Adjusting Free-growing Guidance Regarding Aspen Retention in the Cariboo-Chilcotin

Research to Operational Implementation

2016

British Columbia

Adjusting Free-growing Guidance Regarding Aspen Retention in the Cariboo-Chilcotin

Research to Operational Implementation

Teresa A. Newsome and Jean L. Heineman

BRITISH COLUMBIA

ISBN 978-0-7726-6997-1 – Print version
ISBN 978-0-7726-6998-8 – Digital version

Citation
Newsome, T.A. and J.L. Heineman. 2016. Adjusting free-growing guidance regarding aspen retention in the Cariboo-Chilcotin: research to operational implementation. Prov. B.C., Victoria, B.C. Tech. Rep. 102. www.for.gov.bc.ca/hfd/pubs/Docs/Tr/Tr102.htm

Prepared by
Teresa A. Newsome
B.C. Ministry of Forests, Lands
and Natural Resource Operations
Cariboo Region
Williams Lake, B.C.

Jean L. Heineman
J. Heineman Forestry Consulting
Vancouver, 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

In 2008, a Working Group that included British Columbia government staff (researchers, stewardship foresters, and wildlife habitat experts), a research consultant, and industry foresters was formed in the Cariboo Region of south-central British Columbia to determine how existing research concerning conifer–broadleaf competitive relationships could be used to suggest change to free-growing guidelines for that region. The objective was to adjust free-growing criteria concerning broadleaf tree presence in coniferous plantations while maintaining consistency with biological thresholds for conifer growth that had been determined by local research. The project focussed on juvenile stands that had not previously received brushing or broadleaf tree spacing treatments in biogeoclimatic units where trembling aspen commonly develops following harvest. Over a 6-year period, recommendations for change to broadleaf-tree–related free-growing guidelines were made for seven Cariboo Region biogeoclimatic subzones/variants. In large part, the project involved examining available research, primarily from Cariboo Region Experimental Project 1152, and verifying the extent to which it could be applied across the landscape.

As a result of this work, in 2013, Chilcotin and Central Cariboo Forest District policy declared aspen a non-deleterious brush species in the SBPSxc and IDFdk4. In 2015, recommended adjustments to free-growing guidance for the IDFdk3, SBSdw1, SBSdw2, SBPSmk, and SBPSdc were incorporated into the *Silviculture Survey Procedures Manual* as an accepted alternative within South Area guidelines for the Williams Lake, Quesnel, and 100 Mile Timber Supply Areas. For the biogeoclimatic subzones/variants examined in this project, universal adjustments were made to the definition of a competitive broadleaf tree, and the term "conifer–brush ratio" was replaced with "brush–conifer ratio." Broadleaf trees can now be up to 125% taller than crop lodgepole pine (brush–conifer ratio of 1.25) and up to 150% taller than other acceptable conifer species (brush–conifer ratio of 1.5) before they have to be considered in free-growing surveys. The new brush–conifer ratios are used to define both countable broadleaves (i.e., those considered when assessing broadleaf density within free-growing plots) and broadleaf presence within a 1-m cylinder around crop conifers. The allowable number of occupied quadrants within the 1-m cylinder was also universally increased; whereas only one quadrant was previously allowed to be occupied, either one or two adjacent quadrants can now be occupied with countable broadleaf vegetation.

The allowable number of countable broadleaves was also adjusted from previous levels that had ranged from 400 to 1000 stems/ha, depending on conifer species and site series. Following change to free-growing guidelines for the IDFdk3, 3000 countable broadleaf stems/ha can be present in conifer plantations (regardless of conifer species) on mesic and drier site series, and 1000 countable stems/ha are allowed on wetter than mesic site series. For the SBSdw1, SBSdw2, SBPSmk, and SBPSdc, the allowable number of countable broadleaves (again regardless of conifer species) was set at 1000 stems/ha for all site series.

ACKNOWLEDGEMENTS

The authors acknowledge the contribution of all those who participated in Working Group activities conducted since 2008 that led to successful culmination of this project. We also thank Dave Weaver for facilitating the incorporation of our recommendations into provincial free-growing guidance, Amanda Nemec for statistical analysis, George Harper and Phil Comeau for exploring modelling possibilities and providing advice regarding the long-term development of mixed stands, and Janet and Scott Zimonick for their many hours of fieldwork. We appreciate the assistance we received from Nola Daintith in all aspects of the project. We are grateful to Deb McKillop, Peter Ott, Bruce Rogers, and Dave Weaver for reviewing the manuscript. We especially thank Tolko Industries Ltd., West Fraser Mills Ltd., BC Timber Sales, Ainsworth Lumber Co. Ltd., and Canadian Forest Products Ltd. for financial contributions that enabled focussed remeasurement of some of the EP1152 sites and field testing of proposed guidelines. Funding assistance was also received from the British Columbia Ministry of Forests, Lands and Natural Resource Operations, Forest Resource Development Agreement, Forest Renewal BC, and Forest Investment Account. Funding assistance does not imply endorsement of any statement or information in this report.

CONTENTS

APPENDICES

TABLES

FIGURES

1 INTRODUCTION

In British Columbia, most forest land is publicly owned, with the right to harvest timber managed through a tenure system (B.C. Ministry of Forests, Lands and Natural Resource Operations 2012). Volume-based Timber Sale Licences, which grant the right to harvest standing timber in specific management units but not ongoing rights to timber produced in subsequent rotations in those units, are the most common form of tenure. Under this system, the forest licensee has an obligation to satisfactorily reforest harvested areas. To ensure that this obligation would be met, the Province of British Columbia enacted legislation in 1987 that defined free-growing standards that characterized juvenile stands in good condition, with crop trees that were expected to remain healthy and grow to maturity at predicted rates (Powelson 2012). These standards were applied across British Columbia according to ecological differences that are defined by the biogeoclimatic ecosystem classification system of British Columbia (Meidinger and Pojar 1991). This system, which forms the basis for forest management in British Columbia, defines biogeoclimatic zones, subzones, and subzone variants, and allows classification of individual sites down to the level of site series based on local soil moisture and nutrient status. Free-growing standards developed in 1987 specified allowable broadleaf tree presence for individual crop conifer species across broad groupings of biogeoclimatic units.

The first free-growing standards specified target and minimum stocking levels for preferred and acceptable conifer species, minimum crop conifer height, and allowable height of vegetation relative to the crop conifer within a 1-m cylinder. Although ecosystem and vegetation community differences were recognized when the first standards were developed, there was a general lack of research regarding crop conifer responses to the wide range of vegetation communities that could develop following harvest in individual biogeoclimatic subzones/variants. To address this limitation, and to standardize the criteria used to assess free-growing on a province-wide basis, expert opinion was used to determine how best to extend findings from the limited research that was available (e.g., Brand 1986). The original guidelines deliberately erred on the conservative side with respect to the presence of non-crop vegetation in an effort to ensure the well-being of timber as a public resource. The shortcomings of this approach were acknowledged, and the intention to revise standards as ecosystem-specific research results became available was understood.

Local practitioners in many areas of British Columbia considered early free-growing standards to be overly restrictive for some ecological units, and research projects were established in various parts of the province to quantify biologically appropriate ecosystem- and species-specific competition thresholds (e.g., Simard et al. 2001; Hawkins et al. 2012). Little adjustment to free-growing standards took place during the first decade after they were initially implemented, despite recommendations that resulted from a comprehensive examination of the issue (Davis 1998[1]). Standards that specified the presence of broadleaf tree species such as trembling aspen (*Populus tremuloides*) and paper birch (*Betula papyrifera*) in coniferous plantations were particularly controversial because they resulted in the need to brush virtually

1 Davis, I. 1998. Non-crop vegetation, detrimental or not?: redefining free growing. Ecosystems Management Ltd. B.C. Min. For., For. Pract. Br., Victoria, B.C. Unpubl. rep.

all sites where these species occurred. In response to these concerns, standards regarding broadleaf tree presence were revised between 2000 and 2002 to allow the presence of overtopping broadleaf trees in one quadrant within a 1-m cylinder around crop conifers, and to specify allowable densities for retaining these species across broad groupings of biogeoclimatic units. For some crop conifer species, it was recognized that the thresholds for broadleaf tree presence could differ according to soil moisture availability, and different allowable broadleaf densities were specified for drier and moister site series (B.C. Ministry of Forests 2002). Nonetheless, many professionals continued to maintain that these species were commonly being brushed for administrative reasons rather than because brushing was necessary to meet conifer growth objectives.

In 2003, with the introduction of the *Forest and Range Practices Act* (FRPA), free-growing standards became guidelines, and this legislation continues to be in effect as of 2016. In theory, deviation from the guidelines can now be achieved through professional reliance as long as the alternative plan is supported by appropriate research and passes a series of tests designed to ensure that forest management and timber supply principles are adhered to. In practice, however, it is very difficult to deviate from the guidance, and proposals that differ from the provincial free-growing guidelines are rarely approved by government decision-makers. This is largely because research results are available for only some biogeoclimatic units, and evaluating the extent to which specific findings can be applied across the land base is a complex undertaking, even for trained researchers. Furthermore, none of the existing studies has been in place long enough to provide rotation-length data, and currently available modelling tools have variable success in projecting the long-term development of young, dynamic mixed stands. Overall, the process of attempting to deviate from current free-growing guidelines through professional reliance has had little success.

Concerns about broadleaf competition extend beyond economics. In addition to financial considerations, adjusting free-growing standards related to broadleaf tree species has a high priority because of increasing recognition that broadleaf trees play an important role in maintaining ecosystem health (Simard and Vyse 2006). Benefits conferred by broadleaves include retention of nutrients within ecosystems (Pastor 1990), improved root disease resistance (Morrison et al. 1991; Peterson and Peterson 1995; Gerlach et al. 1997; Simard et al. 2005), protection from frost damage (Stathers 1989; DeLong 2000) and weevil attack (Taylor et al. 1994), and increased mechanical stability (Frivold 1985; Yang 1989). Broadleaf trees also increase the complexity of vertical stand structure, which is beneficial to wildlife diversity. Trembling aspen, for example, provides habitat for cavity-nesting birds when mature, and when juvenile, provides foraging area for birds, browse for ungulates, and cover for small mammals (Enns et al. 1993).

In the Cariboo Region of south-central British Columbia, trembling aspen, which commonly forms juvenile mixtures with various conifer species, was the focal point of dissatisfaction with the existing free-growing guidelines. In 1992, Experimental Project 1152 (EP1152) was initiated with the specific objective of examining trembling aspen–lodgepole pine (*Pinus contorta* var. *latifolia*) competitive relationships. By 2008, it had produced a substantial body of work demonstrating that the competitive ability of aspen varied by biogeoclimatic unit (Newsome et al. 2012), and that adjustment to Cariboo free-growing guidelines was warranted for several biogeoclimatic units (Newsome et al. 2003, 2004a, 2004b, 2006a, 2006b, 2008). Unfortunately, concurrent discontinuation of the primary funding source for the project hindered completion of the final step that was necessary before change could be proposed—that of evaluating the applicability of results at the landscape level. The Cariboo Region forestry community responded by forming a Working Group to determine how this project could be moved forward. It consisted of government partners (researchers, stewardship foresters, and wildlife habitat experts) who provided expert knowledge, a private consultant who assisted with research-related aspects of the project, and industry partners that contributed financial, intellectual, and logistical support. Over a 6-year period, the Working Group reviewed and proposed change to free-growing guidelines in seven biogeoclimatic subzones/variants: the very dry, cold Sub-Boreal Pine–Spruce subzone (SBPSxc), the Chilcotin variant of the dry, cool Interior Douglas-fir subzone (IDFdk4), the Fraser variant of the dry, cool Interior Douglas-fir subzone (IDFdk3), the Horsefly variant of the dry, warm Sub-Boreal Spruce subzone (SBSdw1), the Blackwater variant of the dry, warm Sub-Boreal Spruce subzone (SBSdw2), the moist, cool Sub-Boreal Pine–Spruce subzone (SBPSmk), and the dry, cold Sub-Boreal Pine–Spruce subzone (SBPSdc) (Steen and Coupé 1997).

In this report, we first of all describe the Working Group process (Section 2). We then present recommendations and rationale for free-growing guidance adjustments in seven Cariboo Region biogeoclimatic subzones/variants in Section 3. First we describe those that concern lodgepole pine (Section 3.1) and next we present those that concern more shade-tolerant hybrid spruce (*Picea engelmannii* × *glauca*) and Douglas-fir (*Pseudotsuga menziesii*) (Section 3.2). In Section 4, we describe the process of implementing the changes and having them accepted as provincial government guidance, and finally in Section 5, we present an overall discussion of the project and make suggestions about how similar work could be conducted elsewhere in British Columbia.

2 THE WORKING GROUP PROCESS

The Working Group examined free-growing issues in Cariboo Region ecosystems in the order of the apparent increasing competitiveness of aspen. First to be examined were the SBPSxc and the adjacent IDFdk4, where research and subjective observations suggested that aspen was not a serious competitor with lodgepole pine. Secondly, attention was turned to the IDFdk3; in this more productive ecosystem, research indicated that there was a threshold density of aspen beyond which lodgepole pine growth was affected, but that it was higher than the allowable density specified by free-growing guidelines. Thirdly, broadleaf–conifer relationships were examined in the SBSdw1 and SBSdw2, where aspen was recognized as a potentially strong competitor, not only with lodgepole pine but with more shade-tolerant hybrid spruce and Douglas-fir. Lastly, the Working Group considered the SBPSmk and SBPSdc, for which less research information was available. These subzones occur geographically and ecologically between the IDFdk3 and SBSdw1/SBSdw2, and aspen was expected to have intermediate competitive ability.

Working Group recommendations were, to the extent possible, based on results from EP1152, which includes experiments in a range of Cariboo Region ecosystems (Table 1). Individual EP1152 studies were conducted on zonal (circum-mesic) sites within biogeoclimatic subzones/variants of interest. These experiments, which focussed primarily on lodgepole pine, were designed following statistically valid procedures; however, they were not replicated at the landscape level. In order to move from research to operational application, it was necessary to demonstrate that broad application of the findings was appropriate. To overcome this constraint, a field-based verification sampling protocol was used to determine whether aspen–lodgepole pine competitive relationships at individual research sites were representative of those in the subzone/variant as a whole. The protocol involved collecting data to describe

TABLE 1 *Description of the studies used to develop free-growing guideline adjustment*

Experiment	Site name	Year established	Biogeoclimatic unit	Type of experiment
EP1152.01	Hayfield Two-mile Moffat Meldrum[a]	1992 1992 1992 1992	SBSdw1 SBSdw1 IDFdk3 IDFdk3	Retrospective examination (i.e., no treatments were applied) of naturally regenerated lodgepole pine responses to naturally occurring tall-aspen[b] densities ranging from 0 to 10 000+ stems/ha. Repeated assessments were conducted to stand ages of 31–34 years.
EP1152.02	Tyee	1994	SBSdw2	Spatial study comparing planted lodgepole pine responses to aspen removal in 50- or 100-cm radii versus broadcast removal and an uncut control.
EP1152.03	Meldrum[c]	1998	IDFdk3	Variable density study comparing planted lodgepole pine responses to 0, 1000, 2500, or 4000 tall-aspen stems/ha with those in an uncut control.
EP1152.04	Clusko	2001	SBPSxc	Variable density/spatial study comparing naturally regenerated lodgepole pine responses to 0, 1000, or 2500 tall-aspen stems/ha versus aspen removal in a 1-m radius and an uncut control.
EP1152.09	Miner Lake 14 km	2008 2008	SBPSmk SBPSmk	Adaptive management study (i.e., a study conducted at an operational scale under operational conditions) to compare planted or natural lodgepole pine responses to a tall-aspen retention level of 2500 stems/ha with those of broadcast aspen removal (0 stems/ha) and an uncut control.
	Philemon Gavin Lake Sausser Lake	2009 2009 2011	SBSdw2 SBSdw1 SBSdw2	Adaptive management study to compare planted lodgepole pine, hybrid spruce, and Douglas-fir responses to a tall-aspen retention level of 2000 stems/ha with those of broadcast aspen removal (0 stems/ha) and an uncut control.
EP1269.02	McKinley	1999	SBSdw1	Variable density study to compare stand-level planted lodgepole pine responses (i.e., in growth and yield plots only) to 0, 500–800, 1000–1500, or 2000–2800 tall-aspen stems/ha and an uncut control.
EP1080	Pine Ridge	1988	SBSmk1	Variable aspen retention study examining lodgepole pine and hybrid spruce growth under conditions of light aspen presence (average 1360 stems/ha) or heavy aspen presence (average 2820 stems/ha).
EP841.07	Sheridan	1988	SBSdw1	Twenty-four-year-old Douglas-fir growth was examined under a wide range of naturally occurring aspen densities. This stand developed in a single block of a site preparation study; the block was eliminated from the original experiment due to the development of dense aspen.

a The EP1152.01 Meldrum study (a different site than EP1152.03) was destroyed by mountain pine beetle attack.

b "Tall-aspen" are as tall as or taller than the crop conifer.

c The Meldrum EP1152.03 study area was originally classified as IDFxm; it was reclassified as IDFdk3 after the experiment was initiated.

aspen–conifer competitive relationships from a range of randomly selected clearcut sites that were stocked with juvenile lodgepole pine and had sufficient aspen presence that operational brushing was deemed necessary to meet free-growing obligations (full methodology described in Appendix 1). Attributes of particular interest for comparison between the research and operational sites were height of the dominant aspen, height ratio of dominant aspen to pine, and height growth ratio of dominant aspen to pine. We also examined pine vigour across a range of stand ages to see whether there was evidence that the competitive effects of aspen on pine were worsening with time since harvest. Lodgepole pine size was compared at operational and research sites to determine whether there was any indication that abnormally good growth of lodgepole under research conditions was influencing our conclusions. If aspen had, on average, similar or lesser competitive ability at verification sites than at the research site in question, we concluded that the proposed changes could be broadly applied (on mesic or drier sites).

For the SBPSxc, IDFdk4, and IDFdk3, multiple years of data were available from the Clusko (EP1152.04) and Meldrum (EP1152.03) variable density experiments, which allowed for statistical comparison (using *t* tests) of individual verification sites with the variable density study in the same (or associated in the case of the IDFdk4) ecological unit. For the SBSdw1 and SBSdw2, early experiments suggested threshold densities for aspen retention (i.e., EP1152.01, EP1152.02, EP1269.02) (Table 1), but variable density studies to directly test specific levels of aspen presence were not established until 2008 and had at the time received only a single remeasurement when this project to adjust free-growing guidance was under way. We therefore relied more heavily on results from the earlier SBSdw1/SBSdw2 experiments, even though their design did not permit statistical comparison of aspen–pine competitive relationships with those at verification sites. Instead, we examined trends in the data to confirm that, at the suggested density threshold, the competitive ability of aspen at typical operational sites was not greater than that observed at the various research sites. Verification data were also collected in the SBPSmk and SBPSdc, and trends were examined to determine whether aspen–pine competitive relationships were more similar to those of the IDFdk3 or SBSdw1/SBSdw2. Neighbouring aspen density criteria governing the selection of crop pine at verification sites varied by ecosystem and were set to bracket thresholds suggested by research findings (Table 2).

TABLE 2 *Verification sampling criteria*

Subzone/variant	Number of sites	Year sampled	Neighbouring aspen density classes sampled (stems/ha)	Number of plots sampled at each site
SBPSxc	8	2010	Any	10–13
IDFdk4	6	2010	Any	
IDFdk3	17	2010	0, 1000–3000, 4000–6000, > 6000	0 stems/ha: 3 Other classes: 4
		2011	0, 1000–3000, 4000, 5000	
SBSdw1/SBSdw2	9	2011	0, ≤ 4000	0 stems/ha: 3 ≤ 4000 stems/ha: 8
SBPSmk	10	2012	0, 1000, 2000, 3000, 4000	Each class: 3
SBPSdc	8	2012	0, 4000, ≥ 1000	0 stems/ha: 3 4000 stems/ha: 4 ≥ 1000 stems/ha: 8

Experimental Project 1152 focussed on lodgepole pine, and was not originally designed to examine the effects of aspen on more shade-tolerant hybrid spruce and Douglas-fir. Consequently, as described in Section 3.2, the Working Group relied, to a large extent, on expert interpretation of research that was relevant to, but not specifically designed to test, competitive relationships between aspen and hybrid spruce or Douglas-fir in the Cariboo Region ecosystems of interest.

3 FREE-GROWING GUIDELINE ADJUSTMENTS

Free-growing surveys are conducted according to specific guidelines that are described in the annually updated *Silviculture Survey Procedures Manual* (B.C. Ministry of Forests, Lands and Natural Resource Operations 2016). In these surveys, data are collected in 3.99-m radius (50 m^2) free-growing plots at specified sampling densities. Within each plot, well-spaced conifers of species that are preferred or acceptable for the specific biogeoclimatic subzone/variant/site series and that meet minimum height and health criteria (B.C. Ministry of Forests 2002) are identified. For each of these crop conifers, the presence of non-crop vegetation (referred to as "brush") is examined within the 1-m radius cylinder that surrounds it; shrubs or herbs that are taller than the conifer can occupy one quadrant, but if more than one quadrant is occupied by this type of vegetation, the tree is rejected from free-growing. If the tree is not rejected due to the presence of overtopping shrubs or herbs, broadleaf tree presence is examined. Prior to the adjustments described in this report, the crop conifer was free-growing if there was no overtopping broadleaf vegetation within the 1-m cylinder (including branches originating from broadleaf trees outside the cylinder); the crop conifer was rejected from free-growing if more than one quadrant was occupied. Conifers that had one quadrant occupied were considered "potentially free-growing." When all eligible conifers had been examined, the median height of potentially free-growing trees was determined by conifer species, and the number of broadleaf trees that exceeded each median height was counted within the 3.99-m plot. The allowable number of countable broadleaves within the 3.99-m plot ranged from 2 to 5 (400–1000 stems/ha), depending on the biogeoclimatic subzone/variant, site series, and crop conifer species. Below, we describe the research and policy development work that was conducted in this project to adjust free-growing criteria and survey procedures for relevant ecosystems and Timber Supply Areas (TSAs) within the Cariboo Region. The revised guidelines first appeared in the *Silviculture Survey Procedures Manual* in 2015, and are currently available in the 2016 version (B.C. Ministry of Forests, Lands and Natural Resource Operations 2016). Readers are advised that the date associated with the *Silviculture Survey Procedures Manual* changes annually.

3.1 Lodgepole Pine

With the exception of the adaptive management experiments (i.e., studies established at an operational scale under operational conditions) (EP1152.09) that were established between 2008 and 2011, all EP1152 experiments that contributed to our recommendations have published results. However, we also used data that had been collected after the latest publications, which in most cases were critical to our recommendations because of their longer-term nature. To the extent possible, we present both new results and key features of published results.

3.1.1 Research findings that apply universally across subzones/variants

Individual EP1152 experiments were designed to allow flexible examination of neighbourhood characteristics that affect crop lodgepole pine performance. This was achieved through the comprehensive collection of data to describe both the size of individual neighbourhood trees and their distance from the crop pine. This approach, although time consuming, allowed for flexible examination of the roles that aspen density and spatial arrangement played on conifer performance. The density of aspen that were as tall as or taller than the subject pine (hereafter called tall-aspen) within 1.78-m radius neighbourhoods became a primary focus of the experiments fairly early on in the project, but spatial data continued to be collected.

During our consideration of possible adjustments to Cariboo Region free-growing guidelines, the EP1152 experiments provided information about aspen density thresholds for a range of subzones/variants. However, density is not the only criterion used to determine the free-growing status of crop conifers on sites where broadleaf tree species are present, and the comprehensive range of variables that we assessed allowed us to also examine criteria related to the relative height relationships of broadleaves and conifers. Conifer–broadleaf height ratios are used to describe the presence of aspen within a 1-m radius around the crop tree and to define countable broadleaf stems. Focussed analysis of data collected through the years in the SBPSxc, IDFdk3, and SBSdw1 experiments demonstrated that there were height ratio thresholds that applied across all three of these biogeoclimatic units, and that because of this, a universal change to current free-growing guidance was warranted. Likewise, data collected in recent field assessments indicated that it was appropriate to suggest a universal adjustment to the current criterion that only one quadrant within the 1-m cylinder around crop conifers could be occupied.

Conifer–brush ratio (aka brush–conifer height ratio) Early results from retrospective studies in the IDFdk3 and SBSdw1 (EP1152.01) demonstrated that neighbouring aspen that were shorter than crop lodgepole pine did not contribute significantly to competition; subsequent investigation of density thresholds therefore focussed on tall-aspen (Newsome et al. 2003). As stands aged, it became increasingly apparent that aspen that were < 1.25 times the pine height also had little competitive effect. This phenomenon was particularly obvious at the SBSdw2 Tyee site (EP1152.02). Although dense juvenile aspen developed following site preparation at Tyee, it was browsed by moose, and consequently, was never more than about 1 m taller than the planted pine. Under these conditions, the planted lodgepole pine easily outgrew aspen by age 15 years (Figure 1). Based on these observations, we conducted a focussed analysis of aspen–lodgepole pine height relationships that included previously collected data from SBPSxc, IDFdk3, and SBSdw1 research sites. Our findings indicated that neighbouring aspen presence did not significantly reduce pine diameter growth until aspen was at least 1.25–1.5 times the height of pine, regardless of ecosystem (Newsome et al. 2012). This discovery was consistent with other work demonstrating that light availability in aspen stands increased with height in the canopy (Comeau et al. 2006). Comeau's research

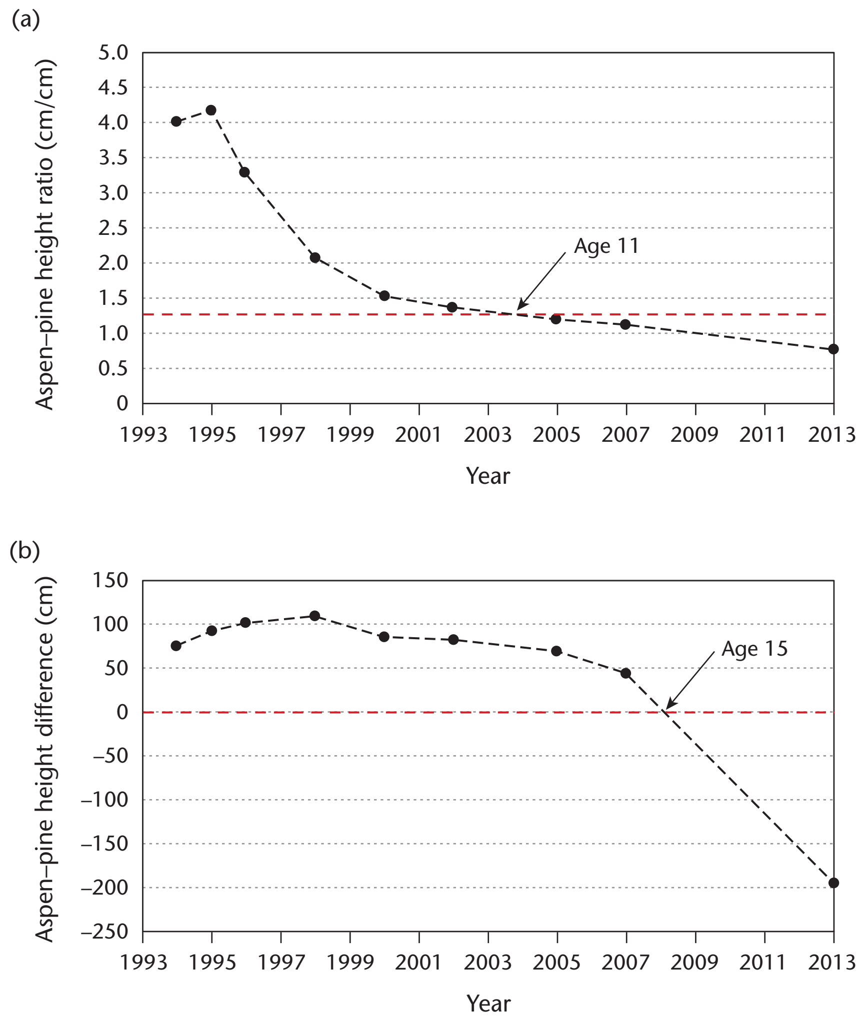

FIGURE 1 *Aspen–pine height relationships in the uncut control treatment at the SBSdw2 Tyee site (EP1152.02) from 1994 (age 1) to 2013 (age 20): (a) aspen–pine height ratio (the dashed line indicates a brush–conifer ratio of 1.25, which defines countable aspen according to revised guidelines), and (b) aspen–pine height difference (the dashed line indicates no height difference). Values are based on height of the tallest aspen within a 1.78-m radius of the crop pine. On average, the aspen–pine height ratio (aka brush–conifer height ratio) was 1.25 at a stand age of 11 years, and pine achieved the same height as the tallest aspen at age 15 years.*

suggested that if conifers were at least 60% as tall as aspen, they received 70–72% full sunlight. On the basis of the Newsome et al. (2012) and Comeau et al. (2006) results, we proposed that the conifer–brush ratio for lodgepole pine should be universally decreased to 80% for the Cariboo Region ecosystems where changes to free-growing guidelines were being considered. In hopes of minimizing confusion, we also proposed that the ratio should be referred to as a "brush–conifer ratio" rather than a "conifer–brush ratio," and should be expressed as a decimal (i.e., we were proposing a brush–conifer ratio of 1.25).

