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White Spruce Basal Area as a Predictor of Seed Rain During an Exceptional Seed Year in Northwestern Alberta

Introduction

The boreal mixedwood forest region of Canada, encompassing 600,000 km^2 and stretching from the Prairie Provinces to northeastern British Columbia and Alaska, is dominated by mixtures of quaking aspen (*Populus tremuloides*), balsam poplar (*Populus balsamifera*), and white spruce (*Picea glauca*). An increasingly sophisticated public would like to see a departure from the conventional clear-cut and plant silvicultural system of forest management currently practiced in northern Alberta and interior British Columbia (Youngblood and Titus 1996, Gilmore 1997). Aspen and balsam poplar utilization in Alberta has increased by upwards of 800% during the past 15 yr (David et al. 2001) and this has provided opportunities for the implementation of silviculture systems that incorporate natural regeneration. The high cost of conifer planting programs also makes the implementation of silviculture systems that promote the natural regeneration of white spruce attractive.

The amount of white spruce seed fall and young seedlings per unit area reported in the literature is highly variable. Seed rain normally varies from 500,000 to 4 million seeds ha^{-1} (Zasada et al. 1992). To our knowledge, the review by Zasada et al. (1992) reported the highest known seed rain for white spruce as 40 million seeds ha^{-1} from a stand in Alaska. Stewart et al. (2000), however, reported a white spruce seed rain of 4 million seeds ha^{-1} during an exceptionally good seed year in Alberta. Good to excellent seed years may occur at 2-6 yr intervals, but 10-12 yr intervals have been reported (Nienstaedt and Zasada 1990). The irregular frequency of exceptionally good seed years may partially contribute to regeneration pulses that have been documented in boreal forests and are often associated with specific stages of stand development (Stelfox 1995, Zackrisson et al. 1995).

In another Alberta study focusing on established white spruce regeneration, maximum regeneration density equaled 15,778 seedlings ha^{-1} (Stewart et al 2001). In a comprehensive observational study of white spruce regeneration in the same area as our study, mean 1 yr seedling survival was < 17,000 seedlings ha^{-1} and 2 yr seedling survival was < 5,000 seedlings ha^{-1} (Berger 2002). In the context of silviculture, Greene et al. (2002) recommended a minimum of 6 m^2 ha^{-1} of mature white spruce, or an aerial seeding rate of 500,000 conifer seeds ha^{-1} for adequate stem density and percent stocking. The objective of this study is to develop an equation to predict white spruce seed rain from basal area during an exceptionally good seed year using data collected from three boreal forest cover types (white spruce; mixed white spruce - quaking aspen - balsam poplar; and quaking aspen - balsam poplar) in northwestern Alberta.

Methods

Study Area

The study site is located north of Hines Creek, Alberta (approximate latitude 57° N, longitude 119° W). Elevation ranges from 677 to 880 m. Soils are relatively uniform, fine textured, and of glaciolacustrine origin. Climate is continental, with average daily maximum and minimum temperatures of 21°C and 8°C for summer and -10°C and -21°C for winter. Stands developed following natural disturbances and ranged in age from 62 to 124 years (Spence and Volney 1999).

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Stand Characteristics and Harvest Treatments

Prior to harvest, stands were selected based on species composition, age, and estimated volume of the stands (Spence and Volney 1999). We installed 57 seed collection traps in 9 stands in 3 forest cover types of white spruce dominated (>70% white spruce basal area), mixed (conifer and deciduous composition each 35-65% basal area), and quaking aspen and balsam poplar dominated (>70% aspen and balsam poplar basal area). Quaking aspen and balsam poplar were from the same regeneration cohort and grew in approximate equal proportions. Trees were felled from machine corridors 5 m wide and spaced 20 m apart.

Field Procedures

Seed Collection

Seed traps (1 m^2) were constructed using nylon mesh screen (1 x 1 mm) on the bottom to capture seeds, plastic hardware cloth (0.5 x 0.5 cm) on the top to exclude seed predators, and elevated off the ground with four, 40 cm tall plastic legs (Wiese et al. 1998). A 2-factor metric prism was used to measure basal area at each seed trap. Seeds were collected in autumn and spring for the 1999, 2000, and 2001 seed years from the seed traps (Table 1). Mean seed rain and basal area were computed for each stand. Seed rain within each stand was assumed to be homogenous throughout the stand. Because we were not tracking the seed rain of individual trees, the distance of the seed collection trap from individual trees was not measured. Thirty samples of 10 seeds from the 1999-2000 collection period were dissected to estimate viability, assuming that filled seeds are viable.

Pearson correlation analyses were conducted to determine the relationship between white spruce seed rain in 1999, 2000, and 2001 and white spruce basal area. Linear regression was used to predict white spruce seed rain from basal area. A significance level of P = 0.05 was used. All analyses were done with Systat (SPSS, Inc. 2000).

TABLE 1. Summary of seed rain collection trap locations.

