Occurrence and extent of internal stem rot in living trees across multiple species in the eastern US: Comparison of statistical approaches and influential factors

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Introduction

- Wood value is generally estimated using:
  1) wood volume
  2) wood quality
- Depending on the end product wood quality may be defined in terms of wood properties such as wood density, strength, and presence/absence of decay.
- Relatively little attention has been given to modeling internal properties (especially decay) in hardwoods of the northeast US (Defo 2015)

Rot estimates also play into how the United States estimates biomass and carbon.

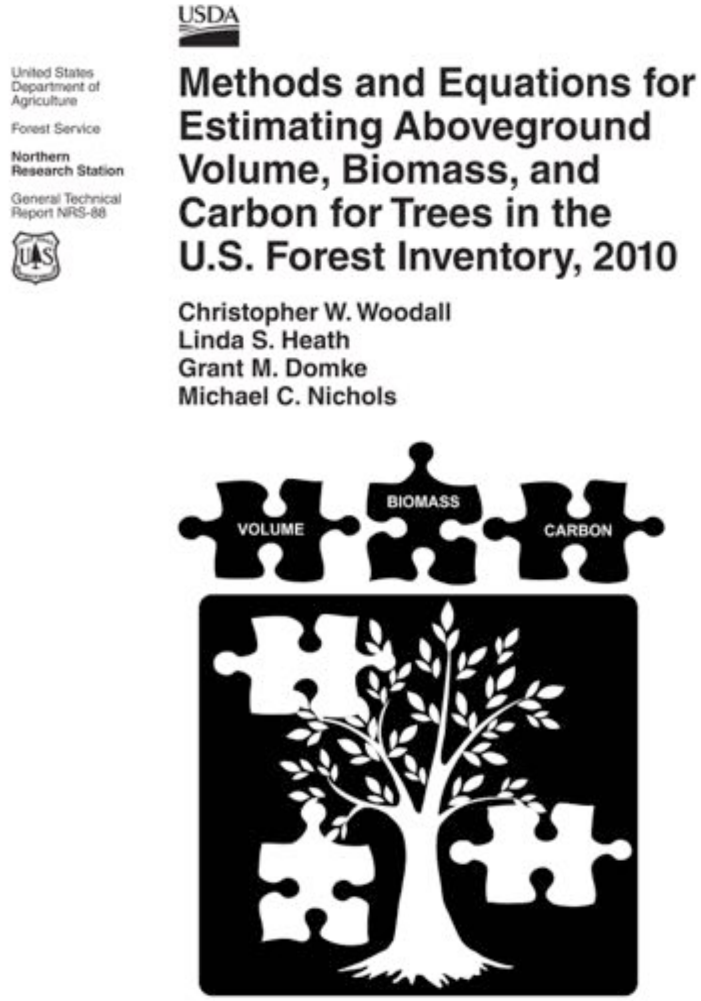
<u>The Component Ratio Method (Woodal et al., 2011)</u>

1) Estimates tree gross volume using regional volume equations.

2) Deducts cull/rot from gross volume to estimate sound volume

   - Visually estimated on standing trees in some regions & predicted in others

3) Uses biomass conversion (wood density) and expansion factors (bark ratios, component ratio estimaors) to estimate above-ground biomass.



Defining stages of decay

1) Discoloration: Wood is evidently discolored, likely due to a fungal pathogen. However, there is no evident loss of wood density.

2) Rot: Onset of decay. Structure/weight/density of the wood has evidently changed. Wood is “spongy”, “soft to the touch”.

3) Cull: The wood is hollow, or all that is left crumbles when the wood is sawn. Density and mass is nearly 0.

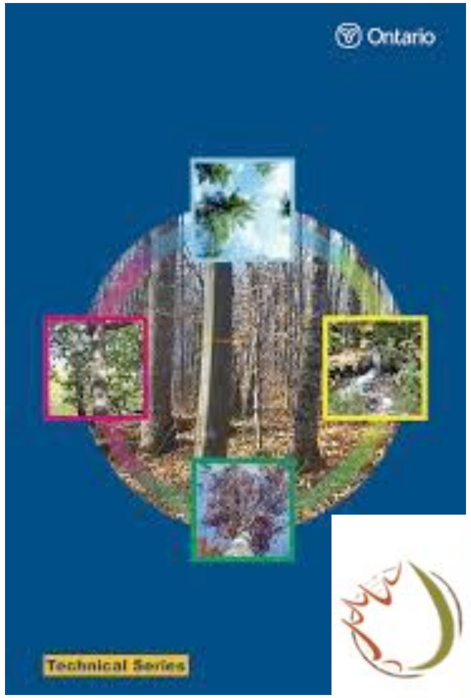
Factors influencing decay and discoloration

