TECHNICAL REPORT 120

Tree Damage after Fertilization of Thinned Lodgepole Pine, Douglas-fir, and Spruce Stands in the British Columbia Interior

Synthesis Report on up to 18-year Responses from EP886

2019

BRITISH COLUMBIA

Tree Damage after Fertilization of Thinned Lodgepole Pine, Douglas-fir, and Spruce Stands in the British Columbia Interior

Synthesis Report on up to 18-year Responses from EP886

Woongsoon Jang, Bianca N.I. Eskelson, and Louise de Montigny

ISBN 978-0-7726-7315-2 – Print version
ISBN 978-0-7726-7316-9 – Digital version

Citation
Jang, W., B.N.I. Eskelson, and L. de Montigny. 2019. Tree damage after fertilization of thinned lodgepole pine, Douglas-fir, and spruce stands in the British Columbia interior: synthesis report on up to 18-year responses from EP886. Prov. B.C., Victoria, B.C. Tech. Rep. 120. www.for.gov.bc.ca/hfd/pubs/Docs/Tr/Tr120.htm

Prepared by
Woongsoon Jang and Bianca N.I. Eskelson
University of British Columbia
Department of Forest Resources Management
Vancouver, B.C.

Louise de Montigny
B.C. Ministry of Forests, Lands, Natural Resource Operations and Rural Development
Resource Practices Branch
Victoria, B.C.

Copies of this report may be obtained, depending upon supply, from:
Crown Publications, Queen's Printer
2nd Floor, 563 Superior Street
Victoria, BC V8W 9V7
1-800-663-6105
www.crownpub.bc.ca

For more information on other publications in this series, visit www.for.gov.bc.ca/scripts/hfd/pubs/hfdcatalog/index.asp

As a silvicultural practice, forest fertilization has emerged to mitigate risks and reduce the effect of damage agents on timber supply due to climate change and on subsequent extensive landscape-scale natural disturbances in British Columbia. In total, 61 installations were established in the central and southern interior of British Columbia to quantify fertilization responses of major commercial tree species. One-time fertilization with two to five kinds of fertilizer blends was applied, and the stand ages at fertilization ranged from 9 to 58 years. Plots were repeatedly measured at 3-year intervals, although a few plots were measured 2–4 years after fertilization. The repeated measurements (up to 18 years after fertilization) indicated that trees were damaged by various damage agents in the experimental sites, and that the fertilization may have been associated with the damage agents' activities. This report provides a descriptive overview of the damage that occurred after fertilization in the EP886 installations.

First, the major damage agents after fertilization were identified by comparing proportions of damage records for each plot. Second, to account for different measurement years since fertilization, annual damage rates were calculated. The damage record proportions and damage rates were summarized at different scales (i.e., plot and installation), and by size classes, age, and fertilization treatments.

The results of the analyses indicated the following:

1. The four most prevalent damage agents after fertilization were squirrels (accounting for 11.8% of total damage records), western gall rust (16.4%), mountain pine beetle (19.5%), and white pine weevil (10.8%).
2. Squirrels, western gall rust, and mountain pine beetle were observed only in lodgepole pine stands, whereas white pine weevil was exclusively observed in spruce stands. The four major damage agents were not observed in Douglas-fir stands.
3. The squirrel attack was concentrated in the stand age class of 25–30 years, which implied a potential association between susceptibility and stand age.
4. Throughout the study periods, fertilized plots showed slightly lower average plot-level damage than control plots for squirrel (0.1%) but higher damage rates for western gall rust (1.0%), mountain pine beetle (5.2%), and white pine weevil (6.6%).
5. Annual damage rate throughout the study periods after fertilization for squirrel, western gall rust, mountain pine beetle, and white pine weevil were 1.1, 1.2, 1.8, and 3.3%, respectively. Those annual damage rates for control plots were 1.0, 1.1, 1.2, and 2.9%, respectively.

The results presented are purely descriptive. Further analyses are required to assess more detailed associations between fertilization and tree damage. The findings in this study will provide insights for further research, and subsequent research efforts will provide useful information about the relationship between fertilization and forest health for managing interior British Columbia forests sustainably.

Keywords fertilization, Douglas-fir, lodgepole pine, spruce, forest health, natural disturbances

ACKNOWLEDGEMENTS

We thank Robert Brockley, Timothy Ebata, and Derek Sattler for sharing their valuable knowledge and insights. A.Y. Omule is gratefully acknowledged for his database assistance. This project was supported by the British Columbia Ministry of Forests, Lands, Natural Resources Operations and Rural Development Research Program.

CONTENTS

APPENDICES

TABLES

FIGURES

1 INTRODUCTION

Fertilization is a silvicultural treatment that accelerates stand development and individual tree growth without loss of stand volume (Brockley 2005). Because forests are closely connected with the industry, economy, and culture of British Columbia's communities, public concerns about potential adverse effects on sustainability of our forests due to climate change, and related extensive natural disturbances, have emerged (Spittlehouse 2005). Thus, fertilization can provide a relevant option for sustaining wood and biomass production in British Columbia.

Climate change can alter environmental conditions, and in turn, affect the "biological balances" between biotic pests (insects, diseases, wildlife) and abiotic damage and trees because they are linked with each other and interact with the changed environment (Woods et al. 2010). An example of the recent mountain pine beetle (*Dendroctonus ponderosae* Hopkins) epidemic in British Columbia clearly shows these alterations due to changing climate and their effects on forest health (Kurz et al. 2008). The effects of fertilization on forest health are difficult to interpret because fertilization can cause both positive and negative effects, even on the same damage agent (Jactel et al. 2009). Namely, fertilization can increase food quality for some herbivores (Lindgren and Sullivan 2018) and/or increase synthesis of secondary defensive chemicals such as terpene and phenolic compounds (Herms 2002). In British Columbia, there are several reports of fertilization effects on tree damage by mammalian herbivores such as snowshoe hares and red squirrels (e.g., Sullivan and Sullivan 1982; Brockley 2001). However, understanding of the associations between fertilization treatment and various damage agents is still limited.

Experimental Project (EP) 886 research sites provide a unique opportunity to fill knowledge gaps. Over 25 years, a network of fertilization experiments was established and regularly remeasured across the central and southern interior forests of British Columbia, which has provided abundant data on diverse fertilization rates and blends. The objectives of this study were to identify major damage agents in the EP886 fertilization installations and provide a descriptive overview of damage in conjunction with fertilization.

2 MATERIALS AND METHODS

2.1 Data Description

Repeatedly measured tree data from EP886 were acquired from the British Columbia (B.C.) Ministry of Forests, Lands, Natural Resource Operations and Rural Development. In total, data from 61 installations, including 692 plots of tree data, were collected from four EPs (EP886.01, 886.13, 886.14, and 886.15). Each EP consisted of a single installation or multiple installations, and each installation contained 9–24 plots (Table A1.1). Experimental installations were located throughout the central and southern interior of British Columbia (Figure 1), and encompassed six biogeoclimatic zones: Montane Spruce, Engelmann Spruce – Subalpine Fir, Interior Cedar – Hemlock, Interior Douglas-fir, Sub-Boreal Pine – Spruce, and Sub-Boreal Spruce (Meidinger and Pojar

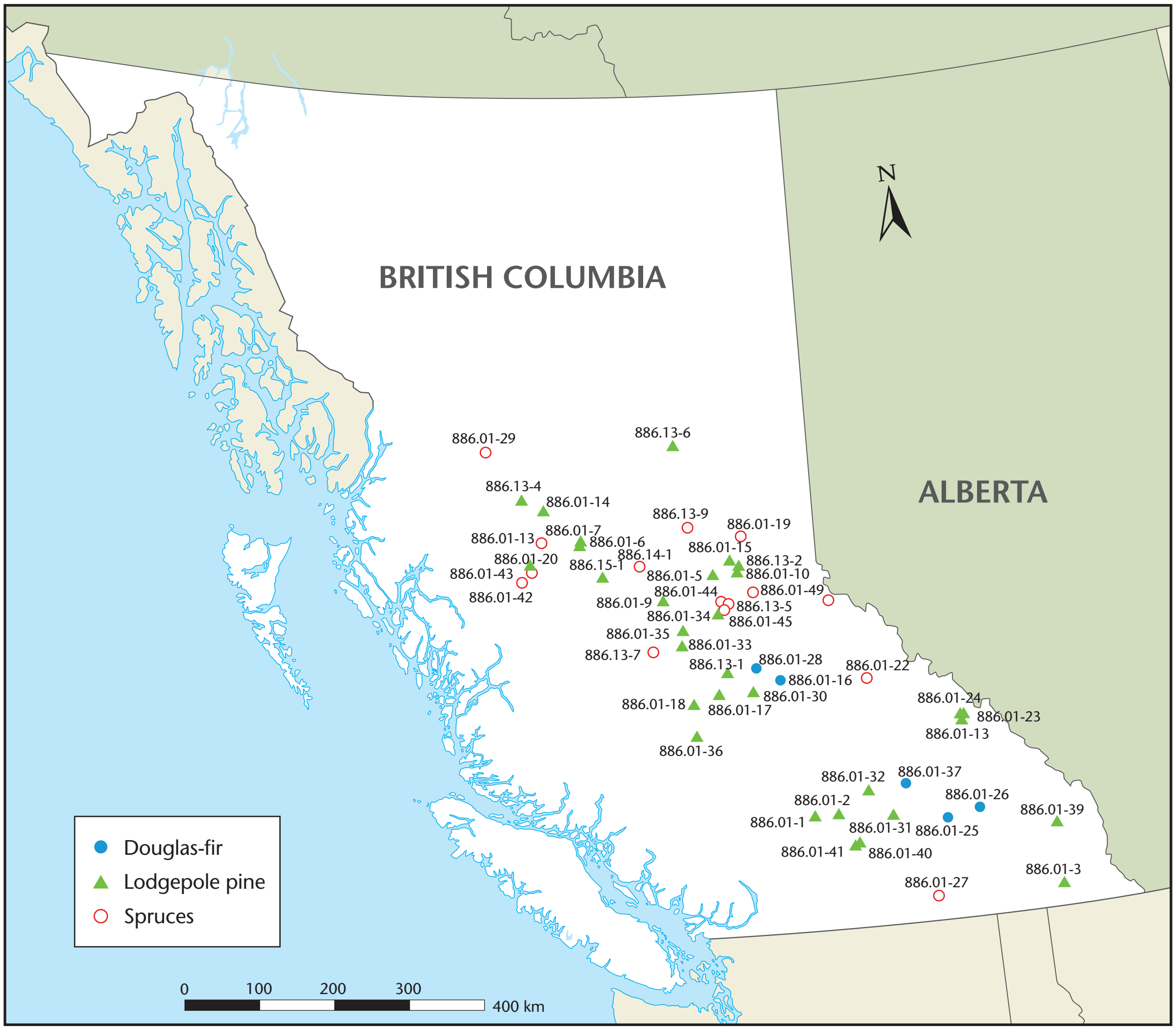

FIGURE 1 *Locations of installations used in this study.*

1991). The plots were established on naturally regenerated stands or plantations with three representative interior tree species: lodgepole pine (*Pinus contorta* Douglas ex Loudon var. *latifolia* Engelm. ex S. Watson) (40 installations), interior Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco var. *glauca* (Beissn.) Franco) (6 installations), and white and hybrid spruce (*Picea engelmannii* Parry × *Picea glauca* (Moench) Voss × *Picea sitchensis* (Bong.) Carr) (15 installations). The Stand Establishment Decision Aid (SEDA) distinguishes specific biogeoclimatic (sub-) zones where the white pine weevil problem potentially arises (Stock et al. 2005). Of the 15 spruce installations, 2, 1, 6, and 6 were located in the high, moderate-high, moderate, and low hazard zones, respectively (Tim Ebata, pers. comm.).

