bees work a limited area. Honey bees foraging dandelion for nectar do not switch to apple bloom after dandelions close in the afternoon. Dandelions are beneficial to the bee colonies in providing pollen and nectar, but they appear to be a serious drain on the numbers of available pollinators for apple.

ACKNOWLEDGEMENT

We thank Lora Rathbone and Gene Milizcky for their help and Lewis Orchards for the use of their orchard. We also thank the Washington Tree Fruit Research Commission for partial funding of this research.

REFERENCES

Filmer, R.S. 1941. Honeybee population and floral competition in New Jersey orchards. J. Econ. Entomol. 34:198-191.

Free, J.D. 1968. Dandelion as a competitor to fruit trees for bee visits. J. Appl. Ecol. 5:169-178.

Free, J.D. 1970. Insect Pollination of Crops. Academic Press, New York.

Kremer, J.C. 1950. The dandelion and its influence on bee behavior during the fruit blossoming period. Proc. Amer. Soc. Hort. Sci. 55:14-146.

Mayer, D.F., C.A. Johansen, D.M. Burgett. 1986. Bee pollination of tree fruits. Wash. St. Univ. Coop. Ext. PNW 0282. 10 pp.

Steel, R.G.D. and J.H. Torrie. 1980. Principles and Procedures of Statistics. A Biometrical Approach. 2nd ed. McGraw-Hill, New York.

Percival, M.S. 1955. The presentation of pollen in certain angiosperms and its collection by *Apis mellifera*. New Phytol. 54:353-68.

Unseasonably low fall and winter temperatures affecting mountain pine beetle and pine engraver beetle populations and damage in the British Columbia Chilcotin Region

L. SAFRANYIK and D.A. LINTON

FORESTRY CANADA, PACIFIC FORESTRY CENTRE
506 W. BURNSIDE RD., VICTORIA, B.C. V8Z 1M5

ABSTRACT

Unseasonably low temperatures in the fall and winter of 1984 and the fall of 1985 resulted in the decline and termination by 1987 of a major mountain pine beetle infestation which had been in progress since the late 60's. Following the winter of 1984-85, brood survival on lodgepole pine trees in plots near Tsuh Lake in the west-central Chilcotin area of British Columbia was restricted to the lower 0.5 m of infested boles, and the estimated average emergence of female beetles per tree was about 10% of the number required for replacement of the parent generation. Pine engraver beetle populations which built up during the mountain pine beetle epidemic killed many trees in 1985 and 1986, but collapsed by 1987, due mainly to tree resistance and other natural factors. The rise and fall of tree mortality from the pine engraver within the plots paralleled that in the rest of the central Chilcotin following the collapse of the mountain pine beetle outbreak.

INTRODUCTION

Mortality from cold is one of the major factors determining the distribution and abundance of the mountain pine beetle (*Dendroctonus ponderosae* Hopk.)(Safranyik 1978; Amman and Cole 1983). Mountain pine beetles normally overwinter as late-instar larvae, the stage at which they are the most cold-hardy (Safranyik 1978; Amman and Cole 1983). Cold-hardiness of mountain pine beetle increases with the accumulation of glycerol in body fluids in response to gradually decreasing temperatures in the fall and early winter

Table 1

Selected minimum daily temperatures* and month-end snow depths at Alexis Creek B.C. in 1984 and 1985. (Source: Monthly records of Meteorological Observations in Canada 1984, 1985. Environment Canada, Atmospheric and Environment Service.)

	Date	Minimum daily temp. (°C)	Snow depth (cm)
1984			
	Oct. 30	-23.0	
	Oct. 31	-31.0	7
	Nov. 1	-21.0	
	Dec. 29	-40.0	
	Dec. 30	-43.0	
	Dec. 31	-38.0	36
1985			
	Nov. 11	-27.5	
	Nov. 12	-20.0	
	Nov. 22	-31.0	
	Nov. 23	-35.0	
	Nov. 24	-23.5	
	Nov. 25	-26.0	
	Nov. 26	-39.0	
	Nov. 27	-43.0	
	Nov. 28	-39.0	
	Nov. 29	-36.0	
	Nov. 30	-29.0	16
	Dec. 1	-34.5	
	Dec. 2	-32.0	

