



Province of
British Columbia
Ministry of
Forests

SPRUCE BEETLE MANAGEMENT SEMINAR AND WORKSHOP

PROCEEDINGS IN ABSTRACT



ISBN 0-7719-8736-6

PEST MANAGEMENT REPORT NUMBER 1

Canadian Cataloguing in Publication Data

Spruce Beetle Management Seminar and
Workshop (1980: Prince George, B.C.)
Spruce Beetle Management Seminar and
Workshop, October 7-8, 1980 Prince George,
B.C.

(Pest management series, ISSN 0710-7935; 1)

Bibliography: p.
ISBN 0-7719-8736-6

1. Spruce bark-beetles - Control - British
Columbia - Congresses. I. Dyer, E.D.A. (Eric
David Arthur), 1919- . II. Hodgkinson, Robert
Sidney. III. British Columbia. Ministry of Forests.
IV. Series.

SB945.S69S6 634.9'6768 C81-092357-2

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Published by the
Information Services Branch
Ministry of Forests
Province of British Columbia
Victoria, B.C.
V8W 3E7

R15-81005



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Introduction

I am pleased to present this publication as the first in a series devoted to the exploration of various aspects of Forest Pest Management in British Columbia. This is part of a concerted effort to keep industry, educators and the public well informed on our activities in this field. The problems are diverse and pose a serious threat to our forest resource.

Spruce beetle, *Dendroctonus rufipennis* (Kirby), is currently devastating spruce forests east of Prince George and at several locations elsewhere in British Columbia. This publication is a record of a productive gathering of authorities on this pest and those engaged in forest planning and harvesting. The goal was to formulate firm beetle-management strategies. These are outlined in the text.

Forest pest management is making significant strides in British Columbia. The B.C. Ministry of Forests has stationed a pest management co-ordinator in each region and staff at Victoria headquarters has been strengthened to further the work. There are several immediate priorities, including establishment of an accurate inventory of significant pest problems in the province's forests and defining management policies and goals.

Meetings such as this can do much to further overall pest management and, ultimately, forest management activities in British Columbia.

W. Young
Chief Forester

Spruce Beetle Biology and Management

L. Safranyik*

Biology

The spruce beetle, a native insect, is principally an enemy of mature (over 120 years) spruce forests. In B.C., the main host trees are white spruce (*Picea glauca* [Moench] Voss) and Engelmann spruce (*P. engelmannii* Parry) but all species of native spruce can be attacked. Normally, injured, windfallen, diseased and stressed trees, and slash are preferred by the beetles. However, during periodic epidemics, apparently healthy trees are attacked and killed over large areas.

The length of the life cycle varies from one to three years, depending on temperature conditions for development. In the Prince George Forest Region, the two-year cycle is the norm, with a variable proportion of the broods developing on a one-year cycle. During hot, dry years, the one-year cycle development may predominate. The three-year cycle is rare and confined to cool environments and higher elevations. The main features of the life cycle are as follows:

Peak flight usually occurs from late May to mid-June. Females initiate the attack by boring through bark and constructing an egg tunnel in the phloem-cambium region. Females release a population-aggregating pheromone that attracts beetles of both sexes. The host material is mass-attacked, usually within a few days. Completed egg tunnels average about 12 cm in length, and about 60 eggs are laid in groups in covered niches cut along the sides of each egg tunnel. In a one-year cycle development, larvae mature by the end of the summer, pupate and turn into adults. In a two-year cycle development, the larvae overwinter, and development to the adult stage takes place during the next summer. Regardless of the length of the life cycle, broods must overwinter as young adults in order to complete their development and reproduce. Symptoms of attack are boring dust or pitch tubes, woodpecker-drilled bark during winter, or fading of foliage to pale green or yellow before dropping, usually the year after attack. Thus, attacked trees are difficult to detect by aerial surveys. All above symptoms must be verified by the presence of egg tunnels and broods under the bark.