The experimental installations were established from the early 1980s to the late 2000s. All stands that were selected for fertilization had been thinned earlier or just before fertilization. Various fertilizer blends (different nutrients and/or concentrations of nutrients) were applied at the plot level throughout the installations (Table A1.2). Within each installation, treatments consisted of a control (no fertilizer) and two to five fertilizer blends replicated 2–4 times (mainly 3 times). In most of the installations, one-time fertilization was applied and stand ages (total stand age) at fertilization ranged from 9 to 58 years ($\bar{x} = 21$; $s = 8$). The treatments were randomly assigned to measurement plots within an installation. Plot size among installations ranged from 0.0154 to 0.0833 ha ($x = 0.0456$; $s = 0.0139$). Measurements were taken before fertilization, 2–3 years after fertilization, and then up to six subsequent remeasurements were taken every 2–4 years (primarily 3-year intervals, up to 18 years after treatments). Tree diameter at breast height (dbh [cm]) and height (m) were measured, and any tree damage incident, regardless of its location on the stem and its severity, was recorded following the B.C. Forest Inventory and Monitoring Program Standards (B.C. Ministry of Sustainable Resource Management 2003).

2.2 Tree Damage Analysis

Damage agent records were tallied across all measurements. Repeatedly reported damage records for a tree were assumed to be present from the first recording until the last measurement. By combining all records, the major damage agents—which accounted for more than 10% of the pooled damage records—were identified. Damage record proportions (ratio of number of damaged records to total measurements; hereafter called damage) of the major damage agents were investigated based on tree dbh, tree height, and stand age. To evaluate the damage rates measured in different measurement intervals, annual damage rates for the agents were calculated, similar to the classic annual mortality rate provided in Hamilton and Edwards (1976):

$$\text{annual damage rate} = 1 - (N_f / N_0)^{(1/t)}$$

where N_f is the number of damage-free trees at remeasurement, N_0 is the initial number of trees, and t is the number of years since initial measurement. The annual damage rates were summarized by installation and fertilization treatments. There were also repeated fertilizations in some installations (i.e., Installation 886.01-16 and EP886.13). In these cases, only data taken prior to the year of the second fertilization application were included in the analyses.

3 RESULTS

3.1 Tree Damage Overview

In total, 17 627 damage records from 36 992 trees were tallied; on average, there were 0.48 damage records per tree (Table A2.1). Approximately 64.3% of the total trees (fertilized + control) were damage-free, and 25.5%, 8.6%, and 1.6% of the total trees had one, two, and more than three types of damage agent record, respectively. Most of the damage agents were diseases (50.8%), followed by insects (32.6%), and animals (15.1%). Among those damage agents, four could be identified: squirrel (11.8% of total damage records), western gall rust (16.4%), mountain pine beetle (19.5%), and white pine weevil (10.8%). Squirrel, western gall rust, and mountain pine beetle damage was observed exclusively on lodgepole pine trees, whereas white pine weevil had attacked only spruce trees (Table 1).

TABLE 1 *Summary of damage records for major damage agents. Damage record proportions, with standard deviations in parentheses, are shown for specific host species according to installation, plot, and tree levels.*

Damage agent	Damaged species	Damage type[a]	Mean damage record proportion (%)						
				Plot			Tree		
			Installation	All	Fertilized	Control	All	Fertilized	Control
Squirrel	Lodgepole pine	Maimer – animal	10.5 (3.7)	8.2 (1.0)	8.2 (1.2)	8.3 (1.8)	8.0	8.0	7.8
Western gall rust	Lodgepole pine	Maimer – disease	10.3 (1.8)	10.7 (0.6)	11.0 (0.7)	10.0 (1.1)	11.1	11.5	10.0
Mountain pine beetle	Lodgepole pine	Killer – insect	11.6 (4.0)	14.9 (1.4)	16.3 (1.7)	11.1 (2.3)	13.2	14.6	9.6
White pine weevil	Spruce	Maimer – insect	21.1 (7.2)	23.0 (2.2)	24.8 (2.6)	18.2 (3.9)	23.9	25.7	18.7

a Woods et al. 2017.

When we ignored the differences in the measuring period by installation, fertilized plots had a slightly lower squirrel damage record proportion (0.1%) than control plots. Conversely, control plots showed 1.0, 5.2, and 6.6% lower damage record proportions than the fertilized plots for western gall rust, mountain pine beetle, and white pine weevil, respectively (Table 1). At the tree level, fertilized trees tended to have higher damage levels than control trees for all the major damage agents.

3.1.1 Squirrel damage Squirrel damage was recorded in approximately 70% of all lodgepole pine installations (30 of 43 installations). Five installations (886.01-1, 886.01-2, 886.01-5, 886.01-10, and 886.01-11) that were heavily attacked by squirrels had damage exceeding 50%. The mean damage for other installations was less than 15%. As a result, variation in squirrel damage among plots within an installation was large. Only 69 of 499 total lodgepole pine plots (13.8%) had squirrel damage that exceeded 10% (Figure 2a). The average squirrel damage across all installations and plots was 10.5 and 8.2%, respectively (Table 1).

In total, 2076 lodgepole pine trees (8.0% of all measured lodgepole pine trees) were damaged by squirrels over time (Table 1). Including controls, most squirrel damage (>75%) was recorded around 6 years after fertilization (Figure 3a), and there was no difference in the damage record distributions between fertilized and unfertilized trees (Figure 4a). More than 90% of the squirrel damage was observed within 9 years after fertilization. Most of the squirrel attack (82%) occurred in the 25- to 30-year age class (Figure 2b), and this age class comprised 26% of all tree measurements. Average tree height and diameter at the first year of recorded squirrel damage were 9.7 m (Figure 2c) and 11.5 cm (Figure 2d), respectively. The height classes of 8–10 m and 10–12 m and the dbh class of 8–12 cm exhibited moderately higher squirrel damage record proportion than the other distributions (Figure 2c, d).

3.1.2 Western gall rust damage Western gall rust damage was observed in almost every lodgepole pine installation (39 of 43 installations). Severely damaged installations were rare, and no installation had more than 50% of

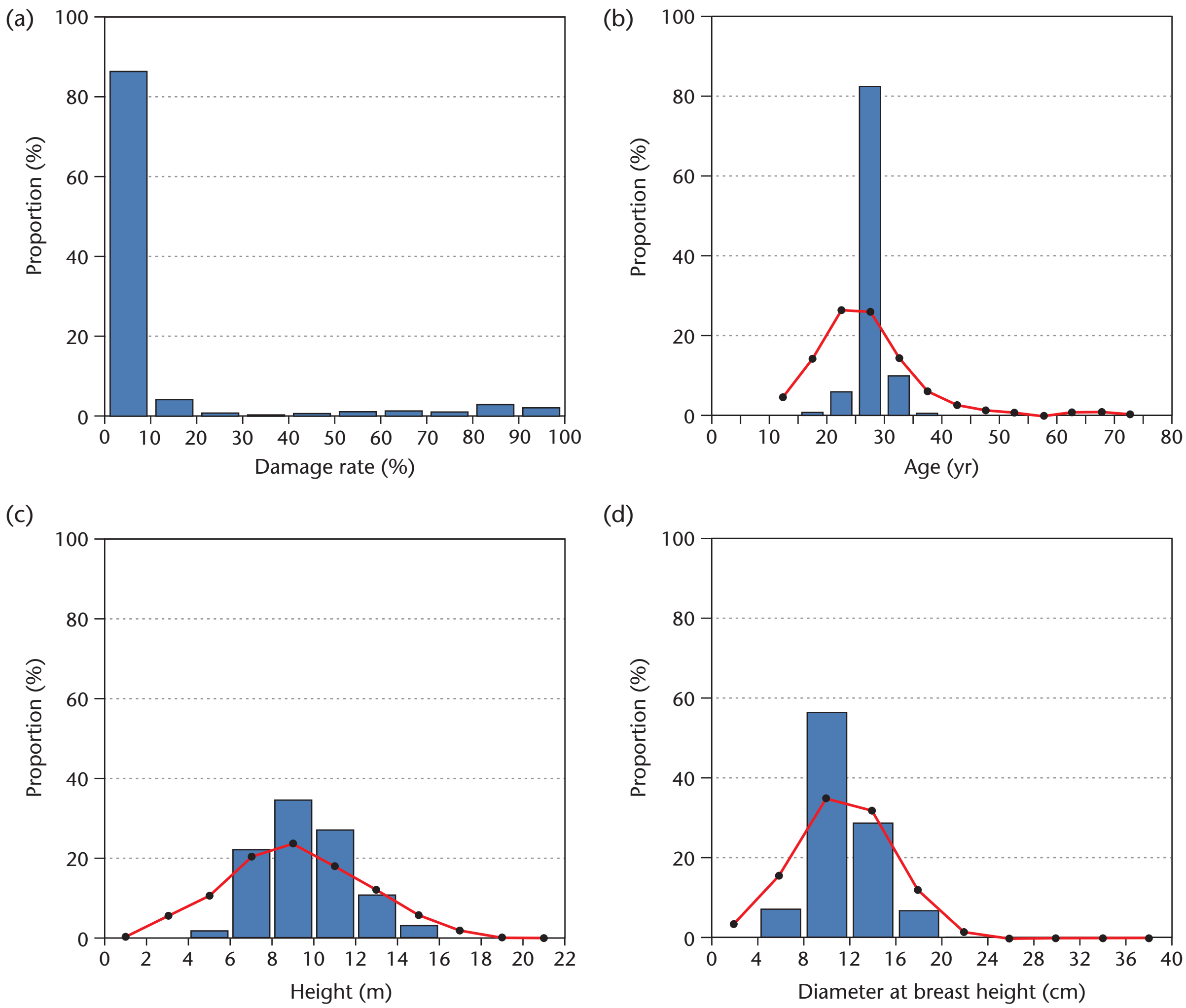

FIGURE 2 *(a) Plot-level (fertilized + control) squirrel damage distribution for lodgepole pine and individual tree (b) age, (c) height, and (d) diameter at breast height distributions at first recorded squirrel damage. Lines with dots represent corresponding distributions of all lodgepole pine tree records (*n *= 26 109).*

damage record proportions. About 90% of all plots had less than 30% damage record proportion (Figure 5a). Mean western gall rust damage record proportion at installation and plot levels was 10.3% and 10.7%, respectively.