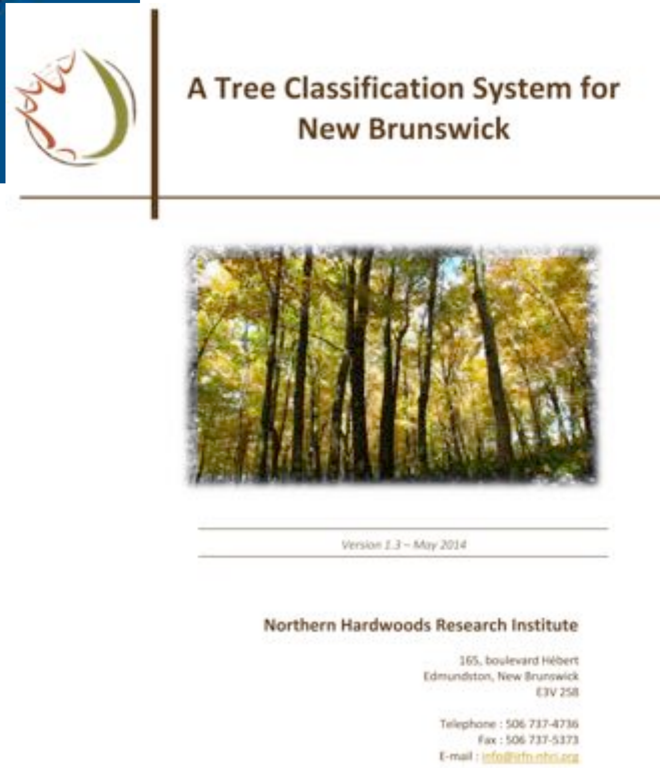
Species	Factor	Response	Location	Reference
Sugar maple	Soil acidity Nutrient content Minimum temperature	Heart size Decline Red heartwood	Northern States Northeast U.S. Quebec	Yanai et al. 2009 Horsely et al. 2002 Havreljuk et al. 2013
Paper birch	Sun exposure Diameter and vigor	heartwood	Quebec Quebec	Giroud et al. 2008 Drouin et al. 2009
Yellow birch	Cracks, mechanical injury, broken branches	Trunk rot	Quebec	Lavallee & Lortie 1968
American Sycamore	Forking, age, diameter increment	Brown heart	Slovenia	Kadunc (2007)

Range of factors have been identified that affect discoloration and rot but vary by study, location, and species

Tree Classification Systems

- Ontario Tree Marking Guide (OMNR 2004)
- ABCD Classification System
- Northern Hardwoods Research Institute (Pelletier 2014)
- Acceptable Growing Stock (AGS) /Unacceptable Growing Stock (UGS) System





Modeling decay

Highly problematic because:

1) Zero-inflated (many of trees have no defect)

2) Proportion of decay in trees is highly variable

3) Highly non-normal

4) Proportions are constrained between 0 and 1

Objectives

1) Test statistical approaches for modeling trees with and without decay

2) Examine differences in rot between species and location.

3) Assess which factors are most significant when predicting the probability and proportion of rot in a tree.

Tested Three Modeling Frameworks

1) Two part conditional model
2) Generalized additive models for location shape and scale (Stasinopolous et al., 2008)
   - semi-parametric
   - Advantage of modeling different parameters:
     Nu represents probability of occurrence
     Mu the mean
     Sigma the shape
     Tau, prob of entirely rotten
   - Greater flexibility
3) Multinomial model

