Abundance of secondary structure in lodgepole pine stands affected by the mountain pine beetle in the Cariboo–Chilcotin

K.D Coates[1], T. Glover[1], B. Henderson[2]

Mountain Pine Beetle working paper 2009-20

[1]British Columbia Forest Service, Forest Sciences, Bag 6000, Smithers, BC V0J 2N0

[2]Bulkley Valley Centre for Natural Resources Research and Management
1188 Main St., Smithers, BC V0J 2N0

Mountain Pine Beetle Program Project # 7.22

Natural Resources Canada
Canadian Forest Service
Pacific Forestry Centre
506 West Burnside Road
Victoria, British Columbia V8Z 1M5
Canada

2009

Library and Archives Canada Cataloguing in Publication

Coates, K. Dave
Abundance of secondary structure in lodgepole pine stands affected by the mountain pine beetle in the Cariboo-Chilcotin [electronic resource] / K.D. Coates, T. Glover, B. Henderson.

(Mountain pine beetle working paper ; 2009-20)
"MPBP Project # 7.22".
Includes bibliographical references.
Type of computer file: Electronic monograph in PDF format.
Issued also in printed form.
Includes abstract in French.
ISBN 978-1-100-13454-3
Cat. no.: Fo143-3/2009-20E-PDF

1. Mountain pine beetle--British Columbia--Cariboo Region. 2. Lodgepole pine--Diseases and pests--British Columbia--Cariboo Region. 3. Understory plants--British Columbia--Cariboo Region. 4. Forest management--British Columbia--Cariboo Region. 5. Forest ecology--British Columbia--Cariboo Region. I. Glover, T II. Henderson, B III. Pacific Forestry Centre IV. Title. V. Series: Mountain Pine Beetle Initiative working paper (Online) 2009-20

SB945 M78 C62 2009 634.9'7516768 C2009-980228-7

Abstract

The extent and abundance of secondary structure was studied in the Cariboo–Chilcotin region of the central interior of British Columbia. Plots were selected from age class 4 and higher pine stands in the Quesnel, Williams Lake, and 100 Mile House Timber Supply Areas. A total of 1,649 plots were established, of which 1,109 were determined to be pine-leading. Secondary structure included all understorey and overstorey trees that survive the current mountain pine beetle epidemic. All lodgepole pine trees 7.5 cm in diameter or greater were assumed to die in the epidemic. The forest health status of a large dataset of individual trees was also summarized.

Secondary structure was abundant in all biogeoclimatic zones of the Cariboo–Chilcotin and was consistent with pine-leading stands elsewhere in British Columbia. Conifer seedlings and saplings had a median density of 1800 stems per ha. This varied from a high of 4,700 stems per ha in the Engelmann Spruce–Subalpine Fir zone to a low of 1019 stems per ha in the Sub-Boreal Spruce zone. Across all ecological units, about 70% of sample plots in pine-leading stands exceeded a 1000 stems per ha threshold for understorey conifer seedling and sapling density. Species composition of the understorey tree layer varied considerably in each biogeoclimatic zone. Lodgepole pine was by far the most common understorey tree species in the Montane Spruce and Sub-Boreal Pine–Spruce zones (79% and 74%, respectively). About 34% of all plots had at least 5 m^2 ha^{-1} of secondary structure basal area, varying from 25% in the Montane Spruce zone to 57% in the Engelmann Spruce–Subalpine Fir zone. Substantial amounts of the secondary structure basal area were found on non-merchantable stems.

The relationship between overstorey pine basal area and non-merchantable secondary structure basal area was weak. Assumptions about non-merchantable secondary structure basal area cannot be based on the proportion of overstorey pine basal area.

There was also little evidence to support a relationship between the average piece size of lodgepole pine and the basal area of non-merchantable secondary structure. Across the ecological units, 31%–68% of pine-leading stands currently have secondary structure equivalent to or better than a 20-year-old pine plantation.

The forest health of secondary structure was examined. Damage data are difficult to summarize, as not all damage agents are equal. Understorey pine trees (seedlings and saplings) averaged 3.3% infection by mistletoe across all ecological units. Fewer than 10% of all understorey pine trees were damaged, whereas just fewer than 20% of all understorey interior spruce were, though often of a minor nature. Sub-canopy and canopy secondary structure trees (non-pine species) had similar or more damage than the same species in the understorey.

The variable levels of secondary structure found in the Cariboo–Chilcotin provide considerable management flexibility. The suitability of managing the secondary structure will depend on the value being considered (e.g., timber supply and hydrological recovery period).

Keywords: Mountain pine beetle, timber supply, conservation, stand structure.

Résumé

L'étendue et l'abondance de la structure secondaire ont été étudiées dans la région Cariboo–Chilcotin de la Colombie-Britannique centrale-intérieure. Des parcelles de peuplements de pins ont été sélectionnées à partir d'une classe d'âge de quatre ans et plus dans les zones d'approvisionnement forestier de Quesnel, Williams Lake et du 100 Mile House. Au total, 1649 parcelles ont été constituées, desquelles 1109 étaient majoritairement composées de pins. La structure secondaire est composée d'arbres du sous-étage et de l'étage dominant qui survivent à l'épidémie actuelle du dendroctone du pin ponderosa. Tous les pins tordus latifoliés de 7,5 cm ou plus de diamètre étaient présumés avoir succombé à l'épidémie. Un résumé de l'état sanitaire de la forêt d'un vaste ensemble de données d'arbres isolés a aussi été effectué.

La structure secondaire était abondante dans toutes les zones biogéoclimatiques de la région Cariboo–Chilcotin et correspondait aux résultats obtenus dans les autres régions de la Colombie-Britannique où les peuplements à prédominance de pins ont été étudiés. La densité moyenne de semis d'arbres résineux et de gaules dans la région Cariboo–Chilcotin était de 1 800 tiges à l'hectare. Ceci représente une fluctuation du point culminant de 4 700 tiges à l'hectare dans la zone d'épinettes d'Engelmann et de sapins subalpins au point le plus bas de 1 019 tiges à l'hectare dans la zone de l'épinette subboréale. Dans l'ensemble des unités écologiques, environ 70 % des parcelles d'échantillonnage des peuplements majoritairement composés de pins ont dépassé un seuil de 1 000 tiges à l'hectare pour les semis de conifères du sous-étage et la densité des gaules. La composition de la strate d'arbres du sous-étage variait considérablement dans chaque zone biogéoclimatique. Le pin tordu latifolié était de loin l'essence d'arbres du sous-étage la plus répandue dans les zones de forêts alpestres d'épicéas et de pins subboréaux (79 % et 74 %, respectivement). Environ 34 % de toutes les parcelles avaient ou dépassaient 5 m^2 ha^{-1} de surface terrière de structure secondaire. Ceci représente une fluctuation de 25 % du point le plus bas des parcelles dans la zone d'alpestres d'épicéas à 57 % au point culminant dans la zone d'épinettes d'Engelmann et de sapins subalpins. Des quantités substantielles de surface terrière de structure secondaire ont été trouvées sur des tiges non vendables.

La relation entre la surface terrière du pin de l'étage dominant et la surface terrière de la structure secondaire était faible. Les présomptions concernant la surface terrière de la structure secondaire non vendable ne peuvent être fondées sur la proportion de la surface terrière du pin de l'étage dominant.

Il y a aussi peu d'éléments probants pour valider une relation entre la taille moyenne d'un pin tordu latifolié et la surface terrière de la structure secondaire non vendable. Dans l'ensemble des différentes unités écologiques, entre 31 % et 68 % des peuplements majoritairement composés de pins ont actuellement une structure secondaire équivalente ou supérieure à une pineraie de 20 ans.

L'état sanitaire de la structure secondaire de la forêt a été étudié. Les données relatives aux dommages sont difficiles à résumer, car les agents responsables des dommages ne sont pas d'égale nature. Les pins du sous-étage (semis et gaules) ont une moyenne de 3,3 % d'infestation par le gui pour l'ensemble de toutes les unités écologiques. Moins de 10 % de tous les pins du sous-étage avaient une certaine sorte de dommage, bien qu'à peine un peu moins de 20 % de tous les épicéas du sous-étage de l'intérieur aient eu une certaine sorte de dommage, mais d'ordre secondaire la plupart du temps. Les arbres de la structure secondaire sous le couvert forestier et dans le couvert forestier (d'essences autres que le pin) avaient des niveaux similaires ou plus élevés de dommages que les arbres du sous-étage de la même essence.

Les niveaux variables de structure secondaire étudiés dans la région de Cariboo–Chilcotin présentent une considérable latitude de gestion. La pertinence de la gestion de la structure secondaire sera fonction de la valeur prise en compte (p. ex., l'approvisionnement forestier et le temps de remplacement hydrologique).

Mots clés : Dendroctone du pin ponderosa, approvisionnement forestier, conservation, structure de peuplement.

Table of Contents

List of Tables

List of Figures

1 Introduction

The term *secondary structure* was coined as a way to describe the abundance, composition and distribution of trees that will remain alive in stands impacted by the mountain pine beetle (MPB, *Dendroctonus ponderosae* Hopkins) epidemic (Coates et al. 2006). The epidemic has been killing extensive swaths of lodgepole pine in the interior forests of British Columbia since the late 1990s.

Secondary structure can be broken into two main components: understorey and overstorey trees. Understorey trees include seedlings and saplings and can include smaller lodgepole pine trees that survive the epidemic. Overstorey trees that survive the beetle epidemic are typically of non-host species (e.g., interior spruce, subalpine fir, Douglas-fir, or broadleaf species). Overstorey pine can and will survive through the current epidemic; however, numbers will be highly variable and unpredictable. For the purpose of this report, we will take a conservative approach and not include any overstorey pine trees (sub-canopy or canopy trees) in abundance of secondary structure calculations.

The magnitude and extent of the current beetle outbreak in British Columbia requires thoughtful planning to recover economic value from the impacted timber while maintaining other resource values. Forest planners and managers are now paying attention to secondary structure as a key consideration in planning for the sustainability of forest resources (timber supply, range management, wildlife management, carbon storage, species diversity, hydrological recovery period, viewscapes, and tourism).

The first study of secondary structure abundance was conducted for the sub-boreal forests of the northern interior (Coates et al. 2006) and focused on how secondary structure might mitigate mid-term timber supply through strategic management decisions on harvest priority. Other similar studies have followed in the Prince George (Pousette 2009) and Kamloops (Vyse et al. 2009) Timber Supply Units, in the Montane Spruce zone of the southern British Columbia interior (Nigh et al. 2008) and in South Okanagan watersheds (Huggard unpublished report 2009).

Concurrent to these studies, the Cariboo–Chilcotin region of the central interior was identified as a vast area with limited information on the abundance of secondary structure in extensive stands and landscapes dominated by lodgepole pine. This project addresses the shortfall in the current information available for beetle-affected stands by compiling existing information on stand structure in pine-leading stand types of the Cariboo–Chilcotin.

This study addresses the following key questions.

1. What are the attributes of secondary structure in pine-leading forest types after the beetle epidemic within the Cariboo–Chilcotin? Is there variability in secondary structure attributes by biogeoclimatic zone? We will examine:
   a) Median density, cumulative abundance—stems per ha (sph) exceeding density thresholds and species composition of secondary structure seedlings and saplings for all plots combined and by biogeoclimatic zone;
   b) Cumulative basal area (m^2 ha^{-1}) of secondary structure saplings, sub-canopy and canopy trees for all plots combined and by biogeoclimatic zone; and
   c) Basal area of merchantable and non-merchantable secondary structure in comparison to the percentage of overstorey pine for all plots and by biogeoclimatic zone.
2. How long would it take a newly established lodgepole pine plantation to reach the current basal area of secondary structure in each plot? This question addresses the concept of clearcut equivalency (Coates et al. 2006).
3. What is the relationship between merchantable lodgepole pine piece size and secondary structure?

4. What is the forest health status of secondary structure in pine-leading stands?
   a) We summarize the incidence of forest health damaging agents and conditions for seedlings and saplings by species for all plots combined and by biogeoclimatic zone.
   b) We summarize the incidence of forest health damaging agents and conditions for all sub-canopy and canopy secondary structure for all plots combined and by biogeoclimatic zone.

2 Materials and Methods

2.1 Data sources

Data for this project came from mature and older (age-class 4 and higher) pine stands in the Quesnel, Williams Lake and 100 Mile House Timber Supply Areas. This encompasses the Quesnel, Central Cariboo, Chilcotin, and 100 Mile House Forest Districts located in the Southern Interior Forest Region (Figures 1 and 2). A total of 1649 plots from pine stands were obtained (Table 1) covering six different biogeoclimatic zones in the Cariboo–Chilcotin (Table 2).

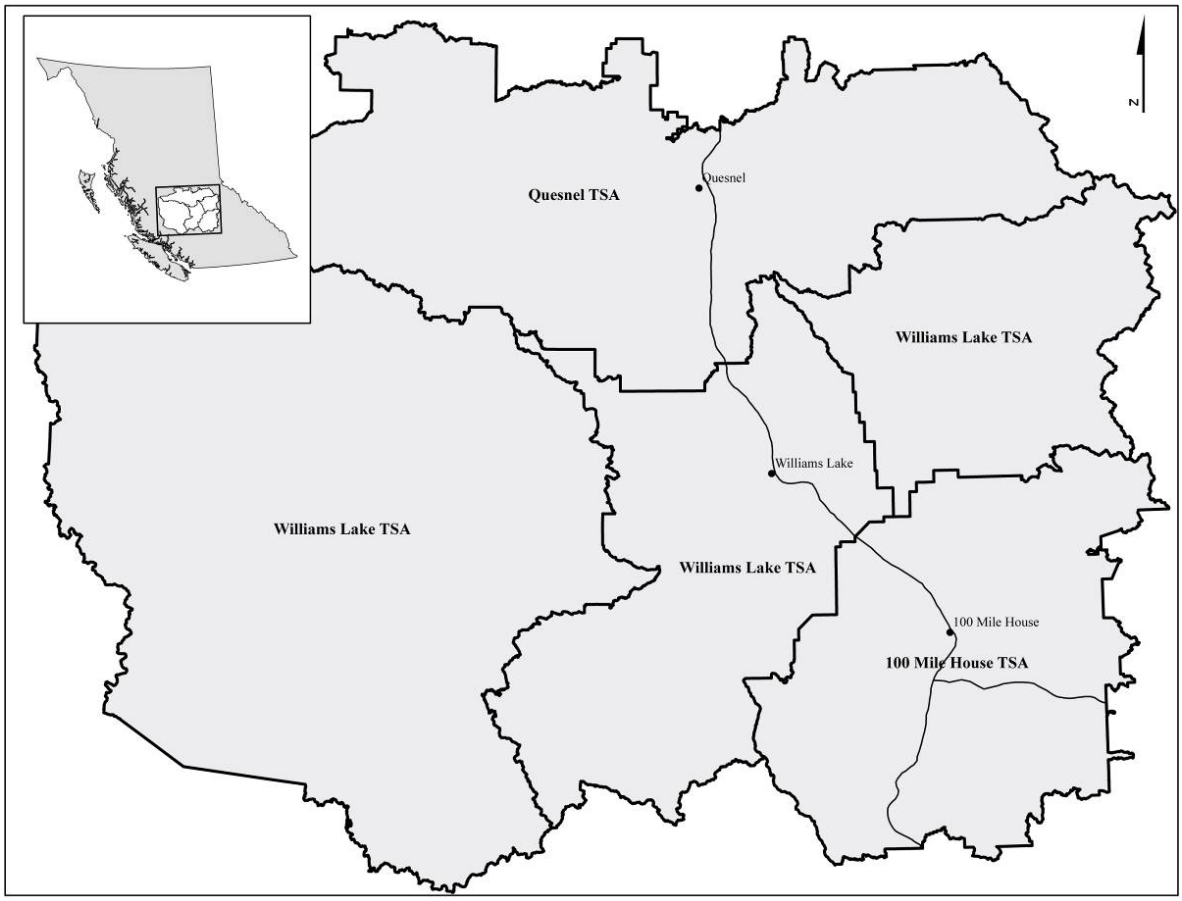

Figure 1. Study area showing the Quesnel, Williams Lake, and 100 Mile House Timber Supply Units in the Southern Interior Forest Region.