Some effects on spruce stands include proportionately greater loss of the larger DBH (over 30 cm) trees and a great resistance and survival of the small DBH trees. Change in stand composition (age, size, species) and an increase in fuel loading result, but there is no evidence to indicate significant increase in fire incidence following outbreaks, although dead trees may remain standing for many years. All documented outbreaks followed either large-scale windfallen trees or large accumulation of man-made slash.

Long-term Management Goals

- To assign management priorities.
- To plan harvesting of susceptible stands in high-priority areas.

*L. Safranyik is a research scientist at Pacific Forest Research Center, Canadian Forestry Service, Victoria, B.C.

Status of Spruce Beetle Populations in B.C. (September 1980)

*J.S. Monts**

*J.S. Monts is a former survey technician with Canadian Forestry Service, Victoria, B.C. (present address: B.C. Ministry of Forests, Kamloops, B.C.).

To grow spruce on a short rotation (100 years or less).
To develop a mosaic of age classes and/or mixed stands.

Proximate Goals

Windfall and slash management should include:

- prompt salvage of wind-thrown trees;
- control of cutting boundary layout;
- close utilization standards;
- treatment of large-diameter slash, stumps and landings; and
- avoidance of extensive soil disturbance near stand edges.

Annual survey for spruce beetle damage and abundance.

Prompt and thorough action on incipient outbreaks (salvage, logging, trap trees).

Development and marketing of wood products from killed trees.

Spruce beetle outbreaks are detected by ground and aerial surveys and reported annually according to forest region. The largest and most damaging outbreaks in 1980 occurred in the southeastern Prince George and northern Cariboo Forest Regions, while infestations in the Prince Rupert Region declined. Infestations in the Kamloops and Nelson Forest Regions were small and located near logging operations. The Prince George outbreaks are illustrated in Figure 1.

Infestations generally declined in the Fort St. James District except at Tarnezell Creek, where moderate outbreaks continued in isolated mature stands, and in the Prince George West District near Carp and Weedon Lakes, but significant increases were recorded along the tributaries of the Upper Parsnip River. Tree mortality in the Mackenzie District was light but recent windfall along Williston Lake, north of Nation Bay, contains potential for beetle population build-up. Isolated leave blocks were severely infested in logged areas south of the Manson River.

