The applicability of available hazard rating systems for mountain pine beetle in lodgepole pine stands of southeastern Wyoming

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Five hazard rating systems for *Dendroctonus ponderosae* Hopkins in *Pinus contorta* Dougl. stands were compared under nonoutbreak conditions in the Medicine Bow Mountains of southeastern Wyoming. The applicability of these systems, which were designed in other regions of the United States, to *P. contorta* stands in southeastern Wyoming was investigated. Thirty-two stands in four different age and diameter categories were sampled and rated by each system. Diameter at breast height did not correlate well with phloem width in any of the stands, as implied by the system of Amman and co-workers. A direct phloem width measurement could further refine this system. Periodic growth ratio, used in both the Berryman and Mahoney systems, did not differentiate between fast- and slow-growing trees. Crown competition factor did not positively correlate with increasing diameter at breast height, as implied by the system of Schenk and co-workers. Stand production ranged from 11.1 to 51.0 g wood · m leaf area^{-2} · year^{-1}, applying a modified system based on that designed by Mitchell and co-workers, indicating very high risk in every stand sampled. Further development and validation of hazard rating systems is necessary for improved analysis of risk to *P. contorta* stands from *D. ponderosae* in this region.

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Cinq méthodes d'évaluation des risques au *Dendroctonus ponderosae* Hopkins ont été comparées en situation non-épidémique dans des peuplements de *Pinus contorta* Dougl. situés dans les Medicine Bow Mountains au sud-est du Wyoming. Les auteurs ont étudié l'applicabilité de ces méthodes, conçues dans d'autres régions des Etats-Unis, aux peuplement de *P. contorta* du sud-est du Wyoming. Trente-deux peuplements répartis en quatre classes d'âge et de diamètre furent échantillonnés et classés d'après chaque méthode. Le diamètre à hauteur de poitrine n'était pas bien corrélé avec l'épaisseur du phloème dans tous les peuplements tel que requis par la méthode d'Amman et ses collègues. Cette méthode pouvait être améliorée par la mesure directe du phloème. Le rapport des taux d'accroissement périodique utilisé dans les méthodes de Berryman et de Mahoney ne permettait pas de distinguer entre les arbres à croissance rapide et lente. Le facteur de compétition de la cime n'etait pas directement proportionnel à l'augmentation du diamètre à hauteur de poitrine tel qu'assumé par la méthode de Schenk et ses collègues. La productivité des peuplements variait de 11,1 à 51,0 g matière ligneuse · m de surface foliaire^{-2} · an^{-1} selon une modification de la méthode de Mitchell et ses collègues et indiquait un risque très élevé dans tous les peuplements échantillonnés. L'amélioration des méthodes d'évaluation des risques et leur validation sont nécessaires pour une meilleure analyse de la prédisposition des peuplements de *P. contorta* au *D. ponderosae* dans cette région.

[Traduit par le journal]

Introduction

The mountain pine beetle (MPB) *Dendroctonus ponderosae* Hopkins, is one of the most destructive forest insects in western North America. Outbreaks develop over extensive areas of lodgepole pine, *Pinus contorta* Dougl., causing mortality rates of up to 85% of the large-diameter trees (Cole and Amman 1980).

In an attempt to predict susceptibility of stands to MPB outbreaks, several hazard rating systems have been developed. They can be divided into regional and stand-level systems. Regional systems are based on historical infestation trends (Crookston et al. 1977) as well as climate (Safranyik et al. 1974). Regional classifications are valuable in designating large geographic areas as being hazardous, but more specific systems are required to locate individual stands at risk. The various stand-level classifications are based on (*i*) tree age, diameter, and climatic suitability (Amman et al. 1977), (*ii*) phloem width, stand resistance to attack, and climate (Berryman 1978), (*iii*) periodic growth ratio (PGR) (Mahoney 1978), (*iv*) tree growth efficiency (TGE) in grams of wood (WD) produced per square metre of leaf area (LA) per year (Mitchell et al. 1983; Waring and Pitman 1980), (*v*) crown competition factor (CCF) and percent lodgepole pine basal area (PLPP) (Schenk et al. 1980), and (*vi*) current annual increment − mean annual increment (Safranyik et al. 1974).

To compare systems *i* to *v*, they were applied to lodgepole pine stands in southeastern Wyoming. All except system *i* were originally designed in the Pacific northwest or northern Rocky Mountain regions. The system designed by Amman et al. (1977) is the only system tested that was based on data collected from a large geographical area.

The variables used in the different systems (i.e., dbh, phloem width, PGR, CCF, TGE) were selected by the various authors because they were associated statistically with outbreaks or were correlated with other variables that were associated with outbreaks (i.e., dbh correlates with phloem width). These relationships were tested under the assumption that if they fail in the test areas, then the applicability of the system was unsuitable or needed modification for southeastern Wyoming.