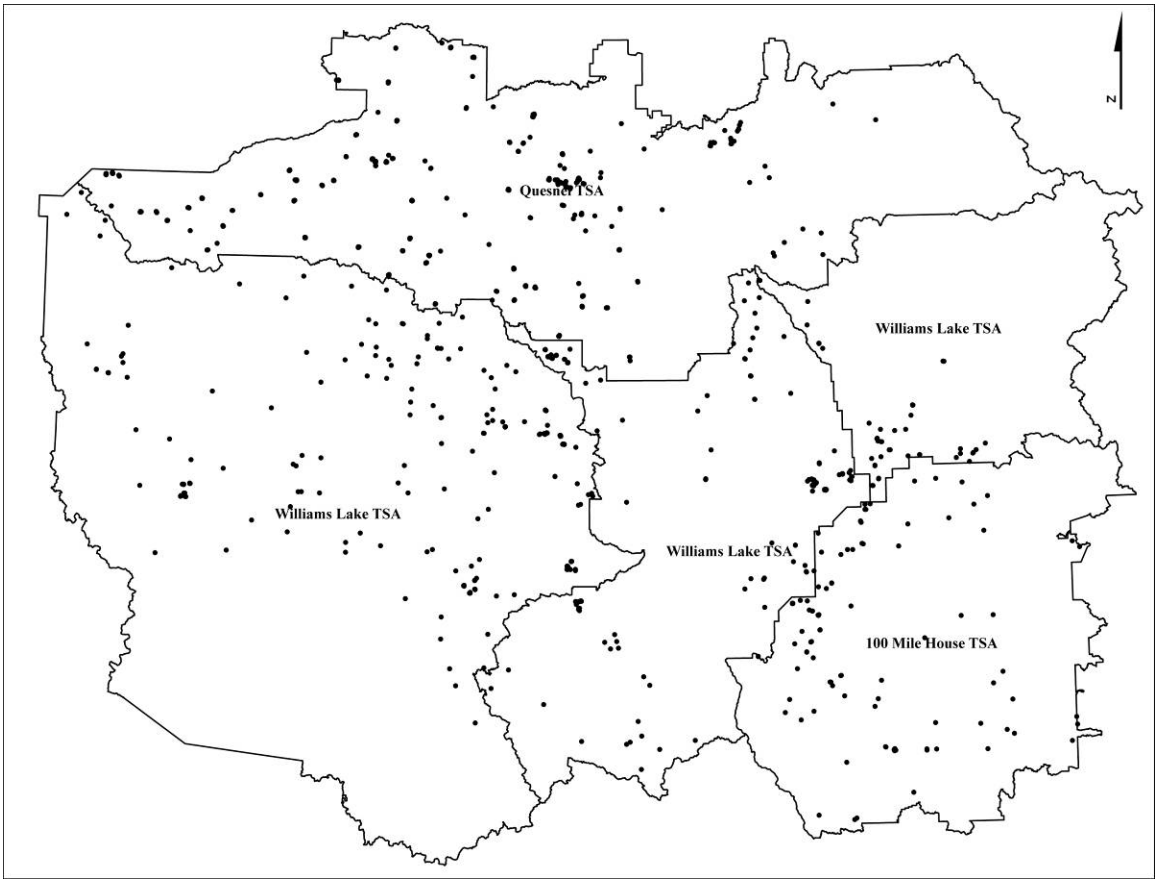

Figure 2. Distribution of sample plots throughout the Quesnel, Williams Lake, and 100 Mile House Timber Supply Units.

Table 1. Summary of sample plot sources and breakdown of sample plot distribution by biogeoclimatic zone.

Summary by Source	Total Plots	Pine-Leading Plots	Funding Source and Experimental Details
Marshal	181	160	FSP M075015. http://www.bcfsp.com
UBC Research Forest	49	27	http://www.forestry.ubc.ca/resfor/afrf/index.htm
NIVMA	44	42	http://www.nivma.bc.ca/
Permanent Sample Plots	233	209	http://www.for.gov.bc.ca/hts/vri/ip/psp/
Vegetation Resource Inventory	327	296	http://www.for.gov.bc.ca/hts/vri/
Tolko Cariboo (Lignum Plot Establishment Programs)	114	58	http://www.for.gov.bc.ca/hfd/library/FIA/2004/FIA-04-05-0016.pdf
Forest Analysis and Inventory Branch, BCMoFR	701	317	Contract 10005-40/FS09SAM007. Matt.Makar@gov.bc.ca
Total	1649	1109	

[a] Pine-leading plots contained greater than 50% basal area of pine in the sub-canopy and canopy, based on merchantability limits for pine and non-pine species.

Table 2. Summary of sample plots used in the analysis by biogeoclimatic zone.

Plots Summarized by Biogeoclimatic Zones	Number of Pine-leading Plots
Total Plots	1649
Total Pine-leading Plots	1109
Engelmann Spruce–Subalpine Fir (ESSF)	28
Interior Cedar–Hemlock (ICH)	3
Interior Douglas-Fir (IDF)	250
Montane Spruce (MS)	186
Sub-Boreal Pine–Spruce (SBPS)	484
Sub-Boreal Spruce (SBS)	158

2.2 Criteria for plots to be used in the secondary-structure dataset

To be considered pine-leading and included in the dataset used in this analysis, individual sample plots needed at least 50% of their overstorey basal area (m^2/ha) to contain lodgepole pine, based on merchantability limits for pine and non-pine species. Of the 1649 total plots, 1109 qualified as pine-leading (Tables 1 and 2). This report focuses on five biogeoclimatic zones: the Sub-Boreal Pine–Spruce (SBPS), the Engelmann Spruce–Subalpine Fir (ESSF), the Sub-Boreal Spruce (SBS), the Interior Douglas-fir (IDF), and the Montane Spruce (MS) zones. We provide limited information on the Interior Cedar–Hemlock (ICH) zone because of low sample sizes.

The dataset used in our analysis was collated from projects established at different times relative to the mountain pine beetle attack (Table 1). Plots in the dataset were established before the current epidemic hit the Cariboo–Chilcotin, during the current epidemic, or after the worst of the current epidemic had passed. For example, plots from the Marshal dataset (Table 1), established shortly after an earlier mountain pine beetle infestation in the early 1980s, provided measurements of dead and fallen overstorey pine to re-create pre-beetle stand conditions.

In all datasets used in this analysis, sub-canopy and canopy pine trees were not considered secondary structure even if they were alive when measured. The only pine trees that could contribute to secondary structure composition or abundance were seedlings and saplings smaller than 7.5 cm diameter at breast height (DBH). This may be conservative, as some sub-canopy and canopy pine trees will survive mountain pine beetle attack. We used this approach to reduce the risk of overestimating secondary structure and to provide a clear representation of the non-pine secondary structure present in the sub-canopy and canopy layers of the Cariboo–Chilcotin.

2.3 Data structure and organization

Data structure and study objectives varied between the individual research projects contributing data (Table 1). Nevertheless, we were able to take data from the individual plots and summarize the information into several tree layers: seedlings, saplings, and sub-canopy and canopy trees (Table 3a), with seedlings and saplings forming the understorey, and sub-canopy and canopy trees forming the overstorey (Table 3a). Merchantability limits in British Columbia vary by tree species, which we used in calculations throughout the report. Individual lodgepole pine trees of at least 12.5 cm DBH are considered merchantable; the minimum for other conifer species is 17.5 cm DBH. Broadleaf tree species are not considered in this report.

Tree species names and abbreviations used in the report's figures and tables are found in Table 4.

Secondary structure was identified as pine trees less than 7.5 cm DBH and all other non-pine species, including broadleaf species. Merchantable secondary structure was identified as non-pine conifers ≥ 17.5 cm DBH. Non-merchantable secondary structure was identified as pine < 7.5 cm DBH, other conifers < 17.5 cm DBH and all broadleaf species (Table 3b). In this report, total secondary structure refers to all tree layers of both conifer and broadleaf species.

Table 3. Description of tree size criteria, tree layers, and categories of secondary structure used in the analysis.

Table 3a. Size class criteria.

Size	Secondary Structure Layer	Canopy Layer
10-130 cm height	understorey	seedlings
0 - <7.5 cm DBH	understorey	saplings
>= 7.5 - <15 cm DBH	overstorey	sub-canopy
>=15cm DBH	overstorey	canopy

Table 3b. Secondary structure descriptions.

Total secondary structure	all understorey saplings, overstorey non pine conifers, and broadleaf species
Non-merchantable secondary structure	all understorey saplings, all overstorey broadleaf species, and overstorey non pine conifers < 17.5 cm DBH
Merchantable secondary structure	all overstorey/canopy non pine conifer trees ≥ 17.5cm DBH

Table 4. Tree species names and species codes used in the report.

Conifer Species	Scientific Name	Species Code	Broadleaf Species	Scientific Name	Species Code
lodgepole pine	*Pinus contorta*	Pl	cottonwood	*Populus balsamifera ssp. Trichocarpa*	Act
whitebark pine	*Pinus albicaulis*	Pa	trembling aspen	*Populus tremloides*	At
interior spruce	*Picea glauca x engelmanni*	Sx	paper birch	*Betula payrifera*	Ep
black spruce	*Picea mariana*	Sb			
subalpine fir	*Abies lasiocarpa*	Bl			
Douglas-fir	*Pseudotsuga menziesii*	Fd			

2.4 Data analysis and summaries

Tables 3a and b provide a description of size class criteria and terms used to describe secondary structure and canopy layers in this report. We summarized the data by all plots and for each biogeoclimatic zone in the following groupings.

1. Tree species composition, by tree layer (seedlings, saplings, sub-canopy, and canopy) and reporting methods (densities, basal area), for each biogeoclimatic zone (Tables 5 and 6).
2. Cumulative percentage of plots in pine-leading stands, with combined densities of conifer and broadleaf seedlings and saplings exceeding specified density thresholds.
3. Cumulative percent of plots exceeding basal area thresholds by:
   a) total secondary structure,
   b) merchantable secondary structure,
   c) non-merchantable secondary structure, and
   d) non-merchantable conifer secondary structure.
4. Cumulative percent of plots exceeding basal area thresholds by:
   a) secondary structure ≥ 7.5cm DBH
   b) secondary structure ≥ 17.5 cm DBH
   c) conifer secondary structure > 0 cm DBH
   d) conifer secondary structure ≥ 7.5 cm DBH
   e) conifer secondary structure ≥ 17.5 cm DBH
5. Basal area of total secondary structure and non-merchantable secondary structure compared to the percent of basal area of overstorey pine. (This analysis determines whether the abundance of secondary structure varies with the proportion of overstorey pine. Total secondary structure is expected to correlate with the proportion of overstorey pine; how non-merchantable secondary structure varies in response to the proportion of overstorey pine is of more interest.)
6. Basal area of secondary structure compared to the basal area of a clearcut lodgepole pine stand. We calculated the basal area of all saplings, sub-canopy, and canopy trees in each sample plot (excluding live pine trees > 7.5 cm DBH), then used TIPSY to determine basal area development of an average lodgepole pine plantation for each ecological unit (Table 6). We assigned a clearcut equivalence age to each sample plot to quantify secondary structure in terms of how long it would take a typical pine plantation to reach basal areas equivalent to those found in pine-leading stands (Table 7).
7. The relationship between average pine piece size and non-merchantable secondary structure. (Average piece size was calculated by determining an average DBH for all live and dead pine trees ≥ 12.5 cm DBH in each plot. We combined measured heights from the plot data with species-specific height:DBH equations to estimate tree height with no height measurement. Volume per tree was based on tree height to a 10.2 cm top (3 m was deducted from the estimated height). Piece size was extrapolated and assigned to each plot in our database.)

Lastly, we compiled an extensive database of individual trees by tree species, canopy layer, and ecological units where forest health and damage had been recorded (Tables 8 and 9). (Forest health is a major concern for the future viability of secondary structure, especially in the Cariboo–Chilcotin, where understorey pine is both common and vulnerable.)

Table 5a. Distribution of understorey seedlings and saplings by species and zone of the Cariboo–Chilcotin.

Percentage of Understorey Seedlings and Saplings Combined

Zone	Pl	Pa	Sx	Sb	Bl	Fd	Ep	At	Act
ESSF	10	5	10	0	75	0	0	0	0
IDF	52	0	3	0	0	28	0	16	0
MS	79	0	12	0	8	0	0	0	0
SBPS	74	0	13	0	0	2	0	10	0
SBS	19	0	28	1	28	9	10	4	0

Percentage of Understorey Seedlings

Zone	Pl	Pa	Sx	Sb	Bl	Fd	Ep	At	Act
ESSF	7	5	9	0	79	0	0	0	0
IDF	51	0	3	0	0	25	0	21	0
MS	68	0	19	0	13	0	0	1	0
SBPS	73	0	11	0	1	2	0	14	0
SBS	14	0	26	0	34	11	8	6	0

Percentage of Understorey Saplings

Zone	Pl	Pa	Sx	Sb	Bl	Fd	Ep	At	Act
ESSF	31	2	23	0	45	0	0	0	0
IDF	53	0	4	0	0	33	0	10	0
MS	89	0	7	0	4	0	0	0	0
SBPS	76	0	15	0	0	2	0	7	0
SBS	25	0	31	1	22	7	12	3	0

Table 5b. Distribution of saplings, sub-canopy, and canopy secondary structure trees by species and zone of the Cariboo–Chilcotin.

Percentage of Secondary Structure by Species for the Sapling Layer

Zone	Pl	Pa	Sx	Sb	Bl	Fd	Ep	At	Act
ESSF	29	1	16	0	55	0	0	0	0
IDF	57	0	4	0	0	33	0	6	0
MS	90	0	6	0	3	0	0	0	0
SBPS	81	0	13	0	0	2	0	3	0
SBS	34	0	27	1	26	8	2	2	0

Percentage of Secondary Structure by Species for the Sub-canopy Layer

Zone	Pa	Py	Sx	Sb	Bl	Fd	Ep	At	Act
ESSF	31	0	29	3	36	0	0	0	0
IDF	1	0	6	3	0	76	2	11	1
MS	1	0	76	2	21	0	0	0	0
SBPS	8	0	56	15	0	11	0	9	0
SBS	13	3	24	13	23	15	3	5	0

Percentage of Secondary Structure by Species for the Canopy Layer

Zone	Pa	Sx	Sb	Bl	Fd	Ep	At	Act
ESSF	14	49	0	36	0	0	1	0
IDF	0	9	0	0	75	1	15	0
MS	0	66	3	12	19	0	0	0
SBPS	0	66	0	0	18	0	16	0
SBS	0	38	0	9	29	2	20	2

Table 6. Details of TIPSY pine plantation runs.
Site index is based on averages from zone, sub-zone and sites.

Tipsy Parameter	ESSF	IDF	MS	SBPS	SBS
Site Index	16.5	16.3	18	15	19.7
Stems/ha	1600	1600	1600	1600	1600
Regen delay	3 years	3 years	3 years	3 years	3 years
OAF 1	85%	85%	85%	85%	85%
OAF 2	95%	95%	95%	95%	95%
Merch Limit	12.5	12.5	12.5	12.5	12.5
Stock Height	13 cm	13 cm	13 cm	13 cm	13 cm

Table 7. Cumulative percentage of plots in pine-leading stands with a basal area equivalent to a developing lodgepole pine clearcut in biogeoclimatic zones of the Cariboo–Chilcotin.

