

The Spruce Weevil, Pissodes strobi Peck
(Coleoptera: Curculionidae)

A Review of its Biology, Damage and
Control Techniques with Reference to the
Prince George Timber Supply Area

by
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ABSTRACT

The spruce weevil, Pissodes strobi Peck (Coleoptera: Curculionidae), is a potentially serious insect pest of immature spruce forests in the Prince George Timber Supply Area.

Significant amounts of research have been directed toward the development of effective measures to control P. strobi in eastern North America and, more recently, in the west. Very little effort related to this weevil, however, has been expended in the central interior of the Province of British Columbia where vast areas of spruce plantations are currently established. The dependance of the forest industry in the Prince George T.S.A. upon spruce necessitates an active programme of research and operational trials directed toward forest management practices which incorporate P. strobi control strategies.

A summary of control efforts to date is presented and discussed with reference to the management of white spruce and the control of P. strobi in the Prince George T.S.A. Implications and recommendations pertaining to the Prince George T.S.A. are proposed in the areas of weevil detection, damage appraisal and determination of the best options for both direct and indirect control.

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1. INTRODUCTION

The Prince George Timber Supply Area (T.S.A.) contains approximately 7 773 000 hectares consisting of 5 941 470 hectares of productive forest land and 1 791 530 hectares of non-productive forest land (Anon. 1982). It encompasses either totally or partially 16 Public Sustained Yield Units, two Tree Farm Licences, two Special Sale Areas and the Sustut Block, formerly part of Tree Farm Licence No. 1. Figure 1 shows the location of the Prince George T.S.A. in the Province of British Columbia. The Timber Supply Area is subdivided into nine Supply Blocks, each forming a supply unit to existing manufacturing centres. Supply Blocks provide flexibility in allocating the T.S.A. allowable annual cut to various licensees in different parts of the T.S.A. and in altering that allocation from one time period to another as may be required.

The annual allowable cut for the Prince George T.S.A. was set at 8 700 000 m³ by the Chief Forester for the initial five-year period commencing 1 January 1981 (Anon. 1982). One of the major factors related to the maintenance of this rate of harvest must be to ensure that species volume harvested equate with species volumes of the forest inventory. The present mature volume breakdown in the T.S.A. is: 39% spruce, 19% subalpine fir, 35% lodgepole pine and 7% comprised of other species. Figure 2 shows the age class distribution by species and area for the T.S.A.

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The eastern portion of the T.S.A., specifically Supply Blocks E, G and H, contributes heavily to the spruce component harvested with over one-half of their merchantable volumes being comprised of this species. As the present mature spruce stands are harvested, in almost every instance spruce plantations will be established in their place. The final result will be vast areas of relatively even-aged immature spruce forests. There are currently 92 817 hectares of spruce and spruce-mixture plantations in the Prince George T.S.A. as displayed in five-year age classes in Table 1 (Anon. 1983).

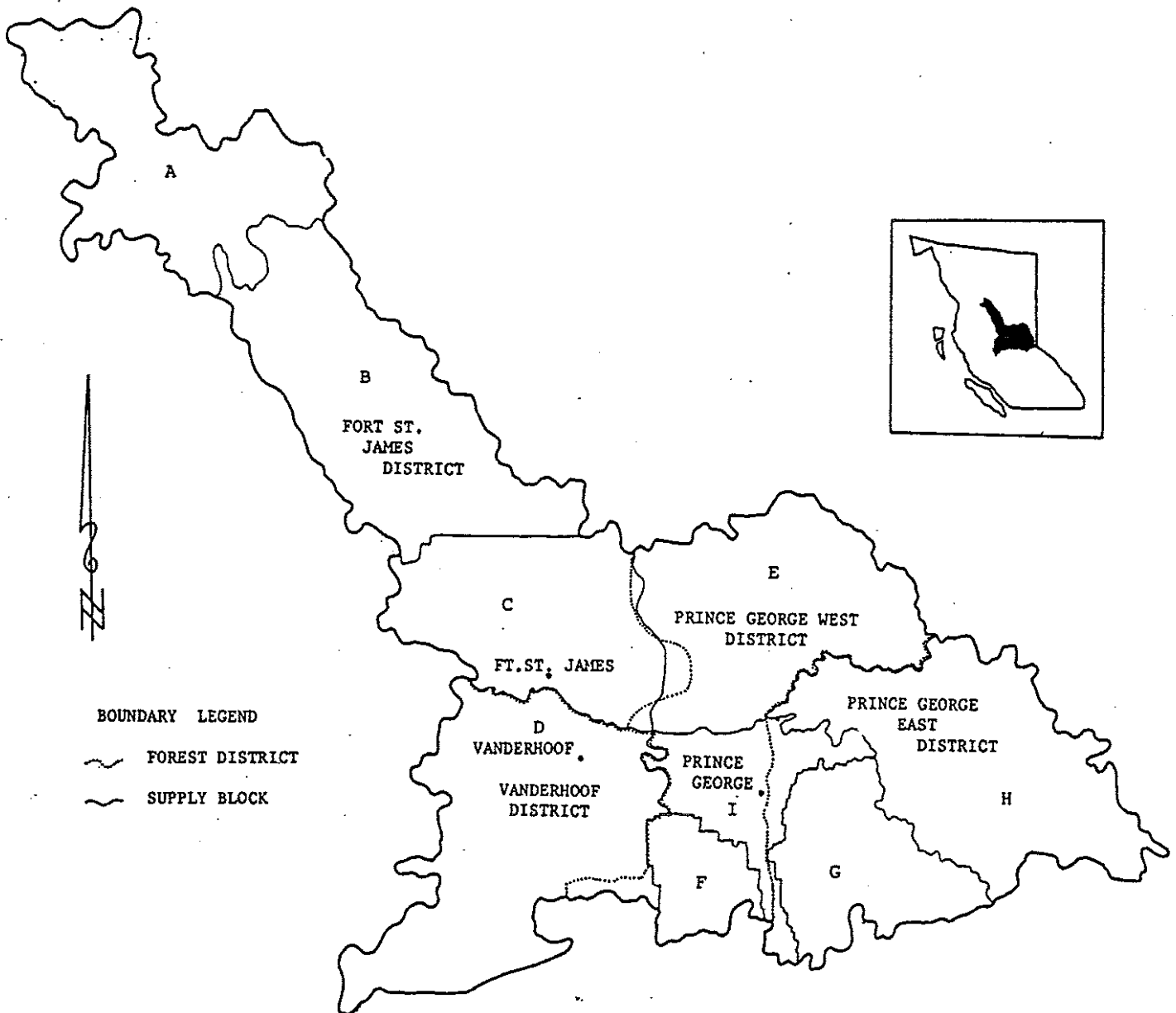
It should be clear that we, while possibly not being fully aware of the fact, are already dependent upon our immature spruce forests to ensure maintenance of an annual allowable rate of harvest to maintain a viable forest-based economy. The investment in these immature forests necessitates their management and protection. While, in many instances, general practices have been established, each situation will require specific pest management prescriptions taking into consideration significant local conditions.

The primary objective of Timber Supply Area management planning is to supply raw material of specific dimensions and shapes to the conversion plants¹. This can be interpreted to mean that timber must be supplied to maintain our sawmills and plywood mills. To accomplish this we must be capable of supplying uniformly regular logs absent of crooks, forks and other defects. Our immature stand management guidelines should be such that a clean butt log of at least ten metres can be realized. The management practices anticipated by some Licensees may differ from the overall objectives but are still quite specific in their intent. In anticipation of a fibre-oriented economy some are anxious to pursue forest management that will produce the greatest amount of wood fibre over the shortest rotation in the most economical manner². This maximization of fibre production would not

¹R.J. Barrett. T.S.A. Planning Forester. B.C. Forest Service, Prince George Forest Region. Prince George, B.C. personal communication.

²M.S. Litchfield. Planning Supervisor. Northwood Pulp and Timber Ltd. Prince George, B.C. personal communication.

Figure 1 - The Prince George Timber Supply Area.



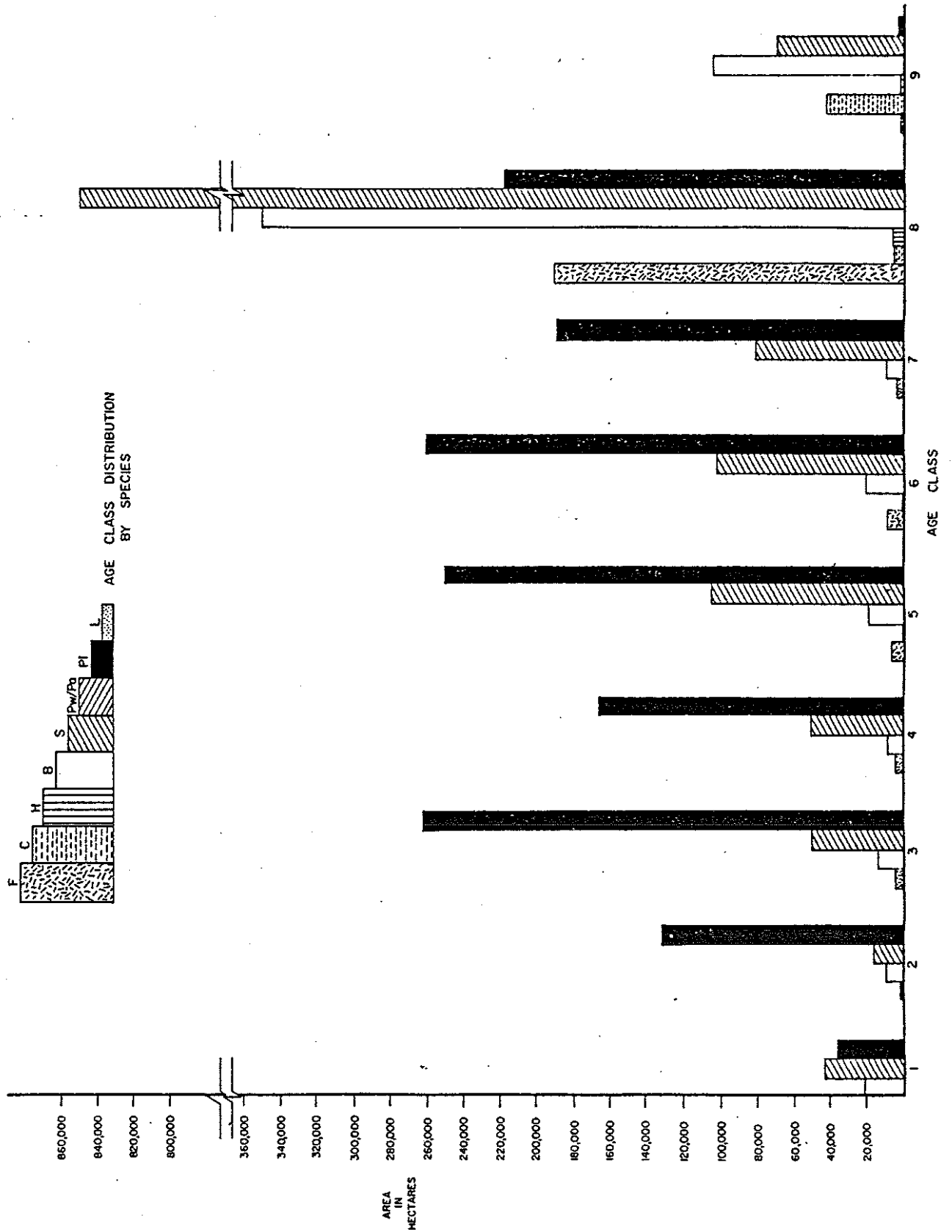


Table 1 - Area in hectares of forest plantations containing significant proportions of spruce by five-year age groupings and Forest District for the Prince George T.S.A. Data compiled from Site History Record Summaries, Anon. 1983.

