FSP Project Y081260
Development of a spatially explicit crown model

Final Technical Report

1. Abstract

Recent changes in forest management goals have led to a diversification of silvicultural practices to maintain complex, mixed-species stands. Managing such stands requires an understanding of competitive interactions among individual trees. In this project, we used an individual-based, spatially explicit "neighbourhood" analysis to develop new models of crown radius and crown length for subalpine fir (*Abies lasiocarpa*), lodgepole pine (*Pinus contorta*), and interior spruce (*Picea glauca* x *engelmanii*). We parameterized our models using spatially explicit crown measurement data from ~2400 trees collected in the subboreal spruce forest near Smithers, in north-central British Columbia.

Using maximum likelihood methods, we quantified crown radius and length for each species as a function of tree size and neighbourhood competition, estimated by the identity and spatial arrangement of neighbouring trees. In the absence of competition, spruce and fir showed similar patterns of increasing crown radius and length with tree dbh and height respectively. Compared to fir and spruce, pines growing in the absence of competition were associated with wider, shallower crowns.

The effect of competition on crown dimensions was strong. All species showed declines in predicted crown size with increasing neighbourhood competition, an index that varied with the abundance, size, distance, and species identity of neighbouring trees. The best models fit separate competition coefficients for each species of neighbouring trees, indicating that there are important differences among species in their competitive effects on tree crowns. The strongest competitors for fir and pine were conspecifics, while spruce was most sensitive to competition from fir neighbours. Although there was no single means to assess sensitivity to competition, pine was generally the most sensitive species to increasing levels of crowding in monospecific stands, while in mixed-species stands, spruce was most sensitive to crowding.

We used our results to parameterize a new, individual-based, distance-dependent crown model for the stand simulation model SORTIE-ND. Including a competition-dependent canopy model in SORTIE-ND is likely to improve the model's accuracy in predicting dynamics of mixed-species stands, understorey light availability, and sapling and sub-canopy tree dynamics.

2. Introduction

Maintenance of ecological complexity is becoming a common forest management goal (Puettnamm et al. 2009). This has led to recent diversification of silvicultural practices to promote multi-cohort, mixed-species stands. Although the ecological benefits of complex stands are well established, they present a serious challenge from a growth and yield modelling perspective.

Traditional forestry focused on development and maintenance of even-aged, monocultural stands. Growth of these stands is predicted using yield tables, aspatial empirical models that predict timber volumes based on site class and stand age. Yield tables are associated with very accurate volume predictions for even-aged, single-species stands, but are insufficient to capture the complexity of multi-cohort, mixed-species stands. Since there is a nearly infinite number of possible ways in which residual trees can be configured in terms of species, sizes, and spatial layout, predicting growth of complex stands requires use of individual-based, spatially explicit models such as SORTIE-ND.

A critical step towards developing and parameterizing individual-based, spatially explicit growth models is obtaining quantitative estimates of competitive interactions among canopy trees. Extensive research has been carried out in north-central British Columbia to quantify competitive interactions among canopy trees (e.g., Canham et al. 2004; Coates et al. 2008), but this research represents the first attempt to examine the effects of competition on the structure of individual tree crowns in the study region.

In this project (Y081260), we aimed to develop and parameterize a distance-dependent crown allometry behaviour for the growth model SORTIE-ND. In a previous FSP project, we performed an evaluation of SORTIE-ND as a growth model for mixed aspen-spruce stands (Astrup 2006). We evaluated the conceptual structure of SORTIE-ND, conducted a sensitivity analysis, and compared model predictions to independent data from permanent sample plots. The evaluation suggested that SORTIE-ND is a suitable model for growth prediction in complex, mixed-species stands, but that targeted improvements to the model could improve its robustness and predictive ability (Astrup 2006). The most critical topic identified for model development was crown structure.

In SORTIE-ND, crown radius of an individual tree is estimated as a nonlinear function of diameter at breast height (dbh: 1.3 m) and crown length is predicted as a linear function of tree height. These relationships are completely independent of the surrounding trees (Coates et al. 2003). Simultaneously, SORTIE-ND allows individual crowns to overlap. Thus, both crown radius and crown length are often overestimated in dense stands and underestimated in open stands. The result is a potential bias where understory light availability is underestimated in dense stands and overestimated in open stands. In SORTIE-ND, growth of individual understory trees is predicted based on light availability and mortality of individual understory trees is a function of recent growth

(Coates et al. 2003). Thus, a bias in understory light predictions could lead to biased predictions of subcanopy tree growth and survival.

