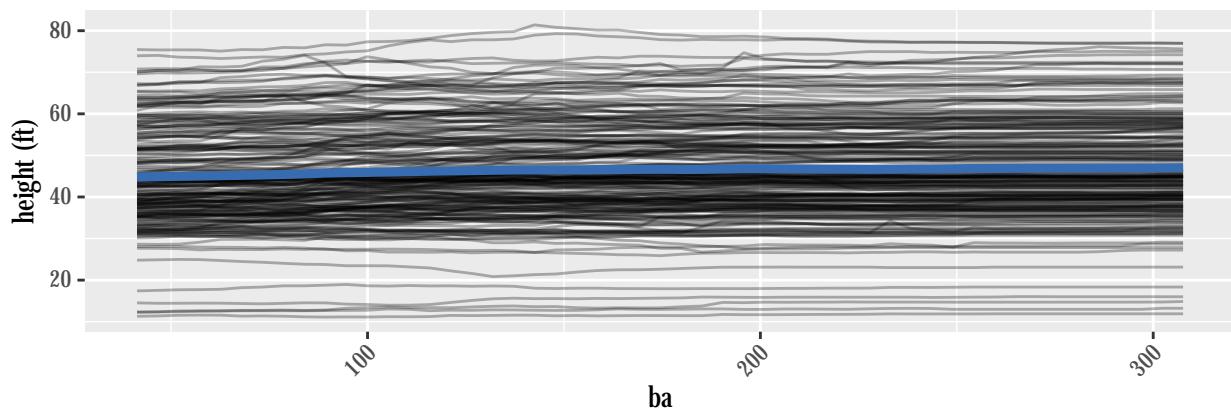
Centered ICE plot for tree_class



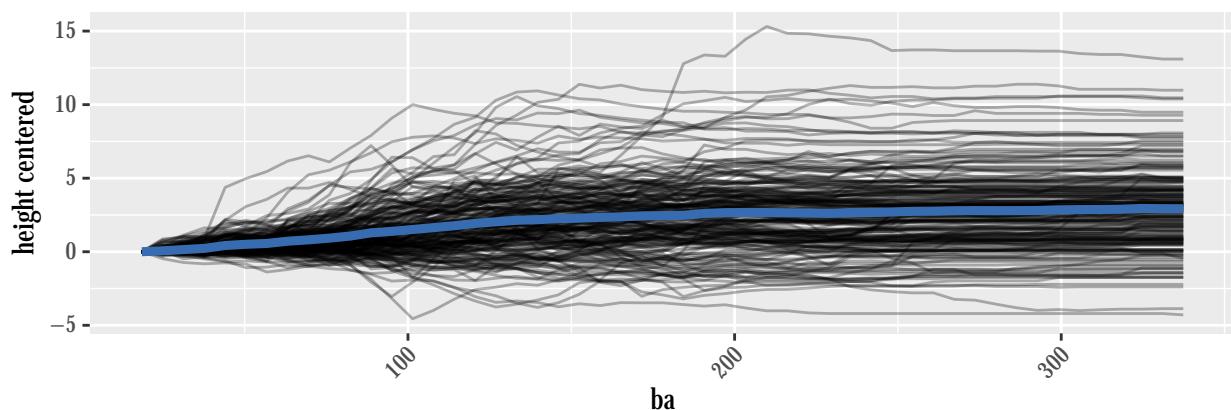
PDP for ba



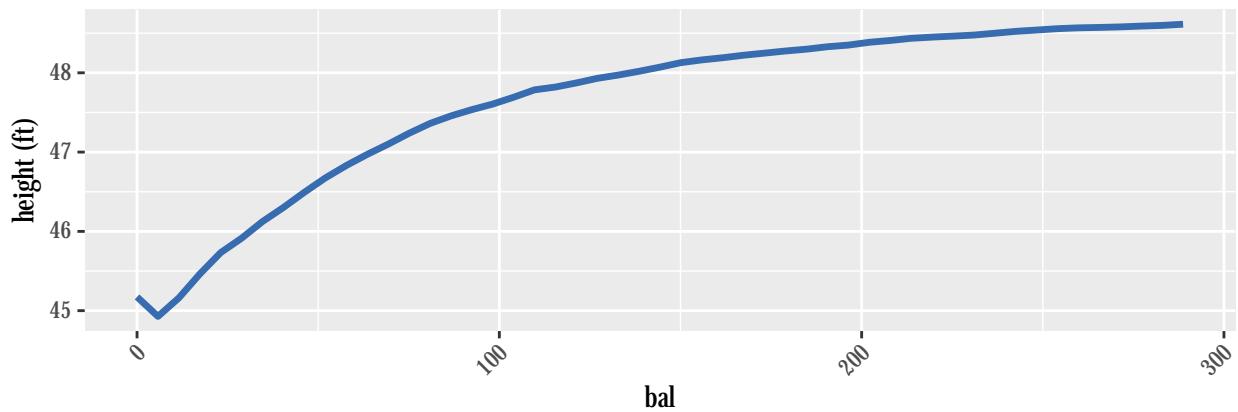
ICE plot for ba



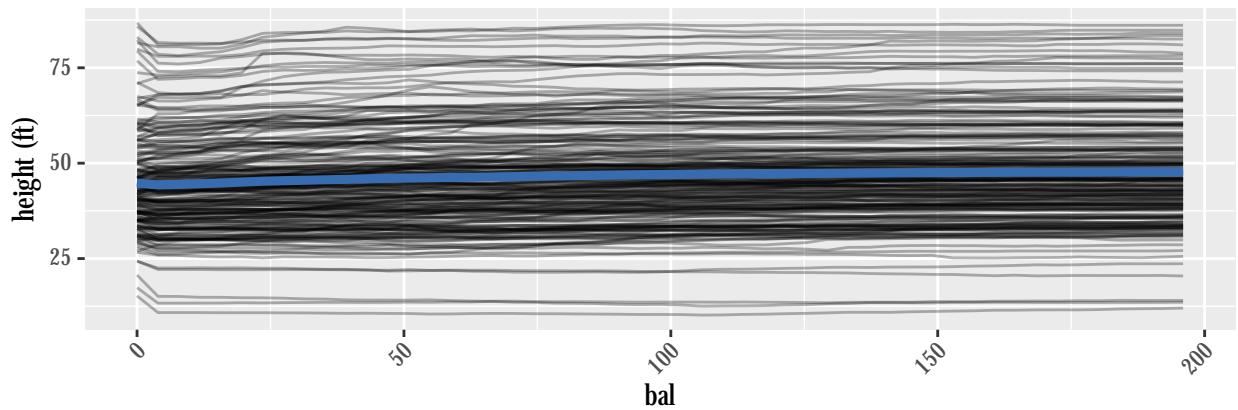
Centered ICE plot for ba



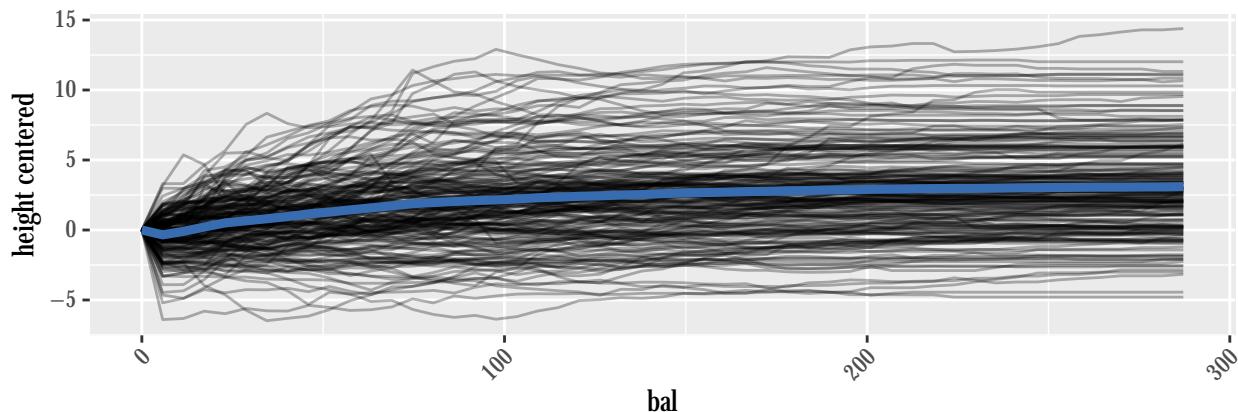
PDP for bal



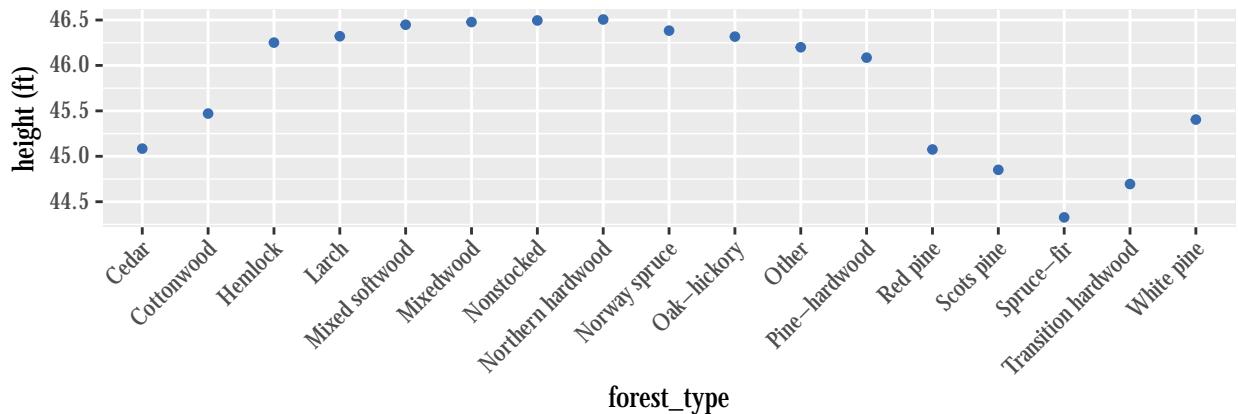
ICE plot for bal



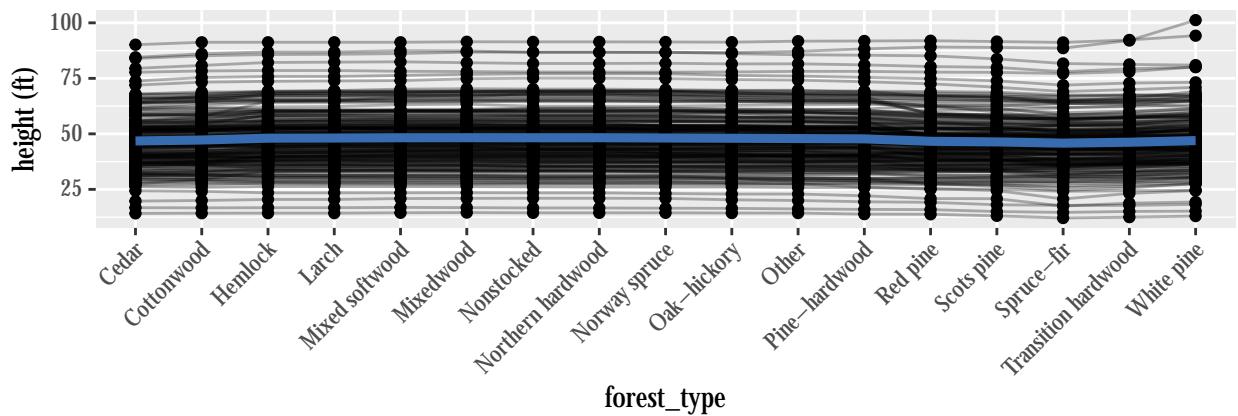
Centered ICE plot for bal



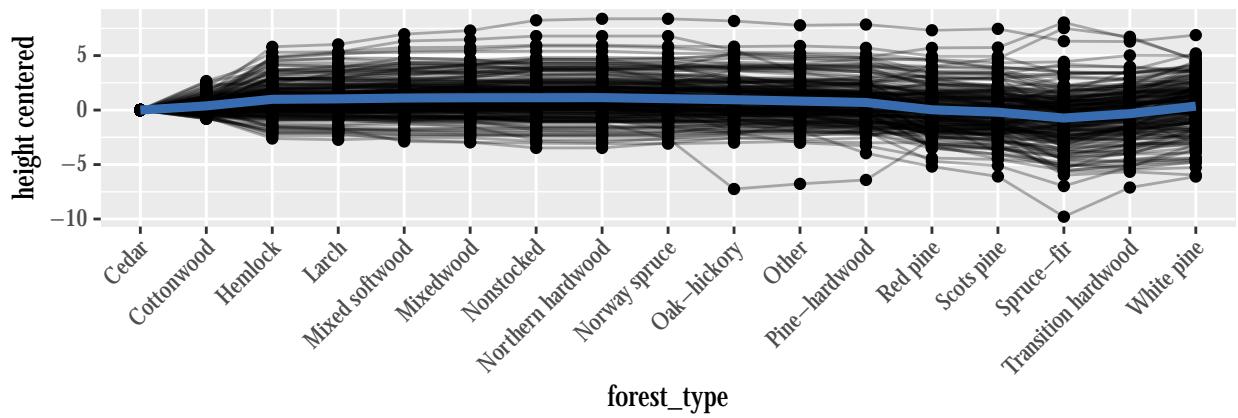
PDP for forest_type



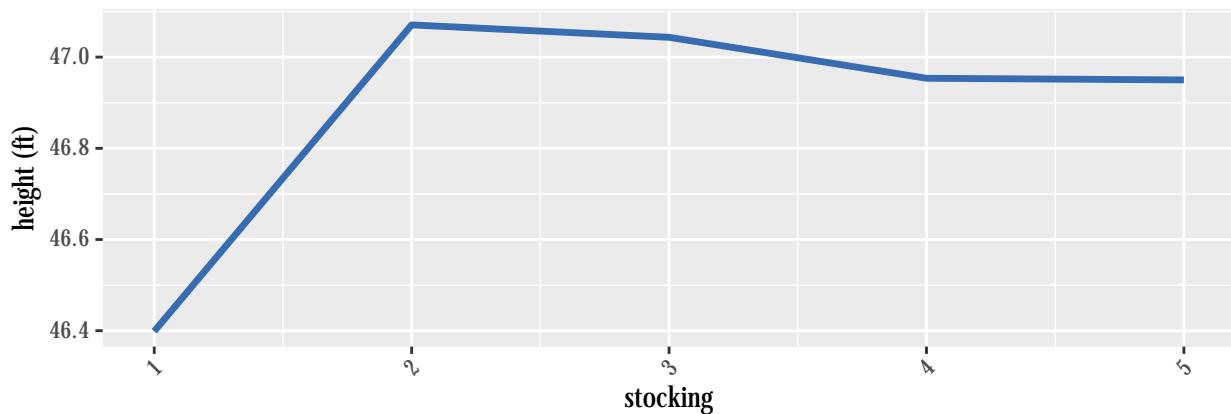
ICE plot for forest_type



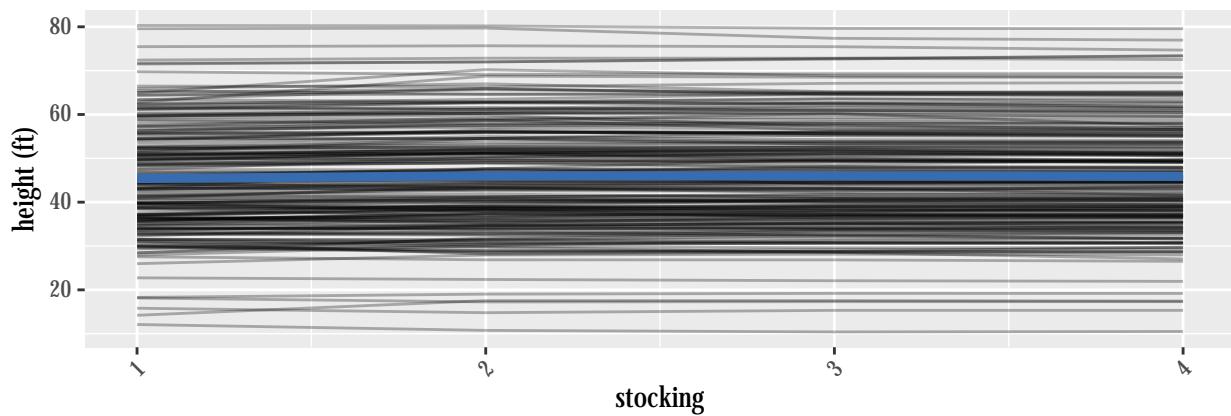
Centered ICE plot for forest_type



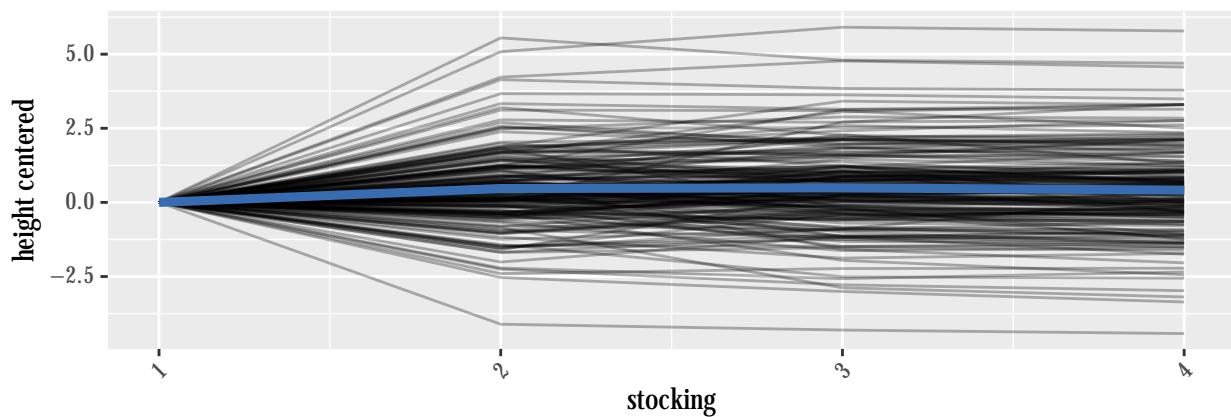
PDP for stocking



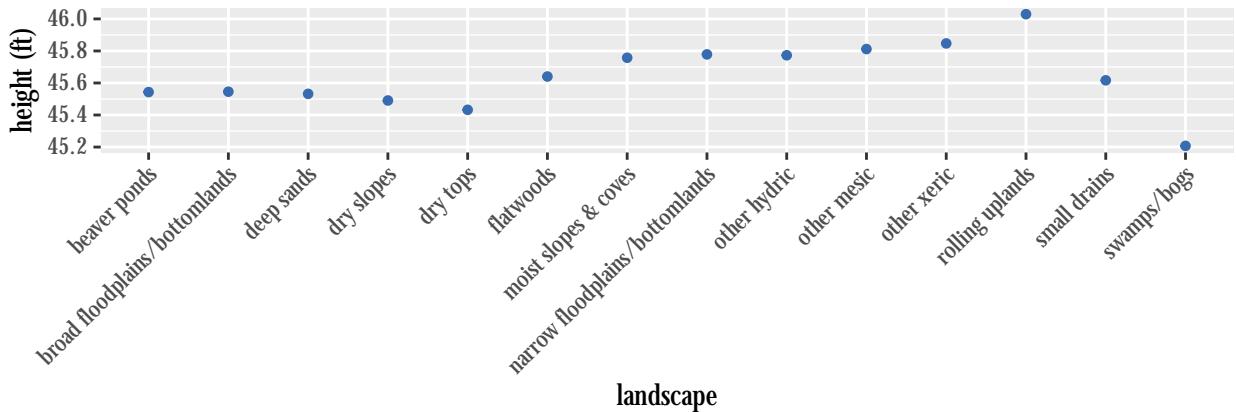
ICE plot for stocking



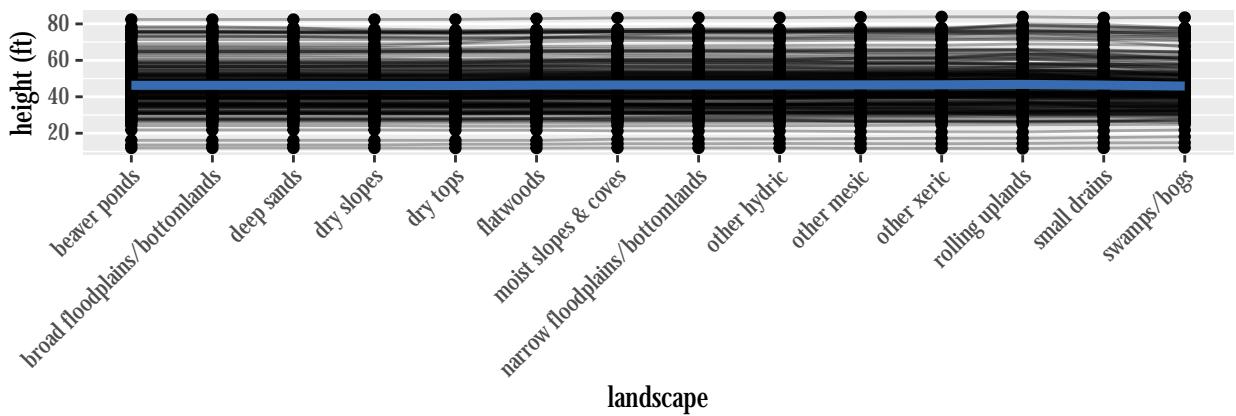
Centered ICE plot for stocking



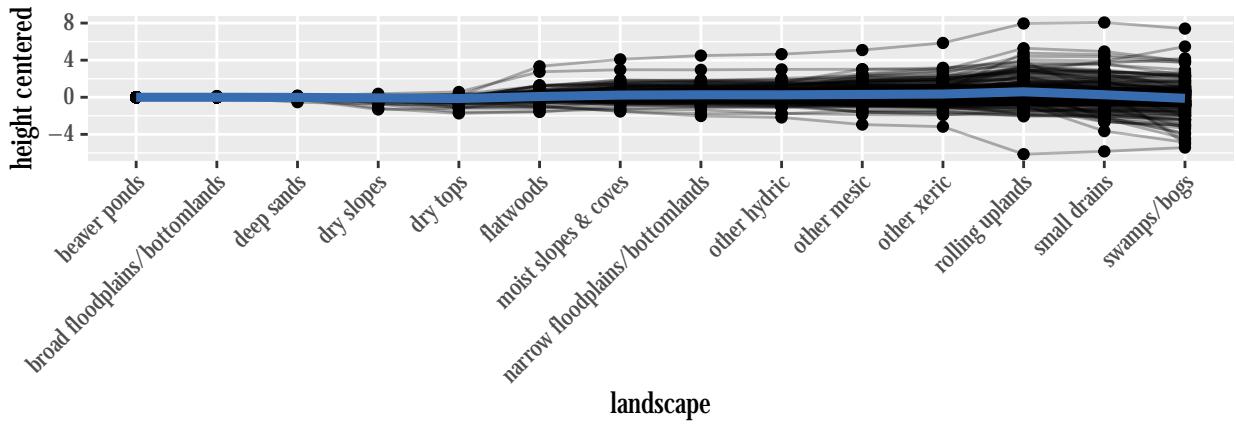
PDP for landscape



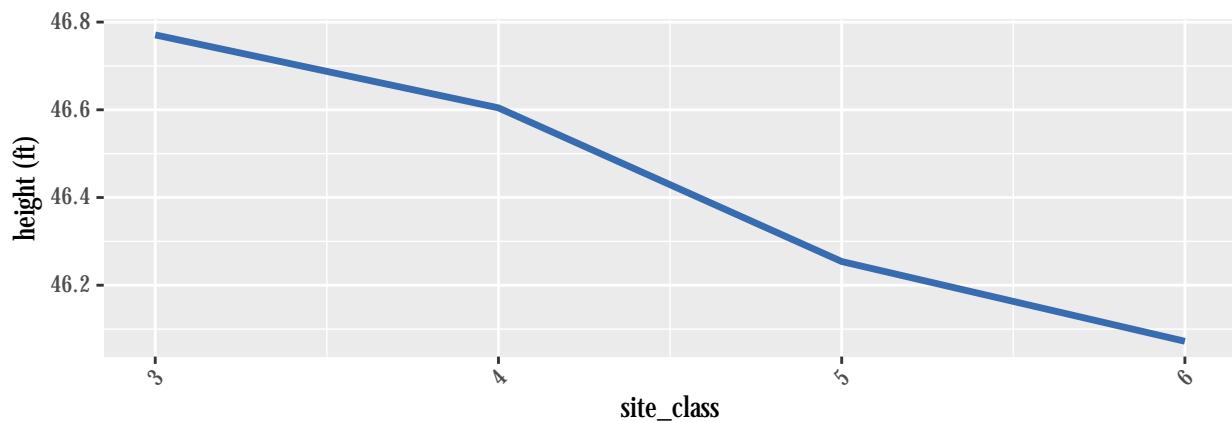
ICE plot for landscape



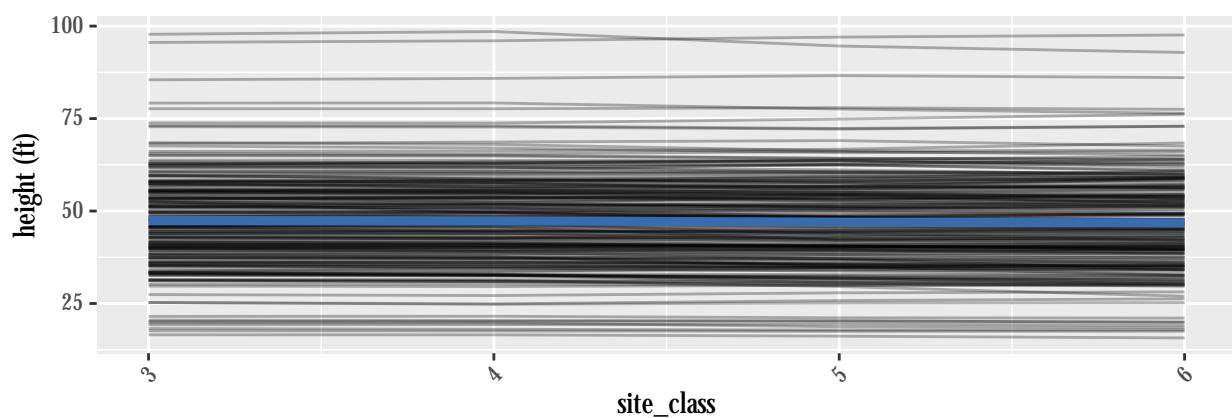
Centered ICE plot for landscape



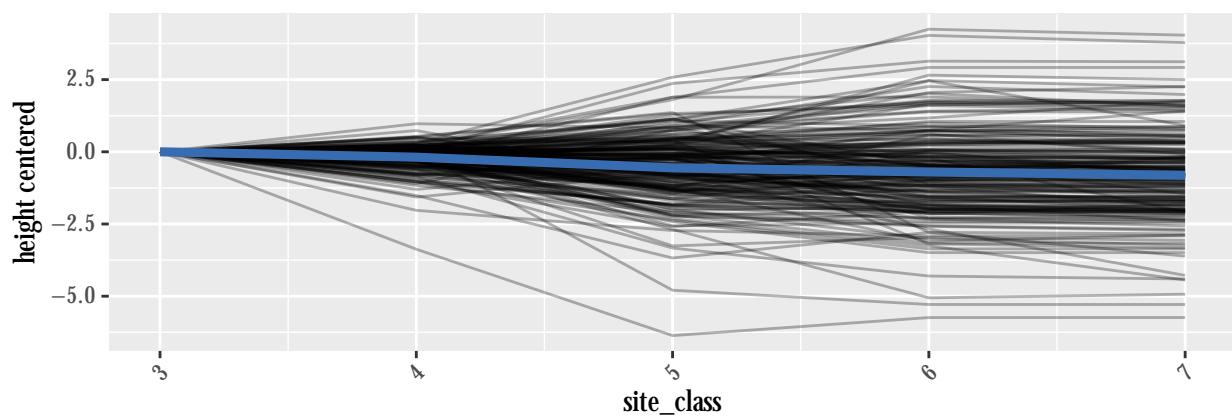
PDP for site_class



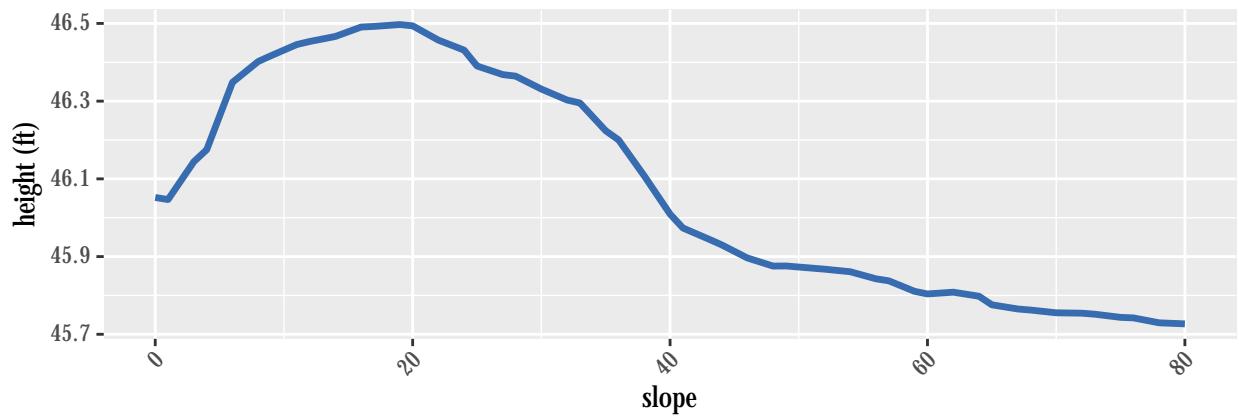
ICE plot for site_class



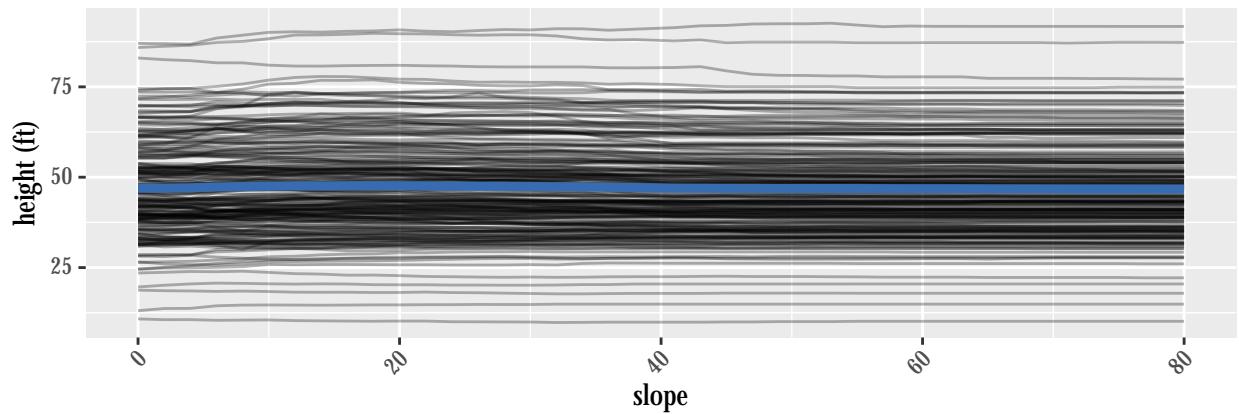
Centered ICE plot for site_class



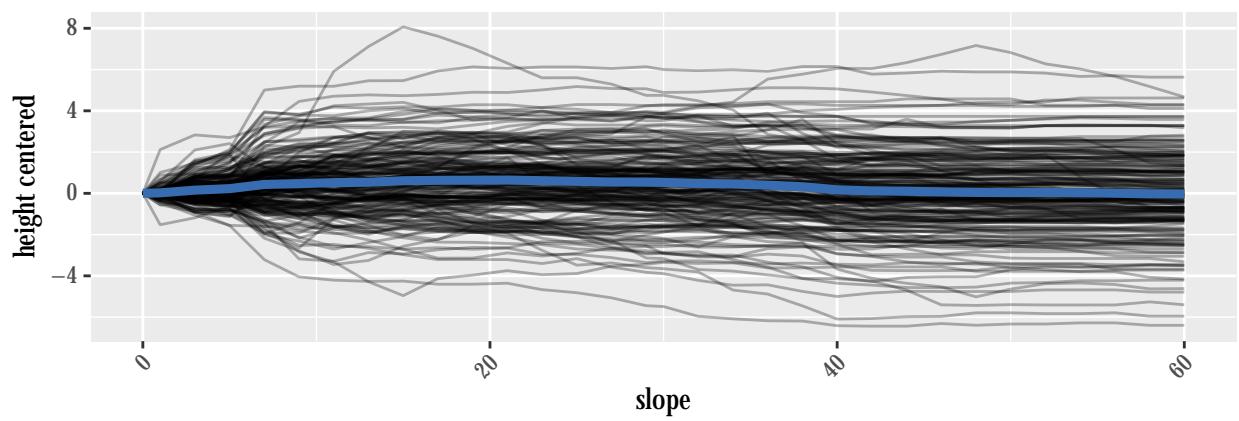
PDP for slope



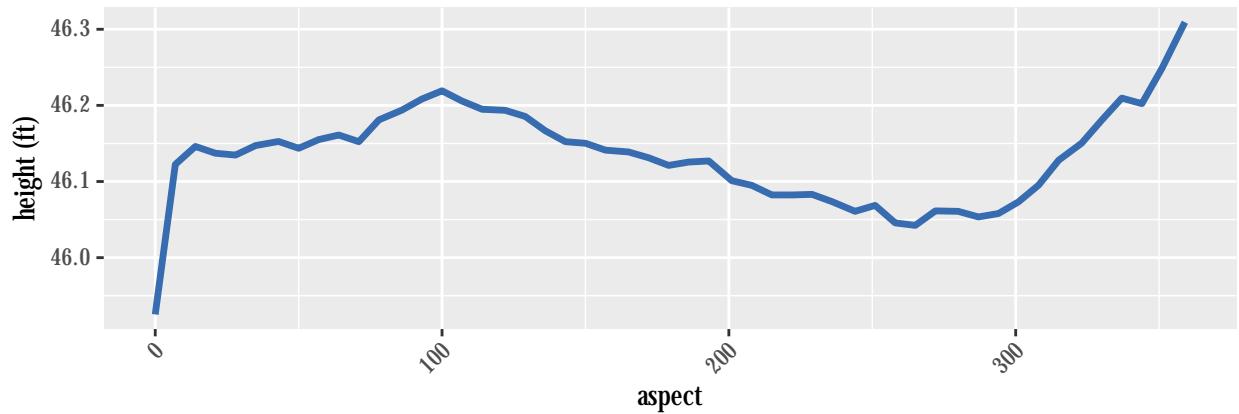
ICE plot for slope



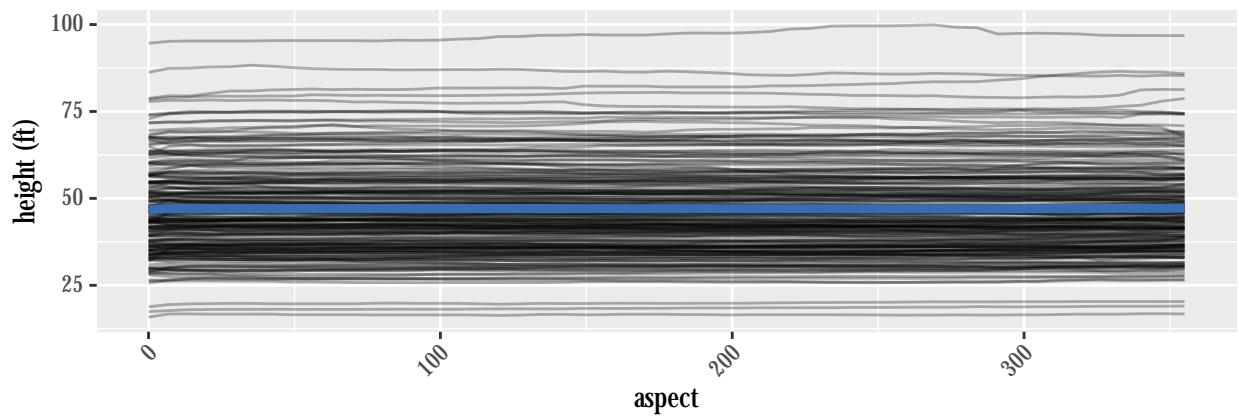
Centered ICE plot for slope



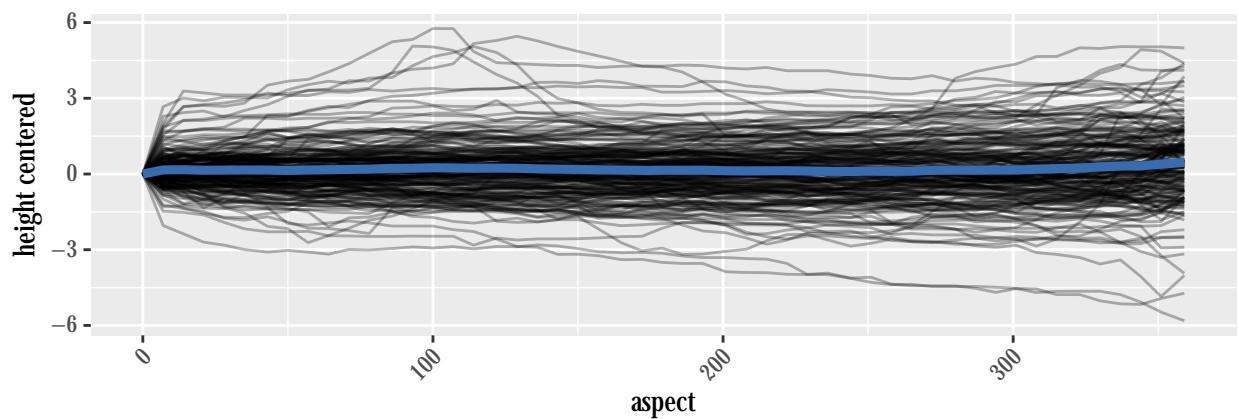
PDP for aspect



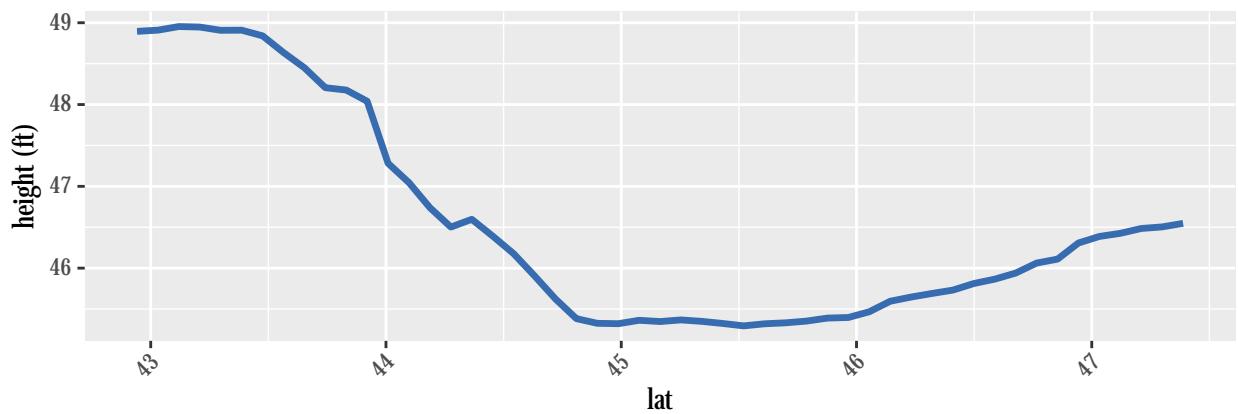
ICE plot for aspect



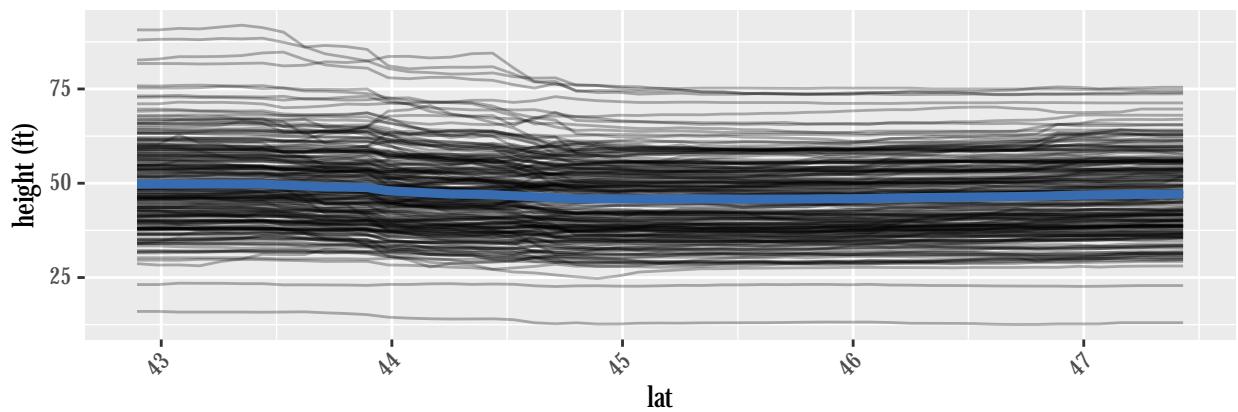
Centered ICE plot for aspect



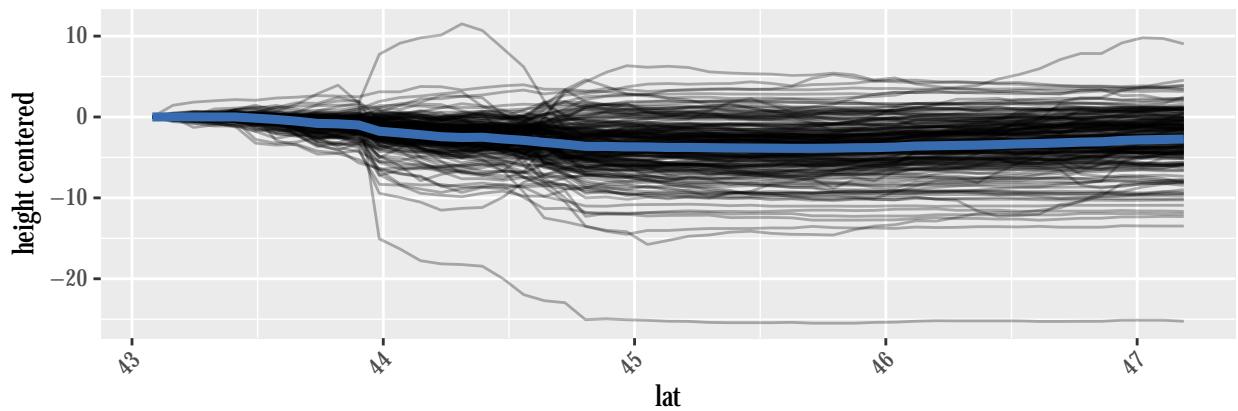
PDP for lat



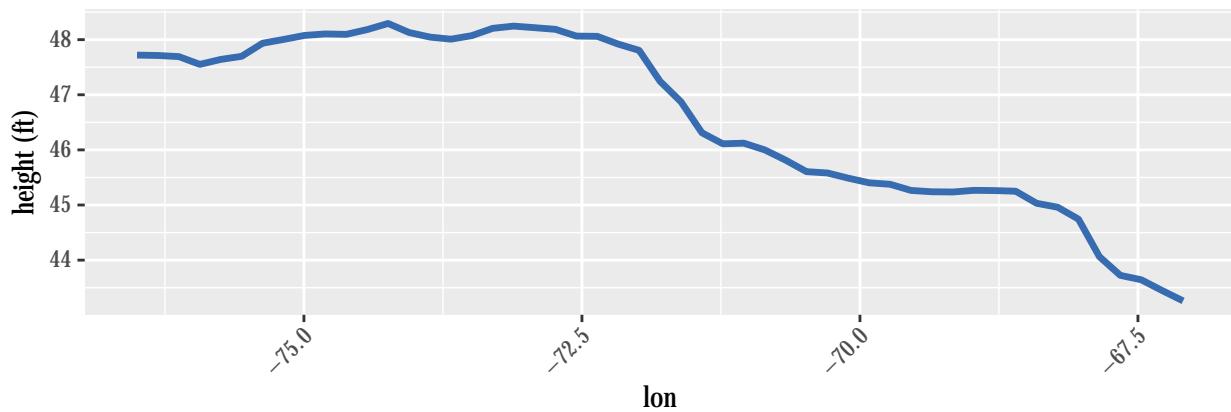
ICE plot for lat



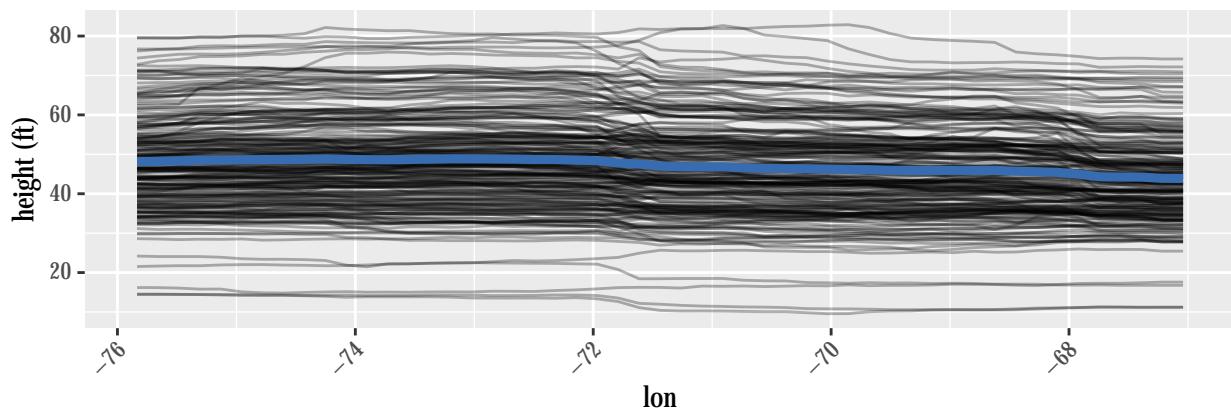
Centered ICE plot for lat



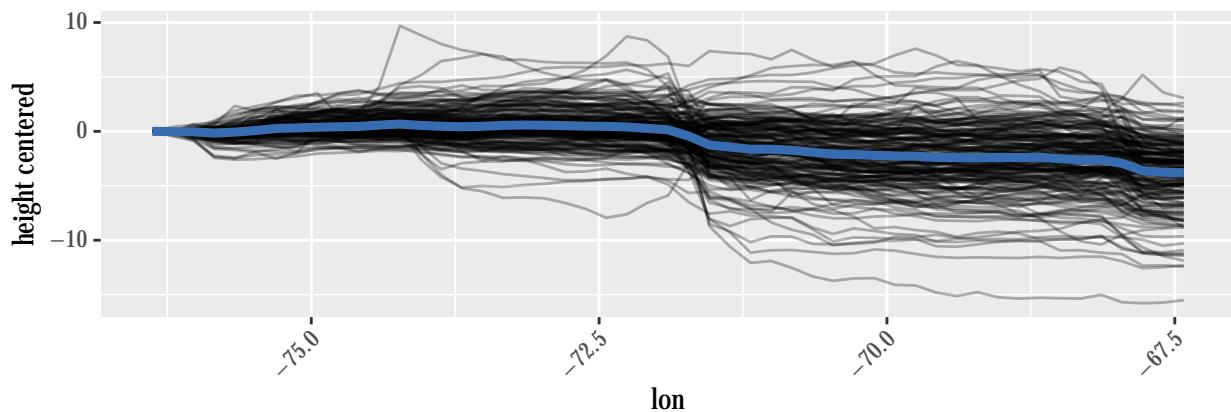
PDP for lon



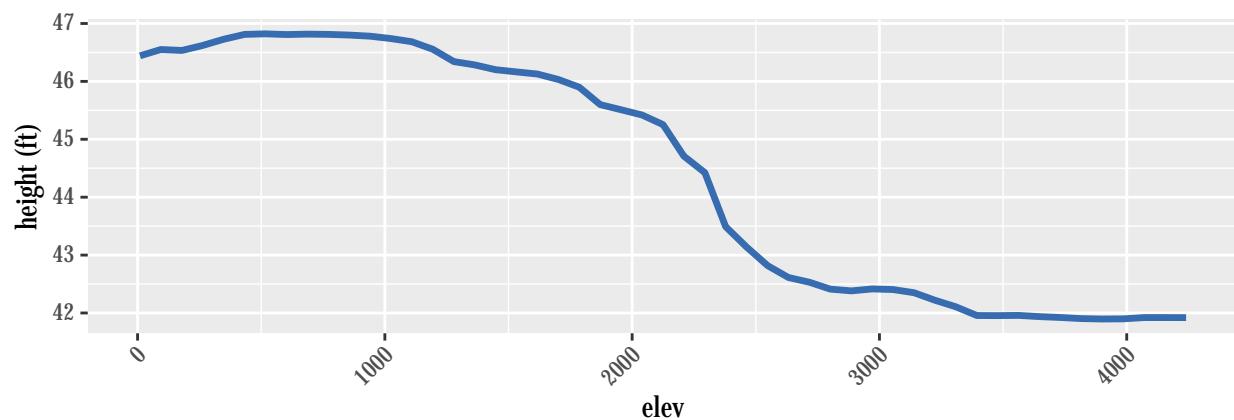
ICE plot for lon



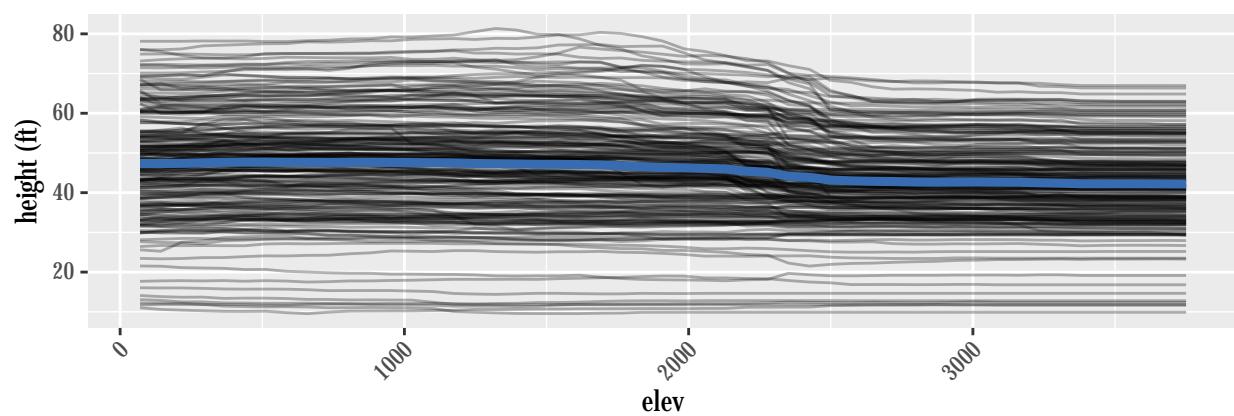
Centered ICE plot for lon



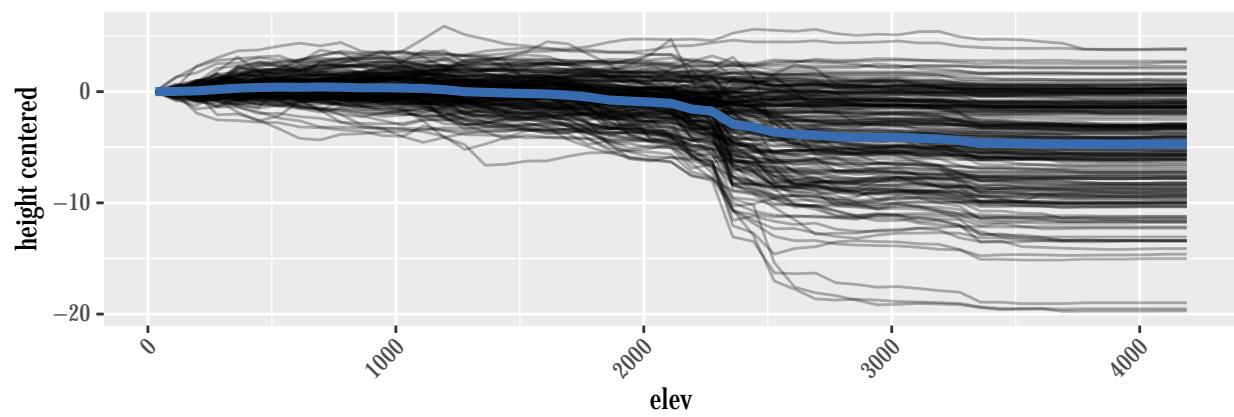
PDP for elev



ICE plot for elev



Centered ICE plot for elev



Height Growth Submodel

Table 6: Accuracy estimates, calculated on out of bag data

RMSE	R ²	MAE
1.177167	0.112	0.876506

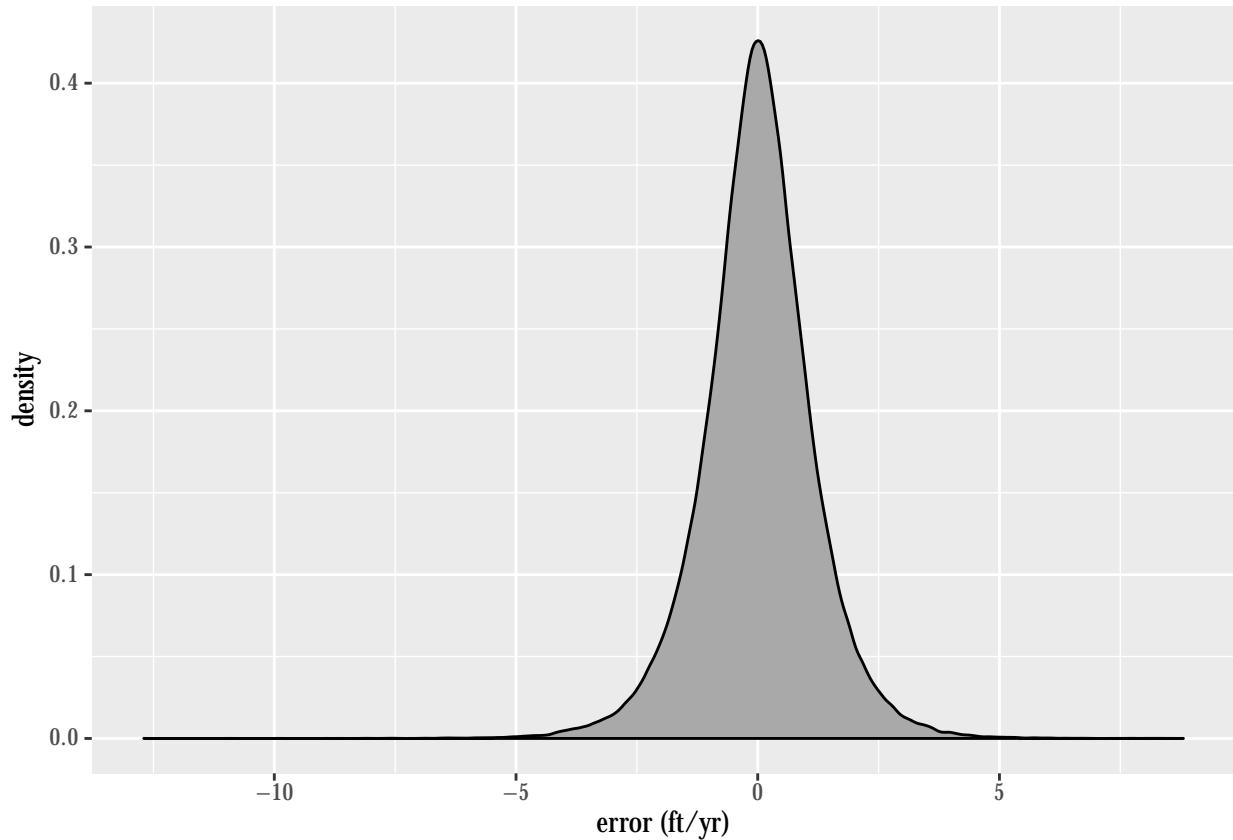


Figure 5: Overall error distribution estimated with kernal density.

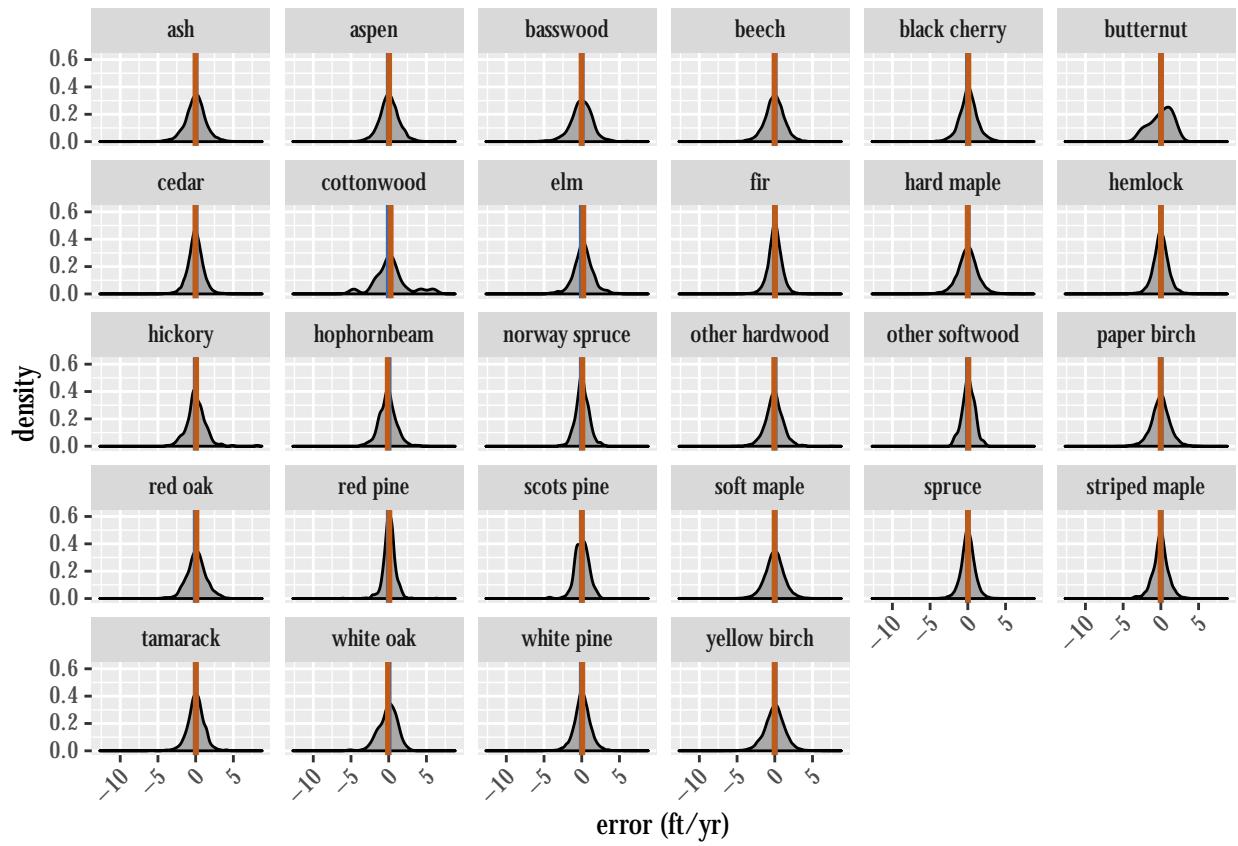
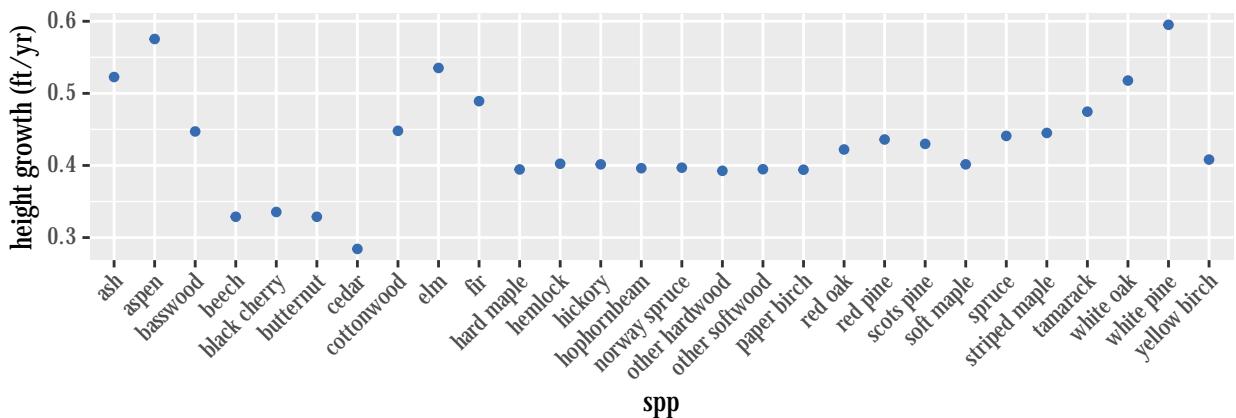


Figure 6: Error distributions for individual species estimated with kernel density. Blue vertical lines indicate 0 (no error). Brown vertical lines indicate mean species errors.

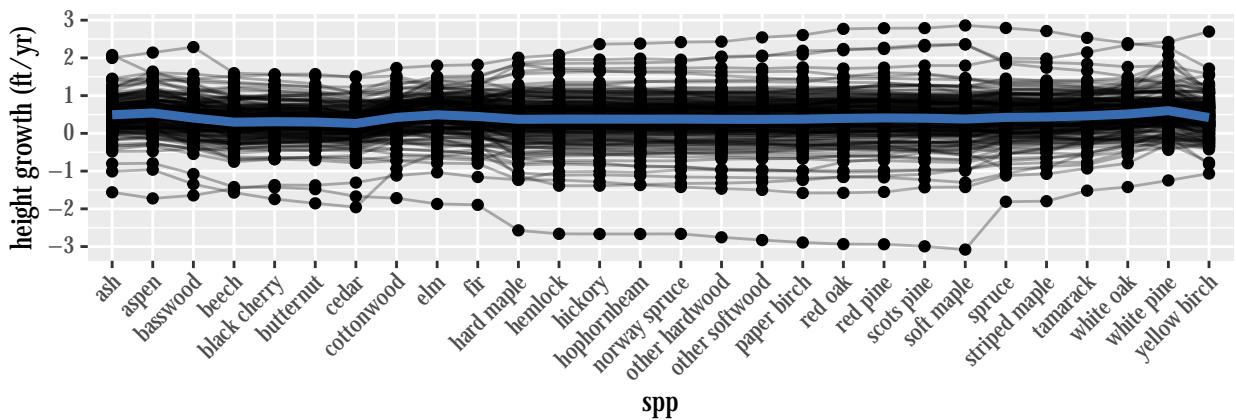
Table 7: Sample sizes and normalized root mean square errors by species

spp	n	nRMSE
spruce	30688	2.1073
fir	29752	1.3178
soft maple	27043	4.1677
cedar	17037	9.9401
hard maple	16884	5.1781
yellow birch	12617	3.7984
beech	12308	3.8358
hemlock	11880	1.9999
paper birch	11722	7.0794
white pine	8338	1.2405
aspen	5885	1.9939
ash	5288	3.2142
red oak	2773	2.2640
black cherry	1804	2.5515
other hardwood	1801	3.7303
tamarack	1082	2.1404
hophornbeam	1049	4.5005
red pine	1006	0.7475
striped maple	696	2.3387
elm	517	1.4152
norway spruce	494	0.9960
basswood	449	3.6663
hickory	276	1.8848
scots pine	149	1.3091
white oak	136	2.4425
other softwood	103	0.9657
butternut	29	3.1121
cottonwood	19	1.9858