Zone	Year	BA/ha	Cumulative % Plots
ESSF	20	3	68
ESSF	30	12	18
ESSF	40	21	11
ESSF	50	28	7
IDF	20	3	57
IDF	30	12	17
IDF	40	20	3
IDF	50	28	0
MS	20	4	31
MS	30	15	7
MS	40	25	2
MS	50	32	1
SBPS	20	2	48
SBPS	30	9	14
SBPS	40	17	3
SBPS	50	24	1
SBS	20	6	47
SBS	30	18	15
SBS	40	29	3
SBS	50	36	1

[a] Basal area of pine plantations are based on TIPSY runs (Table 5). For example, in the MS zone, a 20-year-old plantation has 4 m^2/ha. The cumulative percent of plots indicates the percent of total secondary structure basal match or exceed that of the pine plantation.

Table 8. Forest health sample size by species and canopy layer used to access damage types.

Canopy Layer	Act	At	Bl	Cw	Ep	Fd	Pa	Pl	Py	Sb	Sx
Saplings	8	207	152	0	11	1777	0	12407	0	144	1660
Sub-canopy	21	485	162	3	26	1025	3	22503	1	169	1636
Canopy	11	355	99	3	34	693	14	19043	0	34	916
Total	40	1047	413	6	71	3495	17	53953	1	347	4212

Table 9. Forest health sample size by species from each biogeoclimatic zone.

Zone	Act	At	Bl	Cw	Ep	Fd	Pa	Pl	Py	Sb	Sx
ESSF	0	4	79	0	0	1	17	514	0	0	115
ICH	0	3	0	5	4	40	0	75	0	0	3
IDF	2	353	0	0	9	1968	0	13919	1	9	508
MS	0	0	32	0	0	19	0	2594	0	13	75
SBPS	0	311	5	0	6	836	0	28973	0	101	1884
SBS	38	376	297	1	52	631	0	7878	0	224	1627
Total	40	1047	413	6	71	3495	17	53953	1	347	4212

3 Results and Discussion

3.1 Seedlings and saplings

The composition and abundance of seedlings and saplings in the Cariboo–Chilcotin was consistent with pine-leading stands elsewhere in British Columbia (Coates et al. 2006; Vyse et al. 2009; Huggard unpublished report 2009). The median density of conifer seedlings and saplings varied by biogeoclimatic zone with the highest median densities in the ESSF and IDF zones, approximately 4,700 and 2,900 sph, respectively (Figure 3). The overall median density of seedlings and saplings across all ecological units in the Cariboo–Chilcotin was 1800 sph. Seedlings and saplings densities were lowest in the SBS zone (1019 sph, Figure 3).

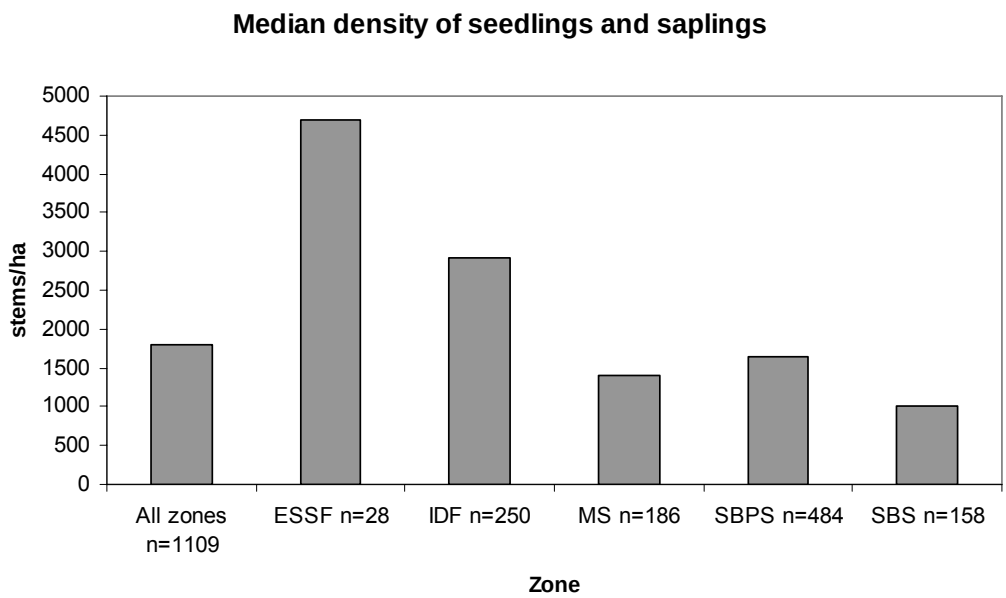

Figure 3. Median density of conifer seedlings and saplings in pine-leading stands by biogeoclimatic unit.
Note: The median represents the middle number in the distribution of densities from the sample plots. For example, in the IDF, the median was approximately 2900 stems/ha, meaning that 50% of pine-leading stands in the IDF zone had more than 2900 stems/ha while the other half had lower densities. Median conifer densities: all zones = 1799; ESSF = 4700; IDF = 2917; MS = 1400; SBPS = 1651; SBS = 1019.

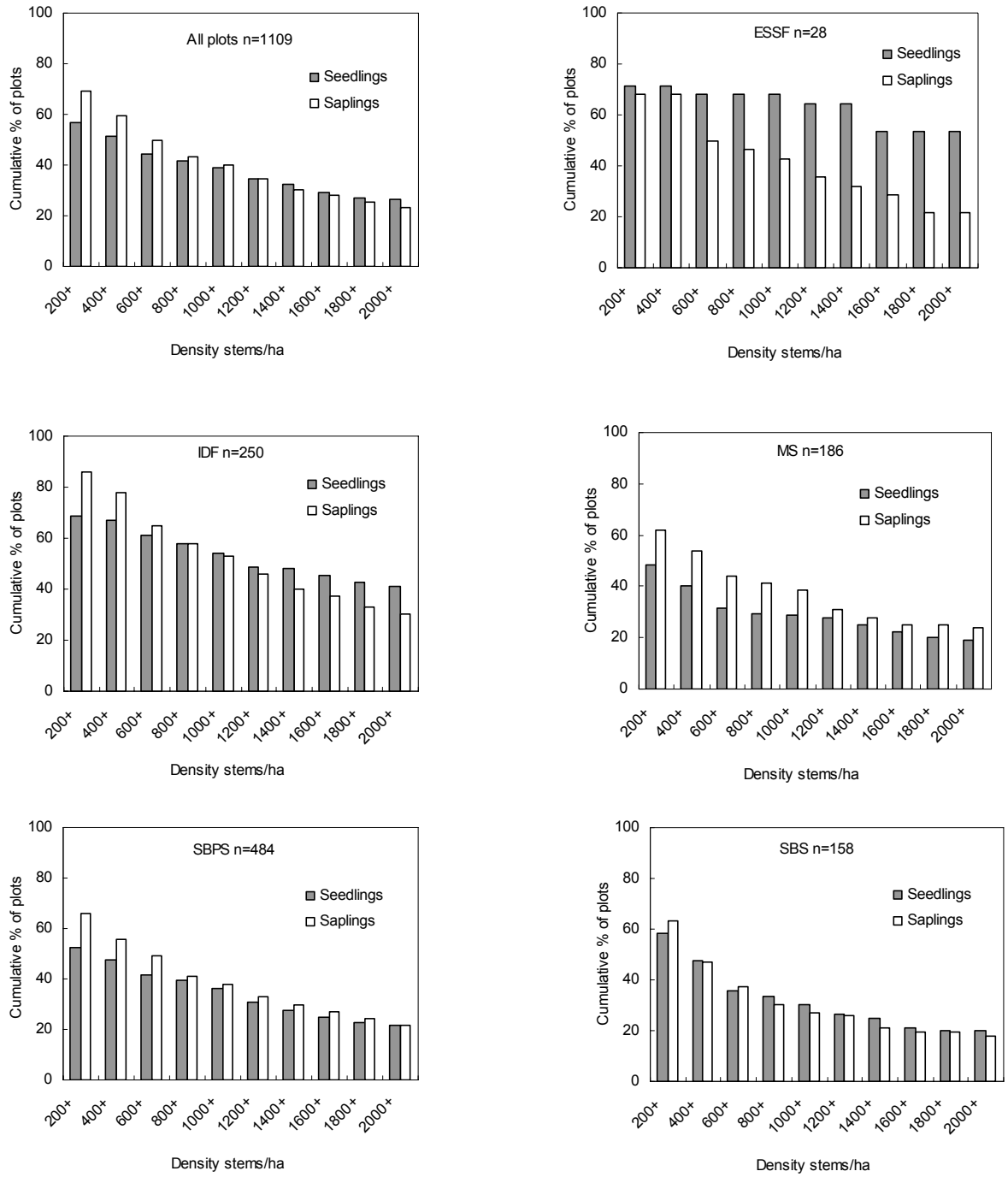

Figure 4. Cumulative percentage of plots in pine-leading stands in the Cariboo–Chilcotin in central British Columbia with densities (stems per ha) of conifer seedlings (0.1–1.3 m tall) and saplings (≥ 1.3 m tall and < 7.5 cm DBH) above specified density thresholds.

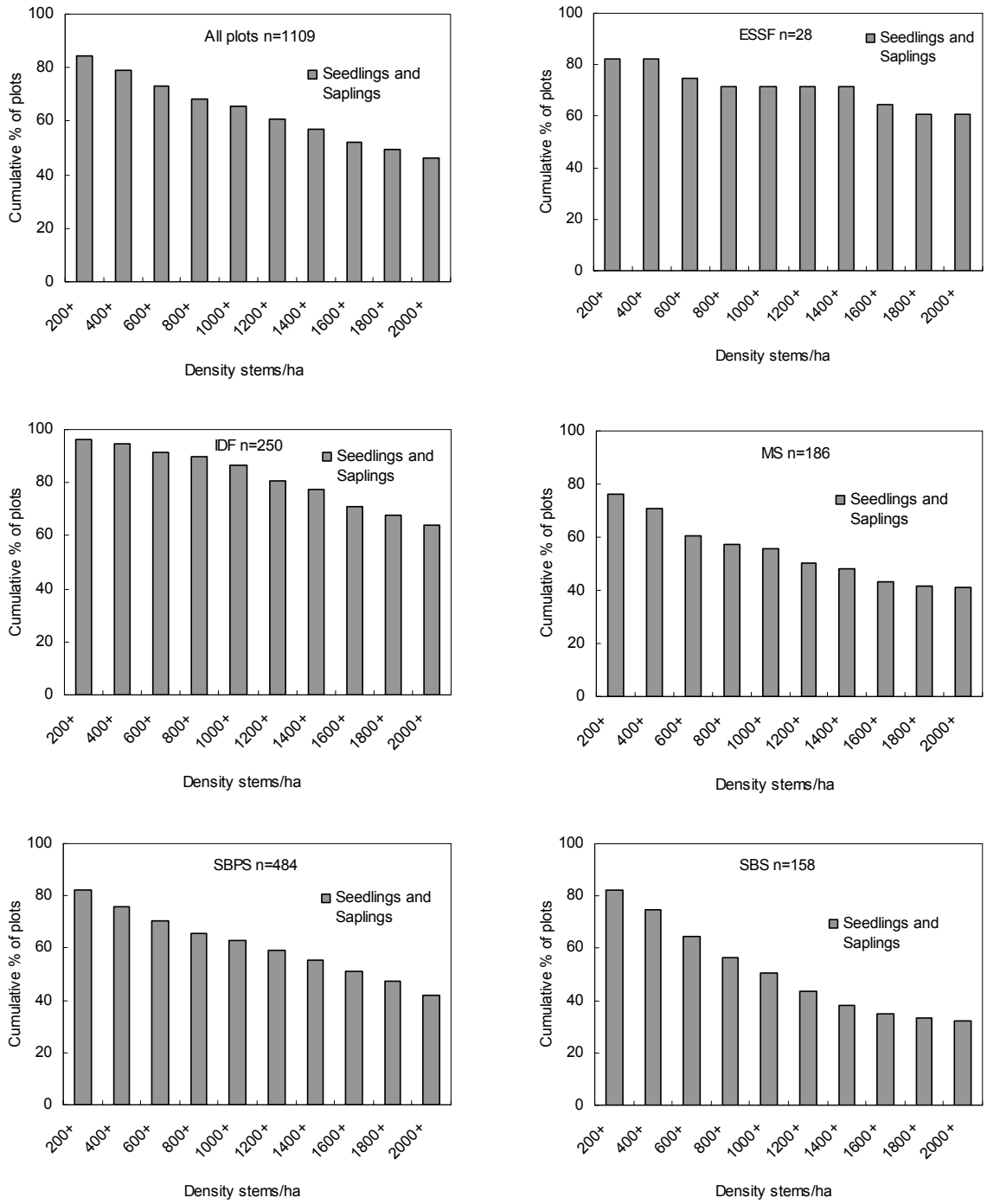

Figure 5. Cumulative percentage of plots in pine-leading stands in the Cariboo–Chilcotin in central British Columbia with combined densities (stems per ha) of conifer seedlings (0.1–1.3 m tall) and saplings (≥1.3 m tall and < 7.5 cm DBH) above specified density thresholds.

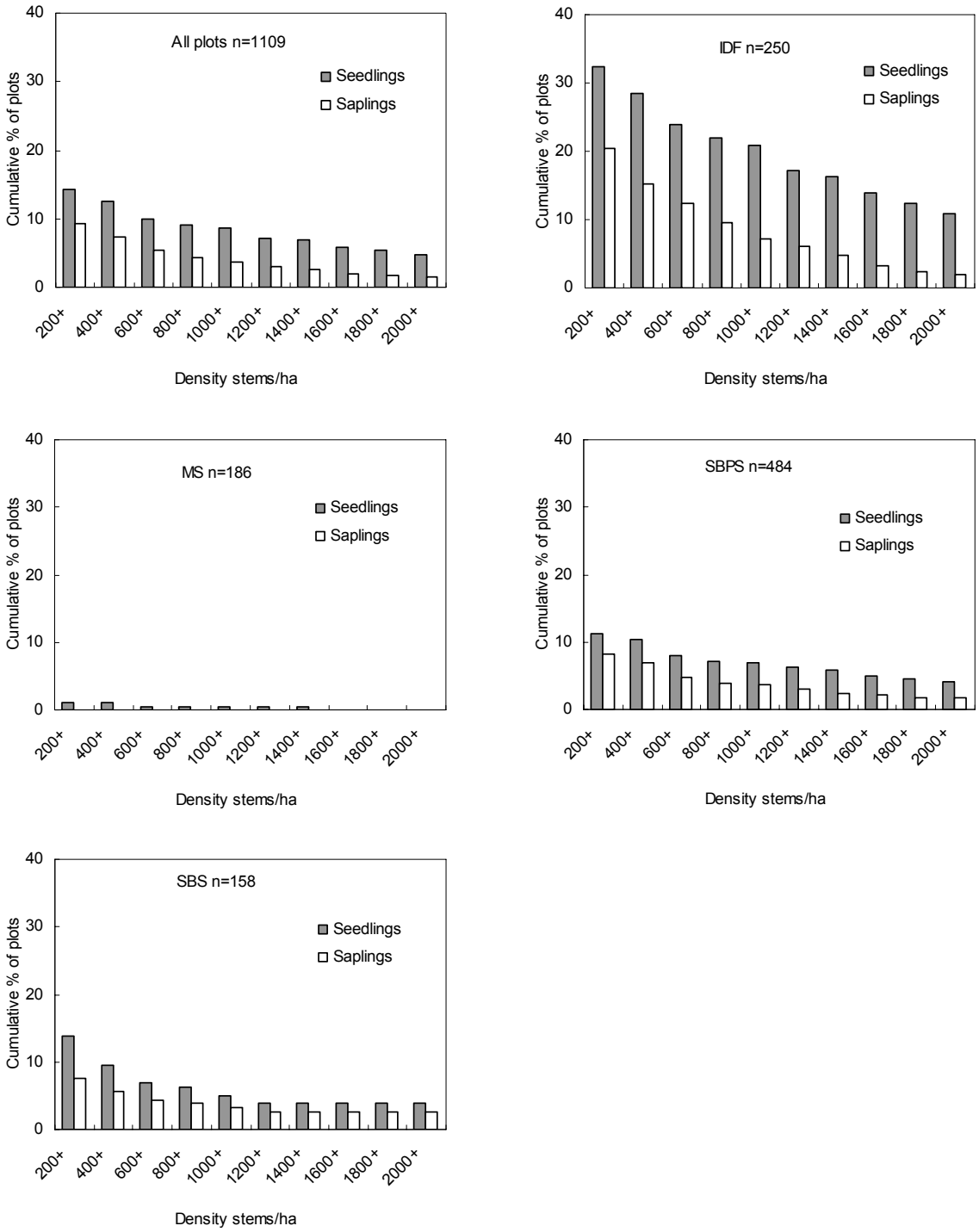

Figure 6. Cumulative percentage of plots in pine-leading stands in the Cariboo–Chilcotin in central British Columbia with densities (stems per ha) of broadleaf seedlings (0.1–1.3 m tall) and saplings (≥ 1.3 m tall and < 7.5 cm DBH) above specified density thresholds.