The primary objective of this study was to develop and parameterize a competition-dependent model of crown structure to incorporate into SORTIE-ND. We anticipate that this will make SORTIE-ND a more robust model for predicting development of complex stands. Thus, our research will be useful for managers and researchers interested in predicting growth in complex stands.

3. Methods

STUDY SITES

Our 15 study sites were located near Smithers, British Columbia (54°35′N, 126°55′W), in the Sub-Boreal Spruce Moist Cold subzone, Babine Variant (SBSmc2; Meidinger and Pojar 1991). We collected data in circum-mesic sites that spanned a range of stand ages, densities and species composition. Stands were dominated by combinations of lodgepole pine (*Pinus contorta*), interior spruce (*Picea glauca x engelmanii*), and subablpine fir (*Abies lasiocarpa*). Other species included trembling aspen (*Populus tremuloides*), black cottonwood (*Populus balsamifera ssp. Trichocarpa*), western hemlock (*Tsuga heterophylla*), and black spruce (*Picea mariana*).

FIELD SAMPLING

We collected data in 15 previously established square stem-mapped plots that ranged in size from 0.07 to 0.22 hectares (Fig. 1). For all trees ≥ 5 dbh, we measured dbh, height, species, average crown length, and average crown radius measurements. We obtained x-y coordinates from previous data collection efforts. We calculated average crown length from crown length measurements (tree height – height of lowest live branch) taken in the field in each of the four cardinal directions. We derived average crown radii values from crown area values ($\text{radius} = \sqrt{\text{area}/\pi}$). To obtain estimates of crown area, we outlined tree crowns on 5-cm resolution winter aerial photographs in the field. Later, we digitized crown outlines using using GIS software (Manifold System 8.0, 2008, Manifold Net Ltd.) and obtained an area value from each crown polygon.

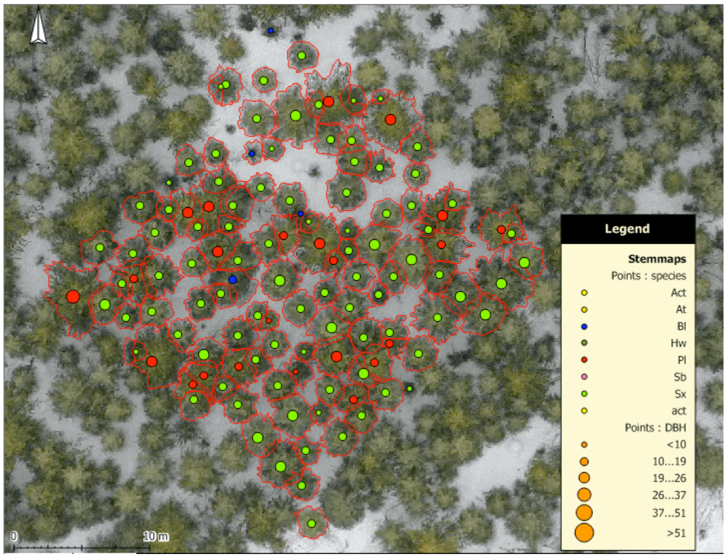

Figure 1. Example plot showing digitized crown areas.

In total, we measured the crowns of 2391 live trees ≥ 5 cm dbh across 15 sites, including 524 subalpine fir, 1029 lodgepole pine, and 813 interior spruce (Table 1).

Table 1. Summary of data.

Plot no.	Area (m^2)	No. fir stems	No. pine stems	No. spruce stems	No. other spp stems	Total no. stems	Density (no./ha)
1	5370	30	130	194	13	367	683
2	1351	5	108	40	0	153	1132
3	1761	6	197	41	0	244	1385
4	900	11	132	13	0	156	1733
5	1645	13	109	68	3	193	1173
6	1045	85	9	28	0	122	1167
7	2037	203	25	66	6	300	1473
8	639	62	1	39	0	102	1596
9	429	0	57	38	0	95	2214
10	667	1	23	91	0	115	1724
11	464	0	62	0	0	62	1336
12	1656	13	57	146	2	218	1115
13	428	0	16	31	1	48	1121
14	690	11	101	11	0	123	1783
15	673	84	2	7	0	93	1382
Totals	20055	524	1029	813	25	2391	

VALIDATION OF CROWN RADII ESTIMATES

To test the validity of our new digital vs. traditional manual crown radii measurement methods, we compared 50 trees using traditional tape and clinometer/bullhorn methods and compared them to radii we digitally extracted from crown outlines (Fig. 2). The first plot shows radii estimates (where each cardinal direction was measured independently from the stem) and the second plot shows diameter measurements (which are the sum of the N and S radii measurement, and the E and W measurement. We found high correlation values between traditional field measurements and our digitally extracted measurements from high-resolution aerial images. The increase in correlation from radii to diameter assessment is attributed to errors associated with asymmetry of the crown. It is important to note that traditional field measurements contain their own error.