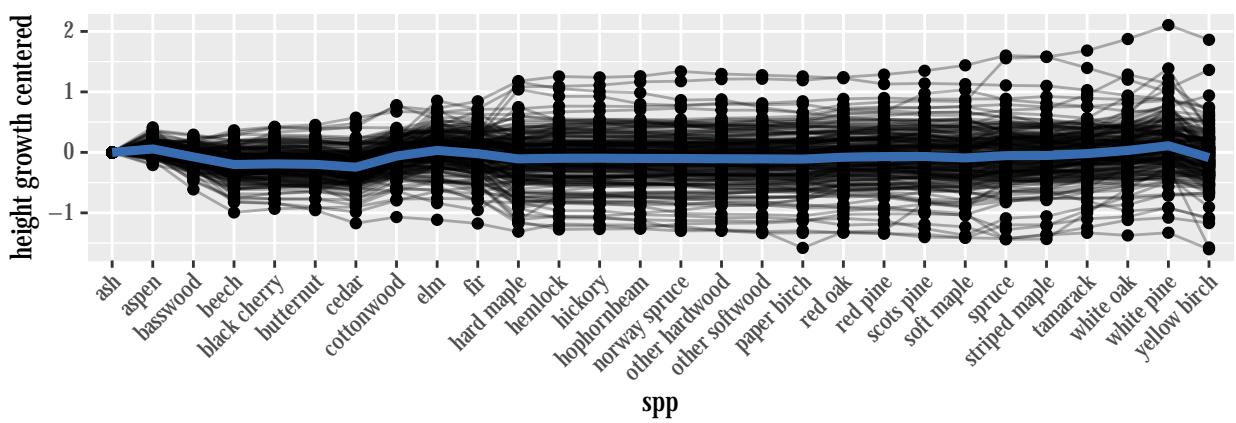
PDP for spp



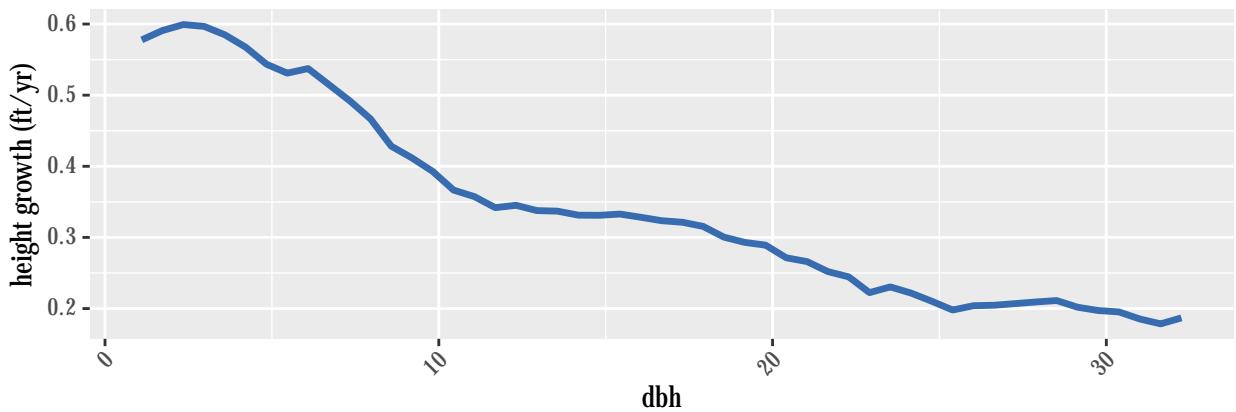
ICE plot for spp



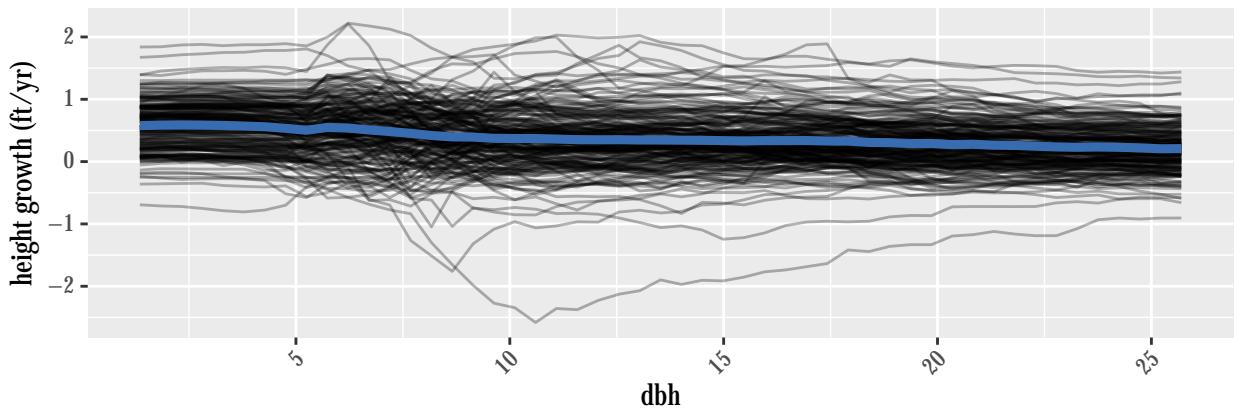
Centered ICE plot for spp



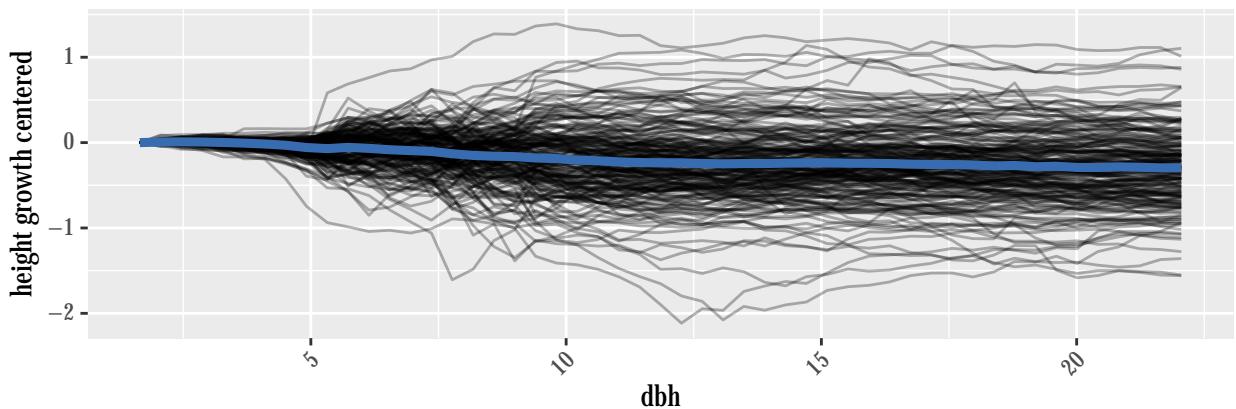
PDP for dbh



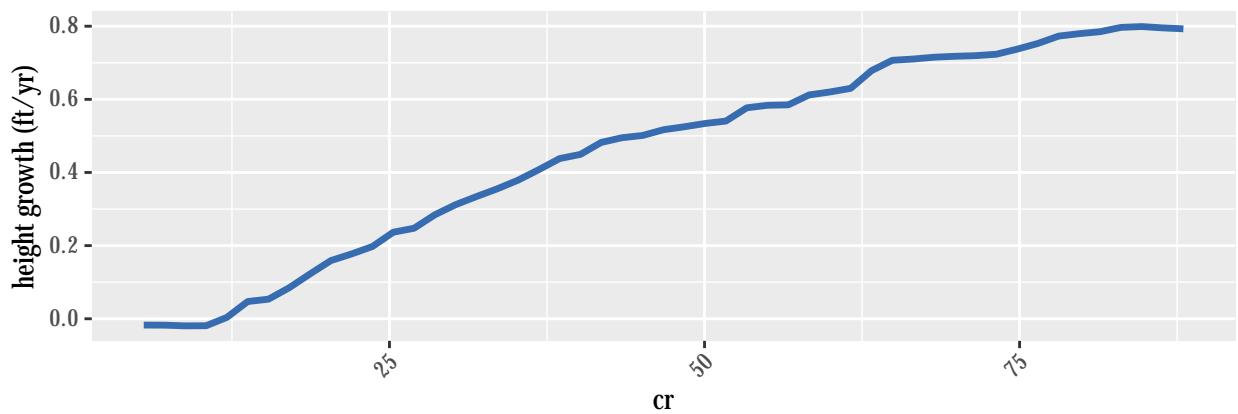
ICE plot for dbh



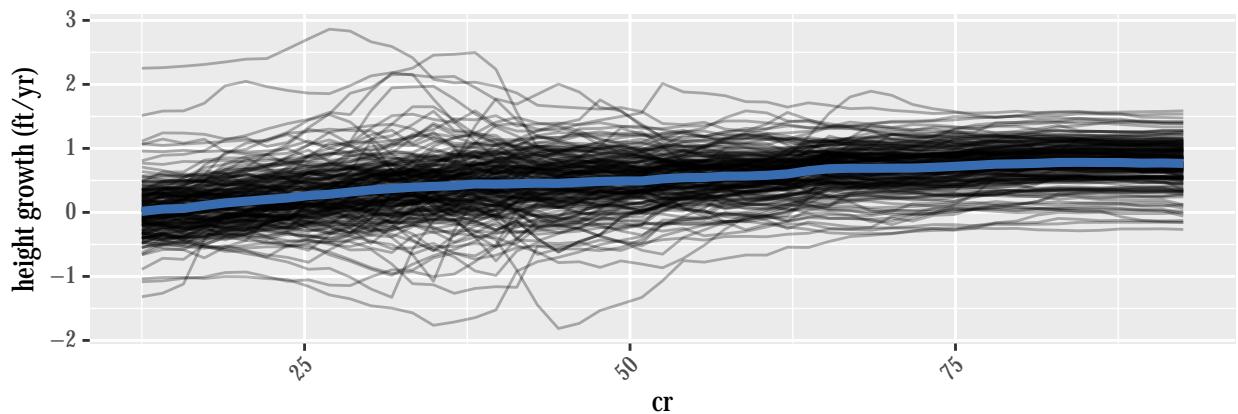
Centered ICE plot for dbh



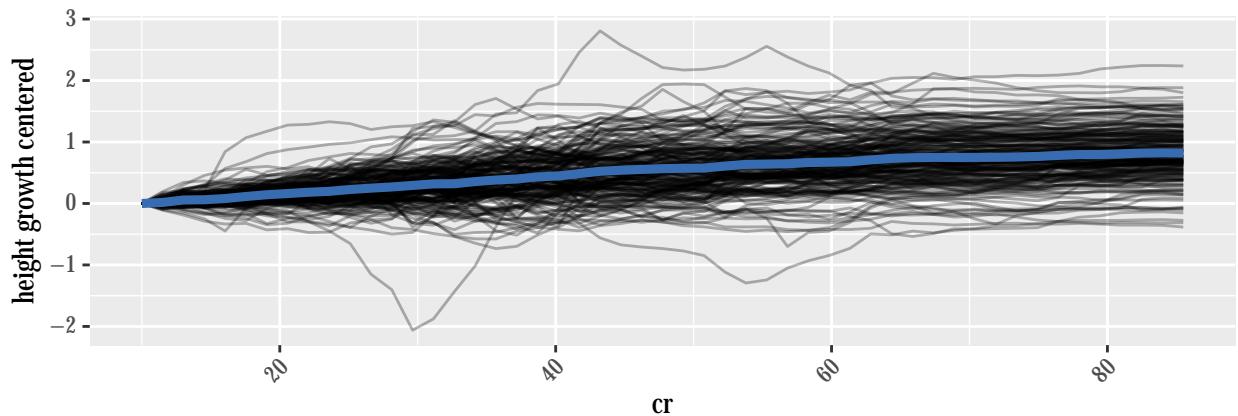
PDP for cr



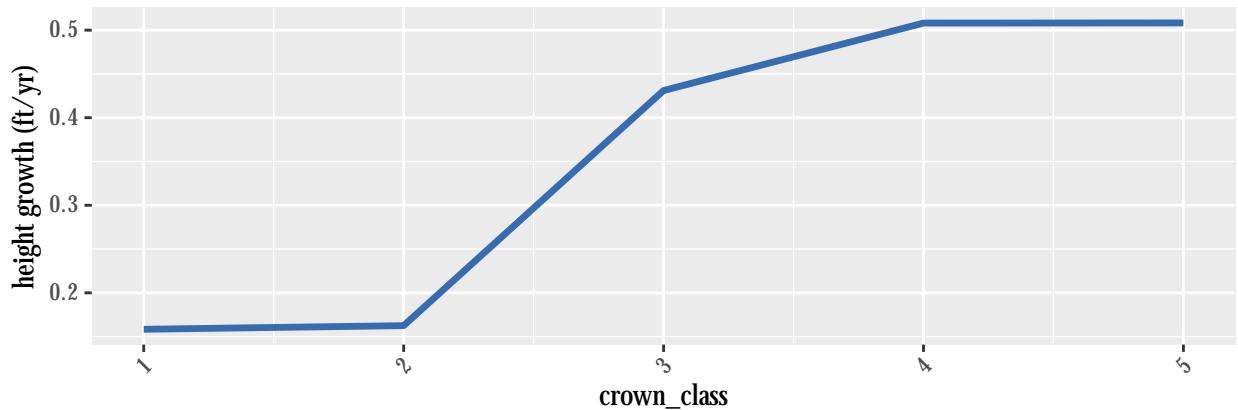
ICE plot for cr



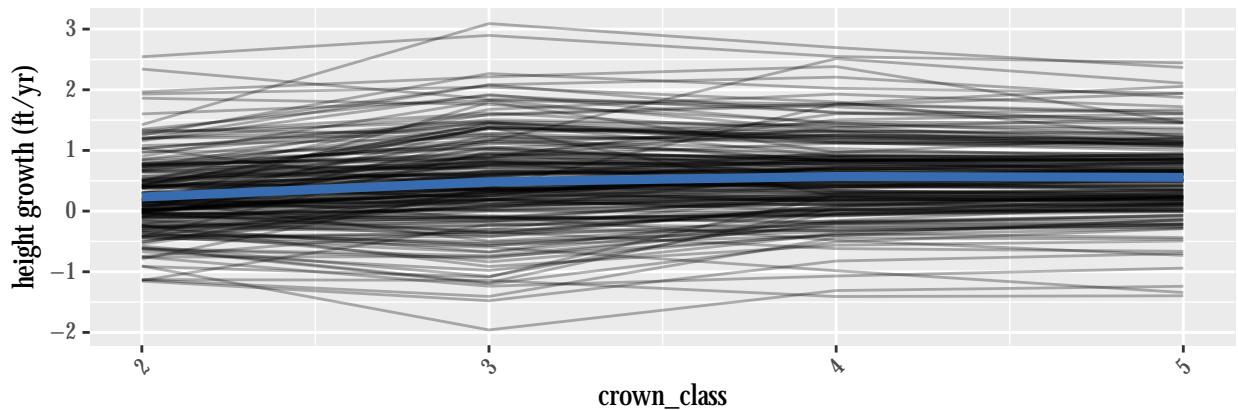
Centered ICE plot for cr



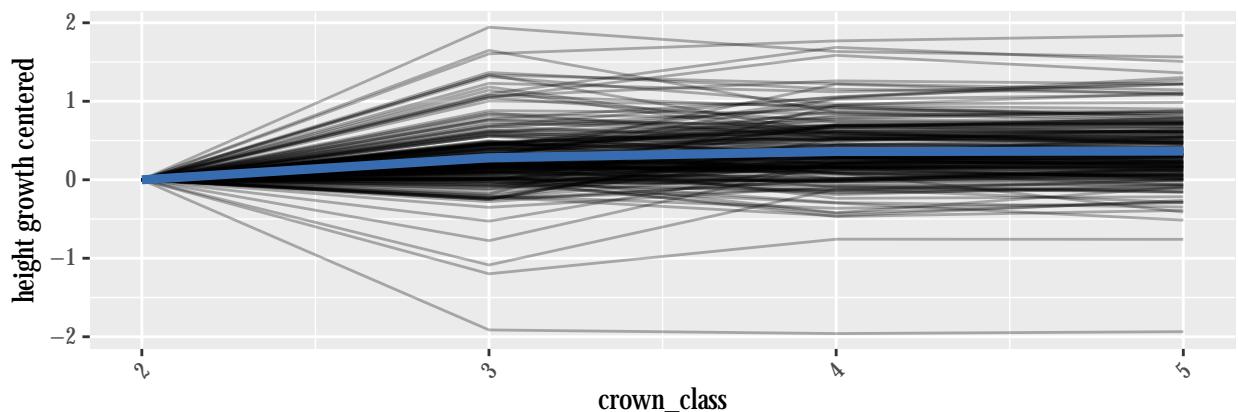
PDP for crown_class



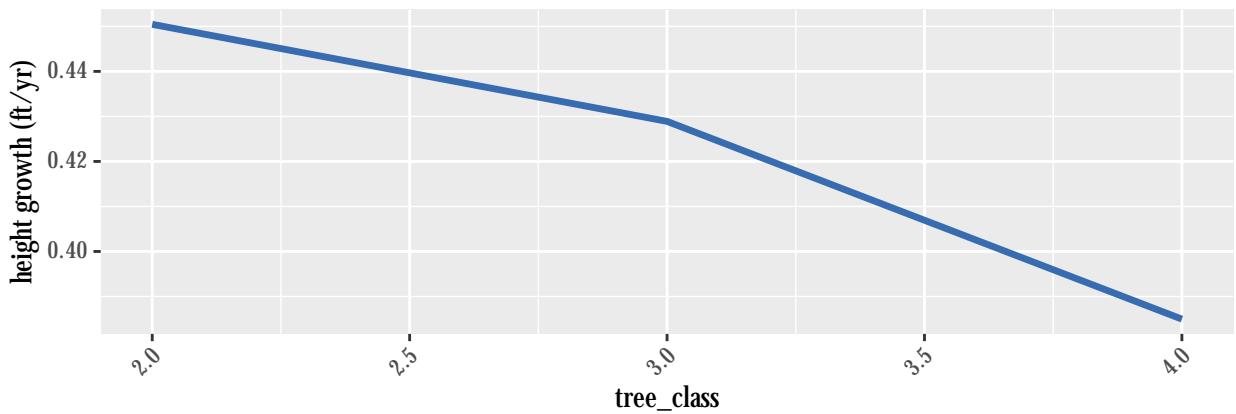
ICE plot for crown_class



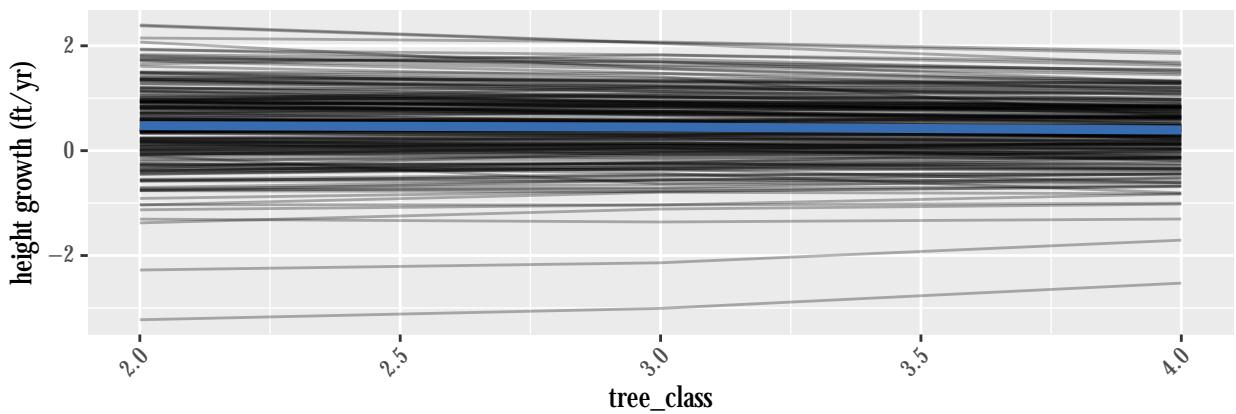
Centered ICE plot for crown_class



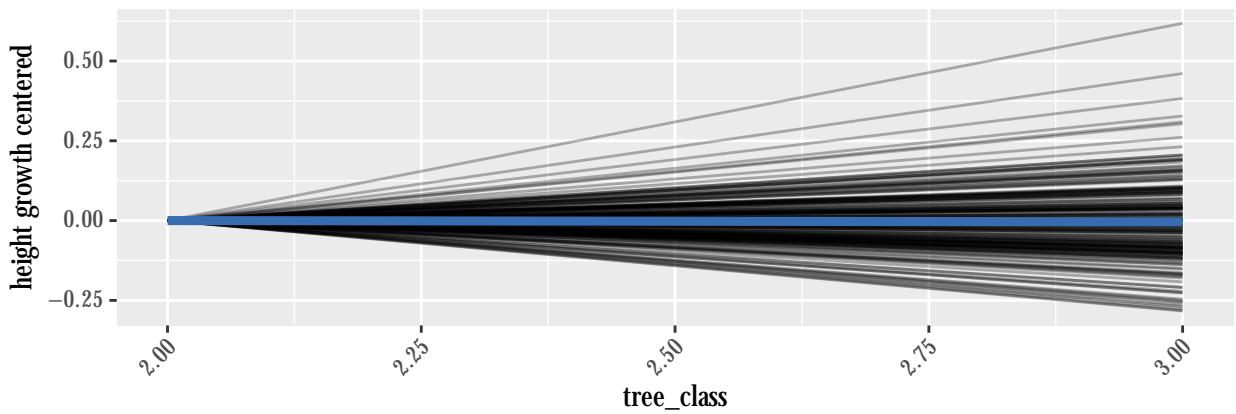
PDP for tree_class



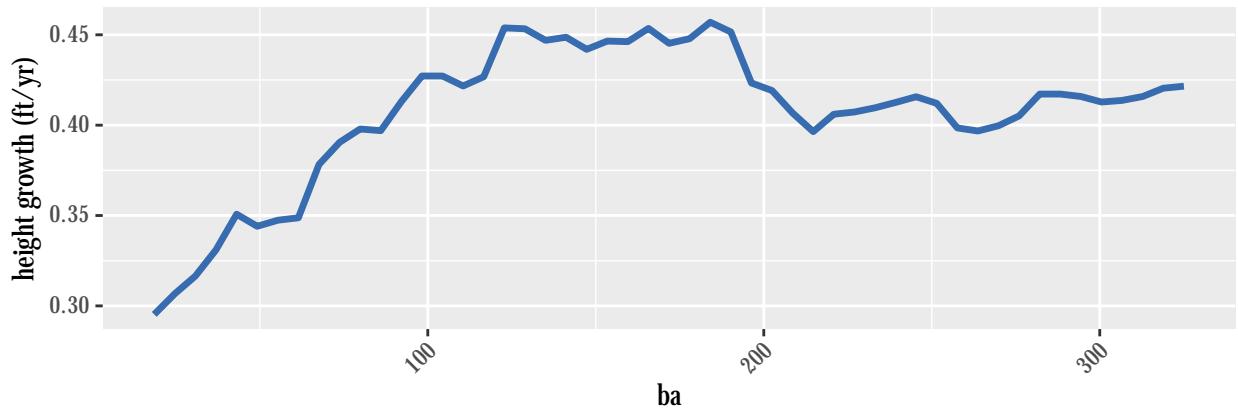
ICE plot for tree_class



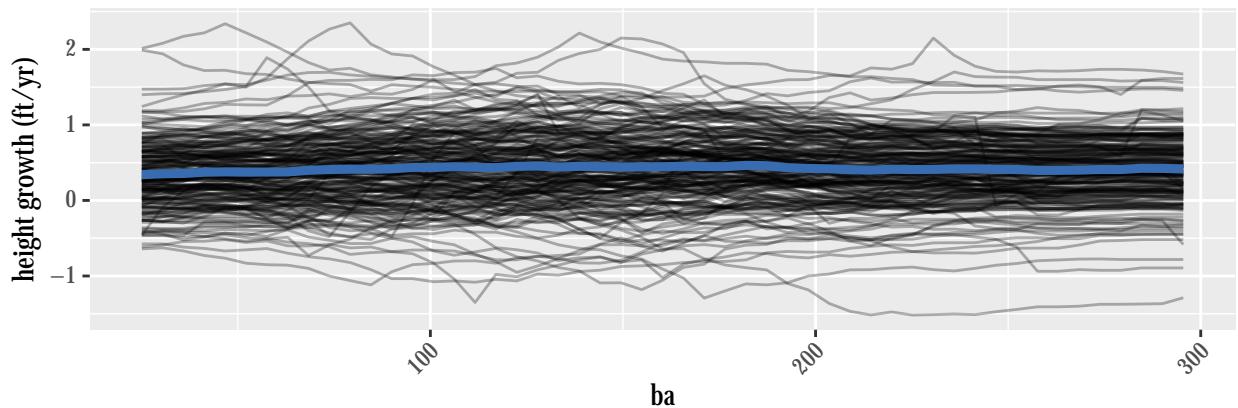
Centered ICE plot for tree_class



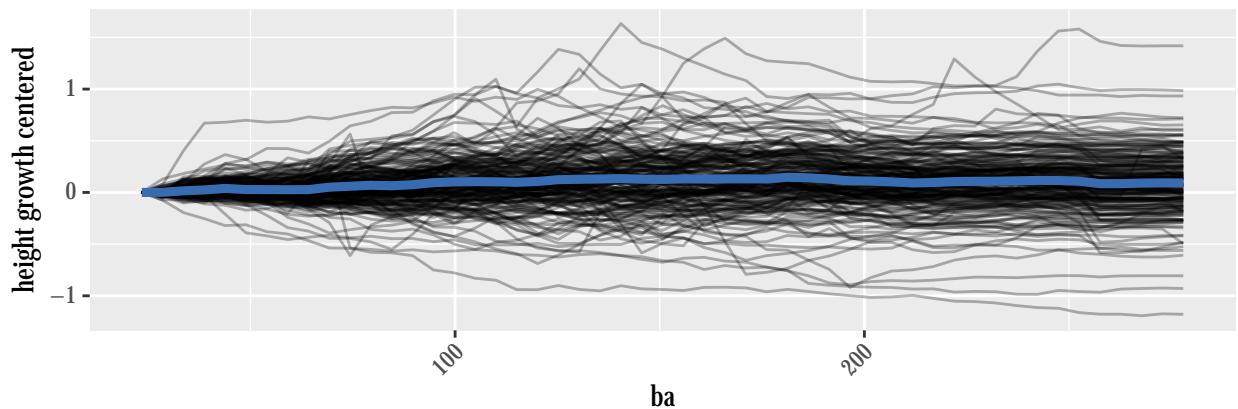
PDP for ba



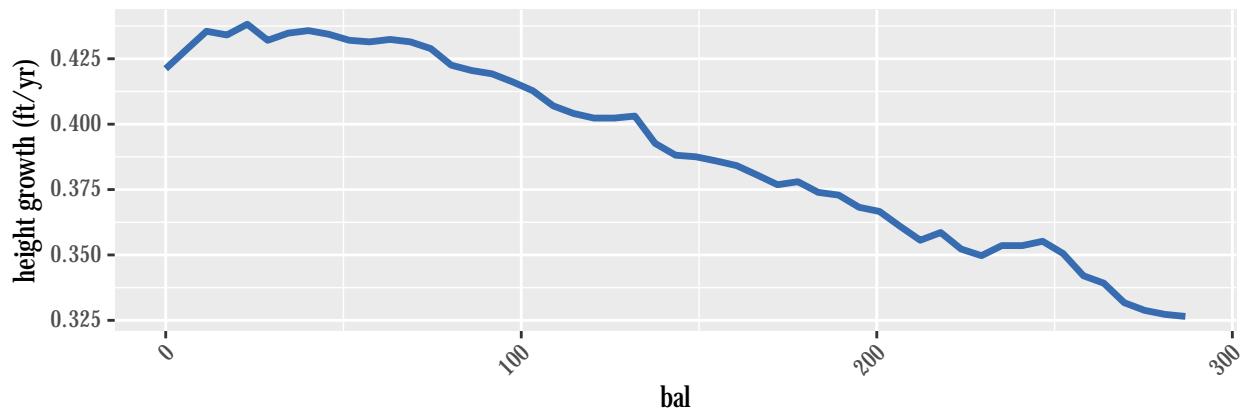
ICE plot for ba



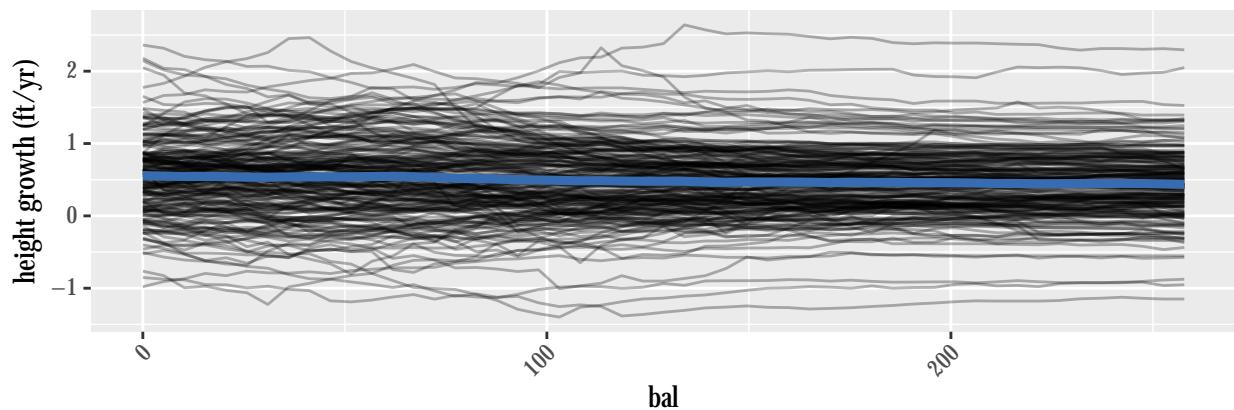
Centered ICE plot for ba



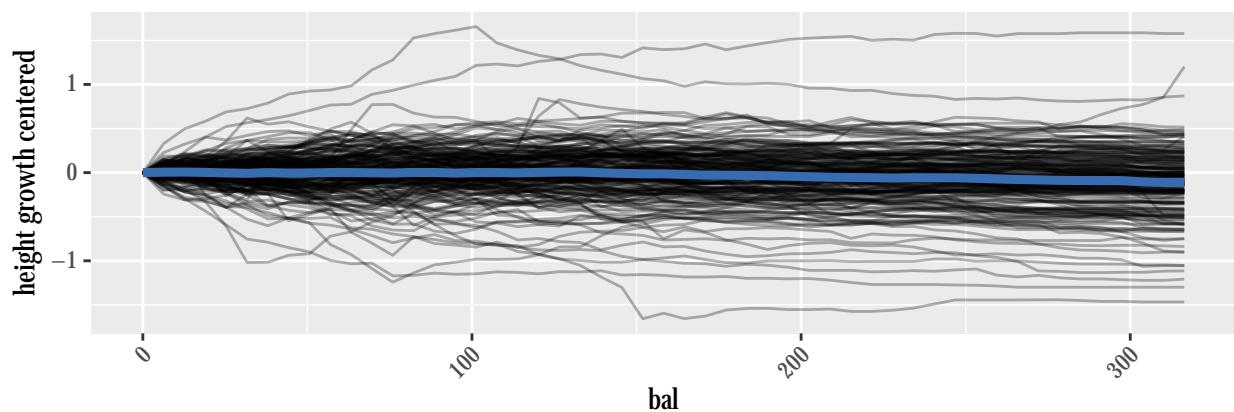
PDP for bal



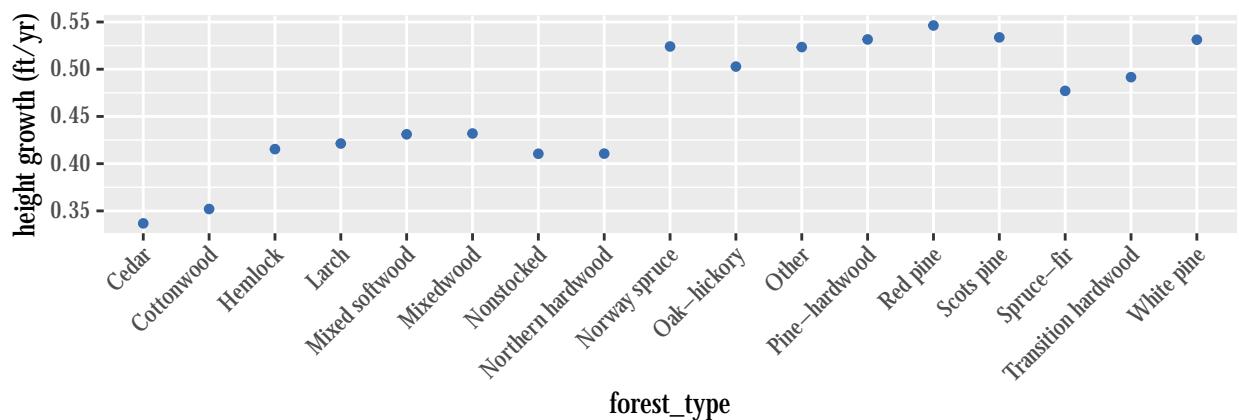
ICE plot for bal



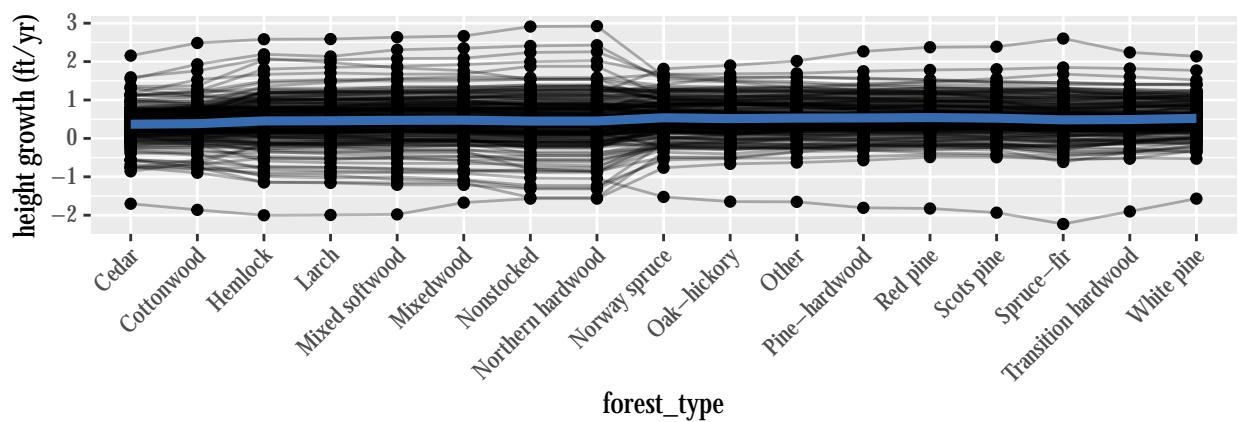
Centered ICE plot for bal



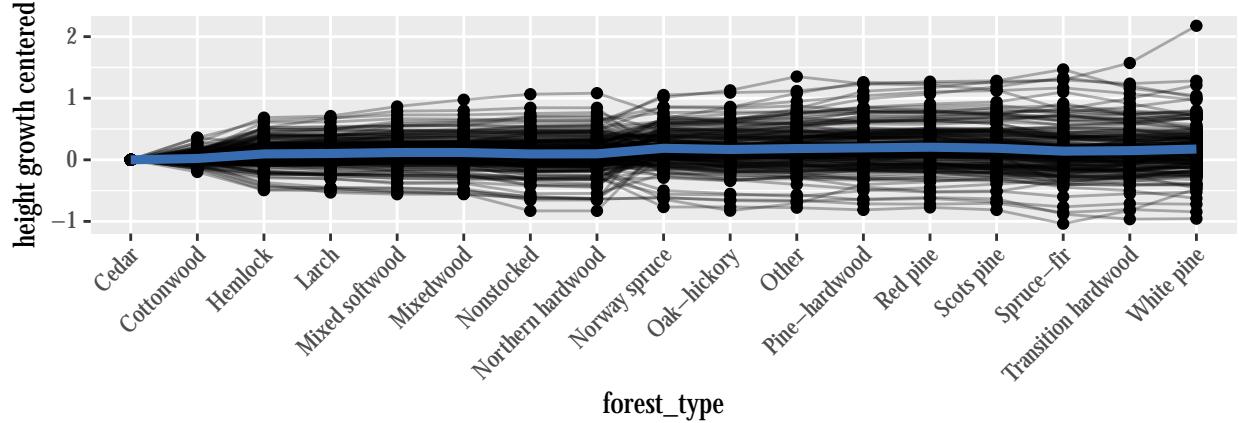
PDP for forest_type



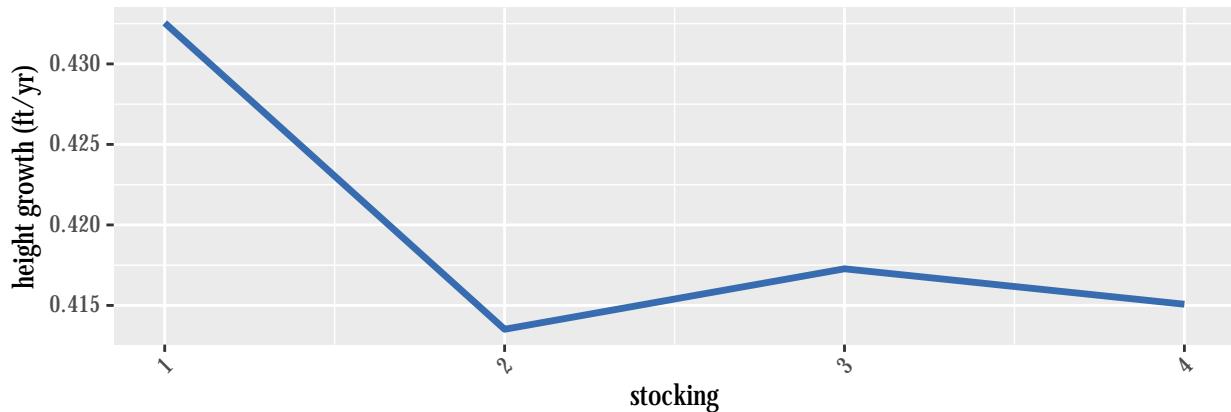
ICE plot for forest_type



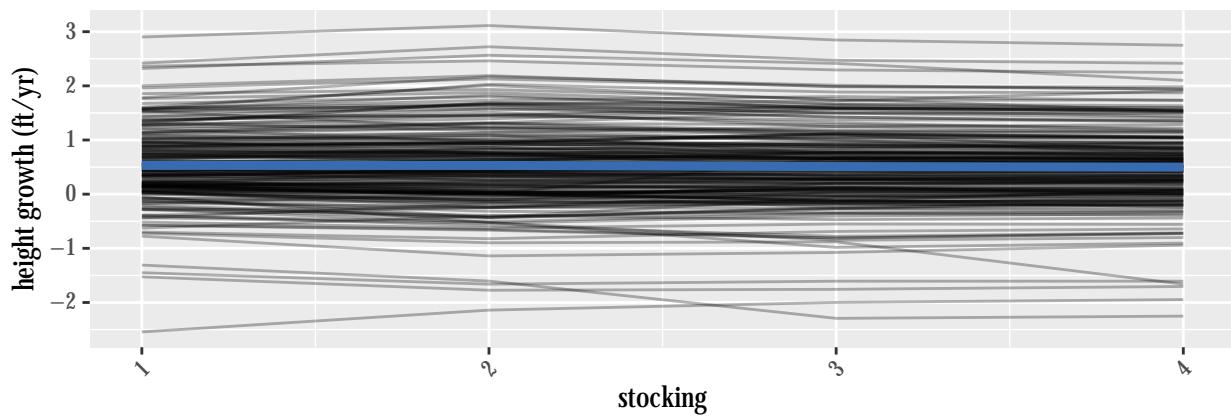
Centered ICE plot for forest_type



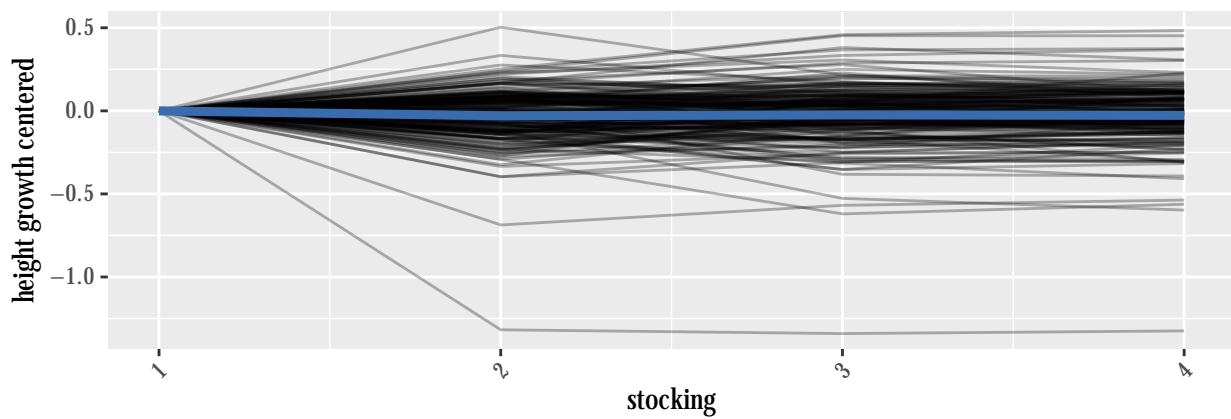
PDP for stocking

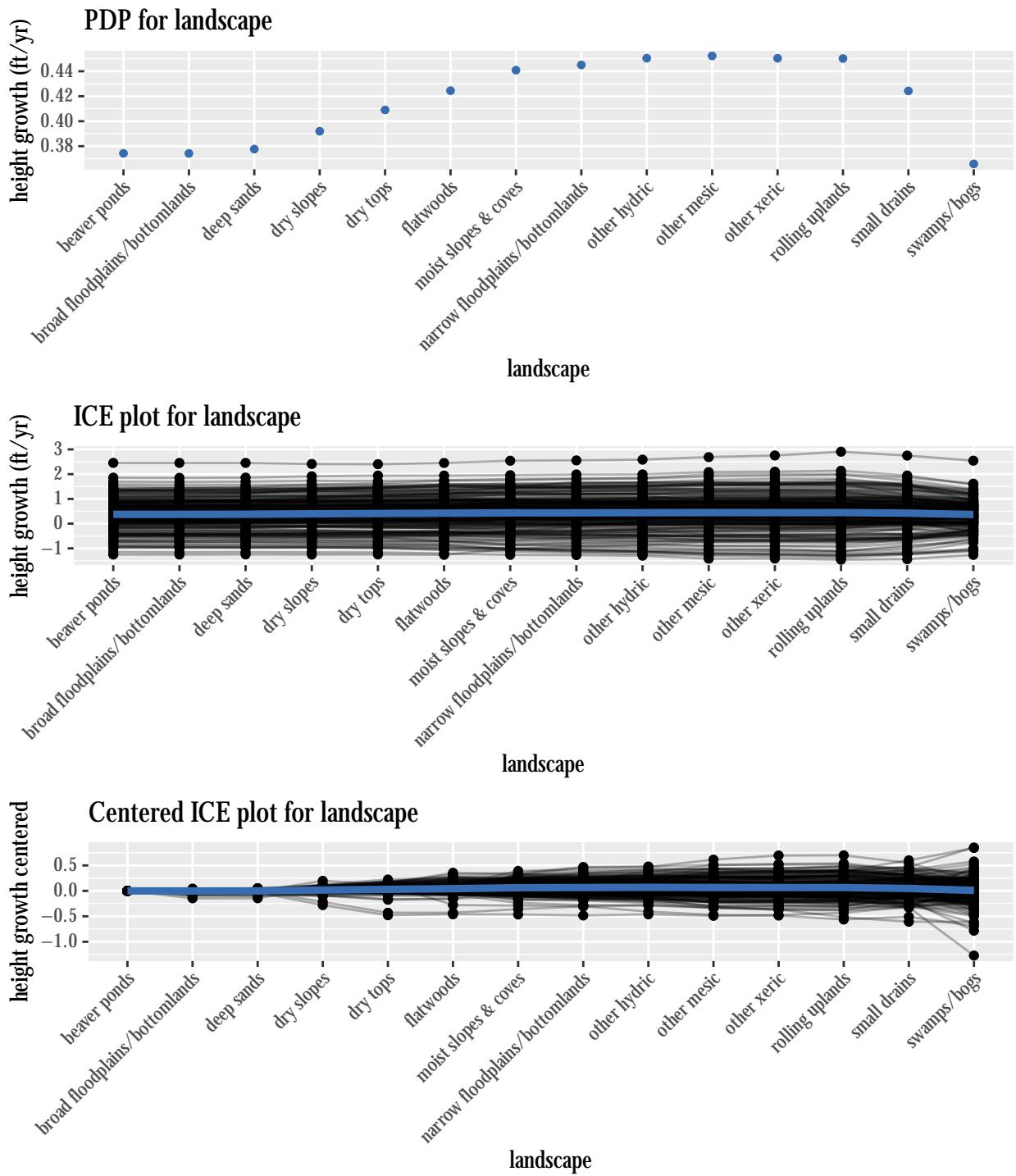


ICE plot for stocking

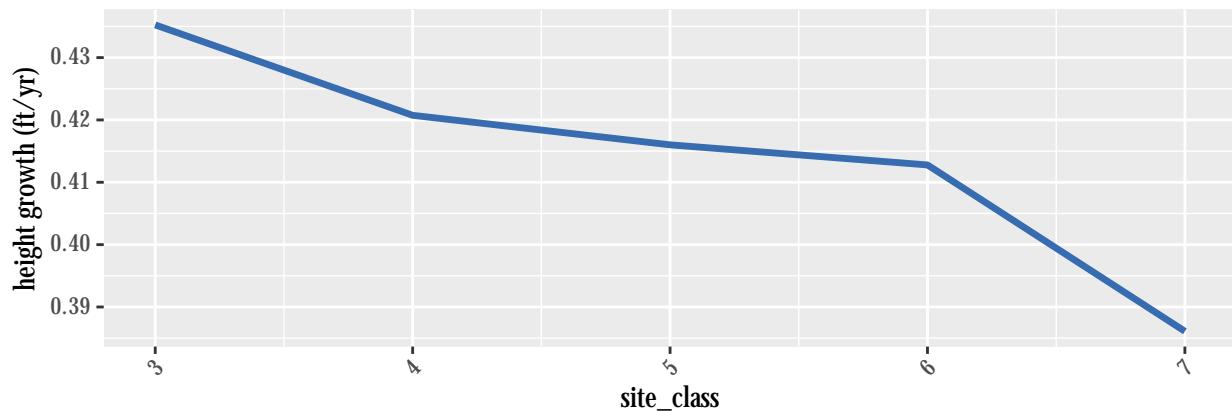