Data used in analysis

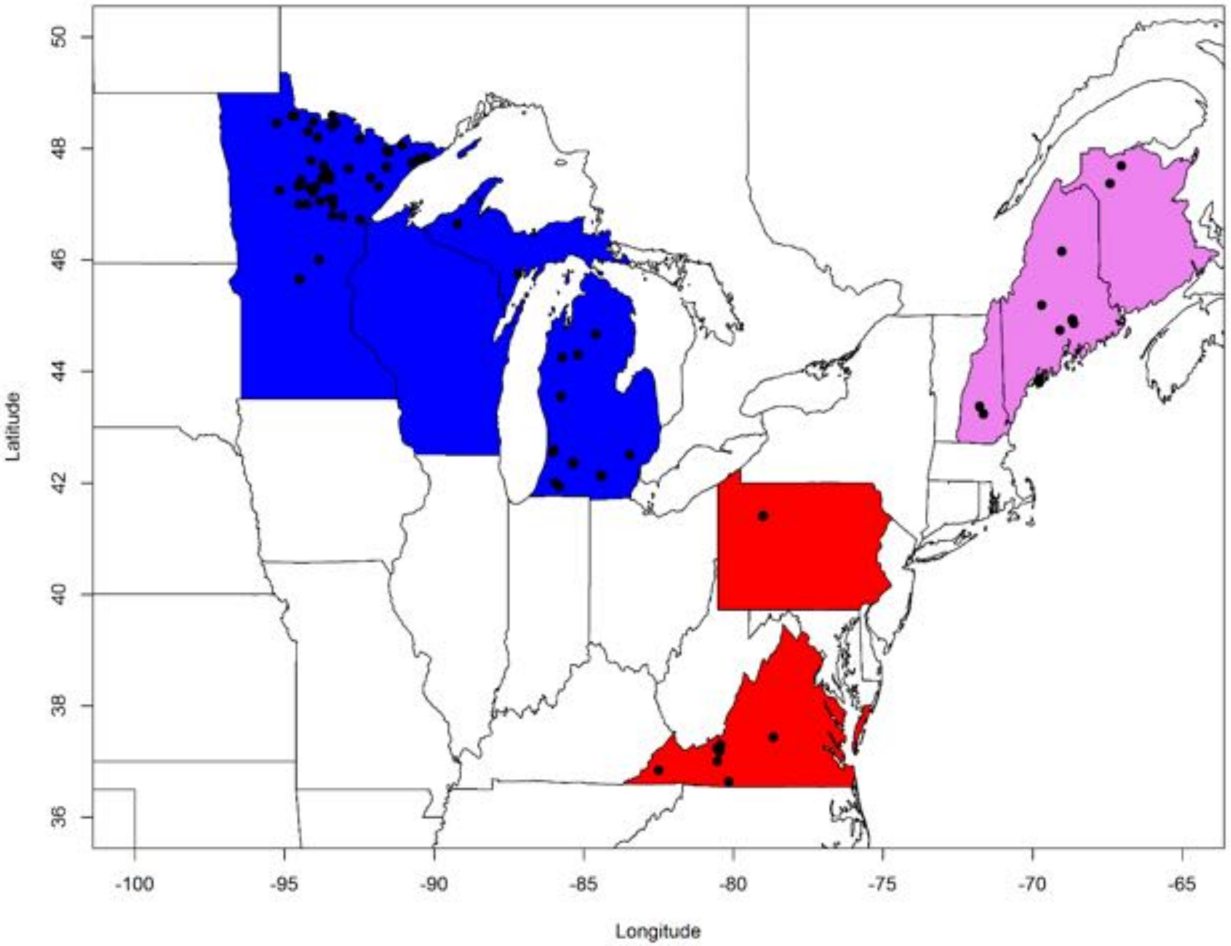