Cover Type	Percent residual basal area	Number Seed Traps	Number of Stands
White spruce	100%	12	2
Mixed	50%	6	1
Mixed	75%	6	1
Mixed	100%	12	2
Aspen - poplar	100%	21	3

Results

We encountered white spruce seed rain ranging from 17 seed m^{-2} in unharvested quaking aspen and balsam poplar stands to 44.7 million seeds ha^{-1} in unharvested white spruce dominated stands. White spruce basal area averaged 13 m^2 ha^{-1} and the percentage of white spruce basal area within a stand ranged from 0 to 100%. Seed rain averaged 1291 seed m^{-2} in 1999, 114 seeds m^{-2} in 2000, and 22 seeds m^{-2} in 2001. There was an approximate 10-fold difference in seed rain between 1999 and 2000. The year 2001 was an exceptionally poor seed year. Seeds collected in October 1999 were 40% filled. Percent germination for 1999 was 70% for seeds sampled across all plots.

White spruce seed rain during the exceptionally good seed year of 1999 had a significant linear correlation (r = 0.88, P = 0.004) to white spruce basal area. Pearson correlation analyses revealed no significant relationship between seed rain and basal area in 2000 or 2001. Thus, the equation developed to predict white spruce seed fall from white spruce basal area across cover types only includes data from the exceptionally good 1999 seed year (Figure 1).

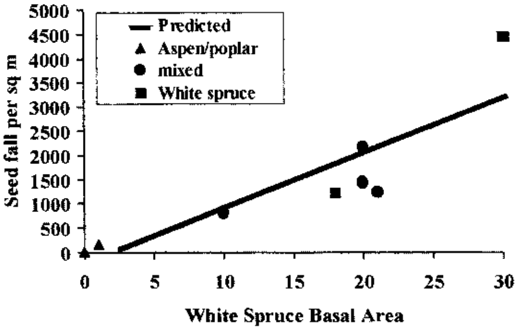

Figure 1. Observed and predicted seed rain during an exceptional seed year in white spruce; mixed white spruce - quaking aspen - balsam poplar; and quaking aspen - balsam poplar dominated stands in northwest Alberta. The prediction equation illustrated is: Y = -207.46 + 112.42 X, where Y = seed rain per m^2, and X = basal area of white spruce in $m^2 ha^{-1}$.

Discussion

We witnessed one exceptionally good seed production year for white spruce in Alberta that the literature (Zasada 1992, Stewart et al. 2000, 2001) indicates is greater than normally encountered. Surprisingly, no correlation was found between seed fall and white spruce basal area to the normal seed year of 2000 and the poor seed year of 2001.

Seed fall was linked to regeneration and compared to other studies in Alberta (Stewart et al. 2000, 2001, Berger 2002) by using several assumed values. We used an exceptional seed rain of 40 million seeds ha^{-1}, 10% and 90% estimates of viability, 70% germination, and summer and over-winter survival values of 72% and 14.5%, derived from Berger (2002). The calculations provide an estimate ranging from 292,320 to 2,630,880 seedlings ha^{-1} after the second winter following an exceptionally good seed year. Our minimum density value for an exceptional year is ≥ 60,000 above the maximum of the range for 2-yr-old natural white spruce regeneration of 170,000 to 230,000 seedlings ha^{-1} on scarified sites (Stewart et al. 2000).

Our calculated seedling densities are substantially higher than those actually encountered in the study area (Berger 2002) and elsewhere in Alberta (Stewart et al. 2000). This discrepancy can be explained in several ways. Our calculated seedling densities and those reported by Stewart et al. (2000) are maximum values. One- and two-year-old seedling densities of < 17,000 and < 5,000 white spruce seedlings ha^{-1} observed by Berger (2002) were averaged values across all cover types. The maximum regeneration density of 15,778 white spruces seedlings ha^{-1} reported by Stewart et al. (2001) was not age based; seedlings were defined as < 1 m tall. One-year-old seedlings in our study area were <20 cm tall (Berger 2002). Substantial undetected seedling mortality likely occurred when height was used as a criterion to define a seedling as opposed to actual seedling age.

The amount of seed necessary to regenerate a white spruce stand successfully depends on a multitude of factors, including desired density and stocking, seedbed conditions, weather conditions, herbivory, distance from a seed source, and the occurrence of insect and disease out breaks. Recommendations for residual basal densities to encourage natural regeneration and rates of aerial seeding vary. Greene et al. (2002) suggested the retention of a minimum of 6 m^2 ha^{-1} of mature white spruce for successful natural regeneration or an aerial seeding rate of 500,000 seeds ha^{-1} for adequate density and stocking. Using our model for an exceptionally good seed year (Figure 1), 6 m^2 ha^{-1} of white spruce basal area would produce 4.67 million seeds ha^{-1}. Inferences made from the extrapolation of our results beyond the region of model development and for normal seed years should be interpreted with caution. We assumed that white spruce seed rain was homogenous throughout a given stand. Distance to a seed source is important (Stewart et al. 1998), particularly when residual basal area is not retained. The stands in this study all had residual white spruce basal areas following harvest and no stands were clearcut. Given the nearly 10-fold difference in mean seed rain between the first 2 yr of this study, our results suggest that the minimum residual basal area of 6 m^2 ha^{-1} recommended by Greene et al. (2002) would produce approximately 470,000 seeds ha^{-1} during our estimated normal seed year, which is close to the minimum range of documented natural white spruce seed fall of 500,000 seeds ha^{-1} (Zasada 1992).

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