* The estimated lethal low temperature threshold for larvae during the winter period is near -38°C; during the late October-early November period it is near -26°C. (Safranyik *et al.* 1974, Fig.25)

(Somme 1964). Maximum cold-hardiness is attained by December-January, and some large larvae can survive short exposures to -38°C during this period. During the fall before maximum hardiness is attained and as it wanes in the spring, the insects are susceptible to extreme cold, so that unseasonably low temperatures (less than -26°C) can cause widespread mortality (Safranyik *et al.* 1974; Safranyik 1978).

Unseasonably low temperatures in late October and late December of 1984, and again for several days in November of 1985, provided an opportunity to observe their effect on mountain pine beetle populations, tree mortality, and the incidence of attacks by some associated species of bark beetles. The plots had been established in June 1985 to investigate the dispersal of mountain pine beetle within stands. In this paper we present data which describe the infestation trends of mountain pine beetle and *Ips pini* Swaine (pine engraver beetle) between 1984 and 1987, and some characteristics of the infested trees.

MATERIALS AND METHODS

The plot area was established in a stand of mature lodgepole pine (*Pinus contorta* var. *latifolia* Dougl.) near Tsuh lake, about 80 km west of Williams Lake, British Columbia, within a massive epizootic of mountain pine beetle which began in the late 1960s (Wood and Van Sickle 1987). The study area was generally flat, 5.6 ha in area with about 2 ha of esker-like ridges 2-3 m in height in the southeast portion. It was surrounded on three sides by open meadows 10 to 40 m wide, and on the fourth by a stand of lodgepole pine less than 40 years old containing a few veteran Douglas-firs (*Pseudotsuga menziesii* (Mirb.) Franco). Within the study area, the tree cover averaged 592.3 stems per ha with diameter at breast height (dbh) greater than 5 cm, consisting of 83% lodgepole pine, 11% engelmann spruce (*Picea engelmannii* Parry)(mainly in depressions) and the balance scattered

Douglas-fir and aspen (*Populus tremuloides* Michx.). The average age of the lodgepole pines was 102 years in 1985.

In 1985 all trees over 5cm dbh were counted by species, and the dbh of trees attacked by mountain pine beetle or pine engravers in 1984 and 1985 were tallied. In the years 1986 and 1987 the dbh of all newly infested lodgepole pine trees were recorded. Tree heights and maximum height of attack were estimated for a random sample of infested trees using an Abney level; binoculars were used to determine the location of the highest attacks where necessary.

Mountain pine beetle attack and brood densities and totals per tree were estimated for trees infested in 1983 and 1984 only and were multiplied by the total infested bark surface area to estimate total population within the study area annually. Emergence in 1984 was estimated based on counts of emergence holes on 15 x 15 cm areas of bark at breast height on trees attacked in 1983. In 1985, the density of emergence of mountain pine beetle was estimated using total counts of beetles which emerged from caged infested bolts and counts of emergence holes on bark areas painted with light colored latex paint to enhance the visibility of the holes (Safranyik and Linton 1985). Brood and attack totals per tree were estimated based on measurements of dbh, total or infested tree height, and attack and brood densities at breast height (Safranyik 1988).

Minimum daily temperature and snow accumulation for the years 1984-85 (Table 1) were obtained using Environment Canada records from Alexis Creek, about 30 km west of the study area.

RESULTS AND DISCUSSION

The effect of unseasonable cold on mountain pine beetle

Trees attacked in 1984 are described by the data in Table 2. The mean mountain pine beetle attack height (11.36 m) was about 60% of total tree height, which is considered normal for the dbh and height of the attacked trees (Safranyik, 1969). The maximum height at which live mountain pine beetle brood were found, however, was only 63 cm (mean 53 cm)-less than 5% of the infested height. Normally, some beetles mature near the top of the infested bole region. Careful examination of infested trees in mid-May of 1985 indicated that survival was confined to the bark areas which were probably below snow during the winter. Recorded snow accumulation at Alexis Creek (Table 1) was less than the average height of live brood. It is, however, likely that snow depth inside the stand was greater than in the open area where the weather station is located. Dead larvae found beneath the bark higher up the stems were dark grey to black, and stretched out; both of these symptoms are indicative of winter mortality.