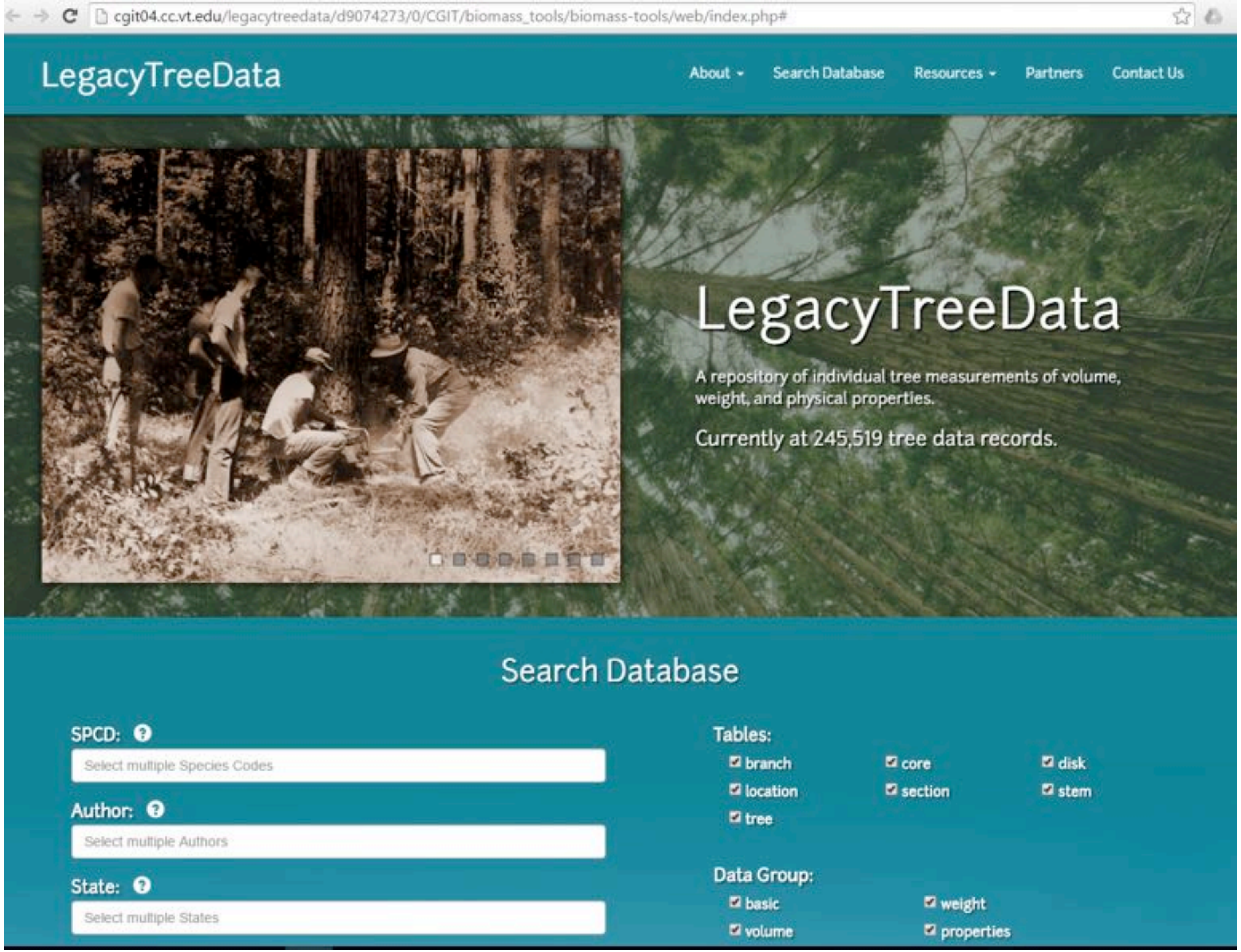