Forest District	Area of Plantations by Year of Establishment (Ha)				Totals (Ha)
	before 1968	1968-1972	1973-1977	1978-1982	
Prince George West	35	514	6137	11321	18007
Prince George East	1064	5065	23449	34684	64262
Vanderhoof	0	0	1399	2442	3841
Ft. St. James	0	291	3233	3183	6707
Totals for Prince George Timber Supply Area	1099	5870	34218	51630	92817

preclude sawn lumber or veneer production but may result in changes in the conversion processes to adapt equipment and procedures to the raw material. Regardless of the chosen path of forest management the economic livelihood of the forest industry is dependant upon maximization of production from each hectare of forest land and a continuous supply of timber from our forest lands.

This is where a potential problem lies. The conditions that are created by our efforts to maintain our forest industry are ideal for the maintenance of serious insect pests of the forest. One such pest which is of extreme economic importance in plantation management is the spruce weevil¹, Pissodes strobi Peck (Coleoptera: Curculionidae).

The purpose of this report is to discuss the host/pest relationship and examine the potential impacts on T.S.A. management. Attempts at and research into the control of the weevil will also be examined by way of a thorough literature review. Finally, the problem of how to successfully regenerate spruce in the Prince George Timber Supply Area will be discussed. It is anticipated that a thorough understanding of this pest of immature stands will result in forest management systems that will minimize its economic impact. This report will supply the ground work and identify areas requiring further action to begin making well-informed management decisions.

2. THE HOST

2.1 Taxonomy

The precise taxonomy of the spruce occurring in the central interior of British Columbia is difficult to accurately determine. Variation within and between the native species of spruce has created a complex of botanical types which is found throughout the length of British Columbia (Garman 1957).

¹While the correct common name associated with P. strobi is white pine weevil it is referred to in British Columbia as the spruce weevil since it attacks spruces - white, Engelmann and Sitka - and does not attack western white pine (Pinus monticola Dougl.) in B.C. (McMullen 1976a).

Though the true nature of the variation cannot be demonstrated by taxonomic studies Garman (1957) makes it quite obvious that there are variants which exhibit the features of both white spruce (Picea glauca (Moench) Voss) and Engelmann spruce (Picea engelmanni Parry). Some authors describe the western white spruce (Picea glauca (Moench) Voss var. albertiana (S. Brown) Sarg.) (Fowells 1965; Anon. 1966; Harlow et al. 1979) as the species found in the central interior of the Province but Garman (1957) attributes this variety to a product of natural hybridization between white spruce and Engelmann spruce. Both Garman (1957) and Roche (1967) agreed that the variety albertiana should be discarded since it, in fact, refers to the white spruce-Engelmann spruce hybrid.

Genetic variation, ecotypic response and the species hybridization creates not a clear-cut species definition but a number of varied populations throughout the range of spruce in the interior of British Columbia. It seems quite evident, according to Roche (1967), that both P. glauca and P. engelmanni freely hybridize, and that the resulting hybrid, P. glauca x engelmanni is occupying an ecological niche, between that of the parental forms. This niche, in British Columbia, is available in the broad transition zone between the low elevation P. glauca of the montane forest and the high elevation P. engelmanni of the subalpine forest. The selection pressures associated with altitudinal change generally vary progressively and, as one would expect, the transition from pure P. glauca through the hybrid swarms to pure P. engelmanni will also be progressive. Roche (1967) demonstrated this progression through the use of transects in the Stone Creek area, south of Prince George. Garman (1957) indicated that generally the populations east of the Cascade Mountains vary from Engelmann spruce in the south, and probably through British Columbia at high elevations, to white spruce at or near base levels in the central and northern part of the Province. Meidenger¹ suggested that the spruce in the southern portion of the Prince George Forest Region (ie. - the Prince George T.S.A.) is the hybrid P. glauca x engelmanni even though it is commonly called white spruce. The silvical characteristics are generally considered to be similar to those of P. glauca.

¹D. Meidenger. Forest Ecologist. B.C. Forest Service, Research Branch.
Victoria, B.C. personal communication.

2.2 Habitat Conditions

White spruce has a transcontinental distribution, occurring in British Columbia in the boreal forest as far west as the Cascade Mountains and as far north as the limit of trees (Fig. 3; Fig. 4) at elevations from sea level to over 1700 metres. It grows under a wide range of conditions - from the wet Maritime climate of Nova Scotia, where it experiences more than 125 cm annual precipitation to the semi-arid conditions of southern Manitoba with less than 25 cm annual precipitation. The soils upon which it grows range from heavy clays to moist alluvial materials where its best growth occurs. It is a very hardy tree, capable of enduring temperatures from -55°C to $+45^{\circ}\text{C}$ with mean daily July temperatures between $+13^{\circ}\text{C}$ and $+21^{\circ}\text{C}$. The growing season varies from 160 days in Maine to as short as 20 days in the northern ranges. Generally, however, it grows south of a line indicating a growing season of 60 days with a considerable part of its range falling within the permafrost zone (Fowells 1965).

White spruce grows on a variety of soils of glacial, lacustrine, marine or alluvial origin (Fowells 1965) but makes its best growth on moist alluvial soils (Anon. 1966). It will tolerate a wide range of moisture conditions but its growth will be stunted and scrubby on both too wet and too dry soils. For maximum development it requires a supply of well-aerated water (Nienstaedt 1957). Flood resistance of white spruce is high so that it is able to become established and thrive in alluvial habitats which are frequently flooded (Krajina et al. 1982).

Fowells (1965) indicated that white spruce is very exacting in its nutrient requirements with deficiency symptoms including stunting of its growth and yellowing and early-dropping of its needles. It does, however, respond well to fertilizer treatments. This species will tolerate a wide range in pH - from 4.5 to 8.4 - with its optimum range being 5.0 to 6.0 (Nienstaedt 1957). Forest fires, in the natural environment and prescribed burning, in the managed forest situation, promote regeneration of white spruce stands by causing rapid decomposition of organic materials, which reduces acidity to levels which can support thrifty white spruce stands (Krajina

Figure 3 - Distribution of white spruce in British Columbia. From Krajina et al. 1982.



Figure 4 - Distribution of Engelmann spruce in British Columbia. From Krajina et al. 1982.



et al. 1982).

It occurs naturally in extensive pure stands but is commonly found in mixtures with subalpine fir (Abies lasiocarpa (Hook.) Nutt.), lodgepole pine (Pinus contorta Dougl. var. latifolia Engelm.), Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco), western red cedar (Thuja plicata Donn), western hemlock (Tsuga heterophylla (Raf.) Sarg.), black spruce (Picea mariana (Mill.) BSP.), trembling aspen (Populus tremuloides Michx.), balsam poplar (Populus balsamifera L.), black cottonwood (Populus trichocarpa Torr. and Gray) and western white birch (Betula papyrifera Marsh. var. commutata (Regel) Fern) throughout its range in British Columbia.

2.3 Life History

Flowering occurs in May to June, depending upon environmental factors, and lasts for up to five days. The cones ripen in late August and first open in mid-September with most of the seed being shed within nine weeks of opening (Fowells 1965). Seed production starts at age 30 to 40 but can occur on trees as young as 15 years of age. White spruce produces good crops of seed every two to seven years with light crops in the intervening years. Seed dispersal has been observed to be about 100 metres but strong winds are likely to extend this figure to over 500 metres.

Germination takes place in June and July of the year following seed dispersal, once the seedbed temperatures become favourable. Seedbed moisture retention is critical to seedling development since the germinant is very small and has shallow root penetration. Mineral soil is the best seedbed since it generally maintains a relatively constant moisture level throughout the early growth of the germinant. While white spruce will frequently germinate in moss, litter, humus and decayed logs the overall survival and growth is far superior in mineral soil (Fowells 1965).

Although considered a low to moderately shade tolerant species (Krajina et al. 1982), white spruce, in part because of its small size in the first few years, is unable to compete with dense perennial growth and is, therefore,

very difficult to maintain where it is growing in a mixture with hardwood species (Nienstaedt 1957). A heavy brush cover also creates an ideal habitat for the snowshoe hare which will, in times of peak populations, damage nearly all young trees (Fowells 1965). It is often, therefore, necessary to reduce or eliminate brush cover and competition if white spruce survival and growth is to be maximized in its early years.

White spruce grows rapidly in its early years under ideal nutrient regimes and sunlight conditions (Harlow et al. 1979). However, being a relatively tolerant species, it will survive 40 or 50 years of suppression and still show growth response when released. Where white spruce grows with hardwoods established at the same time it will fall behind and remain an understory tree until it is released (Nienstedt 1957). In coniferous mixtures it will maintain growth with and eventually exhibit dominance over the other conifers over the other conifers. Leader dimensions of immature spruce trees, commonly 0.75 cm in diameter and 30 cm long, can be as large as 2.0 cm in diameter and as long as 60 cm.

Mature trees may be as tall as 60 metres but are more commonly in the 35 metre range with a diameter at breast height of 60 centimetres. Yields at maturity of 300 cubic metres per hectare are not uncommon on the better sites in the Prince George T.S.A. with individual tree volumes commonly greater than 1.0 cubic metres and as high as 1.5 cubic metres.

3. SPRUCE WEEVIL BIOLOGY

3.1 Introduction

The spruce weevil is an economically important native insect. While once considered as two species - the Engelmann spruce weevil attacking white and Engelmann spruce and the Sitka spruce weevil attacking Sitka spruce - genetic studies have shown that they are not only the same species but that the spruce weevil and the white pine weevil of eastern forests are also the same species (Smith and Sugden 1969).

P. strobi was first described as a forest insect of importance in 1817 by W.D. Peck, Professor of Natural History and Botany at Havard University with the first detailed life history being described by Hopkins in 1907 (Belyea and Sullivan 1956). A diagrammatic representation of the life cycle of P. strobi in the interior of British Columbia is presented in Figure 5.

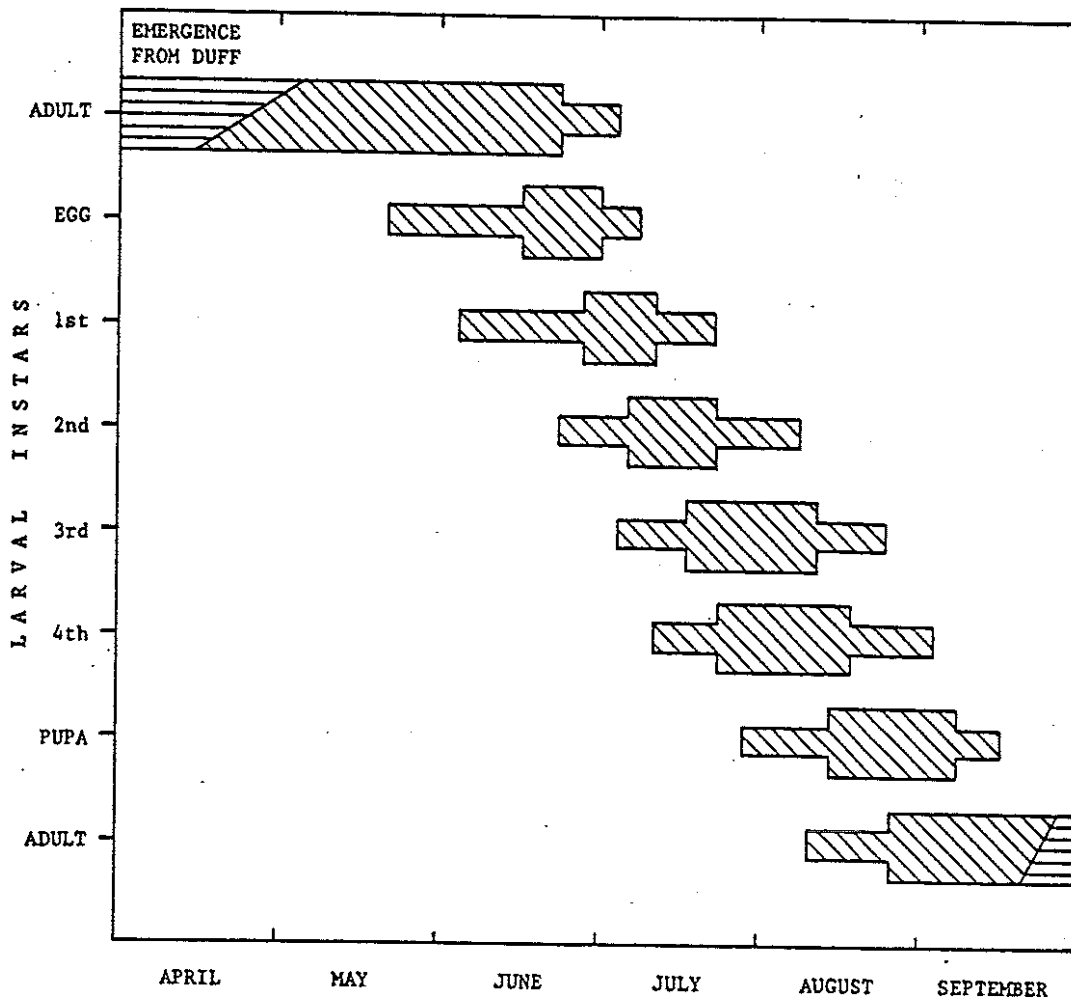
3.2 Spring Flight, Feeding and Oviposition