As a result of this change:

- quadrants would not be considered occupied within the 1-m cylinder unless aspen (any part of the aspen that extended into the cylinder, including the branches of aspen trees outside the cylinder) was > 1.25 times the pine height; and
- within 3.99-m radius free-growing plots, individual aspen trees would not be countable unless they exceeded 1.25 times the median height of potentially free-growing pine.

Number of occupied quadrants Under the free-growing guidelines that existed in 2008, a common challenge faced by Cariboo Region operational foresters was that any overtopping aspen (even the tip of a single branch) within a single quadrant of the 1-m cylinder around a crop conifer rendered that tree "potentially free-growing" and subject to rejection if the allowable broadleaf density within the 3.99-m free-growing plot was exceeded. Considerable subjective field observation suggested that because of the clumpy growth habit of aspen, it often occupied more than one quadrant, even where it was present on only one side of the crop conifer and was not apparently affecting vigour or growth. We reasoned that from the perspective of light availability, there should be little difference between one occupied quadrant and two occupied quadrants that were adjacent to each other, thereby leaving one-half of the 1-m cylinder entirely open.

Although a variety of spatial data was collected, none of the original EP1152 experiments had been designed specifically to address the question of how many quadrants could be occupied within a 1-m radius of crop pine without having a negative impact on growth. By 2007, it was clear that an answer to this question was needed, and subsequently, data regarding the number of occupied quadrants around crop lodgepole pine were routinely collected. Results from the IDFdk3 Moffat site (EP1152.01) and the SBSdw1 Hayfield and Two-mile sites (EP1152.01) confirmed that, at the aspen densities that we considered to be thresholds for lodgepole pine growth (3000 stems/ha in the IDFdk3 and 1000 stems/ha in the SBSdw1) (Section 3.1.2), between one and two quadrants tended to be occupied by tall-aspen (Figure 2). At the SBSdw2 Tyee site (EP1152.02), there were no statistically significant differences in lodgepole pine height, diameter, or height/diameter ratio between crop pine with one versus two quadrants occupied by overtopping aspen (i.e., aspen with a brush–conifer ratio > 1.0) (Figure 3). Likewise, 4 years after aspen removal treatments had been applied at the SBPSmk and SBSdw1/SBSdw2 adaptive management sites (EP1152.09), there were no significant differences in height growth, diameter growth, or volume growth between pine growing with one versus two occupied quadrants (Figure 4). In the adaptive management studies, lodgepole pine that had any aspen presence within the 1-m cylinder tended to have greater height growth and less diameter growth than those that had no occupied quadrants, whereas stem volume growth was statistically similar where up to three quadrants were occupied.

Together, the results from these EP1152 projects confirmed our earlier subjective observation that there was little difference in pine growth where two quadrants rather than one were occupied by aspen. We specified adjacency of the two quadrants to ensure a high degree of light availability in at least one-half of the 1-m cylinder around crop conifers. We recommended that

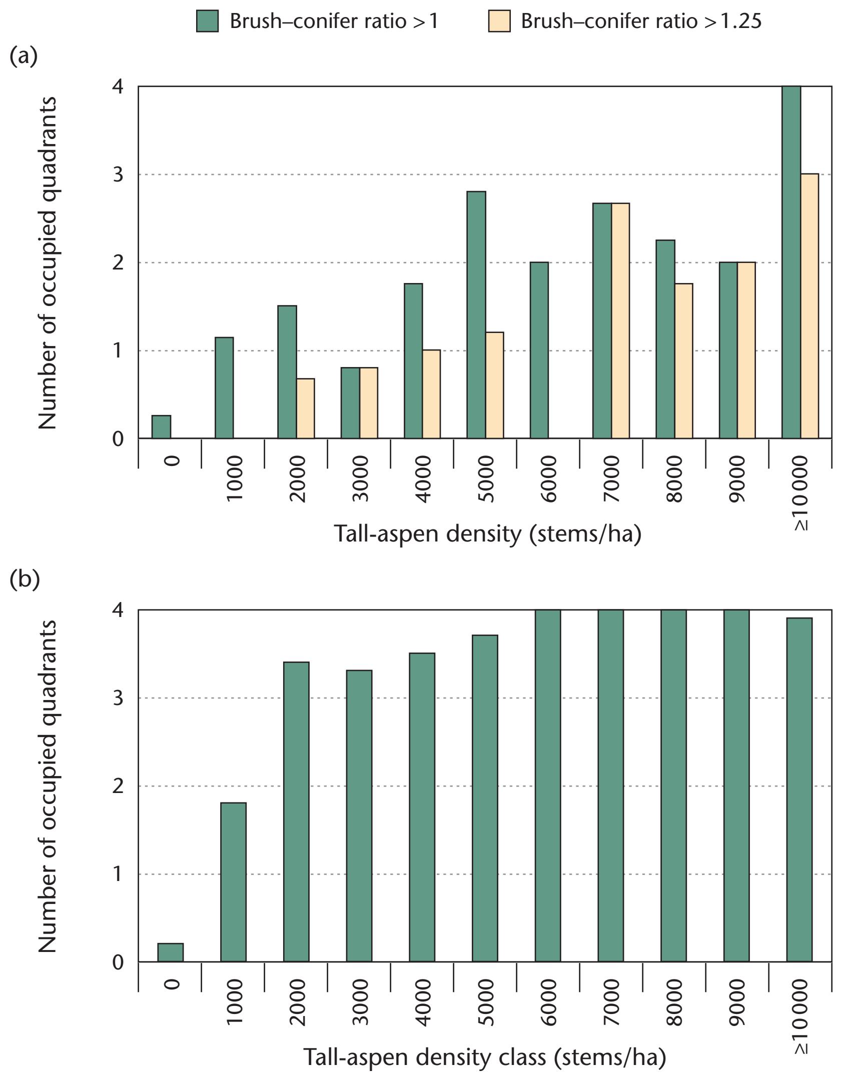

FIGURE 2 *Number of occupied quadrants within a 1-m cylinder around crop lodgepole pine in the EP1152.01 study at (a) the IDFdk3 Moffat site (age 31) using brush–conifer ratios of 1.0 (aspen is taller than the pine) or 1.25 (aspen is > 1.25 times the pine height) to define an occupied quadrant, and (b) the SBSdw1 Hayfield and Two-mile sites (age 33–34) using a brush–conifer ratio of 1.0 to define an occupied quadrant. Density classes are based on the density of tall-aspen at age 16 years (2004) at Moffat and age 16–17 years (1994) at Hayfield and Two-mile.*

guidelines for lodgepole pine be universally changed across all subzones/variants included in this project to allow up to two adjacent quadrants to be occupied by aspen that was up to 1.25 times the height of the pine. In other words, a crop pine would be free-growing if no broadleaf vegetation within the 1-m cylinder was > 1.25 times its height. The tree would be potentially free-growing, and subject to the allowable density criterion, if it had one or two adjacent quadrants occupied by broadleaf vegetation that was > 1.25 times its height.

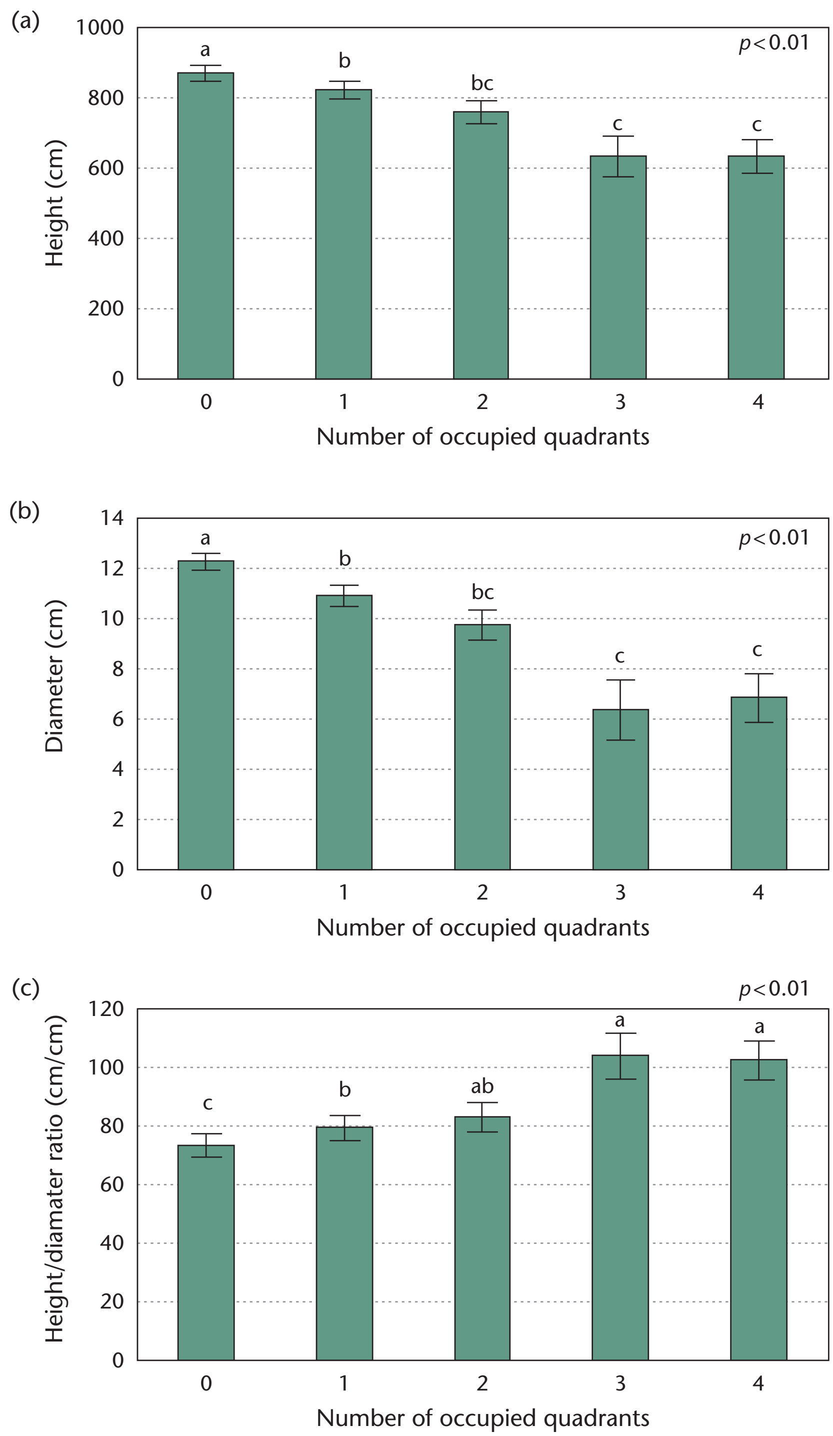

FIGURE 3 *Effect of the number of occupied quadrants on 20-year-old lodgepole pine (a) height, (b) diameter (dbh), and (c) height/diameter (dbh) ratio at the SBSdw2 Tyee research site (EP1152.02). An occupied quadrant is defined as one where the brush–conifer ratio was > 1.0 (i.e., aspen was taller than pine) at age 14 years (2007).*

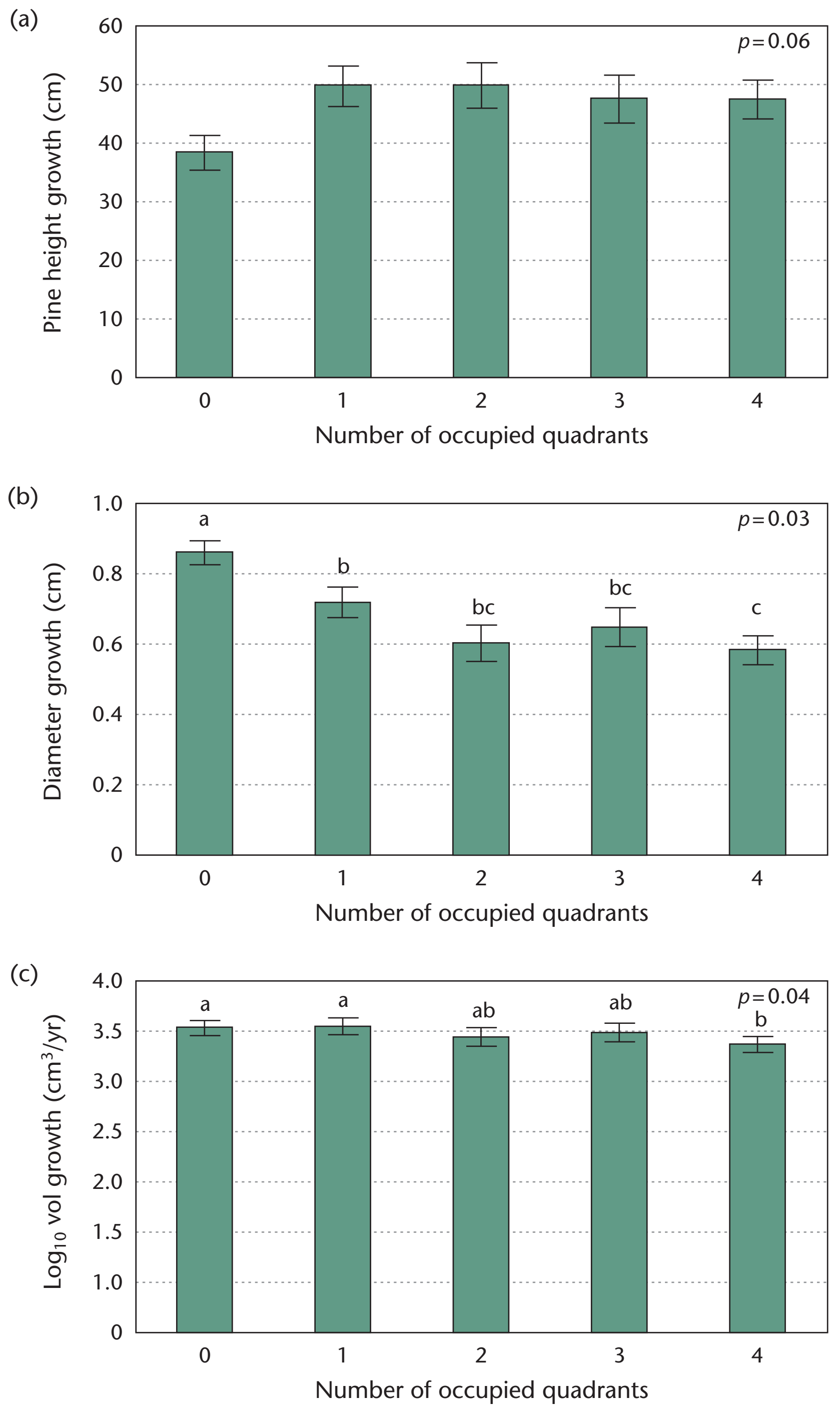

FIGURE 4 *Comparison of lodgepole pine mean annual (a) height, (b) ground-level diameter, and (c) stem volume (log_{10} transformed values) where 0, 1, 2, 3, or 4 quadrants are occupied at SBSdw1/SBSdw2 and SBPSmk adaptive management studies (EP1152.09, combined data from four sites). Means are based on growth during the 4-year period immediately following aspen-removal treatments, and an occupied quadrant is one where the brush–conifer ratio was >1.0 (i.e., aspen was taller than pine) in year 4. Where $p \leq 0.05$, means with the same letter do not differ significantly according to the Bonferroni mean separation test.*

3.1.2 Subzone/variant–specific research and verification outcomes regarding allowable density We proposed adjustments to the allowable density of countable broadleaves for individual subzones/variants based on the research that is summarized in Table 3, and then confirmed that it was appropriate to apply that research at a landscape level through verification sampling. In the following subsections, we describe our rationale and final recommendations by subzone/variant.

SBPSxc and IDFdk4 The SBPSxc (~1.1 million ha) and the IDFdk4 (~370 000 ha) are relatively low-productivity ecosystems that dominate the Chilcotin plateau west of the Fraser River. Together, these ecosystems represent 29% of the Williams Lake TSA. In 2008, when the Working Group first convened, free-growing guidelines for the SBPSxc and IDFdk4 made it necessary to brush aspen on most sites where it occurred. However, foresters working in these ecosystems thought that the competitive ability of aspen was so low that it should perhaps not even be considered a deleterious species. By 2008, EP1152 results had confirmed that trembling aspen was less competitive with lodgepole pine in the SBPSxc than in either the IDFdk3 or SBSdw1/SBSdw2, and that there was no apparent threshold associated with vigour reductions in the SBPSxc (Newsome et al. 2012). Consultation with the Cariboo Region ecologist[2] confirmed that the SBPSxc and IDFdk4 climates were similar enough that research findings for the SBPSxc could logically be extended to the IDFdk4.

Early in the Working Group process, a rationale document for the SBPSxc and IDFdk4 (Misener 2009[3]) was prepared at the request of the District Managers[4] who were responsible for areas covered by these biogeoclimatic units. The report provided a rationale for change to current free-growing guidelines from a number of perspectives, and demonstrated that proposed changes were consistent with the Timber Supply Review, as defined by FRPA test 5 (Section 26, *Forest and Range Practices Act* 2003). It argued convincingly that the substantial benefits to forest health that were expected to be realized following a reduction in biologically unnecessary brushing far outweighed any minor risks to timber supply. Information subsequently collected by the Working Group confirmed this early analysis (Misener 2009[5]).

Free-growing guidelines that were in place in 2008 specified a maximum of 1000 countable broadleaf trees per hectare for mesic or drier site series of the SBPSxc and IDFdk4, and a maximum of 400 countable broadleaves per hectare on wetter site series (Table 4). On the basis of the Misener (2009[6]) work and the EP1152 research and verification sampling results described below, we recommended that aspen be considered a non-deleterious species in the SBPSxc and IDFdk4.

2 R. Coupé (retired), Research Ecologist, Cariboo Region, B.C. Ministry of Forests, Lands and Natural Resource Operations, pers. comm., 2009.

3 Misener, B. 2009. Supporting rationale document, Central Cariboo and Chilcotin Forest Districts, IDFdk4 and SBPSxc District policy. B.C. Min. For. Range, Williams Lake, B.C. Unpubl. rep.

4 Michael C. Pedersen, District Manager, Chilcotin Forest District; Al Balogh, District Manager, Central Cariboo Forest District.

5 Misener, B. 2009. Supporting rationale document, Central Cariboo and Chilcotin Forest Districts, IDFdk4 and SBPSxc District policy. B.C. Min. For. Range, Williams Lake, B.C. Unpubl. rep.

6 Ibid.

TABLE 3 *Research results related to the adjustment of lodgepole pine free-growing guidelines concerning allowable broadleaf tree density*

Subzone/variant	Adjustment	Study[a]	Key results and interpretation
SBPSxc/IDFdk4	Aspen is non-deleterious	Clusko variable density study (EP1152.04)	• At a stand age of 18 years, there were no significant treatment effects on lodgepole pine height or leader length (Table 5). • There were no significant differences between the 1000 tall-aspen[b]/ha treatment and higher-density treatments (Table 5). Although pine had significantly larger stem diameter in the complete removal treatment (0 stems/ha) than in the uncut control from ages 13 to 18 years, the low height/diameter ratio and bushy form of the open-grown trees was not considered a positive attribute. • At age 18, pine had high survival and good vigour (Figure 6). • The difference in height between aspen and pine decreased between stand ages 11 and 18 years, and the density of tall-aspen also decreased during this time period. Together, these results indicated that pine was growing through the aspen canopy (Figure 5).
IDFdk3	3000 stems/ha for mesic and drier site series	Moffat and Meldrum[c] retrospective studies (EP1152.01)	• Vigour of 15- to 19-year-old pine at Moffat and Meldrum did not begin to decline until tall-aspen density was ≥ 5000 stems/ha (Newsome et al. 2003). • There was a trend of decreasing lodgepole pine diameter growth as tall-aspen density increased from 2000 to 5000 stems/ha in 15- to 19-year-old stands at the Moffat and Meldrum sites (data combined); however, the diameter of pine growing among aspen did not consistently differ significantly from that of pine that were free of aspen (0 stems/ha) until tall-aspen density was ≥ 5000 stems/ha (Newsome et al. 2003). • When the stand at Moffat was 31 years old, survival and the proportion of original tagged pine that were in good or fair vigour was higher in neighbourhoods with 2000–4000 tall-aspen/ha than 0–1000 tall-aspen/ha (Figure 11b). • At age 31 years at Moffat, although there were minor trends of declining pine size with increasing aspen density, there were no significant differences in pine height, diameter, or stem volume between tall-aspen density classes of 0–9000 stems/ha (Figure 12). • At a stand age of 31 years, the average aspen–pine height ratio at Moffat was only slightly > 1.25 in density classes up to 8000 tall-aspen/ha (Figure 13a). The aspen–pine height ratio decreased by approximately 20% in tall-aspen density classes up to 5000 stems/ha between ages 25 and 31 years (Figure 13b); this suggests that pine would gradually grow through the aspen canopy where tall-aspen density was ≤ 5000 stems/ha.
		Meldrum variable density study (EP1152.03)	• There were no significant differences in lodgepole pine height or diameter between any of the aspen density treatments at Meldrum at ages 6–20 years (Table 7). At age 14 years, although the height/diameter ratio was significantly lower where there were no neighbouring aspen (0 stems/ha) than in the uncut control, there were no differences between density treatments ranging from 0 to 4000 stems/ha. • Tall-aspen density in the uncut control decreased from approximately 14 000 stems/ha at age 6 years to < 3000 stems/ha at age 20 years (Figure 10). Both aspen mortality and reduced height growth of aspen relative to that of pine appear to have contributed to this phenomenon; at age 20 years, approximately one-half of the aspen that had achieved diameter at breast height (dbh) ≥ 2 cm in growth and yield plots in the 1000, 2500, and 4000 stems/ha treatments and the uncut control had some form of critical stem damage (Table 9). • Because pine was growing through the aspen canopy by age 10 years in the nominal 4000 stems/ha treatment (Figure 10), existing data were reorganized to allow for a focussed analysis of actual density classes ranging from 0 to 4000 stems/ha. Results of this analysis are summarized in Table 8.

SBSdw1/SBSdw2	1000 stems/ha	Hayfield and Two-mile retrospective studies (EP1152.01)	• In naturally regenerated pine-aspen mixtures, lodgepole pine height and diameter were similar at tall-aspen densities of 0 and 1000 stems/ha but declined steeply between densities of 1000 and 2000 stems/ha; this trend was clear at stand ages of 18–19 years (Newsome et al. 2003), and continued to be evident at stand ages of 33–34 years (Figure 15a, b). • The vigour of 18- to 19-year-old pine declined where tall-aspen density was ≥ 2000 stems/ha (Newsome et al. 2003), and this trend continued to a stand age of 33–34 years (Figure 16). • At age 33–34 years, pine was growing through the aspen canopy where 1000 tall stems/ha were present but not where density was higher; at a tall-aspen density of 1000 stems/ha, the average aspen–pine height ratio decreased by about 10% between ages 26–27 and 33–34 years (Figure 17).
		McKinley variable density study (EP1269.02)	• Nine years after density treatments of 0 to > 2800 tall-aspen stems/ha were installed, there were no significant effects on 20-year-old lodgepole pine height, diameter, or stem volume (Figure 18).
		Tyee variable radius study (EP1152.02)	• This study was not originally designed to examine density effects; to provide information about density effects, individual pine were assigned to density classes according to the number of aspen that were > 125% their height at a stand age of 12 years. Aspen height had been somewhat compromised due to light early moose browsing at the Tyee site. • At age 20, pine height was relatively unaffected by neighbouring aspen presence (Figure 19a). Pine tended to have significantly smaller diameter and stem volume where aspen was present than where it was absent, but there were only minor differences where aspen density ranged from 1000 to 4000 stems/ha (Figure 19b, d). • On average, pine at the Tyee site outgrew aspen at approximately age 15 (Figure 1), and we expect that minor size differences between the density classes will gradually disappear.
		Pine Ridge study (EP1080)	• At age 22, there was a weak significant trend of declining pine diameter (dbh) with increasing aspen density ($p = 0.02$) and aspen basal area ($p = 0.03$) over densities ranging from 500 to 5000 stems/ha. The effect was driven mainly by densities > 1000 stems/ha. • Lodgepole pine averaged 94% as tall as aspen in the light aspen treatment (average 1360 stems/ha) at age 22 years.
		Adaptive management variable density study (EP1152.09)	• Thirteen- to 14-year-old lodgepole pine that was growing among 1000 aspen/ha that was > 1.25 times the pine height (brush–conifer ratio of 1.25) had significantly greater annual height growth and significantly less annual ground-level diameter growth than pine that was growing in neighbourhoods with no aspen (0 stems/ha) (Figure 20a, b). There were no differences in pine height or diameter growth between the 1000, 2000, and ≥ 3000 aspen stems/ha density classes. Individual tree volume was statistically similar across density classes (Figure 20c).
SBPSmk	1000 stems/ha	Adaptive management variable density study (EP1152.09)	• Twelve- to 15-year-old lodgepole pine that was growing among 1000 aspen/ha that was > 1.25 times the pine height (brush–conifer ratio of 1.25) showed a non-significant trend of increasing annual height growth relative to pine in neighbourhoods with no aspen (0 stems/ha) (Figure 23a). The difference in height growth was significant when the 2000 and 0 stems/ha density classes were compared. Annual ground-level diameter growth was significantly less in aspen density classes ≥ 1000 stems/ha than in the 0 stems/ha density class (Figure 23b), but there were no differences in individual stem volume between the 0, 1000, and 2000 stems/ha aspen classes (Figure 23c).

a Refer to Table 1 for descriptions of the individual studies.

b "Tall-aspen" are as tall as or taller than the crop conifer.

c The Meldrum retrospective study was destroyed by the mountain pine beetle and did not contribute data after the stand was 19 years old.

TABLE 4 *Previous[a] and revised free-growing guidelines for lodgepole pine in the SBPSxc and the IDFdk4*

Guideline	Subzone/ variant	Site series	2002–2011	Following 2011 revision
Conifer–brush ratio (brush–conifer ratio in brackets)	SBPSxc	All	150% (0.67)	n/a (non-deleterious)
	IDFdk4		125% (0.80)	
Allowable number of occupied quadrants within 1-m radius	SBPSxc/ IDFdk4	All	1	
Definition of potentially free-growing tree	SBPSxc/ IDFdk4	All	Broadleaf vegetation exceeds conifer height in 1 quadrant	
Definition of countable broadleaf	SBPSxc/ IDFdk4	All	Taller than median height of potentially free-growing trees	
Allowable number of countable broadleaf trees per 50-m^2 plot	SBPSxc	01, 02	5 (1000 stems/ha)	
		03, 04, 05, 06	2 (400 stems/ha)	
	IDFdk4	01, 02, 03, 04, 05, 06, 07	5 (1000 stems/ha)	
		08, 09, 10	2 (400 stems/ha)	

a As described in B.C. Ministry of Forests (2002).

Research results The Clusko variable density study (EP1152.04) provides the basis for our recommended changes to free-growing guidelines for the SBPSxc, and by extension, the IDFdk4 (Newsome et al. 2006a). The Clusko stand was 11 years old when EP1152.04 was initiated in 2001; at that age, there were approximately 10 000 tall-aspen/ha in uncut plots, and they averaged 2.5 times taller than crop pine. By the time the stand was 18 years old (2008), it was obvious that lodgepole pine was growing through the aspen canopy; tall-aspen density had decreased to approximately 2500 stems/ha, and on average, these aspen were 1.4 times taller than pine (Figure 5). There were no significant differences in lodgepole pine height or leader length between the various levels of aspen retention at age 18 years (Table 5). Although there were ongoing significant differences in pine stem diameter and height/diameter ratio between the complete removal treatment and the uncut control, neither of these treatments differed significantly from treatments where 1000 or 2500 tall-aspen/ha had been retained. Almost all pine survived to age 18 years, and most had good or fair vigour (Figure 6). There was a very minor decline in vigour in the uncut control relative to the other treatments, but approximately one-half of the decline was related to factors other than aspen presence (mainly competition from other lodgepole pine and foliar disease).