At the tree level, 11.1% of all lodgepole pine trees were damaged by western gall rust (Table 1). There was no distinct change in damage observation trend over time and between fertilized and unfertilized trees (Figures 3b and 4b). Distributions of tree age (Figure 5b), height (Figure 5c), and dbh (Figure 5d) at year of attack by western gall rust corresponded quite well with distributions of all measured trees. Mean height and dbh at first recorded year of attack by western gall rust were 10.3 m and 12.8 cm, respectively (Figure 5c, d); the data did not indicate whether the western gall rust canker was located on the stem or branch.

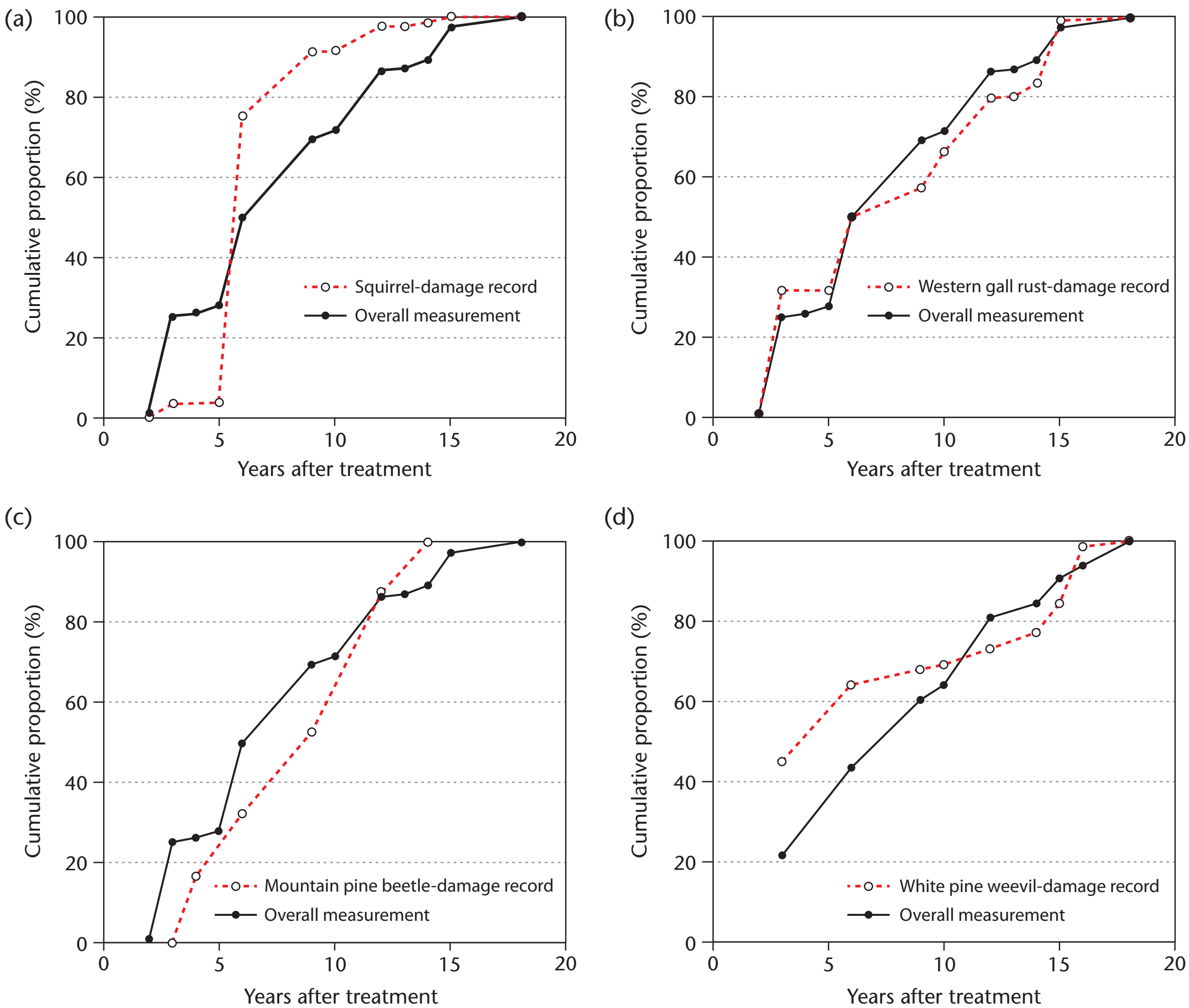

FIGURE 3 *Cumulative distributions (dotted line; fertilized + control) of (a) squirrel-damaged trees, (b) western gall rust–damaged trees, (c) mountain pine beetle–damaged trees, and (d) white pine weevil–damaged trees. The solid line shows the cumulative distribution of all trees (fertilized + control).*

3.1.3 Mountain pine beetle damage Severe mountain pine beetle attacks (> 20% damage) occurred in 8 of 43 installations: 886.15-2 (damage rate = 94.4%), 886.01-38 (86.0%), 886.13-6 (77.8%), 886.14-1 (72.8%), 886.01-17 (62.2%), 886.01-34 (38.8%), 886.01-16 (32.1%), and 886.01-36 (28.7%). At other installations, mountain pine beetle damage was low. In total, 109 (of 499) plots were completely free of mountain pine beetle damage. Average damage for installations, plots, and individual trees was 11.6, 14.9, and 13.2%, respectively (Table 1). More than 80% of measured plots (401 of 499) had less than 10% of the mountain pine beetle attack (Figure 6a), and damage for 390 plots (78.2%) was less than 1%.

The proportion of observed mountain pine beetle damage did not show any notable increase up to 10 years after fertilization when compared to all

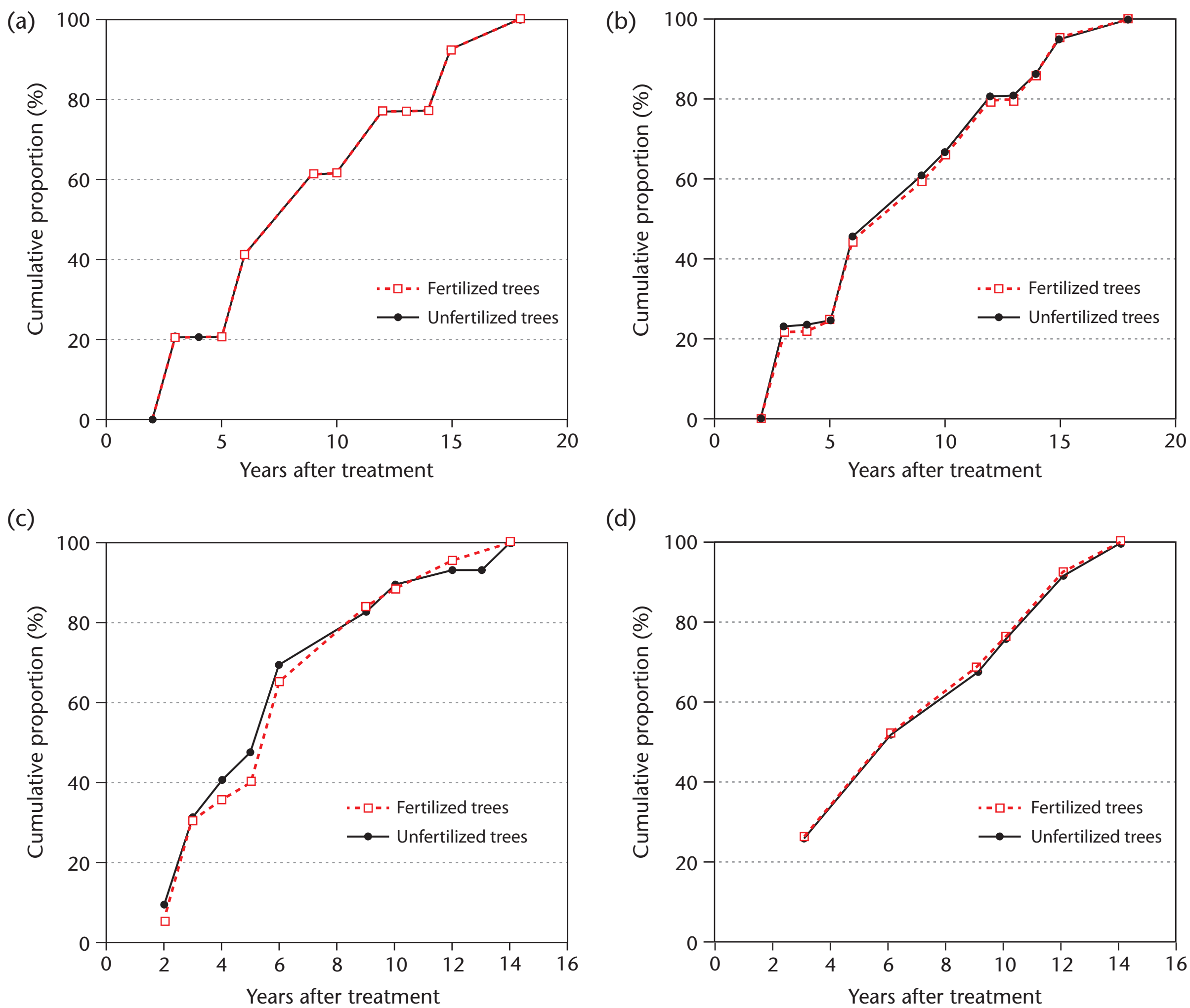

FIGURE 4 *Cumulative distributions of (a) squirrel-damaged trees, (b) western gall rust–damaged trees, (c) mountain pine beetle–damaged trees, and (d) white pine weevil–damaged trees by treatment.*

records (Figure 3c). Up to 6 years after fertilization, the fertilized trees showed a relatively lower proportion of mountain pine beetle damage than did unfertilized trees (Figure 4c). The average height and dbh at year of first damage were 11.2 m and 15.1 cm, respectively (Figure 6c, d), which suggests that more mountain pine beetle damage occurred in the larger size classes than at mean sizes of all trees. There was distinctly higher damage in the 50- to 55-year age class (Figure 6b) than in its adjacent age classes. Only one installation (886.01-38) was in this age class, and it was severely attacked (average damage = 86%). However, despite the higher age class, the site had low site productivity (site index 15.0 m at age 50), so any distinct peak in damage at larger height and dbh size classes was not found (Figure 6c, d).