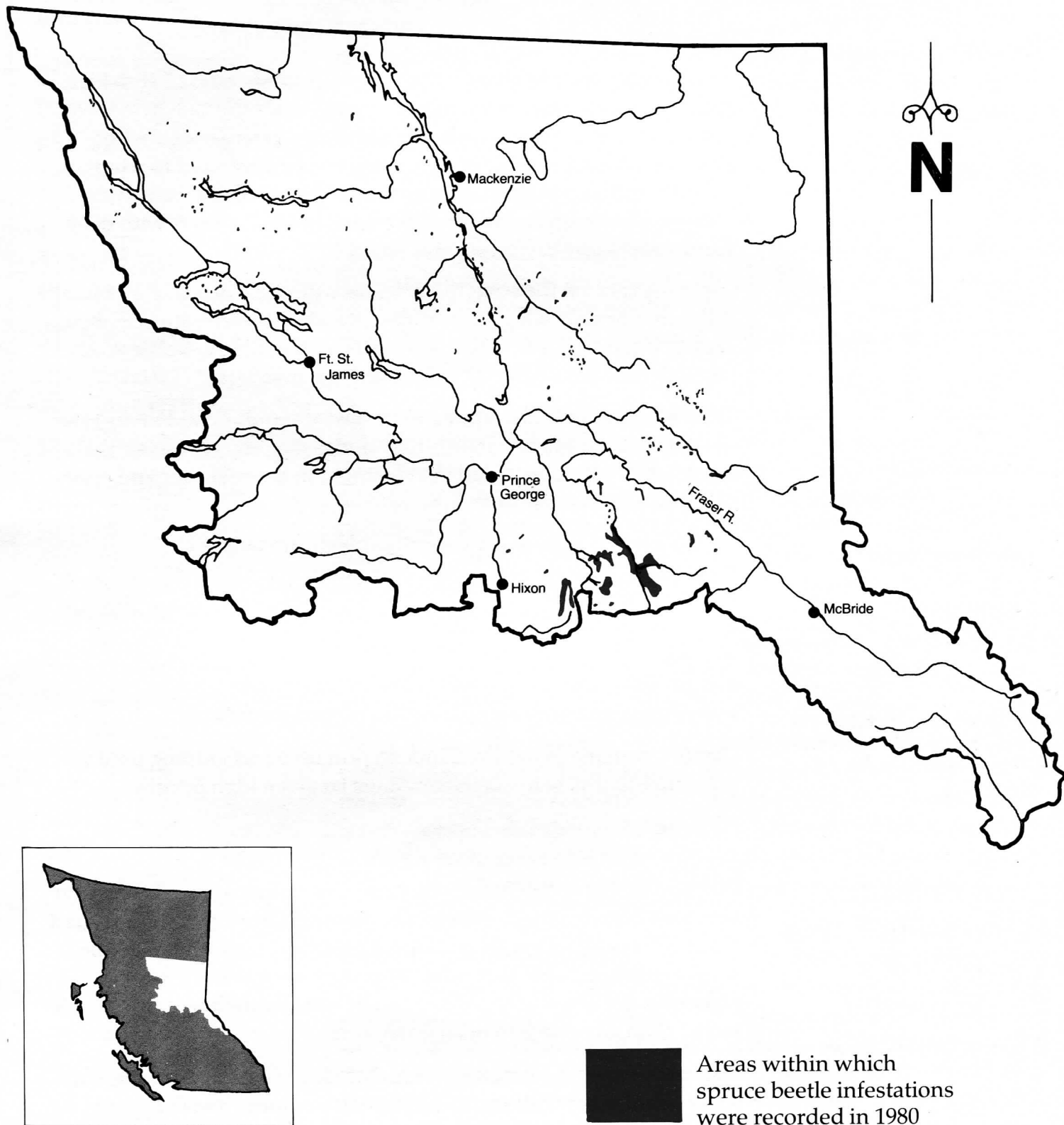
The major spruce beetle outbreak occurred in Prince George East District and killed thousands of hectares of merchantable white spruce. Mortality increased considerably in the upper basin of the Bowron River Valley, Wendle Creek, Upper Willow River, Narrow and Stony Lakes, where infestations covered 34 800 hectares (Figure 1).

On nine cruise strips in this area, an average of 36% of the white spruce had been attacked in 1980, a dramatic increase from an average of 4% recorded in 1979. A higher-than-normal percentage of one-year cycle broods have developed in infestations of 1980 near Wendle, Stony and Narrow Lakes, and will be capable of attacking mature trees remaining in these areas in 1981.

In the McGregor River tributaries, tree mortality was confined to small areas and 1980 attacks were concentrated on susceptible spruce.

Figure 1

Prince George Region (southern half)
Spruce Beetle Infestation



Timber Management Panel: Causes of the Current Spruce Beetle Problem

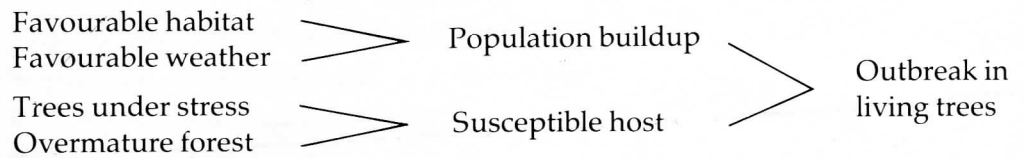
*R.B. Dickens**

*R.B. Dickens is an instructor with Forest Resources, College of New Caledonia, Prince George, B.C.

Does Present Harvesting Policy Contribute to Proper Beetle Management?