Overall, these findings indicated that aspen, even at very high densities, was not a serious competitor with lodgepole pine at the Clusko site. The rapid decline in tall-aspen density demonstrated that pine was growing through the canopy and out-competing neighbouring aspen. Lodgepole pine had significantly smaller stem diameter and significantly higher height/diameter ratio in the uncut control than in the broadcast removal treatment at Clusko, but we did not judge that this would have negative implications for long-term stand development under the low-productivity conditions of the Chilcotin Plateau (age 50 site index of 13.7 m) (B.C. Ministry of Forests, Lands and Natural Resource Operations 2013). Lodgepole pine height/diameter ratios were as low as 43–55 in the broadcast aspen removal treatment, and they tended to be associated with a squat, branchy growth habit. Observations by researchers and operational staff suggested that the increase in lodgepole pine height/diameter

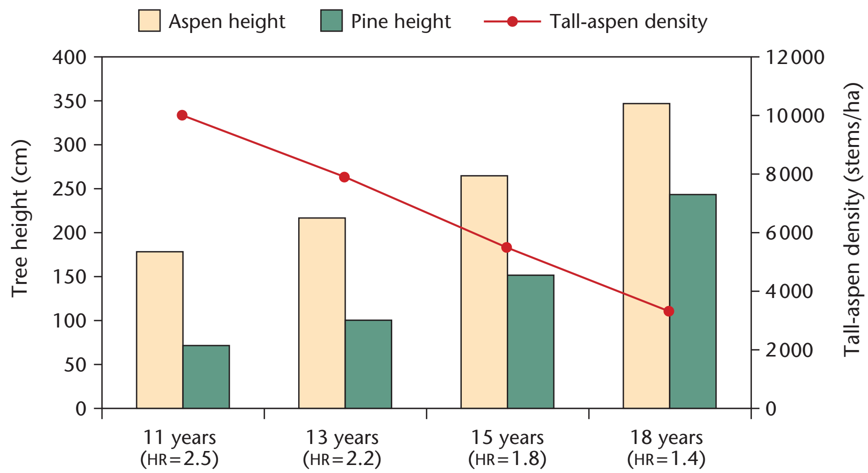

FIGURE 5 *Trends in aspen height, lodgepole pine height, and tall-aspen density in untreated control plots at Clusko (EP1152.04) between stand ages 11 years (2001) and 18 years (2008). HR is aspen–pine height ratio.*

TABLE 5 *Mean[a] size of crop lodgepole pine at Clusko (EP1152.04) in aspen removal treatments in 2001 (immediately following treatment [pine age 11]), 2003 (2 years post treatment [pine age 13]), 2005 (4 years post treatment [pine age 15]), and 2008 (7 years post treatment [pine age 18])*

		Treatment					
	Year	0 tall-aspen/ha	1000 tall-aspen/ha	2500 tall-aspen/ha	Aspen removed in 1-m radius	Uncut control	*p*-value[b]
Height (cm)	2001	74 ± 7	68 ± 7	73 ± 6	73 ± 7	70 ± 7	0.96
	2003	103 ± 7	95 ± 7	103 ± 6	99 ± 7	99 ± 7	0.92
	2005	158 ± 8	144 ± 9	158 ± 9	149 ± 8	150 ± 9	0.71
	2008	257 ± 10	237 ± 10	257 ± 10	247 ± 10	239 ± 10	0.50
Leader length (cm)	2001	16 ± 1	16 ± 1	17 ± 1	16 ± 1	16 ± 1	0.87
	2003	16 ± 1	14 ± 1	15 ± 1	14 ± 1	15 ± 1	0.34
	2005	33 ± 1	30 ± 1	31 ± 1	30 ± 1	29 ± 1	0.19
	2008	36 ± 1	34 ± 1	36 ± 1	36 ± 1	33 ± 1	0.20
Ground-level diameter (cm)	2001	1.37 ± 0.09	1.27 ± 0.09	1.40 ± 0.09	1.34 ± 0.09	1.34 ± 0.09	0.86
	2003	2.37 ± 0.11 a	1.99 ± 0.11 ab	2.12 ± 0.11 ab	1.98 ± 0.11 ab	1.86 ± 0.11 b	**0.04**
	2005	3.50 ± 0.10 a	2.90 ± 0.10 ab	3.20 ± 0.10 ab	2.90 ± 0.10 ab	2.80 ± 0.10 b	**0.01**
	2008	4.80 ± 0.20 a	4.10 ± 0.20 ab	4.50 ± 0.20 ab	4.10 ± 0.20 ab	3.90 ± 0.20 b	**0.03**
Height/ ground-level diameter ratio (cm/cm)	2001	55 ± 2	53 ± 2	52 ± 2	54 ± 2	52 ± 2	0.89
	2003	43 ± 2 a	47 ± 2 ab	49 ± 2 ab	50 ± 2 ab	53 ± 2 b	**0.01**
	2005	45 ± 2 a	49 ± 2 ab	50 ± 2 abc	52 ± 2 bc	55 ± 2 c	**0.002**
	2008	54 ± 2 a	58 ± 2 ab	58 ± 2 ab	61 ± 2 b	63 ± 2 b	**0.008**

a Values are presented as mean ± 1 standard error. Values for 2001, 2003, and 2005 are from Newsome et al. (2010); values for 2008 have not previously been published.

b Values in **bold** are significant at *p*-values ≤ 0.05 according to analysis of variance. Means are assigned different letters if they are significantly different within the given year according to the Bonferroni test.

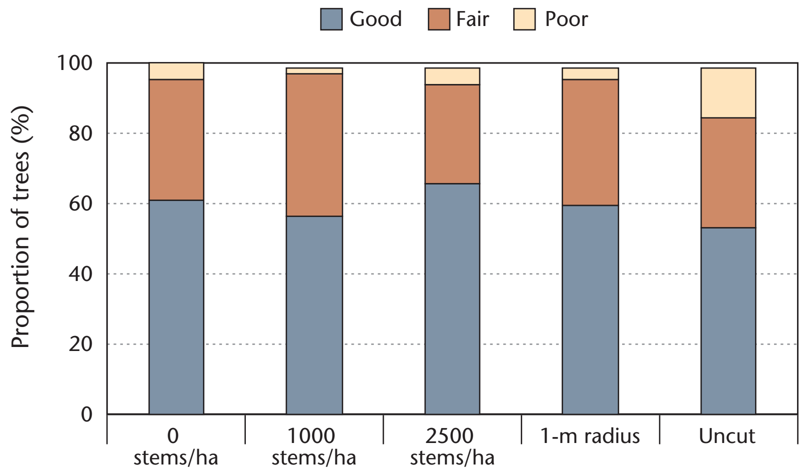

FIGURE 6 *Lodgepole pine survival (total bar height) and vigour at a stand age of 18 years (2008) in aspen removal treatments at the Clusko research site (EP1152.04). Vigour categories are defined in Appendix 1.*

ratio (up to an average of 63 in the uncut control) that accompanied aspen retention was likely to have a positive effect on long-term tree form and stand development. The very small vigour loss that was associated with aspen presence in the uncut control was considered acceptable, especially considering the potentially greater risk that was associated with manual cutting-related damage (Hart and Comeau 1992). We concluded that even high-density aspen was having negligible negative effects on lodgepole pine performance at Clusko.

Verification results We did not target a specific density range for verification sampling in the SBPSxc and IDFdk4 because research results had suggested that aspen was non-deleterious at all densities, and therefore had no density threshold. With the exception that the number of "no aspen" plots was limited to three per site, we sampled pine that met our selection criteria as we encountered them along transects, regardless of the number of tall-aspen that were present within their 1.78-m radius neighbourhoods. Variables that described aspen–pine competitive relationships at individual SBPSxc or IDFdk4 verification sites were compared with those at Clusko.[7]

Average height of the three tallest aspen (or fewer for plots where tall-aspen density was < 3) did not significantly exceed that of Clusko at any of our SBPSxc or IDFdk4 verification sites (Figure 7a). Where significant differences did occur, they consistently showed that aspen at Clusko was taller than aspen at the randomly selected operational sites.

Verification results also confirm that aspen at average operational sites was not growing faster relative to pine than it was at Clusko. *T* tests indicated that, at verification sites in both the SBPSxc and IDFdk4, the aspen–pine height growth ratio was either significantly lower than, or statistically similar to, that of Clusko. At verification sites, aspen was consistently growing more slowly than pine regardless of stand age (i.e., ratios were < 1) (Figure 7b). In contrast, at the Clusko research site, the height growth ratio between ages 11

7 Using *t* tests for individual comparisons; for each comparison, Clusko data were used that had been collected during the measurement year when age most closely matched that of the verification site.

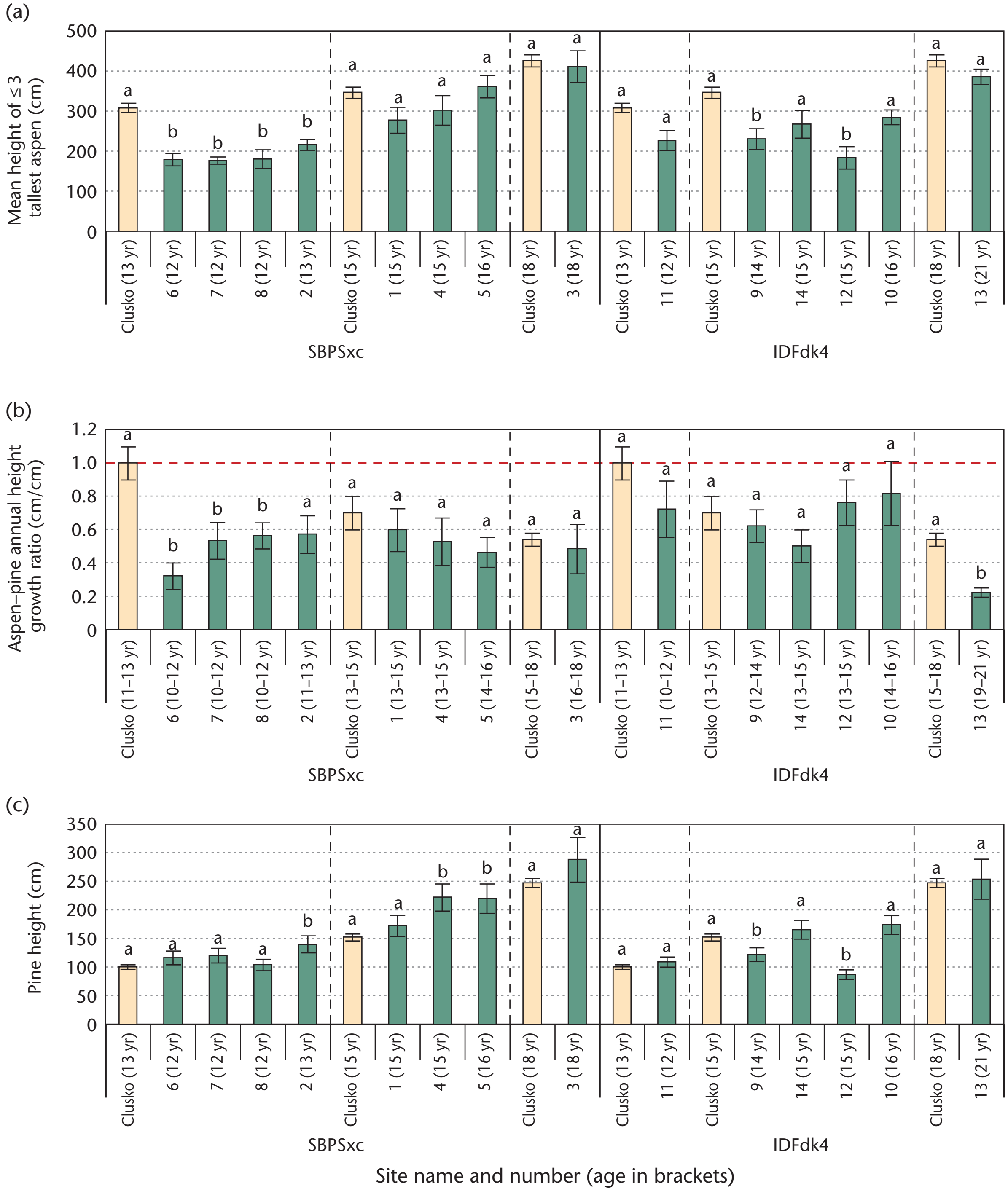

FIGURE 7 *Comparison of Clusko at ages 13, 15, and 18 years (pale yellow bars) with individual SBPSxc and IDFdk4 verification sites of similar age (dark green bars): (a) mean height of the ≤ 3 tallest aspen, (b) mean annual height growth ratio for aspen versus lodgepole pine (the dashed line at a height ratio of 1 indicates aspen and pine are growing at the same rate), and (c) lodgepole pine height. In each figure, verification sites that have a different letter from that of Clusko in the same age grouping (as delineated by dashed vertical lines) are significantly different from Clusko according to the* t *test (verification sites were not tested against each other). Error bars are one standard error.*

and 13 years was approximately 1, indicating that aspen and pine were growing at about the same rate. Beyond age 13, the height growth ratio at Clusko also dropped below 1, which demonstrated that aspen growth at the research site was slowing down relative to that of pine.

Mean height of lodgepole pine sampled at each of the verification sites was compared with that of Clusko (when Clusko was of similar age) to ensure that our interpretations were not confounded by abnormally good pine growth at the research site. For the SBPSxc, our findings confirmed that pine at the verification sites was, if anything, taller than that at Clusko (Figure 7c). Lodgepole pine at IDFdk4 verification sites tended to be shorter than that at SBPSxc verification sites, possibly due to slightly drier site conditions. There were two IDFdk4 sites where pine was significantly shorter than pine at Clusko, but since aspen at those sites also tended to be shorter, this result did not affect our conclusions.

Because we were suggesting that aspen be declared a non-deleterious species based on Clusko results, we wanted to confirm that representative tall-aspen density at average operational sites was not higher than that of uncut plots at Clusko. We anticipated that tall-aspen density would be higher at the research site due to the statistical requirement for random allocation of experimental treatment plots. For the Clusko experiment, this meant that tall-aspen had to be present at a minimum density of 2500 stems/ha (the highest treatment density we tested) across the entire study area. This was a difficult criterion to meet, and it resulted in the selection of a site with healthy, apparently aggressive aspen; this phenomenon is illustrated with regard to dominant aspen height in Figure 8a. Statistical comparison confirmed that tall-aspen densities at individual SBPSxc and IDFdk4 verification sites were, in all cases, either lower than that of Clusko or statistically similar (Figure 9). There were no verification sites where tall-aspen density was significantly higher than that of Clusko; rather, at most sites, tall-aspen density tended to be less than one-half that of untreated control plots at Clusko, regardless of stand age. The average density of tall-aspen was declining with stand age at Clusko because pine was gradually growing through the canopy (Figure 5). The verification sites were sampled at a single point in time, but since pine was growing faster than aspen at these sites (i.e., aspen–pine height growth ratios were < 1), we assume that if repeated measurements were conducted, there would be similar declines in tall-aspen density over time as we observed at the Clusko research site.

In conclusion, the research and verification work we conducted supports a decision to declare aspen a non-deleterious species on mesic and drier sites in the SBPSxc and IDFdk4. We found no evidence that aspen was more competitive with pine at typical operational sites in the SBPSxc or IDFdk4 than at the Clusko research site. If anything, aspen that was representative of operational site conditions was less competitive with pine than aspen at Clusko. Our research did not extend to wetter than mesic site series, which, according to Steen and Coupé (1997), are small and localized, and occur primarily at the fringe of wetlands and along stream channels. Such areas have value as wildlife habitat and would generally not have been brushed based on free-growing guidelines that were in place in 2008. Following consultation with Working Group government specialists, we recommended that aspen be declared non-deleterious in wetter site series as well as those that are mesic and drier. In

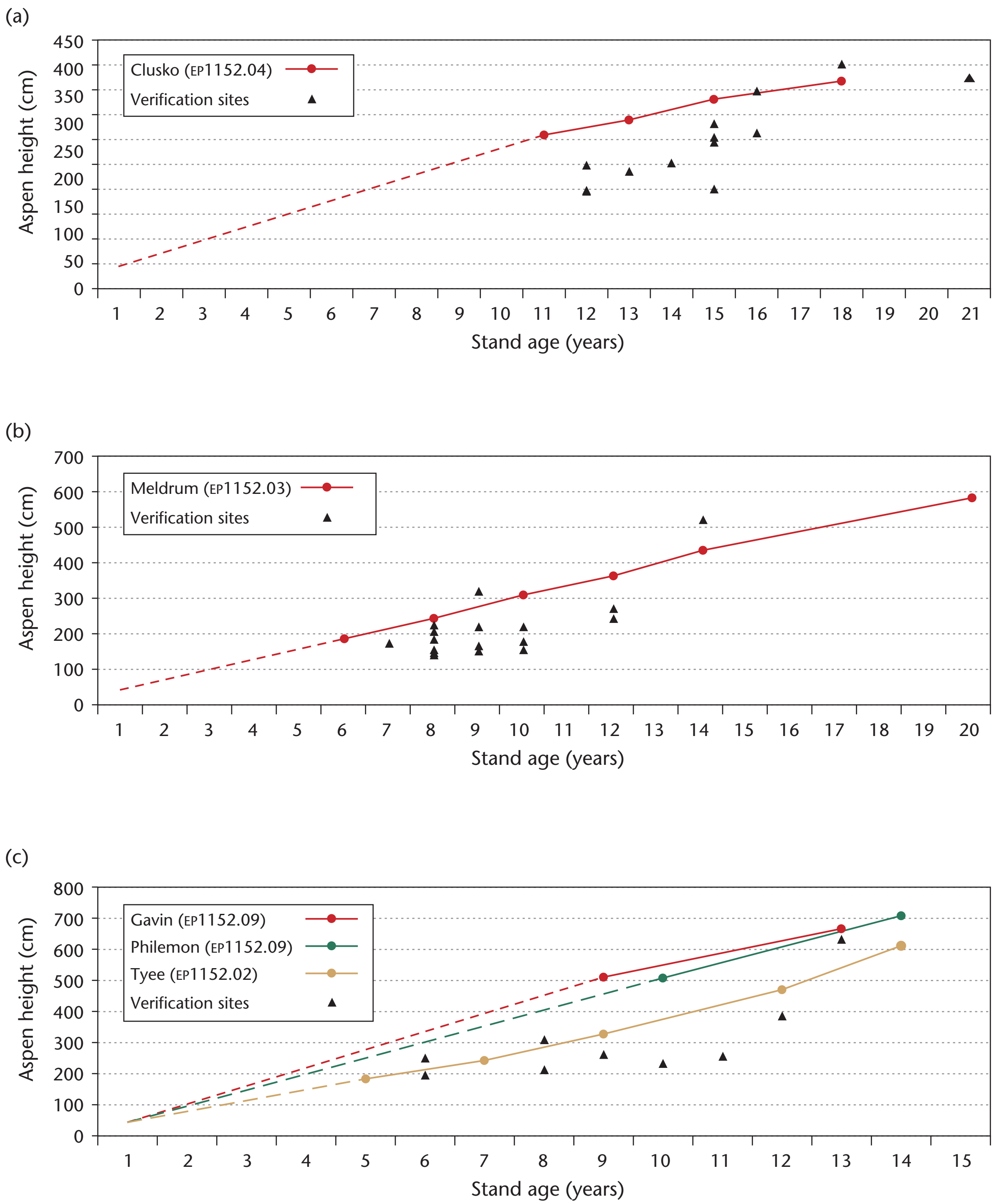

FIGURE 8 *Height of the ≤ 3 tallest aspen in (a) the uncut control at Clusko versus SBPSxc verification sites (no density limits), (b) the uncut control at Meldrum versus IDFdk3 verification sites in 1000–3000 tall-aspen/ha density classes, and (c) the uncut controls at the Gavin, Philemon, and Tyee research sites versus SBSdw1/SBSdw2 verification sites in 1000–2000 tall-aspen/ha density classes. For research sites, markers represent measurement years, solid lines represent average growth between measurements, and dashed lines represent estimated growth based on aspen height of 40 cm in year 1.*

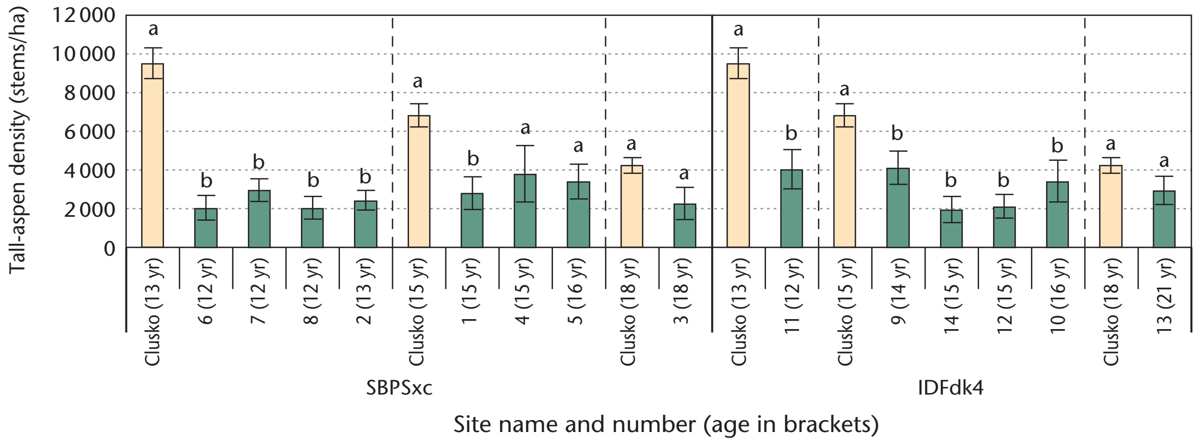

FIGURE 9 *Comparison of tall-aspen density at Clusko (EP1152.04) at ages 13, 15, and 18 years (pale yellow bars) versus SBPSxc and IDFdk4 verification sites of similar age (dark green bars). Verification sites that have a different letter from that of Clusko in the same age grouping (as delineated by dashed vertical lines) are significantly different from Clusko according to the* t *test (verification sites were not tested against each other). Error bars are one standard error.*

2011, the Chilcotin and Central Cariboo District Managers declared aspen a non-deleterious species in all SBPSxc and IDFdk4 site series (Table 4).

IDFdk3 The IDFdk3 occupies approximately 895 000 ha in the Cariboo Region, predominantly in the Williams Lake and 100 Mile TSAs. Since 1980, approximately 28% (251 000 ha) of the total Cariboo Region IDFdk3 area has been harvested. Policies related to aspen management in the IDFdk3 are particularly important because, in addition to its size and contribution to the timber harvesting land base (THLB), thousands of hectares in this biogeoclimatic variant were destroyed by the wildfires of 2010; these required reforestation and hence, will also have to meet free-growing obligations. When the Working Group began considering recommendations for the IDFdk3 in 2010, free-growing guidelines specified an upper limit of 1000 countable aspen/ha for mesic or drier site series and 400 stems/ha in wetter site series (Table 6). On the basis of research and verification results, we recommended that the allowable density of countable aspen be increased to 3000 stems/ha for mesic or drier site series and to 1000 stems/ha for wetter than mesic site series.

Research results Key research results and rationale points that support our proposed allowable density adjustments for the IDFdk3 are presented in Table 3. The Meldrum variable density study (EP1152.03) is the cornerstone experiment for these recommendations (Newsome et al. 2004a); it was established on the basis of retrospective study results (EP1152.01) indicating that the tall-aspen density threshold for lodgepole pine diameter growth was in the range of 2000–5000 stems/ha (Newsome et al. 2003). To further investigate this finding, the Meldrum variable density study was established to compare pine performance at tall-aspen densities of 1000, 2500, and 4000 stems/ha with that of a total removal treatment (0 stems/ha) and an uncut control. The variable density treatments were installed when the Meldrum

TABLE 6 *Previous[a] and revised free-growing guidelines for the IDFdk3*

Guideline	Species[b]	Site series	2002–2013	Interim 2013–2015	Final 2015 revision[c]
Conifer–brush ratio (brush–conifer ratio in brackets)	Pl	All	125% (0.8)	80% (1.25)	80% (1.25)
	Fd	All	125% (0.8)	80% (1.25)	66% (1.5)
Allowable number of occupied quadrants within 1-m radius	All	All	1	1 or 2 adjacent	1 or 2 adjacent
Definition of potentially free-growing tree	Pl	All	Broadleaf vegetation exceeds conifer height in 1 quadrant	Broadleaf vegetation > 1.25 times the conifer height in 1 or 2 adjacent quadrants	Broadleaf vegetation > 1.25 (Pl) or 1.5 (Fd) times conifer height in 1 or 2 adjacent quadrants
	Fd	All			
Definition of countable broadleaf	Pl	All	Taller than median height of potentially free-growing trees	Taller than 1.25 times the median height of potentially free-growing trees	Taller than 1.25 (Pl) or 1.5 (Fd) times the median height of potentially free-growing trees
	Fd	All			
Allowable number of countable broadleaf trees per 50-m² plot	Pl	01, 02, 03, 04, 05, 06	5 (1000 stems/ha)	15 (3000 stems/ha)	15 (3000 stems/ha)
		07, 08, 09	2 (400 stems/ha)	2 (400 stems/ha)	5 (1000 stems/ha)
	Fd	01, 02, 03, 04, 05, 06	3 (600 stems/ha)	3 (600 stems/ha)	15 (3000 stems/ha)
		07, 08, 09	3 (600 stems/ha)	3 (600 stems/ha)	5 (1000 stems/ha)

a As described in B.C. Ministry of Forests (2002).

b Pl: lodgepole pine; Fd: Douglas-fir.

c The final 2015 guidelines presented in this table are based on use of the standard survey procedure rather than the alternative survey procedure presented in the *Silviculture Survey Procedures Manual* (B.C. Ministry of Forests, Lands and Natural Resource Operations 2016).

stand was 6 years old, and 8 years later, at age 14, there were no aspen-related declines in pine vigour or statistically significant growth reductions associated with the 1000, 2500, or 4000 stems/ha treatments relative to 0 stems/ha (Newsome et al. 2010) (Table 7). These results are somewhat confounded, however, by the fact that tall-aspen densities in all treatments decreased over time due to the more rapid height growth of pine than aspen. The 4000 stems/ha treatment was originally intended to represent a scenario where tall-aspen density exceeded the anticipated threshold for lodgepole pine growth; however, beyond age 10, the actual tall-aspen density in this nominal treatment was approximately 2500 stems/ha. Even in the uncut control, tall-aspen density declined from approximately 14 000 stems/ha at age 6 years to an average of about 5400 stems/ha at age 14 years (Figure 10). The phenomenon of lodgepole pine outgrowing aspen in the 4000 stems/ha treatment affected our ability to evaluate the effects of that level of aspen presence beyond age 10. This was a concern because although free-growing surveys are generally conducted as soon as pine trees achieve minimum height, in theory, free-growing does not legally have to be declared until age 20.[8]

To address this issue, and to further examine the implications of our universal recommendation of a brush–conifer ratio of 1.25 for lodgepole pine, we remeasured the Meldrum experiment in 2012 when the stand was 20 years old. In addition to analyzing for treatment effects (Table 7), we reorganized pine data into classes according to the density of neighbouring aspen that, at a stand age of 10 years (2002), had been at least 1.25 times taller than pine (i.e.,

8 *Forest and Range Practices Act*, Forest Planning and Practices Regulation (Section 44) www.bclaws.ca/Recon/document/ID/freeside/14_2004.

TABLE 7 *Mean[a] size of crop lodgepole pine in aspen density treatments at Meldrum (EP1152.03) from age 6 years (1998) to age 20 years (2012)*

Variable	Age (Years)	Tall-aspen density treatment (aspen stems/ha) 0	1000	2500	4000	Uncut control	*p*-value[b]
Height (cm)	6	115 ± 5	115 ± 5	112 ± 5	115 ± 5	113 ± 5	0.98
	8	145 ± 6	145 ± 6	140 ± 6	150 ± 6	143 ± 6	0.84
	10	199 ± 11	200 ± 11	189 ± 11	215 ± 11	204 ± 11	0.58
	14	341 ± 19	346 ± 19	330 ± 19	372 ± 19	340 ± 19	0.62
	20	608 ± 29	598 ± 29	596 ± 29	626 ± 29	575 ± 29	0.79
Ground-level diameter (cm)	6	1.54 ± 0.07	1.51 ± 0.07	1.47 ± 0.07	1.58 ± 0.07	1.51 ± 0.07	0.85
	8	2.29 ± 0.16	2.31 ± 0.16	2.09 ± 0.16	2.31 ± 0.16	2.01 ± 0.15	0.54
	10	3.41 ± 0.27	3.41 ± 0.27	2.98 ± 0.27	3.37 ± 0.27	2.96 ± 0.27	0.58
	14	6.00 ± 0.40	5.80 ± 0.40	5.30 ± 0.40	5.70 ± 0.40	4.80 ± 0.40	0.24
	20	10.30 ± 0.40	10.0 ± 0.40	9.60 ± 0.40	9.50 ± 0.40	8.20 ± 0.40	**0.04**[c]
Diameter at 1.3 m (dbh) (cm)	20	8.5 ± 0.4	8.4 ± 0.4	8.0 ± 0.4	8.0 ± 0.4	7.0 ± 0.4	0.10
Height/ground-level diameter ratio (cm/cm)	6	76 ± 4	77 ± 4	78 ± 4	74 ± 4	78 ± 4	0.96
	8	64 ± 4	65 ± 3	68 ± 3	66 ± 4	71 ± 3	0.51
	10	59 ± 3	60 ± 3	64 ± 3	65 ± 3	69 ± 3	0.15
	14	58 ± 2 a	61 ± 2 a	63 ± 2 ab	66 ± 2 ab	72 ± 2 b	**0.007**
	20	60 ± 3	61 ± 3	64 ± 3	68 ± 3	73 ± 3	**0.03**[c]

a Values are presented as mean ± 1 standard error. Values for ages 6–14 are from Newsome et al. (2010); values for age 20 have not previously been published.

b Values in **bold** are significant at *p*-values ≤ 0.05 according to analysis of variance. Means are assigned different letters if they are significantly different within the given year according to the Bonferroni test.

c Indicates the Bonferroni test was unable to separate means despite $p \leq 0.05$.