3.1.4 White pine weevil damage Because white pine weevil damage occurs only in spruce trees, damage record proportion of white pine weevil was low

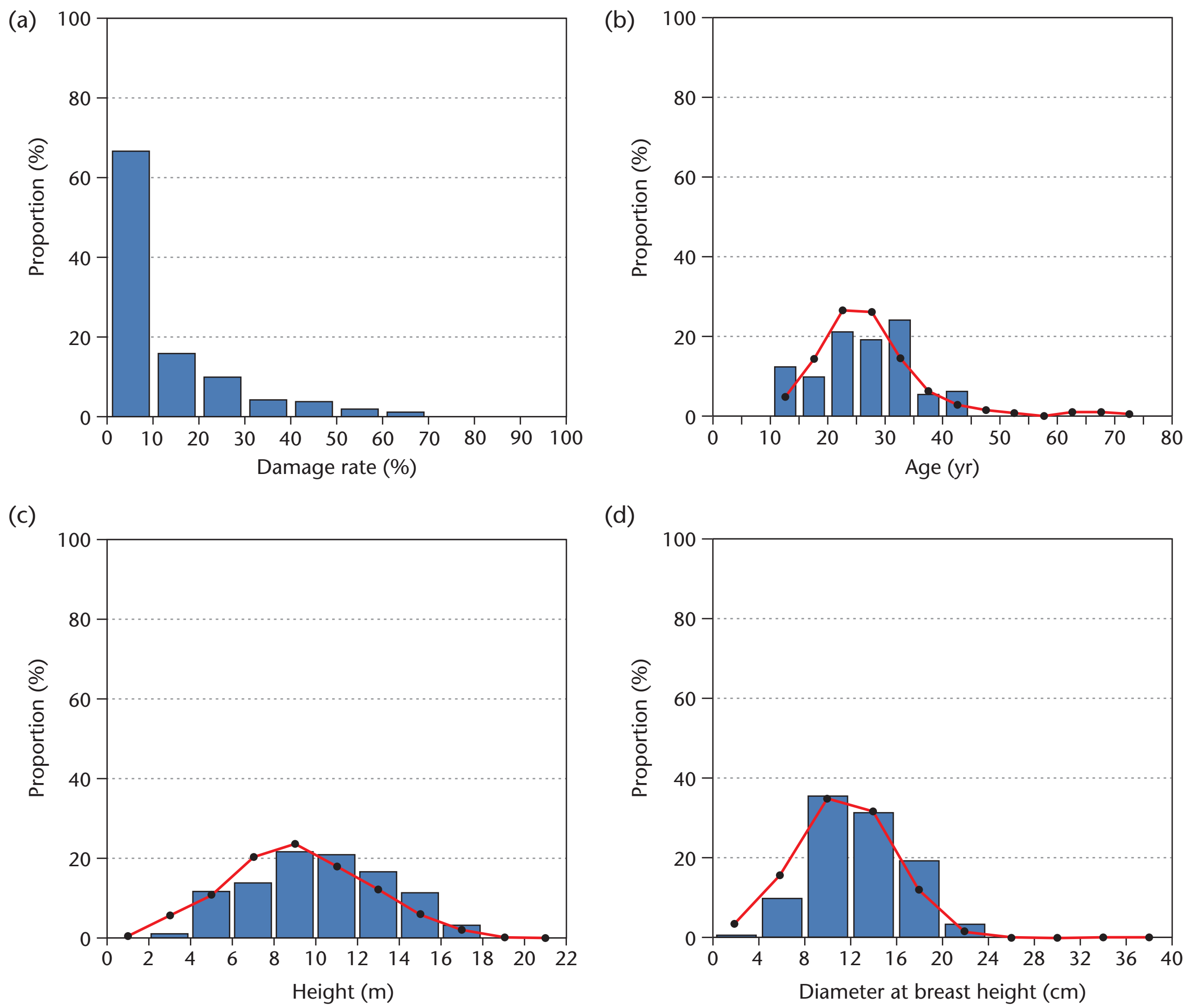

FIGURE 5 *(a) Plot-level (fertilized + control) western gall rust damage distribution for lodgepole pine and individual tree (b) age, (c) height, and (d) diameter at breast height distributions at first recorded western gall rust damage. Lines with dots represent corresponding distributions of all lodgepole pine tree records (*n *= 26 109).*

(up to 10% of all damage) compared to that of the other damage agents (Table A2.1). However, the proportion of trees damaged by white pine weevil tended to be higher than the other damage agents (Figure 7a; c.f. Figures 2a, 5a, and 6a). Average damage at the installation and tree levels was 21 and 24%, respectively (Table 1). No spruce installations were free of white pine weevil damage. Two installations (886.01-21 and 886.13-5) were severely attacked by white pine weevil, with more than 50% of spruce trees showing signs of damage. Installations 886.01-21 and 886.13-5 were located in the high and moderate hazard zone of the SEDA map (Tim Ebata, pers. comm.).

In total, 1095 (of 7972) spruce trees were damaged by white pine weevil. A high incidence of damage was reported in the early years after fertilization; 45% of total white pine weevil damage was observed 3 years after fertilization.

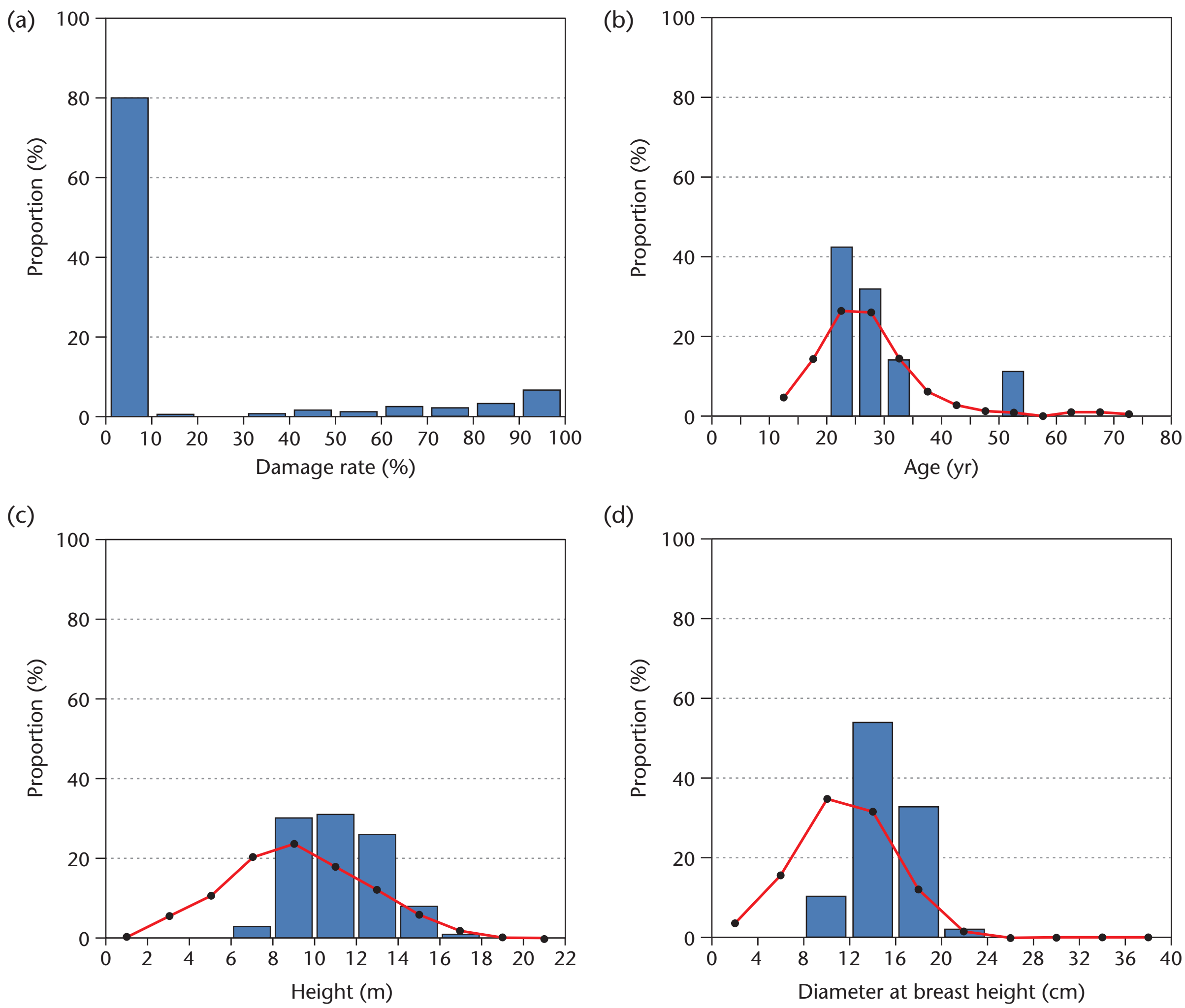

FIGURE 6 *(a) Plot-level (fertilized + control) mountain pine beetle damage distribution for lodgepole pine and individual tree (b) age, (c) height, and (d) diameter at breast height distributions at first recorded mountain pine beetle damage. Lines with dots represent corresponding distributions of all lodgepole pine tree records* (n = *26 109).*

Up to 6 years after fertilization, 64% of total damage from white pine weevil was recorded. Thereafter, the newly observed damage records were added gradually (Figure 3d). However, it seems that there was no difference in the damage observed between fertilized and unfertilized trees (Figure 4d). Age class 20–25 years and height class 4–6 m had slightly higher attack levels than those of all trees, but the age, height, and dbh distributions of the damaged trees followed those of all tree records, in general (Figure 7b, c, d). Average height and dbh in the year that white pine weevil damage was initially reported were 7.0 m and 13.4 cm, respectively.

3.2 Annual Tree Damage Rate

Averages of annual damage rates for squirrel, western gall rust, and mountain pine beetle for all lodgepole pine plots were 1.12 (SE = 0.16), 1.22 (SE = 0.11), and