Figure 1. Study site locations used in this analysis with identified sub-region. Blue is Lake States region, red is Southeastern region, and purple is the Acadian region.

-Sources: Northern Hardwoods Research Institute; USFS FIA Biomass Project; USFS Northern Research Station

Data: Legacy Tree Database



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- > 200,000 taper records; 170 spp.
- ~ 30,000 biomass records; 157 spp.
- > 12,000 wood density records
- 260 unique sources across the United States and Canada

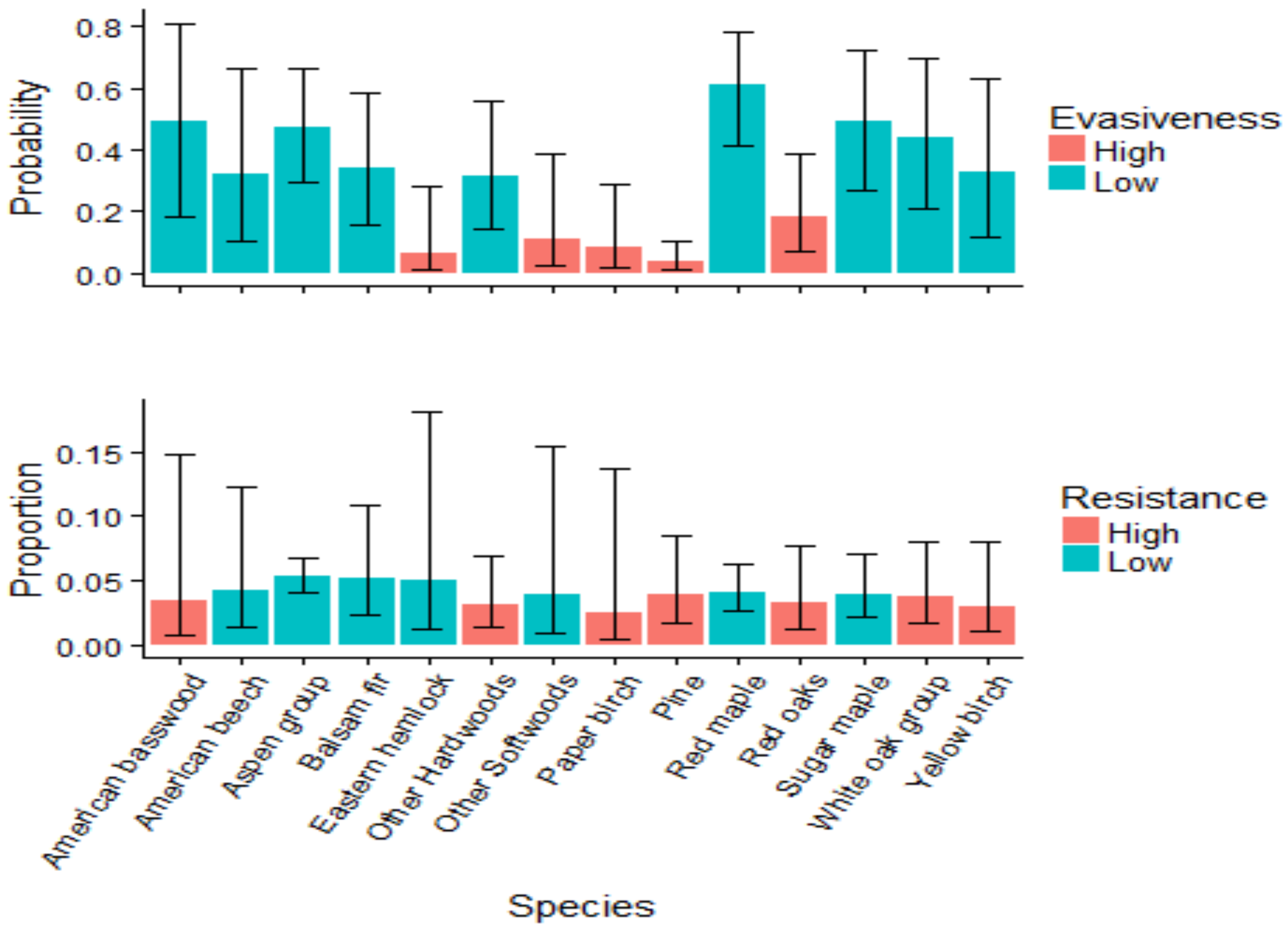
1 - Department of Forest Resources and Environmental Conservation, Virginia Tech
2 - School of Forest Resources, University of Maine
3 - Southern Research Station, USDA Forest Service
4 - Northern Research Station, USDA Forest Service

Data Summary

Species	Diameter (cm)	Height (cm)	Crown Ratio (%)	High	Low	Acadian	Southeast	Lakes
American basswood	14.7 [5.4,37.8]	12.5 [8,22.2]	54.9 [23.2,76.4]	4	19	2	0	21
American beech	31.1 [3,79.8]	19.9 [6.1,33.7]	70.1 [30.9,93.7]	4	25	5	8	16
Aspen group	18.3 [2.8,60.5]	18.3 [4.9,28.3]	40.6 [10.9,93.8]	203	376	7	0	572
Balsam fir	14.6 [2,40.6]	11.7 [2.2,27.3]	67.2 [17.8,99.2]	36	67	40	0	63
Eastern hemlock	24.7 [2,82]	12.8 [2.7,26.8]	74.8 [51.7,88.8]	0	39	1	22	16
Other Hardwoods	24.4 [2.8,81.8]	17.4 [4.1,37.3]	58.7 [22,90.4]	8	79	11	10	66
Other Softwoods	25.2 [5.8,54.9]	13.6 [4.6,25.6]	70.6 [41.3,95.2]	1	19	8	2	10
Paper birch	16.9 [4.6,34.5]	15.4 [6.4,23.1]	65.1 [36.6,88.1]	5	26	8	0	23
Pine	28.5 [1.5,81.3]	18.1 [2.8,40.2]	55.5 [6.3,92]	17	127	38	54	52
Red maple	25.4 [3,85.6]	18.5 [6.5,30.3]	66.2 [26.2,91.3]	41	86	49	25	53
Red oaks	32 [4.8,83.3]	20.4 [7.7,35.8]	60.2 [26.4,89.6]	11	39	15	3	32
Sugar maple	22.1 [2,55.6]	16.5 [3.3,27.3]	63.3 [34.6,98.6]	21	49	32	2	36
White oak group	38.1 [6.3,106.7]	19.8 [7.2,33.3]	69.4 [27.9,93.6]	16	38	4	34	16
Yellow birch	28 [5.3,54.1]	16.6 [7.7,21]	71.8 [36.9,97.9]	14	11	16	0	9
All Species	22.2 [1.5,106.7]	17.4 [2.2,40.2]	54.0 [6.3,99.2]	381	1000	236	160	985