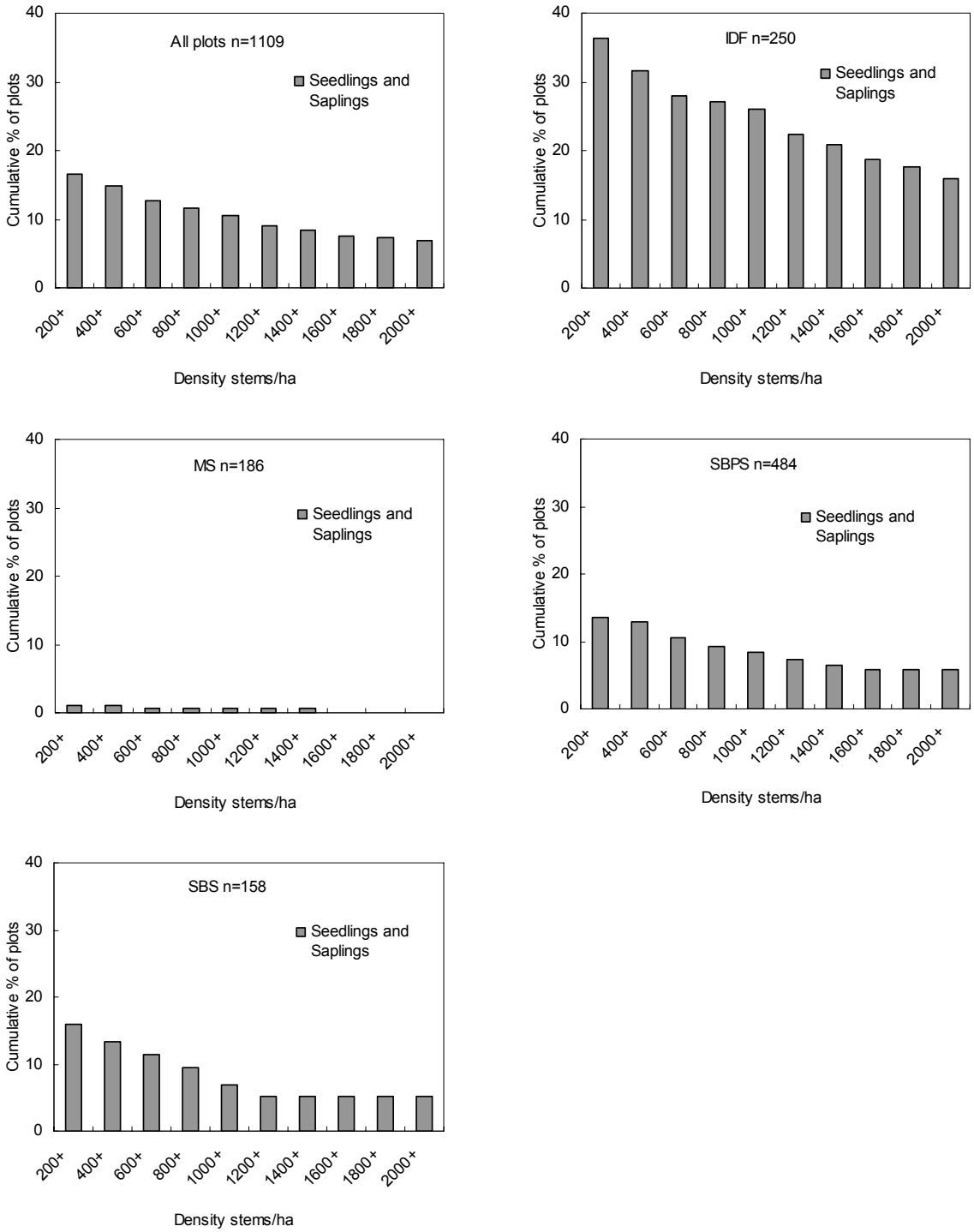

Figure 7. Cumulative percentage of plots in pine-leading stands in the Cariboo–Chilcotin in central British Columbia with combined densities (stems per ha) of broadleaf seedlings (0.1–1.3 m tall) and saplings (≥1.3 m tall and < 7.5 cm DBH) above specified density thresholds.

To illustrate the data, we have provided cumulative stocking graphs for seedlings, saplings and seedlings and saplings combined for conifers (Figures 4 and 5) and broadleaf (Figures 6 and 7) species. Across all ecological units about 70% of sample plots in pine-leading stands exceeded a 1000 sph threshold for understorey conifer seedling and sapling density (Figure 5). In addition, about 12% of sample plots exceeded a 1000 sph threshold for understorey broadleaf seedlings and saplings (Figure 7); however, broadleaf species were highly variable by ecological unit. Broadleaf species were most common in the IDF zone (Figure 7). Understorey broadleaf species were quite rare in the MS zone. Conifer understorey species were more uniformly distributed by ecological unit (Figure 5). The highest numbers were found in the IDF and ESSF zones.

The species composition of the understorey tree layer varied considerably in the individual biogeoclimatic zones (Table 5a). Lodgepole pine was by far the most common understorey tree species in the MS and SBPS zones (79% and 74%, respectively). Pine composition decreased to 52% in the IDF zone and was lowest at 10% in the ESSF zone (Table 5a). Pine dominated the sapling layer (89%) in the MS zone. Subalpine fir was common only in two zones, the ESSF (75%) and the SBS (28%). Interior spruce was common, but not abundant, in all zones, varying from 9% to 26% of the understorey tree composition (Table 5a). Douglas-fir was found in the IDF (28%), SBS (9%), and SBPS (2%) zones, but not elsewhere. Black spruce was rare in the Cariboo–Chilcotin. Trembling aspen represented 16% and 10% of understorey species in the IDF and SBPS zones, respectively (Table 5a).

Given the dominance of lodgepole pine in the understorey of most ecological units, it is clear that information on the current health and projections of future survival and growth of understorey pine is needed to assess the merit of protecting or managing understorey trees after beetle disturbance in the Cariboo–Chilcotin.

3.2 Basal area of sapling, sub-canopy and canopy secondary structure

Studies in the northern interior indicate that pine-leading stands with at least 5 m^2 ha^{-1} secondary structure basal area can potentially contribute to mid-term timber supply (Coates and Hall 2005; Coates et al. 2006). Across all ecological units, 34% of total plots met this standard (Figure 8).

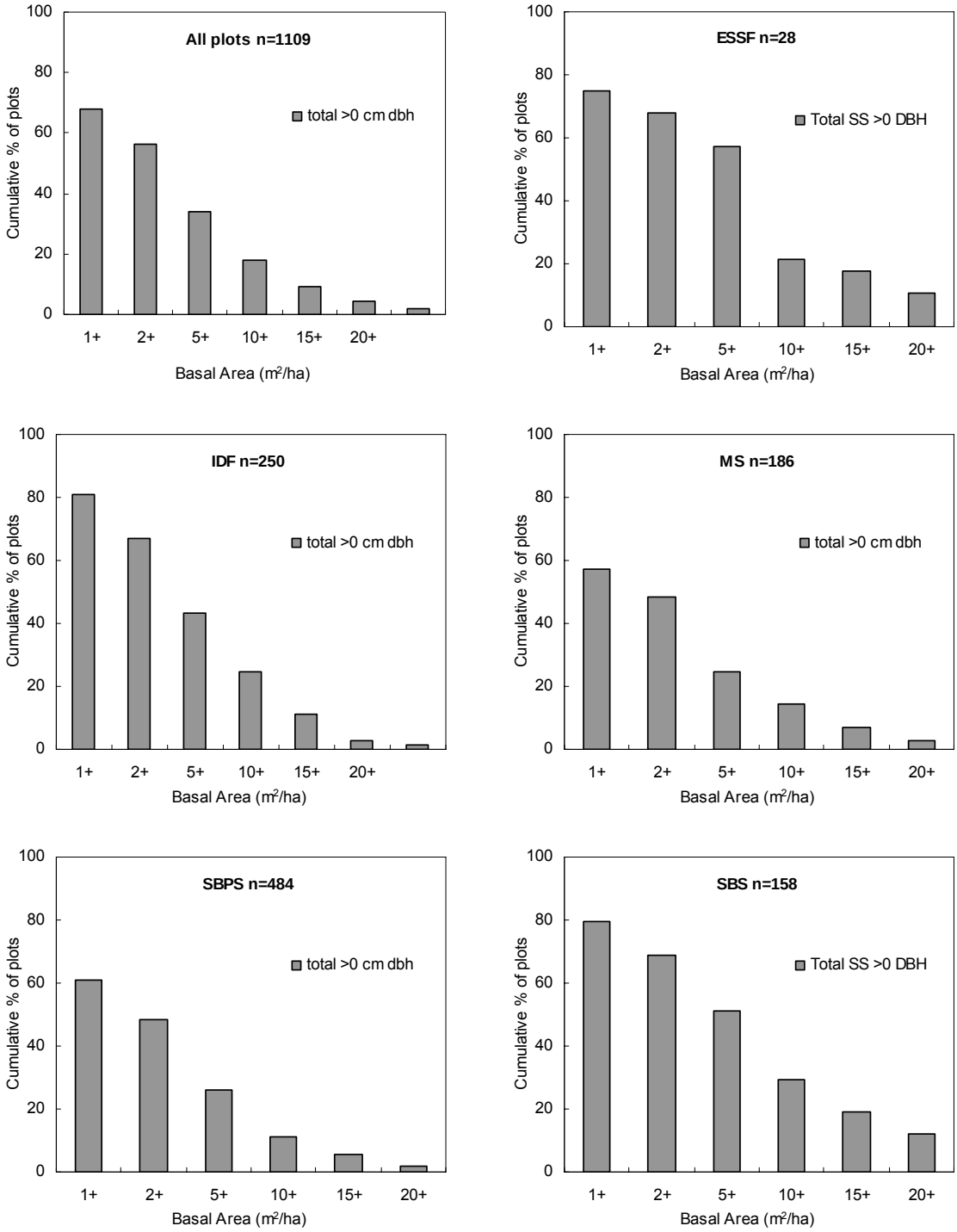

Figure 8. Cumulative percentage of plots in pine-leading stands above specified basal area thresholds by biogeoclimatic zone in the Cariboo–Chilcotin.

Note: Data include all secondary structure, i.e., all lodgepole pine (Pl) < 7.5 cm DBH, and all other conifers and broadleaf species.

Total secondary structure basal area exceeding this threshold varied somewhat by zone, from 25% of plots in the MS to 57% in the ESSF (Figure 8). Of course, secondary structure can be broken down by various tree layers or merchantability standards (Table 3). We have provided various breakdowns of secondary structure basal area in Figures 9-13. For example, secondary structure basal area of conifers only (Figure 11) compared to all tree species (Figure 8) clearly indicates that most secondary structure in the Cariboo–Chilcotin comprise conifer species.

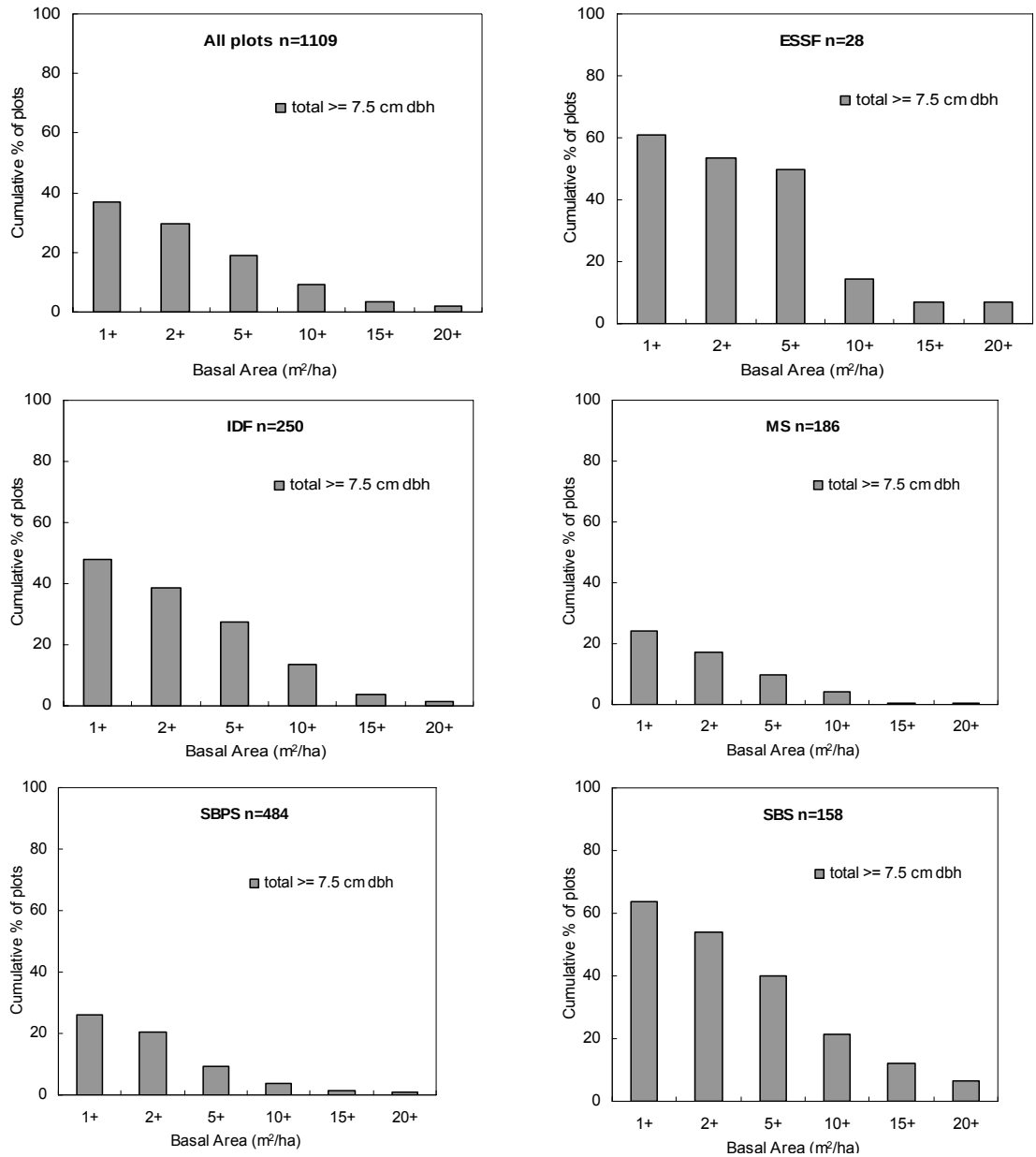

Figure 9. Cumulative percentage of plots in pine-leading stands above specified basal area thresholds by biogeoclimatic zone in the Cariboo–Chilcotin.