Centered ICE plot for stocking

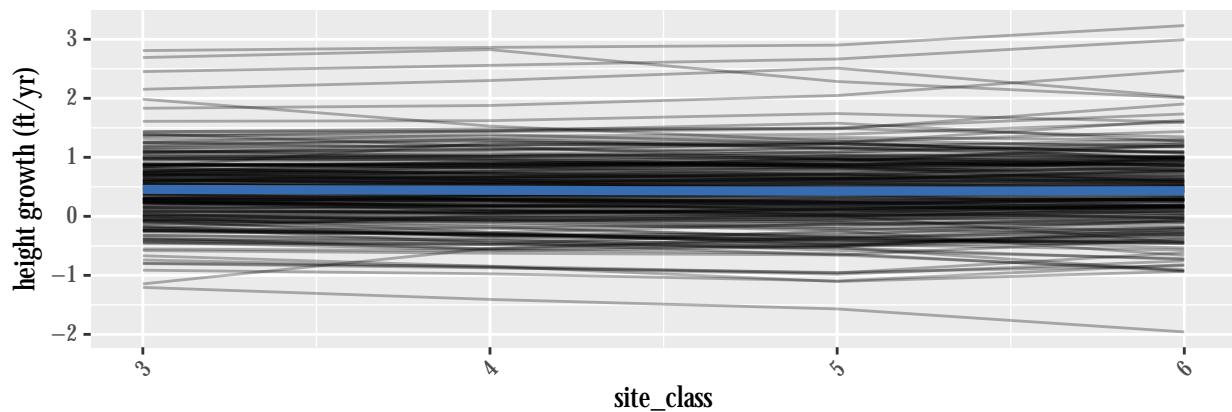




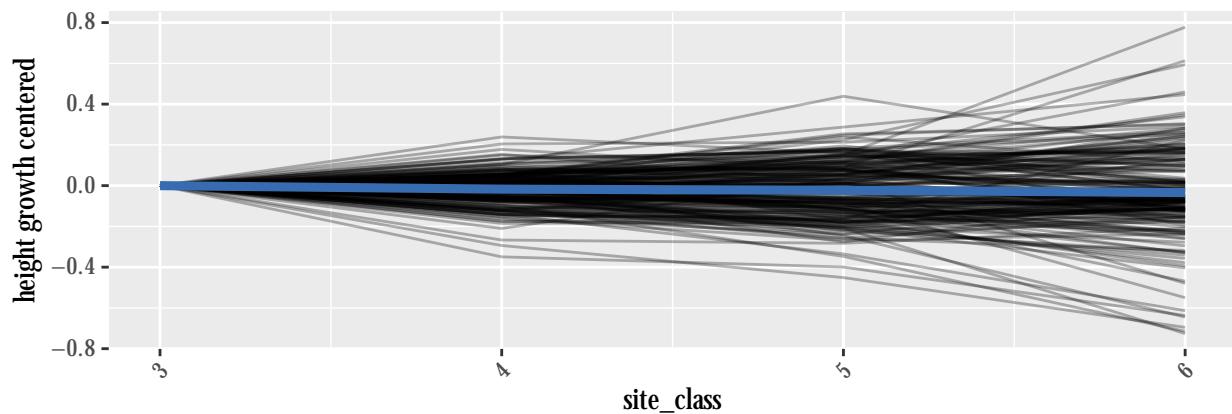
PDP for site_class



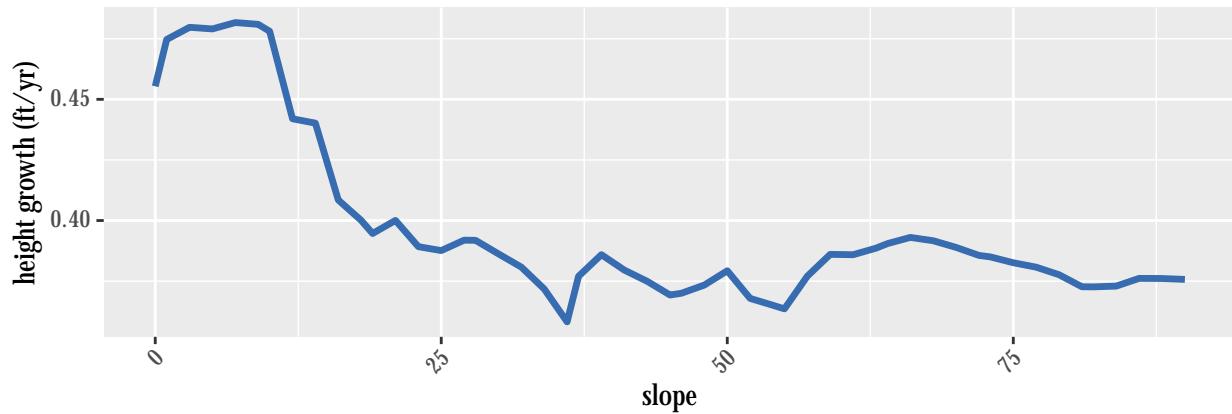
ICE plot for site_class



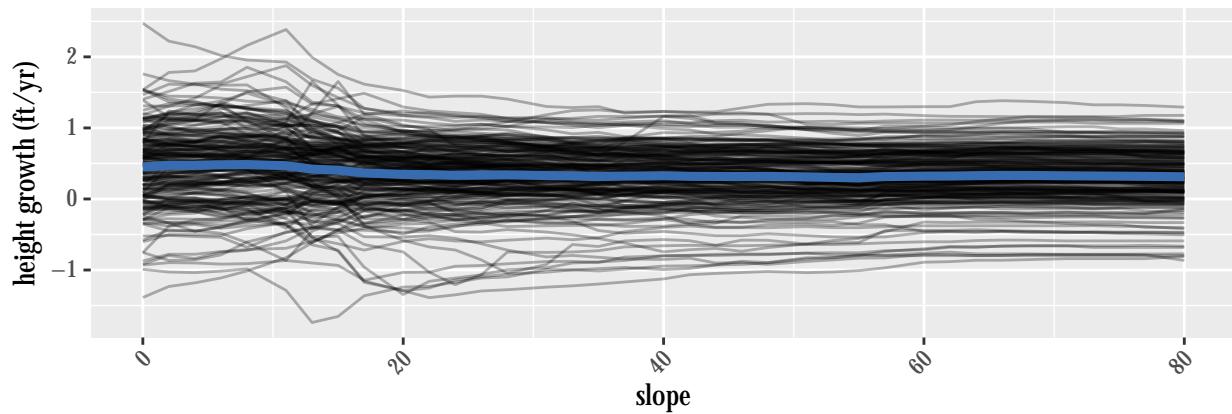
Centered ICE plot for site_class



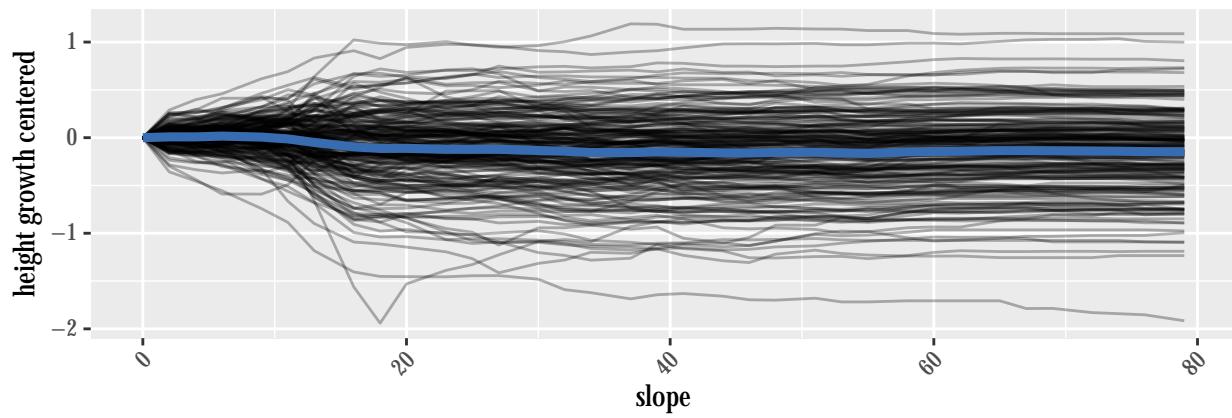
PDP for slope



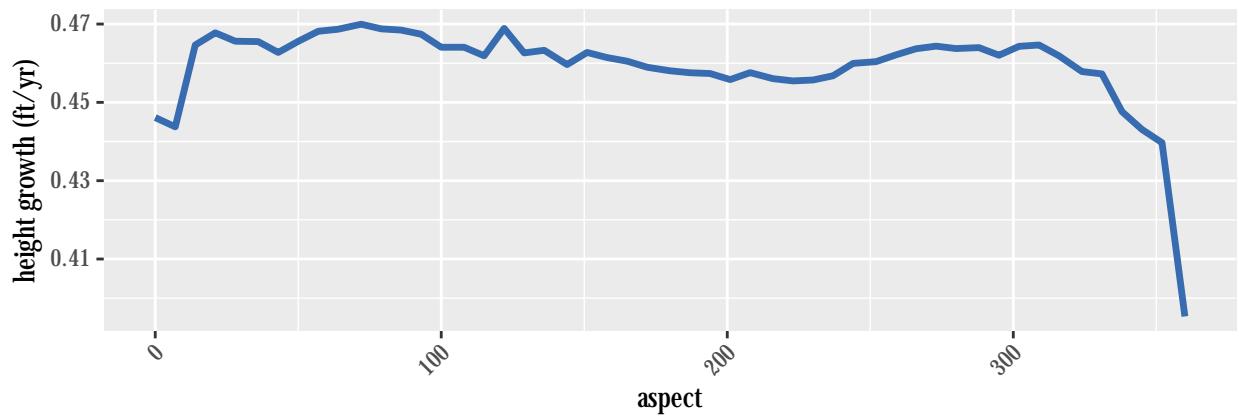
ICE plot for slope



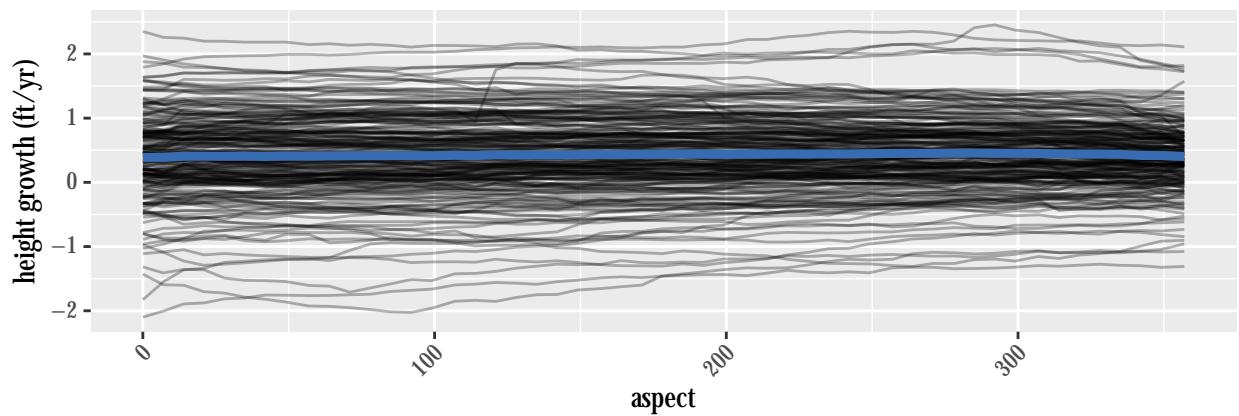
Centered ICE plot for slope



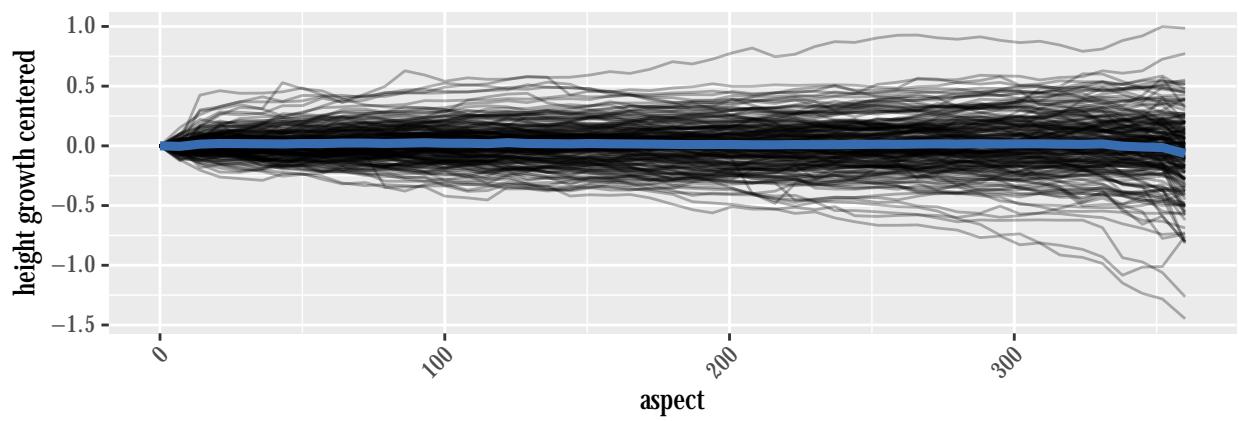
PDP for aspect



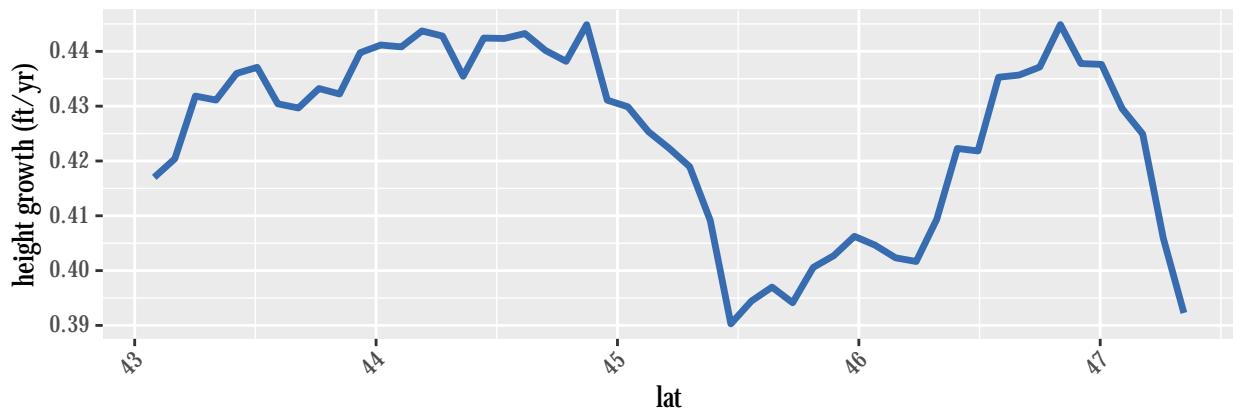
ICE plot for aspect



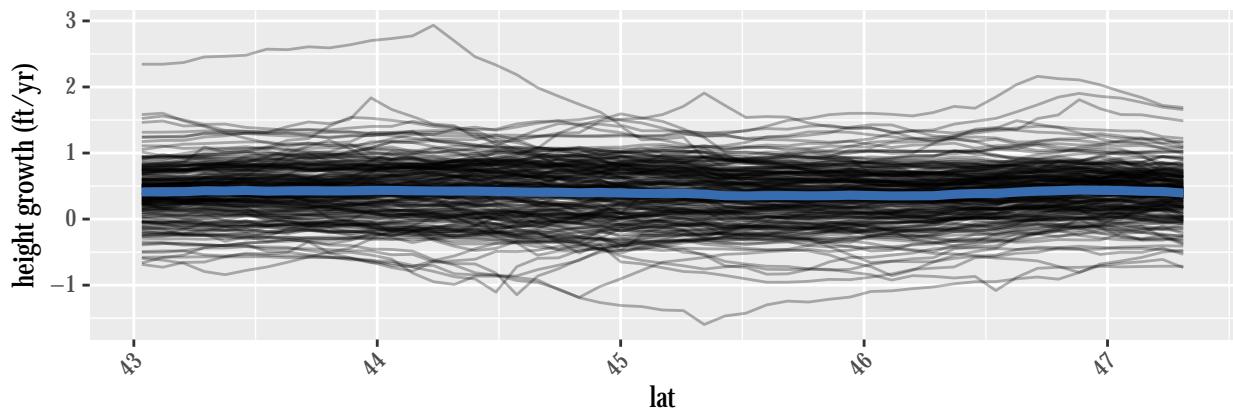
Centered ICE plot for aspect



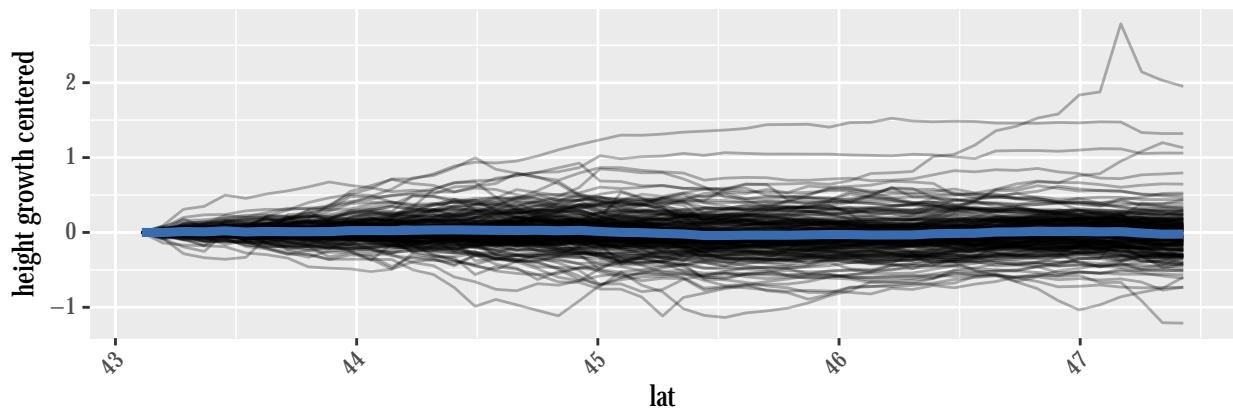
PDP for lat



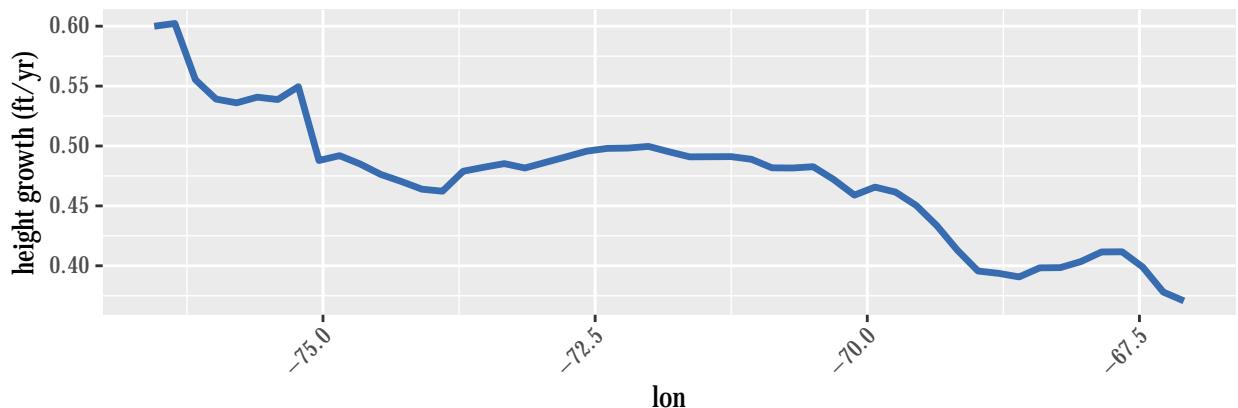
ICE plot for lat



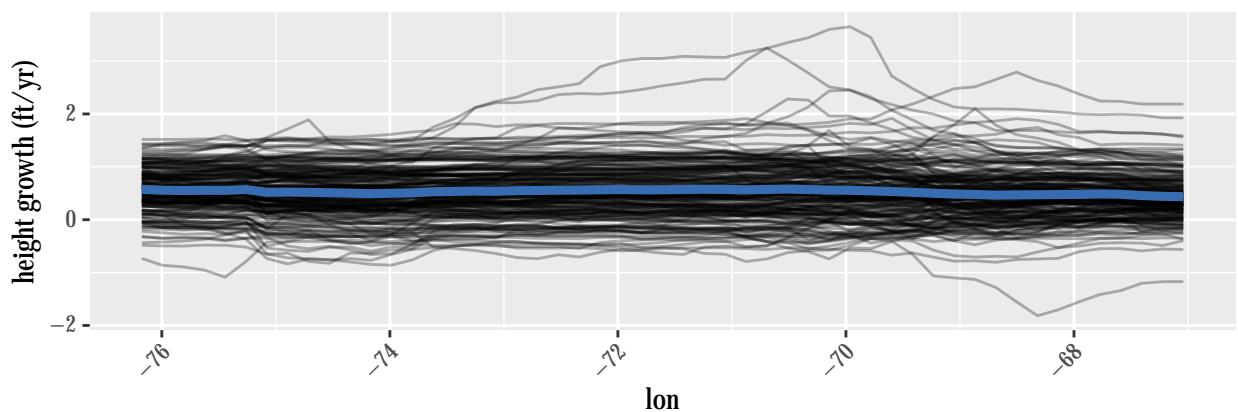
Centered ICE plot for lat



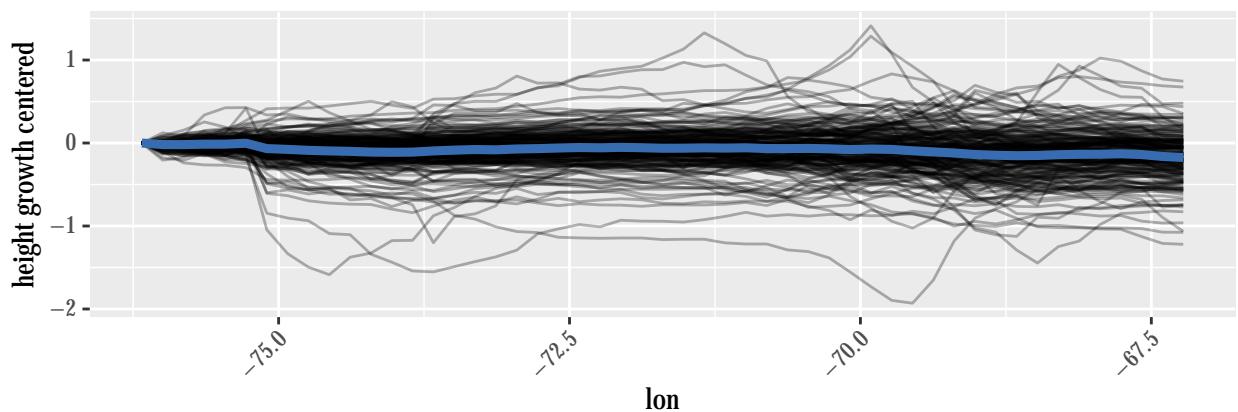
PDP for lon



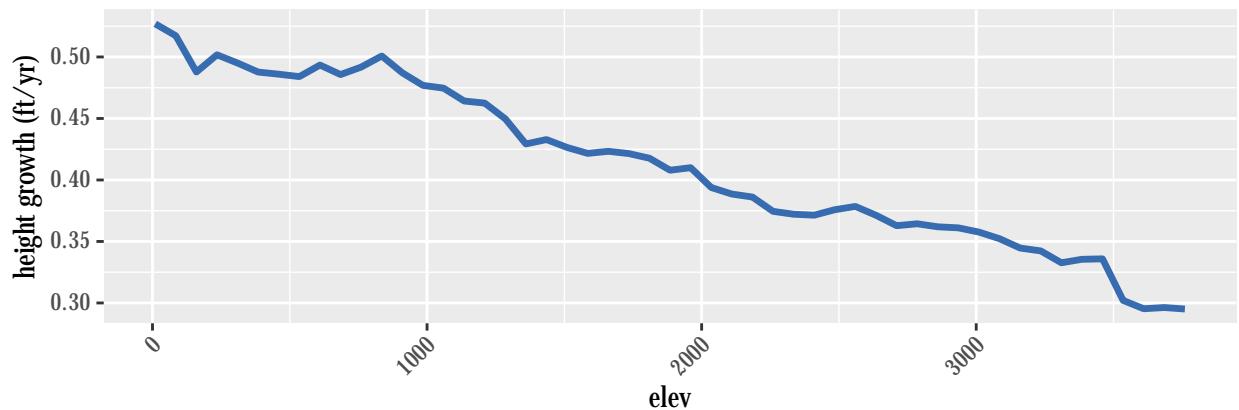
ICE plot for lon



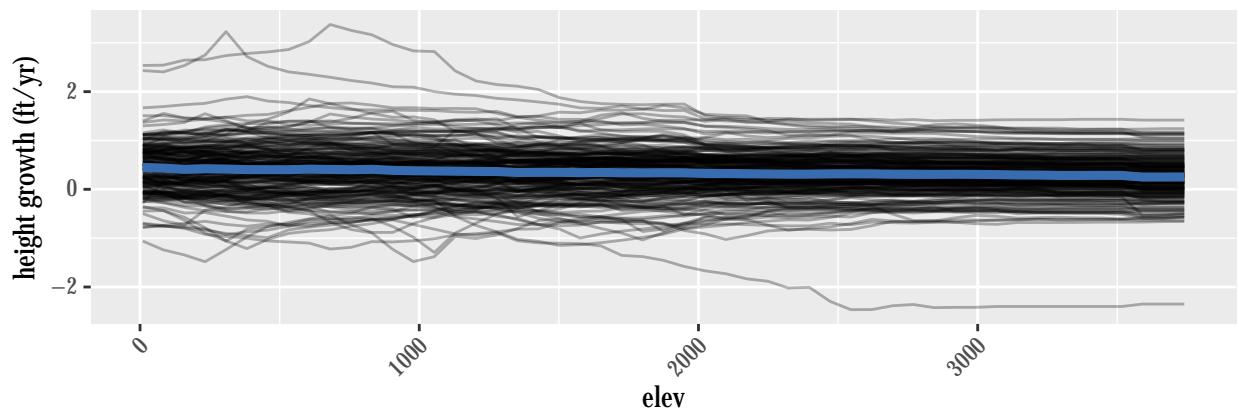
Centered ICE plot for lon



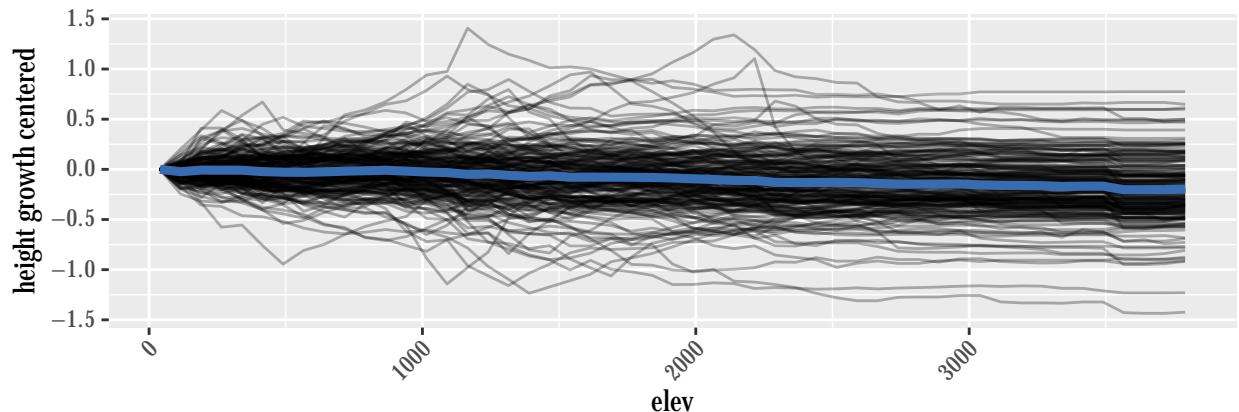
PDP for elev



ICE plot for elev



Centered ICE plot for elev



Crown Ratio Change Submodel

Table 8: Accuracy estimates, calculated on out of bag data

RMSE	R ²	MAE
2.41	0.252	1.79

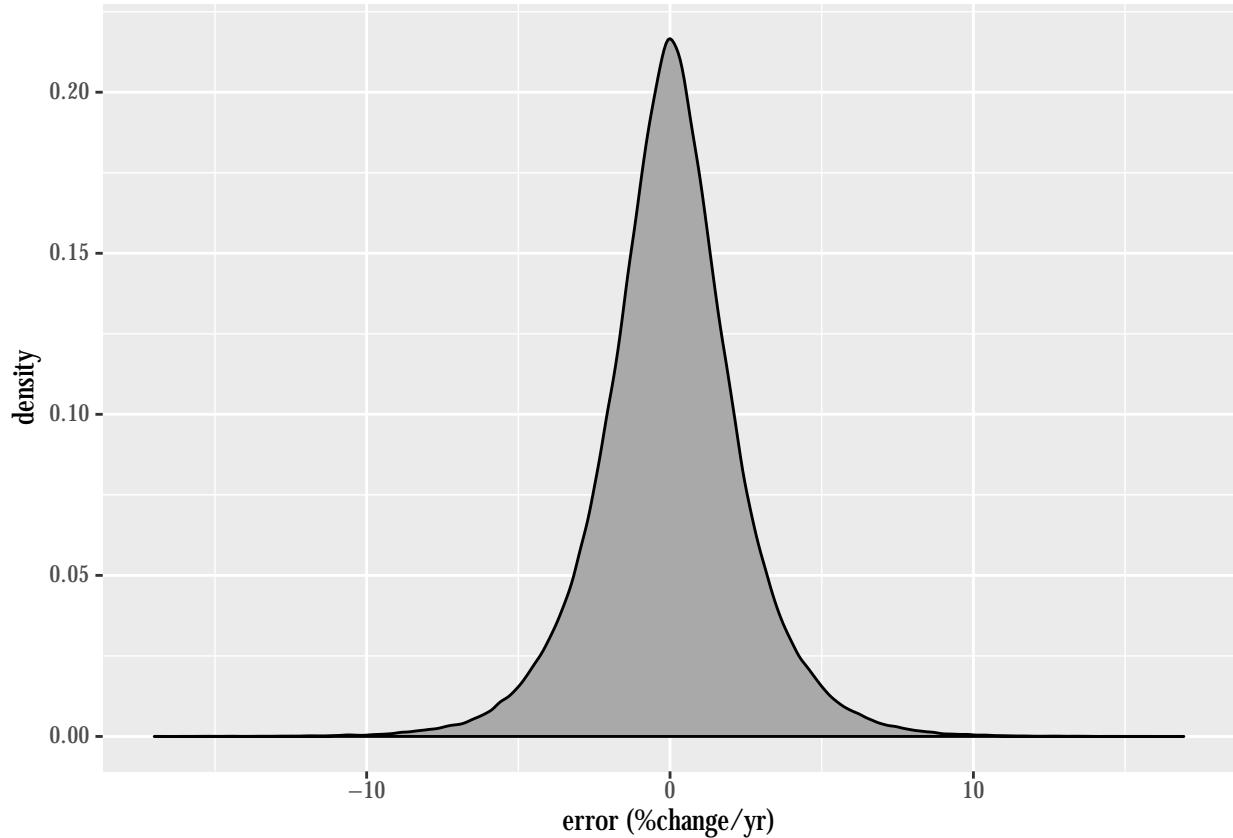


Figure 7: Overall error distribution estimated with kernel density.

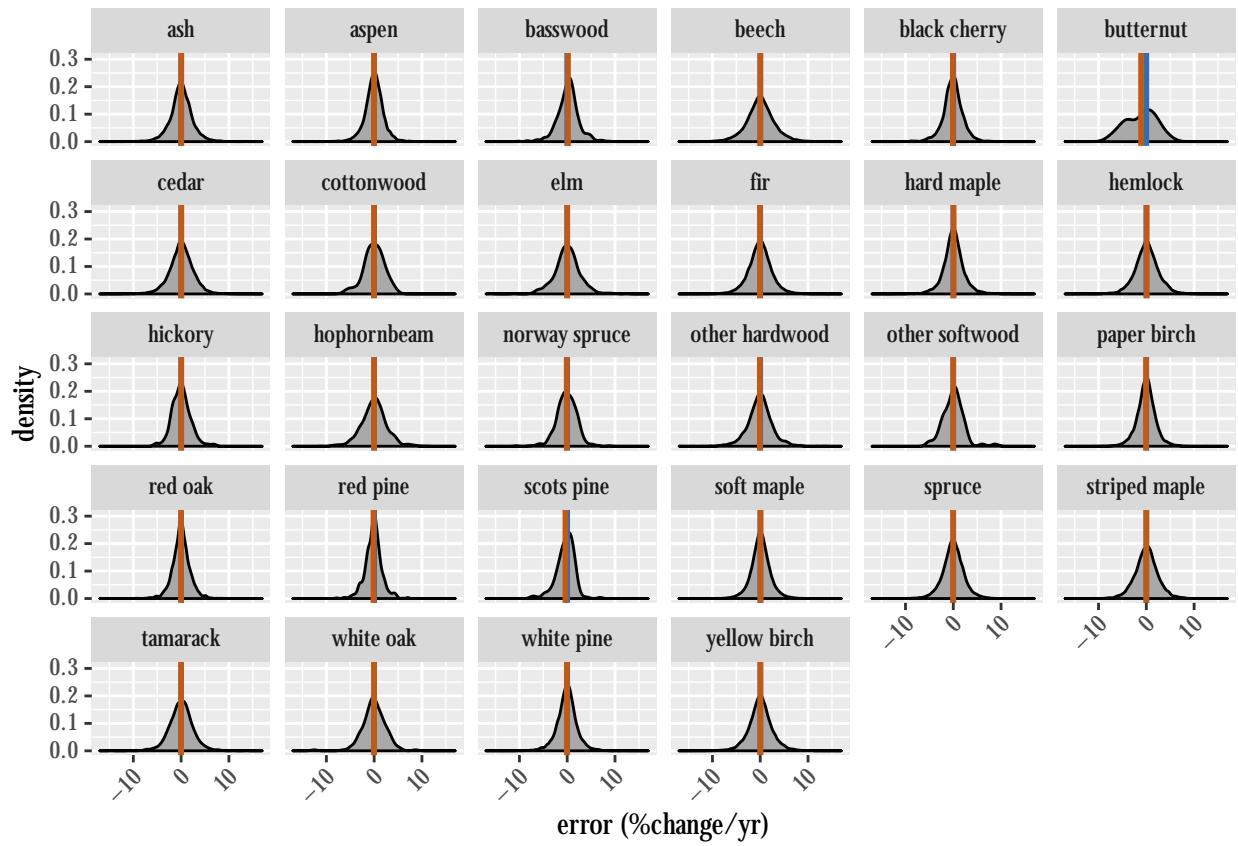
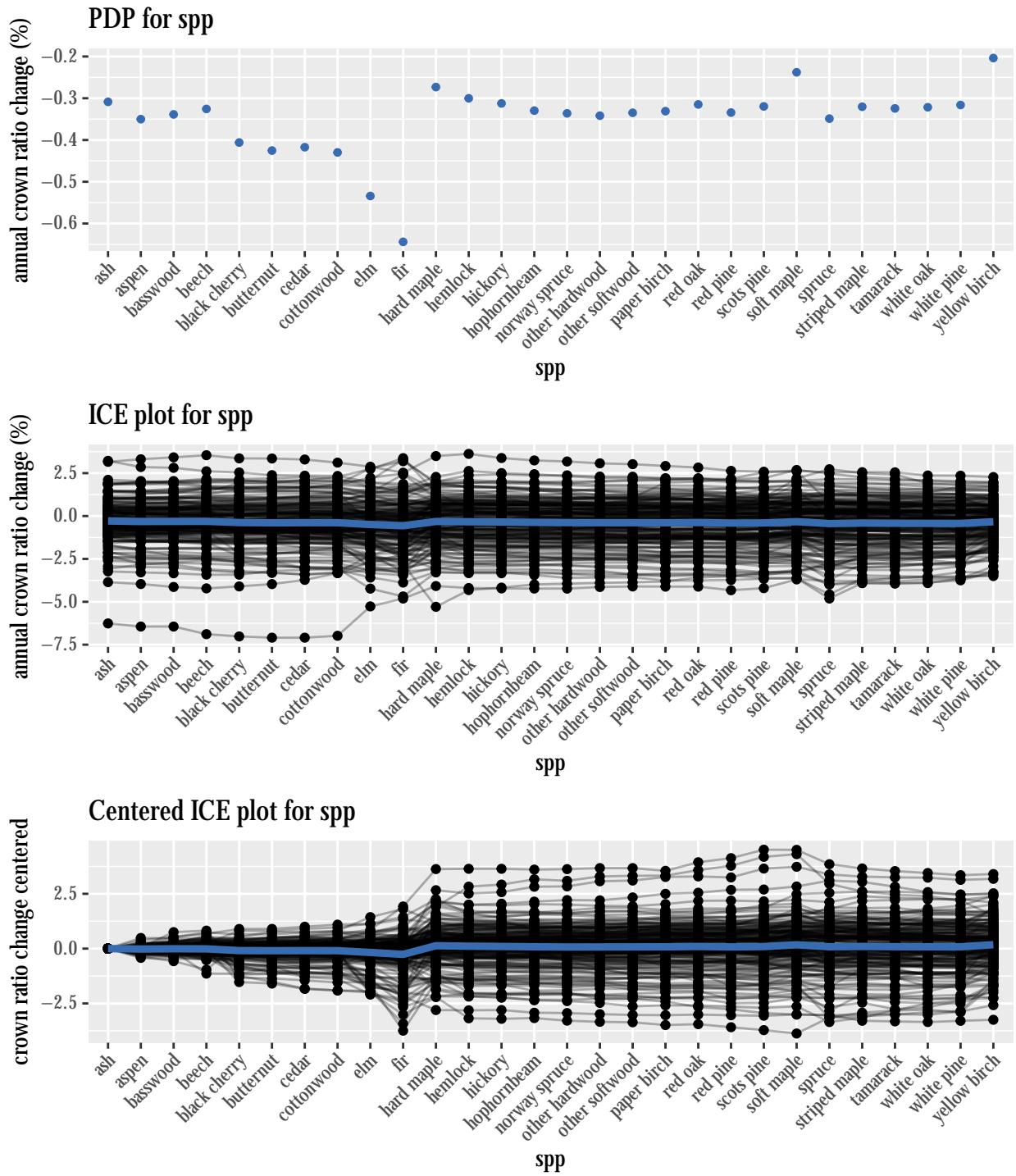


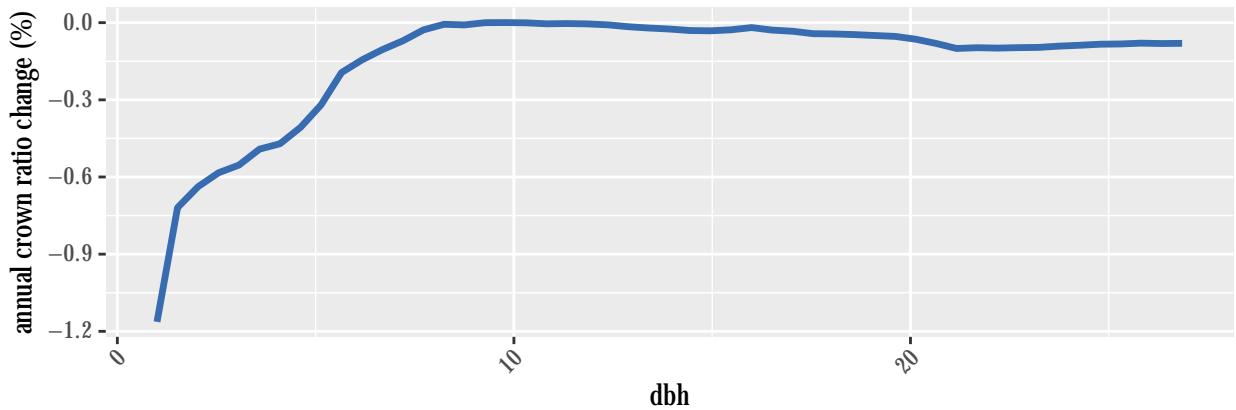
Figure 8: Error distributions for individual species estimated with kernal density. Blue vertical lines indicate 0 (no error). Brown vertical lines indicate mean species errors.