*L. Pederson***

In the 1960s, we experienced a spruce beetle epidemic in the Prince George area and now we are well into another infestation. Let's look at the conditions which contribute to an outbreak of spruce beetle.



Favourable beetle habitats are large spruce slash (over 15 cm), high stumps, decked logs along rights-of-way, and especially windfallen spruce accentuated by the shallow rooting properties of the trees. Outbreaks which are remote from logging can be attributed to windfall. Warm weather conditions favour development of one-year cycle beetles. Optimum beetle survival occurs in mild winters with deep snow conditions (larvae survive - 35° C).

Larger spruce on the best (hygric) sites will suffer drought-stress before those on the xeric sites. Most spruce stands are overmature in the central interior and may become highly susceptible to beetle attacks because they are unable to "pitch out" the invaders.

We should rate the susceptibility of spruce stands (stand rating) and designate the high-risk stands for priority logging. However, this will accelerate logging and road development in the best sites and create more pressure on reforestation.

The primary causes of the current problem are failure to:

- give high priority to susceptible stands;
- reduce windfall;
- salvage windfall promptly;
- practice good utilization;
- burn sites containing large-diameter slash; and
- recognize the early symptoms of a potential epidemic.

Our forest management will remain primitive and groping until we recognize that pest management must be given high priority.

The harvesting policy does contribute, but proper spruce beetle management involves more than just harvesting priorities. The biological function cannot be totally accounted for when dealing with administrative concepts such as regulation of the rate of priority cut. Biological objectives are obviously constrained by administration of the "whole" rather than any one part of an ecosystem.

With our harvesting priorities aimed at stands which are highest in susceptibility to windfall or which are in a reduced state of vigour, we are making the best of a bad situation, namely, our vast inventory of overmature timber.

****L. Pederson is a former zone forester with the B.C. Ministry of Forests, Regional Office, Prince George, B.C. (present address: Drew Sawmills, Malawka, B.C.).**

Would an Alternative Harvesting Technique Successfully Reduce Spruce Beetle Hazard?

*F. Diedrichsen**

***F. Diedrichsen is woodlands manager with Carrier Lumber Ltd., Prince George, B.C.**

Our present method of setting the rate of harvest of our prioritized stands, the Timber Supply Area concept, is an advantageously flexible tool. Not only has it accounted for priority harvest in older age classes, but also for volume losses attributable to management of this over mature crop. Volume loss due to the endemic population is accounted for, first, by the method of inventory and, second, by the deduction made from gross inventory to account for large-volume losses during epidemics. These loss deductions, along with periodic review of Timber Sale Area parameters, provide a very effective administration of the conflict between yield regulation and the need to liquidate overmature stands.

I have been asked to address the question of whether an alternative harvesting technique, for example, progressive clear-cutting, would successfully reduce beetle hazard. With reference to this session, I have stated two objectives: first, to reduce windfall and, second, to reduce slash that beetles will find attractive.

Clear-cutting would minimize the total amount of new susceptible boundary which would be exposed annually to fringe windfall. It would reduce the amount of road construction annually, thereby reducing the fringe windfall along such openings. Progressive clear-cutting would permit the immediate removal of large continuous stands, concentrate cutting in disturbed stands and reduce the necessity of going back continually to remove small windfall strips or fire-damaged fringes. Logging economics would benefit; planning for harvesting and silviculture would be greatly reduced and less complex (for example, each kilometre of road would develop more timber for harvesting sooner).

There are also disadvantages to the clear-cut system. Elimination of reserve strips would reduce the mature cover for ungulates, especially for moose, and at higher elevations cause a major impact on caribou habitat. Watershed management is adversely affected by continuous clear-cutting which opens vast areas without the benefit of natural vegetation to control peak run-offs. There is also, I suppose, a negative visual impact.