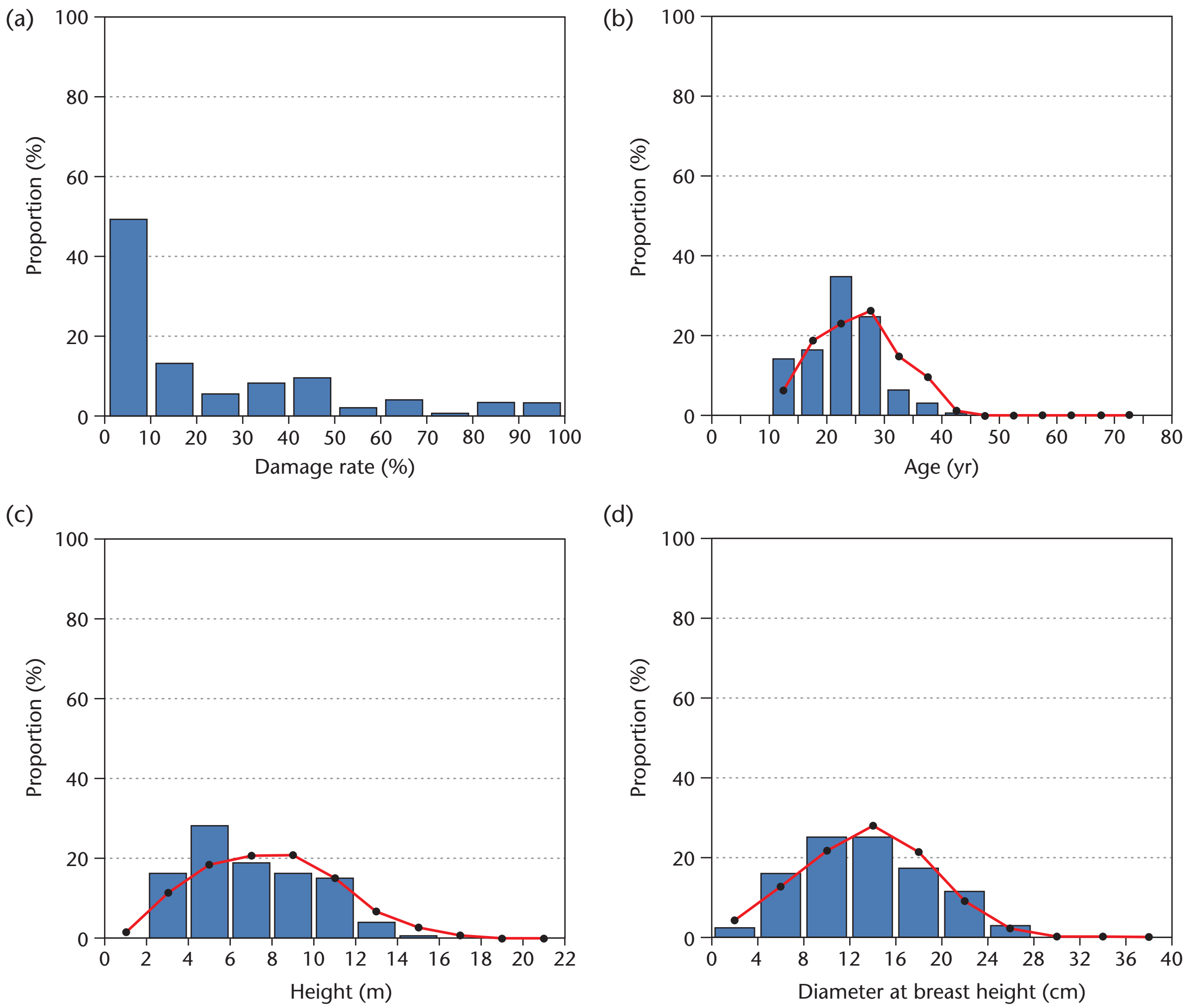

FIGURE 7 *(a) Plot-level (fertilized + control) white pine weevil damage distribution for spruce and individual tree (b) age, (c) height, and (d) diameter at breast height distributions at first recorded white pine weevil damage. Lines with dots represent corresponding distributions of all spruce tree records (*n *= 7972).*

1.81% (SE = 0.24), respectively. The average for white pine weevil damage in spruce stands was 3.29% (SE = 0.53). Eight of 61 installations were completely free of any of the four major damage agents (Table A2.2). Because of species-specificity of damage agents, none of the installations contained all four major damage agents.

Although statistical tests were not conducted, the fertilization treatments exhibited a tendency of slightly higher mean annual damage rates than control plots across all four damage agents. Annual damage rates for squirrel, western gall rust, mountain pine beetle, and white pine weevil in fertilization treatments were 1.4 (SE = 0.2), 1.3 (SE = 0.1), 2.3 (SE = 0.3), and 3.6% (SE = 0.8), respectively. For the control plots, the annual damage rates for squirrel, western gall rust, mountain pine beetle, and white pine weevil were 1.0 (SE = 0.3), 1.1 (SE = 0.2), 1.2 (SE = 0.4), and 2.8% (SE = 1.0), respectively.

Three of 17 total lodgepole pine fertilization treatments had higher annual squirrel damage rates than control plots (Figure 8). In total, eight fertilization treatments were free of squirrel damage.

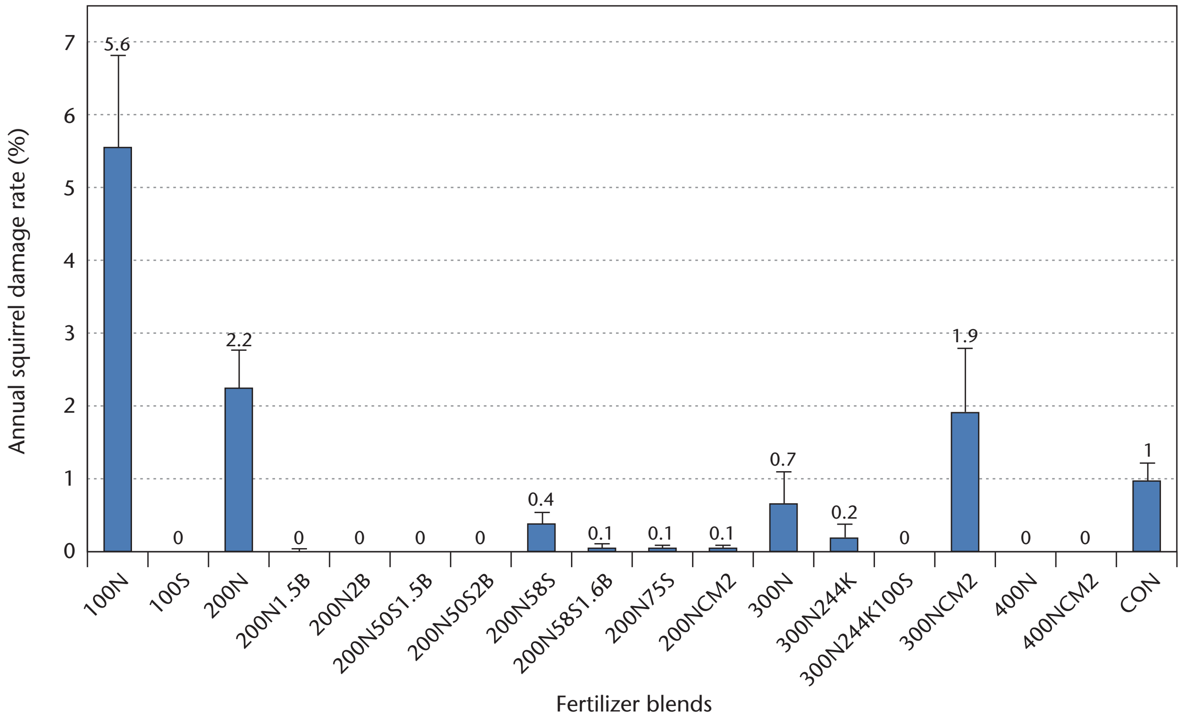

FIGURE 8 *Annual squirrel damage rate in lodgepole pine stands by fertilization blends. Error bars represent standard errors. CON = control. See Tables A1.2 and A1.3 for details about fertilization blends.*

In total, 12 (of 17) fertilization treatments of lodgepole pine stands had higher annual western gall rust damage rates than control plots (Figure 9). The fertilization treatments of 400N, 400N + CM2, and 300N + CM2 had the highest damage for lodgepole pine. Only two fertilization treatments (200N + 2B and 200N + 50S + 2B) had no damage from western gall rust (Figure 9).

Six fertilization treatments in lodgepole pine stands had higher annual mountain pine beetle damage rates than control plots (Figure 10). This might suggest that the fertilizer blends produced larger-diameter trees, which then became more susceptible to mountain pine beetle attack. Five of those fertilization treatments were severely attacked (> 10% of annual damage rates) by mountain pine beetle. Seven of 17 fertilization treatments were not attacked by mountain pine beetle (Figure 10).

Damage by white pine weevil in spruce stands was found throughout the fertilization treatments (Figure 11). Two of six fertilization treatments had higher annual white pine weevil damage rates than control plots. The 200N +58S + 1.6B treatment had the lowest white pine weevil annual attack rate (1.9%, SE = 0.6), whereas the attack rate for control plots in the installation was similar to the average rate for control plots (2.6%).

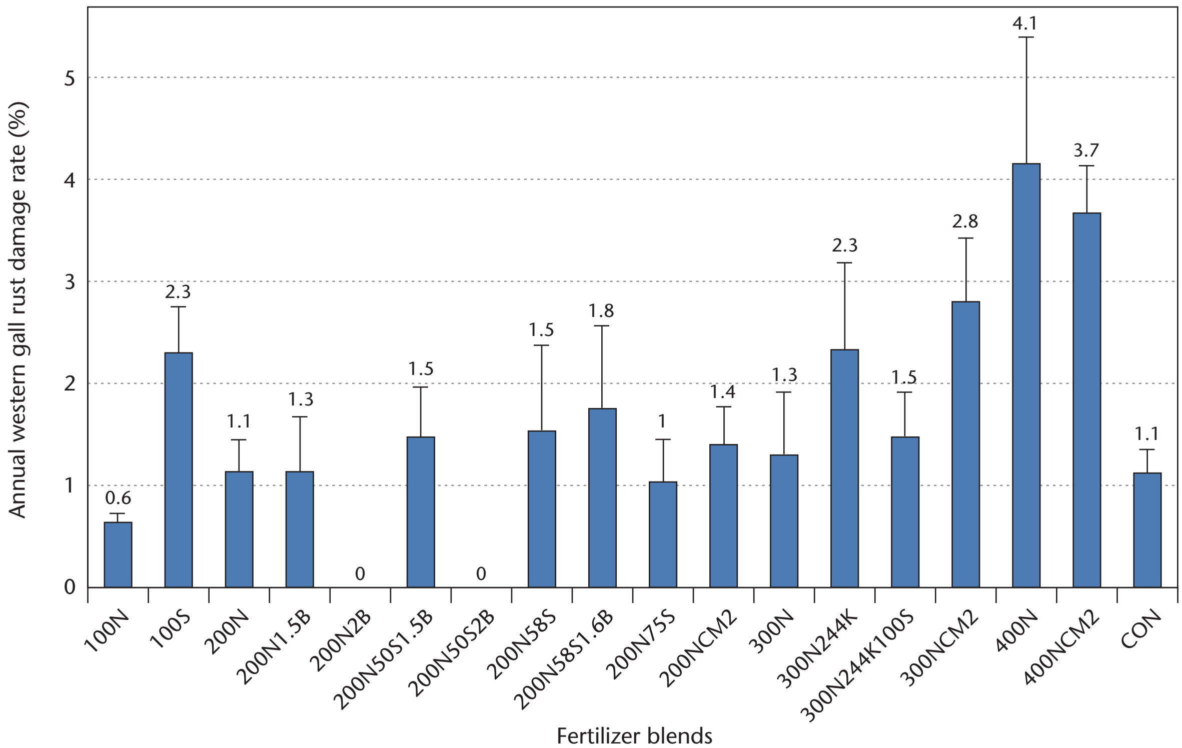

FIGURE 9 *Annual western gall rust damage rate in lodgepole pine stands by fertilization blends. Error bars represent standard errors. CON = control. See Tables A1.2 and A1.3 for details about fertilization blends.*