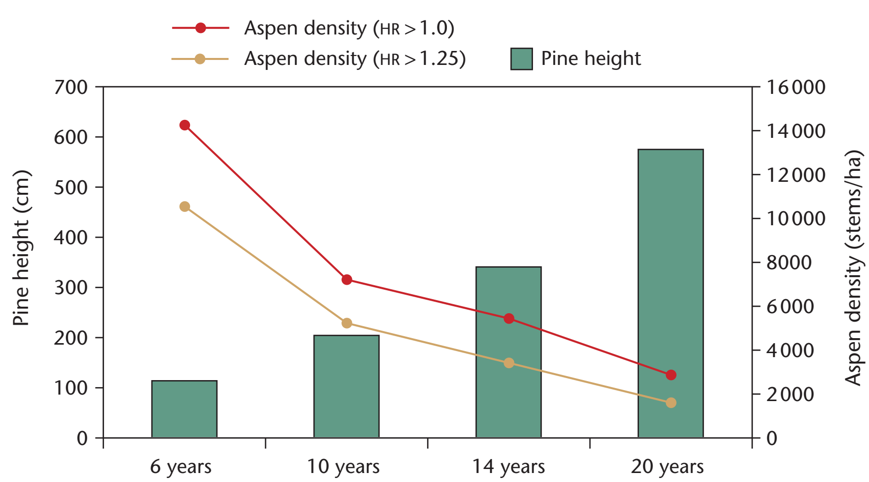

FIGURE 10 *Trends in lodgepole pine height (based on crop pine measurements), aspen density based on a brush–conifer height ratio (HR) > 1.0 , and aspen density based on a brush–conifer height ratio > 1.25 in uncut control plots in the Meldrum variable density study (EP1152.03) from age 6 years (1998) to age 20 years (2012).*

we used the brush–conifer ratio of 1.25 to define countable aspen). We then examined vigour and statistically compared pine growth responses in the 0, 1000, 2000, 3000, and 4000 stems/ha density classes. We were aware that this analysis was somewhat biased because a considerable proportion of pine assigned to the 3000 and 4000 stems/ha classes was from the uncut control treatment, and therefore was likely to have been subject to considerably higher densities of overtopping aspen prior to age 10 (Figure 10). We preferred to err on the conservative side, however, since we were considering a substantial increase in the allowable density of aspen in the IDFdk3. Key outcomes from this focussed analysis are presented in Table 8. Some declines in lodgepole pine vigour and growth were evident in the 4000 stems/ha class relative to 1000–3000 stems/ha (Table 8; Figure 11a), and on this basis, we recommended that the allowable density of countable aspen (defined according to the revised brush–conifer ratio of 1.25) should be 3000 stems/ha.

To further examine the long-term effects of 3000 tall-aspen stems/ha on lodgepole pine vigour and growth in the IDFdk3, the Moffat retrospective study (EP1152.01) was remeasured at a stand age of 31 years (2012). Crop lodgepole pine in that study had been assigned to aspen density classes based on the density of tall-aspen at age 16 years, and the data did not allow us to assign pine to density classes using the brush–conifer ratio of 1.25. At age 31 years, a higher proportion of crop pine survived and were in good or fair vigour in neighbourhoods with 2000–4000 tall-aspen/ha than in neighbourhoods with 0–1000 tall-aspen/ha (Figure 11b). There were no statistically significant differences in age 31 pine height, diameter, height/diameter ratio,

TABLE 8 *Outcomes for focussed analysis of pine vigour and growth performance in the IDFdk3 Meldrum variable density study (EP1152.03) in neighbourhood aspen densities of 0, 1000, 2000, 3000, and 4000 stems/ha (using the revised brush–conifer ratio of 1.25 to define countable aspen)*

Pine factor	**Outcome**
Vigour	• There were slight declines in pine vigour at aspen densities > 3000 stems/ha (Figure 11a); this supports increasing the allowable density of countable aspen to 3000 stems/ha rather than 4000 stems/ha.
Height	• There were no significant differences in pine height between aspen density classes of 0, 1000, 2000, or 3000 stems/ha, but pine was significantly taller in the 0 stems/ha class than in the 4000 stems/ha class; this supports increasing the allowable density of countable aspen to 3000 stems/ha rather than 4000 stems/ha.
Annual height growth	• There were no significant differences in annual height growth of pine between density classes; this supports increasing the allowable density of countable aspen to 4000 stems/ha.
Diameter	• Pine diameter was significantly larger in the 0 stems/ha class than in the 3000 stems/ha class, but there was no significant difference between the 1000 and 3000 stems/ha classes. • Pine diameter in the 0, 1000, and 2000 stems/ha classes was significantly greater than in the 4000 stems/ha class; this supports increasing the allowable density of countable aspen to 3000 stems/ha rather than 4000 stems/ha.
Height/ground-level diameter ratio	• Differences in the pine height/diameter ratio at Meldrum primarily reflect differences in diameter. • The ratio was significantly greater in the 3000 stems/ha class than in the 0 stems/ha class, but the difference between the 1000 and 3000 stems/ha classes was not significant; this supports increasing the allowable density of countable aspen to 3000 stems/ha rather than 4000 stems/ha.
Stem volume	• Differences in pine stem volume also primarily reflect diameter differences. Volume was significantly greater in the 0 stems/ha class than in the 3000 stems/ha class, but the difference between the 1000 and 3000 stems/ha classes was not significant. • This suggests that there may be reductions in individual stem volume with increasing retention of aspen; however, since annual height growth was similar across densities up to 4000 countable aspen/ha, we think relative volume differences between densities will decline with time as pine outgrow the aspen canopy.

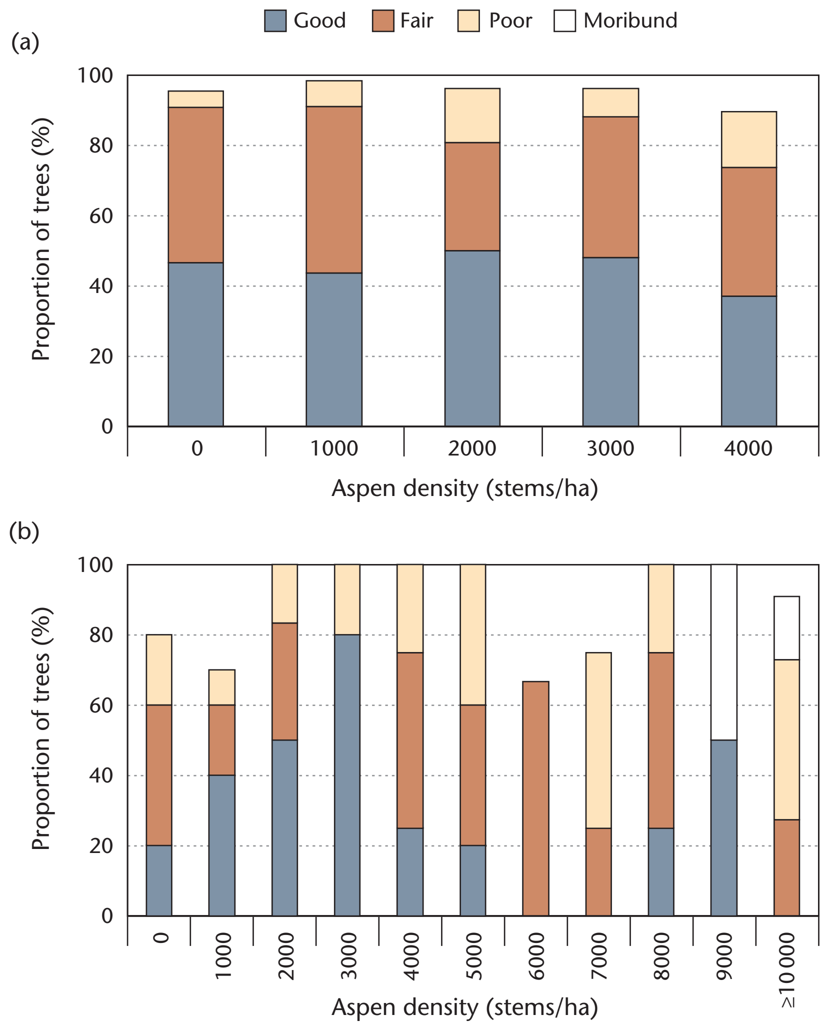

FIGURE 11 *Density effects on lodgepole pine survival (total bar height) and vigour at (a) the Meldrum variable density site (EP1152.03) at age 20 years in density classes up to 4000 stems/ha (density classes are based on the number of aspen that exceeded a brush–conifer height ratio of 1.25 at age 10 years), and (b) the Moffat site (EP1152.01) at age 31 years (density classes are based on the number of tall-aspen [i.e., aspen as tall as or taller than pine] at age 16 years). Vigour categories are defined in Appendix 1.*

or stem volume between the 0 stems/ha class and density classes up to 9000 stems/ha (Figure 12). As in the Meldrum variable density study (EP1152.03), pine at Moffat were gradually growing through the aspen canopy where tall-aspen density was ≤5000 stems/ha (Figure 13). The aspen–pine height ratio at the Moffat site decreased by approximately 20% between stand ages of 25 and 31 years, with the result that the ratio at age 31 years was only slightly greater than 1.25 in tall-aspen density classes as high as 8000 stems/ha.

The Meldrum variable density study (1152.03) and the Moffat retrospective study (EP1152.01) clearly indicated that aspen was not as strong a competitor in the IDFdk3 as had previously been thought, and that the apparent competitiveness of aspen decreased with stand age. To better understand factors that

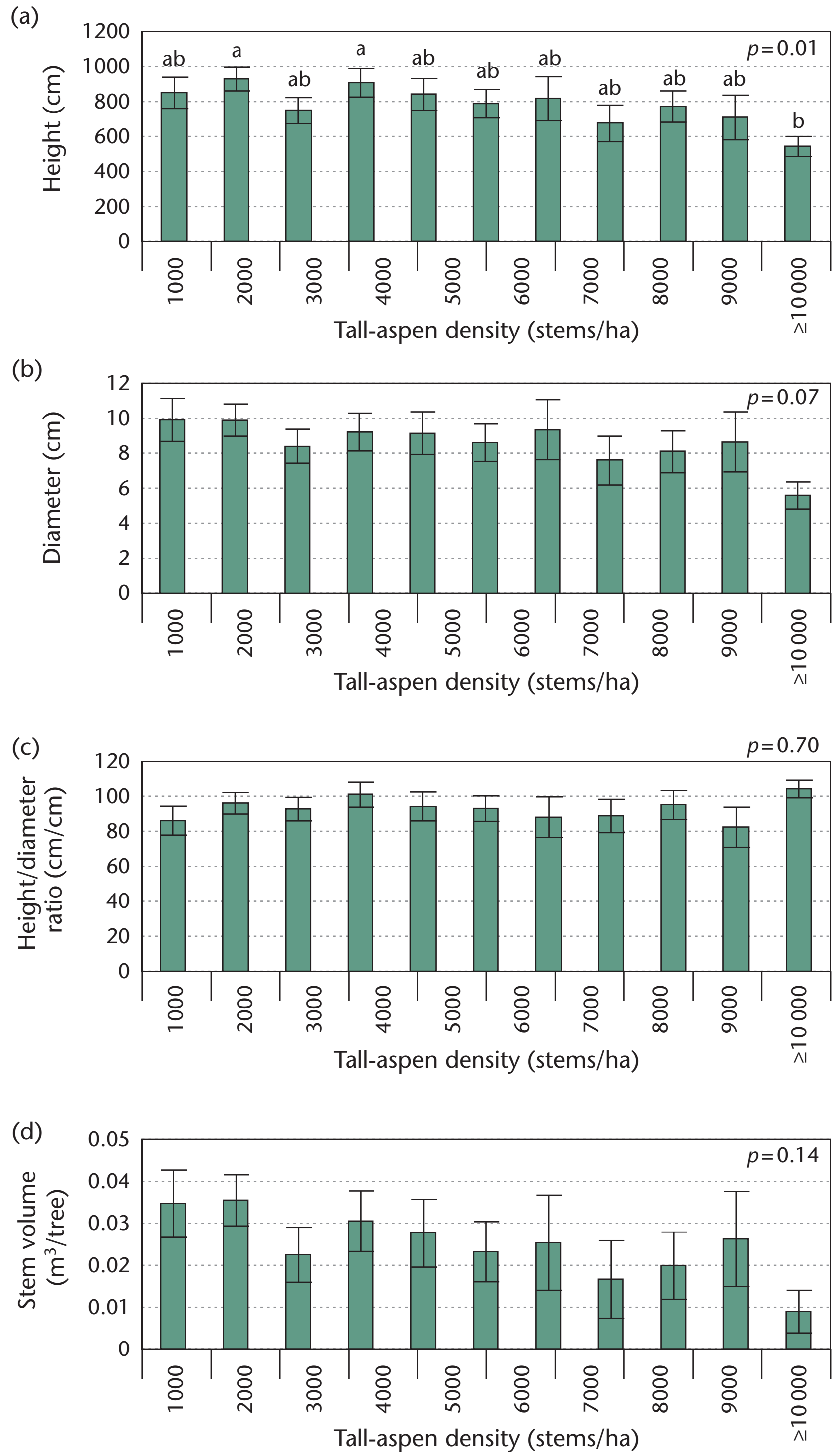

FIGURE 12 *Tall-aspen density effects on lodgepole pine (a) height, (b) diameter at 1.3 m (dbh), (c) height/dbh ratio, and (d) stem volume at the IDFdk3 Moffat site (*EP*1152.01) at age 31 years. Density classes were defined based on tall-aspen density at a stand age of 16 years (1997). Where* $p \leq 0.05$*, means that have the same letter do not differ according to the Bonferroni mean separation test.*

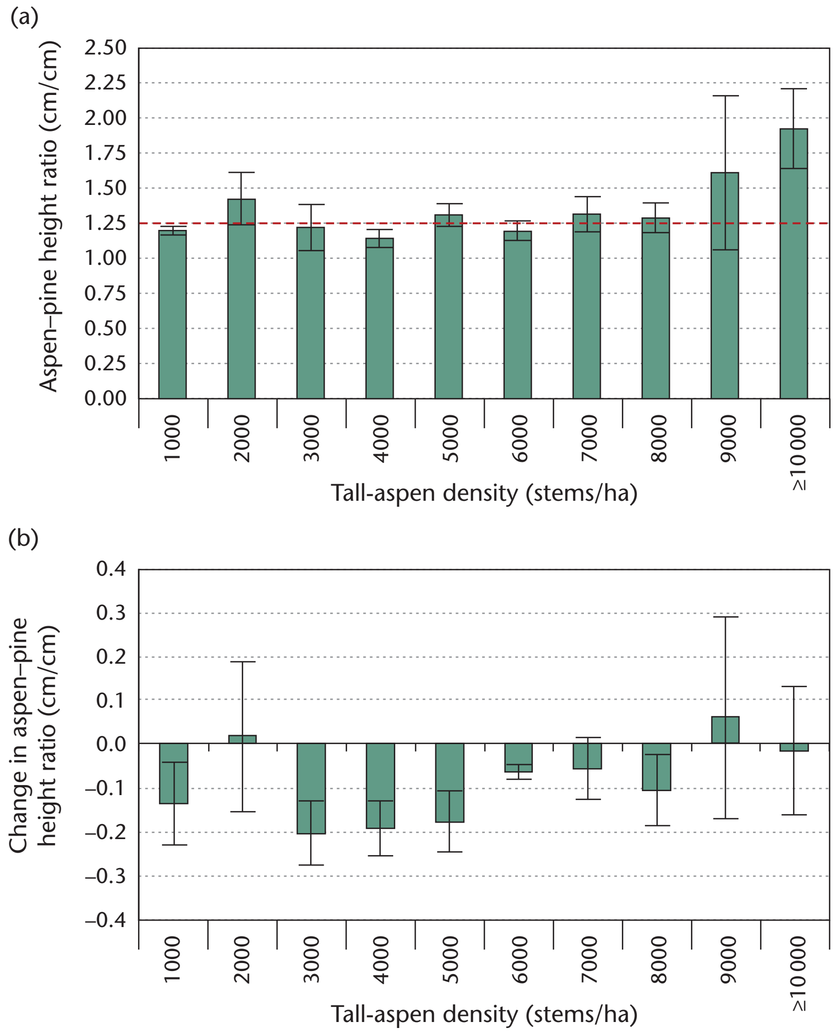

FIGURE 13 *Aspen–pine height relationships at the Moffat IDFdk3 site (EP1152.01): (a) aspen–pine height ratio at age 31 years (2012) (the dashed line indicates a brush–conifer ratio of 1.25, which defines countable aspen according to revised guidelines), and (b) change in aspen–pine height ratio between ages 25 and 31 years (from 2004 to 2012). Density classes were defined based on tall-aspen density at a stand age of 16 years (1997).*

affected aspen growth, we collected detailed aspen health data during the 2012 assessment of the Meldrum variable density study. Across all treatments, approximately one-half of the aspen that had achieved a minimum diameter at breast height (dbh) of 2 cm had some form of serious stem damage that appeared to be reducing its competitive ability (Table 9). Stem cankers were the most common type of damage observed, but a considerable proportion of aspen was simply being out-competed by pine for growing space. Very little research on damaging agents that affect juvenile aspen has been conducted.[9] Based on extensive observation during this project, however, we think the

9 D. Rusch, Regional Forest Pathologist, Cariboo Region, B.C. Ministry of Forests, Lands and Natural Resource Operations, pers. comm., 2011.

TABLE 9 *Percentage of live aspen stems (≥ 2 cm dbh) with critical stem damage[a] in growth and yield plots at the Meldrum variable density study (EP1152.03) in 2012*

	Tall–aspen density treatment (aspen stems/ha)				
Type of stem damage	**0[b]**	**1000**	**2500**	**4000**	**Uncut control**
Crooks/forks from canker disease	1.6	15.4	8.4	10.2	6.7
Stem wounds from canker disease	13.2	14.8	32.6	31.5	37.3
Leaning due to competition from other aspen	0.4	0.6	1.1	1.0	7.6
Leaning due to competition from pine	19.9	16.0	3.3	4.1	2.1
Total critical stem damage	**35.1**	**46.8**	**45.4**	**46.8**	**53.7**

a "Critical stem damage" is damage that assessors subjectively considered likely to seriously compromise the competitive ability of the aspen.

b Tall-aspen in the 0 stems/ha treatment in 2012 were suckers that originated following the cutting treatment.

damage levels observed at Meldrum were probably characteristic of juvenile aspen stands in the IDFdk3 rather than being due to a specific aspen health problem at that site. Juvenile aspen was extremely vigorous when the Meldrum variable density study was installed, as tends to be the case on research sites that meet the necessary criteria for random allocation of treatment plots. Figure 8b illustrates this with regard to dominant aspen height at Meldrum versus that of the verification sites.

Verification results Verification sampling was conducted to compare aspen–lodgepole pine height relationships at typical operational sites in the IDFdk3 with those observed in the Meldrum variable density study (Table 2). Our objective was to verify that the Meldrum experiment was not underestimating the competitive ability of aspen at representative operational sites that were distributed widely across the IDFdk3. We found that none of the 17 verification sites we sampled had significantly taller dominant aspen than Meldrum; mean height of the three tallest aspen (or fewer for plots where tall-aspen density was < 3) at verification sites was either statistically similar to that of Meldrum, or as more frequently was the case, was significantly less than that of Meldrum (Figure 14a). Most verification sites also had significantly lower aspen–pine height growth ratios than Meldrum (Figure 14b). The one exception was verification site 1 (12 years old), where the height growth ratio was significantly higher than it had been at Meldrum when the stand at that site was 12 years old; this appears to be an anomaly, however, since the aspen–pine height growth ratio for plots with 4000 tall-aspen/ha at this site did not differ significantly from that of Meldrum (result not presented). At the Meldrum site, pine grew more slowly than aspen until age 10, but this trend reversed, and by age 12–14 years, pine was increasing in height more quickly than aspen. We interpret the height growth ratio results to mean that at clearcut IDFdk3 sites, regenerated lodgepole pine will gradually grow through the aspen canopy where tall-aspen densities are ≤ 3000 stems/ha.

T tests that compared mean lodgepole pine height between individual verification sites and the Meldrum site showed that, at similar age, pine at some verification sites was shorter than that at Meldrum (Figure 14c). This difference may be partly due to Meldrum having been site prepared using a mechanical ripper tooth prior to planting; none of the verification sites had

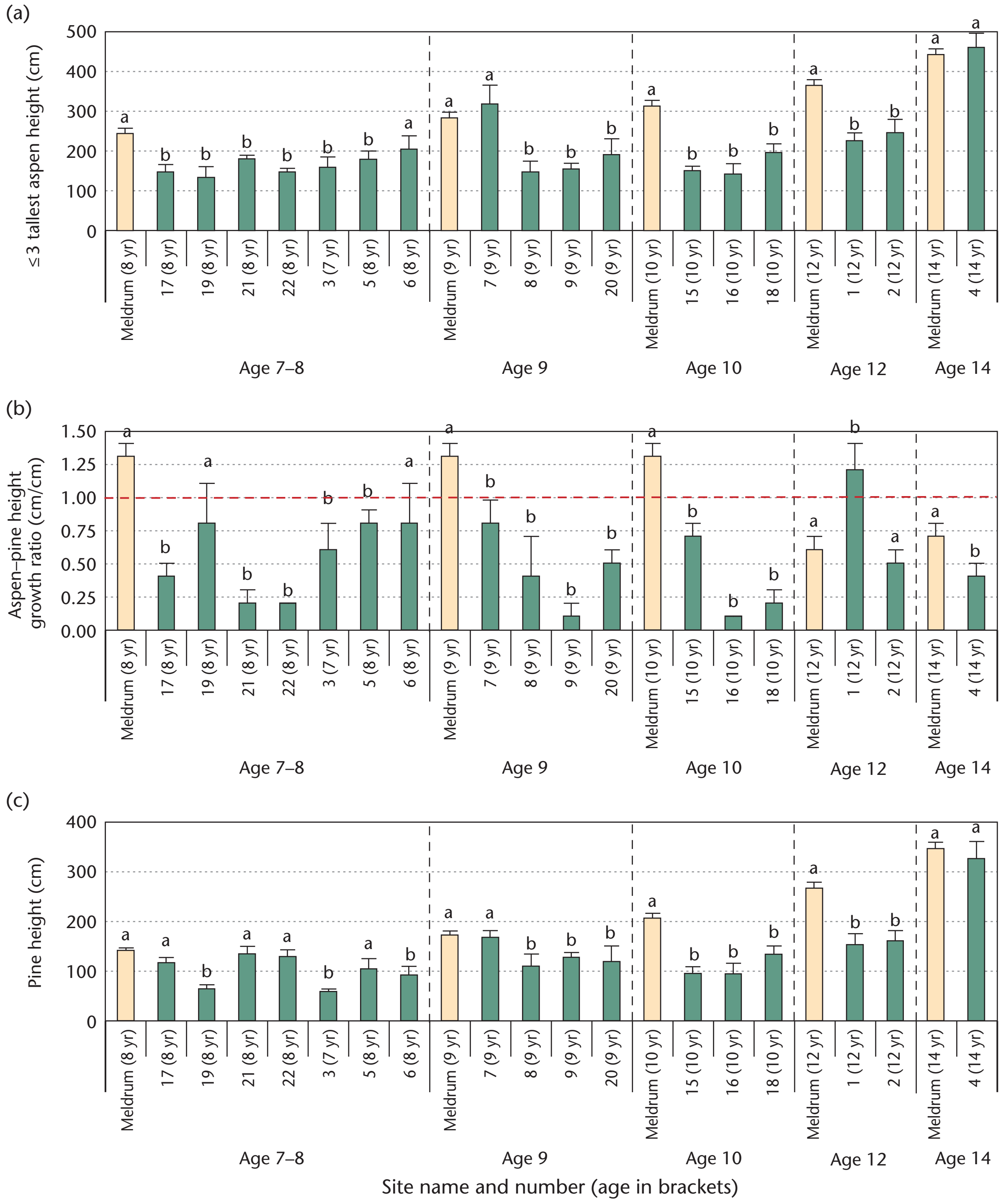

FIGURE 14 *Comparison of Meldrum (EP1152.03) results at ages 8, 9 (interpolated value), 10, 12 (interpolated value), and 14 years (pale yellow bars) with individual IDFdk3 verification sites of similar age (dark green bars): (a) mean height of the ≤ 3 tallest aspen, (b) mean annual height growth ratio for aspen versus pine (the dashed line at a height ratio of 1 indicates that aspen and pine are growing at the same rate), and (c) lodgepole pine height. In each figure, verification sites that have a different letter from that of Meldrum in the same age grouping (as delineated by dashed vertical lines) are significantly different from Meldrum according to the* t *test (verification sites were not tested against each other). Error bars are one standard error.*

received mechanical site preparation (except chain dragging on some sites) (Appendix 2). Nonetheless, we do not think the fact that pine was taller at the Meldrum site influenced our interpretations because aspen also tended to be taller than at the verification sites; in consequence, aspen–pine height relationships at verification sites were either similar to those of the Meldrum site or indicative of a less competitive growing environment. We conclude that although the Meldrum pine had an early growth advantage, this was offset by the presence of a particularly vigorous aspen community.

We observed some risk of physical damage to pine with increasing aspen presence in the IDFdk3, but it appeared to be quite low in neighbourhoods where tall-aspen density was ≤ 3000 stems/ha. At verification sites, up to 21% of pine sustained whipping damage where tall-aspen density was 4000 stems/ha, but this damage type was minimal at lower densities (results not presented). In the Meldrum variable density study, an average of 13% of pine stems had whipping damage, but vigour did not fall below fair.

The combination of EP1152 research results and verification sampling results provides a solid rationale for increasing the allowable density of countable aspen (as defined by the revised brush–conifer ratio of 1.25) to 3000 stems/ha for mesic or drier site series in the IDFdk3 (Table 6). This recommendation was implemented on an interim basis by the Cariboo-Chilcotin District in 2013, and was accepted as provincial guidance in 2015 (B.C. Ministry of Forests, Lands and Natural Resource Operations 2016). We did not specifically examine aspen–pine competitive relationships for IDFdk3 site series that were wetter than mesic, and those guidelines were unchanged in the 2013 interim guidelines. Wetter than mesic site series tend to be small in the IDFdk3 (Steen and Coupé 1997), and based on subjective observations, we were confident that aspen growing in these areas was no more competitive than that of the more productive SBSdw1/SBSdw2 (results presented in following section). We therefore proposed applying the same allowable density limits for wetter than mesic IDFdk3 site series that we were proposing for all site series in the SBSdw1/SBSdw2—that is, that the allowable density on wetter than mesic site series in the IDFdk3 be increased from 400 stems/ha to 1000 stems/ha.

SBSdw1/SBSdw2 For several reasons, the process of identifying suitable adjustments to free-growing criteria was more complex in the SBSdw1/SBSdw2 than in the SBPSxc, IDFdk4, or IDFdk3. First, the SBSdw1/SBSdw2 is moister and more productive (Steen and Coupé 1997), and aspen is recognized as a stronger competitor (Newsome et al. 2012). Second, testing apparent thresholds was more difficult because we lacked a variable density study that had been established for long enough to provide multiple years of data. Nonetheless, a variety of other experiments with slightly different study objectives had been established in the SBSdw1/SBSdw2 (Table 1), and the range of measured variables in these data sets was comprehensive enough that we could retroactively (i.e., using previously collected data) assign pine to tall-aspen density classes. Third, there was a perception that more was at risk with regard to timber supply in the SBSdw1/SBSdw2 than in the subzones/variants we had dealt with earlier in the project. Due to the greater growth potential of aspen in the SBSdw1/SBSdw2, there was concern that it would occupy growing space through to stand maturity, thereby potentially converting stands to mixedwoods and reducing their value. Since we lacked both data that extended through an entire rotation and growth and yield modelling tools that were capable of dealing with the dynamic nature of juvenile mixed pine–aspen stands, we adopted a conservative approach in making recommendations.

In 2011, when the Working Group began examining free-growing guidelines for lodgepole pine in the SBSdw1/SBSdw2, the allowable density of countable aspen was 400 stems/ha on mesic and moister site series (except in the Quesnel District, where 1000 stems/ha was allowed) and 1000 stems/ha on submesic and drier sites (Table 10). On the basis of results from the SBSdw1/SBSdw2 experiments described in Table 1 and verification sampling that characterized aspen–pine height relationships at typical operational sites in the SBSdw1/SBSdw2, we recommended the relatively minor adjustment of extending the allowable density of 1000 stems/ha to all site series (using the revised brush–conifer ratio of 1.25 to define countable aspen).