Wide range of species and tree sizes

Rot evasiveness, resistance, and resilience



Most resilient species after accounting for other factors

- Pine
- Paper birch
- Eastern hemlock
- Other softwoods
- Red oak

Model Selection

- Examined the following variables:

  -DBH, DBH/HT, log (HT), height, risk class, polynomial DBH, log (DBH), wood density, species, region, location, tolerance to environment, climate variables

  Nu: defect.rat ~ f(DBH/HT + HT + log(HT) + crown ratio + risk class + species group + mean annual temperature + winter precipitation

  Mu: Species + risk class

  Sigma: Species + risk class

  Tau: -

  Location random effect still very strong

Table 3. Key model fit statistics for different modeling approaches and alternative formulations for predicting rot occurrence and rot proportion. The fit statistics were the change in Akaike Information Criteria from null model (ΔAIC), area under the curve (AUC), sensitivity (% true positives), specificity (% true negatives), overall classification rate, overall predicted mean, mean bias (MB; pred. - obs.), and root mean square error (RMSE). Observed mean is 0.422.

Formulation	Rot occurrence					Rot proportion		
	Delta AIC	AUC	Sensitivity	Specificity	Classification Rate	Predicted Mean	Mean bias	RMSE
Two Part Conditional Model								
Full	278	0.76	47	84	71	0.0442	0.0020	0.0767
Null w/ random	186	0.71	36	88	73	0.0442	0.0020	0.0769
Reduced	173	0.78	42	91	69	0.0442	0.0020	0.0772
Null	-	0.5	0	100	64	0.0442	0.0020	0.0772
Gamlss Model								
Full	283	0.76	47	84	71	0.0442	0.0020	0.0766
Null w/ random	230	0.78	42	91	73	0.0442	0.0020	0.0772
Reduced	191	0.81	36	88	69	0.0442	0.0020	0.0766
Null	-	0.5	0	100	64	0.0442	0.0020	0.0772
Multinomial Model								
Full	301	-	27	94	70	0.0408	-0.0014	0.0800
Reduced	193	-	36	88	69	0.0387	-0.0035	0.0826
Null	-	0.5	0	100	64	0.0798	0.0376	0.0859