Note: Data are for secondary structure with ≥ 7.5 cm DBH, including non-pine conifers and broadleaf species.

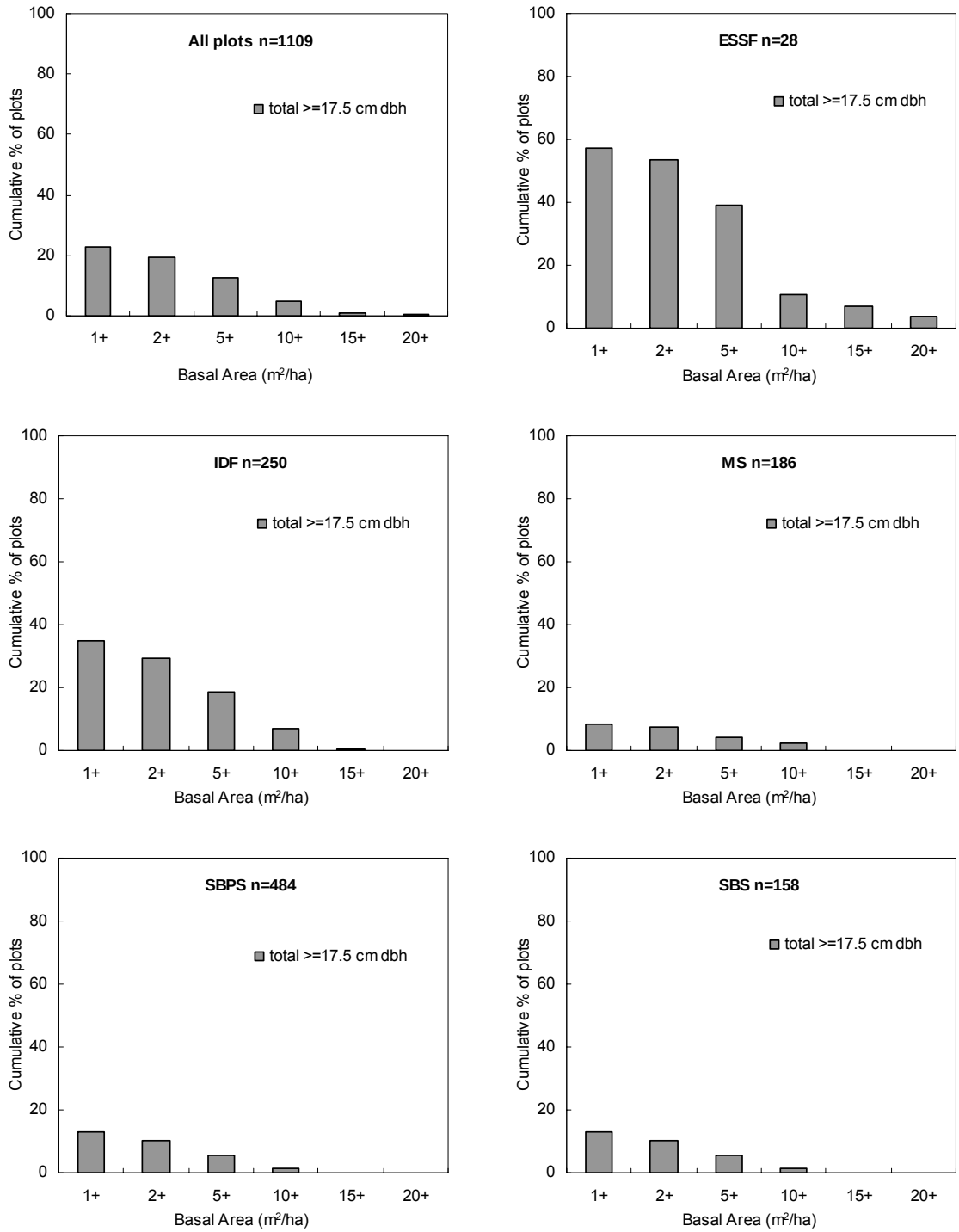

Figure 10. Cumulative percentage of plots in pine-leading stands above specified basal area thresholds by biogeoclimatic zone in the Cariboo–Chilcotin.

Note: Data are for secondary structure with ≥ 17.5 cm DBH including non-pine conifers and broadleaf species.

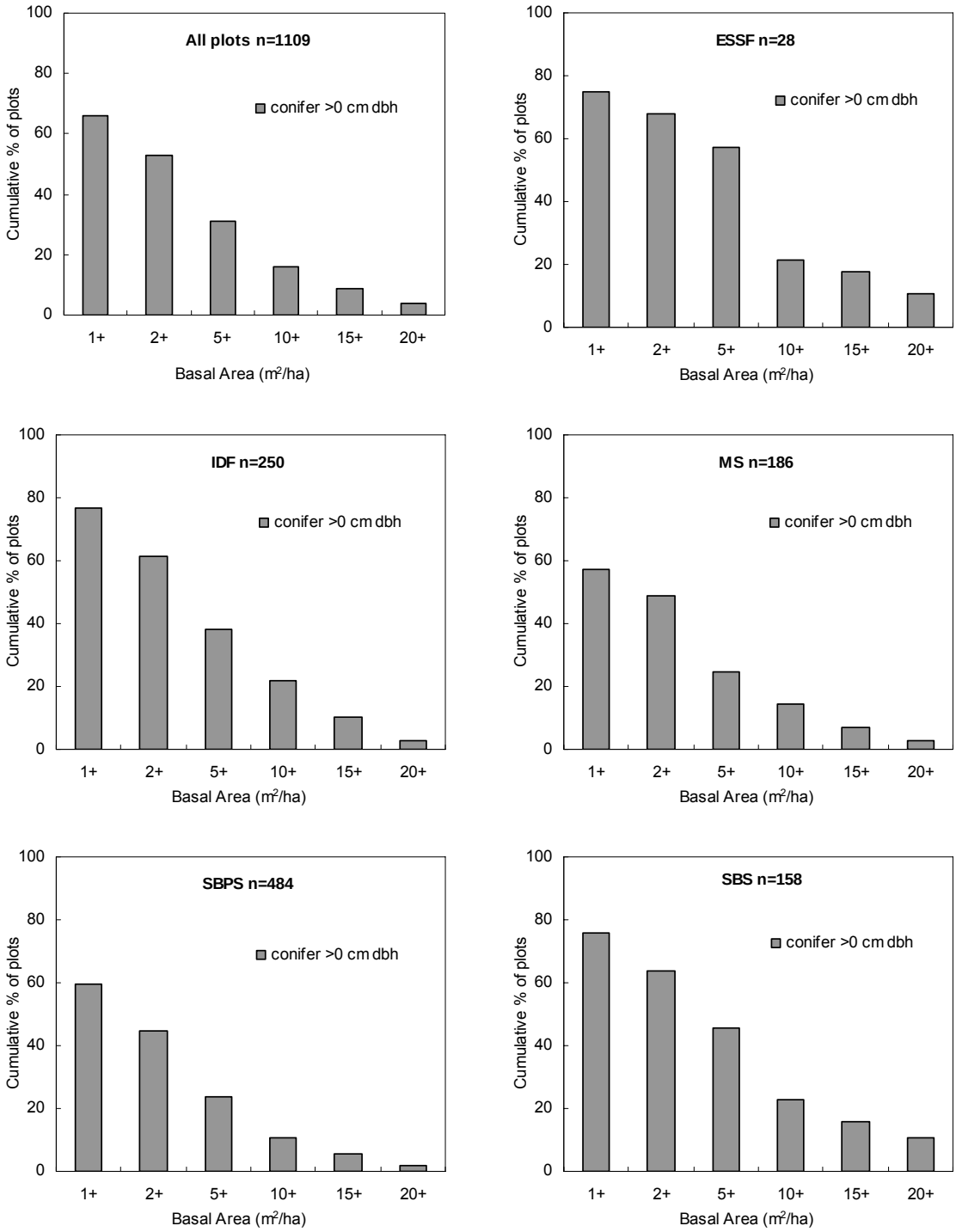

Figure 11. Cumulative percentage of plots in pine-leading stands above specified basal area thresholds by biogeoclimatic zone in the Cariboo–Chilcotin.

Note: Data are for conifer secondary structure with > 0 cm DBH. This includes Pl < 7.5 cm DBH and all other non-pine conifers > 0 cm DBH and excludes all broadleaf species.

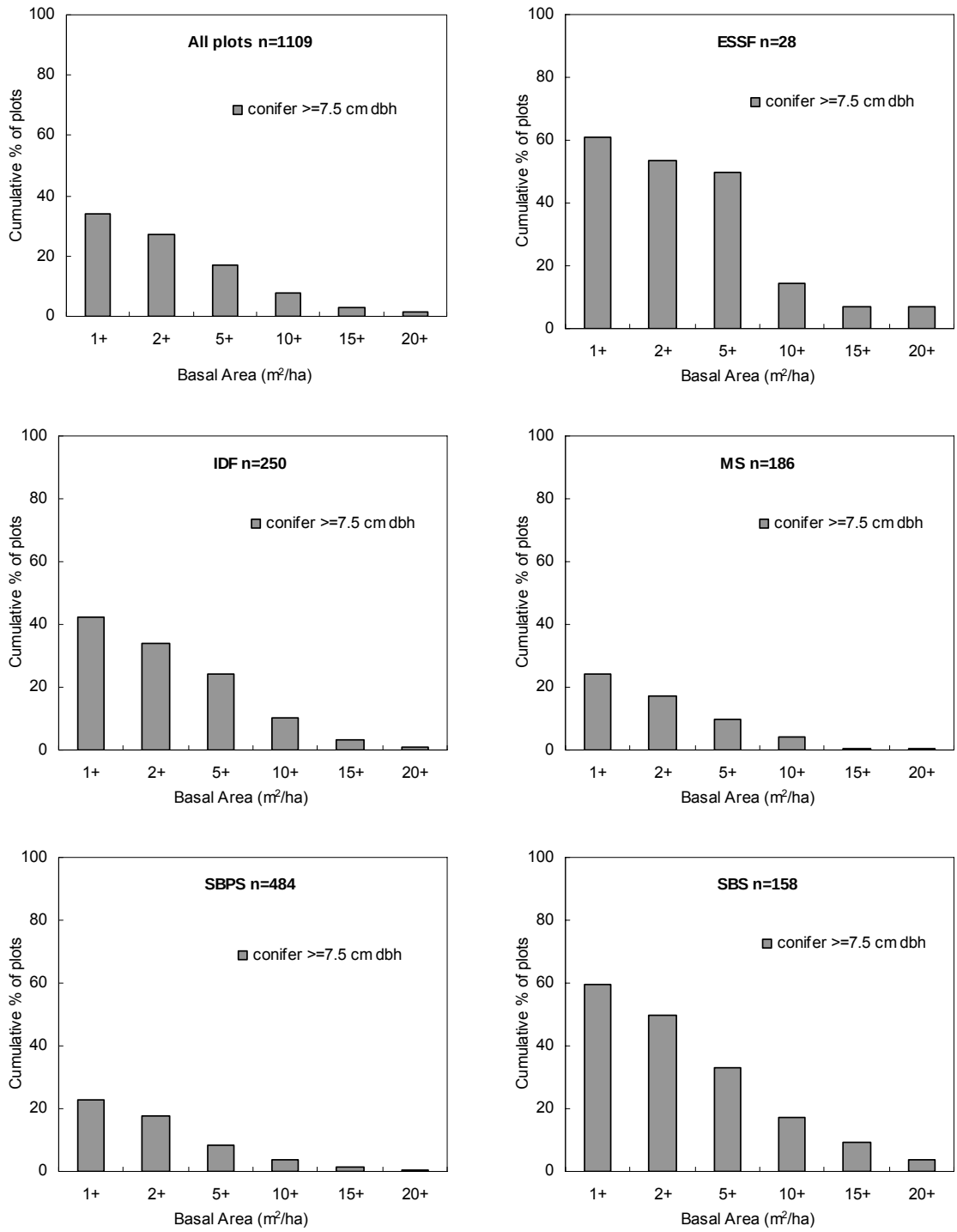

Figure 12. Cumulative percentage of plots in pine-leading stands above specified basal area thresholds by biogeoclimatic zone in the Cariboo–Chilcotin.

Note: Data are for conifer secondary structure with ≥ 7.5 cm DBH. Data excludes all broadleaf species.

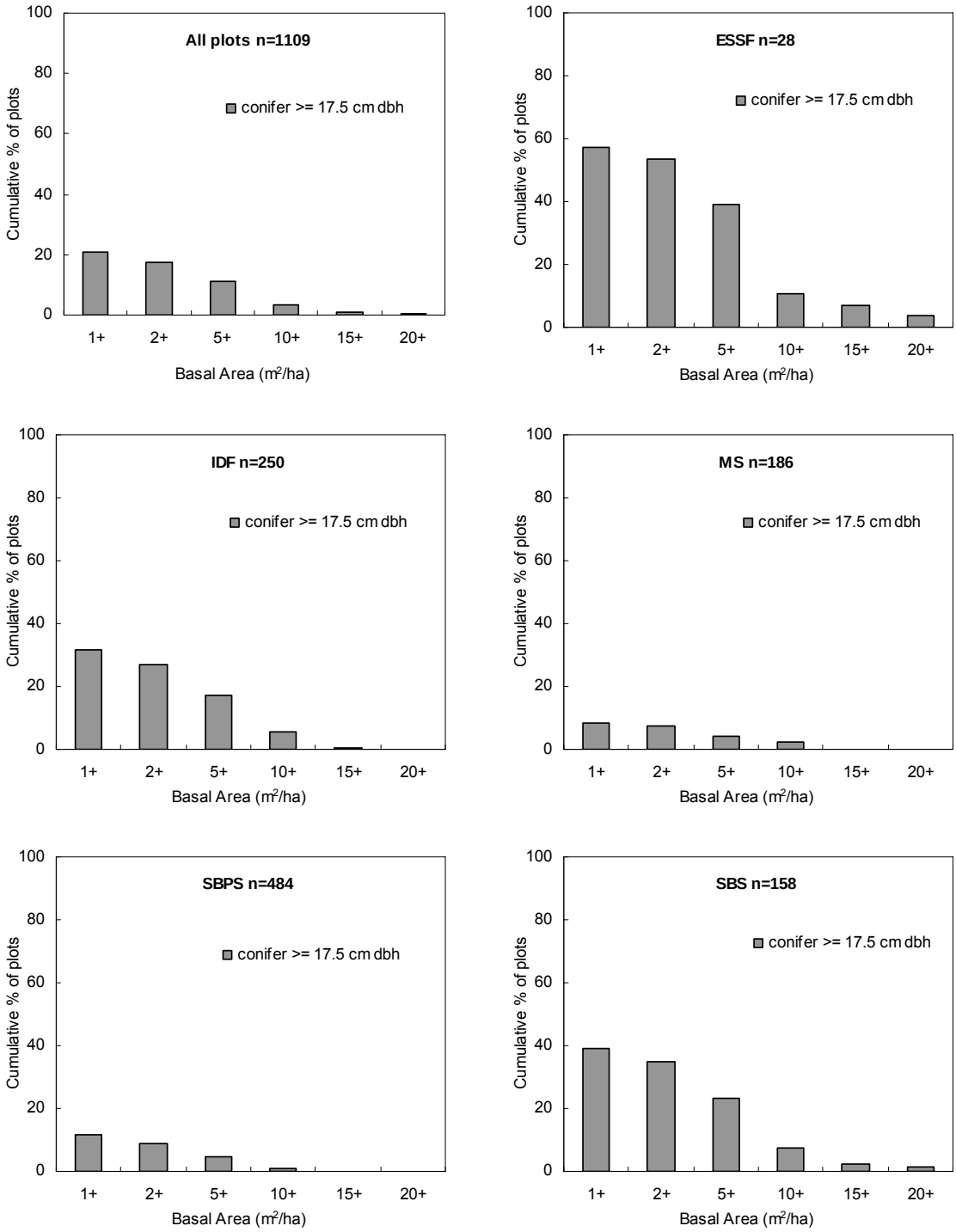

Figure 13. Cumulative percentage of plots in pine-leading stands above specified basal area thresholds by biogeoclimatic zone in the Cariboo–Chilcotin.