The harvesting strategy should be a combination of progressive clear-cutting, burning and planting. In order for the system to work, we have to burn successfully, not only to facilitate planting, but also to reduce the availability of stumps and slash that the beetles infest. However, the most susceptible stands are located on the wetter sites. To achieve successful burns more frequently, spring and summer light-ups will be necessary. The Ministry of Forests must share responsibility with industry for escape and/or "mop-up" costs. The provincial Fish and

What Routine Beetle Management Techniques Could Be Employed to Reduce Spruce Beetle Hazard?

*P.O. Sears**

*P.O. Sears is area forester with Polar Forest Industries, Prince George, B.C.

Wildlife Branch would simply have to accept changes in existing cut-leave guidelines.

True progressive clear-cutting is considerably different than that presently practiced, because the steeper gullies and slopes that are now intentionally placed into reserve strips will have to be logged. Alternative logging methods will require realistic allowances or incentives to harvest some of these more difficult sites.

A more manageable and practical approach might be a patch design logging system combined with continuous clear-cutting. We are authors of our own demise when we create fringe windfall. Our biggest problem is the buildup of small amounts of scattered windfall. Timber managers currently place foreshores, lakes, streams, swamps, non-productive areas and weaker, less attractive stands into reserve strips, which in many cases are attractive to spruce beetles. Surrounding many water-associated reserve strips are tall, mature spruce trees susceptible to windfall. We haven't looked within our first-priority cutting schedules in older aged stands. We haven't examined potential windfall problems within our older aged stands slated for first-priority cutting. We have to reverse our thinking by logging those sites where we anticipate windfall and specifically, pick wind-firm areas as reserve strips. Although that may alter traditional planning and economics of logging, if we wish to address the beetle problem seriously, there's got to be a shift in that direction. We can no longer afford to leave windfall in reserve strips; I think diameter limit cutting in these strips will become a necessity.

Spruce beetle populations can be managed only if all field staff carry an axe, and observe, record, report and then relate their information to regional insect survey reports.

The follow-up, through various forestry operational and management plans, must be based on these specific findings, the conclusions reached by field staff, and then related to other additional site parameters.

Spruce is a shallow-rooted, wet-site species, and this particular niche has not and will not tolerate our present biased and predetermined policy that restricts efficient harvesting.

The stands in the Willow River drainage have been "telling us", through fringe windfall, that they will not remain standing under this present patch-logging system. We must conform and accept alternative management plans.

Research has established that the origins of epidemics are slash and windfall. From my observation and experience, these potential hazards

are manageable under a *planned*, progressive, clear-cut system.

Until such time as abnormal losses resulting from our present management systems are recognized and rectified, present operational, development and longer-term Timber Supply Area plans are futile and meaningless. We can no longer accept these resulting insect "wild fires".

Trap Trees

R.S. Hodgkinson*

Trap trees are living, large-diameter spruce which are felled into the shade and left unbucked and unlimbed to attract infestations of the spruce beetle.¹ They will absorb 10 times the number of beetles that will infest a standing tree.² Traps should always be felled as close to the ground as possible among standing trees, in a direction which offers the greatest amount of shade, preferably with butts toward the road to facilitate skidding.

The number of trap trees felled depends on the size of the attacking beetle population. Nagel *et al.* (1957) recommended one trap for every four to five infested standing trees, while Wygant (1960) advised a ratio of one to ten for static infestations and one to two for increasing infestations.

Trap trees effectively attract spruce beetles up to 0.4 km; less effectively up to 0.8 km.³ Once the traps are infested, they can either be hauled to the mill, burned, peeled or chemically treated to destroy the brood.

Although individually spaced trap trees are most effective, traps are normally felled in groups or truckloads of 15 to 25 trees between November 1 and March 31 and hauled to the mill for processing after all beetle flight. The following season, the trap tree site can be enlarged or an adjacent area can be utilized. Log decks created during road development could be routinely left on landing during the beetle flight.