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Methods

Study area

The study was conducted in the summer of 1983 in unmanaged lodgepole pine stands on the Hayden Ranger District of the Medicine Bow National Forest. Study stands were located at elevations between 2300 and 2700 m on both the east and west sides of the continental divide.

In the lodgepole pine forest zone, mean annual temperature is less than 1.7°C, the minimum and maximum temperatures range from −45.6°C to 32.2°C. Mean annual precipitation is closely tied to elevation, being ca. 38.1 and 63.5 cm at 1829 and 3049 m elevation, respectively. As elevations above 2438 m, ca. 2/3 of the annual precipitation falls as snow between October and May (Wirsing and Alexander 1975).

The stands are of fire origin and are mostly 80-years-old or older. The MPB population has been at endemic levels for the past 10 years. In the late 1970's, two population centers expanded and killed in excess of 2 million board feet of timber.

Study design

The 32 sampled stands were divided into four general categories: (1) age ≥ 80 years, dbh ≥ 20.3 cm; (2) 60 years < age < 80 years, dbh ≥ 20.3 cm; (3) age ≥ 80 years, dbh < 20.3 cm; (4) 60 years < age < 80, dbh < 20.3 cm. Because of the great imbalance in age stand structure that existed in the area (i.e., few stands <80 years old), only five stands in group 2 and three stands within group 4 were sampled. Group 1 had 14 stands and group 3 contained 10 stands.

Stands were inventoried by establishing 10 plots throughout each stand. Plot size was determined by a 10 basal area factor prism: all trees ≥12.7 cm dbh that were determined to be "in" by the prism made up the plot. Species and dbh were recorded for all trees in the plot. Additionally, each of the three lodgepole pines closest to plot center were measured as follows. (*i*) Phloem width: two bark samples were removed 180° from each other at breast height and phloem width was measured in the field. (*ii*) Total tree height. (*iii*) Live crown ratio. (*iv*) Crown class. (*v*) Tree age: two increment cores were extracted 180° from each other at dbh; tree age was determined by counting the number of annual rings on each increment core and adding nine to account for time required for the tree to grow to breast height (Alexander 1974). (*vi*) Last 5-year radial increment was measured as was the previous 5-year increment; PGR was calculated by dividing the last 5-year increment by the previous 5-year increment; width of the last full ring was also recorded. (*vii*) Sapwood width was measured in the field and again in the laboratory using ferric chloride as an indicator of the sapwood–heartwood interface (Kutscha and Sachs 1962).

Data from the 30 intensively sampled trees in each stand were used to obtain stand averages for the measures listed above.

The variable relationships tested were as follows: (*i*) dbh – phloem width (Amman 1969; Amman et al. 1977; Cole 1973; Cole and Amman 1980); (*ii*) PGR (Berryman 1978; Mahoney 1978); (*iii*) grams WD produced per square metre LA per year (Mitchell et al. 1983; Waring and Pitman 1980); (*iv*) CCF – stand dbh (Schenk et al. 1980).

The system of Mitchell et al. (1983) for calculating TGE was modified because it relied on a linear relationship between sapwood area at breast height and leaf surface area (Grier and Waring 1974) with each square centimetre of sapwood area representing 0.15 m^2 of crown leaf area (Waring 1980). Since this relationship did not exist in the study area (Pearson et al. 1984), annual wood production (TGE) was determined by applying an equation developed by Pearson et al. (1984) using dbh changes for the previous 2 years:

$$\text{[1]} \quad BO = -4.3 + 0.305X$$

where BO is the weight of the bole (kilograms) and X is the basal area of the tree (square centimetres).

CCF (Krajicek et al. 1961) for lodgepole pine in the central Rocky Mountains was calculated according to Alexander et al. (1967).

Stand hazard ratings (SHR = CCF × PLPP) were calculated using regression equations developed for the northern Rocky Mountain region (Schenk et al. 1980). PLPP was calculated using basal area for

Analysis of variance (ANOVA) was used to evaluate the relationships of dbh and CCF to phloem width. Student's *t*-test was used to investigate if differences existed between groups 1, 2, and 3 for mean PGR and mean TGE (p = 0.05).