Table 9: Sample sizes and normalized root mean square errors by species

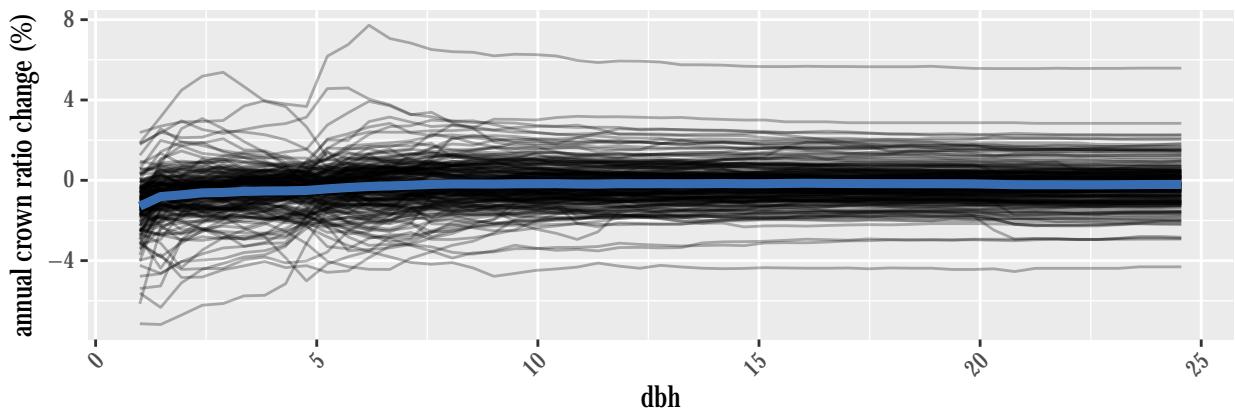
spp	n	nRMSE
fir	62729	-2.2696
spruce	42081	-4.3475
soft maple	36343	20.7422
hard maple	19627	12.0227
cedar	19144	-26.0229
beech	18883	68.4516
yellow birch	16309	24.8857
paper birch	15977	-7.0305
hemlock	14024	26.7587
white pine	9480	-5.6368
aspen	7875	-6.3082
ash	7110	-21.2589
other hardwood	5010	-5.1796
striped maple	4265	-7.0783
red oak	3199	-36.1653
black cherry	2192	-7.3796
hophornbeam	1824	-14.7865
tamarack	1398	-5.2289
red pine	1084	-1.7118
elm	750	-24.7116
norway spruce	533	-2.9006
basswood	525	12.8131
hickory	321	104.6614
scots pine	188	-1.5570
white oak	170	-3280.9489
other softwood	71	-6.8049
butternut	31	-2.2516
cottonwood	26	9.7696



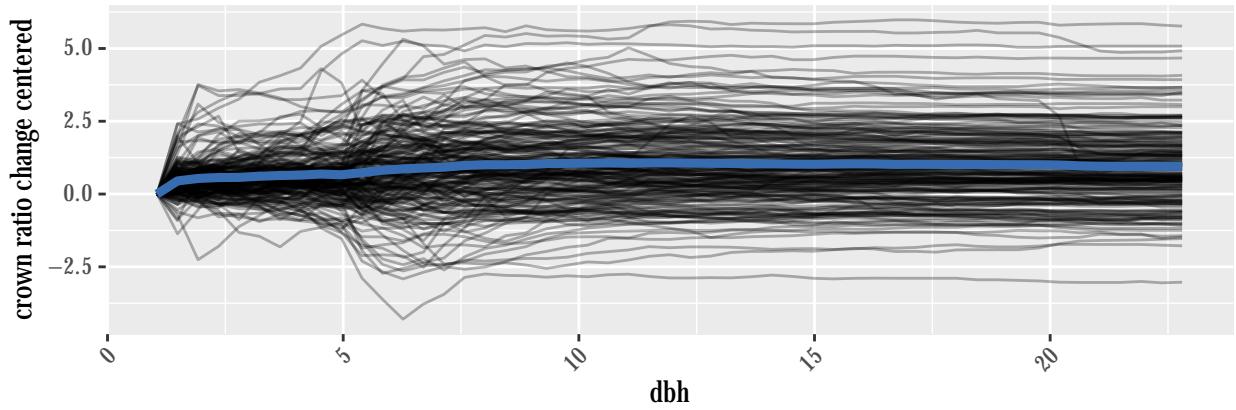
PPD for dbh



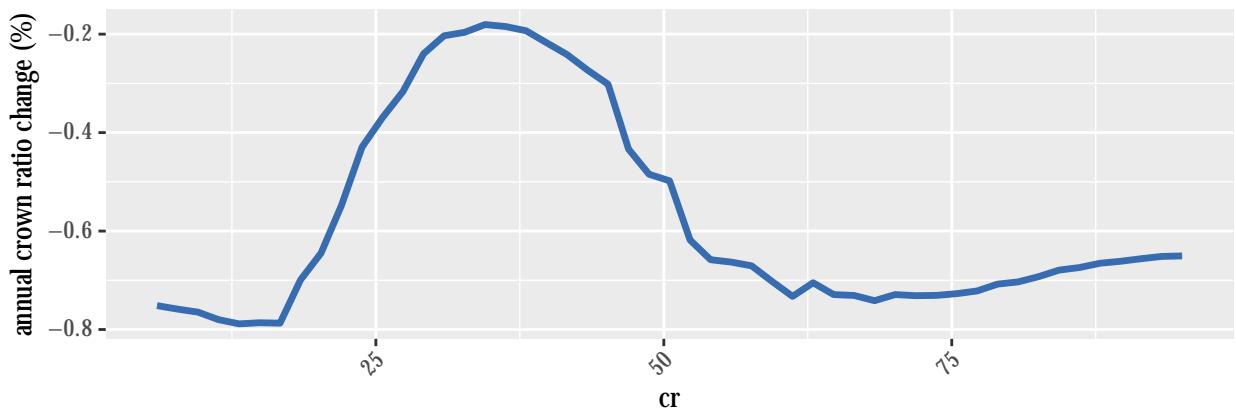
ICE plot for dbh



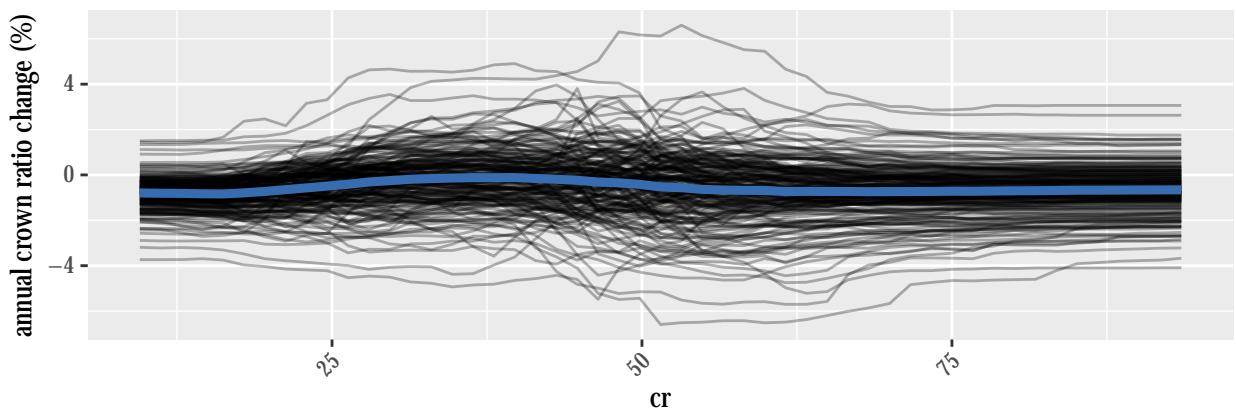
Centered ICE plot for dbh



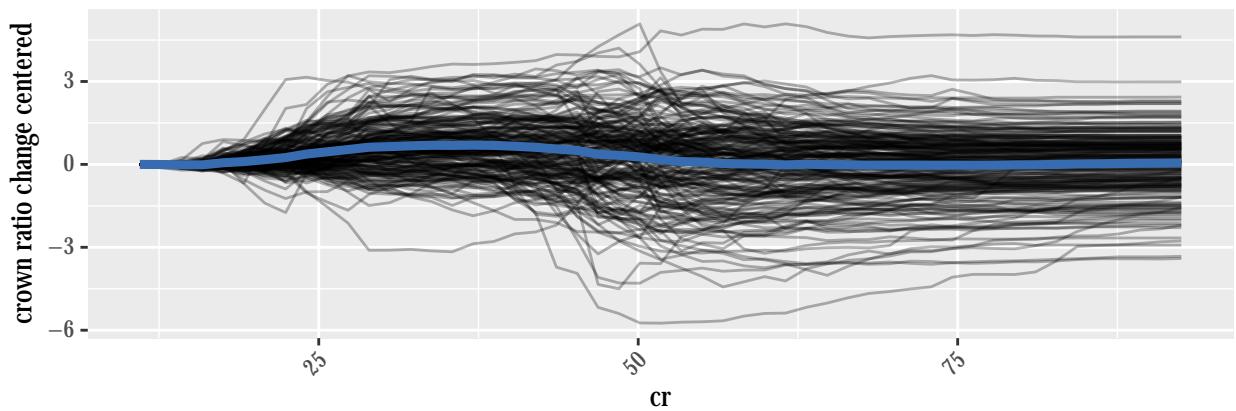
PPD for cr



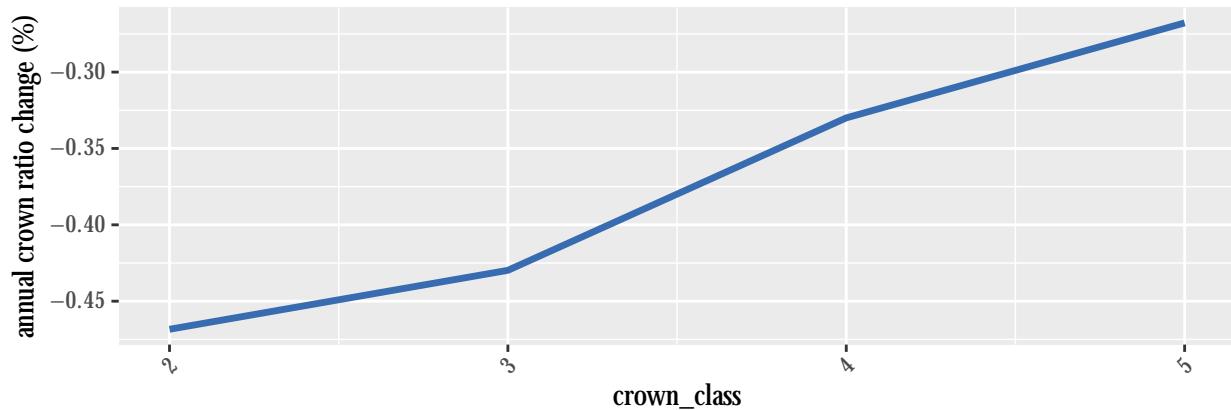
ICE plot for cr



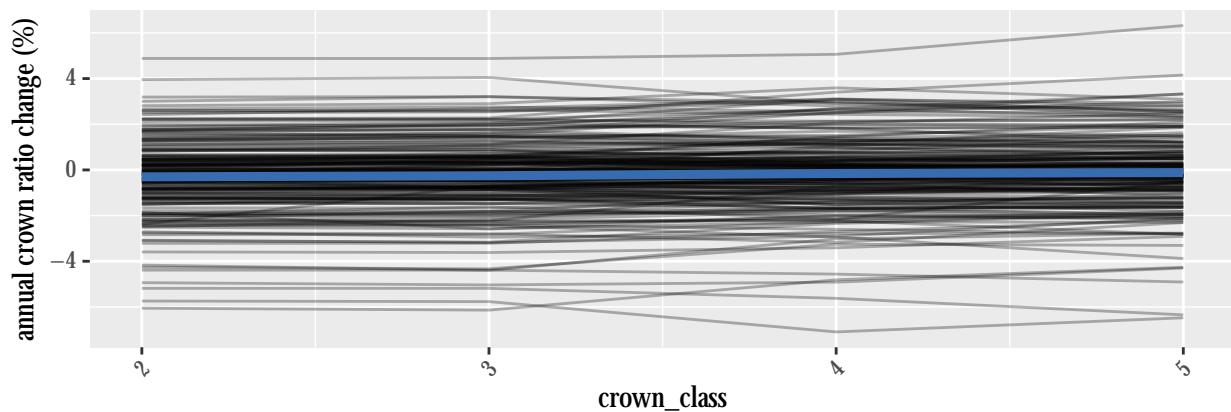
Centered ICE plot for cr



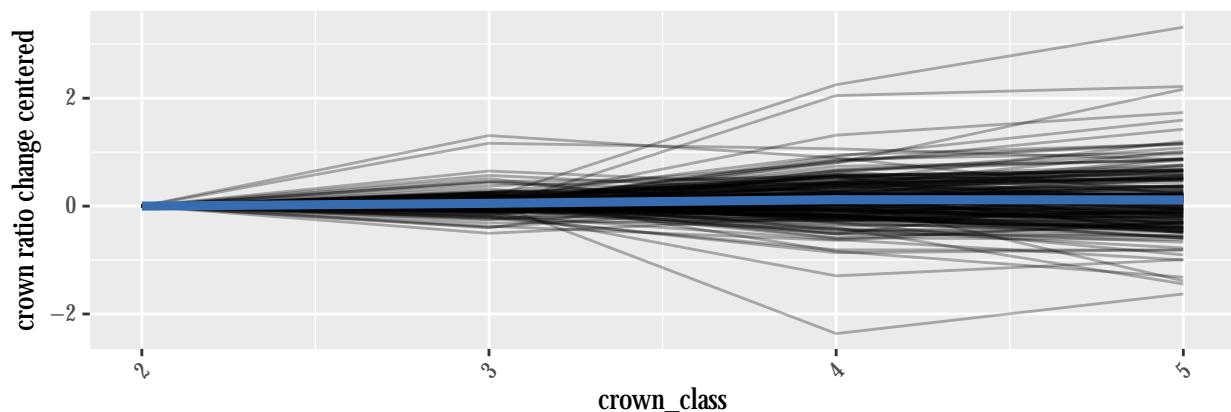
PDP for crown_class



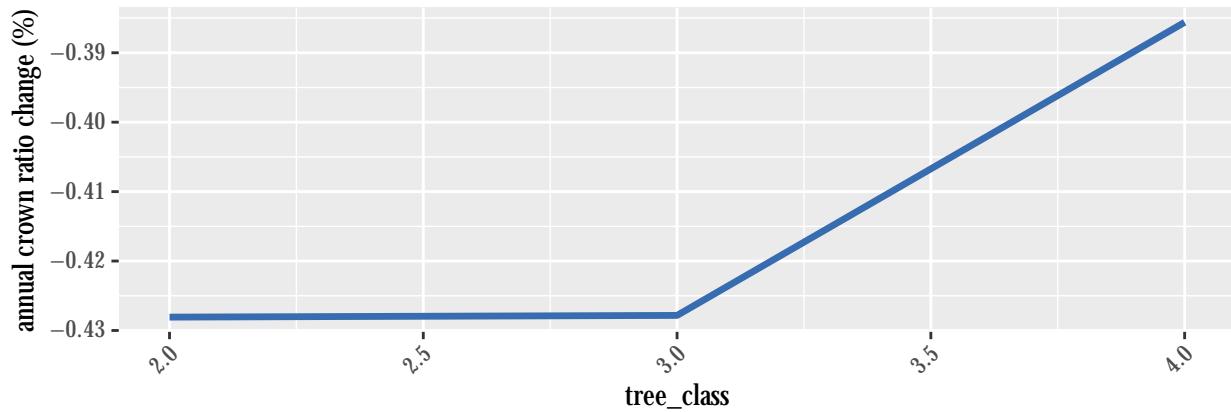
ICE plot for crown_class



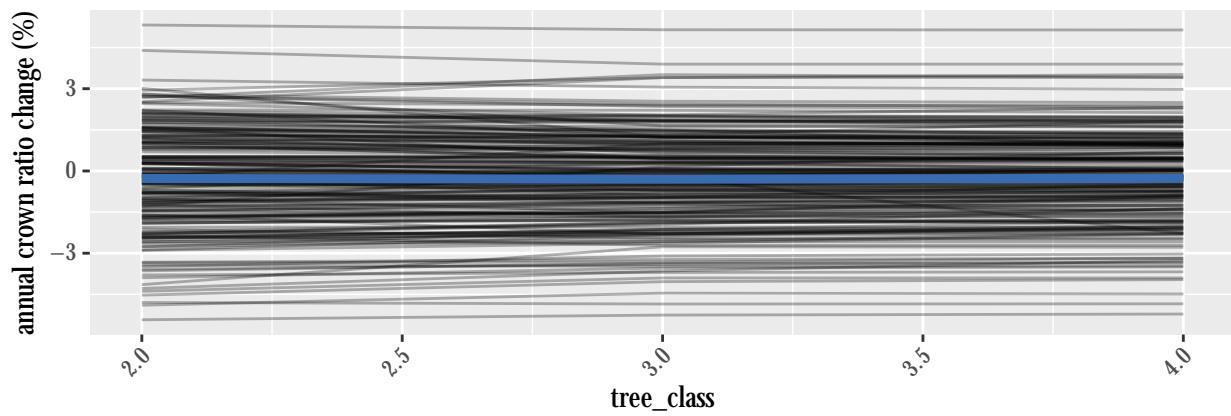
Centered ICE plot for crown_class



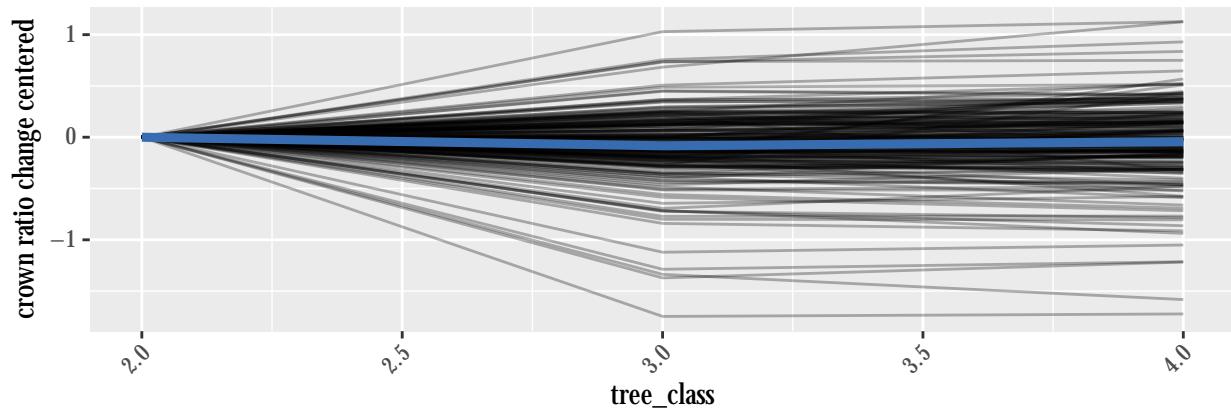
PDP for tree_class



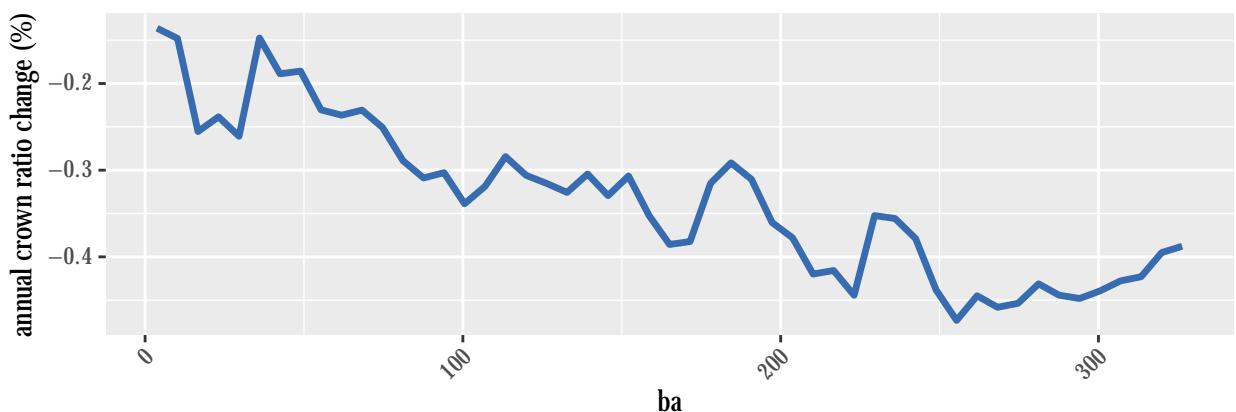
ICE plot for tree_class



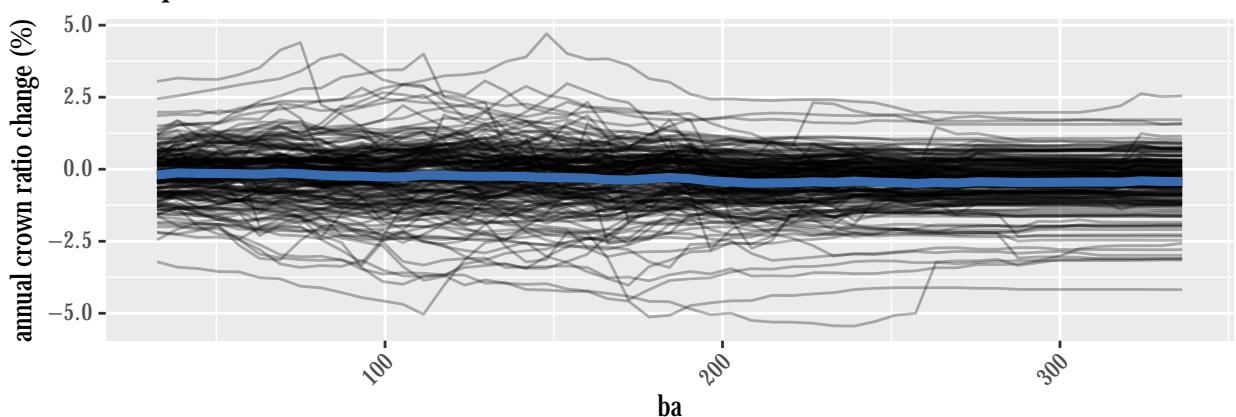
Centered ICE plot for tree_class



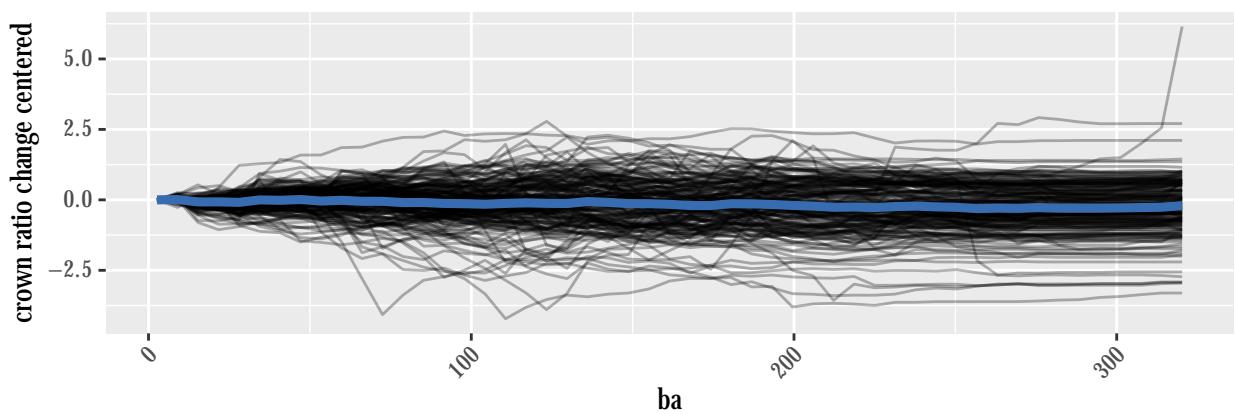
PPD for ba



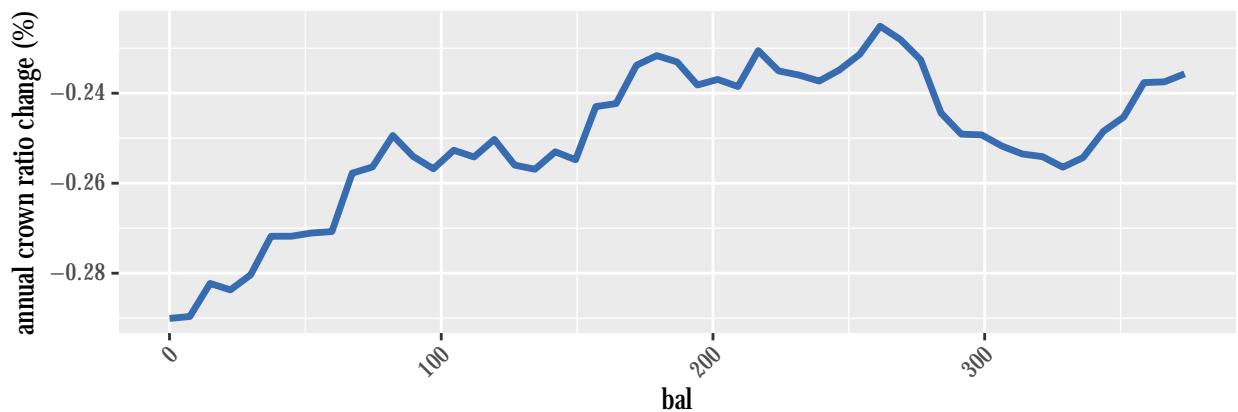
ICE plot for ba



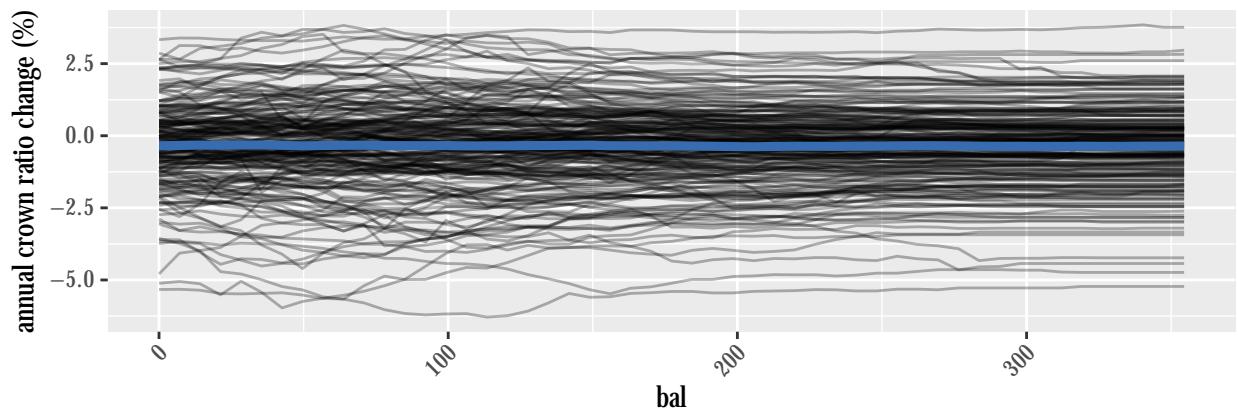
Centered ICE plot for ba



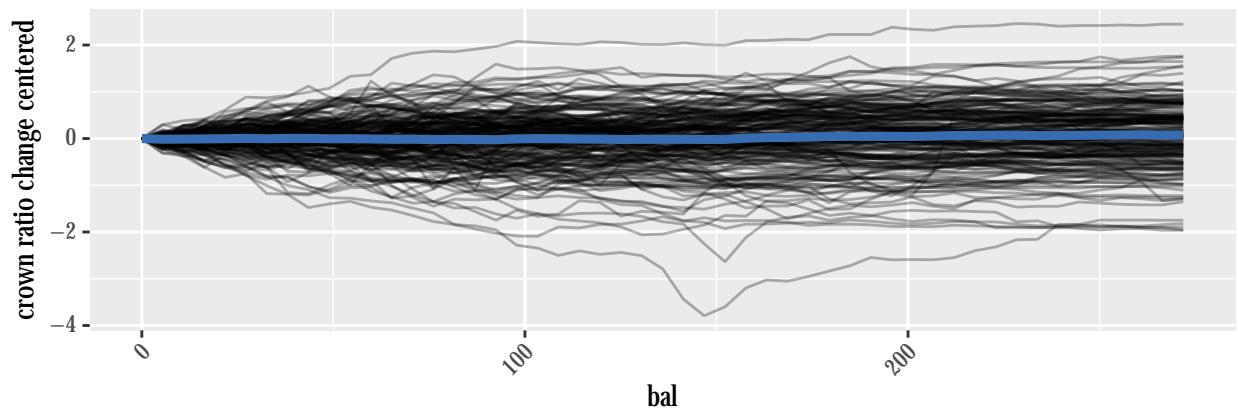
PDP for bal

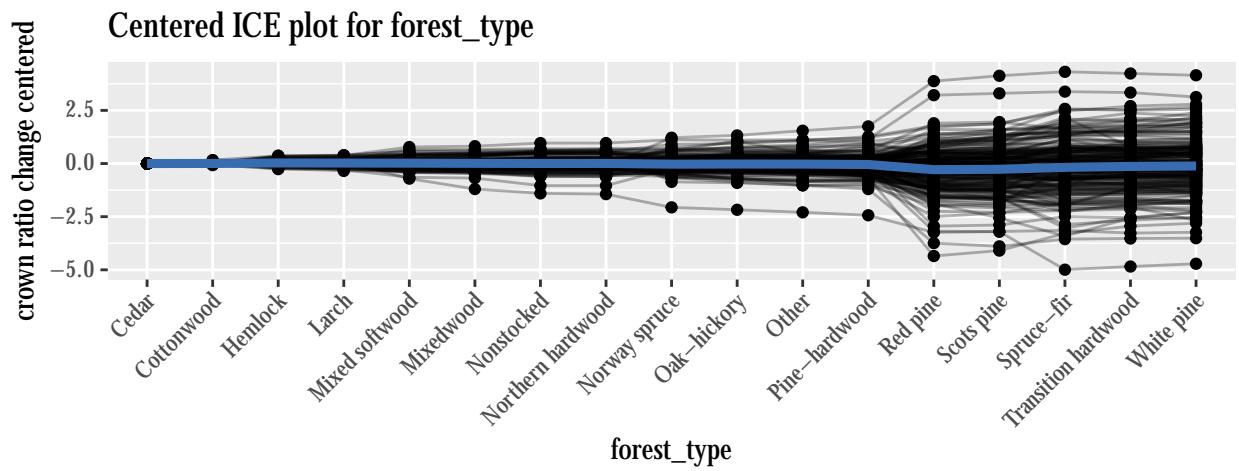
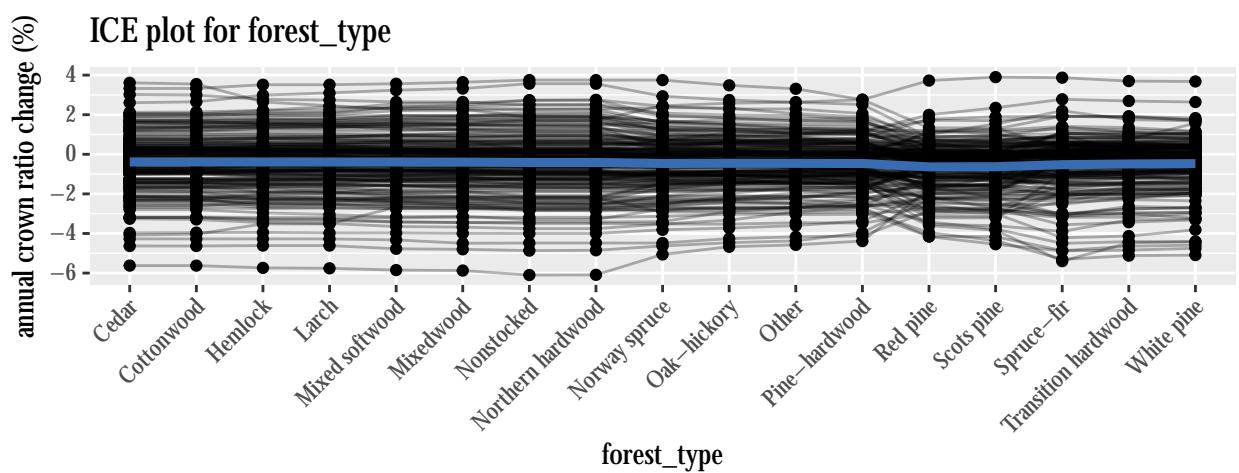
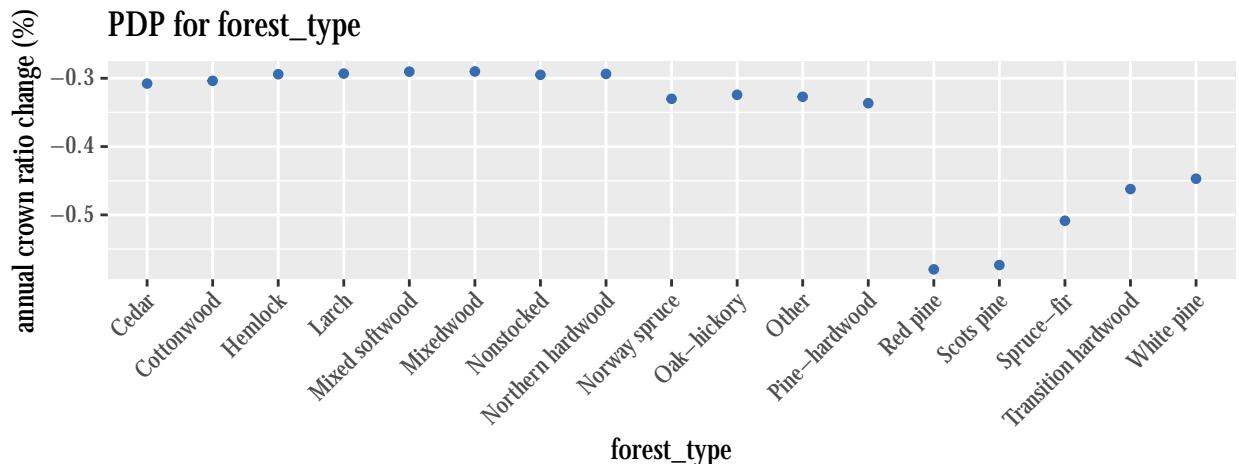


ICE plot for bal

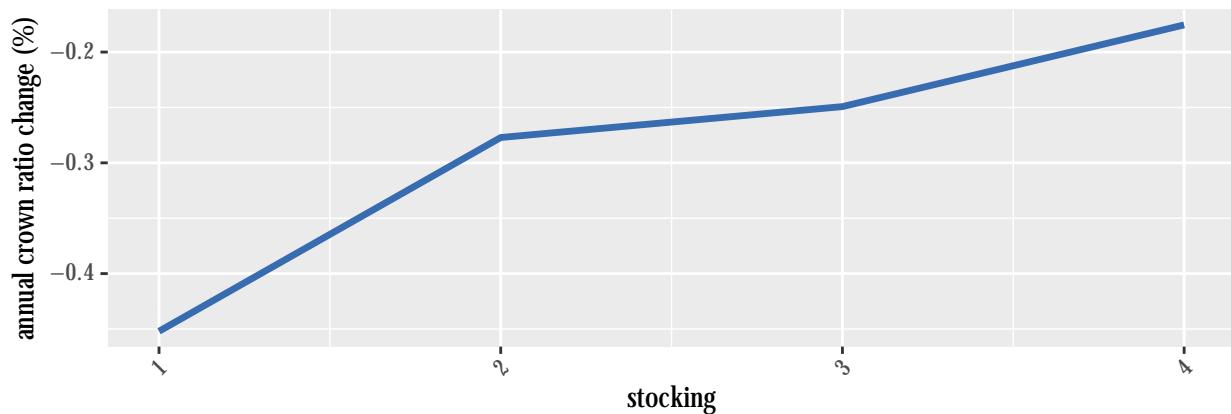


Centered ICE plot for bal

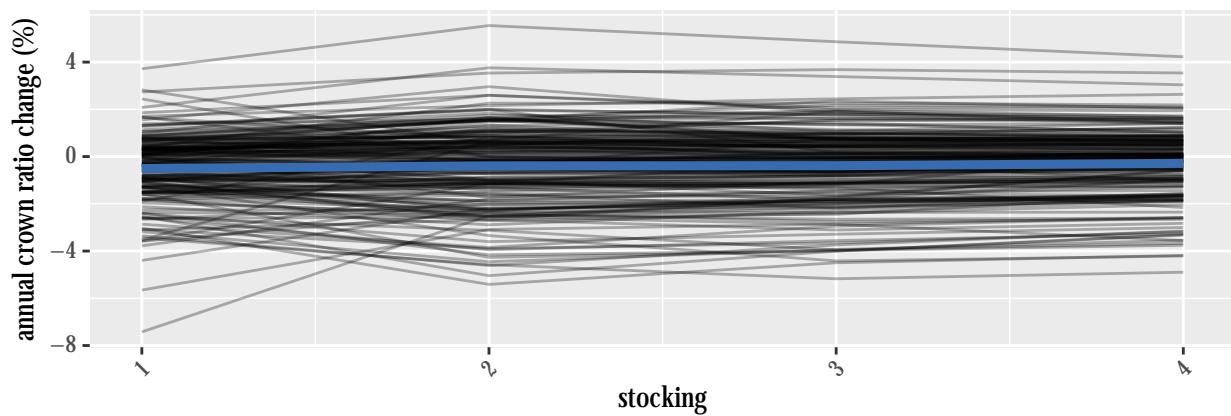




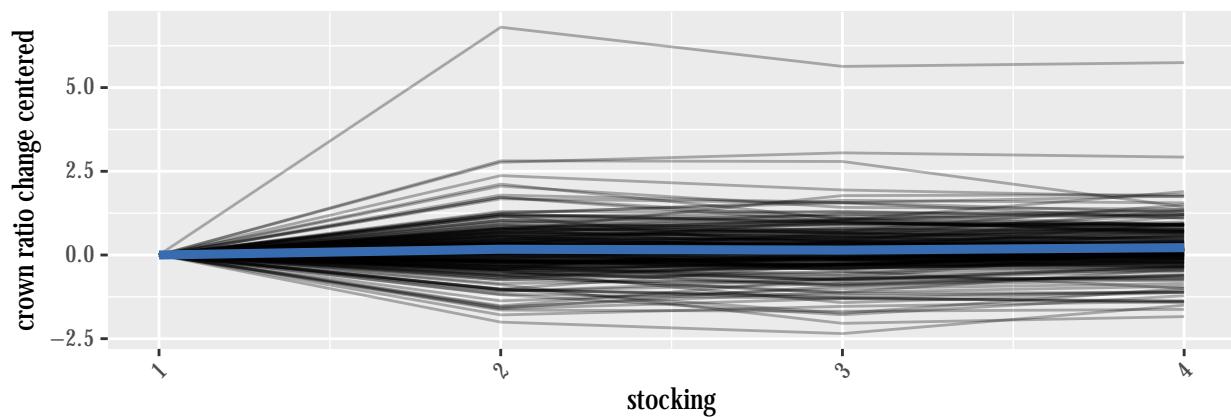
PPD for stocking

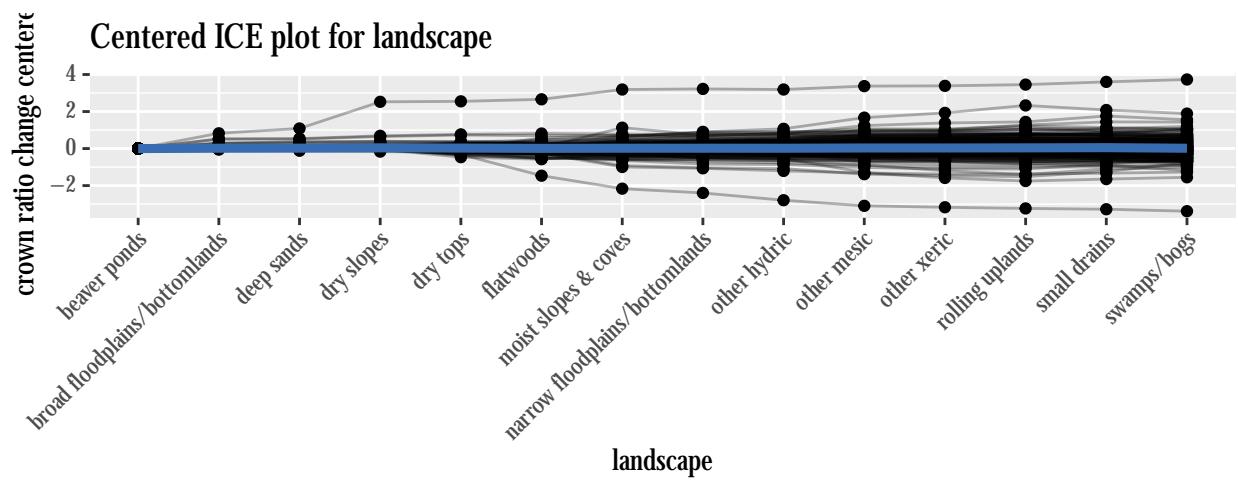
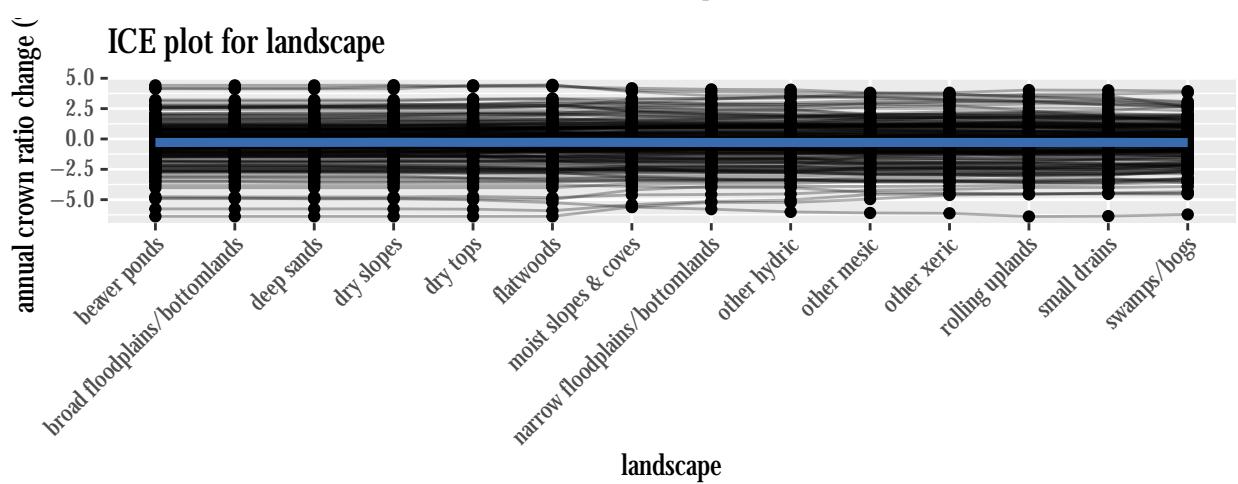
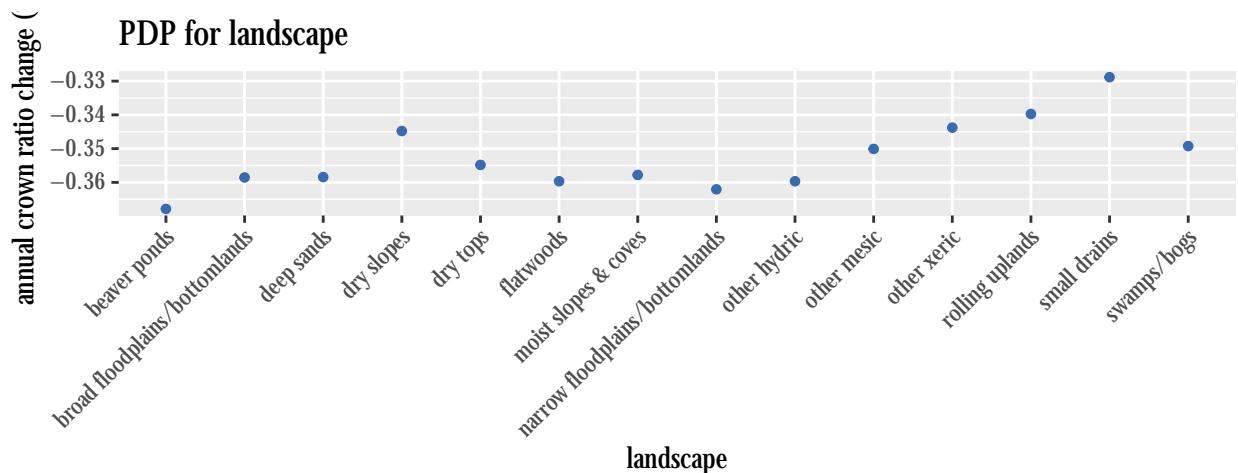