Lethal trap trees can be created by axe-frilling standing, uninfested spruce and applying a translocating arboricide such as half-strength MSMA.^{3,4} Once the MSMA has translocated throughout the tree (two to three weeks), the tree is felled. Lethal traps should be prepared in the fall or spring before or after the beetle flight, while vascular tissues conduct. Past studies have revealed that successfully treated traps have resulted in a brood mortality of over 90%.^{4,5}

Spruce beetle-infested stumps are often a problem, and there is a need for a penetrating, residual insecticide to kill such broods. Unfortunately, no chemical insecticides are presently registered for control of the spruce beetle in Canada.

*R.S. Hodgkinson is regional forest entomologist with the B.C. Ministry of Forests, Prince George, B.C.

Probe Lines

W. Harvie*

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Other Bark Beetles and Wood Borers Associated with Spruce Forests

L. Safranyik*

*L. Safranyik is a research scientist at Pacific Forest Research Center, Canadian Forestry Service, Victoria, B.C.

Lines are established to detect and delineate spruce beetle in standing trees adjacent to either a known or suspected infestation or a trap tree site. Adjacent to trap tree sites, two 200-metre ribboned lines are run at right angles to one another. These are assessed before and after the beetle flights. Attacked trees within two metres of each probe line are tallied and numbered for later identification. Attacked trees outside the probe line are noted in the remarks column of the cruise card. Classifications of attack are "gray", "red", "green", "strip", or "pitch-out". After the beetle flight, probe-line reassessments reveal the effectiveness of trap tree sites and spruce beetle hazard in adjacent timber.

Probe lines within the beetle infested areas will reveal the beetle intensity, attack boundaries and stage of development. These probe lines are run through the area of infestation and extend 200 metres beyond the last noted attack. The data are recorded on cruise cards, lines are measured, ribboned and the distance is marked every 50 metres. Information collected will show the area and intensity of the attack and will establish cut-block boundaries.

Ambrosia beetles do not kill trees but breed in windfall, slash, stumps and freshly killed trees, in logs and sometimes in green lumber. They are responsible for "pin-holes" in logs and lumber as the egg tunnels are constructed in the wood where the beetles and their young feed on ambrosia fungi. Thus, losses are caused by both degrade to lumber, and resulting quarantine regulations of some countries which restrict import of lumber damaged by ambrosia beetles. "Hot logging" and sanitary mill practices are the most effective means of reducing losses.

There are some 40 species of bark beetles that breed in injured, weakened, suppressed spruce trees, in tops of trees and in slash. Frequently, they follow spruce beetles into infested trees. They seldom cause economically important damage. One of the most common associates of spruce beetles are *Ips* beetles which often breed in the tops and more exposed aspects of slash, windfall and trees. There are three species of *Ips* beetle commonly associated with spruce. Their egg tunnels are easily distinguished from those of the spruce beetle in that *Ips* tunnels are much more narrow, always clear of boring dust and often have an X or Y shape. The adults have small spurs on the back ends of the wing covers.

Wood borers breed in slash and dead trees. Damage is done by the larvae constructing tunnels in the wood, thereby causing degrade to lumber cut from infested logs. The same management practices are applicable as for ambrosia beetles.

Current Spruce Beetle Research

*L. Safranyik**

*L. Safranyik is a research scientist at Pacific Forest Research Centre, Canadian Forestry Service, Victoria, B.C.

Workshops

Summary of the Workshop on Harvesting Policies and Practices

*J.W. Burbee**

*J.W. Burbee is resource manager with Northwood Pulp and Timber Ltd., Prince George, B.C.

There has been intensive research on spruce beetle problems in the Naver Provincial Forest of the Prince George Region by the Canadian Forestry Service, Pacific Forest Research Centre (PFRC), Victoria, B.C., since 1972. The main objectives are to discover, develop and promote techniques and forestry procedures for reducing losses.