Note: Data are for conifer secondary structure ≥ 17.5 cm DBH. This data represents merchantable conifer secondary structure and excludes all broadleaf species.

If secondary structure is calculated to include only merchantable trees, then percentages of plots with at least 5 m^2 ha^{-1} secondary structure basal area decrease substantially in all ecological units (Figure 14). Much of the secondary structure basal area in the Cariboo-Chilcotin is on non-merchantable stems (Figure 15), which provides many future management options, depending on the management values being considered (e.g., timber supply, hydrological recovery period).

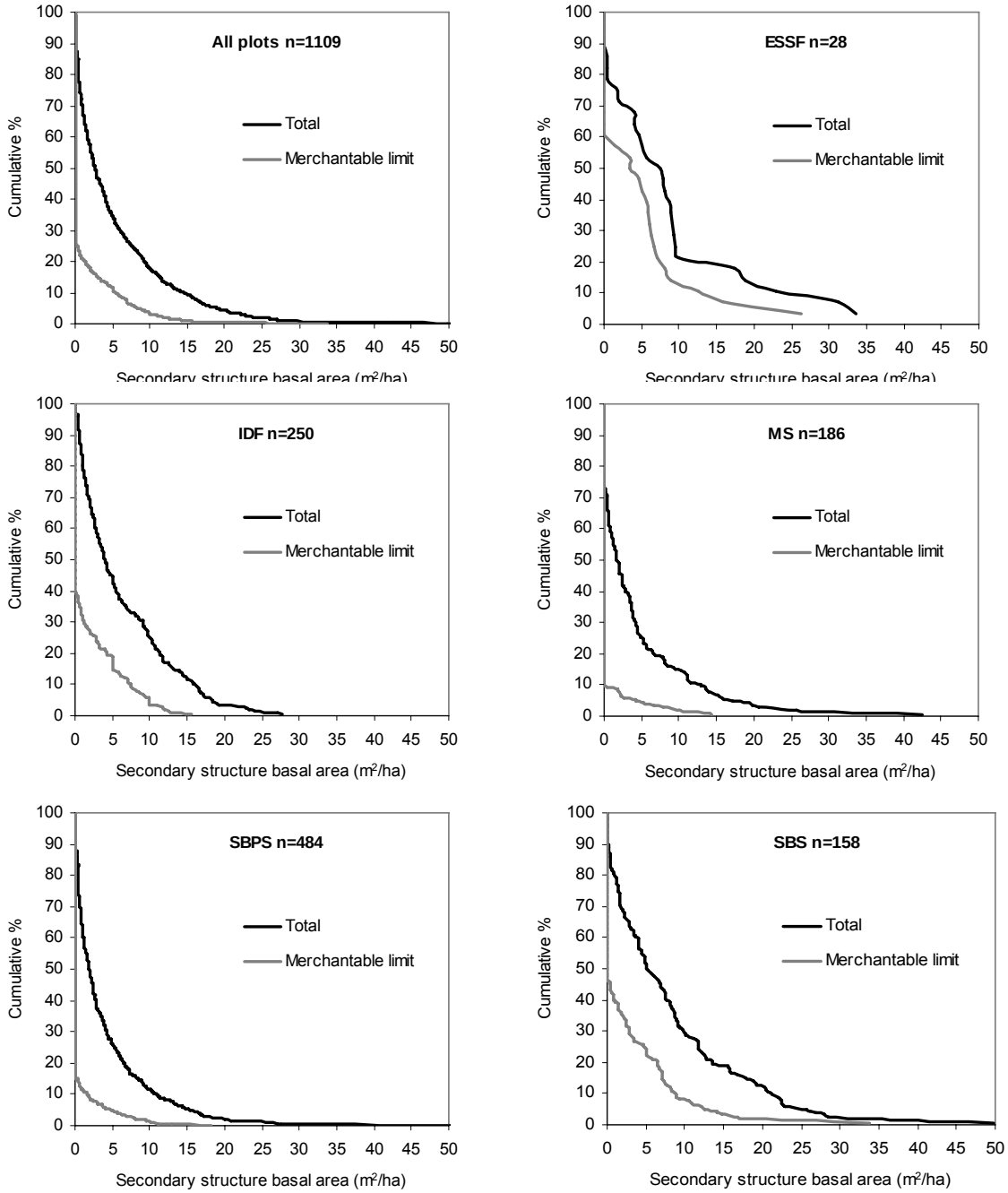

Figure 14. Cumulative frequency of basal area of secondary structure by biogeoclimatic zone. Total is all conifer and broadleaf secondary structure > 0 cm DBH; merchantable limit is conifers ≥ 17.5 cm DBH (see Table 3 for details).

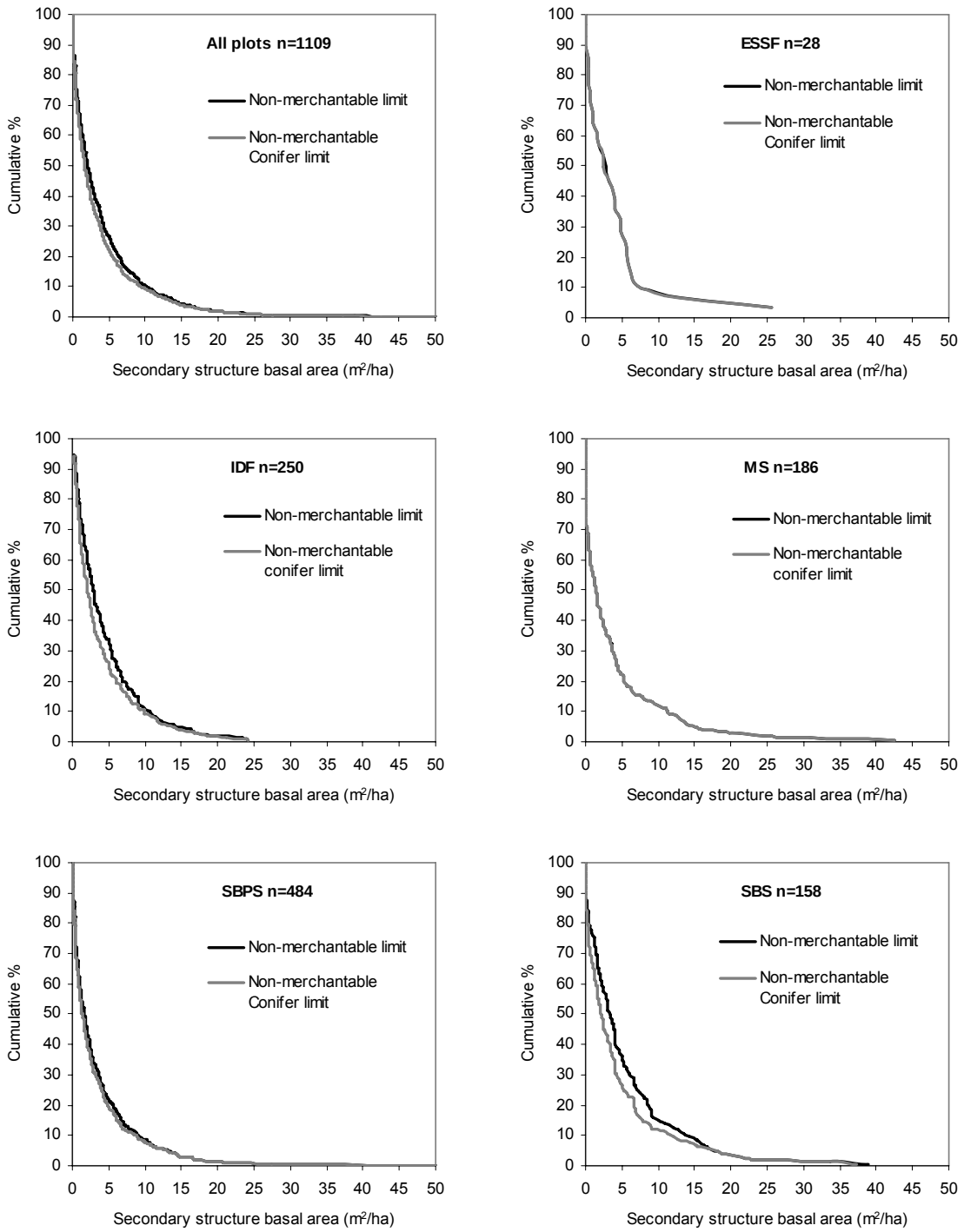

Figure 15. Cumulative frequency of basal area of secondary structure by biogeoclimatic zones. Non-merchantable secondary structure is Pl < 7.5 cm DBH, other conifers < 17.5 cm DBH, and all broadleaf species.

The sapling basal area was dominated by pine in all ecological units except the ESSF zone, where subalpine fir (55%) dominated (Table 5b). Pine varied from a high of 90% in the MS zone to a low of 34% of the sapling basal area in the SBS zone. Interior spruce was the next most common species with sapling basal area varying from 4% to 27% across the ecological units (Table 5b). Douglas-fir comprised 33% of the sapling basal area in the IDF zone. Broadleaf species represented less than 7% of the sapling basal area and were absent from the ESSF and MS zones. The most diverse ecological unit, in terms of sapling composition, was the SBS zone where no single species dominated the composition (Table 5b).

Secondary structure in the sub-canopy and canopy tree layers was comprised of non-pine species. Interior spruce was abundant in all ecological units except the IDF zone where Douglas-fir dominated. Spruce basal area represented between 24% and 76% of the basal area of sub-canopy and canopy trees, excluding the IDF zone (Table 5b). Subalpine fir sub-canopy basal area varied from 21% to 36% in the MS, SBS and ESSF zones (Table 5b). Except for the ESSF zone, the percent of basal area represented by subalpine fir decreased in the canopy layer. The percent of Douglas-fir basal area increased from the sapling to the canopy layer in all zones where it was present. Aspen was most common in the canopy layer, varying from 15% to 20% of the basal area in the IDF, SBS and SBPS zones (Table 5b).

3.3 Secondary structure and proportion of overstorey basal area occupied by pine

As detailed in *Materials and Methods*, basal area of the merchantable pine had to be 50% or more of the total merchantable basal area to be included in the dataset. Hence, by definition, components of the overstorey basal area of secondary structure have to be correlated with the basal area of pine.

One might expect secondary structure basal area to increase as pine basal area decreases. In general, this trend is observed for total secondary structure basal area (Figure 16). Interestingly, any level of pine basal area in any ecological unit has a wide range of possible total secondary structure basal areas. This suggests that generalizations about the total basal area of all secondary structure based solely on the percent of pine basal area are crude at best. In reality, the basal area of secondary structure can vary widely at any level of pine basal area, requiring site-specific field data for a precise value.

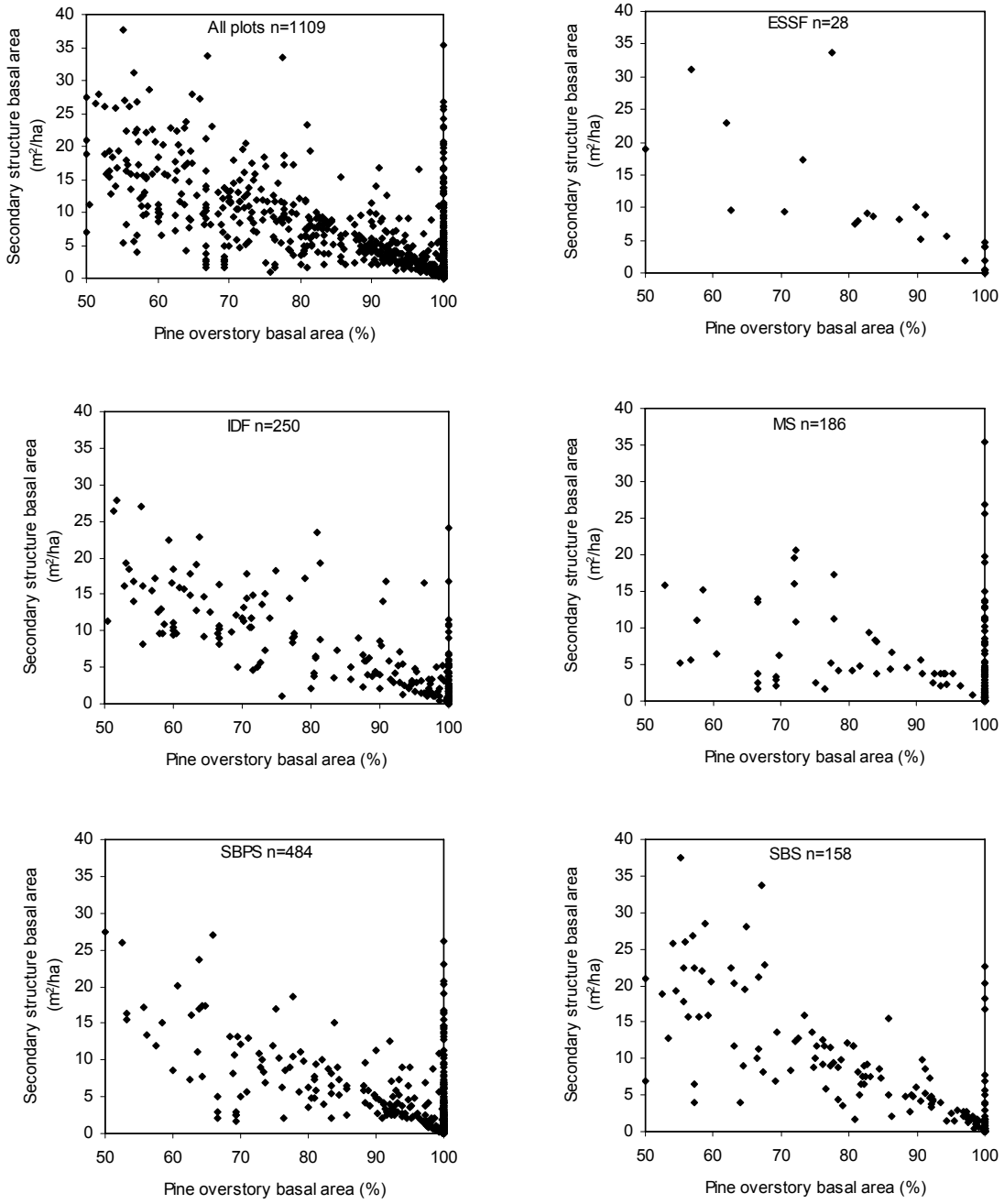

Figure 16. Basal area of secondary structure compared to the percentage of total overstorey basal area (m^2/ha) occupied by pine for all plots in pine-leading stands in the Cariboo–Chilcotin.

Note: Total secondary structure is the sum of Pl < 7.5 cm DBH and all other conifers and broadleaf trees > 0 cm DBH.

The relationship between pine basal area and non-merchantable secondary structure basal area was weak (Figure 17). The data clearly show that any level of non-merchantable secondary structure basal area can exist at any level of pine basal area. Assumptions about non-merchantable secondary structure basal area cannot be made based on the proportion of overstorey pine basal area. Only the SBS zone showed a slight trend of increased non-merchantable secondary structure basal area with decreasing overstorey pine basal area (Figure 17).