ICE plot for stocking

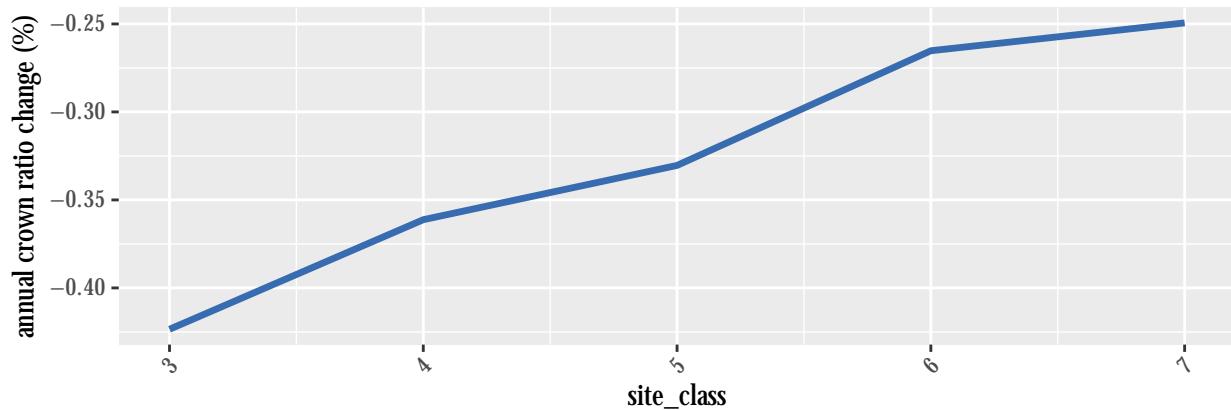


Centered ICE plot for stocking

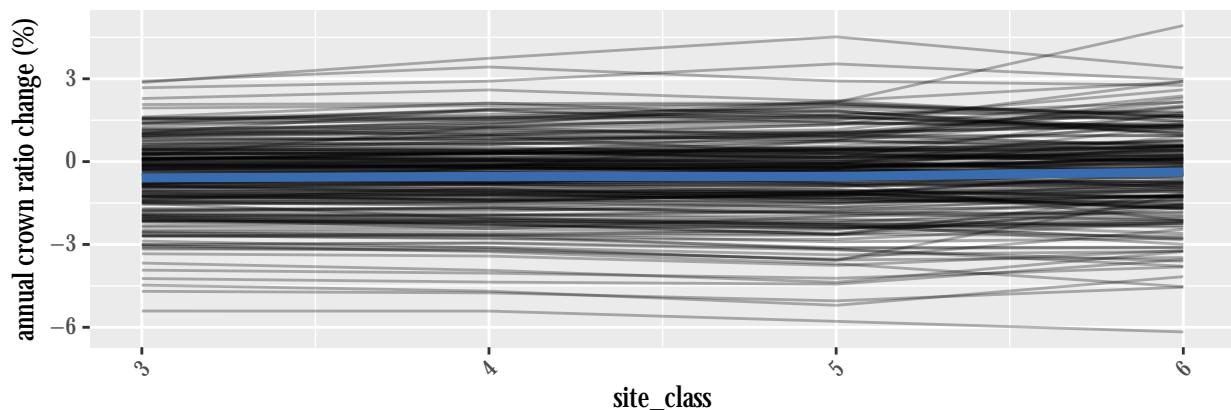




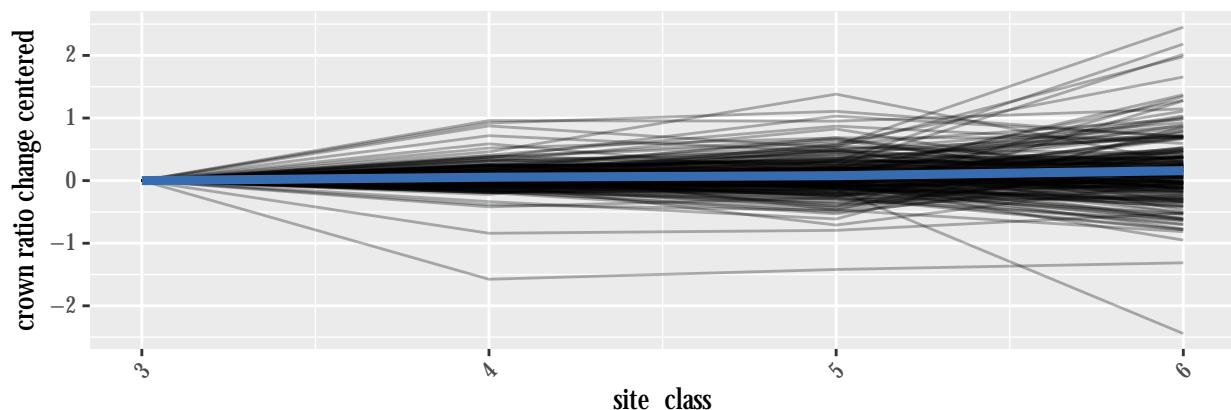
PDP for site_class



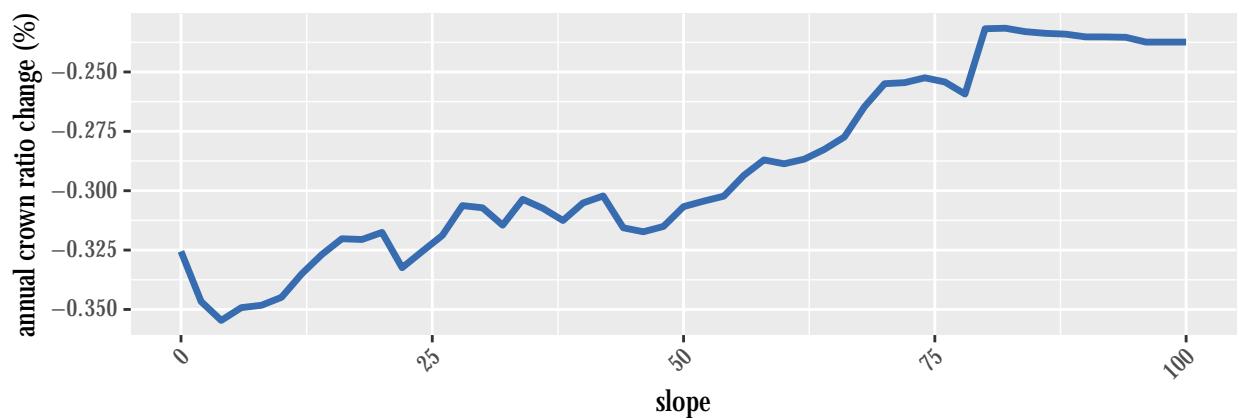
ICE plot for site_class



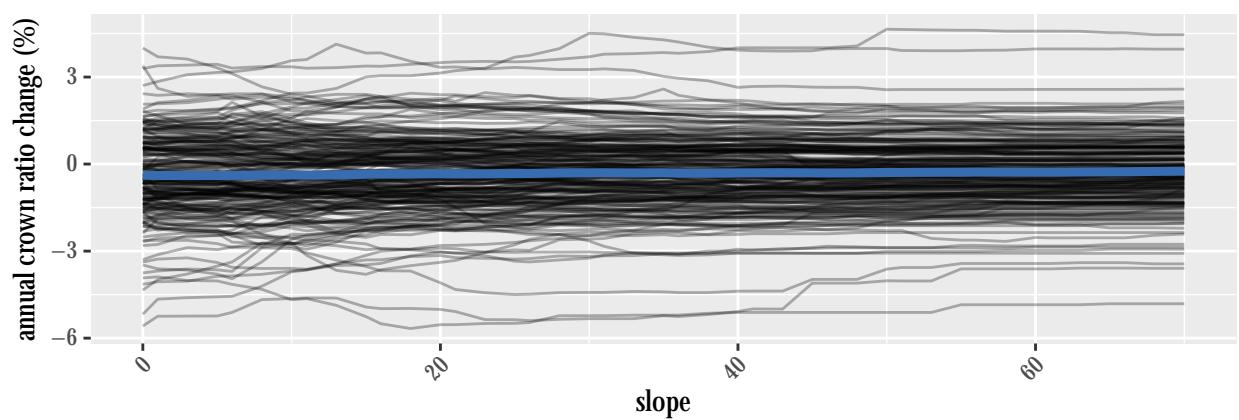
Centered ICE plot for site_class



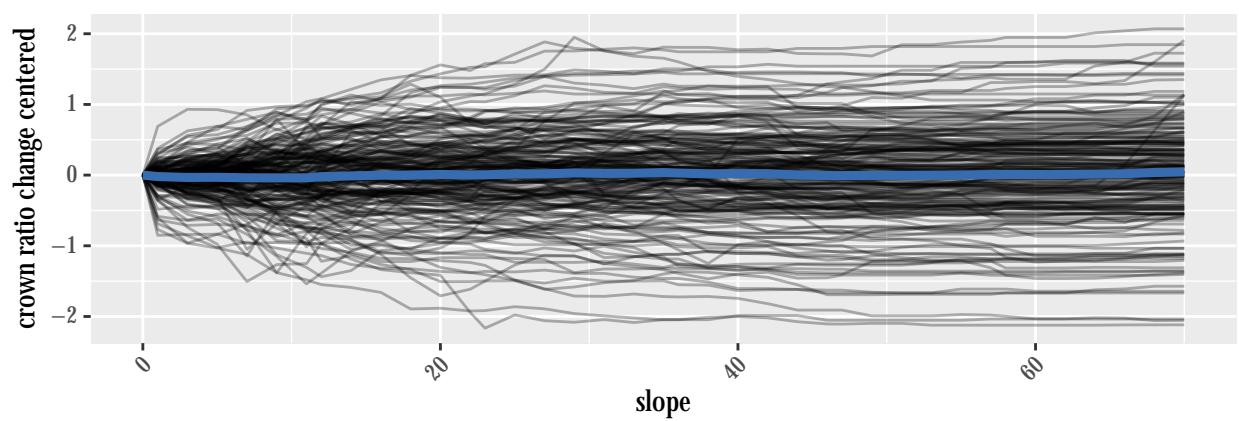
PDP for slope



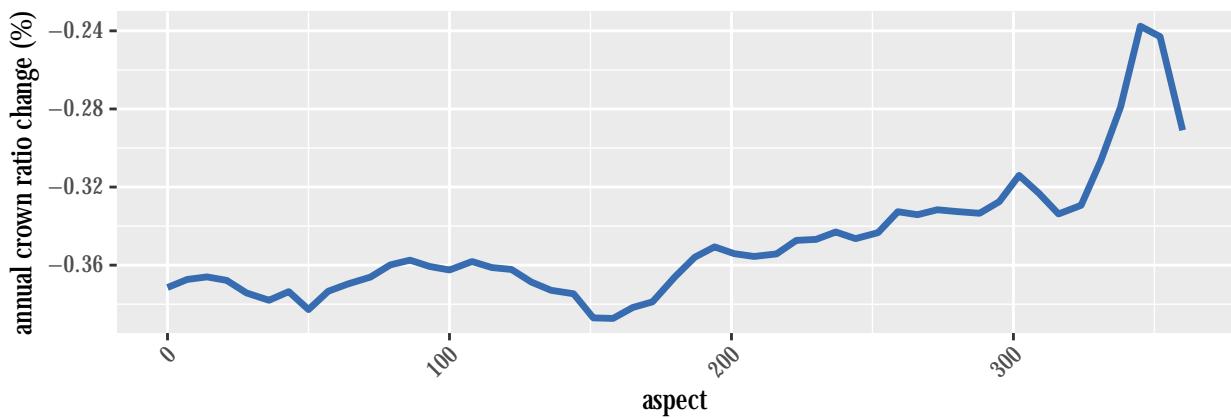
ICE plot for slope



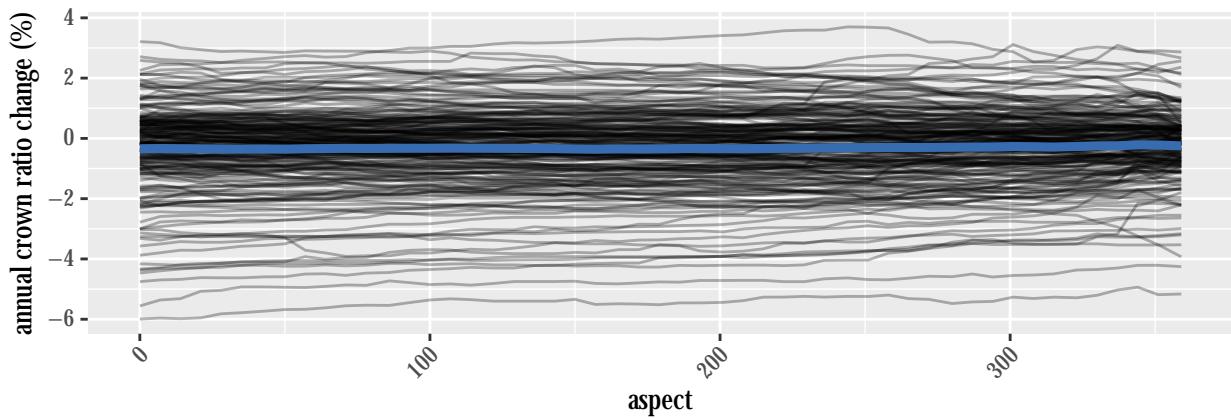
Centered ICE plot for slope



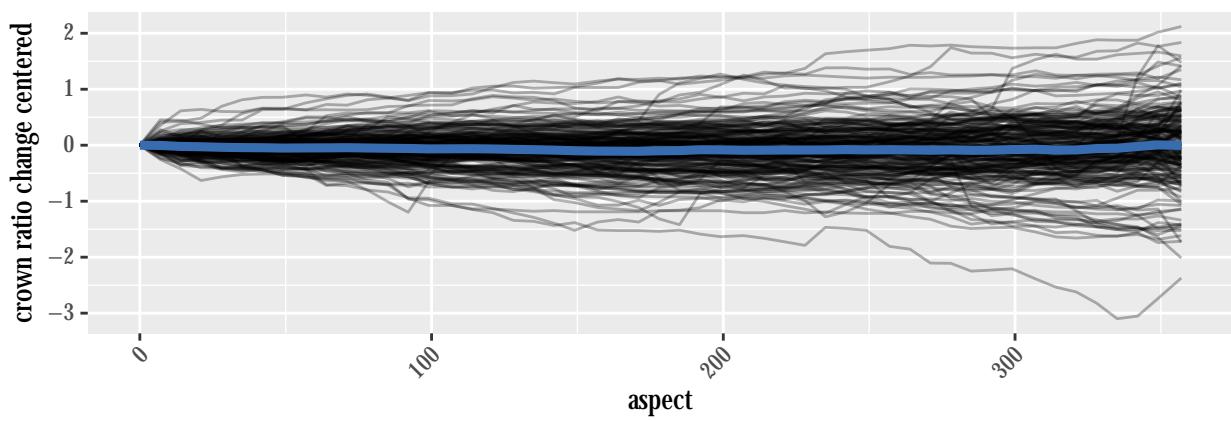
PDP for aspect



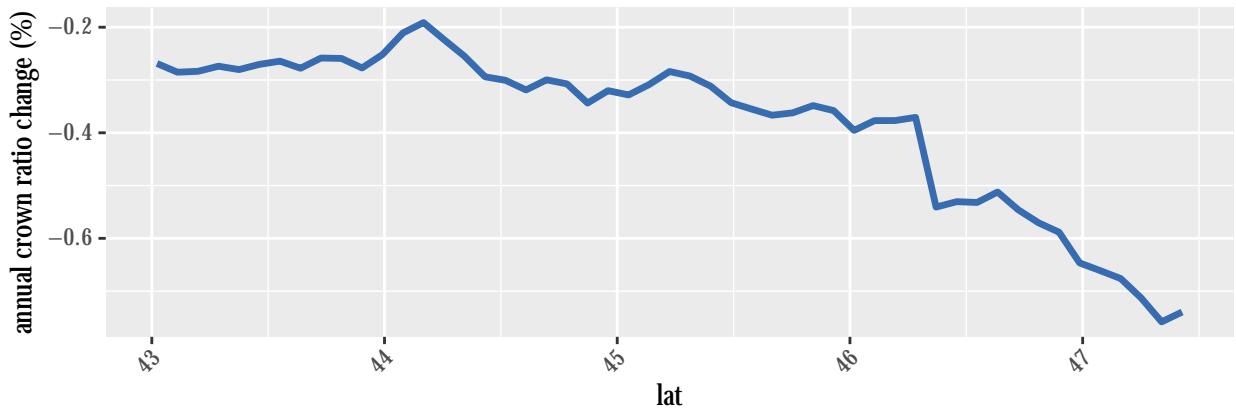
ICE plot for aspect



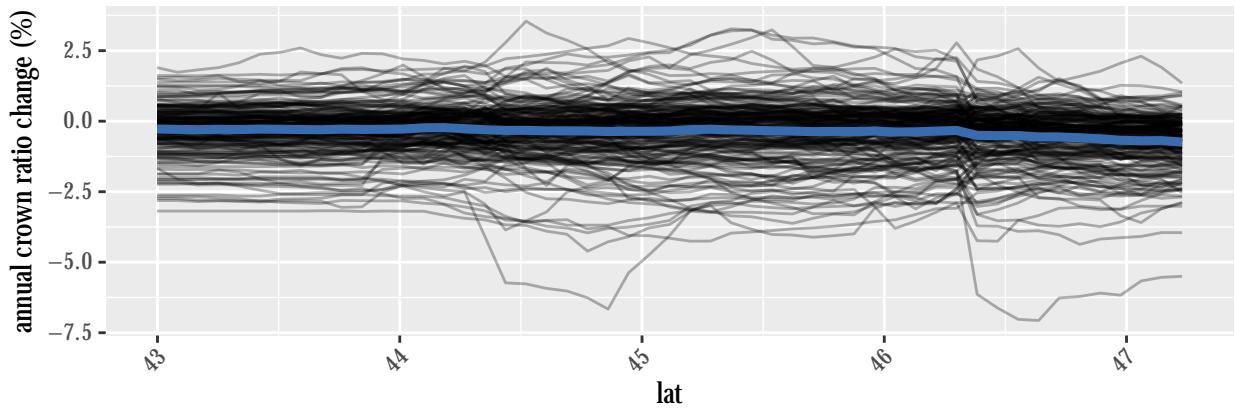
Centered ICE plot for aspect



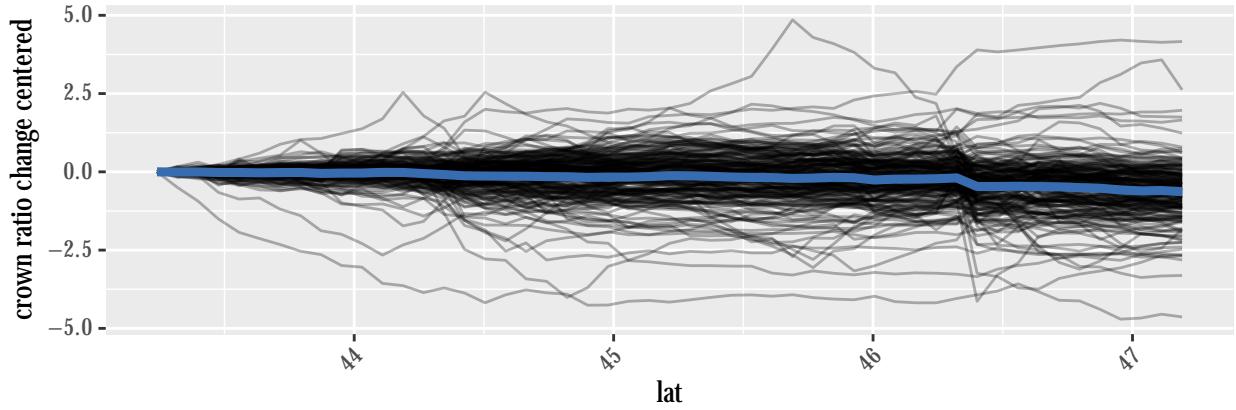
PPD for lat

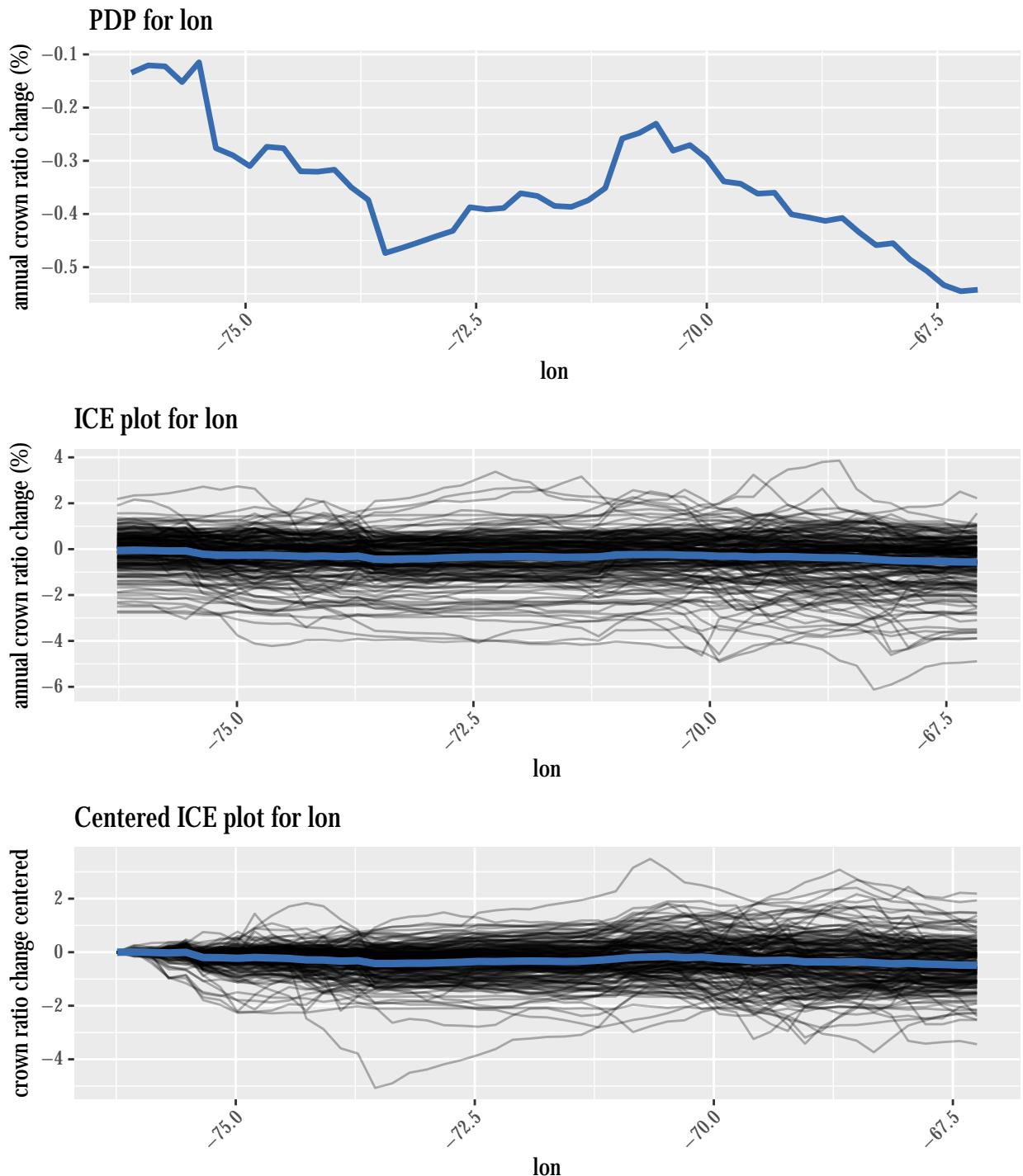


ICE plot for lat

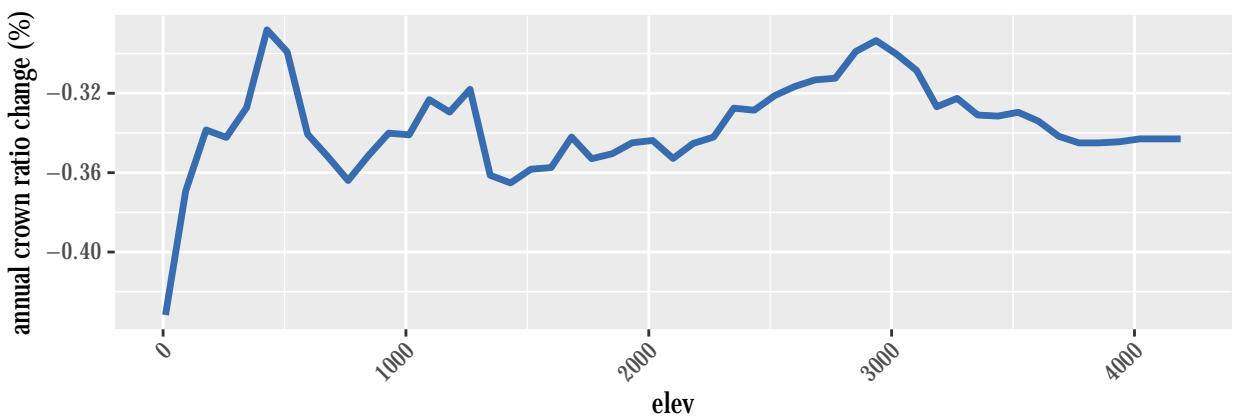


Centered ICE plot for lat

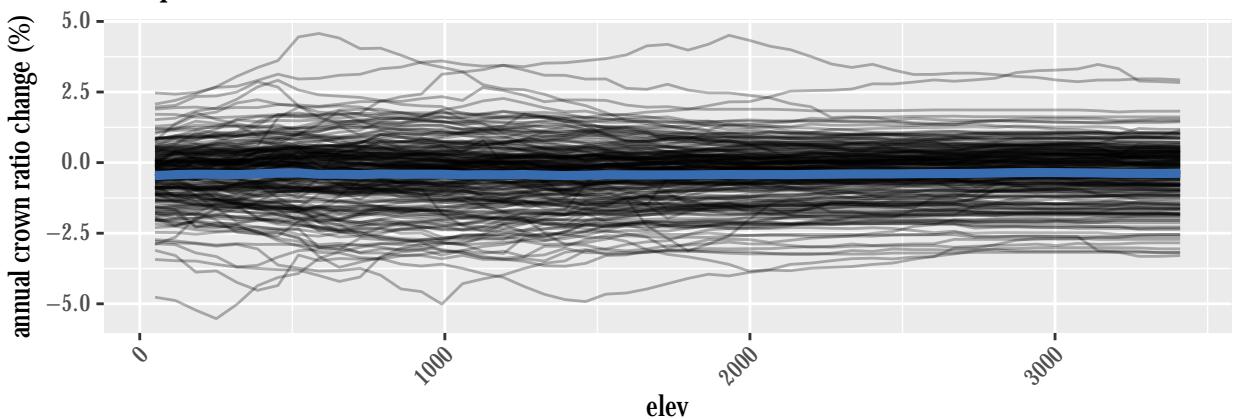




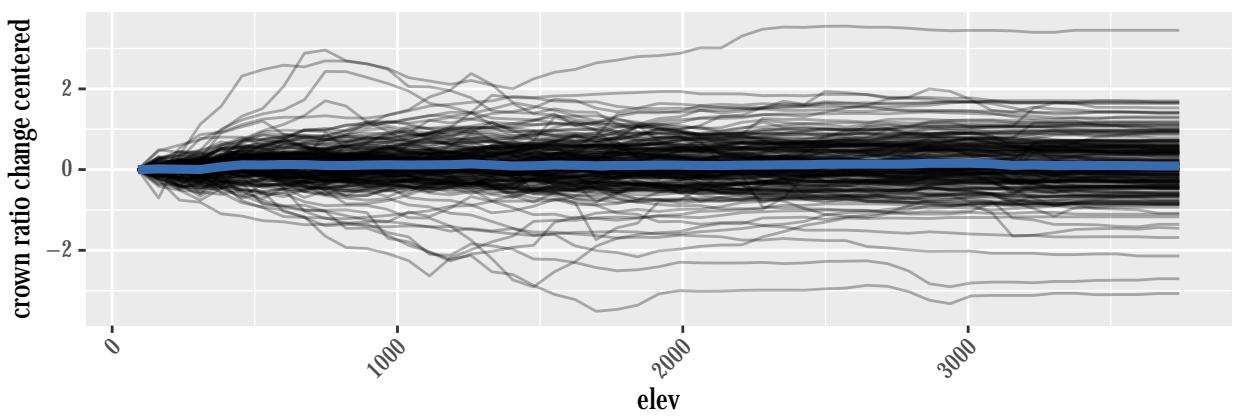
PDP for elev



ICE plot for elev



Centered ICE plot for elev



Survival Submodel

Table 10: Overall accuracy estimates, calculated on out of bag data

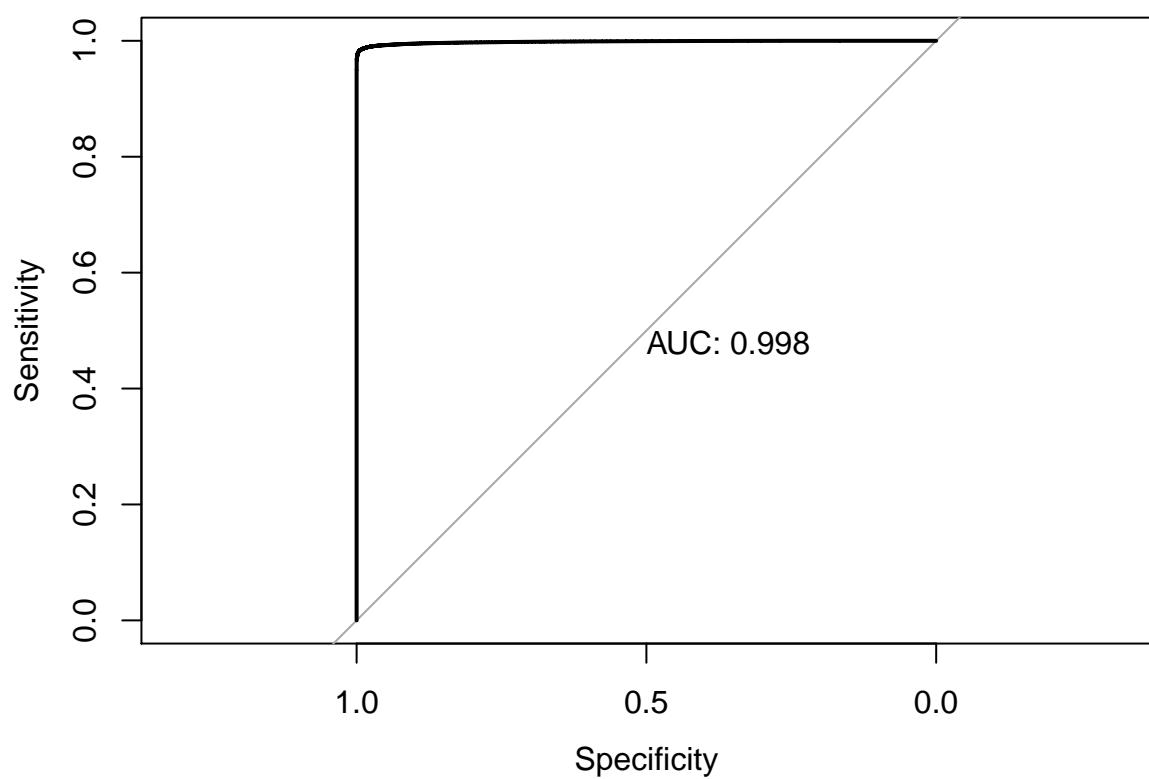
	x
Accuracy	0.969
Kappa	0.435
AccuracyLower	0.968
AccuracyUpper	0.970
AccuracyNull	0.957
AccuracyPValue	0.000
McnemarPValue	0.000

Table 11: Accuracy estimates by class, calculated on out of bag data

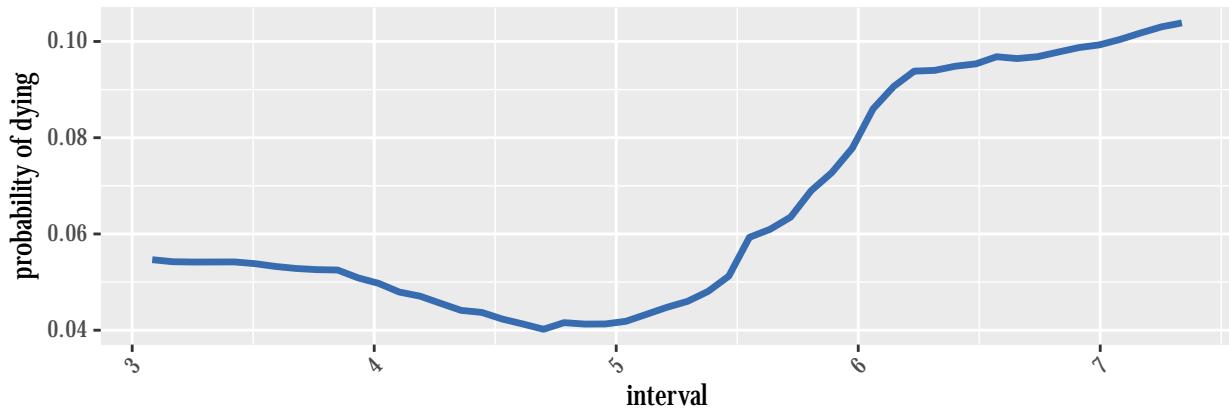
	x
Sensitivity	1.000
Specificity	0.288
Pos Pred Value	0.969
Neg Pred Value	0.994
Precision	0.969
Recall	1.000
F1	0.984
Prevalence	0.957
Detection Rate	0.957
Detection Prevalence	0.987
Balanced Accuracy	0.644

Table 12: Confusion matrix. Columns are actual, observed outcomes; rows are predicted outcomes.