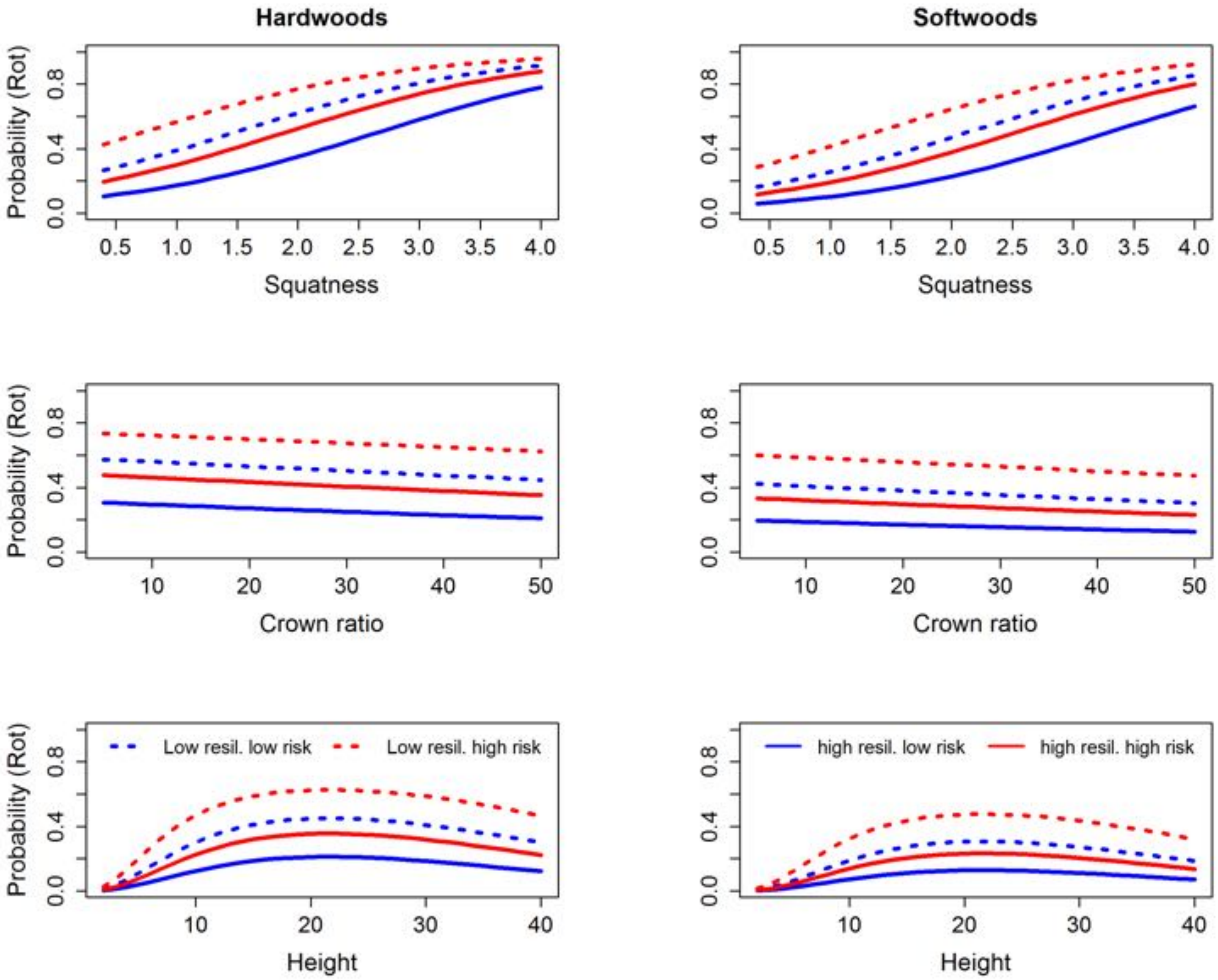
Reduced model includes just risk class and species group

Note: we also have observed favorable results using a 0 inflated parametric approach that assumes a geometric dist. RMSE 0.048 across all data