Results and discussion

Table 1 illustrates that as diameters increased, there was a corresponding significant (p = 0.05) increase in phloem width between 10 cm dbh classes, except between the 30.1- to 40.0-cm group and the >40.0-cm group. The coefficient of determination (r^2) between dbh and phloem width for all trees sampled was calculated to be 0.20 ($n = 948$, $p < 0.01$). Further investigation of individual stands revealed considerable variability in the relationship between phloem width and dbh between stands. The r^2 for individual stands in group 1 ranged from <0.01 to 0.59, with 10 of the 14 stands having $r^2 > 0.25$. The r^2 varied greatly within the other groups as well (Table 2). The coefficients were less than those found by Amman (1978) (r^2 = 0.69–0.95 for 10 different locations).

These results imply that generally large diameter indicates thick phloem in comparison to smaller diameter and, within most stands in this study, dbh does explain a percentage of the variability in observed phloem width. However, the relationship between dbh and phloem width is not strong enough, as indicated by the low r^2 values, for dbh to provide a sensitive measure of actual risk as a result of phloem width.

The reasons for the poor correlation between phloem width and dbh in certain stands were not investigated in this study. However, there are several possible causes that may explain this. These include the presence or absence of dwarf mistletoe, *Arceuthobium americanum,* in stands, as well as stands on the east side of the continental divide versus west-side stands. The poor relationship indicated within group 3 ($r^2 < 0.20$ for 7 of the 10 stands) may be indicative of the narrow range of tree diameters found within these dense, relatively small-diameter stands.

The Amman et al. (1977) system could improve its rating sensitivity by including an actual phloem measurement along with it's other parameters. Phloem widths have been shown to change slowly because of their long retention time (Cabrera 1978). Therefore, field measurements, once made, would be viable for a number of years. Because of the beetles' preference for large-diameter trees and because beetle production in small-diameter trees is low owing to the generally thinner phloem and excessive drying of the tree, dbh sould remain an integral part of the system (Amman et al. 1977).

No difference in mean PGR was found between any two groups despite the age and size differences between them (Table 3). Meanwhile, group means for TGE were significantly different (p = 0.05) (Table 3). Group 2 stands showed the highest growth, which seems reasonable when considering these stands were younger than either groups 1 or 3. Group 4 was not included in the analysis because of its small sample size. The *t*-test results indicate that the system of Mitchell et al. (1983) did differentiate between fast- and slow-growing trees, while Mahoney's (1978) PGR indicator did not. This difference is important when considering that growth rates influence phloem widths as well as growth efficiency.

Schenk et al. (1980) proposed a rating system based on CCF and PLPP within the stand. Two assumptions were made: (*i*) CCF increases with increasing stand diameter (Schenk et al. 1977) and (*ii*) susceptibility of stands should increase with density and purity (Schenk et al. 1980). The first assumption did not prove valid in this study. The relationship between stand

TABLE 1. Mean phloem width in relation to diameter class (number of trees analyzed in parentheses), Hayden Ranger District, Medicine Bow National Forest, Wyoming, 1983

dbh class (cm)	Mean phloem width (cm)
<20.0	0.18(477)*a*
20.0–30.0	0.22(357)*b*
30.1–40.0	0.25(87)*c*
>40.0	0.26(27)*c*
Mean	0.20(948)

NOTE: Means followed by the same letter were not significantly different at the 0.05 level by one-way ANOVA.

TABLE 2. Coefficients of determination (r^2) for the relationship between dbh and phloem width within the 32 study stands, Hayden Ranger District, Medicine Bow National Forest, Wyoming, 1983

Stand No.	*n*	r^2	*F* value[a]
	Group 1		
1	30	0.40	18.1**
2	30	0.42	20.0**
3	30	0.26	9.7**
4	30	0.59	40.1**
5	30	0.42	19.7**
6	30	0.02	0.4
7	30	0.21	7.4*
8	30	<0.01	0.2
9	30	0.47	25.2**
10	30	0.29	12.0**
11	30	0.55	34.2**
12	30	0.11	3.4
13	30	0.50	27.7**
14	30	0.31	13.0**
	Group 2		
15	30	0.40	19.0**
16	30	<0.01	0.3
17	30	0.28	10.9**
18	30	0.33	14.0**
19	30	0.13	4.3*
	Group 3		
20	30	0.32	13.1**
21	30	0.45	22.9**
22	30	0.19	0.2
23	30	0.16	5.4*
24	30	0.07	2.2
25	30	0.17	5.9*
26	30	<0.01	0.2
27	24	0.07	1.7
28	30	0.05	1.5
29	30	0.42	20.6**
	Group 4		
30	30	0.27	10.4**
31	30	0.37	16.5**
32	24	0.33	11.1**

[a]Significance levels: *, $p < 0.05$; ** $p < 0.01$.