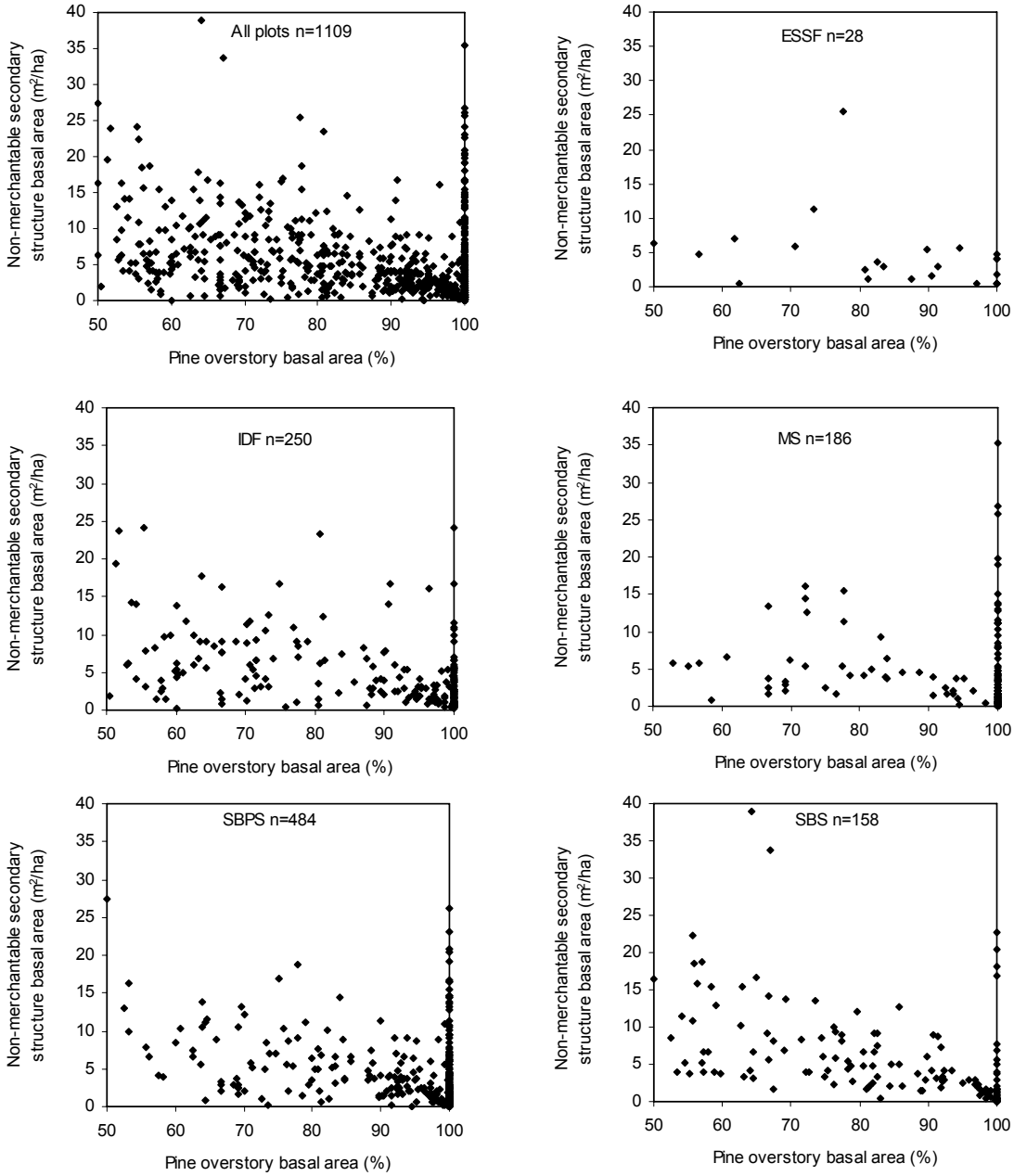

Figure 17. Basal area of non-merchantable secondary structure compared to the percentage of total overstorey basal area (m^2/ha) occupied by pine by zone.

Note: Non-merchantability limits are Pl < 7.5 cm DBH, other conifers < 17.5 cm DBH, and all broadleaf > 0 cm DBH.

4 The Clearcut Equivalence of Secondary Structure

We used TIPSY to determine the basal area development of average lodgepole pine plantations in the ecological units of the Cariboo–Chilcotin,and compared them to the current total secondary structure basal area (Table 6 and Figure 18). This lets secondary structure be quantified in terms of how long it would take a typical pine plantation to reach basal areas equivalent to those found in pine-leading stands damaged by the mountain pine beetle.

Assigning a clear-cut equivalence age does not imply that future performance of these stands will follow that of a managed pine plantation. It simply portrays how long it might take salvaged and planted sites across ecological units to recoup the existing basal area of the secondary structure. The shape of the clear-cut equivalence curve was similar for all ecological units (Figure 18).

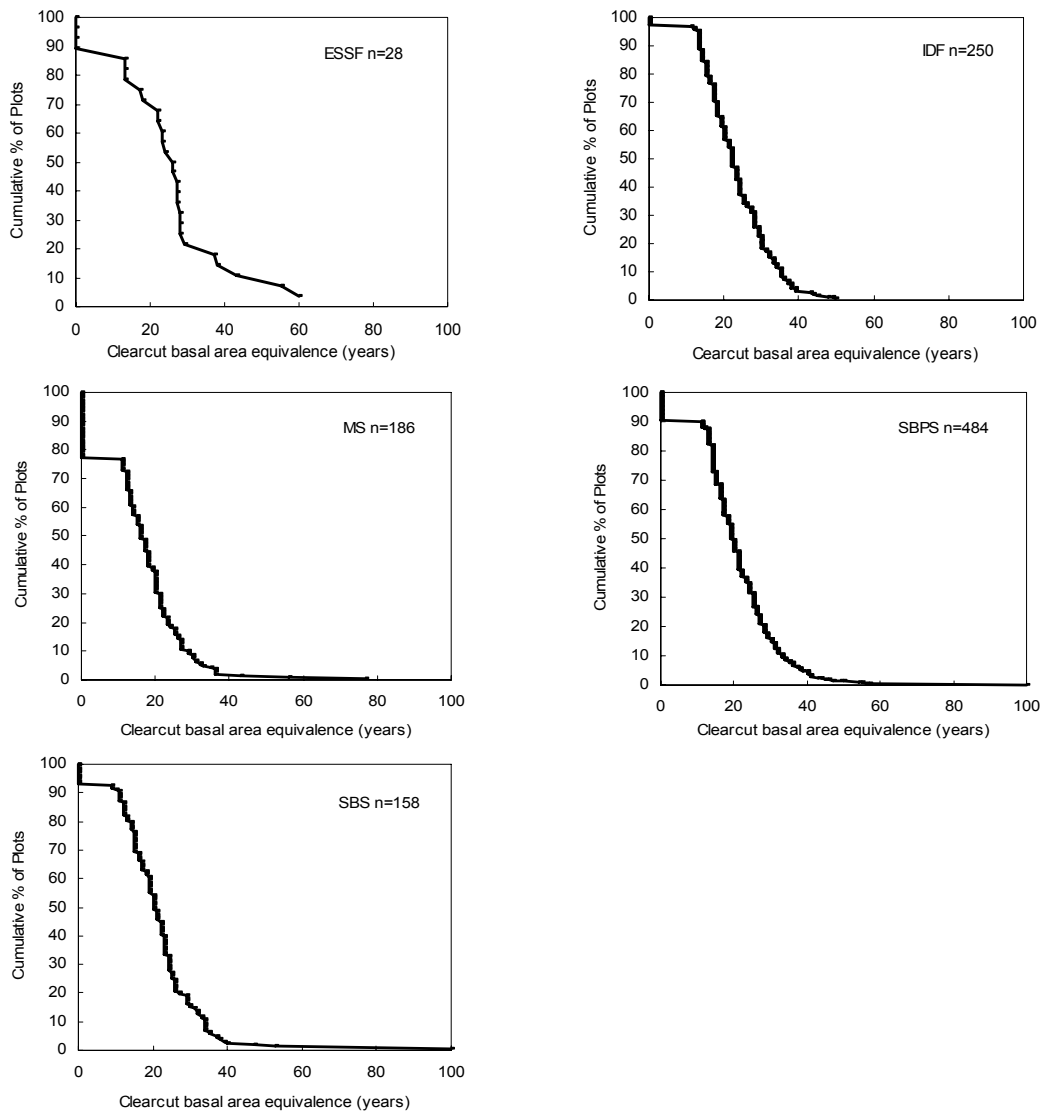

Figure 18. Cumulative percentage of plots in pine-leading stands that have the equivalent basal area to a developing lodgepole pine clearcut (1600 stems/ha) in biogeoclimatic zones in southern British Columbia (see Table 6).

Note: The basal area of secondary structure in each plot was assigned the number of years it would take a pine clearcut to reach that basal area (Table 7).

Across the different ecological units, between 31% and 68% of pine-leading stands currently have secondary structure equivalent to or better than a 20-year-old pine plantation (Table 6). When contrasted with a 40-year-old pine plantation, value decreased to between 2% and 11%. Clearcut equivalence was highest in the ESSF zone and lowest in the MS zone (Table 6).

4.1 The relationship between average lodgepole pine piece size and non-merchantable secondary structure

Average piece size is a commonly used metric to characterize the value of a stand from a logging and convert it to a dimensional lumber perspective. For example, stands with the highest average piece size might be scheduled for logging first, given all else was equal.

There was little evidence to support a relationship between the average piece size of lodgepole pine and the basal area of non-merchantable secondary structure (Figure 19). If anything, there was a slight trend toward higher non-merchantable secondary structure basal area in stands with a lower average pine piece size (see, for example, the SBS zone panel in Figure 19).

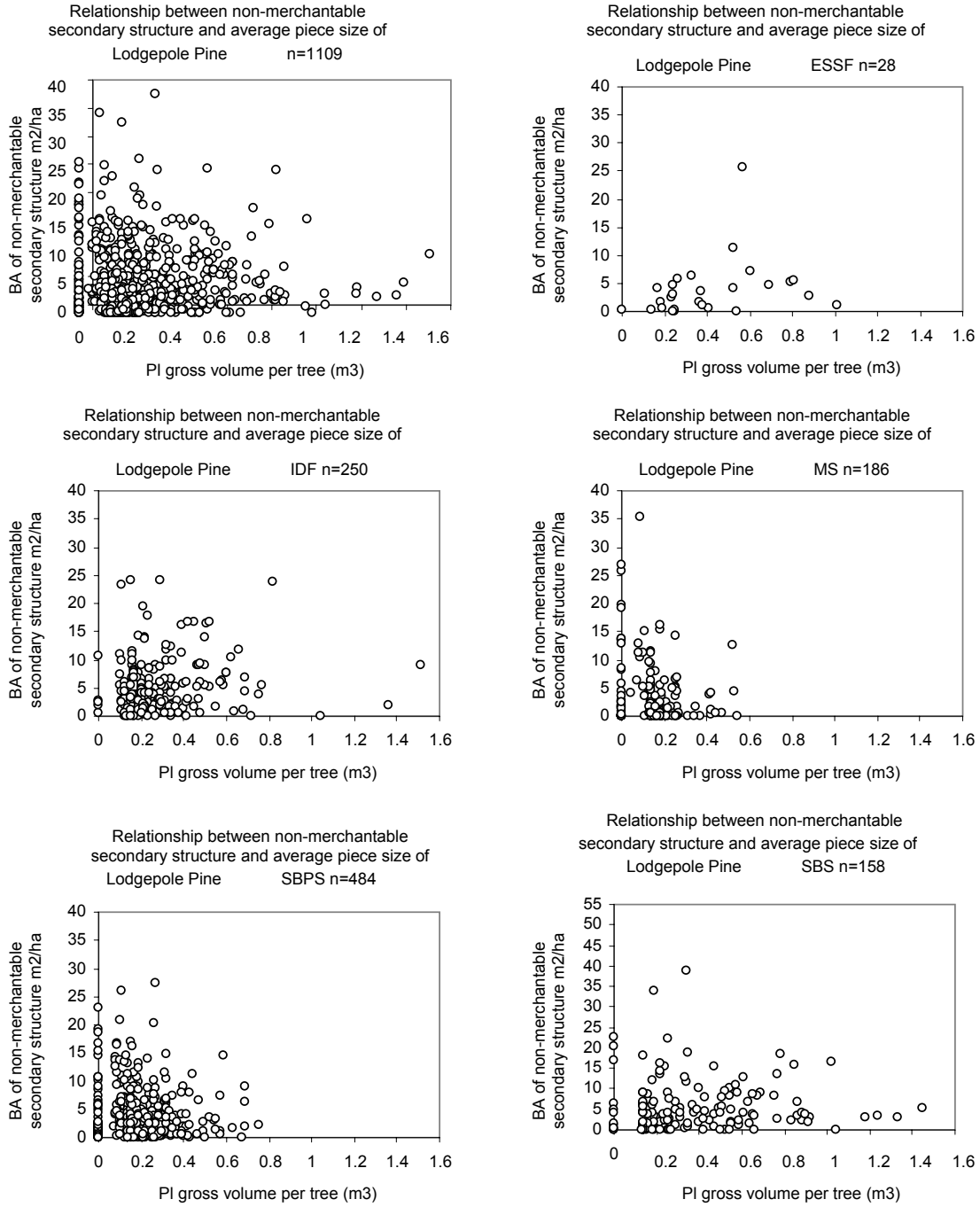

Figure 19. The relationship between the amount of non-merchantable secondary structure and average piece size of merchantable lodgepole pine.

Note: Average piece size was calculated by determining the average DBH for all live and dead pine trees ≥ 12.5 cm DBH in each plot (merchantable pine).Volume per tree was based on tree height to a 10.2 cm top (3 m was deducted from the average tree height).

Similar to the relationship between non-merchantable secondary structure basal area and proportion of pine in the overstorey, any level of secondary structure basal area can be found at any level of average pine piece size. This suggests that stands with sparse secondary structure can be suitable for salvage (high piece size) and that stands thick with secondary structure could be deferred from logging if it is expected to perform well in the future. Again, site-specific decisions are required and generalizations are to be avoided.

4.2 Forest health status of secondary structure in pine-leading stands

Secondary structure health is important throughout British Columbia wherever secondary structure is considered in management decisions for beetle-disturbed stands and landscapes. It is probably most important for growth and yield implications of different management strategies (i.e., salvaging and planting compared to managing the secondary structure).

We compiled an extensive individual tree dataset from the Cariboo–Chilcotin to examine forest health issues of secondary structure (Tables 8 and 9). For example, the information on the health of lodgepole pine is based on a sample size of 53,953 trees well-balanced across tree layers (Table 8). Summary tables are provided by combinations of damage type, tree species, ecological unit, tree layers or category of secondary structure (Tables 10–19).

Table 10. The percentage of trees, within each tree species, with forest health issues. All biogeoclimatic zones are combined.

Damages	At	Bl	Ep	Fd	Pl	Sb	Sx
Anything abiotic such as fire or drought	3.63	1.21	0	1.09	3.15	0.29	1.42
Broom rusts	0	0.24	0	0	0	0.86	1.04
Other foliage diseases	0	0.24	0	1.69	0.09	0	1.12
Pine needle cast	0	0	0	0	0.60	0	0
Lodgepole pine dwarf mistletoe	0	0	0	0	5.04	0	0
Other stem rusts	0.57	0	0	1.72	0.66	0	6.48
Atropellis canker	0	0	0	0	1.86	0	0
Comandra blister rust	0	0	0	0	0.15	0	0.02
Western gall rust	0.10	0	0	0	2.69	0	0.07
Orange stalictiform blister rust	0	0	0	0	0.46	0	0
Cooley spruce adelgid	0	0	0	0.03	0.01	0	4.30
Other bark beetles	0	0	0	0.03	0.13	0	0
Mountain pine beetle	0.10	0	0	0	1.75	0.58	0
Defoliators	0	0	0	1.23	0.01	0	0.02
Lodgepole pine terminal weevil	0	0	0	0	0.09	0	0
Physical damages (e.g., lean, sweep, broken stem)	1.43	5.57	11.27	0.83	0.97	0.86	0.62
Vegatative competition	0.10	0.24	0	0.11	0.18	0	0.74
Wildlife damage	3.15	0	0	0.20	0.41	0	0.02

Table 11. The percentage of trees, within each tree species, in the ESSF zone with forest health issues.