Temperature records (Table 1) show that temperatures near or below the lethal early winter threshold of about -26°C (Safranyik *et al.* 1974) occurred during 3 days at the end of October and during 2 days at the end of December in 1984. On October 31 and December 30 and 31, even the mean daily temperatures were as low as or lower than the fall lethal threshold of ca -26°C or the late-winter lethal threshold of ca -38°C. In 1985, minimum daily temperatures near or below the -26°C threshold were recorded for 13 days between November 10 and December 2; the last 11 of these occurred in an unbroken sequence. In contrast, the records for the years 1975-1983 show no periods when the temperatures fell below the estimated lethal minima for more than two consecutive days.

In 1985 the estimated mean number of potential emerging mountain pine beetle females per tree (1192, Table 2) Represented a static or increasing population over the previous generation (the mean number of attacks per tree in 1984 was 458), even after allowing for loss of beetles during dispersal and host colonization (Cole and Amman 1969). The mean actual emergence per tree (119, Table 2) was about 10% of the potential (i.e. the expected emergence without complete above-snow mortality). Considering a female:male ratio of 2:1 and a flight-establishment loss of 40% (Cole and Amman, 1969), the average of 119 emergents per tree represents 79 females, or 47 attacks. This is about 10% of the average attacks per tree made by the parent generation.

Table 2

Statistics describing lodgepole pine at Tsuh Lake infested in 1984 by mountain pine beetle.

Variables	Mean ± S.D.	N
Diameter (dbh, cm)	25.0 ± 5.7	35
Total height (m)	18.8 ± 2.0	12
Attack height (m)	11.3 ± 3.6	10
Brood height (m)	0.5 ± 0.1	17
Attacks/m^2 at dbh	133.3 ± 47.5	13
Attacks/tree *	458.3 ± 158.7	13
Emergence/m^2	212.7 ± 151.6	10
Emergence/tree **	119.5 ± 85.2	10
Estimated emergence /tree for 1985***	1192.4 ± 850.3	10

* Estimated as in Safranyik 1988 (eq. 13).

** Based on emergence data from caged bolts and emergence holes on infested bolts (Safranyik and Linton 1985).

*** Assumes the usual distribution of brood adults over the total infested bole. Based on mean no. of emerged beetles/tree (see footnote **), mean height of live brood on the bole and a cumulative function for brood on infested bole height (Safranyik 1988, eq. 16).

The mean number of trees per ha attacked by mountain pine beetle in 1985 was 10.23, or about 9% of the 1984 mean (Table 3). This agrees well with the corresponding estimate of 10% based on brood survival. This comparison assumes, however, that mean surface area attacked per tree and mean attack density did not change over the two years. These variables were not estimated for 1985 attacks. Numbers of trees attacked by mountain pine beetle further declined in 1986, and by 1987 no new attacks were found on the plot.

Response of pine engraver beetle population to decline of mountain pine beetle

No trees were killed in 1984 by the pine engraver beetle, a major associate of the mountain pine beetle (Sartwell *et al.* 1971). From 1985 to 1987, the mean numbers of engraver-attacked trees per ha were 15.02, 21.51, and 2.05, respectively. The mean dbh was smaller than that of trees killed by mountain pine beetle, but the difference was not statistically significant ($p>0.05$). The pine engraver normally attacks the uninfested tops and lightly infested areas of trees killed by mountain pine beetle. Consequently, during large outbreaks of mountain pine beetle, large engraver populations can build up. Because these insects overwinter in the duff, populations are not affected appreciably by severe winter temperatures. In 1985 and 1986 large engraver populations (which developed in trees killed by mountain pine beetle) attacked live trees in the absence of trees killed by mountain pine beetle. Many trees colonized by the pine engraver also bore a few mountain pine beetle attacks, and some from *Pityogenes plagiatus knechteli* Swaine, another common associate.