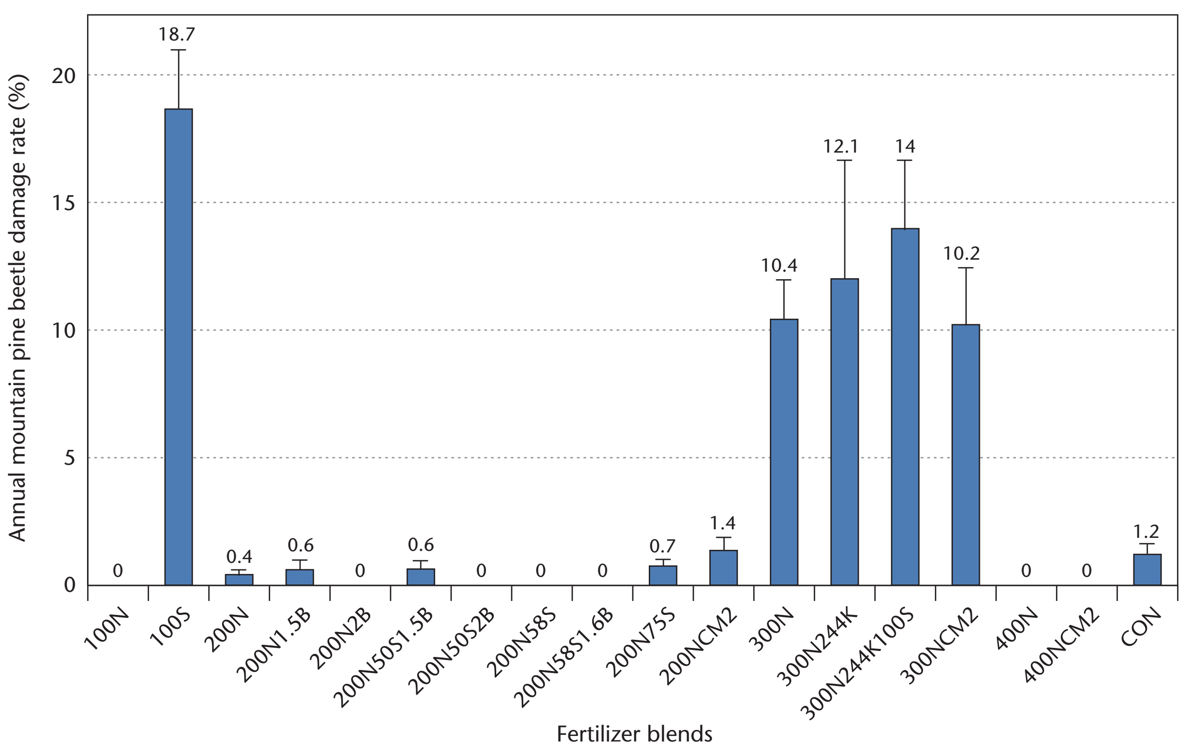

FIGURE 10 *Annual mountain pine beetle damage rate in lodgepole pine stands by fertilization blends. Error bars represent standard errors. CON = control. See Tables A1.2 and A1.3 for details about fertilization blends.*

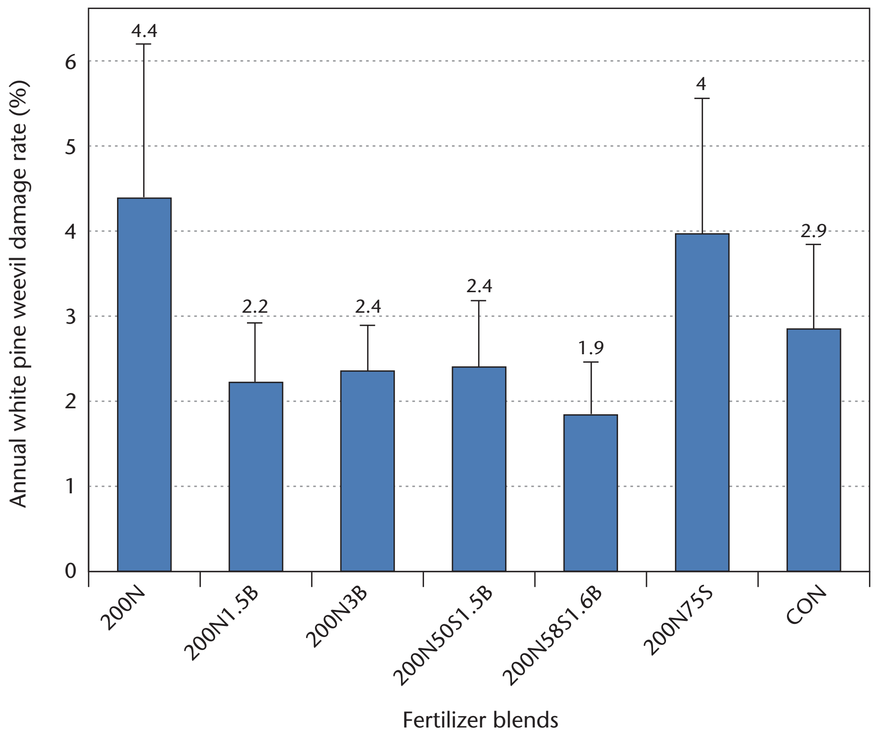

FIGURE 11 *Annual white pine weevil damage rate in spruce stands by fertilization blends. Error bars represent standard errors. CON = control. See Tables A1.2 and A1.3 for details about fertilization blends.*

Damage rates for installations in the moderate hazard zone were higher than those in the low hazard zone (Table 2). High and high-moderate hazard zones had insufficient replication for comparisons. Note that the high annual damage rate in the high hazard zone was influenced by an extremely high-damage installation (886.01-21: 26.61%).

TABLE 2 *Annual white pine weevil damage rate in spruce installations according to the Stand Establishment Decision Aid hazard rate*

White pine weevil hazard rate[a]	High	High-Moderate	Moderate	Low
Annual damage rate (%)	13.78	0.09	2.65	0.91
Number of installations	2	1	6	6

a Hodgkinson et al. 2011.

Sullivan and Sullivan (1982) reported that young lodgepole pine of 7–16 cm dbh are the most susceptible to squirrel damage. This corresponds with our results that squirrel damage peaked in the 8–12 cm dbh size class (Figure 2d). Although damage severity was not investigated in this study, Sullivan and Sullivan (1982) also observed that the severity of damage by squirrels was higher for fertilized trees than control trees, due primarily to increased bark surface area as a result of fertilization. Thus, it seems plausible that fertilized trees are a more attractive food source for squirrels. Our observation of slightly higher annual squirrel damage rates in fertilized stands may support this suggestion. Therefore, forest managers may need to consider fluctuations in regional squirrel populations prior to using fertilization in lodgepole pine stands. A recommended strategy could be to avoid fertilization when stands are at risk for aggressive squirrel populations. Fertilization in conjunction with thinning may be helpful, because it promotes tree growth to pass the susceptible size class quickly. It is also noteworthy that Sullivan and Sullivan (1982) suggested that unless trees are girdled completely, the effects of squirrel damage on tree growth and mortality should be negligible. However, understanding of the effects of squirrel damage on tree growth and timber quality are still limited. Therefore, further work on these topics will be required in order to make optimized silvicultural decisions.

The observed susceptibility of size class of host trees to other major damage agents in this study also agreed with general conclusions from previous studies. It is known that western gall rust infection is not related to stand characteristics (van der Kamp 1994). In contrast, mountain pine beetle prefers lodgepole pine trees in larger size classes (Roe and Amman 1970). For white pine weevil, the spruce size classes of 5–20 cm dbh and 1.5–8.0 m height are known to be susceptible (Mehary et al. 1994), which generally coincides with the damaged tree sizes in this study.

Although we observed higher annual damage rates for four major damage agents in fertilized stands than in unfertilized stands, and some of the fertilization treatments were strongly associated with differences in damage rates, firm conclusions that some fertilization treatments are associated with increased susceptibilities to certain damage agents could not be made based on the descriptive statistics provided in this report. Inherent characteristics of the data and the complicated structure of the EP886 database make a more formal analysis difficult. Repeated measures and a nested experimental design imply that the data contain spatial and temporal hierarchies that need to be accounted for in a modelling approach. In addition, too many zero observations and the non-normal response variable (i.e., damage rate; having values from 0 to 1) raise model assumption violation issues that require a modelling approach that goes beyond simple linear models or conventional ANOVA. Therefore, the construction of models to address associations between fertilization treatment effects and damage rates needs to account for these issues.

5 CONCLUSION

This study indicated that there were three major damage agents (squirrel, western gall rusts, and mountain pine beetle) for lodgepole pine stands and one major damage agent (white pine weevil) for spruce stands after fertilization in interior British Columbia forests. The results suggest that the damage rates for certain fertilization treatments may vary with fertilizer blends. However, statistical significances for the differences were not tested because this was not the goal of this study. Therefore, further work (e.g., modelling the complicated data structure of the database, testing interactions among damage agents, and representing the zero-inflated response variable) is required to assess the associations between the effects of fertilization and damage rates in more detail.

LITERATURE CITED

British Columbia Ministry of Sustainable Resource Management. 2003. Forest inventory and monitoring program: growth and yield standards and procedures. Province of British Columbia, Victoria, B.C. FRDA Rep. 104.

Brockley, R.P. 2001. Fertilization of lodgepole pine in western Canada. In: Proc. Enhanced For. Manag.: Fertil. and Econ. Conf., pp. 1–2.

______. 2005. Effects of post-thinning density and repeated fertilization on the growth and development of young lodgepole pine. Can. J. For. Res. 35(8): 1952-1964.

Hamilton, D.A. and B.M. Edwards. 1976. Modeling the probability of individual tree mortality. U.S. Dep. Agric. For. Serv., Ogden, Utah. Res. Pap. INT-185.

Herms, D.A. 2002. Effects of fertilization on insect resistance of woody ornamental plants: reassessing an entrenched paradigm. Environ. Entomol. 31(6):923–933.

Hodgkinson, R., K. White, and A. Stock. 2011. British Columbia's northern interior forest region: spruce/white pine weevil Stand Establishment Decision Aid. BC J. Ecosys. Manag. 11(3):51–54.

Jactel, H., B.C. Nicoll, M. Branco, J.R. Gonzalez-Olabarria, W. Grodzki, B. Långström, F. Moreira, S. Netherer, C. Orazio, D. Piou, and H. Santos. 2009. The influences of forest stand management on biotic and abiotic risks of damage. Ann. For. Sci. 66(7):701.

Kurz, W.A., C.C. Dymond, G. Stinson, G.J. Rampley, E.T. Neilson, A.L. Carroll, T. Ebata, and L. Safranyik. 2008. Mountain pine beetle and forest carbon feedback to climate change. Nature 452(7190):987–990.

Lindgren, P.M. and T.P. Sullivan. 2018. Influence of repeated fertilization on forage production for native mammalian herbivores in young lodgepole pine forests. For. Ecol. Manag. 417: 265–280.

Mehary, T., R.R. Gara, and J. Greenleaf. 1994. Host selection behavior of *Pissodes strobi* and implications to pest management. In: The white pine weevil: biology, damage and management. R.I. Alfaro, G. Kiss, and R.G. Fraser (editors). Proc. Symp., Jan. 19–21, 1994, Richmond, B.C. B.C. Min. For. Lands, Victoria, B.C. FRDA Rep. 226, pp. 43–53.

Meidinger, D. and J. Pojar. 1991. Ecosystems of British Columbia. B.C. Min. For., Victoria, B.C. Spec. Rep. Ser. 6.

Roe, A. and G. Amman. 1970. Mountain pine beetle in lodgepole pine forests. U.S. Dep. Agric. For. Serv., Ogden, Utah. Res. Pap. INT-71.

Spittlehouse, D.L. 2005. Integrating climate change adaptation into forest management. For. Chron. 81(5):691–695.