Verification (across all trees) by species group and risk class

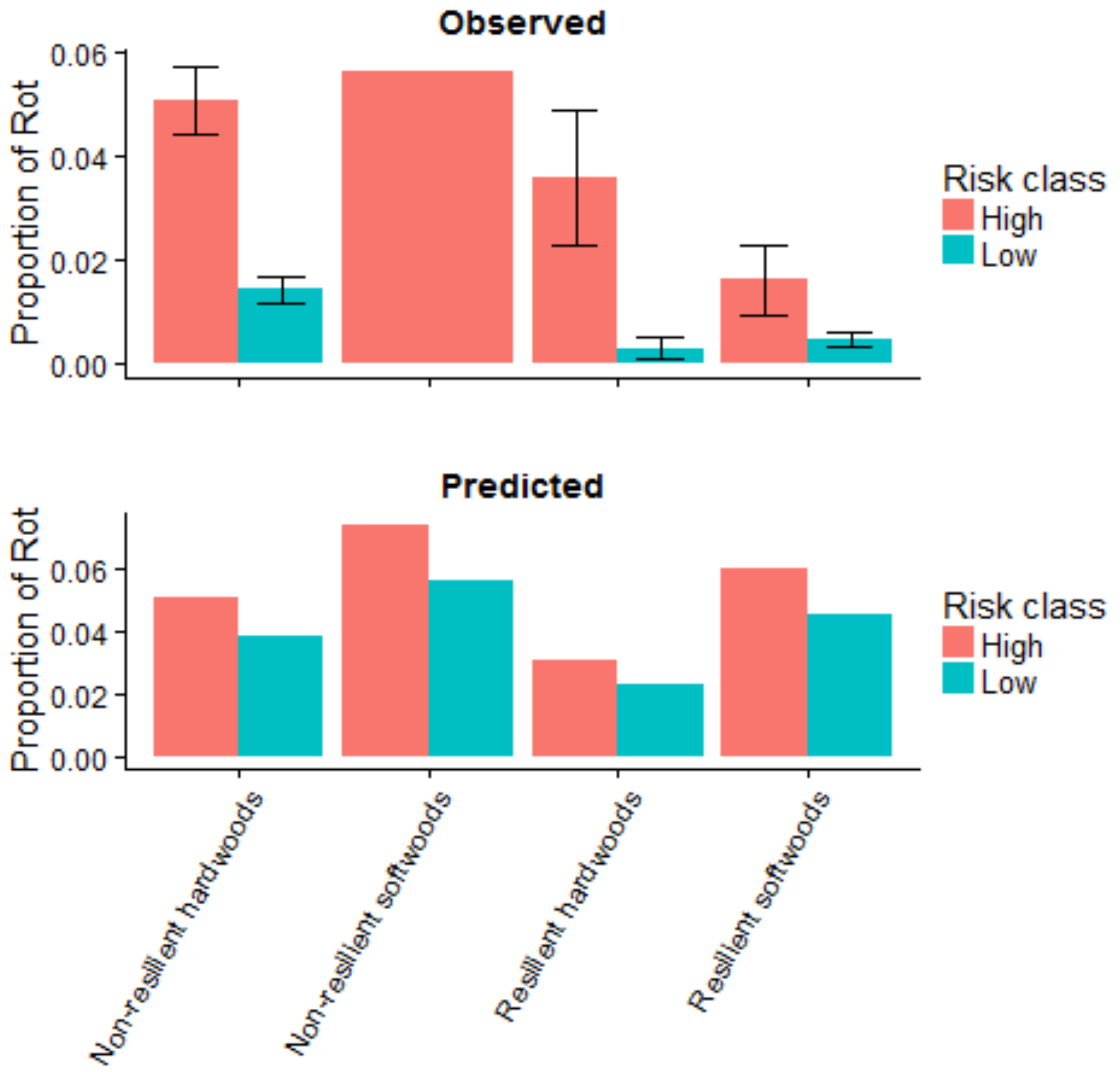
		Observed		Modeled		
Species group	Risk Class	Number of trees sampled	Cull (%)	Gamlss Cull (%)	2-part Cond Cull (%)	Multi-nomial Cull (%)
Resilient hardwoods	High	38	1.96	**1.69**	2.39	2.31
Resilient hardwoods	Low	155	0.29	**0.02**	**0.02**	0
Non-resilient hardwoods	High	289	3.33	4.64	4.61	**3.9**
Non-resilient hardwoods	Low	593	1.19	**0.42**	**0.42**	0.01
Resilient softwoods	High	18	0.58	0.66	**0.62**	0
Resilient softwoods	Low	185	0.7	0	0	0
Non-resilient softwoods	High	36	2.95	4.08	**3.33**	0.44
Non-resilient softwoods	Low	67	1.11	0	0	0
Hardwoods	-	1075	1.66	1.54	**1.56**	1.13
Softwoods	-	306	1.05	**0.52**	0.43	0.05
-	High	381	3.03	4.11	4.08	**3.23**
-	Low	1000	0.95	**0.25**	**0.25**	0.01
All	All	1381	1.53	**1.32**	1.31	0.89

Trends



Hardwoods
Softwoods
Probability (Rot)
0.0
0.4
0.8
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
Squatness
10
20
30
40
50
Crown ratio
Low resil. low risk
Low resil. high risk
high resil. low risk
high resil. high risk
Height

Defect ratio across species groups and risk class



Summary

- Rot remains difficult to model in trees in the northeast but there are fairly clear differences among species

- Using consistent protocols to assess tree form and risk help improve predictions of rot proportion in trees

- Generalized additive models for location shape and scale provided a flexible framework for predicting rot and dealing with zero inflation

- More data needed to assess edaphic, treatment, and climatic influence on rot in trees

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MSU Forestry

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