P. strobi has one generation per year with adults being capable of living and reproducing for up to four years (Wood and McMullen 1983; Kline and Mitchell 1979; McMullen and Condrashoff 1973). Adult weevils emerge from overwintering sites in the duff soon after the snow disappears and hibernation site temperatures have warmed to 6°C to crawl to the top of host trees (Sullivan 1959). Stevenson (1967) noted that adults may fly to other trees but only rarely and only after hibernation since the adult flight muscles are not nearly as well developed in autumn as they are in spring. Weevil flight appears to be temperature dependent as reported by Overhulser and Gara (1975) where a flight threshold of 19°C was perceived to be present. Dispersal studies have shown P. strobi capable of moving up to 1.2 kilometers from release points but McMullen and Condrashoff (1973) recorded 60 to 70 percent of adults being recovered within 18 metres of their point of release. Silver (1968) recorded adult movements of 50 metres.

Adult flight is occasionally at the level of terminals suitable for attack in a stand but Overhulser and Gara (1975) recorded flight levels generally lower than the level of the previous year's leader in plantations with frequent spaces. This suggests that leader choice by the adult is based on a silhouetting process. While it is commonly accepted that the longest, thickest leaders of the tallest trees are selected for attack (Wood and McMullen 1983; Kline and Mitchell 1979; VanderSar and Borden 1977) recent work by Carlson and McLean¹ indicated that this is not always the case.

¹J.A. Carlson and Dr. J.A. McLean. Graduate Student and Associate Professor of Forest Entomology, respectively. Faculty of Forestry, University of British Columbia. Vancouver, B.C. personal communication.

Figure 5 - Generalized life cycle of P. strobi in the Prince George T.S.A.
From Stevenson, 1967. Wide parts represent normal periods of
occurrence; narrow parts indicate extreme ranges.



In their study many of the largest diameter and tallest leaders escaped attack while smaller diameter, shorter leaders were attacked in their study plots. VanderSar and Borden (1977) determined that vision is of significance in short-range host selection. Their studies showed that overwintered weevils were predisposed to respond to vertical Sitka spruce leaders rather than horizontal lateral branches.

Studies of the role of pheromones with respect to P. strobi on eastern white pine indicated the release of a pheromone by the male weevil, when feeding, to aggregate populations for both feeding and breeding (Booth and Lanier 1974a). Booth and Lanier (1974b) concluded that these aggregating pheromones which are attractive to both sexes may promote maximum utilization of scattered food sources and ensure mating in widely distributed populations.

Adult feeding, which begins immediately after emergence from the hibernation site in the spring, is concentrated on leaders and terminal buds (Sullivan 1959; Silver 1968) and often on the northerly side of dominant leaders (Stevenson 1967) of host trees. Mating also begins shortly after emergence from hibernation. Both adult feeding and mating are largely temperature dependent with bark temperature, as well as ambient air temperatures, determining adult activity. During the spring the daily temperatures permit only short and low level feeding and oviposition periods. Later in the season, however, the higher temperatures at feeding and oviposition sites result in high activity persisting throughout most of the daylight hours (Sullivan 1959). Maximum activity occurs between temperatures of 25 and 30°C (McMullen 1976a). However, Sullivan (1959) observed that when temperatures exceeded 31°C the weevils seek out cooler areas. Oviposition occurs from mid-May to mid-July but is most frequent during late June (Stevenson 1967). Feeding and oviposition punctures (Fig. 6) are about 2.5 mm in diameter (Silver 1968) with roughly one quarter to one half of all punctures containing eggs (Stevenson 1967; Silver 1968). Those punctures containing eggs are covered with brown-black fecal material while feeding punctures are usually not covered (Stevenson 1967; Silver 1968). Gara et al. (1980) proposed that the fecal plug serves two main purposes - that of identification of an egg-containing cavity to other ovipositing weevils and



Figure 6 - Feeding and oviposition punctures on spruce leader
(4x magnification).

that of serving as a protection agent against egg predation. The greatest egg concentrations have been determined to be on the side of the leader away from direct morning and evening insolation (Silver 1968; Gara et al. 1971).

The eggs are usually deposited singly, although occasionally in pairs or more, in the punctures in the leader of the host tree. Silver (1969) indicated that females laid all of their eggs in one leader with an average of 64 eggs being deposited in leaders caged with one pair of adults. Field observations showed that leaders contained as many as 245 eggs which suggested that two or more females will oviposit in one leader (Silver 1968). Studies by McMullen and Condrashoff (1973) indicated that female fecundity appeared to remain relatively constant throughout their life span. Stevenson (1967) reported that as many as five eggs have been found in a single puncture; Gara et al. (1971) determined that an average of 1.4 eggs were deposited in each puncture. Wood and McMullen (1983) described the egg of P. strobi as being oval, white opalescent and measuring 1.0 mm by 0.5 mm. The incubation period, based on leader dissection, was estimated by Silver (1968) at two weeks.

3.3 Larval Stage

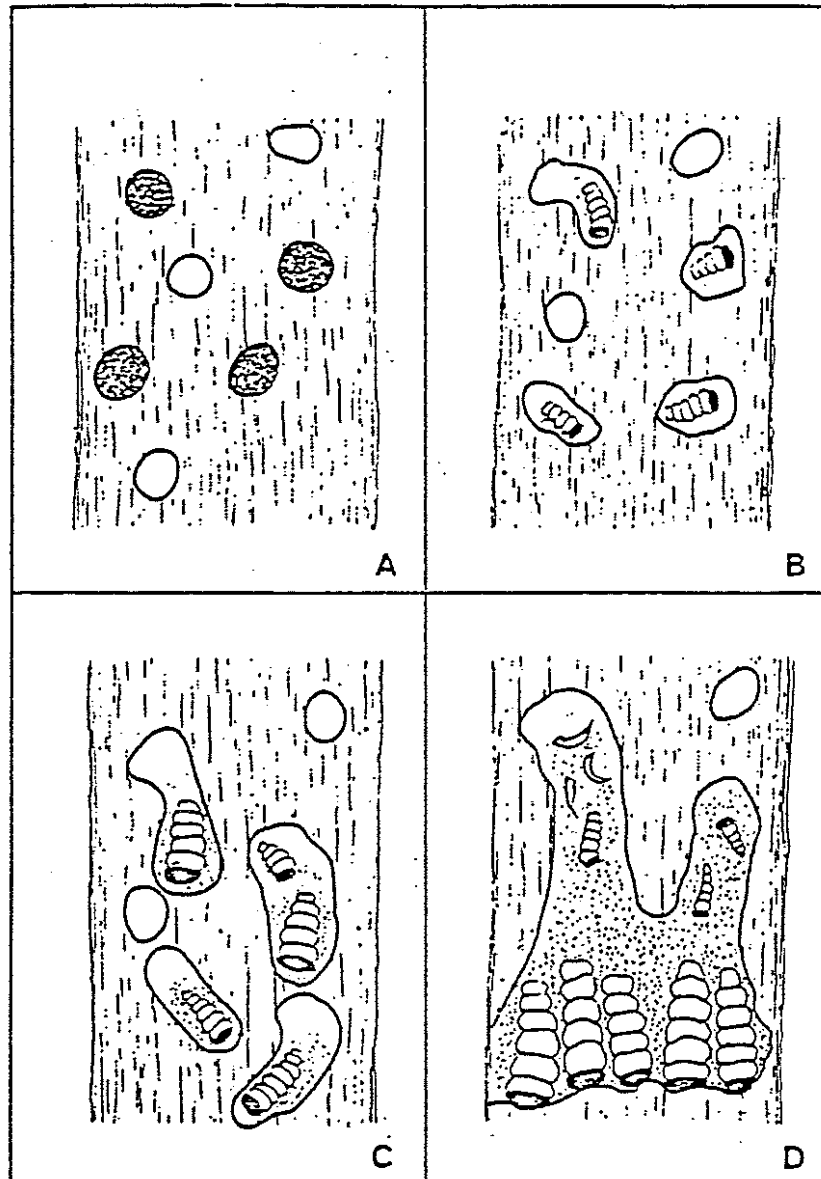
The larvae commence feeding as soon as they hatch, initially enlarging the punctures, and orient themselves head downwards to mine in the cambial area towards the base of the stem (Stevenson 1967; Silver 1968). Larval feeding is initially in individual mines but as the number of larvae increase and after one or two instars, the larvae converge into a single feeding area that normally encircles the stem resulting in leader death. The most obvious characteristics of weevil attack resulting from larval feeding, are a drooping current leader and a yellow hue in the needles of the one-year-old leader (Kline and Mitchell 1979).

The area of larval feeding, commonly known as the feeding ring (Fig. 7; Fig. 8), is apparently essential to the survival of the larvae. Sullivan (1961) and Stevenson (1967) indicated that individuals or small groups of larvae are generally pitch-drowned since they are unable to make sufficient progress to stay ahead of the resin flow. Larvae in low numbers, due to low



Figure 7 - Larvae of P. stobi at the area of the feeding ring
(8x magnification).

Figure 8 - Development of *P. strobil* larval feeding ring. From Stevenson, 1967.
A. - egg punctures; B. - enlarging the puncture;
C. - orientation downward; D. - formation of the
feeding ring.



oviposition rates, which cannot form a feeding ring or larvae which cannot establish a position in the feeding ring due to overpopulation generally die.

Four larval instars are indicated with a period of 34 days generally being required to enter pupation (Stevenson 1967). The larva is yellowish-white, cylindrical, elongate and legless with a light brown head (Wood and McMullen 1983). When full grown it is about 6 mm long.

3.4 Pupation

Pupation, according to Stevenson (1967) and Silver (1968), occurs in two ways and is dependent upon stem diameter as described by Stevenson (1967). In stems over 0.95 cm in diameter the mature larvae excavate shallow chambers in the xylem and enclose themselves in shredded wood tissue. These pupal chambers are known as 'chip-cocoons' (Fig. 9). In stems of 0.95 cm in diameter and less the larvae almost always pupate in the pith. Such pupal chambers are frequently located end-to-end and lack the 'chip-cocoon' construction (Fig. 10). The pupal stage lasts about two weeks. Wood and McMullen (1983) described the pupa, about the same size and form as the adult, as being shiny white at first, darkening while maturing, with well-developed wings and legs. The developing head bears a prominent snout.

3.5 Adult

Adult emergence can be expected during late August and early September based on studies conducted by Stevenson (1967) at Kootenay Crossing in British Columbia. After cutting holes directly from the pupal chamber through the outside bark the freshly-emerged adults generally remain on or near their host tree (Stevenson 1967; Silver 1968; McMullen 1976b). Silver (1968) and McMullen (1976b) indicated that some feeding takes place but activity levels are generally low. The adults crawl down the stems to overwinter in the duff at the base of their host tree. Sullivan (1959) determined that hibernation usually begins when the mean air temperature fails to exceed 5°C.