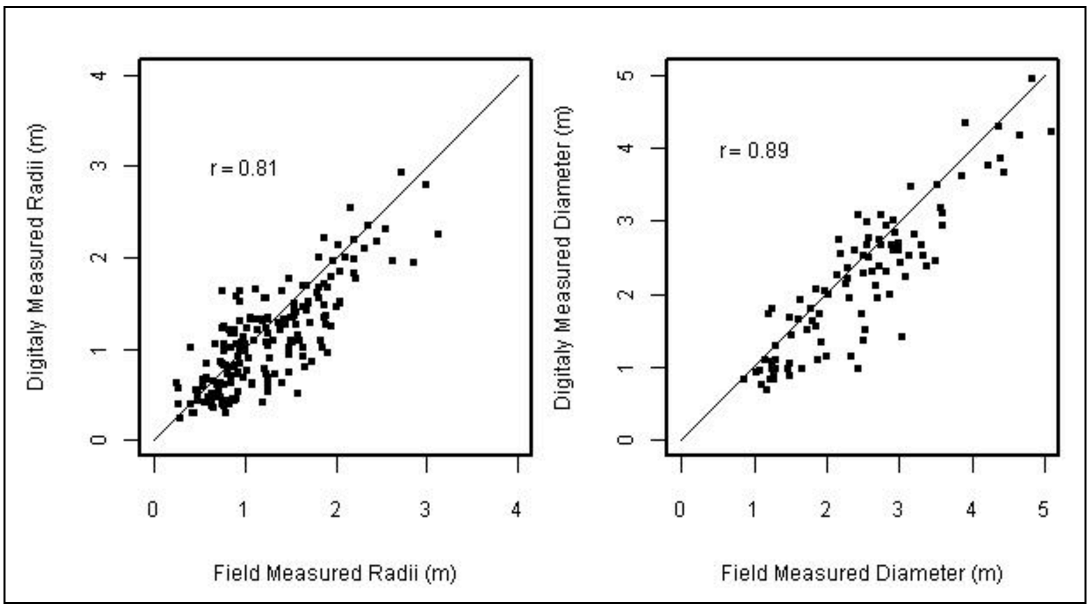

Figure 2. 1:1 Plots comparing field versus digitally measured crown dimensions.

ANALYSIS

We developed statistical models to describe crown radius and crown length as functions of tree size and neighbourhood competition. Here we describe the general approach we took to develop models of crown radius and length for the three study species. For details on statistical methods including equations and model comparisons, see Thorpe, Astrup, Trowbridge, and Coates, manuscript in internal review (hereafter: Thorpe et al., in preparation).

We predicted crown radius and length for each species as a function of the maximum potential crown dimension, the size effect, and the crowding or competitive effect. For each model, the maximum potential crown dimension was estimated as a single parameter, and size and competitive effects were multipliers that acted to reduce predicted crown dimensions from their maximum potential. Crown dimensions were predicted to increase with tree size and to decrease with increasing neighbourhood competition. Competition was estimated using a neighbourhood competition index (*NCI*), which incorporates the size, distance, species, and abundance of neighbouring trees into a compound estimate of competition strength (Canham et al. 2004; Coates et al. 2008).

INCORPORATION OF CROWN MODELS INTO SORTIE-ND

The final step in this project was to incorporate our newly developed models of crown radius and length into the stand simulator SORTIE-ND. Using model equations and maximum likelihood parameter estimates, we programmed new behaviours for crown radius and length and incorporated them into SORTIE-ND. Our crown structure behaviour calculates crown radius and length for each simulated tree as a function of species, size and competitive environment (Thorpe et al., in preparation). This contrasts previous versions of SORTIE-ND in which crown structure was predicted as a function of tree size alone. We have not yet undertaken model testing for this behaviour, but we expect that its incorporation into SORTIE-ND will improve the ability of the model to make accurate predictions of understorey light availability in mixed-species stands.

4. Results

For detailed study results, see Thorpe et al., in preparation.