Stock, A., M. Duthie-Holt, S. Walsh, J. Turner, and K. Swift. 2005. Southern Interior Forest Region: forest health Stand Establishment Decision Aids. BC J. Ecosys. Manag. 6(1):55–73.

Sullivan, T.P. and D.S. Sullivan. 1982. Influence of fertilization on feeding attacks to lodgepole pine by snowshoe hares and red squirrels. For. Chron. 58(6):263–266.

van der Kamp, B.J. 1994. Lodgepole pine stem diseases and management of stand density in the British Columbia interior. For. Chron. 70(6):773–779.

Woods, A.J., K.D. Coates, M. Watts, V. Foord, and E.I. Holtzman. 2017. Warning signals of adverse interactions between climate change and native stressors in British Columbia forests. Forests 8(8), p.280.

Woods, A.J., D. Heppner, H.H. Kope, J. Burleigh, and L. Maclauchlan. 2010. Forest health and climate change: a British Columbia perspective. For. Chron. 86(4):412–422.

APPENDIX 1 Installations and treatments description

TABLE A1.1 *Description of installations*

EP number	Installation number	BEC zone[a]	Major species[b]	Total age at establishment (yr)	Year established	Year last remeasured	Number of plots	Number of measurements	Stem density (stems/ha)	Site index
886.01	1	MS	Pl (N)	20	1981	1999	9	7	1100	18.4
	2	MS	Pl (N)	20	1981	1990	9	4	1100	17.3
	3	MS	Pl (N)	20	1982	2000	9	7	1100	19.6
	4	MS	Pl (N)	20	1982	2000	9	7	1100	19.0
	5	SBSj1	Pl (N)	18	1982	2000	9	7	1100	23.5
	6	SBSe	Pl (N)	25	1982	2000	9	7	1600	16.8
	7	SBSe	Pl (N)	24	1983	1998	9	7	1600	17.1
	8	SBSk2	Pl (N)	24	1983	1998	9	6	2100	18.2
	9	SBSk2	Pl (N)	24	1983	1998	9	6	2100	17.2
	10	SBSj1	Pl (N)	20	1983	1998	9	6	2100	22.3
	11	SBSj1	Pl (N)	20	1983	1998	9	6	2100	21.8
	12	MSdk	Pl (N)	24	1986	2001	9	6	2100	21.1
	13	ICH	Pl (N)	14	1986	2001	9	6	1100	22.7
	14	SBSmc	Pl (N)	60	1986	2001	9	5	1600	15.2
	15	SBS	Pl (P)	15	1986	1998	15	4	1800	21.9
	16	SBPSmk	Pl (N)	10	1992	2006	21	5	600/1100/1600	17.5
	17	IDFk3	Pl (N)	19	1992	2004	9	5	1100	21.2
	18	SBPSxc	Pl (P)	19	1992	2004	12	5	1600	18.8
	19	SBPSvk	Sw (P)	22	1992	2004	9	5	1100	25.2
	20	SBPSmc2	Sw (P)	31	1992	2004	9	5	1100	21.2
	21	ICHmc1	Sw (P)	19	1992	2005	9	5	1357	23.0
	22	ICHwk1	Sw (P)	19	1993	2005	9	5	1100	28.0
	23	ICHmw	Fd (P)	18	1993	2005	12	5	1120	33.5
	24	ICHmw	Pl (P)	20	1993	2005	9	5	1111	22.3

EP number	Installation number	BEC zone[a]	Major species[b]	Total age at establishment (yr)	Year established	Year last remeasured	Number of plots	Number of measurements	Stem density (stems/ha)	Site index
	25	ICHmw	Fd (N)	24	1993	2005	9	5	1111	32.7
	26	ICHmw	Fd (P)	21	1994	2006	9	5	608	39.2
	27	ESSFwc4	Sw (P)	20	1994	2006	9	5	1116	20.9
	28	ICHmk	Fd (P)	21	1994	2006	9	5	1120	28.5
	29	ICHmc2	Pl (N)	25	1994	2006	9	5	1143	23.5
	30	ICHmk	Pl (N)	26	1996	2008	9	5	1100	30.9
	31	ICHmw2	Pl (P)	22	1996	2005	9	4	1103	22.5
	32	IDFmw2	Pl (N)	21	1996	2005	9	4	1106	19.2
	33	SBSmc2	Pl (P)	22	1996	2005	9	4	1600	20.5
	34	SBSmw1	Pl (P)	21	1996	2005	9	4	1100	22.4
	35	SBPSmk	Pl (P)	23	1996	2003	9	3	1100	19.2
	36	SPBSxc	Pl (P)	21	1997	2006	9	4	1100	17.6
	37	ICHmw	Pl (P)	25	1997	2009	9	5	800	25.0
	38	SBSmc2	Pl (N)	42	1997	2006	9	4	1100	15.0
	39	MSdk	Pl (N)	23	1998	2007	9	4	800	22.8
	40	MSdm2	Pl (N)	20	1998	2007	12	4	1100	21.3
	41	MSdm	Pl (N)	18	1998	2010	9	5	1100	22.4
	42	SBSmc2	Pl (P)	26	2000	2014	9	5	1100	24.5
	43	SBSmc2	Pl (P)	21	2000	2014	15	5	1656	21.4
	44	SBSmk1	Sx (P)	20	2000	2014	9	5	1100	23.6
	45	SBSmk1	Sx (P)	25	2001	2014	9	5	1100	22.9
	46	MSxk	Pl (N)	40	2001	2004	9	2	1100	20.8
	47	MSdk	Pl (N)	39	2001	2014	9	5	1100	19.5
	48	SBSmc	Pl (N)	44	2002	2005	9	2	1600	17.0
	49	SBSvk	Sx (P)	24	2008	2014	9	3	1100	25.4

EP number	Installation number	BEC zone[a]	Major species[b]	Total age at establishment (yr)	Year established	Year last remeasured	Number of plots	Number of measurements	Stem density (stems/ha)	Site index
886.13	1	SBSdw2	Pl (N)	13	1992	2004	18	5	1096	20.3
	2	SBSdw2	Pl (P)	12	1993	2005	18	5	1096	24.2
	3	ESSFmc	Sx (P)	10	1994	2012	18	7	1096	29.4
	4	ESSFmc	Pl (P)	9	1995	2010	18	6	1096	20.0
	5	SBSwk1	Sx (P)	10	1995	2013	18	7	1096	27.7
	6	SBSwk2	Pl (P)	10	1995	2007	18	5	1096	23.1
	7	MSxv	Sx (N)	16	1996	2011	18	6	1096	17.1
	8	ESSFdk	Pl (N)	13	1998	2001	18	2	1096	17.9
	9	SBSmk1	Sx (P)	14	1999	2015	18	6	1096	27.7
886.14	1	SBSdw3	Sx (N)	22	1999	2005	15	3	714	21.2
886.15	1	SBSdk	Pl (P)	18	2001	2006	16	3	1623	22.0
	2	SBSwk1	Pl (P)	21	2001	2006	24	3	1101	24.4

a Definitions of Biogeoclimatic Ecosystem Classification (BEC) codes are provided at https://www.for.gov.bc.ca/hre/becweb/resources/codes-standards/standards-becdb.html#_Download_Biogeoclimatic_or_Site_Ser.

b Pl: lodgepole pine; Sw: white spruce; Fd: Douglas-fir; Sx: hybrid spruce.

TABLE A1.2 *Fertilizer blend description. Controls were omitted from the table.*

EP number	Installation number	Fertilizer treatment code				
		F1	F2	F3	F4	F5
886.01	1–11	100N	200N			
	12, 13	200N	200N + 58S			
	14	200N	200N + 58S + 1.6B			
	15	200N	200N + 58S	200N + 58S + 1.6B	200N + CM[a]1	
	16	200N + CM2				
	18, 23, 40	200N	200N + 75S	200N + CM2 (CM3)		
	43	200N	400N	200N + CM4	400N + CM4	
	17, 19, 20, 21, 22, 24–39, 41, 42, 44–47	200N	200N + 75S			
	48	200N + 2B	200N + 50S + 2B			
	49	200N + 3B	200N + 50S + 3B			
886.13	1–9	200N + 1.5B	200N + 50S + 1.5B	200N + CM5	200N + ON1[b]	200N + ON2[b]
886.14	1	300N	300N[c]	300N + CM6	300N[c] + CM6	
886.15	1	300N + 244K[d]	300N + 244K[e] + 100S[e]	300N + 244K[d] + 100S[f]		
	2	300N + 244K[d]	300N + 244K[e] + 100S[e]	300N + 244K[d] + 100S[f]	300N + 244K[d] + 100S[g]	100S[g]

a CM = Complete mix; see Table A1.3.

b Yearly fertilization to maintain foliar N concentration at 1.3 (ON1) and 1.6% (ON2) and other nutrients and nutrient ratios with the “optimum” range.

c Ammonium nitrate.

d Potassium chloride (KCl).

e Potassium sulfate (K_2SO_4).

f Elemental sulphur (raw).

g Elemental sulphur (SulFer95).

TABLE A1.3 *Complete mix (CM) fertilizer blend description*

	CM1	CM2	CM3	CM4	CM5	CM6
Installation number (year)	**886.01-15 (1986)**	**886.01-16 (1992)[a] 886.01-18 (1992) 886.01-23 (1993)**	**886.01-40 (1998)**	**886.01-43 (2000)**	**886.13-1-9 (1993–2000)**	**886.14-1 (1999)**
Nutrient content (kg/ha)						
P	98.7	99.8	99.8	99.7	100.0	100.0
K	102.4	99.6	99.6	99.6	100.0	100.0
Ca	115.9					
Mg	51.1	37.6	35.7	37.9	25.0	39.3
S	50.2	75.2	75.0	75.0	50.0	75.0
B	2.2	3.0	3.0	3.0	1.5	3.0
Cu	2.2					
Fe	13.2					
Mn	5.5					
Mo	1.5					
Zn	5.1					

a Applied multiple times (1992, 1997, 2002).