The precise fate of those larvae, pupae and adults that fail to complete



Figure 9 - Pupal 'chip-cocoon' in xylem of spruce leader (8x magnification).



Figure 10 - Pupae of P. strobi in pupal chambers excavated in pith of spruce leader (8x magnification).

development and emerge from the leader appears to be somewhat confused. Stevenson (1967) reported that pupae that failed to complete their development and adults that failed to exit the stem did not survive the winter in his studies in the Kootenay Crossing area. On the coast, where extreme temperatures are only rarely experienced, McMullen (1976a) indicated that emerged adult P. strobi can overwinter successfully in the lower portions of the host tree crown. VanderSar (1977) indicated that P. strobi can successfully overwinter in the larval stage in Sitka spruce leaders in coastal B.C. Silver (1968) determined that larvae and pupae can successfully overwinter in the coastal environment. Furniss and Carolin (1977) stated that larvae and pupae can overwinter and inferred that this is valid where severe winters are experienced. Stevenson (1967) determined that infested white spruce stems yielded an average of 2.82 adult weevils (range 0-19), based on the number of emergence holes through the bark.

The adult, 5 to 6 mm in length, is typical in appearance with a long, curved snout and a cylindrical, posteriorly-tapered body, usually reddish-brown with patches of lighter brown or grey scales, and ridged, roughened wing covers (Wood and McMullen 1983) (Fig. 11).

3.6 Factors Affecting Population

Accumulated heat, measured in degree-days above a specified threshold temperature, can be used to determine the development of the brood (McMullen 1976a). The accepted threshold temperature for P. strobi brood development is 7.2°C and a total of 785 degree-days above this temperature is required for complete development of the weevil based on studies on collections from the Aleza Lake area, east of Prince George, by McMullen (1976b). A total of 888 degree-days is necessary for development of P. strobi in Sitka spruce on the coast (McMullen 1976b). It has been proposed by McMullen¹ that the difference in heat accumulation requirements between the coastal and interior weevils is an evolutionary feature. Out of necessity, the weevils in the interior must complete their development prior to winter and only the individuals with the low degree-day requirements survive.



Figure 11 - Adult P. strobi (8x magnification).

The status of brood development within any particular stand will not necessarily be uniform due to the time of oviposition but development will likely always require the same number of degree-days (McMullen 1976a). The cycles are brought into synchronization when the adults emerge from hibernation in the spring while those failing to emerge from the leader prior to the onset of winter do not survive to reproduce. The coastal climate results in a more complex situation where those adults overwintering in the leader emerge in late summer to reproduce and the resulting brood actively kill leaders well into the fall.

Mortality is present at all stages of the development of P. strobi (Table 2) with an average generation survival reflecting only small increases in the weevil infestation each year (Dixon and Houseweart 1982). A major factor contributing to population growth and maintenance, according to McMullen¹, is the longevity of the adults. Larval, prepupal and hibernation-related mortalities appear to exert the most influence on population levels.

4. DAMAGE AND LOSSES

The spruce weevil is a potentially serious pest of immature spruce forests (Stevenson 1967; Silver 1968; McMullen 1976; Furniss and Carolin 1977; Drouin 1981; Dixon and Houseweart 1982; Wood and McMullen 1983). It kills the terminal leaders of young spruce ranging in height from one metre to 15 metres, and occasionally over 25 metres, forcing the lateral branches to complete for dominance. This situation results in multiple or crooked stems and height loss which all can be equated with volume and value losses.

Adult P. strobi deposit their eggs in the spring on the previous year's growth. The larvae mine downwards, killing both the current year's growth (Fig. 12) and the previous year's leader growth (Fig. 13). On white spruce, in the central interior of British Columbia, the larvae often feed throughout

¹Dr. L.H. McMullen. Research Scientist. Canadian Forestry Service, Pacific Forest Research Centre. Victoria, B.C. personal communication.

Table 2 - Survival of P. strobil through one complete generation. From Dixon and Houseweart (1982); VanderSar (1978); Silver (1968); Stevenson (1967); Sullivan (1961).

Development Stage	Mortality Factors	% Mortality at each Development Stage	% mortality of eggs laid	Individuals Surviving from an Average Egg Complement of 140 per Infested Leader
egg	pitch drowning infertility	6	6	131.6
larva	pitch drowning starvation predation parasitism	90	84.6	13.2
prepupa	pitch drowning predation	68	6.4	4.2
pupa	predation overwintering losses	5	.1	4.0
adult (before emergence)	unable to emerge overwintering losses predation	4	.1	3.8
adult (before hibernation)	adult inviability predation 'natural' factors	17	.4	3.2
adult (during hibernation)	adult inviability predation 'natural' factors	16	.3	2.8



Figure 12 - Early symptoms of P. *strobi* attack - 'drooping' of current years' growth.



Figure 13 - late symptoms of P. strobi attack - two year's leader growth killed.

two year's growth according to McMullen¹ effectively setting the growth of the host tree back by three years. The loss of a leader and resulting competition of lateral branches for apical dominance logically reduce the tree vigour and height growth. Once a tree has been successfully attacked it is generally not available for re-attack for at least two years after the terminal has been killed - the time it takes for a suitable leader to be produced (Alfaro 1982). It can then be seen that an annual infestation rate of 30 percent implies that 90 percent of the spruce trees are attacked every three years (Alfaro 1982) assuming the weevil population remains static. This creates a situation where attacked trees may be over-topped by deciduous brush or other less-desirable conifers and ultimately be suppressed.

Studies by Brown (1959) on the impact of P. strobil on eastern white pine (Pinus strobus L.) showed that the weevil was responsible for a 13 percent loss in pole timber and a 40 percent loss in sawlogs. Brace (1971) attributed these losses to the effect of weevil attack on tree height, diameter and form, angle knots, wane, cross grain and reaction wood. Subsequent studies by Brace (1972) of eastern white pine aged 60 to 90 years showed a reduction in cubic volume yield of 3 to 21 percent and an average reduction in lumber value of 25 percent directly attributable to weevil attack. Drouin (1981) indicated that secondary organisms such as heartrots can often gain entry through weevil-killed leaders.

5. DETECTION AND SURVEY

The Vancouver Forest Region has initiated an active survey and detection programme for P. strobil in their Sitka and white spruce plantations. All plantations in the Region that have a spruce content of 20 percent or greater and that are five or more years from establishment are scheduled for survey. The age of five years is chosen since most plantations have achieved an average height of 1.5 metres by that time and this has been determined to be a critical height for weevil attack. Over 13 000 hectares of such stands

¹Dr. L.H. McMullen. Research Scientist. Canadian Forestry Service, Pacific Research Centre. Victoria, B.C. personal communication.

currently exist out of a total of 21 500 hectares of spruce plantations in the Vancouver Forest Region¹.

A continuous strip survey of five or ten metres in width (2.5 and 5.0 percent sampling intensity, respectively) on a 200 metre grid is the basis of the survey. On areas where current regeneration survey information is absent (more than three years since the last survey) standard regeneration plots are established every 100 metres (0.25 percent sampling intensity) to determine species composition and stocking levels.

The 'weevil status' of each tree on the strip is recorded under one of the four possible categories:

- free from attack
- current year attack
- one-year-old attack
- two-year-old (and older) attack

This information is utilized to determine the infestation status of the plantation and to assist in making subsequent management decisions. In addition to attack data, parameters that have been or may be related to weevil attack are recorded for each plantation. This information may prove useful in the refinement of hazard ratings for P. strobi in immature spruce stands. A sample survey form is shown in Figure 14.

Large-scale colour infrared photographs taken in mid-August and early September have been used for the detection and assessment of P. strobi damage in Sitka spruce plantations by Carlson and McLean². Photographs produced at a scale of 1:1200 can be stereoscopically viewed with a two-power pocket stereoscope and, after some initial training and orientation, used to determine current weevil attack. Photographic scales of 1:4000 can be viewed with more sophisticated equipment to produce similar results. Wood³

¹E.M.J. Jeklin. Pest Management Forester. B.C. Forest Service. Vancouver Forest Region. Burnaby, B.C. personal communication.

²J.A. Carlson and Dr. J.A. McLean. Graduate Student and Associate Professor of Forest Entomology, respectively. Faculty of Forestry, University of British Columbia. Vancouver, B.C. personal communication.

³P.M. Wood. Pest Management Co-ordinator, B.C. Forest Service. Vancouver Forest Region. Burnaby, B.C. personal communication.

1. Location _____ Opening/Block # _____
District _____ Tenure _____
Photo # _____ Accessibility _____

2. Elevation _____ Plantation Estab. Date _____
Aspect _____ Ha. Planted _____ Species _____
Slope _____ #Sitka Spruce Planted _____ Seedlots _____

3. Hectares Sampled _____
Total strip length _____ m, width _____ m,
sampling intensity _____ %

4. % spruce _____ % other species _____
Av. #stems/ha > 1 m _____ Av. ht. _____ m
Av. Ss/ha > 1 m _____ Av. ht. _____ m
Av. Spruce Leader length _____ m

5. Overstory amount _____ % coverage (est.) Brush _____ % _____ ht. m
Weevil intensity:
Spruce sampled _____ # free from attack _____
'82 attacks _____ # '81 attacks _____
attacks prior to '81 _____
'82 infestation _____ % ('82 attacks/total spruce sampled)
'82 infested leaders/ha. _____

Weevil incidence: local () patchy () homogeneous ()
extent: present in adjacent plantations ()
mature timber () isolated ()

Other insect/disease problems _____

anticipated this technique might cost 20 percent of that of ground surveys and yield similar results. He felt that this technique will definitely supplement the existing ground survey methods and, with refinement, may have the capability of replacing ground surveys. The timing of the photographic mission is critical and must coincide with the weevil development such that the leader is physiologically dead to ensure a detectable change in spectral reflectance in the near infrared. Early September is an anticipated photo-flight time to make this detection and assessment method operationally viable.

6. CONTROL METHODS

6.1 Chemical Control

6.11 Introduction

Chemical insecticides provide the forest manager with a powerful weapon against forest insects. Responsible use of such materials can result in great reductions of wood fibre lost to the ravages of forest insects. This is particularly valid with pests of immature stands, such as P. strobi, where their effects at an early age are long lasting.

The selection of an insecticide and the development of a use pattern involves a complex series of studies over a considerable period of time. DeBoo (1973) summarized this planning and experimentation into five major categories:

- i. assimilation of background information on the chemical (toxicology, hazards, etc.);
- ii. laboratory toxicology experiments with introduced target pest populations on potted trees;
- iii. small scale field trials using ground or aerial application methods;
- iv. semi-operational forest-block application by aircraft including environment impact studies; and
- v. recommendation of the most efficacious and environmentally acceptable insecticide for registration and use.

The challenge to find an effective chemical insecticide for the control of P. strobi has been actively pursued for over 30 years. As yet, however, a practical chemical control is lacking (Drouin 1981; Wood and McMullen 1983). The major problem encountered is that of delivering the active ingredient to the weevil since it is generally in the protection of the host or the duff.

While a number of the chemical insecticides mentioned in the following review are either not registered for weevil control or restricted or both, their inclusion is necessary to show the development of the chemical control option.

6.12 Aerial Application

Insecticides are generally most effectively applied to large areas in the form of an aerial spray. Aerial applications of chemical insecticides against P. strobi have been made on both an operational and experimental basis in Ontario and on an experimental basis in British Columbia (Sippel et al. 1975). To be most effective, the insecticide must be applied soon after the adult weevils are observed in the spring but prior to oviposition. It is therefore necessary to have very close synchronization between the life cycle of the weevil and the control efforts. Table 3 summarizes the major work concerning the aerial application of insecticides to control P. strobi.

The successful use of aurally applied insecticides depends upon many factors. Droplet size is most critical once an insecticide is known to be effective in killing the target insect. Himel (1969) described the optimum droplet size as that size which gives maximum control of the target insect with the minimum amount of insecticide and a minimum of ecosystem contamination. Aerial application of insecticide sprays, by the nature and limitations of the systems involved, result in a very low volume of mixture per unit area, which further reduces the chances for control of the target insect.