Research results Research results used to develop our recommendations concerning the allowable density of countable broadleaves in the SBSdw1/SBSdw2 are summarized in Table 3. Our examination of aspen–pine competitive relationships started with the Hayfield and Two-mile retrospective studies (EP1152.01). At those sites, a threshold of 1000 countable aspen/ha for lodgepole pine diameter growth was identified at stand ages of 10–18 years (Newsome et al. 2003). These sites were remeasured at age 33–34 years, and results confirmed the earlier finding that pine growing among

TABLE 10 *Previous[a] and revised free-growing guidelines for the SBSdw1/SBSdw2*

Guideline	Species[b]	SBS variant	Site series	2002–2015	Following 2015 revision[c]
Conifer–brush ratio (brush–conifer ratio in brackets)	Pl	dw1/dw2	All	150% (0.67)	80% (1.25)
	Sx, Fd, Bl, Sb	dw1/dw2	All	150% (0.67)	67% (1.5)
Allowable number of occupied quadrants within 1-m radius	All	dw1/dw2	All	1	1 or 2 adjacent
Definition of potentially free-growing tree	Pl Sx, Fd, Bl, Sb	dw1/dw2	All	Broadleaf vegetation exceeds conifer height in 1 quadrant	Broadleaf vegetation > 1.25 (Pl) or 1.5 (Fd) times conifer height in 1 or 2 adjacent quadrants
Definition of countable broadleaf	Pl Sx, Fd, Bl, Sb	dw1/dw2	All	Taller than median height of potentially free-growing trees	Taller than 1.25 (Pl) or 1.5 (Fd) times the median height of potentially free-growing trees
Allowable number of countable broadleaf trees per 50-m² plot	Pl	dw1	02, 03	5 (1000 stems/ha)	5 (1000 stems/ha)
			01, 04, 05, 06, 07, 08, 09	2 (400 stems/ha)	
		dw2	02, 03, 04	5 (1000 stems/ha)	
			01, 05, 06, 07, 08, 09, 10, 11	2 (400 stems/ha)	
	Fd	dw1/dw2	All	3 (600 stems/ha)	
	Sx, Bl, Sb	dw1/dw2	All	5 (1000 stems/ha)	

a As described in B.C. Ministry of Forests (2002).

b Pl: lodgepole pine; Fd: Douglas-fir; Sx: hybrid spruce; Bl: subalpine fir; Sb: black spruce.

c The final 2015 guidelines presented in this table are based on use of the standard survey procedure rather than the alternative survey procedure presented in the *Silviculture Survey Procedures Manual* (B.C. Ministry of Forests, Lands and Natural Resource Operations 2016).

1000 tall-aspen/ha was not significantly shorter or smaller in diameter than pine growing in neighbourhoods where no tall-aspen was present within a 1.78-m radius neighbourhood (Figure 15). Furthermore, almost all pine in the 1000 stems/ha density class were in fair vigour (Figure 16), and were gradually growing through the aspen canopy at age 33–34 years (Figure 17).

Next, we reviewed results from the SBSdw1 McKinley study (EP1269.02), which examined the effects of variable density on lodgepole pine growth at the stand level (i.e., in growth and yield plots rather than neighbourhood plots). In this experiment, there were no significant reductions in lodgepole pine height, diameter, or stem volume associated with the retention of more than 2800 aspen/ha relative to that in plots where aspen had been completely removed (Newsome et al. 2006b) (Figure 18).

Third, we revisited the Tyee study (EP1152.02), which had been designed to examine the spatial arrangement of aspen relative to pine rather than to test for an aspen density threshold (Newsome et al. 2004b). To examine the appropriateness of our suggested threshold of 1000 countable aspen/ha and our recommendation that a brush–conifer height ratio of 1.25 be used to define countable broadleaves, we retroactively (i.e., using previously collected data) assigned pine to density classes based on the number of aspen within a 1.78-m radius that had been > 1.25 times the crop pine height in 2005, when the stand was 12 years old. At age 20 years, the height of pine growing in the presence of aspen did not decrease significantly from that of open-grown pine (0 stems/ha) until density was > 4000 stems/ha (Figure 19a). Pine diameter and stem volume tended to be significantly smaller where aspen was present than where it was absent, but there were only minor (non-significant) differences between density classes that ranged from 1000 to 4000 stems/ha (Figure 19b, d). On average, pine at the Tyee site outgrew aspen at approximately age 15 (Figure 1), and we anticipate that the minor size differences between the density classes will gradually disappear.

The Pine Ridge study (EP1080) examined lodgepole pine performance in neighbourhoods with light (average 1360 stems/ha) or heavy (average 2820 stems/ha) aspen presence in the more northerly SBSmk1 (DeLong 2007). Subsequent to the DeLong report, we conducted regression analysis using data that had been collected at age 22 years (2010), and we found that relationships between aspen density and pine height or stem volume were not significant. Although there were weakly significant relationships of declining pine diameter (dbh) ($p = 0.02$) or basal area ($p = 0.03$) with increasing aspen density, the effect was driven mainly by densities > 1000 stems/ha. Twenty-two-year-old lodgepole pine at that site averaged 94% as tall as aspen in the light aspen treatment.

The SBSdw1/SBSdw2 adaptive management experiments (EP1152.09), although they had not been established until 2008, provided a further opportunity to examine juvenile lodgepole pine growth responses at varying densities of countable aspen as defined by the revised brush–conifer ratio of 1.25. These experiments included nominal tall-aspen treatment densities of 0 stems/ha, 2000 stems/ha, and an uncut control, but the data collected were comprehensive enough that pine could retroactively be assigned to 0, 1000, 2000, and ≥ 3000 stems/ha classes based on a brush–conifer ratio of 1.25. During the 4 years after the aspen density treatments were installed, pine height growth was significantly greater in neighbourhoods with 1000 or ≥ 3000 (but

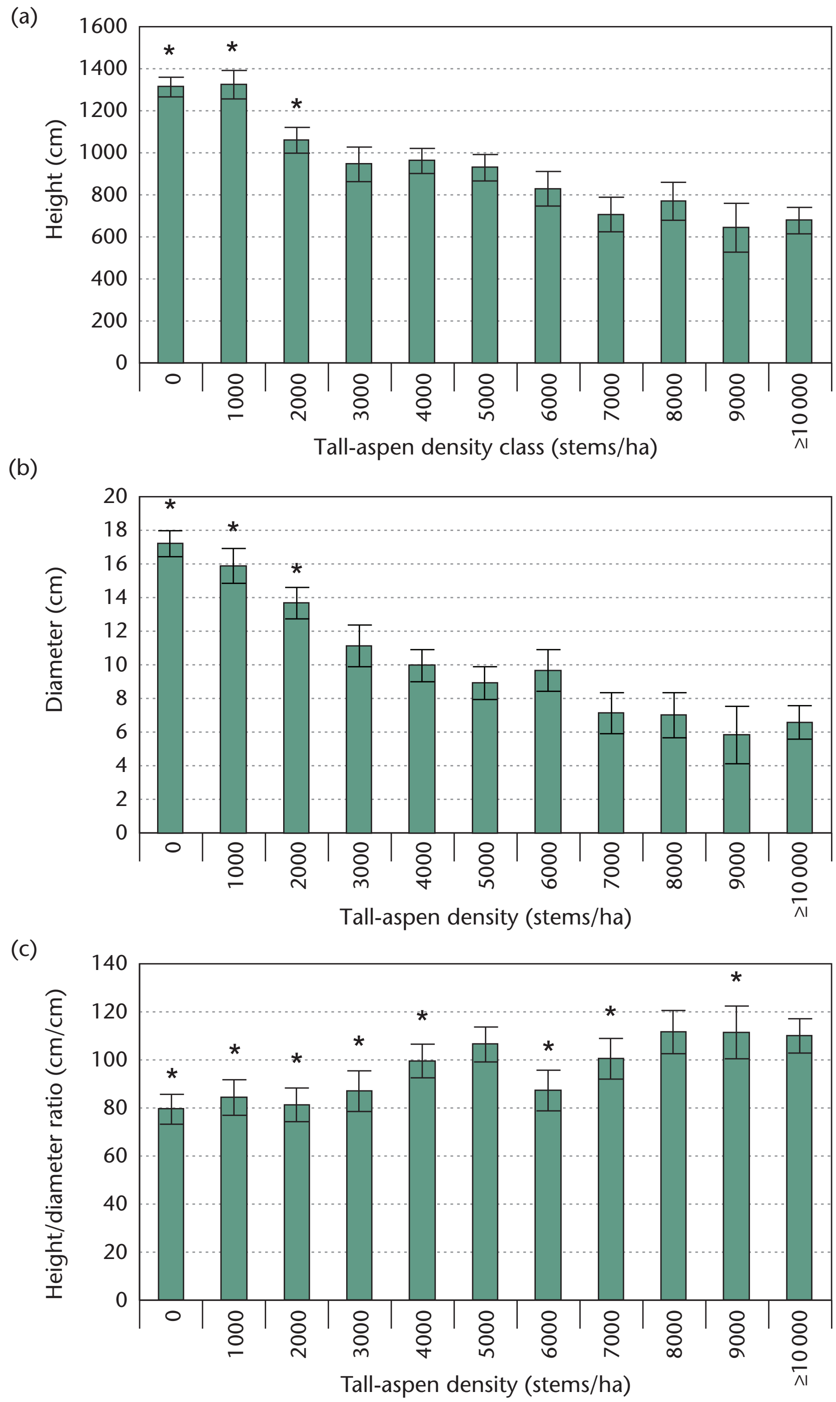

FIGURE 15 *Lodgepole pine (a) height, (b) diameter at 1.3 m (dbh), and (c) height/dbh ratio at the SBSdw1 Hayfield and Two-mile sites (combined) (EP1152.01) at age 33–34 years. Density classes were defined based on tall-aspen density at a stand age of 16–17 years (1994). Means with the symbol "*" do not differ significantly from the mean for the 0 tall-aspen density class according to the Bonferroni mean separation test using α = 0.05 (differences between other pairs of means are not shown in these figures).*

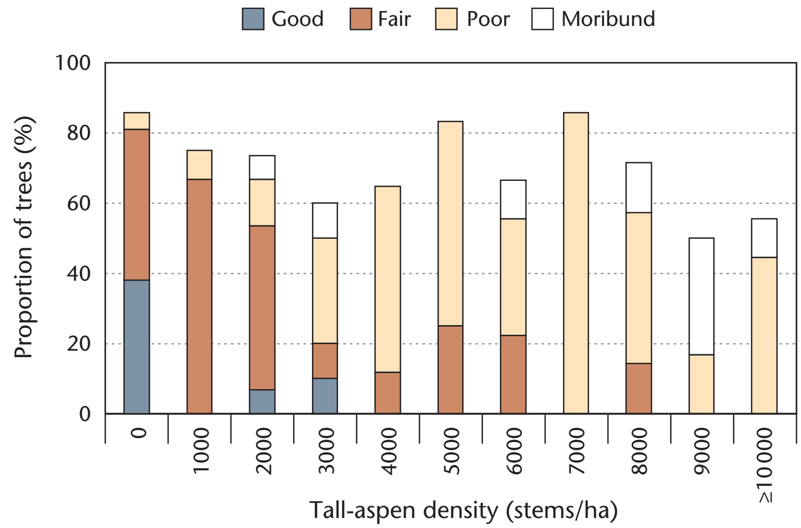

FIGURE 16 *Lodgepole pine survival (total bar height) and vigour at the SBSdw1 Hayfield and Two-mile retrospective study sites (EP1152.01) at age 33–34 years. Density classes represent tall-aspen density at age 16–17 years (1994). Vigour categories are defined in Appendix 1.*

not 2000) aspen/ha than in neighbourhoods with 0 aspen/ha, while pine diameter growth was significantly less in neighbourhoods with 0 aspen/ha than where there was any level of aspen retention; the net outcome was stem volume that was similar across the aspen density classes (Figure 20).

Verification results In 2011, verification data were collected at nine sites in the SBSdw1 or SBSdw2 where juvenile pine–aspen stands were 6–13 years old (Table 2; Appendix 2). The objective was to characterize aspen–pine competitive relationships at tall-aspen densities up to 4000 stems/ha on typical operational sites. The absolute difference in aspen and pine height was highly variable across sites, ranging from 35 cm to more than 3 m (Figure 21a). The aspen–pine height ratio (i.e., the ratio of total aspen height to total pine height) tended to be > 1.25 on most sites (Figure 21b), but nonetheless, the aspen–pine height growth ratio (based on growth during the most recent 2 years) was consistently < 1.0 (Figure 21c). This indicates that although aspen was taller than lodgepole pine at the age of sampling, pine was, on average, growing faster than aspen. This was true of all sites where aspen density was ≤ 4000 stems/ha, which suggests that at low aspen densities, pine would grow through the aspen canopy on SBSdw1/SBSdw2 sites in a similar manner to that observed in the IDFdk3 and SBPSxc. Visual comparison of trends in aspen height at verification sites versus that of the Tyee (EP1152.02) and adaptive management (EP1152.09) research sites (where data had been collected within a similar age range as that of the verification sites) indicated that aspen was growing less vigorously at typical operational sites than at the research sites (Figure 8c). This was anticipated because of the requirement that aspen be vigorous and present at high enough densities throughout the research area to allow random treatment plot allocation.

In order to provide additional insight into the reasons why aspen at densities ≤ 4000 tall-aspen/ha appeared to have low competitive ability, we

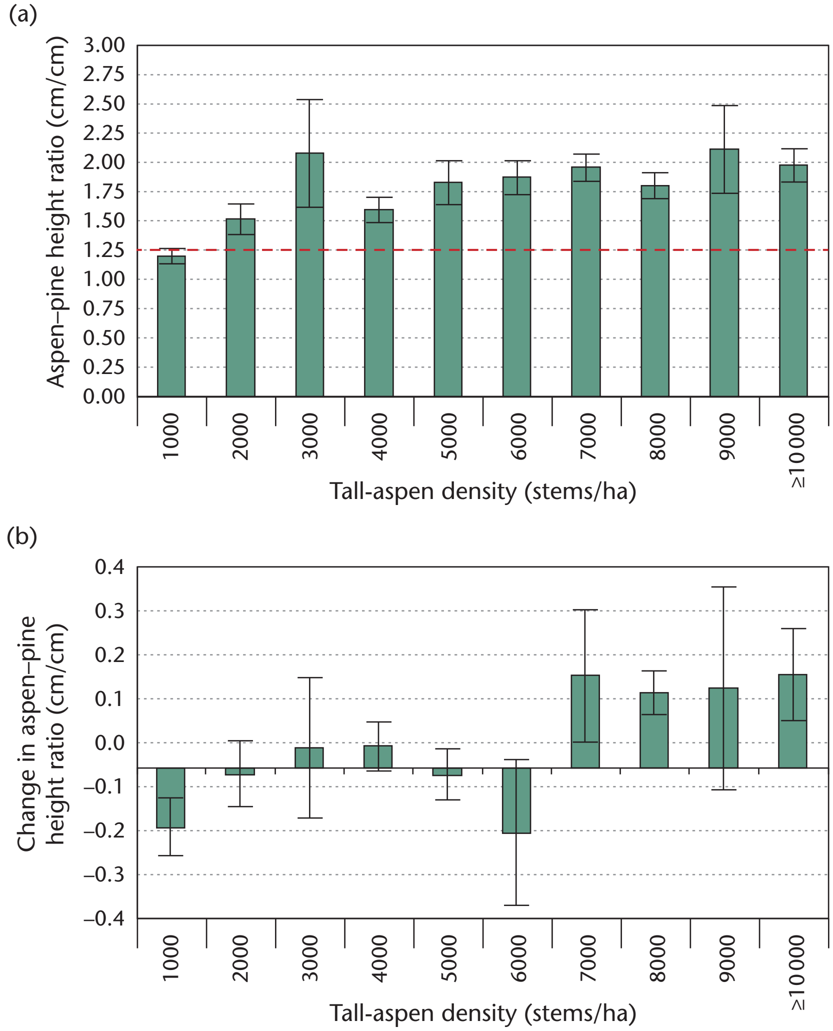

FIGURE 17 *Aspen–pine height relationships at the SBSdw1 Hayfield and Two-mile sites (EP1152.01): (a) aspen–pine height ratio at age 33–34 years (2011) (the dashed line indicates a brush–conifer ratio of 1.25, which defines countable aspen according to revised guidelines), and (b) change in aspen–pine height ratio between ages 26–27 and 33–34 years (from 2004 to 2011). Density classes were defined based on tall-aspen density at a stand age of 16–17 years (1994).*

collected vigour and damage data for the three tallest aspen (or fewer for plots where tall-aspen density was < 3) in a subset of plots at each SBSdw1/SBSdw2 verification site. Of the aspen we sampled, 56% were rated as having good vigour, 30% had fair vigour, 12% had poor vigour, and 2% were moribund (nearly dead). Leaf miner was extremely prevalent in 2011 (Figure 22); it was present at every site, and affected more than 50% of the foliage on every aspen tree that we examined, even those that appeared to have good vigour otherwise. The long-term effects of severe leaf miner in a single year to aspen health are unknown. Canker damage to stems was also common; current stem cankers were present on 34% of sampled aspen, and 58% of sampled trees had crooks or forks, most of which appeared to be the result of

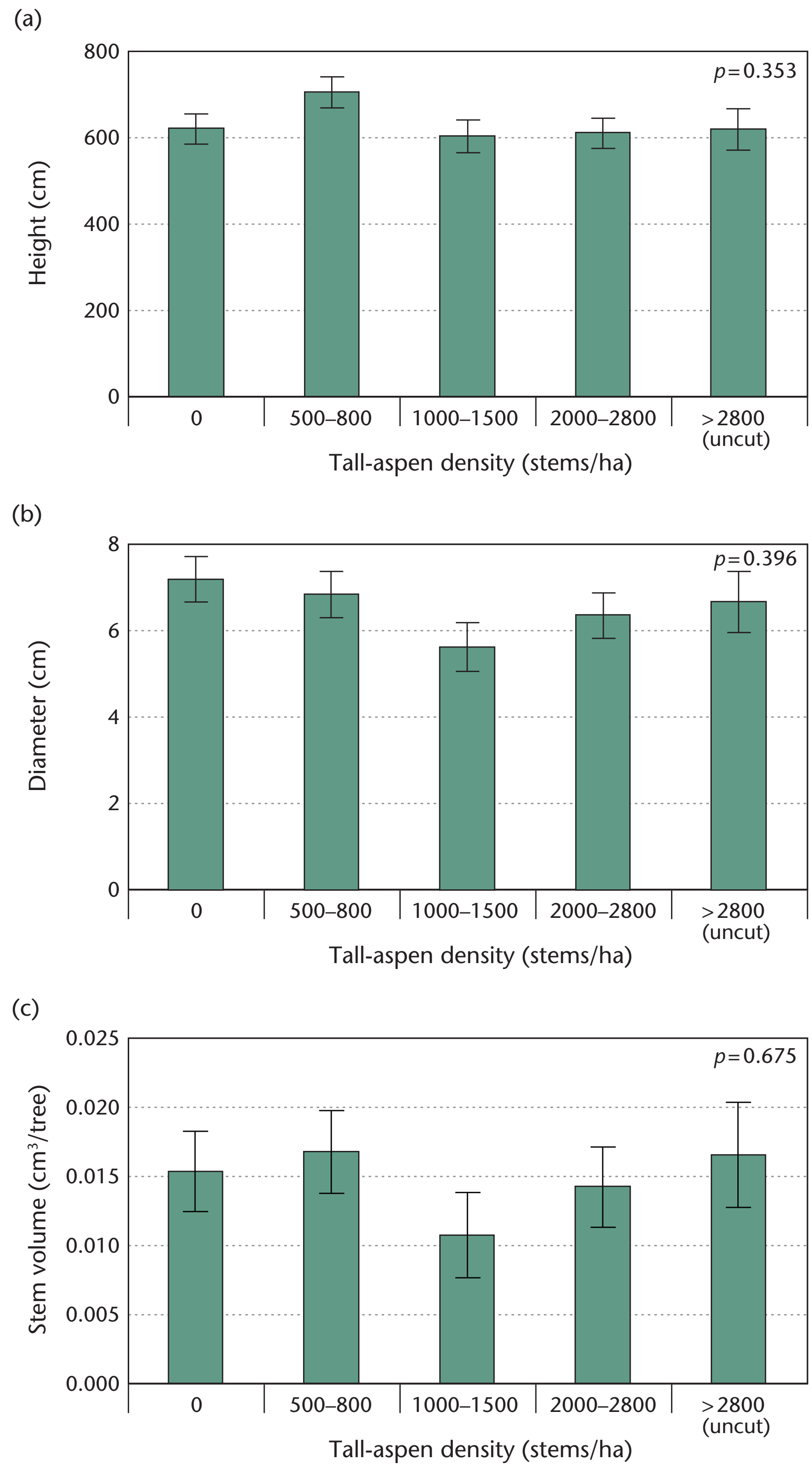

FIGURE 18 *Lodgepole pine (a) height, (b) diameter (dbh), and (c) stem volume in aspen density treatments ranging from 0 to >2800 stems/ha at the SBSdw1 McKinley site (EP1269.02) in 2008 (age 20 years). The trend of lesser diameter and volume in the 1000–1500 treatment may be due to greater presence of western gall rust in those treatment plots.*

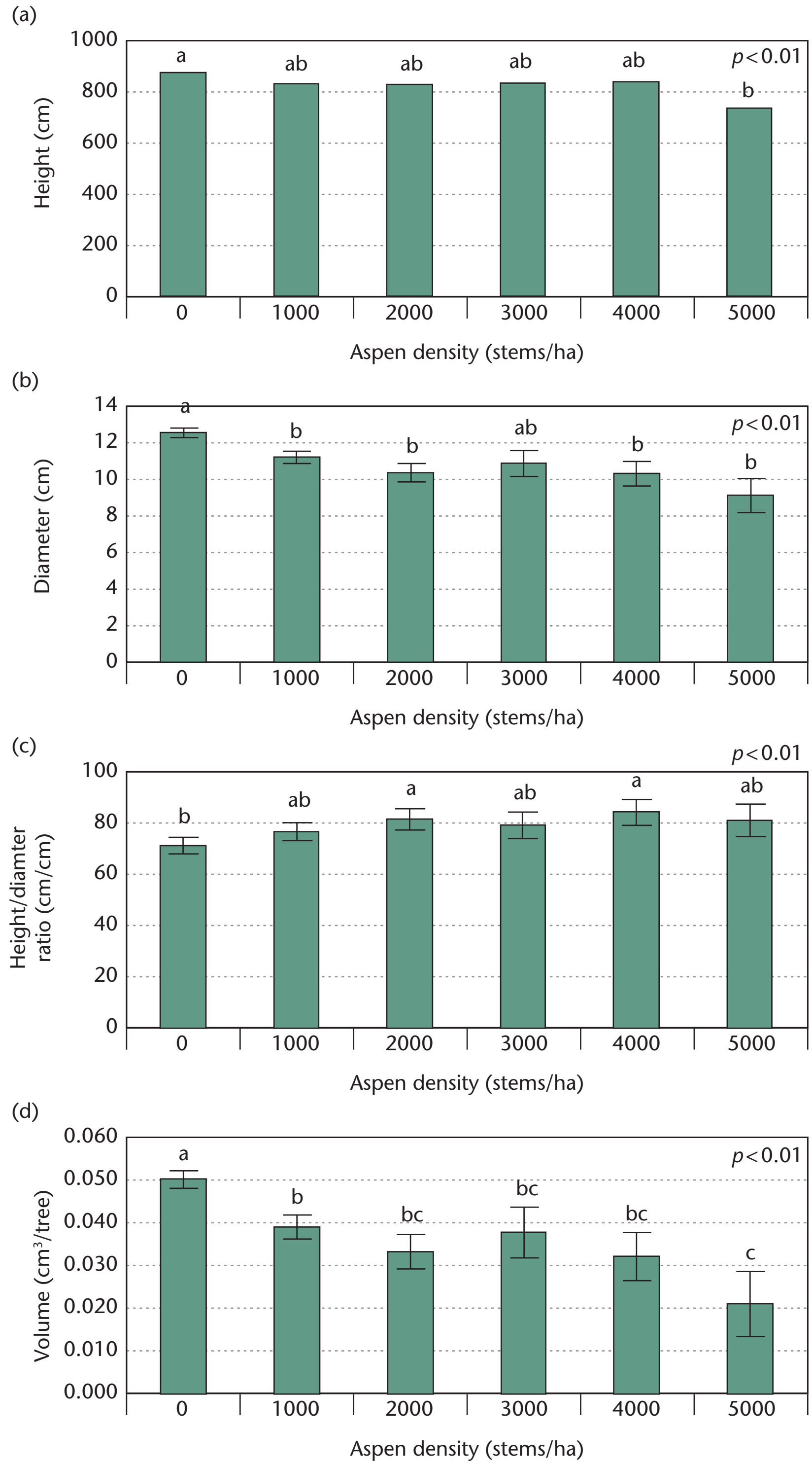

FIGURE 19 *Aspen density effects on 20-year-old lodgepole pine (a) height, (b) diameter (dbh), (c) height/dbh ratio, and (d) stem volume at the SBSdw2 Tyee site (EP1152.02). Aspen density classes are based on the density of aspen with a brush–conifer ratio >1.25 in 2005 (at a stand age of 12 years).*

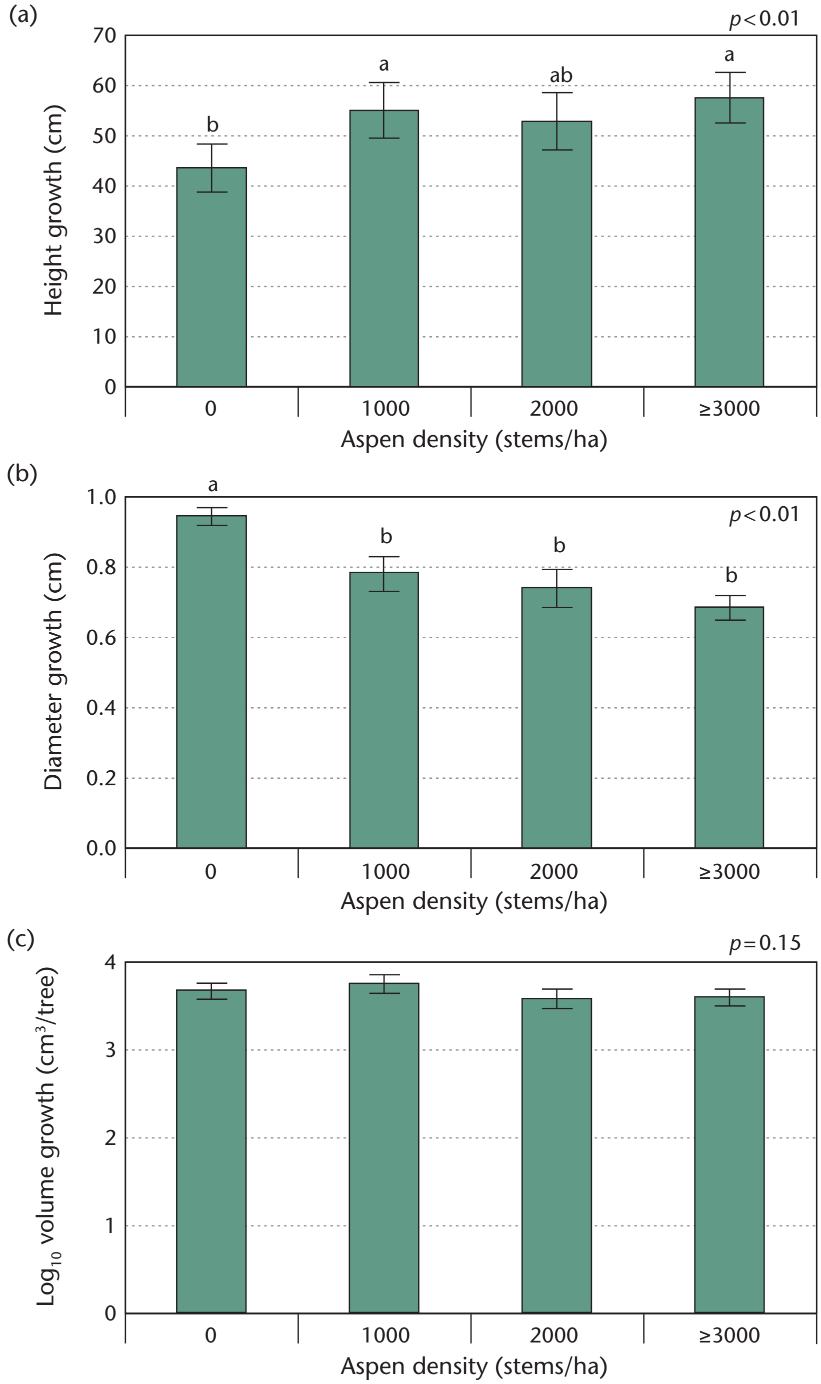

FIGURE 20 *Aspen density effects on lodgepole pine (a) height growth, (b) ground-level diameter growth, and (c) stem volume growth (log_{10} transformed) at SBSdw1/SBSdw2 adaptive management sites (EP1152.09). Growth is annual growth during the 4 years immediately following aspen removal treatments, and density classes are based on the density of aspen with a brush–conifer ratio > 1.25 immediately following treatment. Where $p \leq 0.05$, means that have the same letter do not differ significantly according to the Bonferroni mean separation test. Error bars are one standard error.*