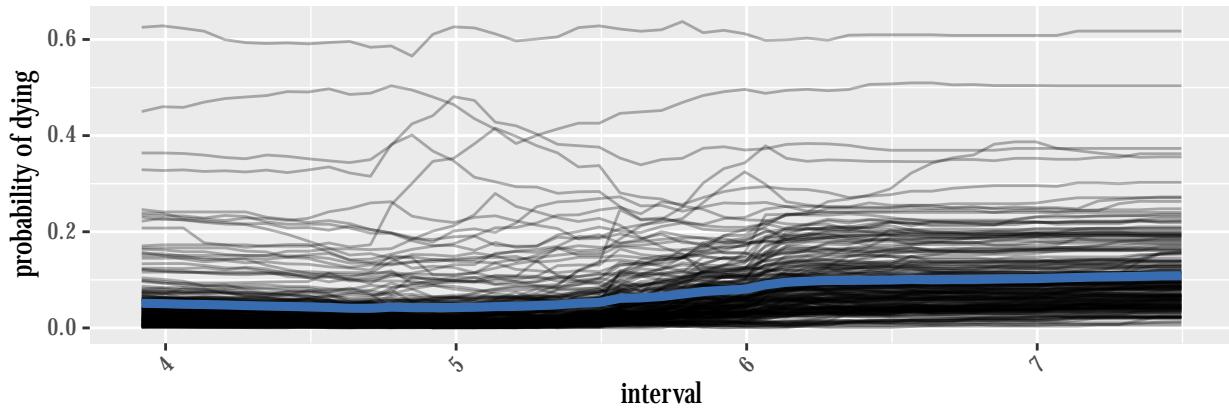
	died	lived
died	3767	24
lived	9333	289345