Table 3 - Summary of significant experimental and operational aerial applications of chemical insecticides in an effort to control P. strobi

year	chemical	application rate (kg a.i./ha)	carrier/diluent/adjuvant	total vol./area (l/ha)	comments	reference
1957 ¹	DDT 25%	4.5	fuel oil	45	- first aerial spray in Ontario	Sippell et al. 1975
1961 ¹ to 1966	DDT 25%	1.9 to 4.5	fuel oil	19 to 45	- 900 ha in Algonquin Provincial Park - damage reduction 63-96% but no evidence that DDT was responsible	Sippell et al. 1975
1968 ¹ to 1972	methoxychlor	2.25, 2.7, 2.8, 3.4	water	22.5	- 3400 ha treated in 10 control operations - 50 to 70% damage reduction	Sippell et al. 1975
1973 ¹	methoxychlor	2.7	water + Target E	22.5	- 1000 ha treated - unacceptable amounts of attack after application; possibly due to poor post-spray weather	Sippell et al. 1975
1971 ²	fenitrothion & Methyl Trithion	.34, .79, 1.12	water	45	- only plots with rate of 1.12 kg/ha showed any significant control. - damage was still unacceptable at 12% - required dosages would have adverse environmental impact	Sippell et al. 1975
1972 ³	methoxychlor	2.8	fuel oil & water	22.5, 45	- oil based sprays approx. 4 X as effective as water based sprays - 45 l/ha superior control to 22.5 l/ha rates	DeBoo and Campbell 1972a

Table 3 - Continued

year	chemical	application rate (kg a.i./ha)	carrier/ diluent/ adjuvant	total vol./area (l/ha)	comments	reference
1973 ³	methoxychlor	2.8	water fuel oil water + Target E	22.5, 45	- methoxychlor in fuel oil at 45 l/ha produced 87-91% reduction in weevil attack - carrier effectiveness: fuel oil water + Target E water	DeBoo and Campbell 1974a
1973 ³	Gardona ^R	1.12, 2.25	water	22.5	- 1.12 kg/ha produced 55% reduction in attack - 2.25 kg/ha produced 66% reduction in attack	DeBoo and Campbell 1974a
1974 ³	methoxychlor	2.25, 2.8	#2 fuel oil	18, 36	- 20-58% control achieved but did not meet objective of 1% leader attack	DeBoo and Campbell 1974b
1974 ³	carbaryl	1.12	#2 fuel oil	9	- 45-55% control achieved but did not meet objective of 1% leader attack	DeBoo and Campbell 1974b

- 1 operational application, Ontario
- 2 experimental application, British Columbia
- 3 experimental application, Ontario

6.13 Ground-based Application

Application of insecticidal sprays from the ground using backpack sprayers, mistblowers or vehicle-mounted hydraulic equipment results in a high volume of insecticide mixture being applied per unit area. In addition to being a forerunner to aerial application trials the application of insecticidal sprays from the ground stands on its own as a legitimate insect pest control technique. Table 4 summarizes some of the significant work done with various chemical insecticides applied from the ground.

6.14 Application to the Ground

In the colder climates of British Columbia the spruce weevil generally overwinters in the duff beneath its host tree (Stevenson 1967) and is therefore 'available' for control during this period. Hastings (1956) spread granulated endrin at rates of 1.12, 2.25 and 4.50 kg a.i. per hectare in the fall over the duff where adults were caged. Almost 100 percent mortality was achieved which indicated that more work in this direction should proceed. Heptachlor granules (5% a.i.) applied within a 60 cm radius of host trees achieved 95 percent control of P. strobi in the second year and showed good control for five years (Nichols 1968). Aldicarb granules (10% a.i.) mixed with Milorganite^R fertilizer as an extender were broadcast by hand at the base of the host tree and provided total control of the weevil on those trees (Kerr 1971). While the reported research is encouraging this technique of P. strobi control has not been actively pursued in recent years. Nichols (1968) suggested that the method may be severely limited due to the possible hazards to wildlife from the use of residual soil insecticides.

6.15 Laboratory and General Research Trials

Nigam (1972), in laboratory tests to find a chemical effective against P. strobi, yet environmentally acceptable, found that Phoxim (1% a.i. in water) gave 100 percent control at rates of 9.0 and 11.0 litres per hectare. Dursban^R and Gardona^R (both at 2% a.i. in water) were almost as effective at similar rates of application. While all three chemicals were recommended

Table 4 - Summary of significant experimental ground - based applications of chemical insecticides in an effort to control P. strobi

year	chemical	application rates	carrier/ diluent/ adjuvant	total volume applied	comments	reference
1961	DDT phosphamidon	1%, 5% a.i.	water	?	good control with DDT and 5% phosphamidon; 1% phosphamidon unsatisfactory	Silver 1968
1964	DDT phosphamidon	5% a.i. 0.5%, 1%, 2% a.i.	water	?	tests not as conclusive as 1961 since overall weevil attack lower; best results from 5% DDT, 1 & 2% phosphamidon	Silver 1968
1965	malathion carbayl Zectran ^R Cuthion ^R DDT endosulfan dieliorin Meta-Systox-R	1% a.i.	water	applied to terminal to run-off point	experimental work to determine capability of insecticides to penetrate leader bark to kill weevil larvae before they damage tissue	not worth further work Johnson 1965
1966	phosphamidon disulfoton dimethoate azodrin oxydemetonmethyl Bidrin ^R	1% a.i.	water	applied to terminal to run-off point	screening test. for further work not worth further work more work warranted	Johnson and Zingg 1966
1968	oxydemetonmethyl Bidrin ^R	1% a.i.	water	sprayed to run-off	provided 'good' control when applied after oviposition	Johnson and Zingg 1968

Table 4 - con't

year	chemical	application rates	carrier/ diluent/ adjuvant	total volume applied	comments	reference
1971	methoxychlor	2.25 kg. a.i. /ha	water	1125 l/ha	2 applications, 2 wks apart gave 100% control	DeBoo and Campbell 1971
	Dursban ^R Cardona ^R	0.55 kg. a.i. /ha			significantly less control than methoxychlor	
1972	methoxychlor	1.12, 1.7, 2.25 kg. a.i. /ha			excellent control achieved	DeBoo and Campbell 1972b
	Dursban ^R	1.12 kg. a.i. /ha	water	1125 l/ha	not sufficiently effective	
	Cardona ^R	1.12 kg. a.i. /ha			excellent control achieved	
1980	Meta-Systox- ^R Reidan ^R	?	water emulsion & dissolved in latex	?	complete control achieved for 1 year	Gara et al. 1980
	Orthene ^R		slow-release polymer		shows indications of being of benefit	

for further testing, only Dursban^R and Gardona^R were examined in the field (De Boo and Campbell 1971, 1972a, 1972b).

Johnson and Zingg (1968) injected Sitka spruce trees with various systemic insecticides to examine their degree of control upon P. strobi. Bidrin^R, oxydemetonmethyl, demeton and schradan appeared to show good control and were recommended as candidates for further examination in the use of this technique.

6.16 Repellents

Pine oil, a derivative of sulphate pulp processing waste, was shown by Nijholt (1980) to be effective in both delaying and reducing ambrosia beetle ((Trypodendron lineatum (Oliv.), Gnathotrichus sulcatus (LeConte), and G. retusus (Le Conte)) attack. Nijholt and McMullen (1980) demonstrated that pine oil could be used to protect living lodgepole pine trees from attack by mountain pine beetles (Dendroctonus ponderosae Hopk.). Further work showed that pine oil was also effective in protecting Douglas-fir from attack by the Douglas-fir beetle (Dendroctonus pseudotsugae Hopk.) and in protecting spruce from spruce beetle (Dendroctonus rufipennis (Kirby)) attack (Nijholt *et al.* 1981). These findings and the apparent lack of phytotoxic effects on the treated trees suggested practical applications in both individual tree protection and in protection related to harvesting operations.

Carlson¹ studied the protection of Sitka spruce stands from P. strobi attack with pine oil repellent based on its success as a bark beetle repellent. Pine oil was applied topically to all leaders in test plots to determine the tree protection values and was used in slow-release devices placed throughout the stand to determine its area effect. Preliminary results showed that pine oil repellent will effectively protect individual trees but has very little effect when used in a slow-release device. The weevils will not attack a topically treated tree, or a tree with a slow release device in it, but were observed to attack the closest untreated tree. Some apparent

¹J.A. Carlson. Graduate Student. Forest Entomology, Faculty of Forestry, University of British Columbia. Vancouver, B.C. personal communication.

phytotoxicity was observed on the topically treated leaders but the damage may actually have been caused by the mechanical application methods used.

6.17 Insect Growth Regulators

The class of chemicals known as insect growth regulators are one of the new approaches to pest control that exploit the physiological system of the target insect pest. The chemicals involved are characteristically non-toxic, labile and specific to insects (Retnakaran et al. 1982). Attempts to narrow the spectrum of activity of control agents and make them at least insect-specific have resulted in materials that block critical biochemical pathways that are found only in insects.

Effective control of P. strobi may be possible through the use of insect growth regulators to induce changes in or interfere with reproduction or normal insect growth processes. Retnakaren (1973) indicated three properties of juvenile hormone analogues that have potential value in P. strobi control; namely the ovicidal, morphogenetic and gonadotropic properties. Applications of a synthetic juvenile hormone analogue to P. strobi eggs resulted in a decrease in larval development and significant larval mortality only 12 days after egg hatch (Retnakaren 1973). The results suggested that the most effective analogue would be one translocated to the cambium of the leader when the eggs were present. Fall application of juvenile hormone analogues to induce feeding and reproduction during a period of environmental stress (winter) has been suggested by Retnakaran (1974). Induced changes in development at a time when the insect normally enters diapause may culminate in increased over-wintering mortality and provide an effective control measure. McMullen and Sahota (1974) observed a reduction in the developmental and growth rates of P. strobi larvae whose parents, as adults, were exposed to the juvenile hormone analogue ZR-777.

Sahota and McMullen (1979) studied the effects of Dimilin, a chitin inhibitor, and precocenes, which inhibit reproduction by suppressing juvenile hormone effects, and found that a simultaneous application of both insect growth regulators had sufficient control to warrant further laboratory

testing. The chemicals appeared to complement each other with the precocenes inhibiting egg maturation and oviposition while Dimilin inhibited successful larval emergence from any deposited eggs.

Field tests conducted by Retnakaran and Smith (1982) used Dimilin and BAY-SIR-8514 (25% W.P. in Sunspray 7-N oil @ 280 g in 18.8 l/ha) in two treatments, one week apart, in May after the adults were observed feeding. Almost a six-fold reduction in the number of emerging adults was realized from this treatment as compared to untreated check populations.

6.18 Persistence in the Environment

The current search for a chemical effective in the control of P. strobi became necessary when DDT was removed as a control option. During the 20-year period from the late 1940's to the late 1960's weevil damage to eastern white pine was minimized by aerial application of this chemical (Sundaram et al. 1972). Both Lindane and BHC were standard and very effective sprays used in P. strobi control from the mid-1950's to the late 1960's in eastern Canada and the north-eastern United States¹. Now, key factors in the acceptance of a chemical for operational use are its persistence in the environment and its effect upon non-target organisms. A great deal of work on the persistence of insecticides has been done by the Chemical Control Research Institute (now incorporated into the Forest Pest Management Institute) of the Canadian Forestry Service.

Methoxychlor was determined to have very low persistence with a rapid dissipation rate and a residue half-life of five days (Sundaram 1973; Sundaram 1975). Gardona^R, while not as effective as methoxychlor, was similarly of low persistence with a residue half-life of five days (Sundaram 1974). Sundaram and LeCompte (1975) found carbaryl to have a high initial decrease in residual rates with a slightly longer residue half-life of six days.

¹Dr. R.F. DeBoo. Manager, Pest Management, B.C. Forest Service. Victoria, B.C. personal communication.