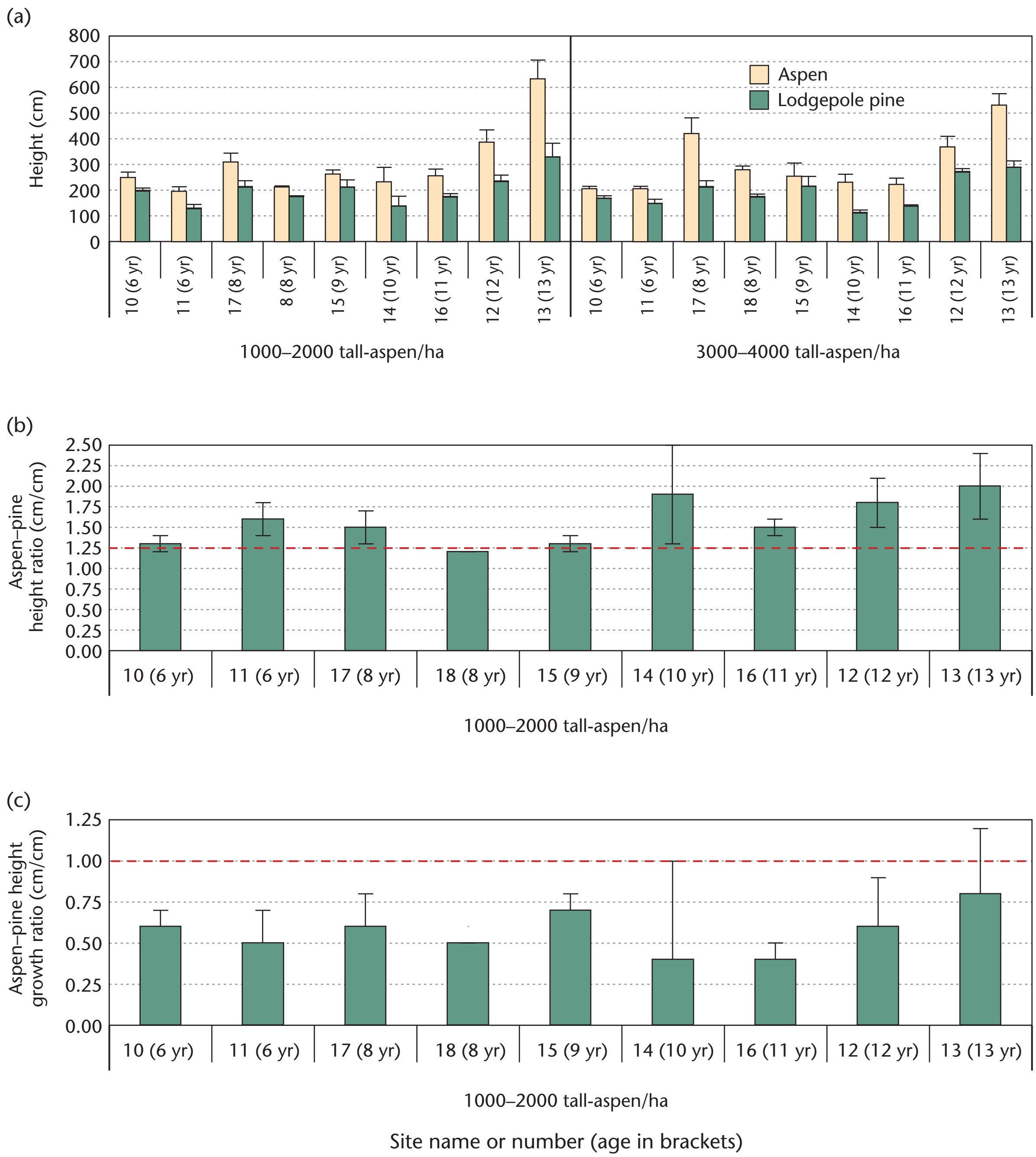

FIGURE 21 *Aspen–lodgepole pine height relationships at SBSdw1/SBSdw2 verification sites: (a) mean height of the ≤ 3 tallest aspen at tall-aspen densities of 1000–2000 and 3000–4000 stems/ha, (b) ratio of aspen–pine height at a density of 1000–2000 tall-aspen/ha (the dashed line indicates a brush–conifer ratio of 1.25, which defines countable aspen according to revised guidelines), and (c) ratio of aspen–pine annual height growth at a density of 1000–2000 tall-aspen/ha (the dashed line is at a ratio of 1.0, which indicates that aspen and pine are growing at the same rate).*

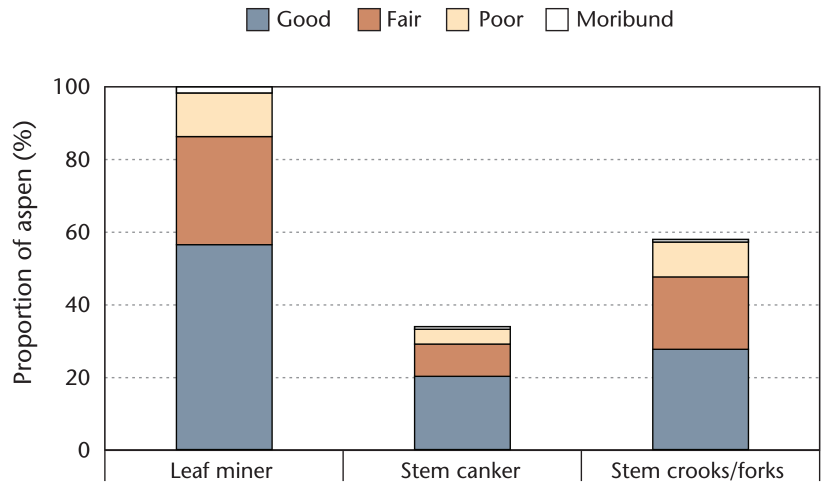

FIGURE 22 *Prevalence of leaf miner, stem canker, and stem crooks or forks on 6- to 13-year-old dominant aspen at SBSdw1/SBSdw2 verification sites. Sampled aspen were the three tallest stems in a randomly selected subset of plots at each of nine sites that were sampled in 2011. For each type of damage, total bar height is the proportion of sampled aspen that had the condition, and shaded portions within the bar indicate the proportion of afflicted aspen that were in good, fair, poor, or moribund condition. Vigour categories are defined in Appendix 1.*

earlier canker damage (Figure 22). Most of these aspen were still considered to have good or fair vigour, but it is likely that repeated death of the leading shoot was reducing the average annual height growth rate.

On the combined basis of research and verification results, we proposed that the allowable density of countable aspen should be set at 1000 stems/ha for all site series in the SBSdw1 and SBSdw2. For mesic and wetter site series, this constituted an increase from the previous allowable density of 400 stems/ha. On the basis of our work, we concluded that at stand ages of 6–13 years, when free-growing surveys are most often conducted,[10] juvenile aspen appears to have low competitive ability where no more than 1000 stems/ha are > 1.25 times the crop pine height. Under these conditions, pine is likely to outgrow aspen, and we anticipate that aspen will have only a minor presence in mature stands. Although our work was conducted on zonal (site series 01) sites, we included wetter than mesic site series in our recommendation on the basis that they generally occur in areas that are too small (< 1 ha) (Steen and Coupé 1997) to require stratification for brushing during free-growing surveys. We also reasoned that for areas larger than 1 ha, our revisions would have little effect; if aspen was vigorous, the countable density would exceed 1000 stems/ha and brushing would be required.

SBPSmk and SBPSdc The SBPSmk and SBPSdc occupy approximately 566 000 ha and 423 000 ha, respectively, in the Cariboo Forest Region. Geographically, the SBPSmk occurs between the dry IDFdk3 and the moister SBSdw1/SBSdw2, while the SBPSdc occurs between the SBPSxc and the IDFdk3. On the basis of their geographic distribution, we speculated that

10 Based on the cohort of operational sites that were provided to us for sampling.

aspen competitiveness in the SBPS subzones might be intermediate between that of the adjacent biogeoclimatic units. Aspen–lodgepole pine competitive relationships have not been rigorously examined for either the SBPSmk or the SBPSdc, but we have early results from two adaptive management studies (EP1152.09) (Table 1) that were established in the SBPSmk in 2008.

Free-growing guidelines that were in place in 2008 specified the same allowable density of countable aspen for the SBPSmk and SBPSdc as for the SBSdw1/SBSdw2—that is, 400 stems/ha for mesic and moister site series and 1000 stems/ha for submesic and drier site series (Table 11). On the basis of the small amount of available research and verification sampling, it appeared that aspen–pine competitive relationships were variable in the SBPSmk and SBPSdc, and that aspen was potentially as strong a competitor as it was in the SBSdw1/SBSdw2. We therefore recommend that the SBPSmk and SBPSdc receive the same adjustments as the SBSdw1/SBSdw2, allowing 1000 countable aspen (as defined by the revised brush–conifer ratio of 1.25) for all site series.

Research results The adaptive management experiments that were initiated in the SBPSmk in 2008 (EP1152.09) were designed to examine lodgepole pine responses to 2500 tall-aspen/ha relative to responses to broadcast removal (0 tall-aspen/ha) and an uncut control. We chose an aspen retention level of 2500 stems/ha for this study on the assumption that aspen in the SBPSmk was likely to have intermediate competitive strength between that of the

TABLE 11 *Previous[a] and revised free-growing guidelines for the SBPSmk and SBPSdc*

<table>
<tr><th colspan="2">Guideline</th><th>Species[b]</th><th>Site series</th><th>2002–2015</th><th>Following 2015 revision[c]</th></tr>
<tr><td colspan="2" rowspan="2">Conifer–brush ratio (brush–conifer ratio in brackets)</td><td>Pl</td><td rowspan="2">All</td><td>150% (0.67)</td><td>80% (1.25)</td></tr>
<tr><td>Sx, Fd, Bl, Sb</td><td>150% (0.67)</td><td>67% (1.5)</td></tr>
<tr><td colspan="2">Allowable number of occupied quadrants within 1-m radius</td><td>All</td><td>All</td><td>1</td><td>1 or 2 adjacent</td></tr>
<tr><td colspan="2" rowspan="2">Definition of potentially free-growing tree</td><td>Pl</td><td rowspan="2">All</td><td rowspan="2">Broadleaf vegetation exceeds conifer height in 1 quadrant</td><td rowspan="2">Broadleaf vegetation > 1.25 (Pl) or 1.5 (other species) times the conifer height in 1 or 2 adjacent quadrants</td></tr>
<tr><td>Sx, Fd, Bl, Sb</td></tr>
<tr><td colspan="2" rowspan="2">Definition of countable broadleaf</td><td>Pl</td><td rowspan="2">All</td><td rowspan="2">Taller than median height of potentially free-growing trees</td><td rowspan="2">Taller than 1.25 (Pl) or 1.5 (other species) times the median height of potentially free-growing trees</td></tr>
<tr><td>Sx, Fd, Bl, Sb</td></tr>
<tr><td rowspan="7">Allowable number of countable broadleaf trees per 50 m² plot</td><td rowspan="4">SBPSmk</td><td rowspan="2">Pl</td><td>02, 03, 04, 05</td><td>5 (1000 stems/ha)</td><td rowspan="7">5 (1000 stems/ha)</td></tr>
<tr><td>01, 06, 07, 08</td><td>2 (400 stems/ha)</td></tr>
<tr><td>Fd</td><td>All</td><td>3 (600 stems/ha)</td></tr>
<tr><td>Sx, Bl, Sb</td><td>All</td><td>5 (1000 stems/ha)</td></tr>
<tr><td rowspan="3">SBPSdc</td><td rowspan="2">Pl</td><td>02, 03</td><td>5 (1000 stems/ha)</td></tr>
<tr><td>01, 04, 05, 06, 07, 08</td><td>2 (400 stems/ha)</td></tr>
<tr><td>Sx, Bl, Sb</td><td>All</td><td>5 (1000 stems/ha)</td></tr>
</table>

a As described in B.C. Ministry of Forests (2002).

b Pl: lodgepole pine; Fd: Douglas-fir; Sx: hybrid spruce; Bl: subalpine fir; Sb: black spruce.

c The final 2015 guidelines presented in this table are based on use of the standard survey procedure rather than the alternative survey procedure presented in the *Silviculture Survey Procedures Manual* (B.C. Ministry of Forests, Lands and Natural Resource Operations 2016).

IDFdk3 and the SBSdw1/SBSdw2. However, within 4 years of treatment installation, it was apparent that aspen–pine relationships in the SBPSmk were more similar to those of the SBSdw1/SBSdw2 than the IDFdk3, and that the threshold of 2500 stems/ha was too high for operational application. Fortunately, the measurement protocol used in the adaptive management experiments permitted us to reorganize existing lodgepole pine data into aspen density classes of 0, 1000, 2000, and ≥ 3000 stems/ha (based on the definition that countable aspen had a brush–conifer ratio > 1.25).

At a stand age of 12–15 years (4 years after treatments were applied), pine growing among 1000, 2000, and ≥ 3000 aspen/ha showed a trend of increasing annual height growth relative to those in the 0 stems/ha class, but statistical significance was inconsistent; height growth differences between the 0 and 2000 stems/ha classes were statistically significant, but differences between the 0 and 1000 stems/ha classes were not (Figure 23a). At the same time that height growth was increasing in response to aspen presence, diameter growth was decreasing, and pine growing in the 0 stems/ha density class had significantly greater ground-level diameter growth than those in ≥ 1000 stems/ha classes (Figure 23b). As a result of the differences in resource allocation to height versus diameter growth, there were no differences in individual lodgepole pine stem volume growth between the 0, 1000, and 2000 stems/ha density classes in these 12- to 15-year-old stands (Figure 23c). Although these results suggest that up to 2000 aspen that are > 125% crop lodgepole pine height can be retained in the SBPSmk without negatively affecting pine growth, longer-term results would be necessary before we could consider recommending a higher allowable aspen density for the SBPSmk than the SBSdw1/SBSdw2.

Verification results In 2012, we conducted verification sampling at ten 8- to 13-year-old operational sites in the SBPSmk and eight 7- to 12-year-old operational sites in the SBPSdc to characterize aspen–pine height relationships at typical operational sites. Interpretations are based on visual assessment of data trends only, and no statistical comparisons were made. Aspen had highly variable height in the SBPSmk and SBPSdc, but on average at similar age, it tended to be slightly taller in the SBPSmk (Figure 24a). Lodgepole pine on sampled sites likewise tended to be somewhat taller in the SBPSmk than in the SBPSdc (results not shown). This could be related to climatic differences, which the lesser minimum height required for lodgepole pine on zonal sites in the SBPSdc (1.4 m) than in the SBPSmk (1.6 m) appears to suggest (B.C. Ministry of Forests 2002). Both the aspen–pine height ratio (ratio of total aspen height to total pine height) and the aspen–pine height growth ratio were somewhat more variable in the SBPSdc than in the SBPSmk (Figure 24b, c).

On the basis of the adaptive management results for the SBPSmk (EP1152.09) and verification sampling in both the SBPSmk and SBPSdc, we recommend similar adjustment to free-growing guidelines for these biogeoclimatic units as for the SBSdw1/SBSdw2—that is, we recommend that the allowable density of countable aspen (as defined by the revised brush–conifer ratio of 1.25) be increased from 400 to 1000 stems/ha for mesic and wetter SBPSmk and SBPSdc site series, and remain at 1000 stems/ha for drier than mesic site series.

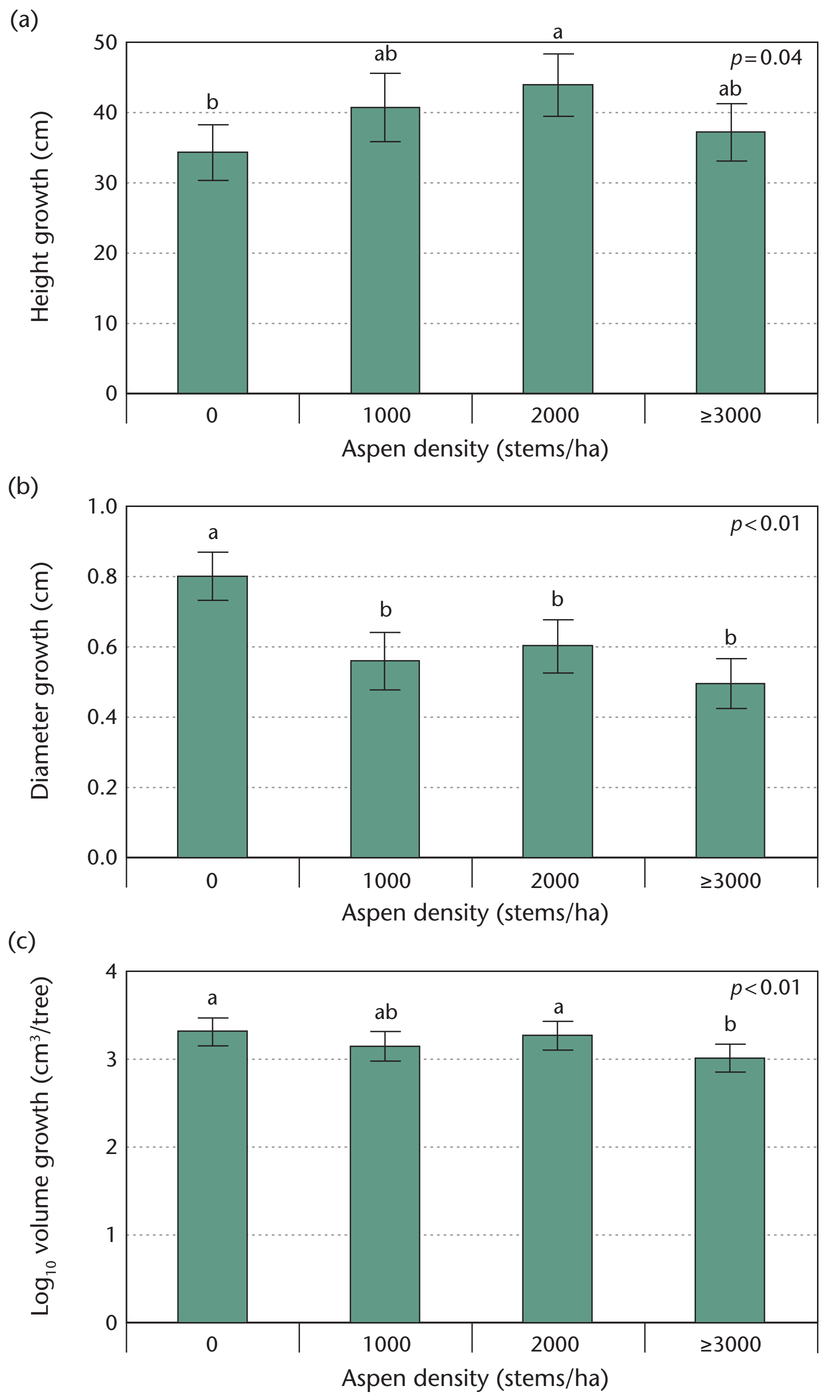

FIGURE 23 *Aspen density effects on lodgepole pine (a) height growth, (b) ground-level diameter growth, and (c) stem volume growth ($\log_{10}$ transformed) at SBPSmk adaptive management sites (EP1152.09). Growth is annual growth during the 4 years immediately following aspen removal treatments, and density classes are based on the density of aspen with a brush–conifer height ratio > 1.25 immediately following treatment. Where $p \leq 0.05$, means that have the same letter do not differ significantly according to the Bonferroni mean separation test. Error bars are one standard error.*

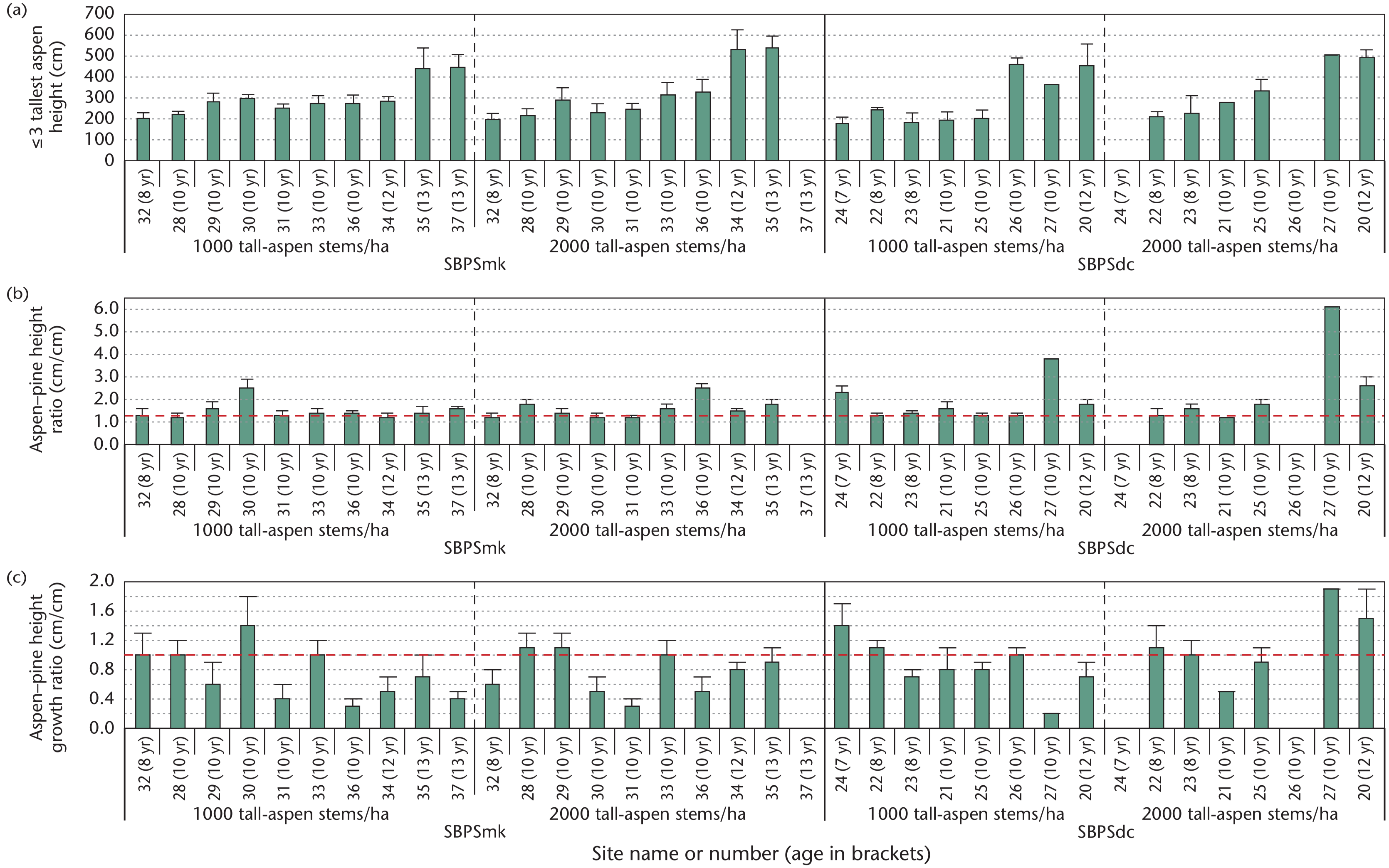

FIGURE 24 *Aspen–lodgepole pine height relationships at tall-aspen densities of 1000 and 2000 stems/ha at SBPSmk and SBPSdc verification sites: (a) mean height of the ≤ 3 tallest aspen, (b) ratio of aspen–pine total height (the dashed line is at a brush–conifer ratio of 1.25, which defines countable aspen according to revised guidelines), and (c) ratio of aspen–pine annual height growth (the dashed line is at a ratio of 1.0, which indicates that aspen and pine are growing at the same rate).*

3.2 Hybrid Spruce and Douglas-fir

Until the Working Group began addressing free-growing issues in the SBSdw1/SBSdw2, it had focussed exclusively on recommending adjustments to guidance concerning lodgepole pine. However, given the increasing need to manage for a diversity of regeneration species in the productive SBSdw1 and SBSdw2, a decision was made to also examine free-growing guidelines for hybrid spruce and Douglas-fir in these ecosystems. These species are more shade-tolerant than lodgepole pine (Klinka et al. 2000), which suggests that they can tolerate greater aspen presence. This understanding is reflected in the free-growing guidance that was in place in 2011 when the Working Group began examining issues in the SBSdw1/SBSdw2 (Table 10).

Very little research is available that specifically examines aspen–spruce or aspen–Douglas-fir competitive relationships in south-central British Columbia. Large research projects begun in the 1990s tended to focus on locally important management questions; in the Cariboo Region, EP1152 focussed almost exclusively on aspen–lodgepole pine mixtures because they were the most widespread, while research concerning aspen–spruce mixtures was conducted primarily in boreal regions, where aspen is more competitive than it is in sub-boreal ecosystems (Comeau et al. 2006). Mixedwood management is also acceptable in boreal regions, which provides for a broader range of options for managing sites where aspen is present (e.g., Comeau et al. 2005). Even less information exists for aspen–Douglas-fir mixtures in the Cariboo Region because most research concerning juvenile Douglas-fir mixtures has involved paper birch, and it was conducted on sites further south in British Columbia (e.g., Simard et al. 2005). In the Cariboo Region, there is some anecdotal information related to hybrid spruce performance when it is growing among aspen on SBSdw1/SBSdw2 sites, but little for Douglas-fir because the species is not planted extensively in these biogeoclimatic variants due to perceived establishment difficulties (Newsome et al. 2016).

When the need for information regarding aspen–spruce and aspen–Douglas-fir competitive relationships in the SBSdw1/SBSdw2 became evident, these species were retroactively tagged (to the extent they were present) at the Philemon, Gavin, and Sausser adaptive management study sites (EP1152.09). These experiments, which had been established between 2008 and 2011 (Table 1), provided some information that we were able to use. Substantial research of a more general nature regarding the light requirements of hybrid spruce in the SBS zone and the ability of aspen to intercept light was also available.

We used a synthesis of research information and expert opinion to arrive at recommendations for change to free-growing guidance concerning hybrid spruce and Douglas-fir in the Cariboo Region SBSdw1/SBSdw2. Free-growing guidelines that were in place for these biogeoclimatic variants in 2011 specified countable aspen density limits of 1000 stems/ha for spruce and 600 stems/ha for Douglas-fir, and a conifer–brush ratio of 150% (brush–conifer ratio of 0.67) for both species (Table 10). As for lodgepole pine, up to one quadrant within a 1-m radius of the crop tree could be occupied. We made the following recommendations for hybrid spruce and Douglas-fir: (1) the conifer–brush ratio should be decreased to 67% (brush–conifer ratio of 1.5), and as we recommended for lodgepole pine, this ratio should be used to define occupied quadrants within the 1-m cylinder and countable broadleaves; (2) a crop tree should be free-growing if no broadleaf vegetation within the 1-m cylinder exceeded the brush–conifer ratio of 1.5 (i.e., there was no broadleaf vegetation taller than 150% of the crop tree); if one or two adjacent quadrants were occupied by broadleaf vegetation that exceeded the brush–conifer ratio of 1.5, the tree would be considered potentially free-growing and subject to allowable density criteria; and (3) the allowable density of countable broadleaves remain at 1000 stems/ha. By extension, we also recommended these adjustments for subalpine fir (*Abies lasiocarpa*) and black spruce (*Picea mariana*), which have moderate to high shade-tolerance (Klinka et al. 2000), and are also ecologically acceptable species for the SBSdw1/SBSdw2 (B.C. Ministry of Forests 2002). Douglas-fir is also an acceptable regeneration species in the IDFdk3, and we recommended that a brush–conifer ratio of 1.5 be similarly applied in that biogeoclimatic variant. Because Douglas-fir is more shade-tolerant than lodgepole pine (Klinka et al. 2000), we reasoned that the allowable density of countable broadleaves could conservatively be set at the same level as we had recommended for lodgepole pine in the IDFdk3—that is, 3000 stems/ha in mesic and drier site series and 1000 stems/ha in wetter than mesic site series.

Research results Research that contributed to our recommendations for hybrid spruce and Douglas-fir in the SBSdw1/SBSdw2 is summarized in Table 12. Four years after aspen removal treatments were applied at the adaptive management sites, hybrid spruce diameter growth had responded more than height growth to reduced aspen presence (Figure 25). Diameter and basal area were significantly greater in the broadcast removal (0 stems/ha) treatment than in the uncut control. Spruce in the 2000 tall-aspen/ha treatment did not differ significantly in height, diameter, or basal area from those in the 0 stems/ha or uncut control treatments.

To further examine the effects of aspen presence on hybrid spruce performance at the adaptive management sites, we assigned tagged spruce from uncut control plots to aspen density classes that were defined according to the proposed brush–conifer ratio of 1.5. Using this approach, neighbourhood aspen density in 1.78-m (10 m^2) subplots around crop spruce ranged from 0 to 16 000 stems/ha. Spruce growth was variable under these conditions; we characterized neighbourhoods for the five largest (height and diameter) spruce at each study site and found that most of those were in neighbourhoods with ≤ 2000 countable aspen/ha (results not presented). This trend was stronger at the 14-year-old SBSdw2 site than at the 13-year-old SBSdw1 site.