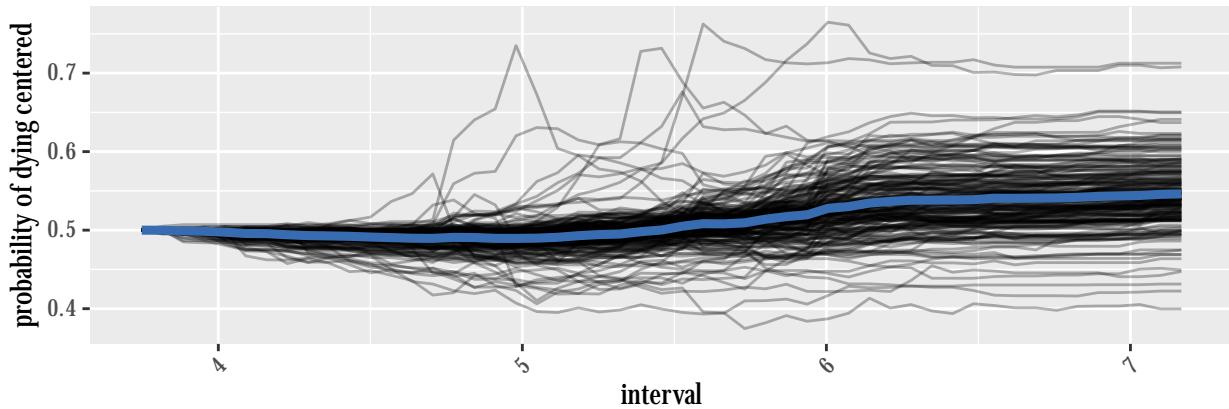
PDP for interval



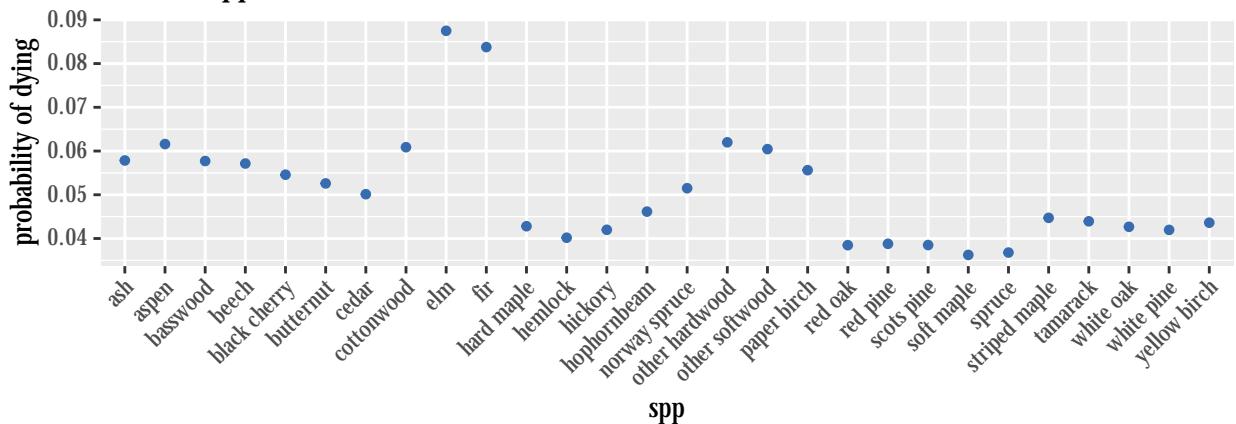
ICE plot for interval



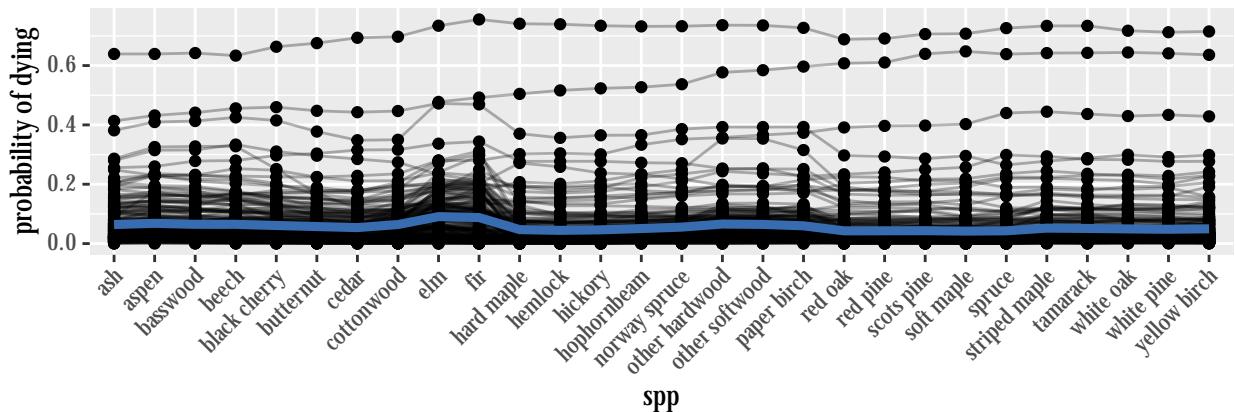
Centered ICE plot for interval



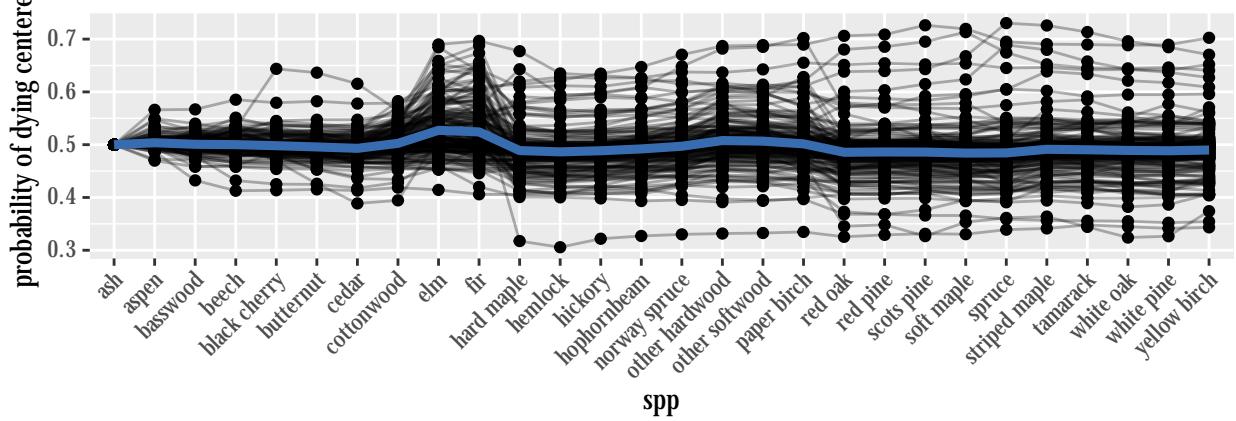
PDP for spp



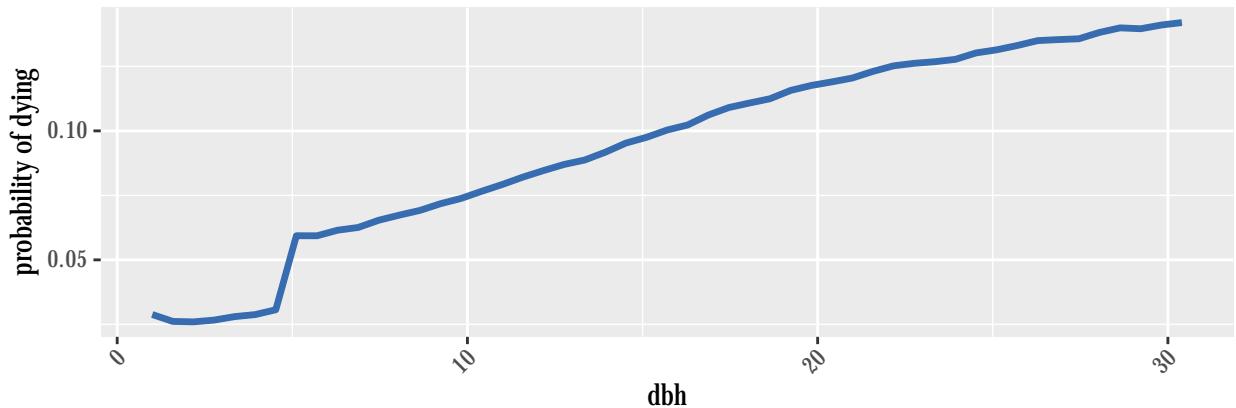
ICE plot for spp



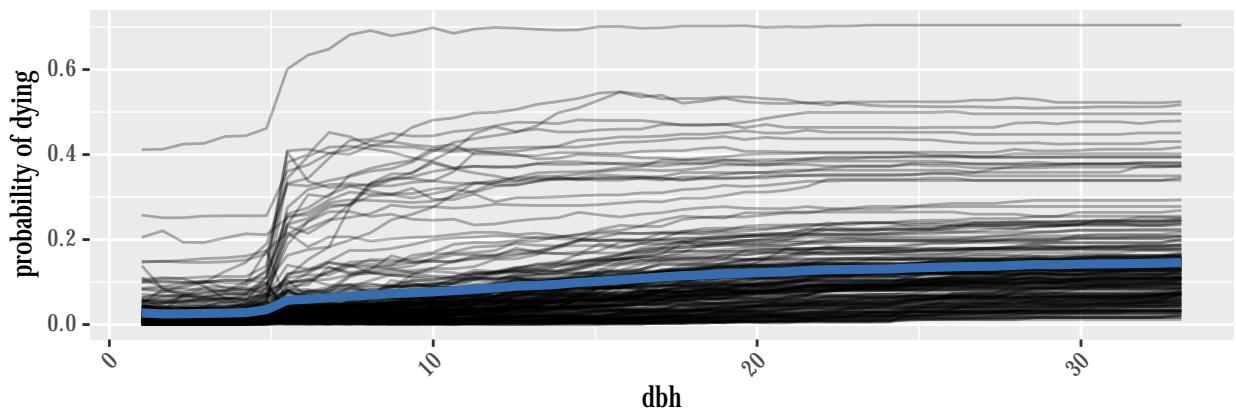
Centered ICE plot for spp



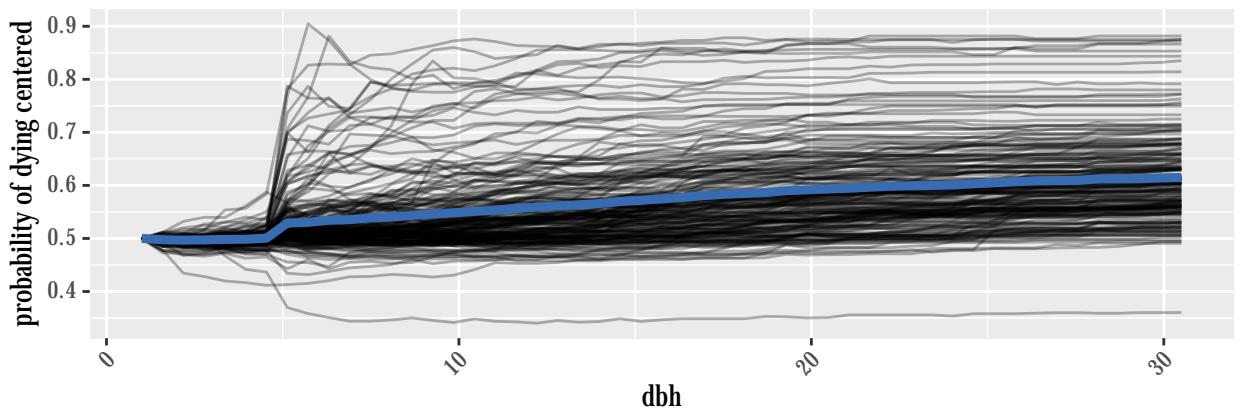
PDP for dbh



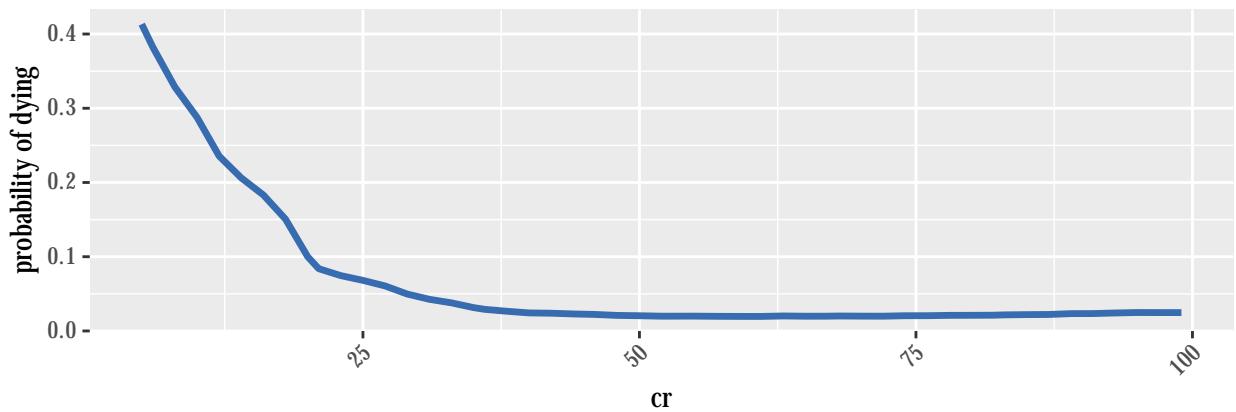
ICE plot for dbh



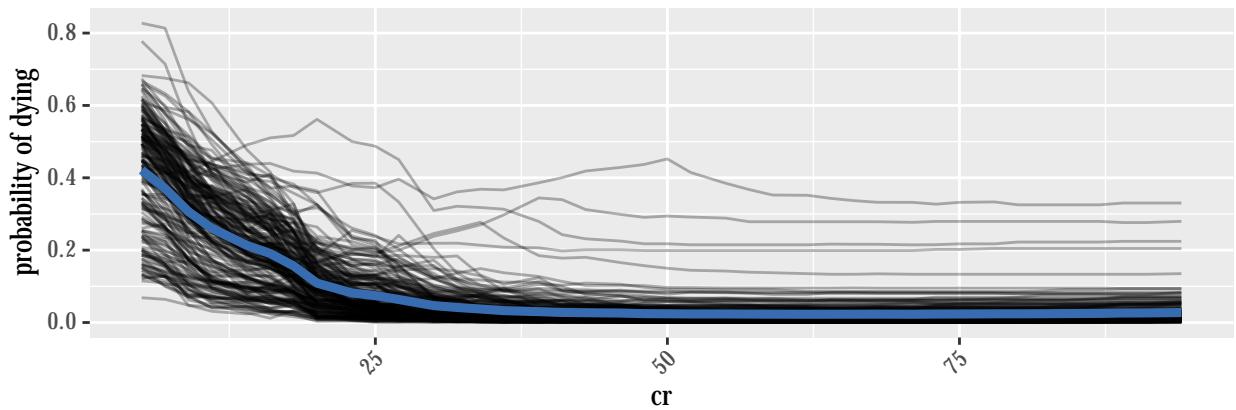
Centered ICE plot for dbh



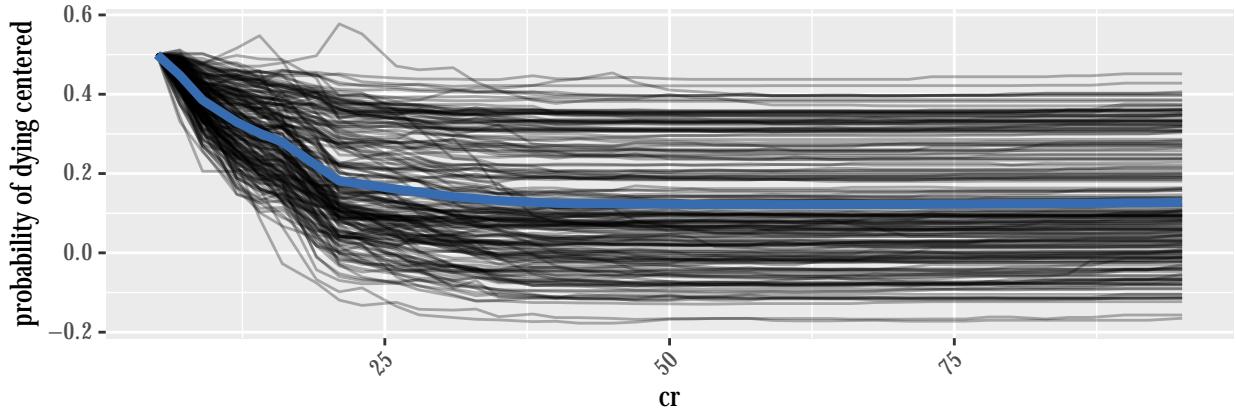
PDP for cr



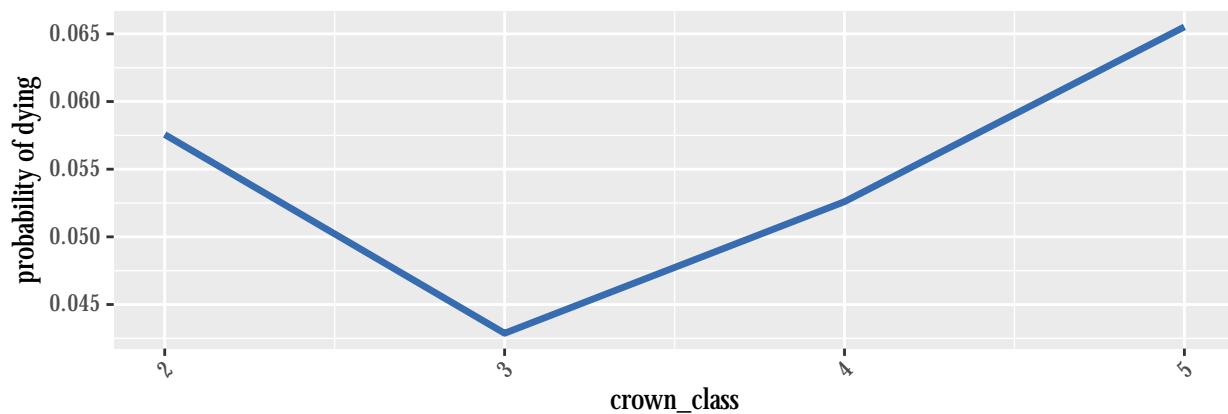
ICE plot for cr



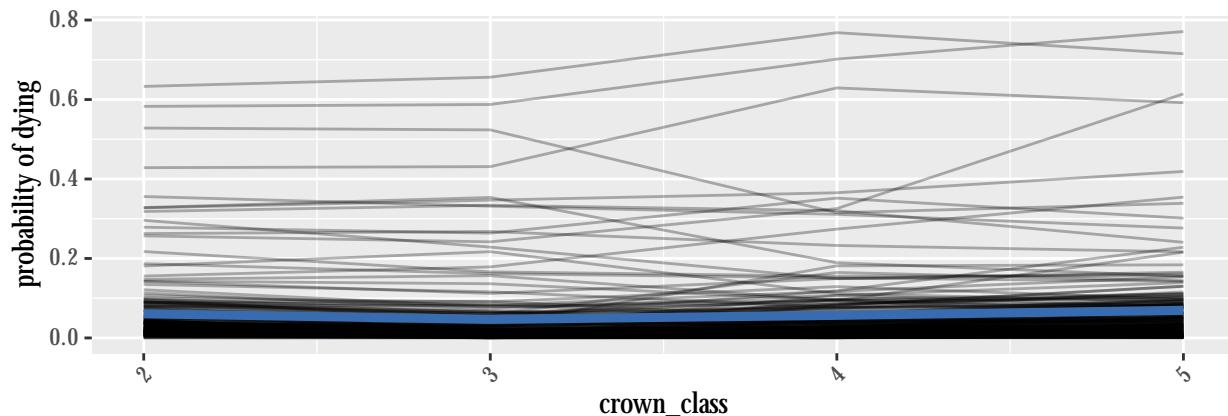
Centered ICE plot for cr



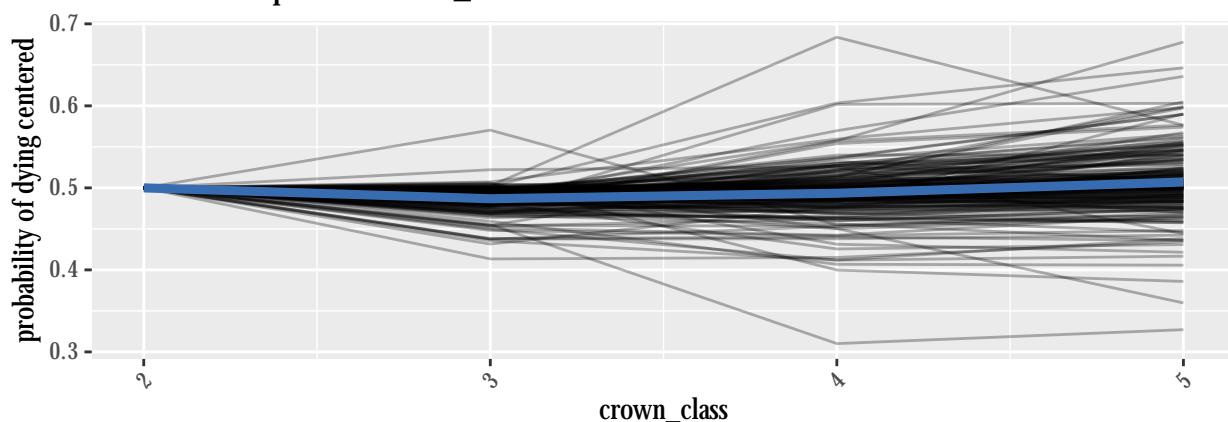
PDP for crown_class



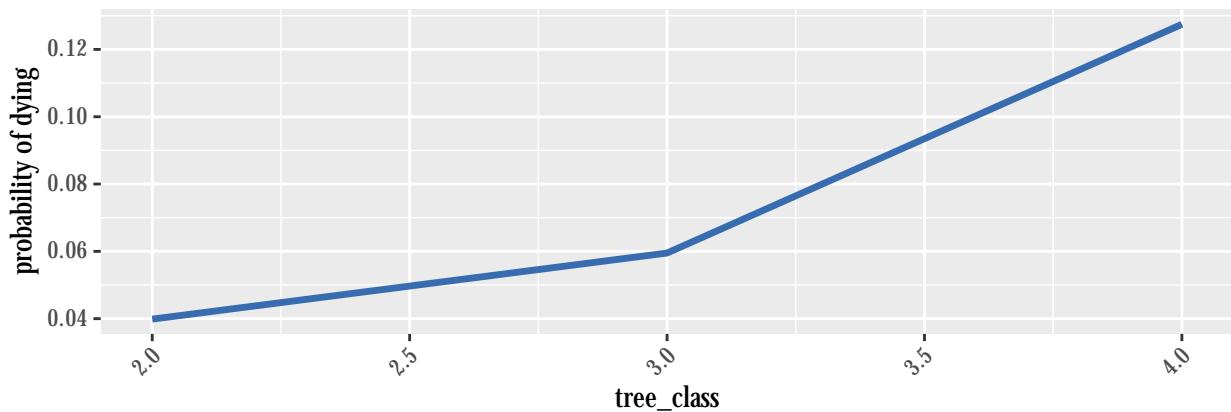
ICE plot for crown_class



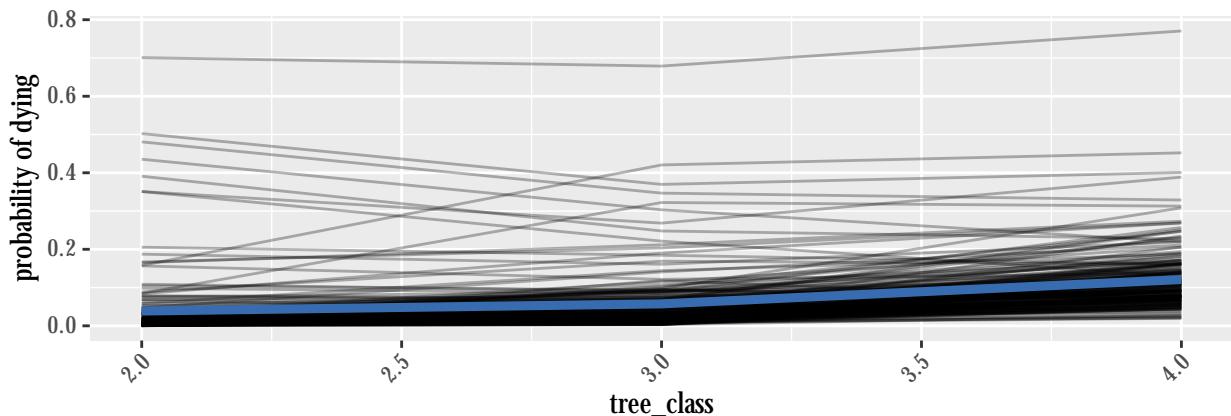
Centered ICE plot for crown_class



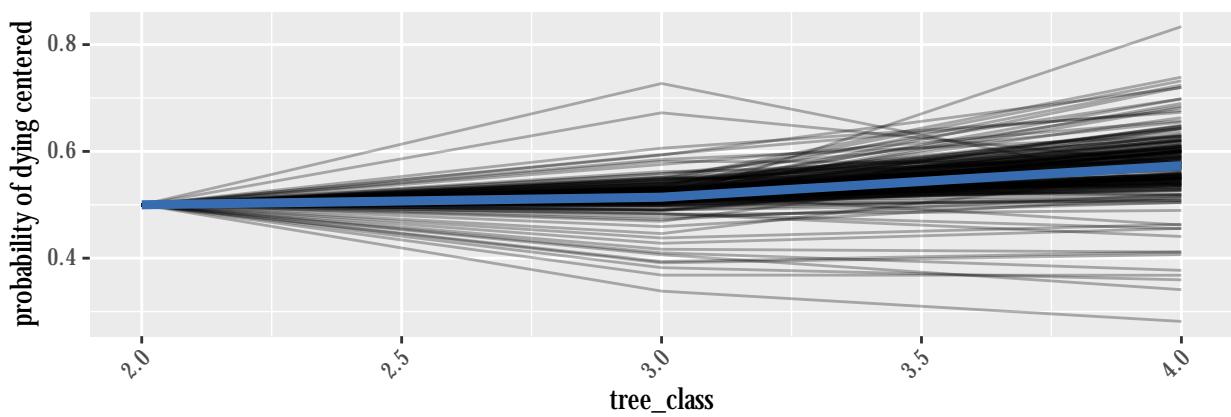
PDP for tree_class



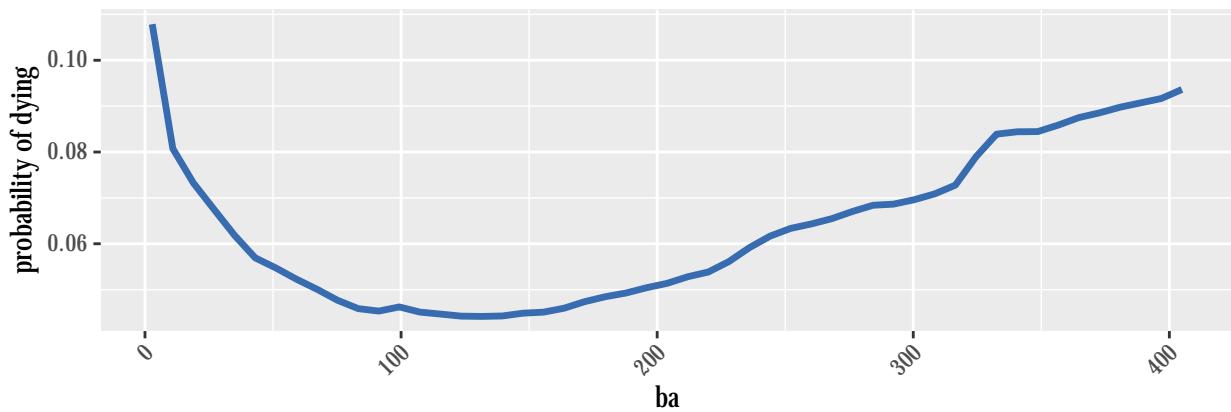
ICE plot for tree_class



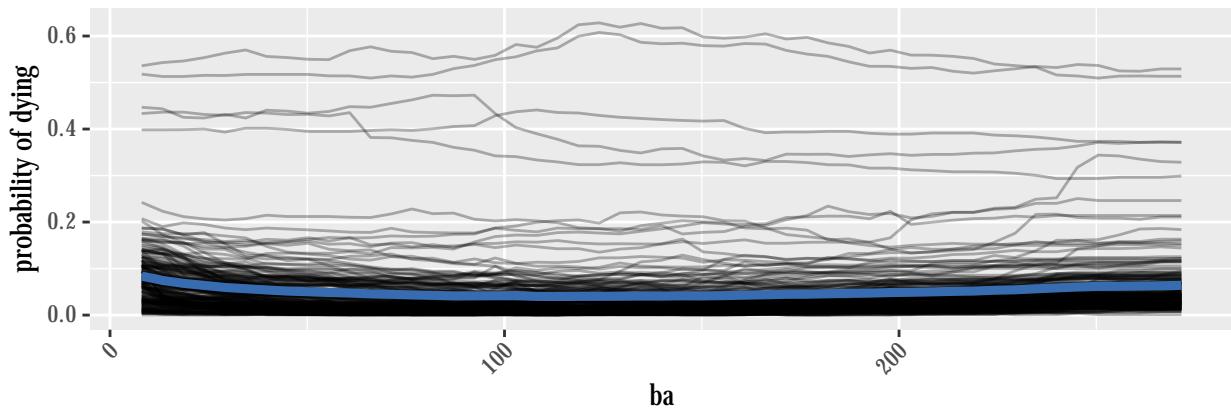
Centered ICE plot for tree_class



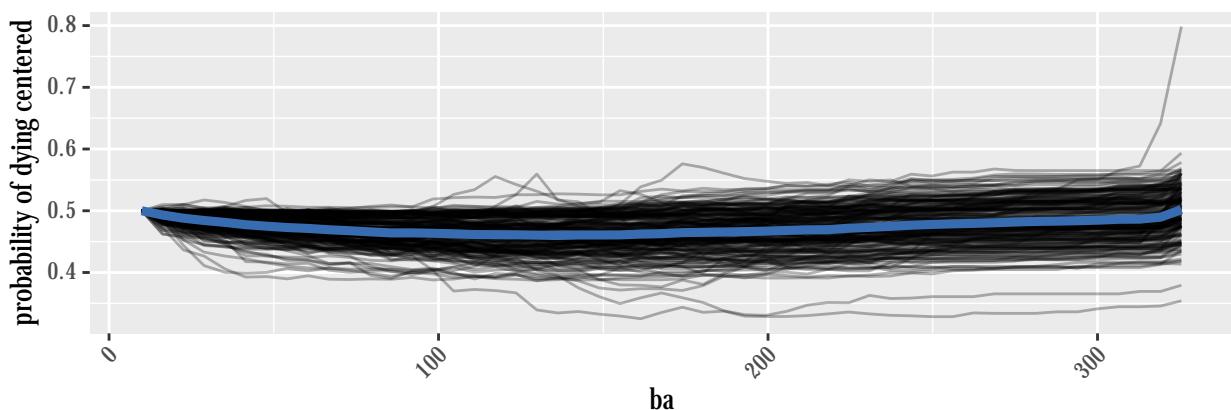
PDP for ba



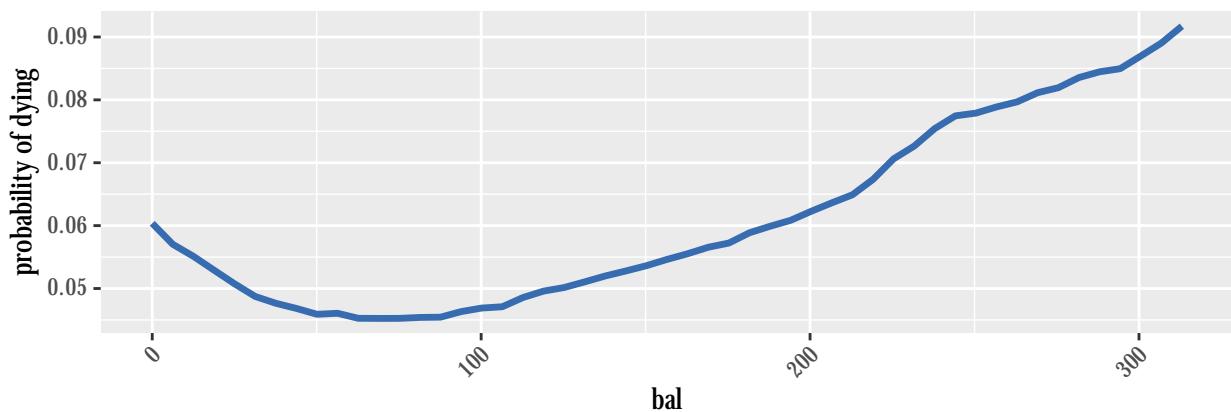
ICE plot for ba



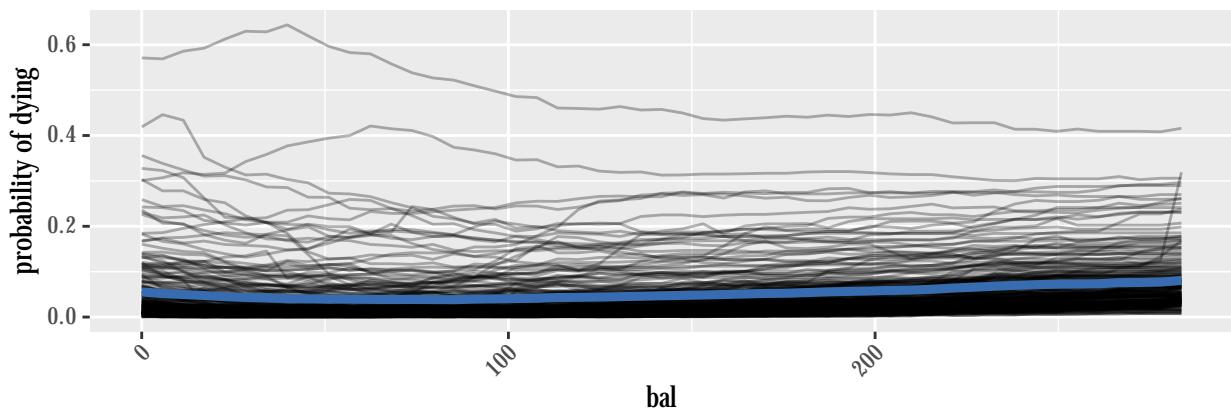
Centered ICE plot for ba



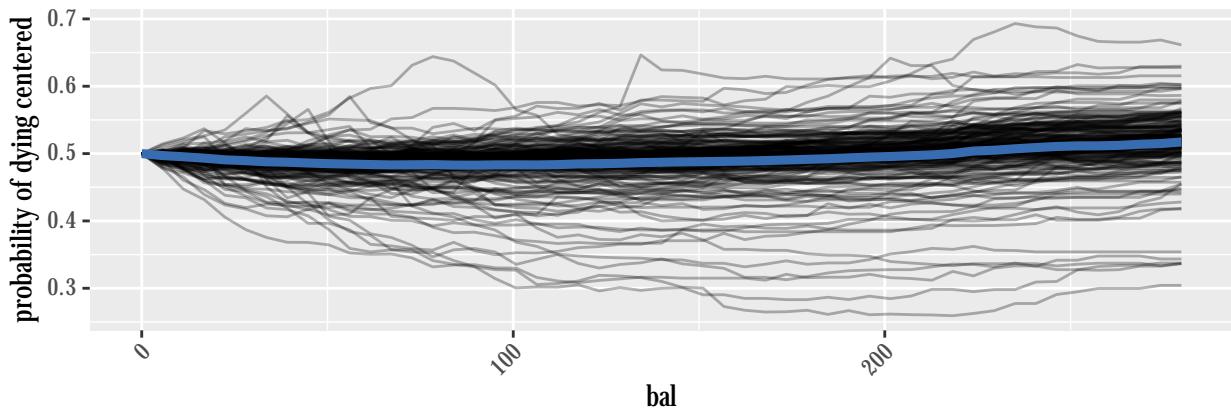
PDP for bal



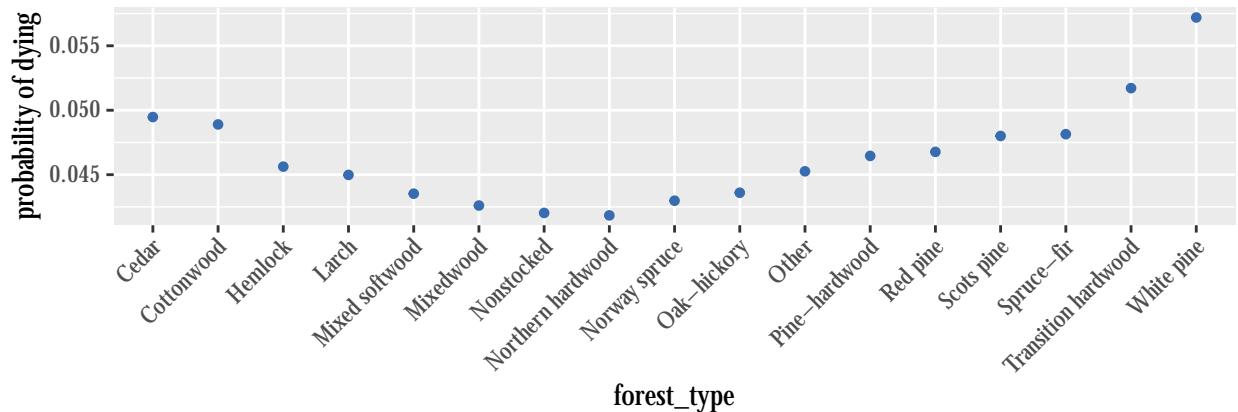
ICE plot for bal



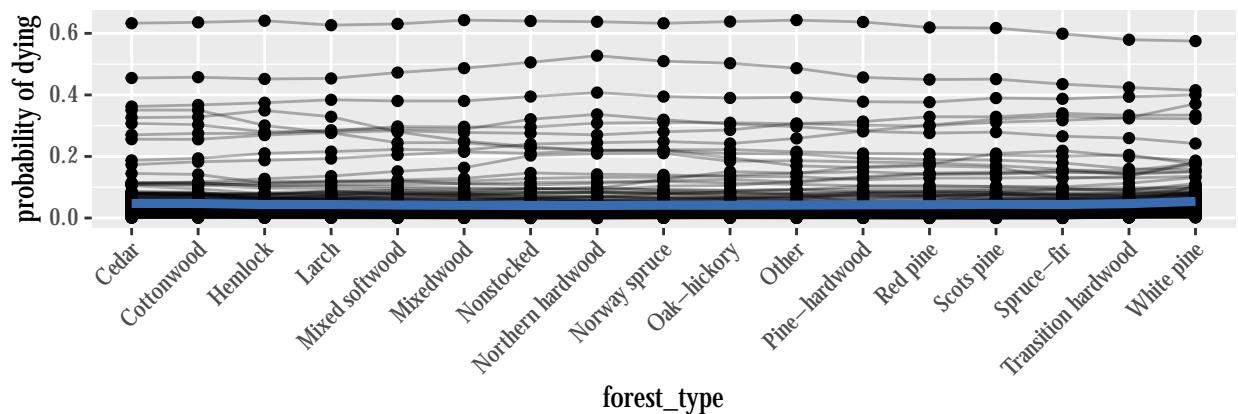
Centered ICE plot for bal