MODEL SELECTION

We used information theoretic criteria to compare alternate models that included effects of: 1) size only; 2) size and competition, where the neighbourhood competition index (*NCI*) assumed competitive effects were equivalent for all species of neighbours; and 3) size and competition, where *NCI* included separate competition coefficients for each species (the full model). In all cases, the full model was selected as the best fit to the data. For crown length in pine and spruce, the selected full model included a size-dependent term in *NCI* such that the sensitivity to crowding by neighbours declined with target tree dbh. For crown radius in all three species and for fir crown length, the *NCI* term in the best model was independent of target tree size. The selected models and associated parameter estimated yielded unbiased predictions of crown structure and a good fit to the data.

SIZE EFFECTS

Tree size strongly influenced crown dimensions in all three study species. In the absence of competition, fir and spruce showed nearly identical patterns of rapidly increasing predicted crown radii in small diameter classes, up to a plateau in the larger size classes.

Pine showed no equivalent levelling off over its observed diameter range and, in the absence of competition, was expected to have wider crowns than spruce and fir.

Spruce and fir showed very similar patterns of near-linear increases in predicted crown length with tree height in the absence of competition. In contrast, pine crown length predictions increased only very slowly with tree height in the absence of competition, and were generally expected to be shallower than the equivalent spruce or fir tree. This is likely a result of pine’s shade intolerance, which leads to self-pruning of lower branches.

COMPETITIVE EFFECTS

Competitive effects of neighbour trees declined steeply with distance from target tree, and neighbours located within 2 m of target trees comprised the bulk of competitive influence. Species identity of neighbouring trees had a large impact on the strength of competitive effects. Intraspecific competition had the strongest effect on fir and pine, while spruce crowns were most affected by competition by fir neighbours. Overall, pine showed the steepest declines in predicted crown dimensions in monospecific scenarios. When neighbours were made up of a mix of spruce, fir and pine, spruce target trees were most sensitive to increased levels of crowding. Fir crowns were generally the least sensitive to crowding.

5. Discussion

The most important result of this study from a stand development modelling perspective is that the species identity of neighbours influences crown dimensions. Given an equivalent level of crowding (same number and sizes of neighbouring trees), we found large differences in predicted crown radius and length depending on the species mix of neighbours. This highlights the idea that individual-based, spatially explicit models are required to model complex, mixed-species stands accurately.

Our results have implications for the study of crown shyness. The empty space often found between individual crowns of similar-sized neighbouring trees, crown shyness is believed to be caused by breakage of branches caused by crown collisions during wind events (Rudnicki et al. 2002), and may be more evident in boreal and sub-boreal forests where branches are brittle during cold winter conditions (Lieffers et al. 2001). From a forest growth perspective, crown shyness can be a cause for concern since it results in reduced canopy occupation and may lead to reduced stand productivity (Meng et al. 2006). Our model predicted much smaller crown sizes for lodgepole pine in crowded, monospecific scenarios than in crowded, mixed-species stands. One possible explanation for this phenomenon is that spruce and fir branches are less brittle and thus less inter-crown breakage occurs. Whatever the cause, this result suggests that growing pine in mixtures of other species is likely to increase their crown size and may improve stand productivity in the long term.

6. Conclusions and Management Implications

Competition for canopy space is an important driver of forest stand dynamics, but little research has focussed on quantifying the influence of crowding by neighbours on the structure of individual tree crowns. The results of our study demonstrate that tree size and neighbourhood competition have a large impact on the crown dimensions of subalpine fir, lodgepole pine, and interior spruce. We found wide variation among the three study species in their sensitivity to competition depending on the size, species, and abundance of neighbouring trees, and thus our results highlight the complexity involved in competitive interactions among canopy trees, even in relatively species-poor ecosystems.

There are two major management implications of this study. First, the finding that the species identities of neighbours influence crown structure of target trees suggests that managers can design silvicultural treatments that maximize positive interactions among neighbours. Pine is the key example here, where crown size is predicted to be much larger in mixed-species stands than in monospecific stands. Thus mixed-species stands of fir, spruce, and pine may be associated with higher productivity than monospecific pine stands of similar ages and densities.

Second, our development of a new competition-dependent crown behaviour for the stand simulator SORTIE-ND will allow researchers and managers to make more accurate predictions of the influence of partial disturbances such as mountain pine beetle outbreak and variable retention harvesting on canopy tree dynamics, understorey light levels, and subcanopy tree growth and mortality.

7. Literature Cited

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