The less than acceptable control of these low-persistence chemicals may be able to be directly attributed to their lack of persistence in the environment. Sundaram (1975) states that for acceptable control (at least 85 percent reduction) the initial deposit concentration on the leader surface should be at least 15-20 ppm and the residue should be sufficiently concentrated to act as a contact toxin and be active on the leaders for at least ten days after application.

6.2 Silvicultural Control

6.21 Introduction

Silviculture is the theory and practice of the control of forest establishment and forest growth. The control of forest pests by silvicultural methods is accomplished through the adjustment of forest conditions and the avoidance of practices that would be detrimental to the general health and vigour of the stands under management (Knight and Heikkinen 1980).

Each stage in the growth of a forest from seedling to maturity has its own specific associated significant insect pests. These insects have their particular requirements for moisture, temperature, food, shelter, light quality and intensity and other variables as do their hosts, the forest trees. Dolph (1979) observed that these factors, the requirements of which may often be significantly different for the host and the pest, have the potential to lead to successful indirect pest control through the intelligent use of silvicultural methods as a pest prevention strategy.

6.22 Control of Sunlight

Research work into the silvicultural control of P. strobi has been primarily concerned with the growth and management of eastern white pine. Control through silvicultural practice was actively encouraged by Belyea and Sullivan (1956) as an alternative to or in combination with chemical control methods to achieve the goal of weevil-free eastern white pine. Shortly after

this Brown (1959) cautioned that a major problem may exist in creating, through silvicultural methods, the correct amount of overtopping to inhibit weevil attack yet permit satisfactory growth of the white pine understory.

In 1967 at the Petawawa Forest Experiment Station a project was initiated to capitalize upon the respective light requirements of P. strobi and eastern white pine seedlings to limit weevil attack on the seedlings (Stiell and Berry 1967). This long-term project was initiated in an attempt to find a satisfactory method to regenerate and grow eastern white pine under conditions where weevil attacks would be minimized. Until that time most regeneration systems were directed towards the growth of the trees under low light conditions - underplanting, shelterwood system or maintenance of a hardwood cover over the seedlings. Such conditions, while limiting weevil invasion, were not conducive to good seedling growth. The trial consisted of clearcut strips in a mature forest aligned in a north-south direction to limit the full sunlight period each day. Strip widths were calculated to allow 25, 50, 75 and 100 percent of the full daily sunlight to reach the forest floor where the four-year-old eastern white pine seedlings were planted. Early results showed that it would not be possible to grow weevil-free eastern white pine on strips in mature hardwood forests unless the strips limited full sunlight to below the 50 percent level (Berry and Stiell 1976). The inherent problem, however, was that while weevil attack may be suppressed so may the plantation growth. In coniferous or mixed stands, however, strips allowing 75 percent of the full daily sunlight appeared to significantly limit weevil attacks. The difference in the infestation levels between strip sizes and adjacent forest types can be attributed to the decreased shading by the pure hardwood stand during weevil flight, mating and oviposition which generally takes place prior to full leaf development (maximum shading) in the deciduous stands. Now, some 25 years after the establishment of this trial, McLean¹ observed that virtually all of the study trees were substantially weevilled at the four-metre level since they have grown out of the shading effect and into full sunlight.

¹Dr. J.A. McLean. Associate Professor of Forest Entomology. Faculty of Forestry, University of British Columbia. Vancouver, B.C. personal communication.

The effects of shading on the growth of eastern white pine and on the incidence of weevilling were studied and reported by Logan (1962). Suppression of seedling growth was attributed to undergrowth influences rather than the aspen overstory which suggested that if the undergrowth is removed the presence of large aspen trees would not significantly affect seedling height growth. The aspen overstory, however, may result in smaller leader diameters and an overall reduction in P. strobi attack. Based on similar logic, research plots were established in the University of British Columbia Research Forest in 1980 to study the effects of an alder (Alnus rubra Bong) overstory on the incidence of P. strobi attack on Sitka spruce seedlings by McLean¹. The effect of the alder overstory upon the growth of the seedlings will also be monitored. Two stock types were planted - 2+1 bareroot and 1+0C Sitka spruce - under a stand of naturally occurring alder of three to four metres in height and in an adjacent cleared area. After three years the height growth in both treatments is similar but the leader diameters of the trees growing under the alder are smaller than the open-grown spruce. The first weevil attack was noted in 1982 on an open-grown 2+1 Sitka spruce seedling. Another advantage of the utilization of an alder nurse crop may be realized from the nitrogen fixation characteristics of the alders and its potential benefit to spruce growth.

6.23 Control of Stand Density

Close spacing of plantations and delayed thinning of dense natural stands has been considered as a possible solution to the weevil problem. Stiell (1979) performed a release thinning 19 years after an eastern white pine plantation was established at 22 900 stems per hectare. Selected crop trees, unweevilled within the first five metres, were released and have since

¹Dr. J.A. McLean. Associate Professor of Forest Entomology. Faculty of Forestry, University of British Columbia. Vancouver, B.C. personal communication.

grown well. Periodic release thinnings will be required to maintain acceptable growth. The untreated portion of the stand sustained heavy mortality from suppression and large losses of unweevilled trees. It was concluded that even a dense stand of eastern white pine will retain only a negligible number of trees without weevil damage to the first log unless some form of protection is provided or periodic thinnings start at an early age.

While it is recognized that plantations at such close spacings are not economically feasible the principles may be applied to the management of natural stands. MacArthur (1964) noted that all crown classes in Norway spruce (Picea abies (L.)) plantations in Quebec, established between 1914 and 1928, were attacked to approximately the same degree by P. strobi with some attacks occurring at the 18 metre level. Over 50 percent of the trees studied had been weevilled at least once. An average of 2.5 attacks per weevilled tree was recorded and was found to be relatively constant over the range of crown classes.

6.24 Soil Factors

A study relating soil and environmental conditions showed that only soil mottling and hardpan location could be correlated with the damage to eastern white pine by P. strobi (Connola and Wixson 1963). Data analysis from stands over five metres in height showed that when soil mottling or hardpan occurred within one metre of the surface weevil damage was significantly higher than when these phenomena were below the one metre level. This information stresses the need for a total site survey prior to making a silvicultural prescription.

6.3 Biological Control

6.31 Introduction

For as many years as the management of insect pests has been actively practiced the use of natural and introduced parasites, predators and pathogens has been recognized as a control alternative. Of all the enemies of forest

insects the parasitic insects have received the most attention from forest entomologists (Knight and Heikkinen 1980). A considerable amount of work has been done in this field of control primarily in the identification of the natural insect enemies of P. strobi. However, Drouin (1981) indicated that natural predators and parasites appear to have little effect on the weevil, particularly once it has become well established.

6.32 Insects as Control Agents

Stevenson (1967) determined that seven significant parasites and predators of P. strobi existed as listed in Table 5. Of the species recorded, it was recommended that further studies to determine the significance and impact of Dolichomitus terebrans nubilipennis (Vierick), Eurytoma pissodis Girault and Lonchaea corticis Taylor be carried out. Winter feeding by birds, primarily the Oregon junco and the white-crested sparrow, was observed to be significant however their non-selective feeding consumed not only the overwintering pupae but the insect parasites and predators in the infested leaders.

Silver (1968) determined that predation was the most important mortality factor. Parasitism had no noticeable effect on the P. strobi population during his study. Mass rearings of infested Sitka spruce terminals yielded six insect species as listed in Table 5. Of the insects collected Lonchaea spp. were predominant, with as many as 183 larvae being found in one leader.

VanderSar (1978) studied the emergence of predators and parasites of P. strobi in Engelmann spruce collected in the Kootenay and Glacier National Parks. Five insects were identified (Table 5) with Lonchaea corticis Taylor being the most abundant. Since the larvae of L. corticis each attack more than one immature weevil to complete their development this predaceous insect is considered to play an important role in the control of P. strobi populations. The significance of predation and parasitism upon populations of P. strobi is shown by the fact that while associated insects emerged from 90 percent of attacked Engelmann spruce leaders only 35 percent showed evidence of successful emergence of P. strobi adults (Vander Sar 1978). White spruce

Table 5 - Identified primary parasites and predators of P. strobil

Order	Family	Species	Identifier ¹	Status ²	Comments
Hymenoptera	Braconidae	<u>Alloporus crassigaster</u> (Prov.)	d	P	
		<u>Eubadizon strigitergum</u> Cushman	a,b	P	
	Ichneumonidae	<u>Bracon pini</u> (Muesebeck)	a,b,c	P	
		<u>Dolichomitus terebrans nubilipennis</u> (Viereck)	a,c	P	destroyed 22.9% of larvae and pupae ³
		<u>Calliephialtes nubilipennis</u> (Viereck)	b	P	
Eurytomidae		<u>Helcostizus rufiscutum</u> Cushman	a	P	
		<u>Eurytoma pissodis</u> Girault	a,b,c	P	destroyed 13.5% of larvae and pupae ³
		<u>Rhopalicus pulchripennis</u> (Crawford)	a,b,c	P	
Diptera	Lonchaeidae	<u>Lonchaea corticis</u> Taylor	a,b,c	PP	destroyed 19.9% of larvae and pupae ³

¹ a - Stevenson 1967

b - Silver 1968

c - Vander Sar 1978

d - Alfaro, et al. 1985

² p - parasite

pp - predator

³ Stevenson 1967

leaders showed 67 percent associated insects and 38 percent emergence of P. strobi in the same study.

Of the parasitic and predaceous insects studied, Lonchaea corticis has been recognized as an important potential regulatory factor of P. strobi populations (VanderSar 1978; Alfaro and Borden 1980; MacSurtain 1981). Alfaro and Borden (1980) determined that L. corticis, while acting in both a scavenging and predation role within the infested leader, has its primary role as an important predator. The young maggots subsist initially on dead weevil larvae and weevil frass with predation becoming evident about the time that the feeding ring is established and heavy predation occurring as the construction of pupal chambers begins (Stevenson 1967). Stevenson (1967) noted that, while larvae in chip cocoons appeared to be protected by the compacted wood, those forming pupal chambers in the pith were quite vulnerable to predation with entire boods in the pith often being destroyed.

6.33 Nematodes as Control Agents

A feasibility study was conducted using a neoaplectanid nematode to explore its potential in the control of forest pests (Schmiede 1963). It had been observed that whenever this particular nematode was able to enter an insect that rapid death resulted. In this study, however, adult P. strobi were not affected by the nematode as a result of its assumed inability to enter the insect pest.

6.34 Pathogens as Control Agents

Streett et al. (1975) noted unexplained mortality in both adult and larval stages during experiments with P. strobi which suggested an evidence of disease. Their studies showed the presence of a parasitic pathogen, Nosema spp., which was determined to be significantly destructive to its hosts' tissues. Nosema spp. was assumed to have been a major contributor to unexplained weevil mortality based on this brief study. Further studies were suggested to more fully determine the mortality agents and to explore the

present involvement and potential of Nosema spp. in the control of P. strobi.

The most widely used entomogenous fungus for insect control is Beauveria bassiana (Bals.) (Roberts and Yendol 1971). Timonin and Morris (1974) determined that larvae, pupae and, to a lesser extent, adults of P. strobi were highly susceptible to both B. bassiana and Metarrhizium anisopliae (Metsch.). Sub-lethal concentrations of the chemical insecticides Gardona^R, phoxim^R and Dursban^R appeared to enhance the virulence of both B. bassiana and M. anisopliae by reducing the LT_{50} by three to five days. It was thought that the chemical insecticide was responsible for stressing the target organism thus making the insect more susceptible to the disease (Timonin and Morris 1974). Benz (1971) suggested that such integrated control of insects is one method of lessening the severe impact of chemical pesticides on the environment. The decreased LT_{50} realized from the use of sub-lethal rates of chemical insecticides with the pathogens is also important since the mortality time may be more critical from a practical point of view than total mortality (Benz 1971).