The EP1152.09 adaptive management studies provided less information for Douglas-fir than for hybrid spruce; Douglas-fir presence was inconsistent because it had been planted in only minor amounts, and it typically has a long establishment period (Newsome et al. 2016). Block 3 of the Sheridan study (EP841.07) (Table 12), offered an opportunity to examine Douglas-fir performances under variable levels of overtopping aspen. The Sheridan experiment was established in 1988 to examine Douglas-fir and lodgepole pine responses to site preparation, but block 3 had been dropped early in the study due to the development of dense aspen. Neighbourhood data collected at age 6 years (1994) indicated that Douglas-fir in block 3 were overtopped by aspen with cover values that ranged from 20 to 90% (average of 56%) and which was 1.2–8.5 (average of 4.4) times taller than the planted fir. Density data were not collected, but the aspen stand was subjectively noted to be extremely dense. In 2011 (age 24 years), crop Douglas-fir were remeasured, and in 2012 (age 25

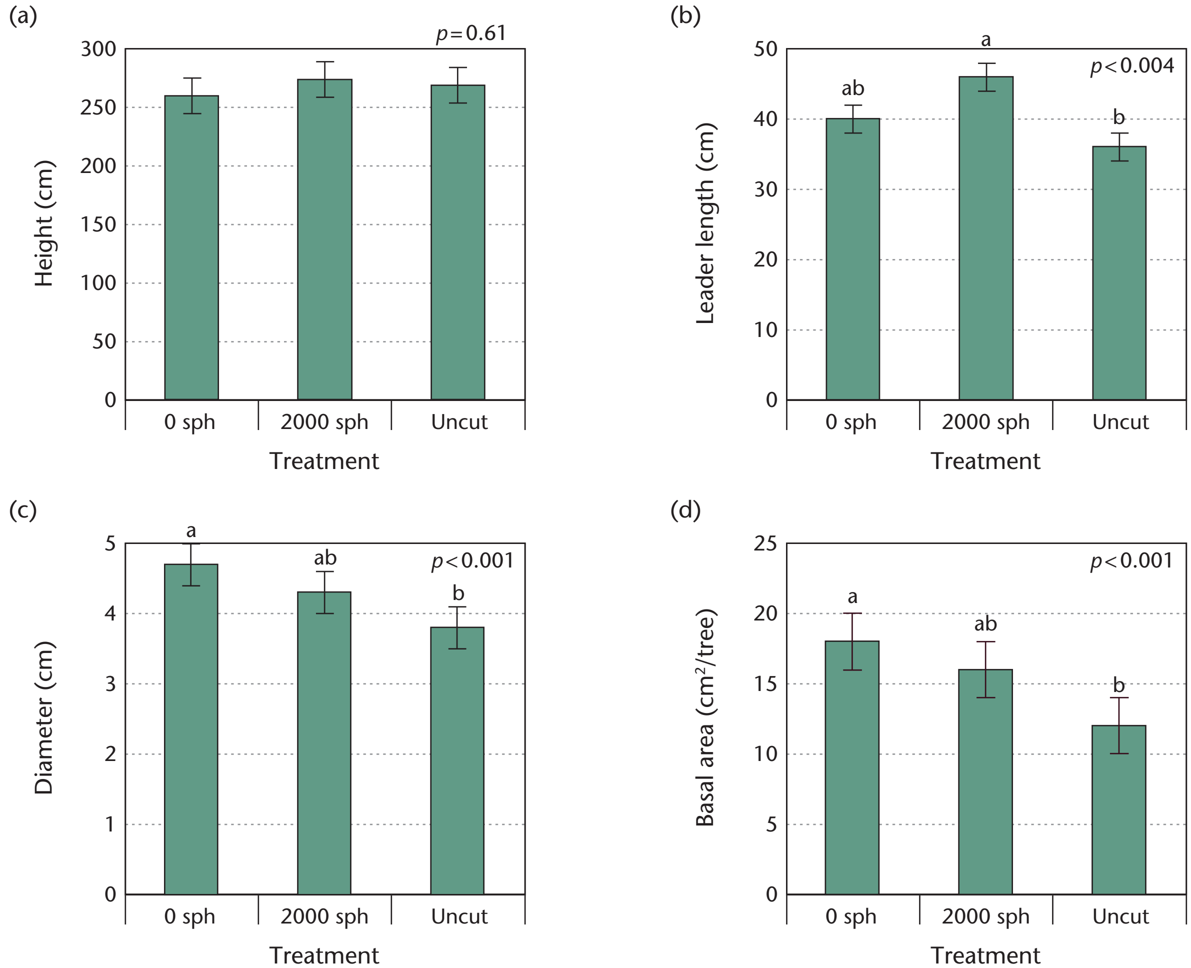

FIGURE 25 *Growth responses of 13- to 14-year-old hybrid spruce in year 4 post treatment (2013) in aspen retention treatments at SBSdw1/SBSdw2 adaptive management sites (EP1152.09): (a) height, (b) leader length, (c) ground-level diameter, and (d) basal area (based on ground-level diameter) (sph: stems per hectare; the 0 sph and 2000 sph treatment names refer to the density of tall-aspen relative to lodgepole pine [not spruce]). Error bars are one standard error. Where* $p \leq 0.05$, *means that have the same letter do not differ significantly according to the Bonferroni mean separation test.*

years), neighbourhood aspen data were collected. At age 24 years, most of the planted Douglas-fir in block 3 survived and maintained good vigour, while almost all the planted lodgepole pine growing under similar conditions had died. Douglas-fir showed trends of decreasing height and diameter as the density of overtopping aspen increased; however, the differences relative to fir that were free of aspen (0 stems/ha) did not become statistically significant until more than 1500 tall-aspen/ha were present. Douglas-fir diameter and volume did not differ significantly from those that were free of aspen until tall-aspen density was > 2000 stems /ha (up to 17 m^2/ha basal area).

In addition to the above-described field measurements, we examined literature regarding the light requirements of hybrid spruce and Douglas-fir, and the light intercepting ability of aspen. Although hybrid spruce is more shade-tolerant than lodgepole pine (Klinka et al. 2000), its best growth occurs at high light levels. Based on a thorough literature review, Alstrup

TABLE 12 *Research results related to the adjustment of free-growing guidelines concerning hybrid spruce and Douglas-fir in the SBSdw1 and SBSdw2*

Study	Key results and interpretation
Adaptive management study (EP1152.09)	• Four years after treatment, hybrid spruce diameter growth had responded more than height growth to aspen removal (Figure 25). Diameter and basal area were significantly greater in the broadcast removal (0 stems/ha) treatment than in the uncut control. Spruce in the 2000 tall-aspen/ha treatment had significantly greater leader growth than those in the control, but did not differ significantly in height, diameter, or basal area from those in the 0 stems/ha or uncut control. • In the uncut control, the density of aspen ≥ 1.5 times spruce height (brush–conifer ratio > 1.5) in spruce neighbourhoods ranged from 0 to16 000 stems/ha. • The largest (height and diameter) spruce in uncut control plots at each study site were generally growing in neighbourhoods where the density of aspen with brush–conifer ratio > 1.5 was ≤ 2000 stems/ha.
Pine Ridge (EP1080)	• At age 23, hybrid spruce was growing well at total aspen densities of 1360 and 2820 stems/ha. Spruce was approximately 70% as tall as aspen.
Sheridan (EP841.07)	• Even under heavy aspen competition, Douglas-fir survived and maintained good vigour at age 24 years. • Douglas-fir showed trends of decreasing height and diameter as the density of overtopping aspen increased; however, height differences between those growing with overtopping aspen and those free of aspen (0 stems/ha) were not statistically significant until tall-aspen density was > 1500 stems/ha; Douglas-fir diameter and volume differences were not significant until tall-aspen density was > 2000 stems/ha (up to 17 m^2/ha basal area).
Spruce light requirements (Alstrup 2005[a] literature review)	• There is a clear positive relationship between light availability and spruce growth. However, the largest diameter gains occurred as light availability increased from 0 to 75%. At light levels ranging from 76 to 100%, relative gains in spruce size were smaller with incremental increases in light availability. • Models developed by Wright et al. (1998) and Kayahara et al. (1996) suggest that 65–75% light is required to achieve 80% maximum spruce diameter growth.
Light availability in aspen stands (Comeau et al. 2006)	• At a given basal area, aspen's ability to intercept light in 10- to 30-year-old stands varies by ecosystem. Aspen is a stronger competitor for light in the BWBS zone than in the SBS zone. Light availability in all ecosystems increased steeply with height in the aspen canopy. • Findings from this study imply that if spruce and Douglas-fir attain 60–70% of the aspen canopy height, they will receive enough light to achieve 80% optimum diameter growth (according to models presented by Wright et al. 1998 and Kayahara et al. 1996).

a Alstrup, R. 2005. Review of the relationship between light availability and growth of understory spruce. B.C. Min. For. Range, Victoria, B.C. Unpubl rep.

(2005)[11] concluded that there is a clear positive relationship between light availability and spruce growth, with the largest diameter gains occurring as light availability increases from 0 to 75% full sunlight. As light availability increased from 76 to 100%, the incremental gains in spruce size were smaller. Models developed by Wright et al. (1998) and Kayahara et al. (1996) indicate that 65–75% light is required to achieve 80% maximum spruce diameter growth. According to Comeau et al. (2006), these light levels are present at about 70% total aspen height (generally about mid-point in the aspen canopy) across a range of aspen basal areas in the SBS zone (Comeau et al. 2006). A spruce tree that was 70% as tall as aspen would have a brush–conifer ratio of approximately 1.5, and we therefore reasoned that it would be biologically appropriate to adjust the brush–conifer height ratio for hybrid spruce to 1.5. This conclusion is supported by the Pine Ridge study (EP1080), where 22-year-old spruce had good vigour and growth when they were growing among up to 2820 aspen/ha that were approximately 1.5 times their height. We found less information regarding light requirements for interior Douglas-fir; however, the species is adaptable to relatively low light levels (Williams et al. 1999), and we recommend applying the same brush–conifer height ratio of 1.5 as we proposed for spruce.

11 Alstrup, R. 2005. Review of the relationship between light availability and growth of understory spruce. B.C. Min. For. Range, Victoria, B.C. Unpubl. rep.

Verification results Data for spruce and Douglas-fir were collected during verification sampling that was conducted at SBSdw1/SBSdw2 sites to describe aspen–pine height relationships at typical operational sites. Spruce and Douglas-fir were sampled when those species occurred within 5 m of crop lodgepole pine and appeared to be of a similar age cohort as the pine. This provided us with spruce data from eight sites (four planted and four naturally regenerated), but we encountered Douglas-fir (of natural origin) at only one site. Spruce and Douglas-fir were sampled regardless of tall-aspen density, but the results we present focus on tall-aspen densities ≤ 4000 stems/ha (i.e., ≤ 4000 aspen as tall as or taller than the spruce or Douglas-fir). The verification sites we sampled had been selected on the basis that lodgepole pine was the primary regenerated conifer species, and due to the generally large height difference between aspen and spruce or Douglas-fir at these sites, neighbourhood tall-aspen densities < 3000 stems/ha were not encountered for these species at most sites.

The height of sampled spruce was highly variable at the verification sites, probably because the trees sampled were of both natural and planted origin. Average height ranged from 39 cm in a 10-year-old stand to 136 cm in an 8-year-old stand (Figure 26a). At all sites where spruce and Douglas-fir occurred, the average aspen–conifer height ratio exceeded 1.5 (Figure 26b), which indicates that even where they met minimum height, these trees would not have met our proposed free-growing criteria.

On the basis of the above-described research involving hybrid spruce or Douglas-fir in the SBS zone, we recommend that the brush–conifer ratio for these species be adjusted to 1.5 and that the allowable density of countable broadleaf trees should be set at 1000 stems/ha for both species; this represents an increase of 400 stems/ha for Douglas-fir, but no increase for hybrid spruce (Table 10). Since these species are more shade-tolerant than lodgepole pine, we recommend a similar increase in the allowable number of occupied quadrants within a 1-m cylinder (i.e., up to two adjacent quadrants can be occupied) as we recommended for lodgepole pine. By extension, we also recommended these adjustments for subalpine fir and black spruce. For Douglas-fir in the IDFdk3, we recommended that the brush–conifer ratio be adjusted to 1.5 and that the allowable density of countable broadleaves be adjusted to the same levels we were recommending for lodgepole pine in that biogeoclimatic variant—that is 3000 stems/ha in mesic and drier site series and 1000 stems/ha in wetter than mesic site series (Table 6). Since the allowable density of countable broadleaves had previously been set at 600 stems/ha for Douglas-fir in all biogeoclimatic units and site series, this represents a relatively large increase of 2400 stems/ha for mesic and drier site series, and a relatively small increase of 400 stems/ha for wetter than mesic site series.

4 IMPLEMENTING RECOMMENDED CHANGES

4.1 Changes to Guidelines

In addition to the research and verification work described in this report, one of the primary responsibilities of the researchers involved in this project was communication. Throughout the 6 years of this project, regular meetings and field trips were organized to report on our findings and solicit input from

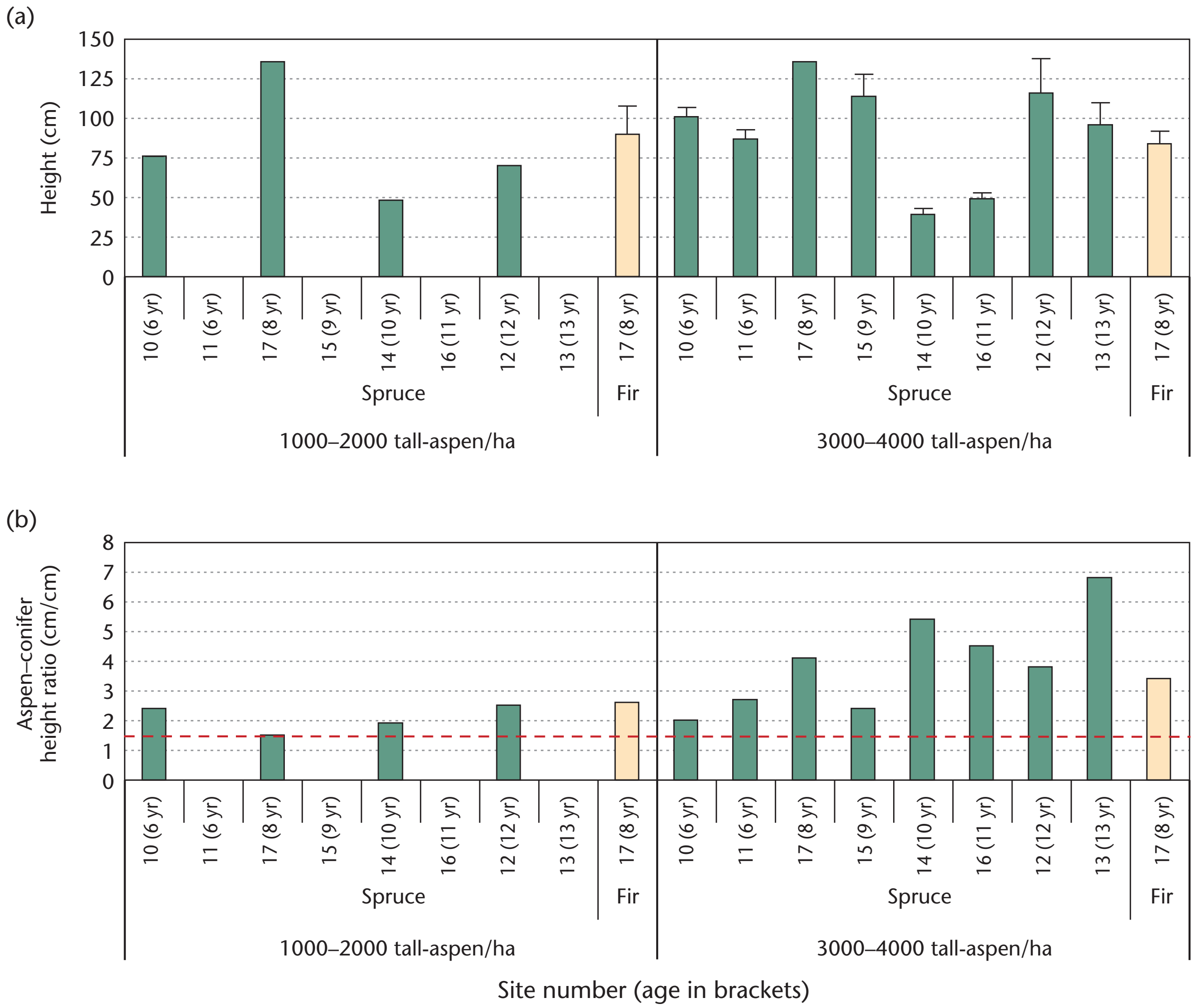

FIGURE 26 *Hybrid spruce (dark green bars) and Douglas-fir (pale yellow bars) (a) height, and (b) aspen–conifer height ratio, at densities of 1000–2000 tall-aspen/ha and 3000–4000 tall-aspen/ha (the dashed line is at a brush–conifer ratio of 1.5, which defines countable aspen in spruce and Douglas-fir neighbourhoods according to revised guidelines) at SBSdw1/SBSdw2 verification sites.*

other members of the Working Group. At each juncture, interim progress and recommendations were discussed with B.C. Ministry of Forests, Lands and Natural Resource Operations personnel at District, Region, and Branch levels, and the feedback we received was incorporated into our work.

Those we consulted acknowledged that our recommendations were based on solid research at stand ages for which we had data, but there was some concern that the proposed revision to guidelines would not meet FRPA test 5, that of consistency with Timber Supply Review. This issue had been addressed earlier for the SBPSxc and the IDFdk4 to the satisfaction of the Chilcotin and Central Cariboo District Managers, largely on the basis that the benefits of aspen retention would outweigh any small risk of reduced timber supply (Misener 2009[12]). This reasoning was also accepted for the IDFdk3, where aspen is not a productive tree species. We had greater difficulty addressing the issue for the more productive SBSdw1/SBSdw2, where

12 Misener, B. 2009. Supporting rationale document, Central Cariboo and Chilcotin Forest Districts, IDFdk4 and SBPSxc District policy. B.C. Min. For. Range, Williams Lake, B.C. Unpubl. rep.

aspen potentially has harvestable volume at rotation age (B.C. Ministry of Forests, Lands and Natural Resource Operations 2013).

Although modelling tools to predict mixedwood stand development exist, we maintain that they do not adequately address the spatial arrangement and dynamic nature of broadleaf–conifer mixtures at very young stand ages; this is particularly true for young stands where aspen is present at low densities. Attempts to model the growth of mixed pine–aspen stands for the SBSdw1/SBSdw2 had suggested that retaining 1000 aspen/ha would result in mixed broadleaf–conifer stands at maturity. This would be in conflict with timber supply review criteria unless mixedwood management was defined as an acceptable option, which is uncommon for most sub-boreal management units. These modelling predictions strongly contradicted our extensive observation that aspen is not a vigorous competitor at such a low density. Models such as the Tree and Stand Simulator (TASS) are based on the assumption of competition for growing space, and when a density of 1000 aspen stems/ha is specified, the model assumes that those trees are growing vigorously and are regularly spaced. In fact, due to its clonal nature, aspen has a clumpy distribution, and where it is growing under conditions such that no more than 1000 stems/ha exceed 125–150% the crop conifer height at age 8–12 years (the age when free-growing surveys are usually conducted), we have consistently observed that it is not growing vigorously. Instead, aspen tends to be increasing in height more slowly than pine, which suggests that it will be out-competed by pine as stand development proceeds. Our recommendations are based on research conducted on sites that, because they were selected to meet the statistical requirement for random treatment plot allocation, consistently had more vigorous aspen than was typical of the relatively low densities we were concerned with at typical operational sites (as measured in verification plots) (Figure 8). We have a high level of confidence that the presence of 1000 countable aspen at free-growing age will not result in mature mixedwood stands. However, even if this assumption is incorrect for some sites, the risk to timber supply is extremely small because, proportionally, brushing activities affect only a small fraction of the THLB. To put this in perspective, the THLB for the Williams Lake, 100 Mile, and Quesnel TSAs is approximately 3.6 million hectares; historical records[13] indicate that brushing activity (most of which concerned aspen) in the subzones/variants we dealt with in this project affected about 2% of this area between 1988 and 2012. Assuming that brushing continues at the same rate during the next three decades, the overall risk that conservative adjustment of free-growing guidelines will negatively affect timber supply is very small.

Once our recommended adjustments to free-growing guidelines were accepted in principle, it was agreed that they should be implemented at the provincial level. In 2013, Working Group researchers began working with the Ministry representative[14] responsible for annual revision to the *Silviculture Survey Procedures Manual*, in which free-growing guidelines are presented (B.C. Ministry of Forests, Lands and Natural Resource Operations 2016). A decision was reached that revisions to Cariboo Region free-growing guidelines would be presented as an acceptable alternative to existing guidance

13 From the B.C. Ministry of Forests, Lands and Natural Resources Reporting Silviculture Updates and Land status Tracking System (RESULTS) database (accessed Mar. 2013).

14 Dave Weaver, Silviculture Performance Assessment Specialist, B.C. Ministry of Forests, Lands and Natural Resources, Harvesting and Silviculture Practices Branch, Victoria, B.C.

within that region, and that the process of change would be considered a pilot that could guide change to guidelines in other areas of the province. Free-growing guidance is organized into separate sections referred to in the *Silviculture Survey Procedures Manual* as North, South, and Coast Areas of British Columbia, and by TSA within those Areas. We decided to limit our recommendations to the Williams Lake, Quesnel, and 100 Mile TSAs in the South Area. We also had to state clearly which ecosystems the revised guidelines applied to. The ecological field guide for the Cariboo Region lists a total of 40 biogeoclimatic subzones/variants (Steen and Coupé 1997), but revisions to free-growing guidelines would apply only to the SBPSxc, IDFdk4, IDFdk3, SBSdw1, SBSdw2, SBPSmk, and SBPSdc where our research and verification studies had taken place.

Although our work on this project had focussed on zonal sites (site series 01), we recognized that in order for recommendations to be operationally useful, they had to encompass all site series that occur within those seven subzones/variants. We reasoned that since aspen does not thrive on dry sites (Klinka et al. 2000), our recommendations could logically be extended to include drier than mesic site series. Aspen is a more vigorous competitor under conditions of greater moisture availability, but it does not develop in all high-moisture site series, and these units are often scattered and small. We identified site series where aspen commonly contributes to post-harvest vegetation by referring to tables that had previously been compiled with the help of the Cariboo Region ecologist[15] for another project.[16] This work indicated that aspen-dominated vegetation was uncommon on wetter site series in the SBPSmk and SBPSdc but was common in site series 06 and 07 in the SBSdw1 and 08 and 09 in the SBSdw2. We then referred to Steen and Coupé (1997) and determined that, for the most part, these site series occur in areas smaller than 1 ha. This suggested that there was little risk attached to applying our recommended allowable density of 1000 stems/ha across all sites series in these subzones/variants. We reasoned that these small areas would rarely be stratified out in surveys, and where they were, our revisions would have little effect; if aspen was vigorous, the countable density would exceed 1000 stems/ha and brushing would be required. For the IDFdk3, where we were recommending a substantial increase in the allowable density for mesic and drier site series (from 1000 to 3000 stems/ha), we were less certain that 3000 highly vigorous aspen/ha would not have a negative effect on conifer growth in wetter site series. Steen and Coupé (1997) indicated that wetter site series in the IDFdk3 were also generally small, but we nonetheless recommended that they should be subject to an allowable density limit of 1000 stems/ha, the same as we were suggesting for wetter site series in the SBSdw1/SBSdw2, SBPSmk, and SBPSdc.

Several ICH and moist SBS variants also occur in the Cariboo Region, but conifer–broadleaf mixtures that develop in those areas generally include paper birch, which is beyond the scope of our research; therefore, we make no recommendation for change to free-growing guidelines in these ecosystems. Neither did we make recommendations for the SBPSmc, which has relatively minor presence at the northeastern boundary of the Cariboo Re-

15 Ray Coupé, Research Ecologist (retired), Cariboo Region, B.C. Ministry of Forests, Lands and Natural Resource Operations.

16 Expert System for Site Preparation and Vegetation Management in Southern Interior British Columbia. Forest Investment Account Project Y073021 (www.for.gov.bc.ca/hfd/LIBRARY/FIA/HTML/FIA2007MR358.htm).

gion. Although our research could likely be extended to include this subzone, most of its area is under North Area free-growing guidance, and we hesitated to make recommendations without appropriate consultation with government personnel in that region. We did, however, decide to extend our IDFdk3 recommendations to the small amount of IDFdk1 that occurs at the southern limits of the Cariboo Region. Recommendations for the IDFdk1 were included based on work that was done in the Kamloops Region in 2013 to examine free-growing guidance for that biogeoclimatic unit (Heineman and Newsome 2014[17]). That project clearly demonstrated that aspen in the IDFdk1 had similar or lesser competitive ability in relation to lodgepole pine than had been observed in the IDFdk3, and that similar adjustment to guidelines would be appropriate. We lacked sufficient time to engage in the level of consultation with Kamloops Region personnel that could lead to guideline adjustment for the IDFdk1 in that region, but we hope the Cariboo Region changes will help justify requests to deviate from current Kamloops Region IDFdk1 guidance.

4.2 An Alternative Survey Procedure

As well as making recommendations for adjustment to the individual criteria that make up free-growing guidelines concerning broadleaves, we proposed an alternative survey approach that would be easier to use than the existing procedure and that would eliminate the need to consider "potentially free-growing" trees (B.C. Ministry of Forests, Lands and Natural Resource Operations 2016). In the alternative procedure, well-spaced conifers are still identified within the 3.99-m (50-m^2) survey plot, and broadleaf tree and other vegetation presence within the 1-m cylinder is assessed in the same way as in the standard method. The main difference between the standard and alternative survey procedures is that, with the alternative approach, countable broadleaves are assessed based on their presence within a 1.8-m radius (~10 m^2) neighbourhood around individual crop conifers rather than in the entire 3.99-m radius plot. Our suggested approach eliminates the possibility that broadleaf trees as much as 6–7 m from well-spaced conifers will affect their free-growing status. Since most of our proposed changes to individual free-growing guidelines are based on EP1152 research that examined lodgepole pine–aspen competitive relationships within 1.78-m (exactly 10 m^2) neighbourhoods, it seemed logical to directly apply this criterion. We reasoned that in a 50-m^2 plot that was fully stocked with well-spaced conifers, 1.8-m radius neighbourhoods around six or more trees occupy almost all the survey plot area, and in some cases, they extend beyond the perimeter of the 3.99-m plot. Diagrams illustrating this concept and a full description of the revised survey procedure are provided in Appendix 13 of the *Silviculture Survey Procedures Manual* (B.C. Ministry of Forests, Lands and Natural Resource Operations 2016).

4.3 Field Testing Recommended Adjustments to Cariboo Region Free-growing Guidelines

A pilot project to field test our recommended changes to free-growing guidance for the Cariboo Region was conducted in the Williams Lake TSA in 2014. Our objectives were to test the recommended adjustments to guidelines for the IDFdk3, SBSdw1, SBSdw2, SBPSmk, and SBPSdc, and to test the alternative survey procedure. The sampling project was designed by Cariboo researchers and was conducted on sites under the management of

17 Heineman, J.L. and T.A. Newsome. 2014. Interpreting and verifying research findings in support of adjusting free growing guidelines concerning trembling aspen in the IDFdk1 and IDFdk2. B.C. Min. For., Lands Nat. Resource Ops., Victoria, B.C. Unpubl. rep.

Tolko Industries Ltd. (Williams Lake), West Fraser Mills Ltd. (Williams Lake), and BC Timber Sales (BCTS) (Williams Lake). Data were collected by five experienced survey contract companies that regularly work for Tolko, West Fraser, or BCTS. The selected sites had not previously received brushing treatments, and were scheduled for operational free-growing surveys. Each had at least one identified stratum where the presence of broadleaves (primarily aspen) was a potential impediment to meeting free-growing requirements (i.e., areas ≥ 1 ha that had been typed out as potentially requiring brushing for aspen). Participating survey contractors were given a 1-day training course and were asked to conduct surveys in the strata containing aspen according to three sets of criteria: (1) using current guidelines and the current survey procedure (for the IDFdk3, this survey approach used guidelines that had been in place prior to the interim recommendations in 2013), (2) using revised guidelines and the current survey procedure, and (3) using revised guidelines and the alternative survey procedure. The objectives were to:

- compare the proportion of trees and plots in each sampled subzone/variant that met free-growing according to current and revised guidelines;
- examine the relative effect that adjustment to individual criteria (e.g., brush–conifer ratio, allowable number of occupied quadrants, allowable density) was having;
- field test the proposed new guidelines for operational practicality;
- compare free-growing outcomes using current survey procedure with the alternative 1.8-m neighbourhood survey procedure, and field test the alternative survey procedure for practical use; and
- establish permanent plots where the effects of the proposed changes to free-growing guidelines can be monitored over time.

Full results of the field testing conducted in 2014 are presented by Heineman and Newsome (2016[18]); here, we briefly summarize the main findings. The extent to which our recommended changes affected free-growing outcomes varied by biogeoclimatic subzone/variant and regeneration species. The effect was greatest in the SBSdw2, where the proportion of well-spaced trees that were free-growing increased from 38 to 82% for lodgepole pine and from 22 to 69% for hybrid spruce. In other subzones/variants, increases in the proportion of trees that were free-growing ranged from 15 to 25%. Revisions to criteria related to the number of occupied quadrants within a 1-m cylinder had the greatest effect on outcomes in the IDFdk3 and the SBPSdc, whereas changes to the allowable number of countable aspen were most important in the SBPSmk, SBSdw1, and SBSdw2. It made very little difference to free-growing outcomes whether the revised guidelines were applied using the alternative or standard survey procedure, but surveyors anecdotally commented that once they were used to it, the alternative procedure was easier and quicker to use.