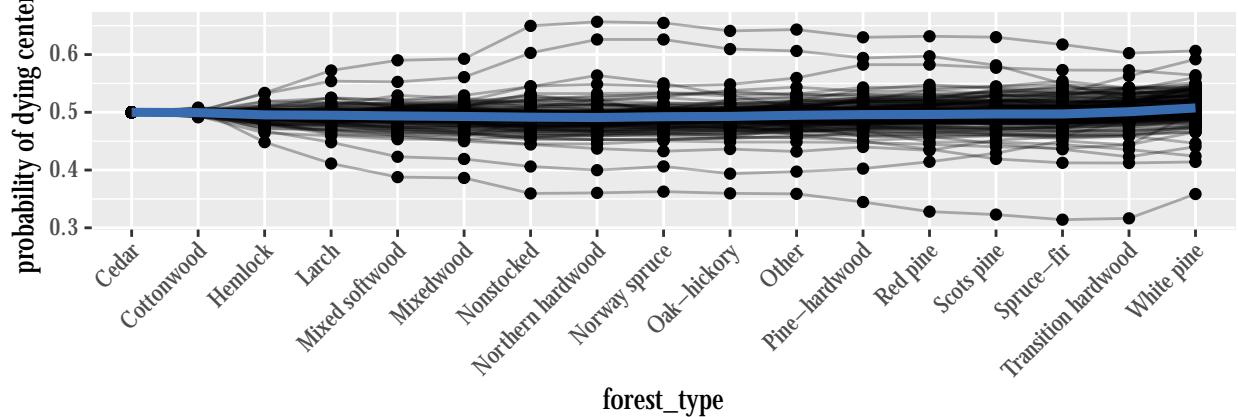
PDP for forest_type



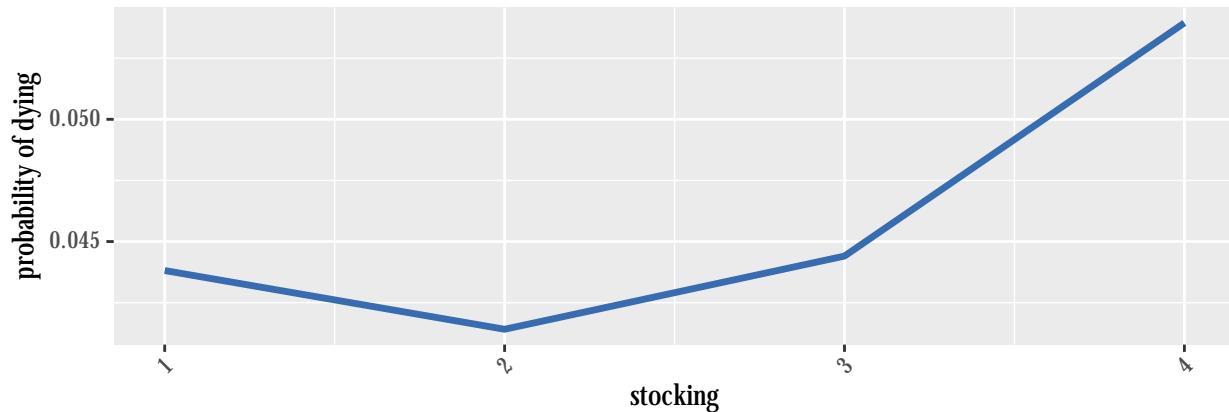
ICE plot for forest_type



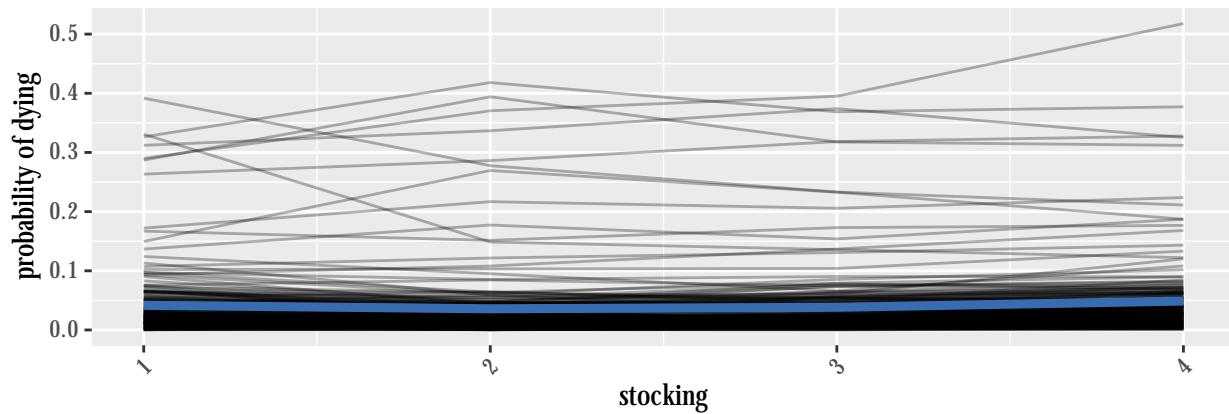
Centered ICE plot for forest_type



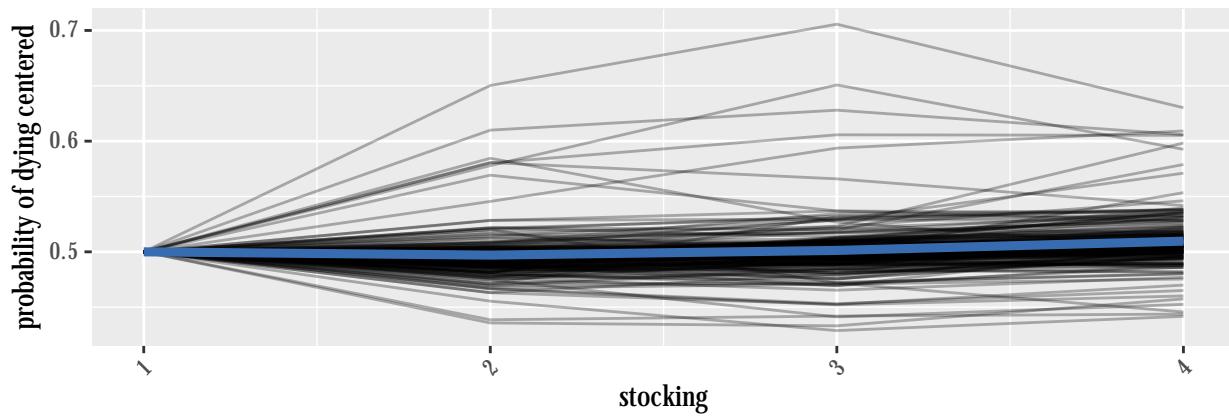
PDP for stocking

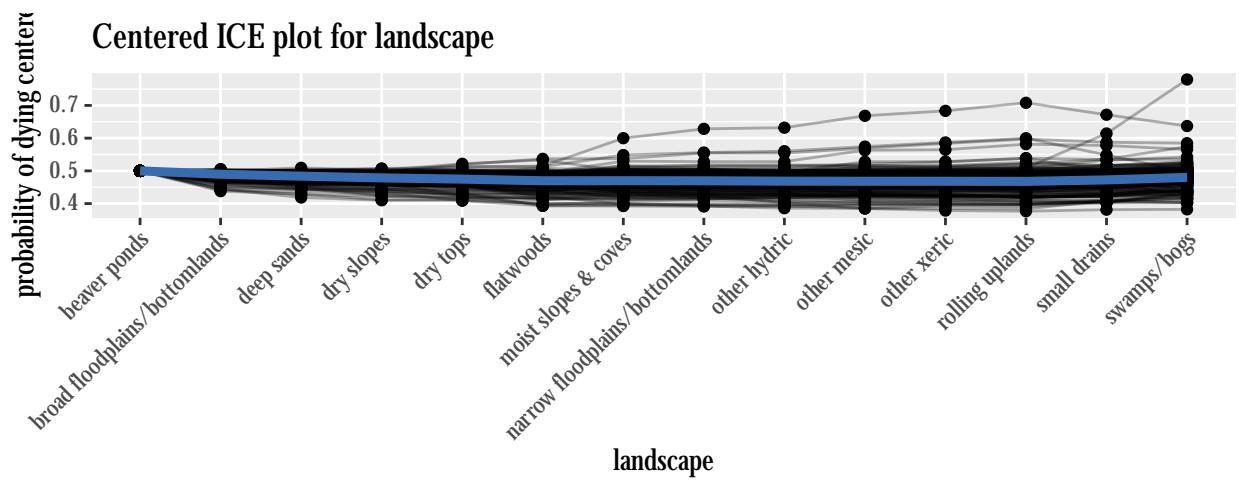
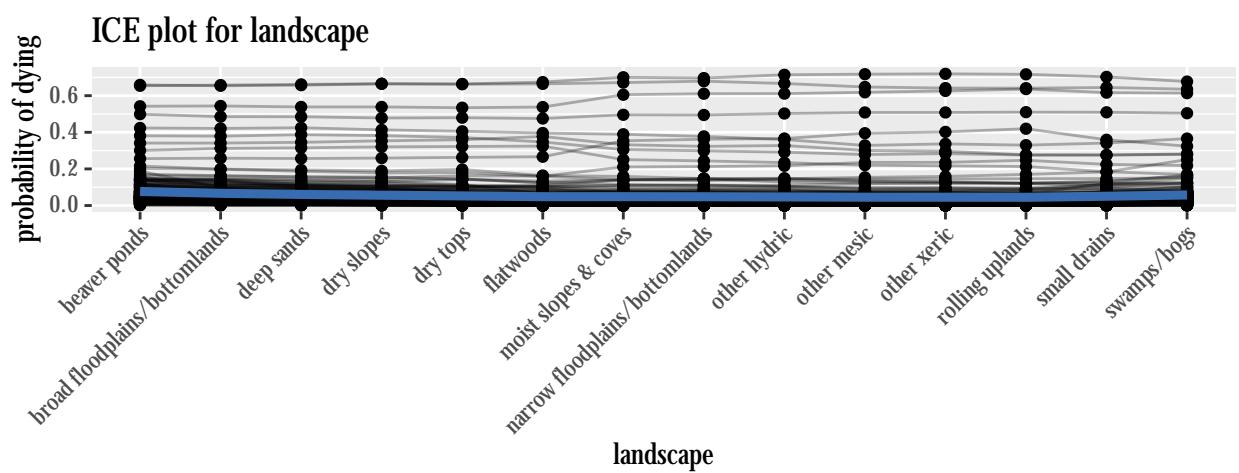
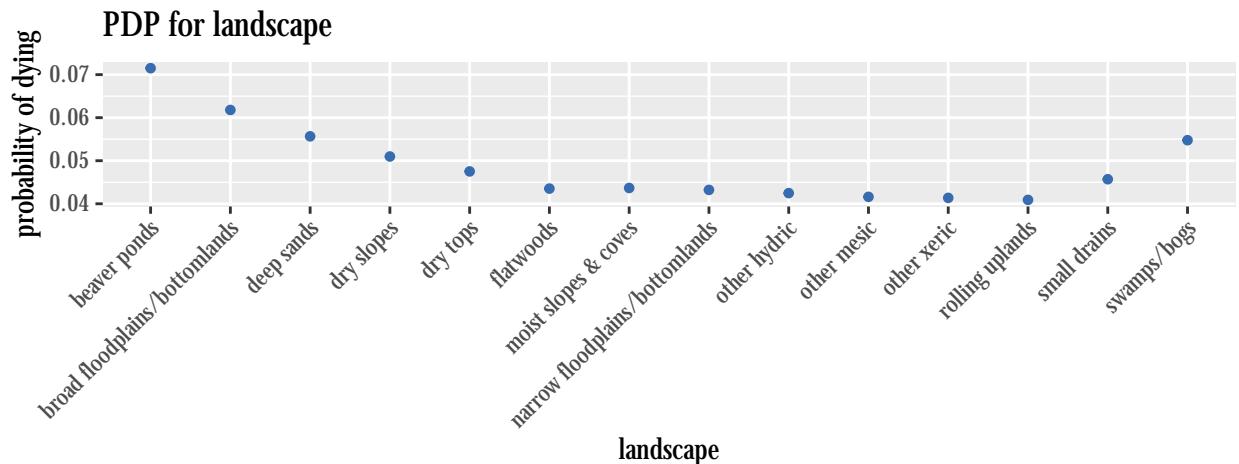


ICE plot for stocking

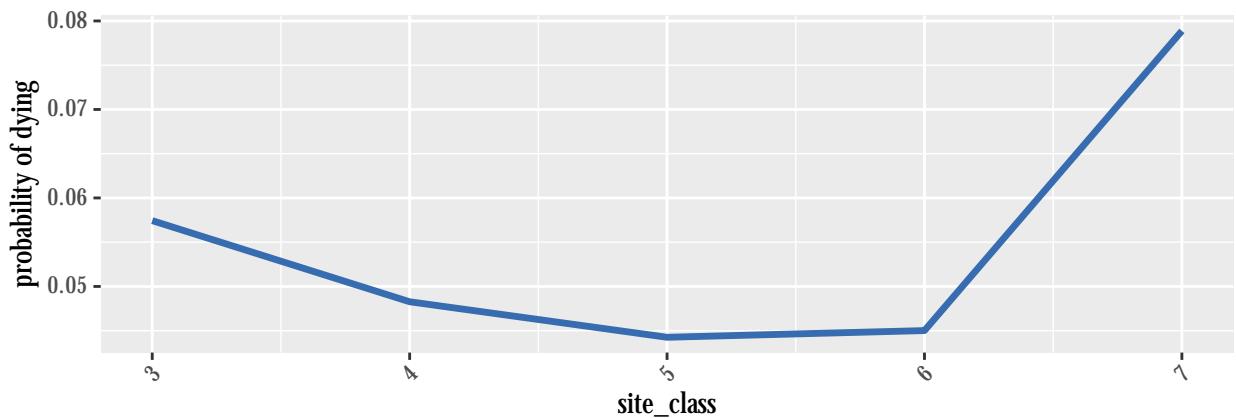


Centered ICE plot for stocking

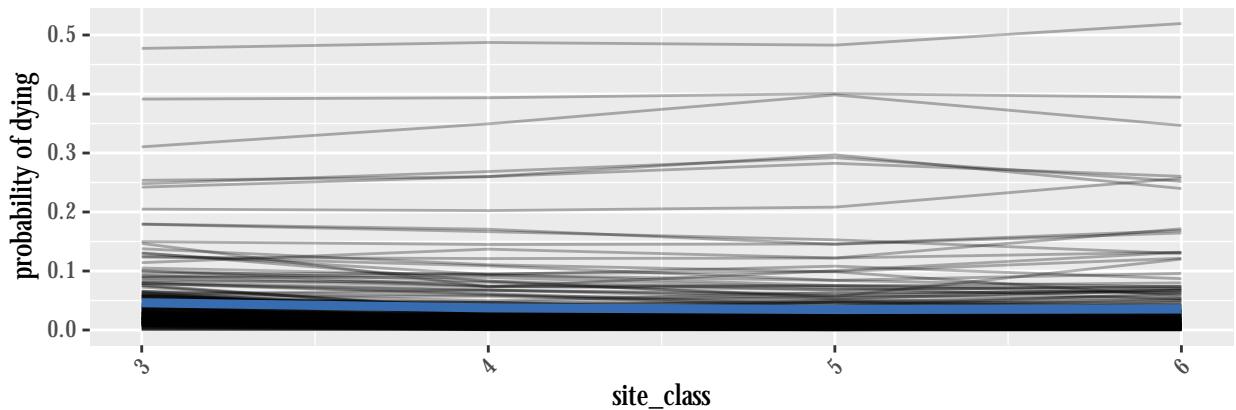




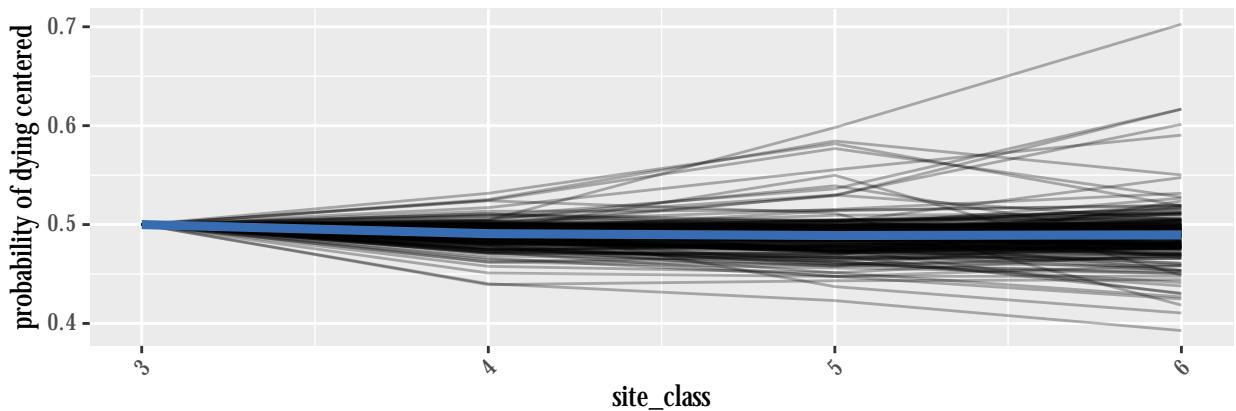
PDP for site_class



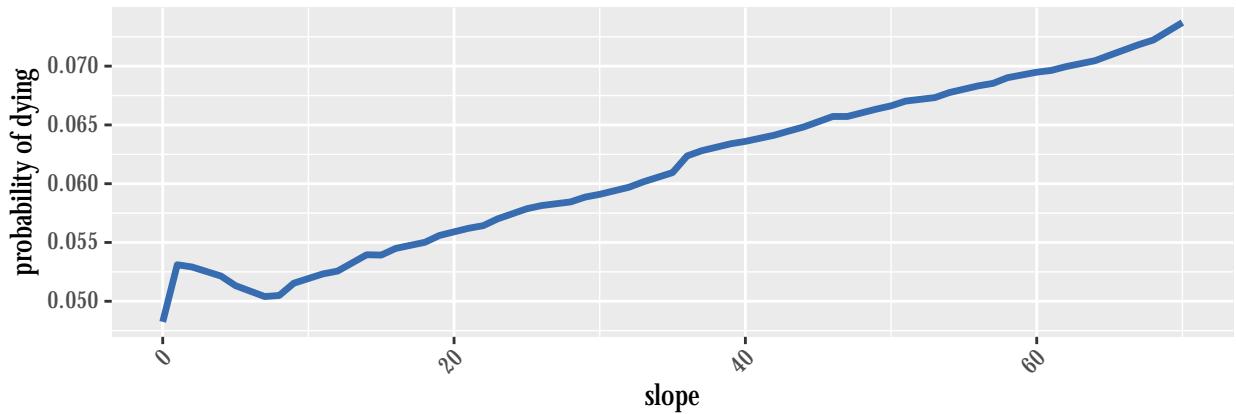
ICE plot for site_class



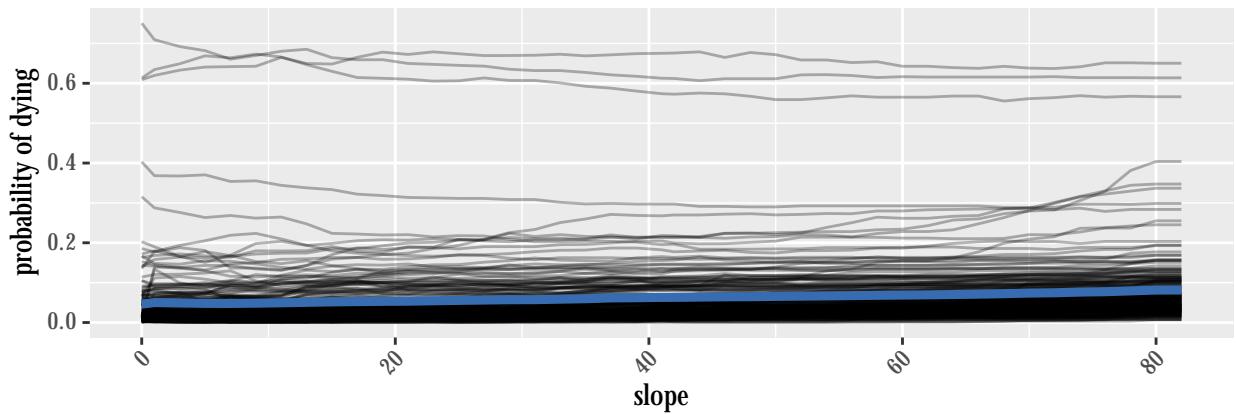
Centered ICE plot for site_class



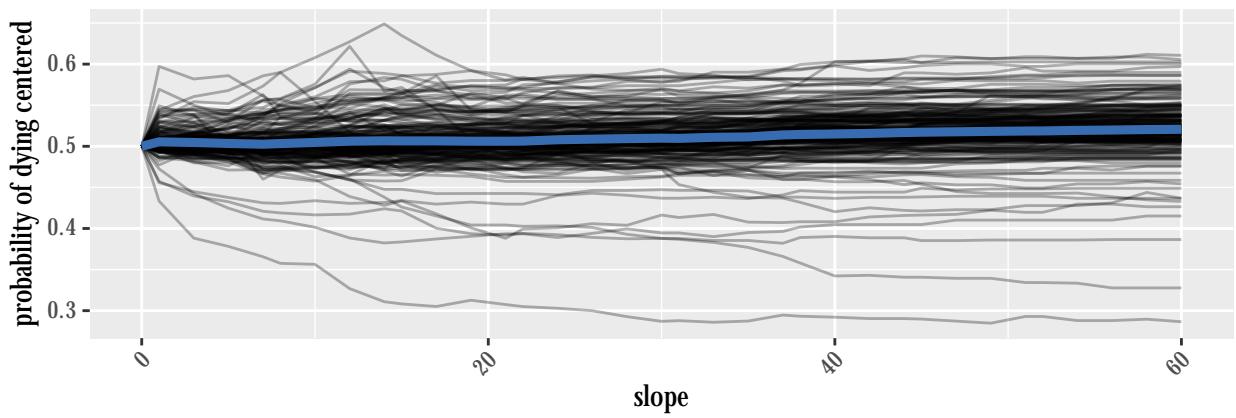
PDP for slope



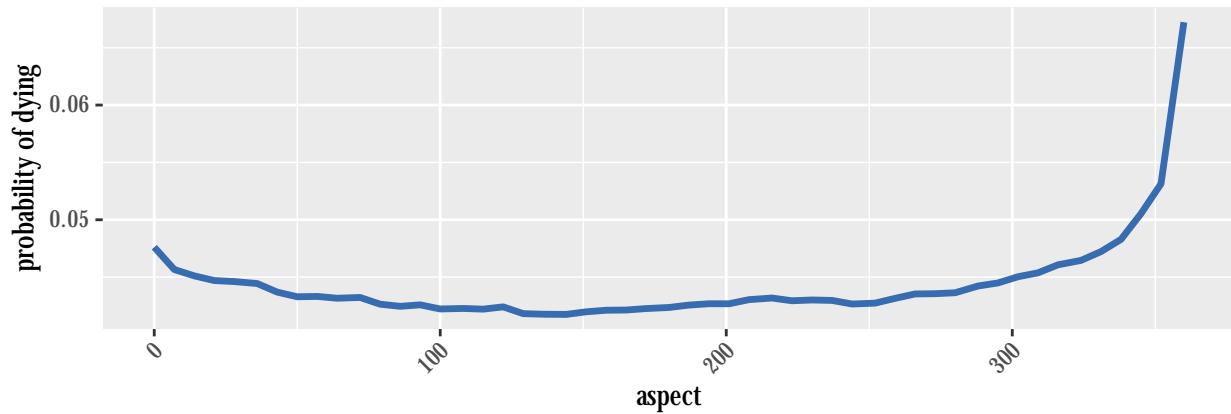
ICE plot for slope



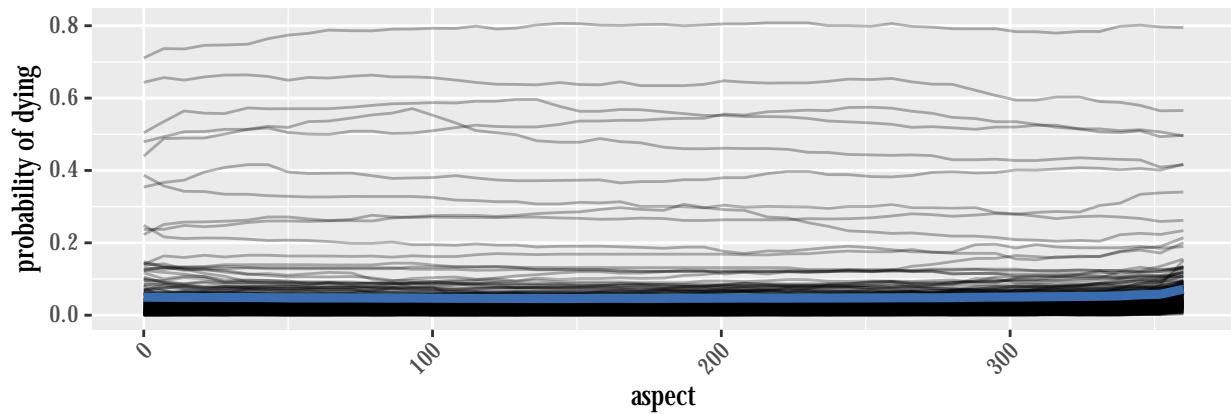
Centered ICE plot for slope



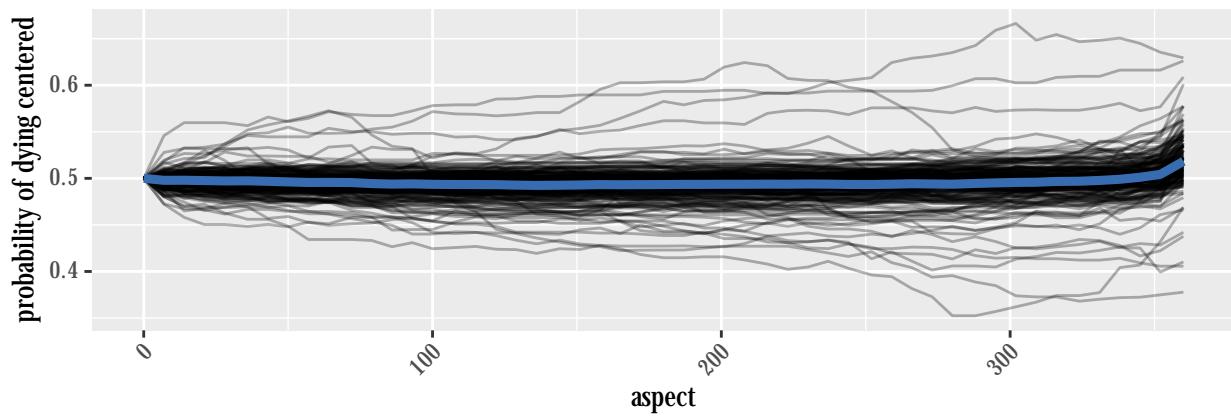
PDP for aspect



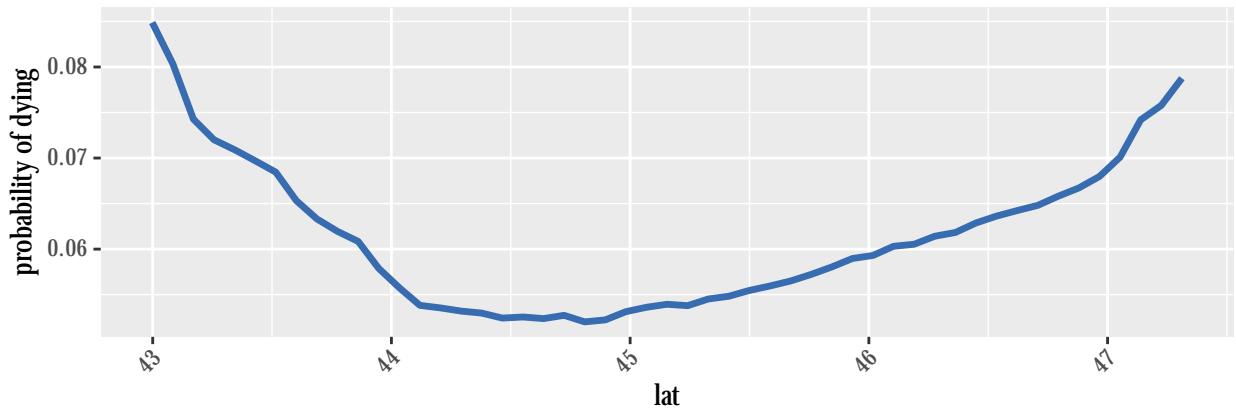
ICE plot for aspect



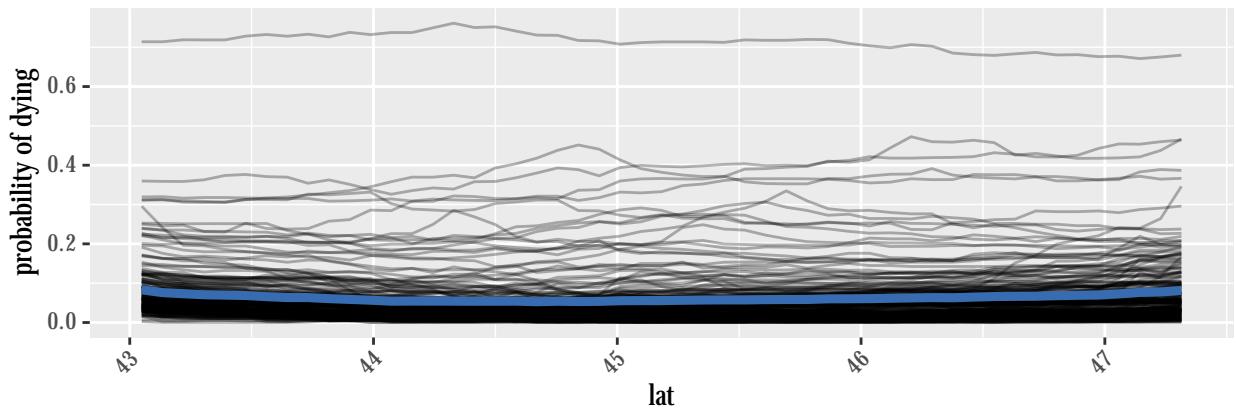
Centered ICE plot for aspect



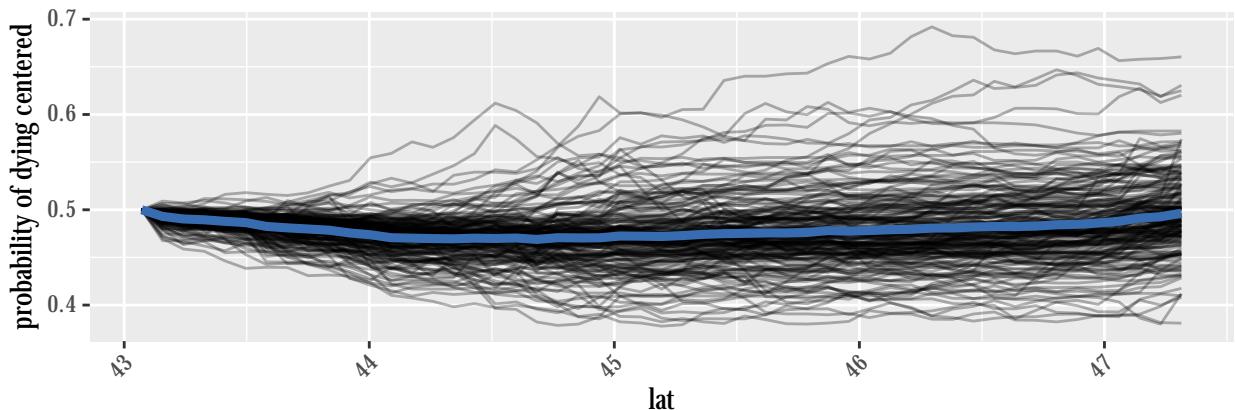
PDP for lat



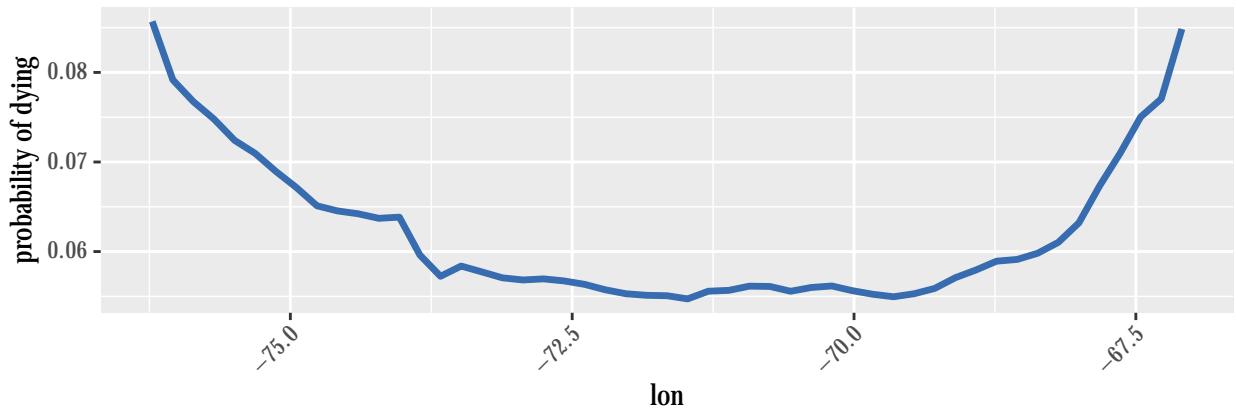
ICE plot for lat



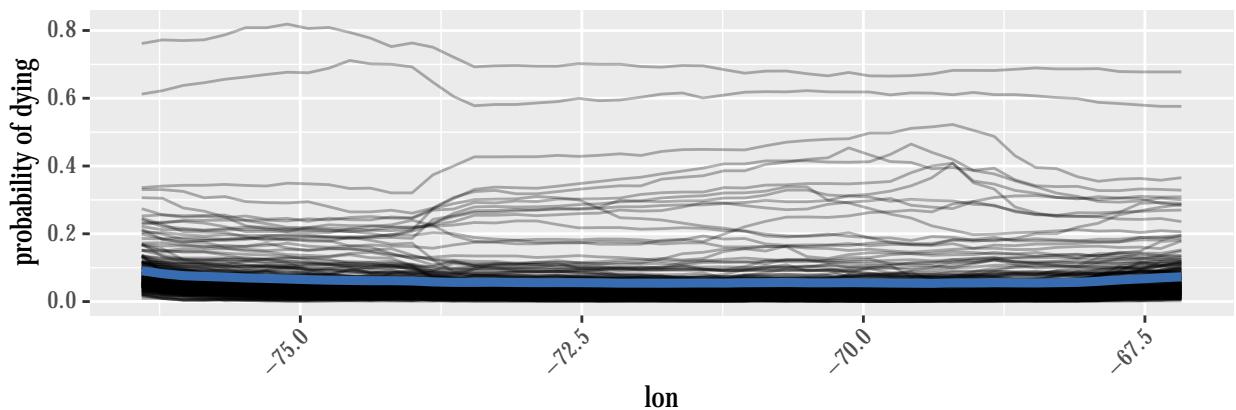
Centered ICE plot for lat



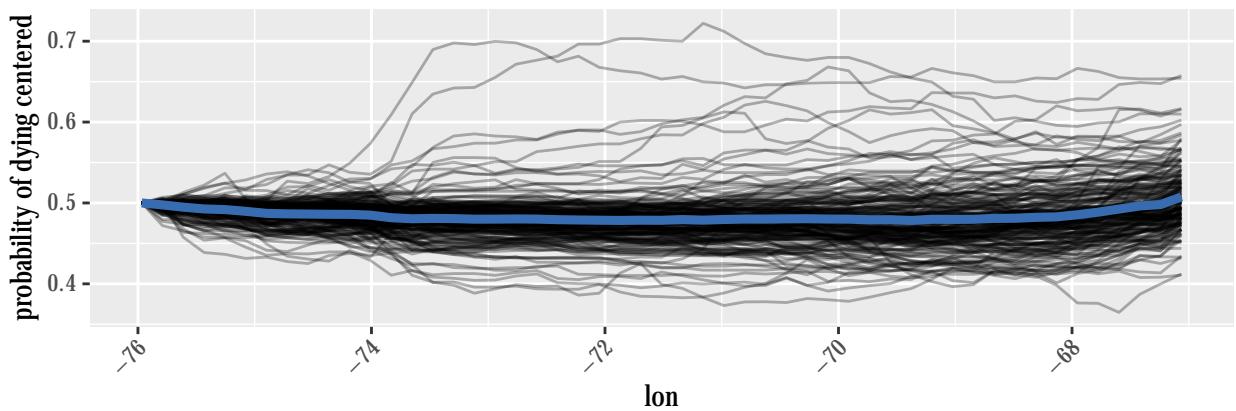
PDP for lon



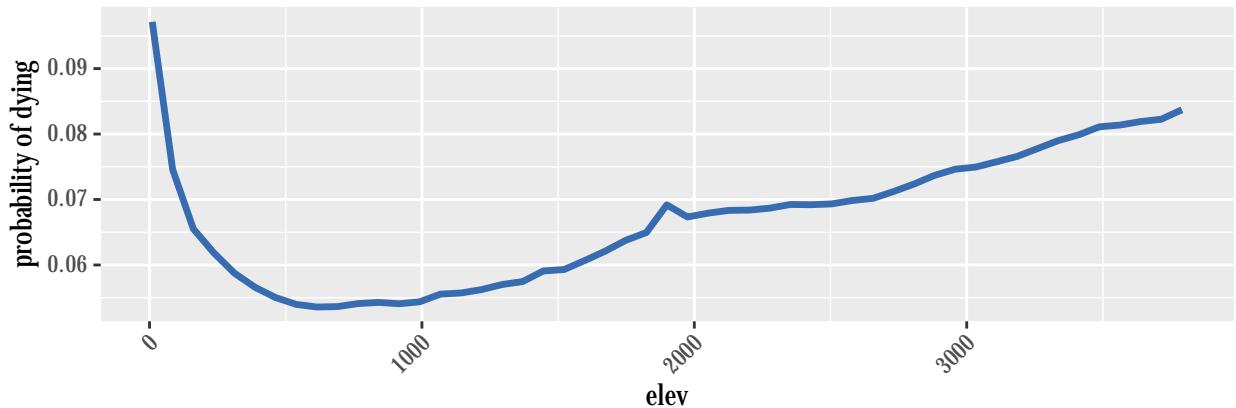
ICE plot for lon



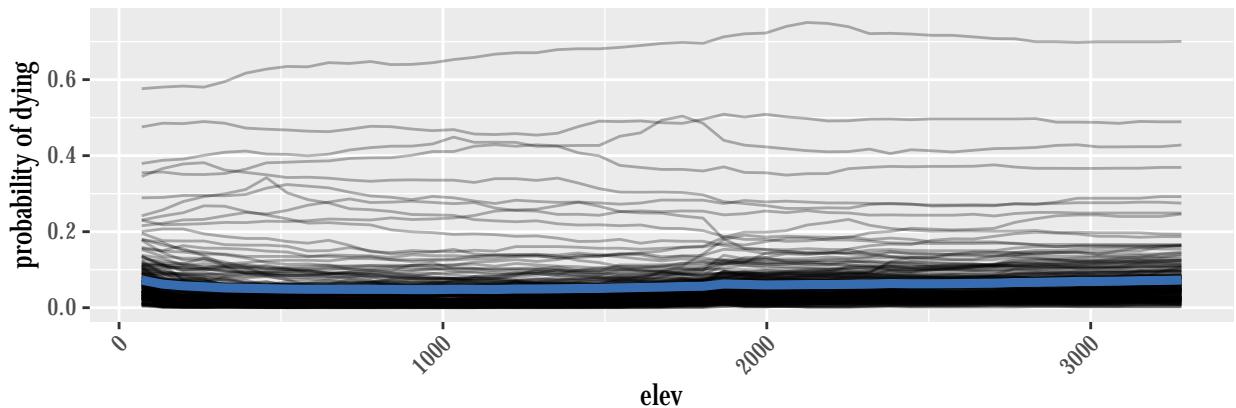
Centered ICE plot for lon



PDP for elev



ICE plot for elev



Centered ICE plot for elev