Damages	At	Bl	Pl	Sx
Anything abiotic such as fire or drought	0	2.53	5.45	2.61
Broom rusts	0	0	0	0
Other foliage diseases	0	0	0	0
Pine needle cast	0	0	0	0
Lodgepole pine dwarf mistletoe	0	0	0.97	0
Other stem rusts	0	0	0.19	0
Atropellis canker	0	0	0	0
Comandra blister rust	0	0	0	0
Western gall rust	0	0	0	0
Orange stalictiform blister rust	0	0	0	0
Cooley spruce adelgid	0	0	0	0
Other bark beetles	0	0	0	0
Mountain pine beetle	0	0	0.39	0
Defoliators	0	0	0	0
Lodgepole pine terminal weevil	0	0	0	0
Physical damages (e.g., lean, sweep, broken stem)	25.00	5.06	7.39	3.48
Vegetative competition		1.27	0.78	0
Wildlife damage	25.00	0	0	0

Table 12. The percentage of trees, within each tree species, in the ICH zone with forest health issues.

Damages	At	Ep	Fd	Pl
Anything abiotic such as fire or drought	33.33	0	2.50	5.33
Broom rusts	0	0	0	0
Other foliage diseases	0	0	0	0
Pine needle cast	0	0	0	0
Lodgepole pine dwarf mistletoe	0	0	0	0
Other stem rusts	0	0	2.50	0
Atropellis canker	0	0	0	0
Comandra blister rust	0	0	0	0
Western gall rust	0	0	0	1.33
Orange stalictiform blister rust	0	0	0	0
Cooley spruce adelgid	0	0	0	0
Other bark beetles	0	0	0	0
Mountain pine beetle	0	0	0	1.33
Defoliators	0	0	0	0
Lodgepole pine terminal weevil	0	0	0	0
Physical damages, (e.g., lean, sweep, broken stem)	0	50.00	10.00	14.67
Vegetative competition	0	0	0	2.67
Wildlife damage	0	0	0	0

Table 13. The percentage of trees, within each tree species, in the IDF zone with forest health issues.

Damages	At	Fd	Pl	Sx
Anything abiotic such as fire or drought	3.97	1.07	3.13	0.40
Broom rusts	0	0	0	0
Other foliage diseases	0	2.18	0.14	0
Pine needle cast	0	0	1.04	0
Lodgepole pine dwarf mistletoe	0	0	6.89	0
Other stem rusts	0	2.08	0.97	3.98
Atropellis canker	0	0	0.68	0
Comandra blister rust	0	0	0.19	0
Western gall rust	0	0	2.64	0
Orange stalictiform blister rust	0	0	0.74	0
Cooley spruce adelgid	0	0.05	0.02	7.16
Other bark beetles	0	0.05	0.07	0
Mountain pine beetle	0.28	0	1.86	0
Defoliators	0	2.18	0.01	0
Lodgepole pine terminal weevil	0	0	0.25	0
Physical damages (e.g., lean, sweep, broken stem)	1.70	0.51	0.76	0.40
Vegetative competition		0.10	0.08	0.20
Wildlife damage	1.13	0.25	0.60	00

Table 14. The percentage of trees, within each tree species, in the MS zone with forest health issues.

Damages	Fd	Pl	Sb	Sx
Anything abiotic such as fire or drought	5.26	2.58	7.69	4.00
Broom rusts	0	0	0	0
Other foliage diseases	0	0	0	0
Pine needle cast	0	2.16	0	0
Lodgepole pine dwarf mistletoe	0	5.24	0	0
Other stem rusts	5.26	0.19	0	0
Atropellis canker	0	0.08	0	0
Comandra blister rust	0	0	0	0
Western gall rust	0	0.69	0	0
Orange stalictiform blister rust	0	0	0	0
Cooley spruce adelgid	0	0	0	4.00
Other bark beetles	0	0.27	0	0
Mountain pine beetle	0	0.35	0	0
Defoliators	0	0	0	0
Lodgepole pine terminal weevil	0	0	0	0
Physical damages (e.g., lean, sweep, broken stem)	0	0.31	7.69	0
Vegetative competition	0	0	0	0
Wildlife damage	0	0	0	0

Table 15. The percentage of trees, within each tree species, in the SBPS zone with forest health issues.

Damages	At	Fd	Pl	Sb	Sx
Anything abiotic such as fire or drought	3.86	0.96	3.38	0	1.91
Broom rusts	0	0	0	2.97	1.86
Other foliage diseases	0	1.91	0.04	0	2.49
Pine needle cast	0	0	0.40	0	0
Lodgepole pine dwarf mistletoe	0	0	5.12	0	0
Other stem rusts	1.61	1.56	0.70	0	13.27
Atropellis canker	0	0	2.81	0	0
Comandra blister rust	0	0	0.09	0	0.05
Western gall rust	0.32	0	3.11	0	0.11
Orange stalictiform blister rust	0	0	0.45	0	0
Cooley spruce adelgid	0	0	0	0	6.42
Other bark beetles	0	0	0.15	0	0
Mountain pine beetle	0	0	1.99	1.98	0
Defoliators	0	0	0.01	0	0
Lodgepole pine terminal weevil	0	0	0.04	0	0
Physical damages (e.g., lean, sweep, broken stem)	0.96	0.12	0.74	0	1.49
Vegatative competition		0.12	0.21	0	0.05
Wildlife damage	8.36	0.24	0.47	0	0.27

Table 16. The percentage of trees, within each tree species, in the SBS zone with forest health issues.

Damages	At	Bl	Ep	Fd	Pl	Sb	Sx
Anything abiotic such as fire or drought	28.95	1.01	0	1.11	2.37	0	1.00
Broom rusts	0	0.34	0	0	0	0	0.56
Other foliage diseases	0	0.34	0	0	0.20	0	0
Pine needle cast	0	0	0	0	0.06	0	0
Lodgepole pine dwarf mistletoe	0	0	0	0	1.73	0	0
Other stem rusts	2.63	0	0	0.63	0.15	0	0.19
Atropellis canker	0	0	0	0	1.22	0	0
Comandra blister rust	0	0	0	0	0.36	0	0
Western gall rust	0	0	0	0	2.06	0	0.06
Orange stalictiform blister rust	0	0	0	0	0.20	0	0
Cooley spruce adelgid	0	0	0	0	0	0	1.31
Other bark beetles	0	0	0	0	0.13	0	0
Mountain pine beetle	0	0	0	0	1.22	0	0
Defoliators	0	0	0	0	0	0	0.06
Lodgepole pine terminal weevil	0	0	0	0	0	0	0
Physical damages (e.g., lean, sweep, broken stem)	13.16	6.40	11.54	2.22	1.85	0.89	0.94
Vegetative competition	2.63	0	0	0.16	0.25	0	0.12
Wildlife damage	5.26	0	0	0	0.03	0	0

Table 17. The percentage of understorey trees 0–7.5 cm DBH with forest health issues from all biogeoclimatic zones.

Damages	At	Bl	Fd	Pl	Sb	Sx
Anything abiotic such as fire or drought	0.48	0	0.90	0.59	0	1.03
Broom rusts	0	0	0	0	1.39	0.54
Other foliage diseases	0	0.66	2.08	0.09	0	1.27
Pine needle cast	0	0	0	1.43	0	0
Lodgepole pine dwarf mistletoe	0	0	0	3.30	0	0
Other stem rusts	0.48	0	2.31	0.20	0	9.43
Atropellis canker	0	0	0	0.85	0	0
Comandra blister rust	0	0	0	0.09	0	0.06
Western gall rust	0.48	0	0	1.68	0	0
Orange stalictiform blister rust	0	0	0	0.02	0	0
Cooley spruce adelgid	0	0	0.06	0.02	0	5.50
Other bark beetles	0	0	0	0.01	0	0
Mountain pine beetle	0	0	0	0.19	0.69	0
Defoliators	0	0	1.97	0.02	0	0
Lodgepole pine terminal weevil	0	0	0	0.21	0	0
Vegetative competition	0	0	0	0.10	0	0.97
Wildlife damage	3.86	0	0.28	0.70	0	0
Total hideous damages	5.31	0.66	7.60	9.49	2.08	18.80

Table 18. The percentage of 7.5–15 cm DBH sub-canopy trees with forest health issues from all biogeoclimatic zones.

Damages	At	Bl	Ep	Fd	Pl	Sb	Sx
Anything abiotic such as fire or drought	3.09	0.62	0	0.68	2.15	0.59	1.65
Broom rusts	0	0	0	0	0	0.59	1.34
Other foliage diseases	0	0	0	1.56	0.04	0	0.98
Pine needle cast	0	0	0	0	0.27	0	0
Lodgepole pine dwarf mistletoe	0	0	0	0	4.49	0	0
Other stem rusts	0.21	0	0	1.66	0.63	0	6.67
Atropellis canker	0	0	0	0	1.37	0	0
Comandra blister rust	0	0	0	0	0.15	0	0
Western gall rust	0	0	0	0	3.10	0	0.12
Orange stalictiform blister rust	0	0	0	0	0.45	0	0
Cooley spruce adelgid	0	0	0	0	0	0	3.55
Other bark beetles	0	0	0	0	0.08	0	0
Mountain pine beetle	0	0	0	0	1.13	0.59	0
Defoliators	0	0	0	0.49	0.00	0	0.06
Lodgepole pine terminal weevil	0	0	0	0	0.08	0	0
Physical damages (e.g., lean, sweep, broken stem)	1.44	9.88	11.54	0.88	0.86	0.59	0.10
Vegetative competition	0.21	0.62	0	0.39	0.26	0	0.49
Wildlife damage	2.06	0	0	0	0.31	0	0
Total hideous damages	7.01	11.11	11.54	5.66	15.38	2.37	14.97

Table 19. The percentage of canopy trees ≥ 15 cm DBH with forest health issues from all biogeoclimatic zones.

Damages	At	Bl	Ep	Fd	Pl	Sb	Sx
Anything abiotic such as fire or drought	6.20	4.04	0	2.16	6.01	0	1.75
Broom rusts	0	1.01	0	0	0	0	1.42
Other foliage diseases	0	0	0	0.87	0.15	0	1.09
Pine needle cast	0	0	0	0	0.45	0	0
Lodgepole pine dwarf mistletoe	0	0	0	0	6.82	0	0
Other stem rusts	1.13	0	0	0.29	0.99	0	0.87
Atropellis canker	0	0	0	0	3.10	0	0
Comandra blister rust	0	0	0	0	0.19	0	0
Western gall rust	0	0	0	0	2.86	0	0.11
Orange stalictiform blister rust	0	0	0	0	0.76	0	0
Cooley spruce adelgid	0	0	0	0	0.01	0	3.60
Other bark beetles	0	0	0	0.14	0.27	0	0
Mountain pine beetle	0.28	0	0	0	3.50	0	0
Defoliators	0	0	0	0.43	0.01	0	0
Lodgepole pine terminal weevil	0	0	0	0	0.01	0	0
Physical damages (e.g., lean, sweep, broken stem)	2.25	7.07	14.71	2.89	1.74	5.88	0.87
Vegetative competition					0.15		0.55
Wildlife damage	4.23			0.29	0.33		0.11
Total hideous damages	14.08	12.12	14.71	7.07	27.33	5.88	10.37

In consultation with forest health professionals, we selected 18 of the most important damaging agents of tree species in the Cariboo–Chilcotin. Table 10 presents damage incidence by species across all the region's ecological units, whereas the summaries in Tables 11 to 16 are specific to its individual ecological units.

Tree damage data is difficult to summarize because damage agents are not equal. Considering the importance of lodgepole pine composition in the Cariboo–Chilcotin, we will focus our results on this species, and specifically on the incidence of lodgepole pine dwarf mistletoe on understorey pine trees. We provide damage information on all tree layers of pine, but sub-canopy and canopy pine trees are not considered secondary structure in this report.

Understorey secondary structure pine trees (seedlings and saplings) averaged 3.3% infection of mistletoe across all ecological units (Table 17), which is lower than the 5% combined average of all pine tree layers (Table 10). The overall incidence of mistletoe varied from 1% in the ESSF zone to 6.9% in the IDF zone. Infection rates were higher in sub-canopy pine (4.5%) and canopy pine (6.8%)—see Tables 18 and 19.

Fewer than 10% of all understorey pine trees were damaged, whereas nearly 20% of all understorey interior spruce were (Table 17). In comparison, nearly 8% of Douglas-fir understorey trees were damaged, as was only 1% of subalpine fir understorey trees. Sub-canopy secondary structure trees (non-pine species) generally had more damage than understorey trees of the same species (Table 18), except Douglas-fir, which had slightly less. Damage levels in canopy trees were similar to those of sub-canopy trees (Table 19).

Caution should be used in translating damage incidence into the percent of trees that are somehow unacceptable for future management consideration. This decision depends on the management value, the tree species, and the damage agent. These data do, however, provide a general sense of forest health in the Cariboo–Chilcotin.

5 Acknowledgements

Funding for this project was provided by the Government of Canada through the Federal Mountain Pine Beetle Program, a program administered by Natural Resources Canada, Canadian Forest Service. Publication does not necessarily signify that the contents of this report reflect the views or policies of Natural Resources Canada, Canadian Forest Service.

We especially thank all those individuals and organizations that so generously provided the data used in this analysis (see Table 1). Ian Moss assisted us in several different ways. We thank staff at the BC Ministry of Forests and Range, Inventory Section, in Victoria for helpful suggestions. Research staff from the Southern Interior Forest Region, BC Ministry of Forests and Range, provided advice and assistance at various stages of the project: thanks.

This project was coordinated by Dave Coates of the Ministry of Forests and Range, Smithers. His two-month contribution of time to this project was all in-kind. Several other staff of the Ministry of Forests and Range, Southern Interior Forest Region, contributed one to three days of in-kind support. There were no outside cash contributions to the project.

6 Contact

Dave Coates, British Columbia Forest Service
Forest Sciences, Bag 6000
Smithers, BC V0J 2N0
Dave.Coates@gov.bc.ca
250-847-6386

7 Literature Cited

Coates, K.D.; DeLong, C.; Burton P.J.; Sachs D.L. 2006. Abundance of secondary structure in lodgepole pine stands affected by the mountain pine beetle. Report for the Chief Forester, August, 2006. 17 p. http://www.for.gov.bc.ca/hfp/mountain_pine_beetle/stewardship/

Coates, K.D.; Hall, E.C. 2005. Implications of alternate silvicultural strategies in mountain pine beetle damaged stands. Technical Report for Forest Science Program Project Y051161. Bulkley Valley Centre for Natural Resources Research and Management. Smithers, BC. 31 p.

Nigh, G.D.; Antos, J.A.; Parish, R. 2008. Density and distribution of advance regeneration in mountain pine beetle killed lodgepole pine stands of the Montane Spruce zone of southern British Columbia. Canadian Journal of Forest Research 38:2826–2836.

Pousette, J. 2009. An update on the impact of mountain pine beetle on timber supply forecasts for the PG Timber Supply Area. Northern Silviculture Committee Meeting, 19–21 Jan 2009, Prince George, BC. http://www.unbc.ca/assets/continuingstudies/events/nscwinter2009/john_pousette.pdf

Vyse, A.; Ferguson, C.; Huggard, D.J.; Roach, J.; Zimonick, B. 2009. Regeneration beneath lodgepole pine dominated stands attacked or threatened by the mountain pine beetle in the south central Interior, British Columbia. Forest Ecology and Management 258(1):S36–S43.