This study is the first to present data on the collapse of a mountain pine beetle outbreak due to cold temperatures, and the subsequent infestation by the pine engraver. After the collapse of the massive Mountain pine beetle infestations in the Chilcotin during 1985-86, pine engraver killed large numbers of the residual trees, mainly along the edges of cut blocks and rights-of-way (Wood and Van Sickle 1986, 1987). As expected, these infestations invariably declined in 2-3 years as populations suffered heavy mortality, apparently from host resistance, intraspecific competition and natural enemies (Sartwell *et al.* 1971).

Table 3
Numbers/ha and mean dbh of lodgepole pine trees attacked by the mountain pine beetle (MPB) and pine engraver beetle (*Ips*) from 1984 to 1987

Year of Attack	Beetle species	Trees/ha	Mean dbh. (cm) ± S.D.	N
1984	MPB	109.4	25.02 ± 5.74	35
	Ips	0	-	-
1985	MPB	10.23	21.48 ± 3.44	60
	Ips	15.02	18.77 ± 4.88	88
1986	MPB	7.68	23.17 ± 5.44	45
	Ips	21.51	18.58 ± 4.00	126
1987	MPB	0	-	-
	Ips	2.05	17.23 ± 6.53	12

REFERENCES

Amman, G.D. and W.E.Cole. 1983. Mountain pine beetle dynamics in lodgepole pine forests. Part II: Population dynamics. USDA For. Serv. Gen. Tech. Rept. INT-145. Intermountain For. and Range Expt. Stn., Ogden UT. 60p.

Cole, W.E. and G.D.Amman. 1969. Mountain pine beetle infestations in relation to lodgepole pine diameters. USDA For. Serv. Res. Note INT-95. Intermountain For. and Range Expt. Stn., Ogden UT. 7p.

Safranyik, L. 1969. Development of a technique for sampling mountain pine beetle populations in lodgepole pine. PhD Thesis. Univ. British Columbia, Vancouver. 195pp.

——- 1978. Effects of climate and weather on mountain pine beetle populations. pp78-86 *in* The theory and practise of mountain pine beetle management in lodgepole pine. D.Kibbee, ed., Symp Proceedings, Wash. State Univ., Pullman. April 25-27, 1978.

——- 1988. Estimating attack and brood totals and densities of the mountain pine beetle in individual lodgepole pine trees. Can. Entomol. 120:323-331.

——- and D.A.Linton. 1985. The relationship between density of emerged *Dendroctonus ponderosae* (Coleoptera:Scolytidae) and density of exit holes in lodgepole pine. Can. Entomol. 117:267-275.

——-, D.M.Shrimpton and H.S.Whitney. 1974. Management of lodgepole pine to reduce losses from the mountain pine beetle. Environment Canada Forestry Technical Report 1. October, 1974. Pac. For. Res. Cent., Victoria, B.C. 24 pp.

Sartwell, C., Schmitz, R.F., and Buckhorn, W.J. 1971. Pine engraver, *Ips pini*, in the Western States. U.S. Dep. Agric. For. Serv. For. Pest Leafl. 122.

Schmitz, R.F. 1988. Understanding scolytid problems in lodgepole pine forests: The need for an integrated approach. pp 231-241 *in* Integrated control of scolytid bark beetles. T.L.Payne and H. Saarenmaa, eds., Proceedings IUFRO Working Party and XVII Internat. Congr. Entomol. Symp., Vancouver, B.C., Canada, July 4, 1988. 356 pp.

Somme, L. 1964. Effects of glycerol on cold-hardiness in insects. Can. J. Zool. 42:87-101.

Wood, C.S., A. Van Sickle. 1987. Forest insect and disease conditions British Columbia and Yukon 1986. Can. For. Serv. Pac. For. Res. Cent. BC-X-287. 35pp.

Wood, C.S., A. Van Sickle. 1988. Forest insect and disease conditions British Columbia and Yukon 1987. Can. For. Serv. Pac. For. Res. Cent. BC-X-296. 40pp.