Investigations are underway at the Pacific Forest Research Centre concerning the use of the B. bassiana as a control agent against P. strobi according to McMullen¹. Laboratory tests have shown effectiveness and field tests, applying B. basiana to the duff in order to contact the adult weevils during hibernation, are expected shortly.

6.4 Control Through Host Genetics

6.41 Introduction

Genetic selection and the development of trees resistant to attacks by specific pests through controlled breeding programmes has been pursued for many years in the practice of forest pest management. The majority of this

¹Dr. L.H. McMullen. Research Scientist. Canadian Forestry Service, Pacific Forest Research Centre. Victoria, B.C. personal communication.

work directed towards resistance to P. strobi has been concerned with eastern white pine but some encouraging work is in progress with Sitka spruce in both British Columbia and Washington State.

The general strategies involved in a resistance breeding programme, as described by Jeffers (1971) are:

- i. Selection of parents from seed sources that have shown variation in pest incidence to ensure genetic variation in progenies.
- ii. Grafting of selected parents to established root stock in breeding arboreta.
- iii. Crossing of parents with pollen-tested parents to produce full-sib parents.
- iv. Testing for pest resistance; providing the basis for new selections.

While apparently resistant trees are selected as potential parents in breeding programmes, the basis for resistance to successful attack by P. strobi is generally not totally known. One of the major problems in selection and breeding for resistance has been the definition of a selection criterion (Stroh and Gerhold 1966). Direct selection of apparently resistant trees based on absence of injury is generally not a satisfactory technique since the selected individual may not have been chosen by the weevil due to its randomly clumped nature of attack.

Tree breeding programmes primarily directed towards resistance of eastern white pine to white pine blister rust (Cronartium ribicola Fisher) and P. strobi have been ongoing in eastern Canada since 1937 (Fowler and Heimburger 1969). These studies have shown that individual tree selection and clonal testing for weevil resistance can be used to locate resistant trees. It is, however, necessary to define the critical factors that determine the acceptance or rejection of a potential host by P. strobi prior to entering into an extensive programme of breeding weevil-resistant trees.

6.42 Selection by Host Putative Resistance

A Sitka spruce plantation, established circa 1930 in the Green Timbers Forest Reserve with seedlings of Queen Charlotte Island provenance, has resulted in five individual trees demonstrating resistance to attack by P. strobi (Alfaro 1982). It is believed that this plantation was originally established as a provenance trial. Wood¹ observed that there are, in fact, only five healthy trees with all others, severely deformed and stunted as a result of weevil attack, being overtopped, suppressed and consequently dying. Alfaro (1982) observed that none of the pure Sitka spruce plantations developed into merchantable stands and in mixed plantations the spruce was almost totally absent. Clones of some of the survivors were established by the Canadian Forestry Service and the British Columbia Forest Service with outplanting scheduled for 1983. Since all five individuals are not represented in the present programme the British Columbia Forest Service collected material in the spring of 1983 for a total representation.

In 1976 some 433 open-pollinated families of Sitka spruce from 38 provenances were planted in an area of high population levels of P. strobi near Kelsey Bay, B.C. (Annon. 1979). This was the first stage of a programme conducted by the Research Branch of the B.C. Forest Service to screen families for putative resistance to attack by P. strobi. An examination in March of 1979 showed that the first weevil attack had occurred on the trees and that the degree of attack appeared to vary considerably between families (Annon. 1979). Ying (unpubl.)² reported that the attack among provenances varied between 16 and 62 percent and that 38 of the 433 families were free from attack. The provenances from the Skeena River area appeared to be generally less susceptible to weevil attack than the others. Ying also suggested that this could be a result of introgressing with white spruce and Engelmann spruce which are considered to be generally more resistant to attack by P. strobi.

¹P.M. Wood. Pest Management Co-ordinator. B.C. Forest Service, Vancouver Forest Region. Burnaby, B.C. personal communication.

²Ying, C.C. 1982. Provenance Forester. British Columbia Forest Service, Research Branch. unpublished memo.

than other spruces or eastern white pine (Belyea and Sullivan 1956; Nienstaedt 1957; Dirks 1964; Fowells 1965; Mitchell et al. 1974; MacSurtain 1981). Further cloning, after selection of the best resistant individuals from the present study, is planned with continued testing in high hazard areas. This work may lead to the development of several families within different provenances which exhibit resistance to attack by P. strobi that can be used in operational reforestation programmes in high hazard areas.

6.43 Indirect Selection for Resistance

These previously described studies are based on apparent resistance to weevil attack. Jeffers (1971) suggested that this exhibited resistance may be a result of the trees escaping attack by accident due to the random nature of P. strobi attack. Wilkinson (1979) stated that, since displayed resistance of individual trees may include environmental factors it may be preferable to use indirect methods of selection for resistance - selection for properties which show a strong correlation with resistance. Several such studies have been and are being pursued and will be described briefly.

6.431 Host-Produced Chemicals

The fact that weevilling only occurs on the previous years' terminals may suggest the presence of chemicals that render current terminals and laterals unsuitable to weevil attack (Gara et al. 1971). Alfaro et al. (1980) determined that the feeding behaviour of P. strobi on Sitka spruce is determined primarily by nonvolatile host-produced chemicals present on the surface of the bark and needles as well as within the phloem of host trees. These chemicals act not only in the initiation of feeding but also as stimulants that maintain continuous feeding. The avoidance of non-host plants was related to the presence of toxic or deterrent chemicals. A complicated profile of volatile and non-volatile compounds is considered to be a determining factor in the final acceptance or rejection of a particular tree as a host. Susceptible trees would be those possessing an adequate diversity

and quantity of feeding incitants and stimulants and an absence or low concentration of feeding deterrents (Alfaro et al. 1980). The identification of the chemicals involved and their role in host selection or rejection may provide the basis for a sound screening and selection programme for trees to be used in a weevil-resistance breeding programme.

Further work was done by Harris (unpubl.)¹ using this approach in a study of the resistant trees in the Green Timber Forest Reserve. An analysis of the monoterpene content of the five resistant trees and of five susceptible trees showed that the least susceptible individuals had a low β -phellandrene and a high α -pinene content. A reference monoterpene profile such as this could be used as an indicator in the selection of weevil-resistant trees but may not be a straightforward problem to solve. Studies have shown that current terminals of Sitka spruce maintain a higher myrcene content than the older stem material which is the preferred feeding and oviposition location of P. strobi (Gara et al. 1971). Further work, however, showed 24 identified monoterpenes composing the total profile in Sitka spruce, many of which vary widely in relative amounts over the seasons and within the tree (Hrutfiod et al. 1974).

The relationship between strobic acid - a major resin acid in the cortex of eastern white pine - and resistance to attack by P. strobi was studied by Santamour and Zinkel (1975) with result that resins with high concentrations of strobic acid crystallized when in contact with larvae of P. strobi. This crystallization would 'pitch-out' the larvae and thereby make that tree more resistant to successful weevil attack. These preliminary results suggested that crystallization of the cortical resins could be used as an aid in resistant tree selection procedures. However, Wilkinson (1979) reported that his investigations of the same phenomenon did not show any correlation between the concentrations of strobic acid and the resistance to P. strobi and he suggested that the relationship be re-examined.

¹Harris, L. 1981. Sitka spruce cortical resin monoterpenes relating to white pine weevil resistance. Simon Fraser University, Department of Biological Sciences. unpublished material. 8pp.

6.432 Host Morphological Characteristics

Stroh and Gerhold (1966) studied 12 morphological characteristics of eastern white pine leaders and their relationship to feeding by P. strobi. Two characteristics were found to significantly influence feeding and oviposition by the female - bark thickness and the depth of inside and outside cortical resin ducts.

Leader bark thickness appeared to be a matter of preference in that while the weevils are capable of feeding on the thinner-barked leaders they preferred to feed on those with thicker bark if the opportunity existed.

The depth of the cortical resin ducts, however, were found to be the most consistently and significantly related to weevil feeding. The distance between two sets of ducts was found to be significantly correlated to feeding cavity dimensions. Stroh and Gerhold (1966) found that once a resin duct was contacted in the excavation of a feeding cavity and there is insufficient room to circumvent the duct the weevil abandons that cavity. After a number of unsuccessful attempts at feeding due to contact of an outside resin duct or to encountering difficulty in circumventing resin ducts, or both, the weevil retreated to select a new feeding site on the same or a new host tree.

6.5 Mechanical Control

The concept of mechanical control of P. strobi is not a new one. Peck, in 1817, recommended the removal and destruction of infested eastern white pine leaders as a control tactic (Belyea and Sullivan 1956). Clipping of not only the infested leader, but the removal of all but one lateral was proposed by Dirks (1964) and Drouin (1981) as a method of elimination of competition for apical dominance with a resulting minimization of crooks and associated defects from weevil attack.

DeBoo (1978) stated that leader clipping was one of the two operational control techniques in eastern white pine plantations - the other being treatment with chemical insecticides. If annual plantation surveys indicated an infestation of P. strobi of two to five percent control action was initiated. It was anticipated that all infested stands would have to be treated from three to five times to protect the management goals.

The Pest Management Section of the Vancouver Forest Region has commenced a programme of leader clipping on Sitka spruce attacked by P. strobi. According to Jeklin¹, after surveys have indicated infestation rates, the stands where infestation levels can be effectively reduced or kept from significantly increasing are prescribed for treatment. Generally, stands are treated when the infestation rate is at or below the two percent level. In those stands where the infestation rate is greater than two percent it has been determined by Jeklin and Wood² that little effect upon the weevil populations will be realized from a clipping programme.

The management objective of the Vancouver Forest Region clipping programme, according to Jeklin and Wood², is to achieve a ten metre butt log free of weevil attack and its associated defects. To achieve this goal they propose that clipping would commence at year five of a plantation - when the trees are about 1.5 metres tall - and continue annually to year 10 or 12, depending upon stand growth performance. Two stand entries per year are required - one each at the end of July and the end of August - to ensure that most of the leaders infested with P. strobi brood are removed. The annual cost of clipping and burning the infested leaders is currently \$20 per hectare

¹E.M.J. Jeklin. Pest Management Forester. B.C. Forest Service, Vancouver Forest Region. Burnaby, B.C. personal communication.

²E.M.J. Jeklin and P.M. Wood. Pest Management Forester and Pest Management Co-ordinator, respectively. B.C. Forest Service, Vancouver Forest Region. Burnaby, B.C. personal communication.

on Forest Service projects. Projects conducted by Licensees as an addendum to their tenure under Section 88 of the Forest Act have resulted in considerably higher costs.

The two-entry strategy may, however, have to be reassessed in the coastal situation since an October 1982 survey of one area indicated a further infestation of 25 percent of the number of infested leaders previously removed that summer. This additional attack, attributed to the populations that overwintered in the leaders as pupae and adults, if not controlled, may render the previous work useless.

Leader clipping, while being effective in limiting the spread of small, isolated infestations (Wood and McMullen 1983) is an extremely labour intensive and, thereby, costly proposition. For this reason, in order to protect the investment in control as well as to meet our management goals, once a project is initiated it must continue unless it is not showing a positive effect in weevil reduction. The keys to success are early problem identification and careful and thorough programme execution.

7. DISCUSSION

7.1 General Observations

The forest industry in the Prince George Timber Supply Area is dependent upon present and future stands of merchantable spruce for its economic survival. While other merchantable tree species may survive and grow, spruce is generally the tree species best suited to the sites previously supporting spruce and spruce-mix stands. To ensure maximization of site productivity we must establish and maintain thrifty stands of spruce on these sites as soon as they are harvested and treated. Our investment in the future - today's spruce plantations - must be managed and protected, often on a site specific basis with specific pest management prescriptions, to ensure maximum return at rotation age.

However, such a forestry practice may not be as beneficial as it superficially appears. The development of a relatively even-aged monoculture establishes conditions conducive to major losses to pest infestations. Spruce monocultures are extremely susceptible to damage and losses from the spruce weevil - a native insect pest of immature spruce trees - and several other pests.