TABLE 3. Mean periodic growth ratios (PGR) and mean tree growth efficiencies (TGE, grams WD per square metre LA per year) produced for stand groups 1 through 3, Hayden Ranger District, Medicine Bow National Forest, Wyoming, 1983

Group	PGR	TGE
1	0.977*a*	15.45*a*
2	0.931*a*	25.92*b*
3	1.023*a*	21.65*b*

NOTE: Means followed by the same letter were not significantly different by *t*-test ($p = 0.05$).

CCF and mean dbh was not positive ($r = -0.24$, $n = 32$, $p = 0.12$). The second assumption was also questioned. Many of the stands in group 3 were rated high hazard (SHR > 1.50) by this system because they were pure to almost pure (82.3–100.0%) lodgepole pine and had CCFs ranging from 145.5 to 230.2 (Table 4). The high hazard estimates for this group seem unreasonable when considering the mean tree dbh is <20.3 cm. Small-diameter trees do not have characteristics conducive to outbreaks (Amman 1969, 1978; Amman et al. 1977; Cole 1973; Safranyik et al. 1974). It is unlikely epidemic populations could sustain themselves in these stands.

The system designed by Berryman (1978) uses a vigor index calculated by dividing PGR by SHR. As stated previously, problems exist with PGR as well as CCF, a component of SHR.

Growth efficiency ratings by the modified system of Mitchell et al. (1983) ranged from 11.1 to 51.0 g WD·m LA^{-2}·year^{-1} for the 32 test stands (Table 4). These values were less than those calculated by Mitchell et al. (1983) of 35–61 g/year for the unthinned stands in that study. Group 1 stands, those most likely to be susceptible, ranged from 11.1 to 22.4 g WD·m LA^{-2}·year^{-1}. Every tested stand was well below the high hazard threshold as determined by Mitchell et al. (1983) of <80 g/year. It seemed unlikely that any unmanaged stand in the area could produce >80 g/year, which makes the system difficult to implement. Low, medium, and high hazard categories for southeastern Wyoming lodgepole pine stands need to be defined for the system to have application in the area.

Conclusions

The system of Amman et al. (1977) could increase its risk sensitivity by including an actual phloem measurement instead of relying on diameter as its phloem indicator. The Berryman (1978) system, which does employ an actual phloem measurement, relies on what appears to be an unreliable predictor of stand resistance (SR) (SR = PGR/SHR) (Berryman 1978; Mahoney 1978). Mahoney's (1978) PGR was unable to differentiate between fast- and slow-growing trees and CCF, a component of SHR, did not correlate positively with dbh as proposed by Schenk et al. (1977). The system of Mitchell et al. (1983), because it rated every stand high risk, needs further refinement to become a practical tool in the area.

This study illustrates the problems of applying a rating system outside of its data base location. Relationships that exist in a certain region do not necessarily pertain throughout the species range.

TABLE 4. Crown competition factors (CCF), percent lodgepole pine basal area (PLPP), stand hazard ratings (SHR), and tree growth efficiencies (TGE) produced for individual study stands, Hayden Ranger District, Medicine Bow National Forest, Wyoming, 1983

Stand No.	LPCCF	Stand CCF	PLPP	SHR	TGE
Group 1					
1	214.4	218.8	97	2.12	11.9
2	162.0	187.5	83	1.55	18.5
3	194.6	211.8	90	1.91	13.5
4	181.0	197.0	92	1.81	18.9
5	233.5	238.4	98	2.34	16.0
6	136.8	185.5	72	1.34	17.1
7	133.4	149.5	88	1.31	15.5
8	169.8	189.7	90	1.70	22.4
9	221.1	236.1	94	2.21	11.3
10	116.5	130.4	89	1.16	14.9
11	180.2	184.2	98	1.80	11.1
12	125.5	162.1	77	1.25	13.2
13	131.2	162.4	81	1.31	15.7
14	194.8	221.3	88	1.95	16.3
Group 2					
15	90.6	120.4	61	0.73	35.5
16	119.4	133.7	82	1.10	27.6
17	230.1	241.7	94	2.28	18.4
18	160.1	161.4	99	1.60	24.0
19	211.6	233.3	91	2.11	24.1
Group 3					
20	223.1	223.1	100	2.23	21.6
21	199.2	210.8	92	1.94	18.6
22	153.7	175.7	82	1.45	22.0
23	198.2	214.3	88	1.89	19.5
24	174.0	174.0	100	1.74	31.6
25	230.2	230.2	100	2.30	14.8
26	172.9	174.2	99	1.73	27.0
27	145.5	145.5	100	1.45	23.0
28	200.5	202.0	99	2.01	16.0
29	183.6	188.9	95	1.79	21.6
Group 4					
30	194.6	202.4	95	1.91	24.1
31	208.4	208.4	100	2.08	21.3
32	157.1	158.0	99	1.56	51.0

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