The following list highlights completed and ongoing studies:

- distribution of spruce beetle attacks in the forest;
- brood survival and development in slash and windfall, and the effect of current management practices;
- distribution of windfall along stand edges and within stands;
- effectiveness of pheromones in managing beetle populations;
- host tree resistance and predisposition to attack;
- disease and common spruce beetle predators and parasites;
- mechanical and chemical means of destroying spruce beetle; and
- development of a spruce beetle population model.

Based on the results of the above studies, scientists at PFRC will produce a management-oriented brochure for reducing losses from the spruce beetle within the next two years.

Discussion in this group centered around five main areas:

- priority of stands;
- flexibility of operations;
- stumpage appraisal;
- regulations; and
- harvesting practices.

In determining priority of stands for harvest, the primary objective is to control the beetle population. To this end, green attack receives highest priority, with salvage of grey attack being secondary. Priorities have to be reassessed regularly.

The ability to be flexible and to react quickly is essential for an effective beetle management program. A more rapidly responsive procedure for issuing cutting authority is required, and a reduction in the number of people involved in approvals would expedite this. Physical constraints, such as mill capacity, annual allowable cut, or road development, may necessitate joint licensee programs.

Cost recognition in stumpage appraisal should be forthcoming in the following circumstances:

- falling product quality and recovery;
- carrying cost and deterioration of unamortized development programs; and
- impact on mill operations of change in log species and size composition (mill furnish).

Summary of the Workshop on Salvage Logging

*R.D. Cozens**

*R.D. Cozens is a pest management co-ordinator with the B.C. Ministry of Forests, Regional Office, Prince George, B.C.

The avenue to open up appraisals in mid-term is necessary to properly reflect changing situations in stumpage rates. Major regulatory constraints centre around licence restrictions on allowable annual cut and the transfer of Section 88 credits between licences. These problems should largely be overcome with the implementation of forest licences which can combine a number of licences into one for administrative purposes.

The consensus on what to do when you have a spruce beetle epidemic was to clear-cut, burn and plant. Burns must be hot to be effective and individual prescriptions should be site-specific.

In non-epidemic situations, good layout can help control populations. Natural boundaries should be considered, regardless of size, to minimize windfall. The favourable habitat of windfallen spruce is recognized as the largest contributor to our current beetle epidemic. Reserves in critical winter habitat areas can be useful, and even essential, to ungulates. However, reserves should only be used where there is a reasonable chance of success.

Maintaining current operations with respect to logging clean-up and site treatment also reduces beetle habitat.

Two questions were asked of the workshop group:

- can the forest industry cope with natural and reserve blowdown, standing "green-attack" and standing dead material? and
- can we improve salvage methodology?

The group opinion was that under the present management system, the forest industry cannot cope but, with changes in the system, the salvage of such material could easily be facilitated.

Plans for salvage of extensive areas should be formulated within the Timber Supply Area plan; main extraction routes should be located or even partially constructed, and potential environmental problem areas should be defined. Extraction of small patches containing beetles must be expedited, possibly on the direct sale basis. Larger areas of infested timber should be sold by auction in a similar manner to the old district forester sales where anyone can bid. In both cases, the wood must be removed prior to beetle flight.

The major holdback at present is funding to pay for detection by governments or industry and for administration of an effective program of detection and good housekeeping.

It is possible to "manage" beetles in endemic and minor epidemic situations, using the methodology mentioned above. However, in a major epidemic, such as the Bowron drainage, we can only salvage merchantable volume and let nature take its course.

Summary of the Workshop on the Use of Trap Trees

*E.D.A. Dyer**

*E.D.A. Dyer is a research scientist, retired from the Canadian Forestry Service.

Summary of the Workshop on Spruce Beetle Detection

*J.S. Monts**

*J.S. Monts is a former survey technician with the Canadian Forestry Service, Victoria, B.C. (present address: B.C. Ministry of Forests, Kamloops, B.C.).