Sampling was conducted on a total of 33 strata on 27 sites. Of the 504 ha that were surveyed for this project, 126 ha required brushing according to current free-growing guidelines compared with 35 ha using the revised guidelines (Table 13). According to current guidelines, brushing was required on 12 of the 33 strata that were surveyed, but under the revised guidelines,

18 Heineman, J.L. and T.A. Newsome. 2016. Pilot project to test revision to Cariboo free growing guidelines 2014: a summary of methods and results (EP1152.11). B.C. Min. For., Lands Nat. Resource Ops., Victoria, B.C. Unpubl. rep.

TABLE 13 *Free-growing outcomes using current or revised guidelines for surveyed area[a] in the 2014 Cariboo Region free-growing field testing project and the effects of guideline change on the overall Cariboo Region brushing program in 2014–2015*

	Area surveyed in 2014 field testing project								Total Cariboo Region brushing program 2014–2015[b]		
			Number of surveyed strata requiring brushing		Surveyed area requiring brushing (ha)		Proportion of surveyed area requiring brushing (%)		Total area requiring brushing (ha)[c]		
Biogeoclimatic unit	**Area surveyed (ha)**	**Number of strata surveyed**	**Current**	**Revised**	**Current**	**Revised**	**Current**	**Revised**	**Current**	**Revised**	**Proportional reduction in total area requiring brushing due to guideline adjustment (%)[d]**
IDFdk3	148	13	5	1	20	10	13	6	168	158	6
SBPSdc	35	2	1	1	3	3	7	7	54	54	0
SBPSmk	125	4	1	0	34	0	27	0	130	96	26
SBSdw1	102	7	3	2	42	23	41	22	85	66	22
SBSdw2	94	7	2	0	28	0	30	0	98	70	29
All units	504	33	12	4	126	35	25	7	535	444	17

a Selected strata were scheduled for operational free-growing surveys by Tolko Industries Ltd., West Fraser Mills Ltd., or BC Timber Sales in 2014. Surveys were deemed necessary due to uncertainty about whether free-growing could be met without brushing; sites where brushing was clearly needed were not included in the project. The numbers in this table in columns headed "Area surveyed in 2014 field testing project" therefore represent only a portion of Cariboo Region brushing in 2014.

b The total Cariboo Region brushing program includes area where brushing was determined to be necessary based on free-growing surveys and area where brushing was prescribed based on a walk-through assessment.

c These values were derived from the average for 2014 and 2015 because brushing programs in 2014 were somewhat disrupted by the pilot project.

d Calculated by dividing the reduction in area resulting from the guideline revision by the total area that would require brushing under current guidelines.

brushing was required on only four strata. The differences were most profound in the SBPSmk and SBSdw2, where none of the surveyed strata required brushing according to the revised guidelines. Revisions to the guidelines approximately halved the amount of surveyed area that required brushing in the SBSdw1 but made no difference in the SBPSdc (where only two sites had been sampled). In the IDFdk3, only 13% of the surveyed area (20 ha) required brushing, even under current guidelines. This small area was distributed across five sites, however, and revisions removed the need to brush small (1–4 ha) areas at four of these sites.

It is important to recognize that the area reported above does not represent the entire brushing program for the Cariboo Region; formal free-growing surveys are expensive, and under standard operational procedure, they are not conducted prior to brushing on sites where operational foresters can easily see that brushing is required. The sites that were part of this project were borderline cases where the decision to brush or not brush could not be made without a formal survey. In 2014, surveys were conducted on approximately one-quarter of the area that required brushing under current guidelines (Table 13). When the total area within the Cariboo Region (averaged over 2014/2015) that required brushing was considered, revisions to free-growing guidelines reduced it by 6% in the IDFdk3, 26% in the SBPSmk, 22% in the SBSdw1, and 29% in the SBSdw2; there was no reduction in the SBPSdc.

5 DISCUSSION

This project resulted in adjustment to free-growing guidance concerning broadleaf tree (mainly trembling aspen) retention in juvenile stands for seven Cariboo Region biogeoclimatic subzones/variants. The work used ecosystem-specific research to adjust free-growing criteria to levels that were closer to the biological thresholds for conifer growth than those that were previously in place. The changes are expected to reduce the need for brushing on sites where it is not biologically necessary to meet conifer growth objectives but not to reduce brushing activity on sites where broadleaves are impeding, or expected to impede, conifer growth. Based on research conducted in stands up to 34 years old, we believe that the risk to timber supply that will result from these changes to free-growing guidance is minimal, and that it is far outweighed by the positive effects of increased broadleaf tree retention on ecosystem health, and also by reduced brushing costs.

The process of moving operational research results through to administrative implementation is not straightforward. This is particularly true of forest research projects where data collection continues over many years, during which time administrative and management goals often shift from those that originally set the project in motion. Even when researchers consider the project to be finished—that is, when they have published their findings and extended results to the operational community—there may be a gap between knowledge acquisition and government policy or guidance change that prevents the findings from being implemented on an operational basis. Our experience with this project suggests that we lack a clearly defined process for incorporating research into policy, and that this is compounded by a shortage of operational specialists whose responsibility it is to lead and facilitate change.

Determining how far research results can be extended, and taking steps to ensure a smooth operational transition when policy change does occur, is a time-consuming process. This is particularly true when the changes potentially affect a range of resource values and require input from the associated managers and specialists. For the most part, neither researchers nor provincial policy-makers who must address these issues on a much wider scale have the capacity to address these issues without support. In this project, the Cariboo Region researcher and a private research consultant (whose time was funded by industry Working Group partners) together took on such tasks associated with this project. These included verifying the extent to which their research could be applied at the landscape level, consulting with District and Regional staff concerning legislative and practical details, and liaising with specialists at the Branch level regarding the incorporation of the recommendations into provincial guidance.

Policy change can take place at different scales. As the Cariboo Region free-growing project unfolded, the Working Group had to decide whether it was most practical to attempt change at the level of the licensee forest stewardship plan, at the District level, or at the Branch (provincial) level. Participants generally agreed that change to government free-growing guidance was preferable because it would be easier to apply over the long term and would allow the most flexibility. Change at the provincial level was favoured, but it was agreed that this should not be undertaken until work in all subzones/variants had been completed. Some Working Group members expressed concern that a perceived need to maintain consistency in free-growing guidance throughout interior British Columbia could stall change at the provincial level.

Early in this project, interim implementation issues were evaluated at the local (District) level. However, as work in the ecosystems of interest neared completion, we required the involvement of the provincial staff member responsible for survey procedures in order to move forward with realizing change at the provincial level. As described in Section 4.1, the provincial Silviculture Performance Assessment Specialist became actively involved in 2012. He participated in the implementation process and drafted change to the 2015 *Silviculture Survey Procedures Manual* to recognize the revised guidelines as an acceptable alternative to previous guidance for the Williams Lake, 100 Mile, and Quesnel TSAs (B.C. Ministry of Forests, Lands and Natural Resource Operations 2016). We emphasize that acceptance of our recommendations was facilitated by the fact that, during the 6 years of this project, we had provided Resource Practices Branch personnel with regular updates in the form of meetings, presentations, and field trips. This process cultivated understanding of the concepts underlying our work and increased the level of comfort regarding the adjustments we were recommending.

This project has given us valuable insight into the process by which research can be implemented as government guidance or policy, and we make several suggestions that may be of use if similar work is undertaken in other parts of British Columbia. First, we stress the importance of forming a cohesive Working Group led by either a government researcher or an extension specialist who has regular contact with a government researcher. A high degree of co-operation and knowledge sharing exists within the Cariboo Region forestry community, but even so, a strong government link was necessary to guide this project through to completion. For this project, the government researcher ensured continuity of individual experiments that were conducted over more than two decades, independently evaluated research findings, assessed the appropriateness of extending them across the ecosystem in question, and made recommendations to policy-makers.

Secondly, we recommend making use of existing research and expert knowledge. In this project, we focussed on Cariboo Region ecosystems where trembling aspen is the dominant broadleaf species that develops following harvest. Due to a lack of both time and local research, we did not investigate conifer–broadleaf relationships in Cariboo ecosystems (mainly the ICH zone) where paper birch can be more common; however, we anticipate that there will be requests for adjustment to free-growing guidance from other parts of the province, and that many of these will involve paper birch. Considerable research concerning juvenile birch–conifer stands is available for southern regions of British Columbia (e.g., Simard et al. 2001; Simard et al. 2005), and this work could be used to assist with developing biologically appropriate adjustments to free-growing guidelines in a range of ecosystems. Likewise, existing research could be examined to determine whether it is appropriate to consider extending Cariboo Region recommendations for aspen–conifer mixtures further north (e.g., DeLong 2007).

Thirdly, concepts that were broadly applicable in the Cariboo Region could be examined for relevance in other regions. For example, we found that it was appropriate to make universal adjustments to free-growing criteria related to the broadleaf–conifer height ratio that defines occupied quadrants and countable broadleaves, and to the allowable number of occupied quadrants. These relationships may hold true in other ecosystems and for other species mixtures; we suggest that these concepts be further explored by research staff in different parts of the province to determine if similar changes may be applicable throughout the province.

Finally, if adjustment to free-growing guidelines concerning broadleaf trees is attempted in a specific region, we recommend initially focussing on subzones/variants where research and anecdotal evidence suggest that the broadleaf species in question has low or intermediate competitive ability. We found that these ecosystems warranted the largest adjustment to the allowable density of countable broadleaves, and that there was little objection to change where the broadleaves were not likely to become productive trees that could affect timber supply.

We stress that the revised free-growing guidelines apply only to sites that have not previously been brushed or subjected to broadleaf tree spacing. Broadleaf tree sprouts or suckers can grow vigorously for a number of years following manual cutting (Haeussler et al. 1990), and the revised guidelines are not appropriate for addressing this phenomenon.

6 CONCLUSION

The adjustments to Cariboo Region free-growing guidelines described in this report are now in active use. Information provided by local licensees suggests that the changes have, to date, reduced annual brushing programs in this region by an average 17%. We recommend ongoing review of outcomes associated with the changes to free-growing guidelines that resulted from this project; this can be accomplished through continued monitoring of the growth and yield plots that are installed at a number of the EP1152 research sites and through remeasurement of the permanent sample plots that were established during field testing of the revised guidelines. In particular, follow-up monitoring is important for changes that concern hybrid spruce and Douglas-fir because those recommendations were made based on less research than was available for lodgepole pine.

The changes we achieved have moved individual free-growing guidelines and criteria used in the Cariboo Region closer to the actual biological thresholds for conifer growth. The adjustments will reduce the need to brush on sites where, according to research, broadleaf trees are clearly not a competitive threat to conifers. We were conservative in our application of research findings, and we intend that the adjustment to guidelines will not reduce the need to brush sites where broadleaf vegetation is vigorous and likely to impede conifer growth over the long term. Overall, we think even the slight increases in broadleaf retention that will result from this work will have a positive effect on a variety of values related to overall forest health and resiliency.

LITERATURE CITED

Brand, D.G. 1986. A competition index for predicting the vigour of planted Douglas-fir in southwestern British Columbia. Can. J. For. Res. 16:23–29.

British Columbia Ministry of Forests. 2002. Establishment to free growing guidebook – Cariboo Forest Region. Version 2.4. (Appendix 9 revised Oct. 2007). Victoria, B.C.

British Columbia Ministry of Forests, Lands and Natural Resource Operations. 2012. Timber tenures in British Columbia: managing public forests in the public interest. Victoria, B.C. www.for.gov.bc.ca/ftp/hth/external/!publish/web/timber-tenures/timber-tenures-2006.pdf. (Accessed Aug. 31, 2016)

________. 2013. Site index estimates by site series (2013 approximation). For. Resources Br., Victoria, B.C. www2.gov.bc.ca/assets/gov/environment/research-monitoring-and-reporting/research/sibec-documents/sisubyregion2013.pdf (Accessed Apr. 12, 2016).

________. 2016. Silviculture survey procedures manual: regen delay, stocking and free growing surveys plus alternative survey methodologies. Resource Pract. Br., Victoria, B.C. www.for.gov.bc.ca/hfp/silviculture/Silviculture%20Survey%20Procedures%20Manual%202016.pdf (Accessed June 14, 2016).

Comeau, P.G., J.L. Heineman, and T.A. Newsome. 2006. Evaluation of relationships between understory light and aspen basal area in the British Columbia central interior. For. Ecol. Manag. 226:80–87.

Comeau, P.G., R. Kabzems, J. McClarnon, and J.L. Heineman. 2005. Implications of selected approaches for regenerating and managing western boreal mixedwoods. For. Chron. 81(4):559–574.

DeLong, C. 2000. Planting white spruce under trembling aspen: 7-year results of seedling condition and performance. B.C. Min. For., Res. Br., Victoria, B.C. Work. Pap. 54.

_______. 2007. Relative impact of aspen competition and soil factors on the performance of lodgepole pine and hybrid white spruce in north-central British Columbia. B.C. Min. For. Range, Res. Br., Victoria, B.C. Tech. Rep. 039.

Enns, K.A., E.B. Peterson, and D. McLennan. 1993. Impacts of hardwood management on British Columbia wildlife: problem analysis. For. Can. and B.C. Min. For., Victoria, B.C. FRDA Rep. 208.

Frivold, L.H. 1985. Mixed broadleaved–coniferous stands – some silvicultural considerations. In: Broadleaves in boreal silviculture – an obstacle or an asset? B. Hahhlund and G. Peterson (editors). Sweden Univ. Agric. Sci., Dept. Silv., Umeå, Sweden, pp. 207–222.

Gerlach, J.P., P.B. Reich, K. Puettmann, and T. Baker. 1997. Species, diversity, and density affect tree seedling mortality from *Armillaria* root rot. Can. J. For. Res. 27:1509–1512.

Haeussler, S., D. Coates, and J. Mather. 1990. Autecology of common plants in British Columbia: a literature review. For. Can. and B.C. Min. For., Victoria, B.C. FRDA Rep. 158.

Hart, D. and P.G. Comeau. 1992. Manual brushing for forest vegetation management in British Columbia: a review of current knowledge and information needs. B.C. Min. For., Victoria, B.C. Land Manag. Rep. 77.

Hawkins, C.D.B., A. Dhar, and B.J. Rogers. 2012. How much birch (*Betula papyrifera*) is too much for maximizing spruce (*Picea glauca*) growth: a case study in boreal spruce plantation forests. J. For. Sci. 58 (7):314–327.

Kayahara, G.J., H.Y.H. Chen, K. Klinka, and K.D. Coates. 1996. Relations of terminal growth and specific leaf area to available light in naturally regenerated seedlings of lodgepole pine and interior spruce in central British Columbia. B.C. Min. For., Victoria, B.C. Res. Rep. 09.

Klinka, K., J. Warrall, L. Skoda, and P. Varga. 2000. The distribution and synopsis of ecological and silvical characteristics of tree species of British Columbia's forests. Canadian Cartographics Ltd., Coquitlam, B.C.

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

Morrison, D., H. Merler, and D. Norris. 1991. Detection, recognition and management of *Armillaria* and *Phellinus* root diseases in the southern interior of British Columbia. For. Can. and B.C. Min. For., Victoria, B.C. FRDA Rep. 179.

Newsome, T.A., J.L. Heineman, and A.F.L. Nemec. 2003. Competitive effects of trembling aspen on lodgepole pine performance in the SBS and IDF zones of the Cariboo-Chilcotin region of south-central British Columbia. B.C. Min. For., Victoria, B.C. Tech. Rep. 005.

_______. 2004a. Early effects of manipulating aspen density on lodgepole pine performance, aspen sucker production, and stand development in the IDFxm subzone near Williams Lake, B.C. B.C. Min. For., Victoria, B.C. Tech. Rep 015.

_______. 2004b. Lodgepole pine response to aspen removal in variable radii in the SBSdw subzone near Williams Lake, B.C. B.C. Min. For., Victoria, B.C. Tech. Rep 014.

_______. 2006a. Early effects of manipulating aspen density and spatial arrangement on lodgepole pine performance, aspen sucker production, and stand development in an 11-year-old stand in the SBPSxc subzone of south-central British Columbia. B.C. Min. For., Victoria, B.C. Tech. Rep 029.

_______. 2006b. Effects of variable aspen retention on stand development, aspen sucker production, and growth of lodgepole pine in the SBSdw1 variant of south-central British Columbia. B.C. Min. For., Victoria, B.C. Tech. Rep 032.

_______. 2008. Competitive interactions between trembling aspen and lodgepole pine in 12–24 year old stands in south-central British Columbia. For. Ecol. Manag. 255:2950–2962.

_______. 2010. A comparison of lodgepole pine (*Pinus contorta* var. *latifolia*) responses to varying levels of trembling aspen (*Populus tremuloides* Michx.) removal in two dry, cool to cold south-central British Columbia ecosystems. For. Ecol. Manag. 259:1170–1180.

_______. 2012. Identifying and characterizing important trembling aspen competitors with juvenile lodgepole pine in three south-central British Columbia ecosystems. Int. J. For. Res. Vol. 2012, Article ID 573640.

_______. 2016. Long-term results from EP841: Douglas-fir, lodgepole pine, and hybrid spruce responses to mechanical site preparation in the Interior Douglas-fir and Sub-Boreal Spruce Zones of south-central British Columbia. Prov. B.C., Victoria, B.C. Tech. Rep. 092.

Pastor, J. 1990. Nutrient cycling in aspen ecosystems. In: Aspen Symp. Proc. 1989. U.S. Dep. Agric. For. Serv., St. Paul, Minn. Gen. Tech. Rep. NC-140.

Peterson, E.B. and N.M. Peterson. 1995. Aspen managers' handbook for British Columbia. For. Can. and B.C. Min. For., Victoria, B.C. FRDA Rep. 230.

Powelson, R.A. 2012. How the use of the term "free growing" in British Columbia is linked to harvest date and assessment date. B.C. Min. For., Lands Nat. Resource Ops., Resource Pract. Br., Victoria, B.C. www.for.gov.bc.ca/hfp/silviculture/stocking_stds/How%20the%20use%20of%20the%20term%20Fg%20varies.pdf (Accessed Mar. 20, 2016).

Simard, S.W., S.M. Hagerman, D.L. Sachs, J.L. Heineman, and W.J. Mather. 2005. Conifer growth, *Armillaria ostoyae* root disease and plant diversity responses to broadleaf competition reduction in temperate mixed forests of southern British Columbia. Can. J. For. Res. 35:843–859.

Simard, S.W., J.L. Heineman, W.J. Mather, D.L. Sachs, and A. Vyse. 2001. Effects of operational brushing on conifers and plant communities in the southern interior of British Columbia: results from PROBE 1991–2000. B.C. Min. For., Res. Br., Victoria, B.C. Land Manag. Handb. 48.

Simard, S. and A. Vyse. 2006. Trade-offs between competition and facilitation: a case study of vegetation management in the interior cedar-hemlock forests of southern British Columbia. Can. J. For. Res. 36:2486–2496.

Stathers, R.J. 1989. Summer frost in young forest plantations. B.C. Min. For. and For. Can., Victoria, B.C. FRDA Rep. 73.

Steen, O.A. and R.A. Coupé. 1997. A field guide to forest site identification and interpretation for the Cariboo Forest Region. B.C. Min. For., Victoria, B.C. Land Manag. Handb. 39.

Taylor, S.P., R. Alfaro, C. Delong, and L. Rankin. 1994. Effects of overstorey shading on white pine weevil damage to interior white spruce. 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. For. Can., Victoria, B.C., pp. 254–261.

Williams, H., C. Messier, and D.D. Kneeshaw. 1999. Effects of light availability and sapling size on the growth and crown morphology of understory Douglas-fir and lodgepole pine. Can. J. For. Res. 29:222–231.

Wright, E.F., K.D. Coates, C.D. Canham, and P. Bartemucci. 1998. Species variability in growth response to light across climatic regions in northwestern British Columbia. Can. J. For. Res. 28:871–886.

Yang, R.C. 1989. Growth response of white spruce to release from trembling aspen. For. Can., North. For. Cent., Edmonton, Alta. Inf. Rep. NOR–X–302.

Verification sampling methodology varied slightly from year to year to accommodate differences in the information that was sought for individual biogeoclimatic subzones/variants and insight that had been gained in previous years' sampling.

Site Selection

Sites for each subzone/variant were selected from lists provided by Tolko Industries Ltd., West Fraser Mills Ltd., BC Timber Sales, Ainsworth Lumber Co. Ltd., or Canadian Forest Products, Ltd. with the intention that they were distributed as widely as possible across the ecosystem in question. Where multiple, suitable sites were available within a small geographic area, the site to be sampled was randomly selected. Sites that were sampled met characteristics related to time since harvest and size of the stratum to be sampled, which varied somewhat from ecosystem to ecosystem. In all cases, selected sites were zonal (site series 01), had at least one stratum that required brushing according to existing guidelines, and had no previous brushing history.

Sampling Protocol

The transect point of commencement and bearing were laid out on the map prior to commencing sampling of each site; if sufficient plots could not be sampled at the predetermined bearings, additional bearings were chosen based on on-site visual assessment of aspen presence. At each site, we sampled plots in the density classes described in Table 2. Plots were selected at transect intervals of 50 m, based on the presence of a healthy lodgepole pine tree (crop pine) that (a) had at least fair vigour (unless it was judged that the vigour decline or damage was due to aspen presence), and (b) was of an age cohort that indicated it was in the original, post-harvest wave of regeneration, whether it was planted or natural (i.e., not advance regeneration and not fill-planted).

Measurements

Crop pine

Crop pine were assessed for:

- height (current year)
- height (current year minus 1)
- height (current year minus 2)
- ground-level diameter
- vigour (*Good:* tree shows no signs of stress, has a vigorous growth rate, and has a generally healthy appearance; *Fair:* tree is under some form of stress, may have minor defects, and has a moderate growth rate; *Poor:* tree is under severe stress, may have major defects, and the growth rate is poor; *Moribund:* tree is almost dead)

Aspen

Within a 1.78-m radius around the crop pine, the following variables were assessed:

- average canopy height (called modal height)
- height of the three tallest aspen (or fewer if there were fewer than three)

- ground-level diameter of the three tallest aspen
- length of the two most recent height growth intervals for each of the three tallest aspen
- In the SBPSxc and IDFdk4 only, the density of aspen that were ≥ 1.0, ≥ 1.25, ≥ 1.5, ≥ 2.0, and ≥ 3.0 times as tall as the crop pine were counted (based on measured heights where the aspen–pine height relationship was not visually obvious).

Analysis

For each biogeoclimatic subzone/variant where verification sampling was conducted, variables describing growth rates and relative growth rates of the crop pine and neighbouring aspen were calculated and summary statistics were produced. To allow for comparison of verification sites with the Clusko or Meldrum variable density studies, similar summaries were prepared from untreated control research site data that were collected in measurement years that most closely matched verification site ages. For each variable of interest, two-sample *t* tests were done to compare the verification site mean with the research site mean.

APPENDIX 2 Location and history information for sites where verification sampling was conducted

SBPSxc and IDFdk4 sites sampled in 2010

Biogeoclimatic unit	Site no.	Regeneration method[a]	Age[b] (years)	FL[c] (or mapsheet)	CP[c]	Block (or opening)	Latitude	Longitude
SBPSxc	1	N	15	A20016	739	3	52°29.029'	124°17.958'
	2	N	13	A20018	832	332	52°12.892'	123°13.651'
	3	N	18	A20028	86Y	2	52°11.341'	124°13.813'
	4	N	15	A45026	983	6	52°26.975'	124°01.652'
	5	N	16	A45026	987	8A	52°25.229'	124°06.283'
	6	N	12	A20020	758	1	51°59.171'	123°04.485'
	7	N	12	A20020	758	3	51°59.462'	123°02.496'
	8	N	12	A55902	914	2	51°46.991'	123°19.352'
IDFdk4	9	N	14	A20019	06H	1	51°38.852'	122°41.897'
	10	N	16	A45024	945	1	51°58.928'	123°36.029'
	11	N	12	A20020	972	3	51°48.200'	122°57.748'
	12	N	15	A20020	967	3	51°53.647'	123°12.352'
	13	N	21	92O 065	–	33	51°41.366'	123°0.016'
	14	N	15	A51708	900	076-236	51°43.933'	122°57.313'

a N: natural regeneration; there was no site preparation.

b Time since harvest.

c FL: forest licence; CP: cutting permit.

IDFdk3 sites sampled in 2010 and 2011

Year sampled	Site no.	Site preparation	Regeneration method[a]	Age[b] (years)	FL[c] (or mapsheet)	CP[c]	Block (or opening)	Latitude	Longitude
2010	15	Chain drag	N	10	A20020	775	6	52°09.263'	122°41.444'
	16	Manual slashing	N	10	A20003	135	3	51°22.553'	121°43.684'
	17	Broadcast burn	N	8	A20018	481	1	52°05.370'	121°49.691'
	18	Manual slashing	N	10	A20003	135	5	51°22.153'	121°39.339'
	19	Chain drag	N	8	A20020	798	11	52°08.744'	122°43.292'
	20	Chain drag	N	9	A20020	3	141-06-00	52°10.980'	122°42.045'
	21	None	N	8	A20018	465	1	52°04.420'	121°43.839'
	22	None	N	8	A20003	067	1	51°34.286'	121°57.184'
2011	1	None	P	12	A59048	–	A	51°13.679'	121°31.235'
	2	Shark fin drag	N	12	A59100	–	1	51°18.746'	121°24.688'
	3	Chain drag	N	7	A20020	605	4	52°18.950'	122°29.379'
	4	None	N	14	A43902	A	4	52°12.697'	122°38.007'
	5	None	N	8	A51793	–	2	52°20.457'	122°31.697'
	6	None	N	8	A51793	–	3	52°19.945'	122°32.136'
	7	None	N	9	A20015	552	WBH001	52°23.399'	122°26.299'
	8	None	P	9	A20015	552	WBH022	52°21.272'	122°25.569'
	9	None	P	9	A20002	424	13	51°11.882'	121°30.715'

a N: natural regeneration; P: planted.

b Time since harvest.

c FL: forest licence; CP: cutting permit.

SBSdw1/SBSdw2 sites sampled in 2011

Site no.	Site preparation	Regeneration method[a]	Age[b] (years)	FL[c] (or mapsheet)	CP[c]	Block (or opening)	Latitude	Longitude
10	Disc trench 2005	P (70% Pl; 30% Sx)	6	A20001	550	1	51°47.612'	121°07.506'
11	Disc trench 2005	P (75% Pl; 25% Sx)	6	A20001	509	4	52°00.568'	121°13.185'
17	Disc trench 2003	P (57% Pl; 43% Sx) plus N (Fd)	8	A20017	576	4	52°40.716'	122°08.833'
Sausser[d]	None	P (44% Pl; 46% Sx; 10% Fd)	8	A20015	15M	HAK036	52°15.000'	121°33.000'
15	None	P (50% Pl; 28% Sx; 21% Fd)	9	A20015	11M	2	52°14.422'	121°40.994'
14	None	N	10	A20018	527	2	52°18.865'	121°54.320'
16	None	N	11	A20018	527	2	52°25.972'	122°09.232'
12	None	N	12	A51835	–	5	52°21.556'	121°58.332'
13	None	N	13	A49496	A	A	52°17.931'	121°14.252'

a N: natural regeneration; P: planted; Pl: lodgepole pine; Sx: spruce hybrid; Fd: Douglas-fir.

b Time since harvest.

c FL: forest licence; CP: cutting permit.

d Sausser is one of the adaptive management (EP1152.09) research sites; verification sampling was conducted in the >10 ha untreated treatment unit, outside the experimental measurement plot.

SBPSmk and SBPSdc sites sampled in 2012

Biogeoclimatic unit	Site no.	Site preparation	Regeneration method[a]	Age[b] (years)	FL[c] (or mapsheet)	CP[c]	Block (or opening)	Latitude	Longitude
SBPSdc	20	None	P	12	A57713	43U	1	52°45.710'	122°58.363'
	21	None	N	10	A61546	1	3	52°48.320'	122°59.522'
	22	None	P	8	A68219	041	1	52°52.033'	123°02.077'
	23	None	P	8	A20011	390	2	52°55.644'	123°32.190'
	24	None	P	7	A67546	705	1	53°06.744'	124°09.985'
	25	None	N	10	A61546	1	2	52°48.216'	122°59.247'
	26	None	P	10	A20020	106	17	52°11.620'	123°40.898'
	27	Chain drag 2003	N	9	A20020	793	6	52°20.766'	122°51.460'
SBPSmk	28	None	N	10	A68555	J	1	52°02.060'	121°42.572'
	29	None	P	10	A20018	436	4	52°09.224'	121°26.384'
	30	None	P	10	A66685	–	1	52°50.118'	122°49.260'
	31	None	N	10	A42998	T	2	52°32.968'	122°47.671'
	32	Disc trench 2005	P	8	A72320	–	1	52°12.393'	121°31.019'
	33	None	P	10	A50655	V	1	52°52.195'	122°52.443'
	34	None	N	12	A20018	441	1	52°07.528'	121°29.800'
	35	None	P	13	A20018	439	4	52°06.707'	121°28.107'
	14 km[d]	None	P	10	A20018	452	2	52°11.030'	121°40.160'
	Miner[d]	Dragged 1997	P	13	A20018	434	3	52°10.240'	121°32.120'

a N: natural regeneration; P: planted.

b Number of years since last harvest or site preparation disturbance.

c FL: forest licence; CP: cutting permit.

d 14 km and Miner are adaptive management (EP1152.09) research sites; verification sampling was conducted in the > 10 ha untreated treatment unit, outside the experimental measurement plot.