While we have recorded incidences of P. strobi throughout the T.S.A. for many years it has not been recognized as the potentially serious forest threat that it truly is. There are many reasons for this; the most important one being that it has not been significantly infesting our plantations but has been evident only in low numbers in even-aged plantations and areas of natural regeneration. It is interesting to note that only a small number of our plantation trees are of such a size to be both attractive to the weevil and capable of supporting a healthy brood production. Where planted spruce trees are above the competition and have the physical attributes desirable to the attacking P. strobi adults there is often evidence of a weevil population. It would not be surprising to observe an increase in the reported incidence of P. strobi as the number of thrifty plantations growing free of brush competition increase.

The impact of P. strobi in the Prince George T.S.A., where there currently exists over 90 000 hectares of spruce plantation, has not yet been realized. It will not be fully realized until the surviving weevil-attacked trees are harvested and processed. Tree deformities will result in reduced lumber yield and value as well as substantial reductions in plywood veneer yield and quality. Individual tree volumes of attacked trees will be reduced and, consequently, a reduced average volume per hectare will be realized at rotation age. Harvesting and conversion costs will be increased due to the reduction in average piece size and the lack of uniformity of the logs. Lumber recovery factors will likely be reduced as a result of tree deformities and breakage during the harvesting process. Height growth reduction at an early age could result in overtopping by deciduous brush and undersirable conifers, stand stagnation and even significant mortality in the extreme cases.

7.2 Detection

Pest detection is a mandatory prerequisite to any successful pest control programme. With the knowledge of pest occurrence and dynamics lacking successful control would be more a matter of chance than plan.

There have been no 'pest-specific' surveys of immature stands in the Prince George T.S.A. as of the date of writing. Mention has occasionally been made of pest activity in some routine inspections of plantations, but only in the broadest of terms. Forest managers generally do not know where P. strobi is active in the T.S.A. nor do they know the degree of activity and damage caused by the weevil. Actually, the overall knowledge of pest status of the immature stands is somewhat of a void. Without this knowledge, in excess of 90 000 hectares of spruce plantations are potentially in jepodary.

While remote sensing techniques can provide the degree of P. strobi attack within an immature spruce stand, this is but one piece of data necessary to properly prescribe a pest management strategy. Parameters describing the trees as well as the survival and growth of the weevil population are requisite and can only be gathered from ground surveys. Remote sensing may have application in the location of plantations that show symptoms of weevil activity which would then be candidates for ground surveys. Trained photo interpreters using 70 mm colour infrared stereo pairs of photographs at scales of 1:1200 to 1:2000 should be capable of accurately detecting weevil activity in the stands surveyed.

All forestry staff should be aware of the pests most likely to be encountered in their particular operating areas. The incidence of pests must be reported and recorded if discovered in routine or random inspections. Once plantation trees are of such a size and vigour to be attractive to pests, specifically P. strobi, specific surveys should be conducted. In the Prince George T.S.A. it appears that, as a generalization, once plantations have been established for ten years they become susceptible to attack by P. strobi.

7.3 Chemical Control

Chemical control methods to date have been varied and have met with limited successes. Two major problems in effectively controlling P. strobi by chemical means are:

- i. Adults are only 'available' for conventional control techniques for a short time during spring feeding and oviposition; and,
- ii. Adults are capable of living and producing progeny for up to four or more years.

The entire conventional chemical control issue is currently clouded with environmental controversy and may not be a readily available option on a general basis. However, spot application under close supervision with environmentally acceptable chemicals may prove effective.

Conventional chemical control techniques may not be the most effective manner in which to practice P. strobi management. Ground-based application methods in the plantations of the Prince George T.S.A. are, very likely, inefficient and impractical when one considers both the terrain conditions and impediments to the movement of personnel and equipment. The aerial application of insecticides may produce varied degrees of control due to the critical timing of chemical application and the relatively short residual life of the approved insecticides. Small insecticide droplet sizes, low volumes of chemical, insecticide properties and the nature of P. strobi populations all act to make satisfactory control of the weevil by conventional means ~~of~~ a difficult proposition.

An opportunity for control of P. strobi in plantations may exist once an effective pheromone complex has been developed. Pheromone-baited traps placed at optimum spacing throughout plantations would attract attacking adult weevils away from potential crop trees. The traps could utilize a conventional insecticide to kill the adults or, possibly, use non-toxic methods, such as a sticky coating to capture the attracted weevils. A system using a reliable pheromone in slow-release capsules in conjunction with sticky traps has many advantages over conventional chemical control methods - the

major ones being that toxic materials are not introduced into the environment and that traps could be placed well in advance of the weevil flight and left unattended for its duration.

The use of repellent materials for the control of P. strobi may have merit for individual tree protection but should not be considered as a practical alternative for plantation management. While the weevils may be repelled from specific trees they will attack in areas of reduced repellence. Thus, the weevil problem will continue to exist, but in a different location - either in the same stand or in an adjacent stand lacking the repellent. Our efforts should be concentrated on eliminating the weevil problem rather than shifting it to another area.

Insect-specific chemicals, such as the insect growth regulators, may prove to be both effective and generally accepted by the environmentally-conscious public. It should not be anticipated, however, that the regulations regarding the use and application of insect growth regulators will be any less-stringent than those governing the use of conventional chemicals.

7.4 Silvicultural Control

Control of P. strobi through silvicultural methods may have merit but the silvics of white spruce may make it a difficult method to pursue successfully. White spruce, while generally being considered a species of relative shade tolerance, performs with greatly reduced vigour when established under a cover of brush. However, once established it appears to grow quite well in harmony with deciduous tree species. The encouragement or maintenance of a mixture of deciduous species into a stocked spruce plantation may result in a reduction in weevil attacks.

It may be possible to maintain a shade cover through selective thinning of the naturally-occurring deciduous species to allow optimum spruce growth yet suppress P. strobi activity to acceptable levels as a result of microclimate manipulation.

Silvicultural manipulation of the host has the potential to be a valuable strategy in the control of P. strobi. The work to date shows that, once we have a sound knowledge of the host-pest relationships, we may be able to use economical indirect methods of weevil control and minimize damage.

7.5 Biological Control

Biological control of insect pests through the use of naturally-occurring enemies of the pest of concern may exert a powerful influence in suppressing populations but, working alone can neither eliminate pests nor totally prevent outbreaks. While parasites and predators may be extremely valuable in pest control they are only a portion of total environmental resistance and will not eliminate their host or prey. This fact becomes quite obvious when we realize that they have lived together for countless generations.

7.6 Genetic Control

The development of genetically improved trees for our reforestation efforts has been a major goal of the B.C. Forest Service. Until recently the concern has been with tree volume and lumber quality. The recent interest in the apparent resistance of several individual trees to attack by P. strobi appears to have created a new pursuit in our tree breeding activities - the fruits of which may be borne many decades from now. While this programme may be interesting, challenging, and potentially the final answer, it cannot be considered as a solution to our problems in the immediate future.

7.7 Mechanical Control

Control of P. strobi through mechanical means is the only option presently available for immediate use. The clipping and burning of infested spruce leaders provides not only a degree of weevil control but can contribute to the tree quality through the removal of all but one lateral branch.

Leader clipping should be initiated at the first evidence of P. strobi activity in a stand. A two-entry strategy should be followed, with clipping operations in late July and late August, unless experience dictates that a third stand entry is necessary. Once treatment has commenced on a stand it must continue until the stand management guidelines have been met.

Leader clipping should be initiated in a stand at any reasonable degree of weevil infestation. At low rates of infestation, clipping productivity should be high and the cost per treated hectare relatively low; as infestation rates increase, the clipping productivity will decrease and costs will increase. There is likely to be an infestation rate at which mechanical control is no longer economically viable. At that time a decision regarding the ultimate disposition of the stand must be made - but it must take into consideration that stand abandonment will serve only to provide an infestation centre from which weevil populations can spread. Stand rehabilitation must then be considered as a method of site productivity maintenance and elimination of weevil populations.

The only operational control method available at present to combat P. strobi in spruce plantation is leader clipping. If initiated at an early stage in the developing stand and continued until the stand management objectives are met, weevil infestations should be kept at minimum levels and the maximum return will be realized from our investment. In the Prince George T.S.A. it is quite likely that all stands can be satisfactorily protected by leader clipping programmes since overall infestation rates are generally low.

7.8 Summary

An integrated approach to weevil control or forest management to minimize P. strobi impact appears to be most promising. We should be considering and developing programmes utilizing several techniques in concert to achieve our forest management objectives.

Early and confident detection and assessment procedures are instrumental since we must know where the pest is and in what numbers before we can formulate control strategies. Management plans should include measures to control P. strobi through microclimate alteration, host/weevil incompatibilities, selective use of chemical control, leader clipping and tree pruning as outlined in Figure 15. Operational research trials should be able to largely determine the most effective management methods for successful weevil control.

Young stands managed under a regime where a major consideration is that of P. strobi control will require more cultural care than is presently provided. Not only will more surveys - either informal 'walkthroughs' or formal pest surveys - be necessary but each young stand will likely require a specific prescription for best growth and, ultimately, timber production. Assessment and interpretation of all significant site factors relative to their influence upon the pest and the host will be necessary. Specific expertise in integrated pest management combined with area-specific data are prerequisites to successfully manage young stands to minimize damage from P. strobi.

The opportunities exist in the Prince George T.S.A. - and in the Prince George Forest Region - to manage the spruce weevil problem and grow spruce plantations to achieve all management objectives. We must, however, act quickly and competently and not wait until the problem is one of the almost impossible magnitude. The investment in immature forests necessitates their management and protection. While, in many instances, general practices have been established each situation will require specific pest management prescriptions taking into consideration significant local conditions.

8. RECOMMENDATIONS

Based on this study of P. strobi and its implications in the Prince George

Figure 15 - Stand management options to meet management objectives of a ten metre clear bole.

Stand Age				
0-10 yr	11-25 yr	26-50 yr	51 yr+	
Routine Inspections	Routine Inspections	Routine Inspections	Routine Inspections	
Mechanical Control if any signs of Weevil	Weevil Surveys if any signs of Weevil	Inspect Adjacent Stands for Weevil Emigration	Inspect Adjacent Stands for Weevil Emigration	
Conifer Release	Mechanical Control if any signs of Weevil	Mechanical Control if any signs of Weevil	Sanitation Thinning to Remove Weevilled Trees	
Inspect Adjacent Stands for Weevil Sources	Pre-commercial Thinning	Commercial Thinning	Commercial Thinning	
Chemical Control	Chemical Control	Chemical Control	Chemical Control	

 Regular Activities
  Weevil-Related Activities

Management Activity

Timber Supply Area the following recommendations are proposed:

Detection

- i. A detailed survey and appraisal of P. strobi should be initiated in the Prince George T.S.A. to enable the formulation of management decisions based on a complete and thorough knowledge of the insect in this particular area.
- ii. Surveys should be commenced immediately, specifically in 10 year-old + spruce stands, to determine the existence and extent of P. strobi in the Prince George T.S.A.

Appraisal

- iii. A weevil hazard index for the Prince George T.S.A. must be developed and put in place. Initially the hazard rating should be based on the degree-day concept proposed by McMullen (1976) and adjusted if significant anomalies are encountered.
- iv. Growth performance studies of planted spruce seedlings when grown under a deciduous canopy, introduced just after a 'free to grow' state has been achieved, should be commenced to determine the amount of overstory that significantly affects spruce growth.
- v. Consideration should be given to a 'species shift' concept for application in high risk areas. The opportunity of utilizing sub-alpine fir as an alternative exists but we know very little about artificially reforesting with this species.
- vi. Potential impact and cost/benefit analyses of P. strobi control should be conducted to estimate our possible losses and determine a break-even point in any control strategies.

Management

- vii. Prompt control action by the removal and burning of infested spruce leaders must be a follow-up practice in any stands showing any treatable infestation in the weevil surveys.
- viii. Studies of environmentally acceptable yet effective and efficient control options should be initiated. These studies may include silvicultural, chemical, biological or mechanical methods - or combinations of them - to combat P. strobi.

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