Trap trees should be felled in spruce harvesting areas every year to continually reduce the beetle population level by removing trap trees before the beetles mature. Predevelopment of spruce harvesting areas by felling trees on roads and landings and leaving them to become infested should be normal procedure, provided the infested trees can be removed within a year. Any extra costs of predevelopment should be considered. Good housekeeping is essential. This includes disposal of slash, having a good sequence of logging and dealing with fringe wind-fall. Competition from *Ips* beetles may be reduced by felling trap trees in shade, but it is considered unwise to fall trap trees late to avoid early *Ips* flights. For areas without roads, experiments with lethal trap trees should be planned whereby beetles are attracted to traps but prevented by chemical treatments from producing broods. Such experiments should have replicated, treated and control plots to allow assessment of effectiveness.

The techniques presently used for detecting, monitoring and assessing spruce beetle damage are sketch mapping, aerial photography and cruising. Sketch mapping is done annually in August by the Canadian Forestry Service Rangers who sketch the infested areas on topographic maps while flying in fixed-wing aircraft. Each aspect of detection was discussed by the group, and Canadian Forestry Service survey methods were explained in detail. The standardization of definitions, classification of damage and rating systems were stressed, and general organization of survey discussed.

Recommendations were made by the workshop group to:

- include spruce beetle detection training in cruising seminars to be held in the Prince George Forest Region;
- ensure that copies of the original Canadian Forestry Service sketch maps are available to the districts; and
- schedule training sessions about this major forest pest for regional and district personnel each spring.

It was also recommended that:

- a pest review committee be formed for the Prince George Region similar to committees in the Nelson and Kamloops Regions;
- a mountain pine beetle workshop be held in the future, and organized in a manner similar to this spruce beetle seminar and workshop.

Summary of the Timber Management Workshop

G.E. Magee*

*G.E. Magee is a resource officer with
Protection, Prince George East
Forest District.

This workshop group was given a management problem covering an area in the Big Valley Public Sustained Yield Unit within the Prince George Timber Supply Area (TSA). The group was also given a fact sheet outlining:

- allowable annual cut of 80 000 m³;
- a large spruce beetle problem;
- moderate to heavy beetle populations in surrounding reserve strips;
- good moose habitat;
- flat with wet soils;
- overmature timber with indicators of high decay;
- numerous small patches of windfall present.

Part of the area has 70% to 90% of beetle-killed spruce, part has 73% attacked in 1980 and part has 15% attacked in 1979 and 1980; 60% of the 1979 beetle broods are in one-year and 40% are in two-year life cycles. The area is visible to recreationists and hunters at Stony Lake.

The group was asked to decide the priority of cutting, the annual volume to be cut, and whether this should be restricted to the allowable annual cut for this area.

Recommendations were to remove green-attacked trees first, then red and grey-dead trees; and to develop, before break-up in 1981, a trap tree program for the area with 15% attack. To be successful, control measures for the total infested area should be considered; heavy attack areas should be logged and the extra allowable cut transferred from other areas within the TSA. Salvage rates for stumpage should apply to all infested timber, whether green, red, or grey. Trees should be topped in the bush to provide fuel for hotter slash burns on the logged areas.

Concluding Remarks

E.D.A. Dyer*

*E.D.A. Dyer is a research scientist, retired from the Canadian Forestry Service.

Footnotes

We at this seminar are responsible for providing protection and management of mature spruce in this region. There is no one else to whom we can "pass the buck." We must develop efficient methods of managing and protecting the green uninfested spruce by finding effective means of detecting and treating the infested green trees and windfall.

The infested trees that are visible after changing color are mainly a salvage problem, not a beetle problem, because most of the beetles have gone before this timber is detected, made accessible and harvested. If only the green infested material gave off smoke, we would find the means to treat it immediately.

We must develop a technical and financial capability similar to fire prevention. We must be capable of detecting and treating infested windthrow and standing trees before the infestation becomes unmanageable.

The responsibility for finding a solution lies with us.

¹Nagel *et al.* (1957), all references on page 16.

²Wygant (1960).

³Monosodium methanearsenate.

⁴Lister *et al.* (1976).

⁵Heath (1980).

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