TABLE A2.1 *Overview of damaged trees after fertilization by agent*

Damage code	Description	No. of damaged trees	Proportion of damaged tree (%)
A	**Animal damage**	**148**	**0.84**
AB	Bear	56	0.32
AD	Deer	53	0.30
AE	Elk	2	0.01
AH	Hare or rabbit	33	0.19
AM	Moose	3	0.02
AP	Porcupine	98	0.56
AS	Squirrel	2 076	11.78
AX	Birds	186	1.06
D	**Disease**	**2**	**0.01**
DB	Broom rust	8	0.05
DBS	Spruce broom rust	95	0.54
DD	Stem rot	3	0.02
DF	Foliage disease	105	0.60
DFC	Large-spored spruce-Labrador tea rust	1	0.01
DFD	Spruce needle cast	127	0.72
DFE	*Elytroderma* needle cast	35	0.20
DFL	Pine needle cast	786	4.46
DL	Disease caused dieback of leader	128	0.73
DLP	*Phomopsis* canker	1	0.01
DMP	Lodgepole pine dwarf mistletoe	2	0.01
DR	Root disease	12	0.07
DS	Stem disease	3 468	19.67
DSA	*Atropellis* canker (lodgepole pine)	1 226	6.96
DSB	White pine blister rust	8	0.05
DSC	Comandra blister rust (ponderosa pine)	8	0.05
DSG	Western gall rust	2 898	16.44
DSR	*Ceratocystis* canker	1	0.01
DSS	*Stalactiform* blister rust	26	0.15
I	**Insects**	**31**	**0.18**
IA	Aphids or adelgids	1	0.01
IAG	Cooley spruce gall adelgid	202	1.15
IB	Bark beetle	51	0.29
IBM	Mountain pine beetle	3 437	19.50
ID	Defoliating insects	69	0.39
IS	Shoot insects	1	0.01
ISP	Pitch module moths	1	0.01
ISQ	Sequoia pitch moth	13	0.07
IW	Weevils	9	0.05

Damage code	Description	No. of damaged trees	Proportion of damaged tree (%)
IWP	Lodgepole terminal weevil	13	0.07
IWS	White pine weevil	1905	10.81
IWW	Warren's root collar weevil	2	0.01
N	**Non-biological (abiotic) injuries**	**1**	**0.01**
NG	Frost	6	0.03
NGC	Frost crack	59	0.33
NL	Lightning	1	0.01
NW	Windthrow	19	0.11
NX	Wounding/rubbing	4	0.02
NY	Snow or ice (includes snowpress)	51	0.29
T	**Treatment injuries**	**3**	**0.02**
V	**Problem vegetation**	**1**	**0.01**
VP	Vegetation press	4	0.02
VT	Tree competition	148	0.84
Total		**17627**	**100.00**

TABLE A2.2 *Summary of annual damage rates (%) by installation. Numbers in parentheses are standard errors. AS: squirrel; DSG: western gall rust; IBM: mountain pine beetle; IWS: white pine weevil; N: number of plots.*

Installation	Major species[a]	AS	DSG	IBM	IWS	*N*
886.01-1	Pl	10.01 (1.40)	1.05 (0.18)	0 (0)	0 (0)	9
886.01-2	Pl	16.49 (0.95)	0.04 (0.02)	0 (0)	0 (0)	9
886.01-3	Pl	0.08 (0.03)	0.24 (0.06)	0 (0)	0 (0)	9
886.01-4	Pl	0.79 (0.30)	0.18 (0.06)	0 (0)	0 (0)	9
886.01-5	Pl	4.47 (0.27)	1.41 (0.27)	0 (0)	0 (0)	9
886.01-6	Pl	0.62 (0.12)	0.61 (0.12)	0 (0)	0 (0)	9
886.01-7	Pl	0.59 (0.13)	0.13 (0.03)	0 (0)	0 (0)	9
886.01-8	Pl	0.42 (0.08)	1.24 (0.18)	0 (0)	0 (0)	9
886.01-9	Pl	0.80 (0.09)	1.03 (0.10)	0 (0)	0 (0)	9
886.01-10	Pl	8.30 (1.89)	0.52 (0.10)	0 (0)	0 (0)	9
886.01-11	Pl	15.23 (1.77)	0.34 (0.05)	0 (0)	0 (0)	9
886.01-12	Pl	0.57 (0.13)	0.30 (0.12)	0 (0)	0 (0)	9
886.01-13	Pl	0.21 (0.10)	0.09 (0.04)	0 (0)	0 (0)	9
886.01-14	Pl	0.20 (0.09)	0.16 (0.07)	0 (0)	0 (0)	9
886.01-15	Pl	0.01 (0.01)	3.51 (0.36)	0 (0)	0 (0)	15
886.01-16	Pl	0.06 (0.02)	0.55 (0.07)	2.74 (1.57)	0 (0)	21
886.01-17	Pl	0 (0)	1.15 (0.19)	1.99 (0.16)	0 (0)	9
886.01-18	Pl	0 (0)	0.37 (0.08)	0 (0)	0 (0)	12
886.01-19	Sw	0 (0)	0 (0)	0 (0)	0.58 (0.15)	9
886.01-20	Sw	0 (0)	0 (0)	0 (0)	0.07 (0.04)	9
886.01-21	Sw	0 (0)	0 (0)	0 (0)	26.61 (1.45)	9
886.01-22	Sw	0 (0)	0 (0)	0 (0)	0.95 (0.19)	9

Installation	Major species[a]	AS	DSG	IBM	IWS	*N*
886.01-23	Fd	0 (0)	0 (0)	0 (0)	0 (0)	12
886.01-24	Pl	0.08 (0.05)	0 (0)	0 (0)	0 (0)	9
886.01-25	Fd	0 (0)	0 (0)	0 (0)	0 (0)	9
886.01-26	Fd	0 (0)	0 (0)	0 (0)	0 (0)	9
886.01-27	Sw	0 (0)	0 (0)	0 (0)	0.11 (0.04)	9
886.01-28	Fd	0 (0)	0 (0)	0 (0)	0 (0)	9
886.01-29	Sw	0 (0)	0 (0)	0 (0)	0.76 (0.12)	9
886.01-30	Fd	0 (0)	0 (0)	0 (0)	0 (0)	9
886.01-31	Pl	0 (0)	0.32 (0.10)	0 (0)	0 (0)	9
886.01-32	Pl	0 (0)	0.54 (0.15)	0 (0)	0 (0)	9
886.01-33	Pl	0.09 (0.09)	0.45 (0.16)	0 (0)	0 (0)	9
886.01-34	Pl	0 (0)	0 (0)	2.14 (0.59)	0 (0)	9
886.01-35	Pl	0.06 (0.04)	0.39 (0.09)	0 (0)	0 (0)	9
886.01-36	Pl	0 (0)	0.47 (0.07)	1.45 (0.48)	0 (0)	9
886.01-37	Pl	0 (0)	0 (0)	0 (0)	0 (0)	9
886.01-38	Pl	0.02 (0.02)	0.60 (0.19)	7.00 (0.61)	0 (0)	9
886.01-39	Pl	0.73 (0.13)	0.07 (0.07)	0.04 (0.04)	0 (0)	9
886.01-40	Pl	0 (0)	0.13 (0.05)	0 (0)	0 (0)	12
886.01-41	Pl	0.04 (0.04)	0.19 (0.07)	0.10 (0.06)	0 (0)	9
886.01-42	Sx	0 (0)	0 (0)	0 (0)	0.09 (0.07)	9
886.01-43	Pl	0.02 (0.01)	4.35 (0.39)	0 (0)	0 (0)	15
886.01-44	Sx	0 (0)	0 (0)	0 (0)	4.00 (0.50)	9
886.01-45	Sx	0 (0)	0 (0)	0 (0)	3.37 (0.39)	9
886.01-46	Pl	0.25 (0.25)	21.46 (3.49)	0 (0)	0 (0)	9
886.01-47	Pl	0.03 (0.01)	0.23 (0.08)	0.08 (0.08)	0 (0)	9
886.01-48	Pl	0 (0)	0 (0)	0 (0)	0 (0)	9
886.01-49	Sx	0 (0)	0 (0)	0 (0)	4.33 (0.59)	9
886.13-1	Pl	0 (0)	1.07 (0.13)	0 (0)	0 (0)	18
886.13-2	Pl	0.05 (0.03)	0.56 (0.10)	0 (0)	0 (0)	18
886.13-3	Sx	0 (0)	0 (0)	0 (0)	0.39 (0.09)	18
886.13-4	Pl	0.02 (0.01)	0.29 (0.08)	0 (0)	0 (0)	18
886.13-5	Sx	0 (0)	0 (0)	0 (0)	5.88 (0.44)	18
886.13-6	Pl	0 (0)	5.72 (0.50)	3.47 (0.33)	0 (0)	18
886.13-7	Pl	0.01 (0.01)	0.69 (0.12)	0 (0)	0 (0)	18
886.13-8	Pl	0 (0)	0 (0)	0 (0)	0 (0)	18
886.13-9	Sx	0 (0)	0 (0)	0 (0)	1.89 (0.21)	18
886.14-1	Pl	1.04 (0.43)	1.91 (0.38)	10.85 (1.31)	0 (0)	15
886.15-1	Pl	0 (0)	1.89 (0.63)	0 (0)	0 (0)	16
886.15-2	Pl	0.06 (0.06)	1.89 (0.36)	30.31 (2.22)	0 (0)	24

a Pl: lodgepole pine; Sw: white spruce; Fd: Douglas-fir; Sx: hybrid spruce.

TABLE A2.3 *Summary of annual damage rates (%) by fertilization blends. Numbers in parentheses are standard errors. AS: squirrel; DSG: western gall rust; IBM: mountain pine beetle; IWS: white pine weevil;* N*: number of plots. Fertilizer blend codes are defined in Tables A1.2 and A1.3.*

Fertilizer blend	AS	DSG	IBM	IWS	*N* (species[a])
100N	5.59 (1.25)	0.63 (0.10)	0 (0)		33 (Pl)
100S	0 (0)	2.30 (0.45)	18.69 (2.34)		4 (Pl)
200N	2.25 (0.53)	1.12 (0.32)	0.42 (0.15)	4.40 (1.81)	96/27 (Pl/Sw, Sx)
200N1.5B	0.02 (0.02)	1.28 (0.38)	0.61 (0.38)	2.22 (0.72)	18/9 (Pl/Sw, Sx)
200N2B	0 (0)	0 (0)	0 (0)		3 (Pl)
200N3B				2.35 (0.53)	3 (Sw, Sx)
200N50S1.5B	0 (0)	1.46 (0.49)	0.65 (0.35)	2.39 (0.80)	18/9 (Pl/Sw, Sx)
200N50S2B	0 (0)	0 (0)	0 (0)		3 (Pl)
200N58S	0.39 (0.16)	1.53 (0.84)	0 (0)		9 (Pl)
200N58S1.6B	0.06 (0.05)	1.75 (0.80)	0 (0)	1.86 (0.60)	6/3 (Pl/Sw, Sx)
200N75S	0.07 (0.03)	1.03 (0.42)	0.72 (0.25)	3.98 (1.58)	48/27 (Pl/Sw, Sx)
200NCM2	0.06 (0.02)	1.40 (0.36)	1.37 (0.50)		21 (Pl)
300N	0.66 (0.44)	1.30 (0.60)	10.42 (1.58)		6 (Pl)
300N244K	0.19 (0.19)	2.33 (0.84)	12.05 (4.65)		8 (Pl)
300N244K100S	0 (0)	1.47 (0.43)	14.00 (2.67)		20 (Pl)
300NCM2	1.92 (0.90)	2.8 (0.61)	10.21 (2.26)		6 (Pl)
400N	0 (0)	4.15 (1.25)	0 (0)		3 (Pl)
400NCM2	0 (0)	3.66 (0.47)	0 (0)		3 (Pl)
Control	**0.98 (0.25)**	**1.12 (0.23)**	**1.23 (0.38)**	**2.85 (0.99)**	**137/39 (Pl/Sw, Sx)**
Treatment mean	**1.40 (0.24)**	**1.27 (0.14)**	**2.30 (0.34)**	**3.59 (0.84)**	

a Pl: lodgepole pine; Sw: white spruce; Sx: hybrid spruce.