# PROBABILITY OF DAMAGE TO SITKA SPRUCE BY THE SITKA SPRUCE WEEVIL, *PISSODES STROBI*

RENE I. ALFARO
FORESTRY CANADA
PACIFIC FORESTRY CENTRE
506 WEST BURNSIDE ROAD
VICTORIA, BRITISH COLUMBIA
V8Z 1M5 CANADA

## ABSTRACT

A nine-year record of attacks to Sitka spruce, *Picea sitchensis* (Bong.) Carr., by the Sitka spruce weevil (=white pine weevil), *Pissodes strobi* (Peck), was analyzed to determine the probability of attack on a tree based on the length of its terminal leader. Equations describing the relationship were developed. Tall trees with long leaders had higher rates of attack than short trees with short leaders.

Additional key words: Pest, impacts, insects, loss, *Picea sitchensis*.

## RÉSUMÉ

Les données compilées pendant neuf ans sur les dégâts causés par le charanon du pin blanc (*Pissodes strobi* Peck.) à des épinettes de Sitka (*Picea sitchensis* Bong.) ont été analyses afin de déterminer les probabilités qu'un arbre soit attaqué d'après la longueur de sa pousse apicale. Des équations reflétant cette relation ont été â aborées. Les arbres de haute taille portant de longues pousses apicales étaient plus fréquemment attaqués que les arbres de faible hauteur à pousses apicales courtes.

## INTRODUCTION

The Sitka spruce weevil (=white pine weevil), *Pissodes strobi* (Peck), is the most damaging pest of Sitka spruce, *Picea sitchensis* (Bong.) Carr., in coastal British Columbia, Washington and Oregon. In early spring, adult weevils crawl or fly to the terminal leader of the previous season and females lay eggs in niches excavated under the bark. The larvae kill the leader by mining and consuming the phloem. Following an attack, the lateral branches from the whorl immediately below the damaged leader develop negative geotropism and assume a vertical position. This process usually results in the formation of crooks and forks at the point of injury (Silver 1968, McMullen 1976, Alfaro 1989). Repeatedly attacked trees are stunted and overtopped by competing vegetation; a severely attacked plantation may be worthless (Alfaro 1982).

Modern pest management is greatly assisted by computer models that integrate pest biological and epidemiological factors into stand growth dynamics. Of particular importance are the factors that determine whether a particular stand or an individual tree within a stand is attacked. Several factors determine the rate at which Sitka spruce is attacked by the Sitka spruce weevil. Because of a climate unfavorable to insect development, stands in coastal locations and on the northern extremes of the distribution of Sitka spruce are less susceptible than stands on inland or southern locations (McMullen 1976, Heppner and Wood 1984). Similarly, a lower susceptibility of trees growing under shade, apparently caused by an unsuitable microclimate, has been reported for the eastern host of *P. strobi*, the eastern white pine *(Pinus strobus L.)* (Graham 1918; Wallace and Sullivan 1985), as well as for Sitka spruce (McLean 1989).

Plantations in the most susceptible areas are infested when trees are about 4 to 5 years old; attack intensity (number of trees attacked/year) increases rapidly thereafter, reaching a maximum when the plantation is 10 to 30 years old (Alfaro 1982; McMullen *et al.* 1987). The overall susceptibility of a stand decreases as trees reach heights above 12 m (Harris *et al.* 1968; McMullen 1976, McMullen and Condrashoff 1973). This makes the Sitka spruce weevil a pest of primarily young forests. Overhulser *et al.* (1972) indicated that weevil oviposition and emergence is lower in trees that had previous attacks, relative to trees that had never been attacked. Based on this finding, they hypothesized that older plantations have lower attack rates because they have a small number of unattacked trees and hence do not produce large numbers of weevils.

Graham (1951) studied the attack records for a Sitka spruce plantation established in 1930-1932 at Green Timbers Nursery, in Surrey, British Columbia. He concluded that the frequency of *P. strobi* attacks per tree could not be attributed to chance alone, but that some trees had higher rates of repeated attack than others. Graham did not speculate on the reasons for this non-randomness. In 1960, G.T. Silver, formerly with the Canadian Forestry Service in Victoria, British Columbia, established four plots to study the biology of this insect and possible means of control. Silver(1968) analyzed data collected in these plots between 1960 and 1963 and reported that the tallest trees in a stand, with the longest leaders, had higher rates of attack than shorter trees with short leaders. Gara *et al.* (1971) and VanderSar and Borden (1977) corroborated Silver's (1968) findings. McMullen *et al.* (1987) and McLean (1989) present figures that display the relationship between proportion of trees attacked and their leader length. However, these authors did not develop mathematical equations to quantify the relationship. The pictorial relationship in McMullen *et al.* (1987) is one of the several relationships used in a comprehensive population dynamics model these authors report in the same paper.

McMullen *et al.* (1987) used data collected by Silver between 1960 and 1963. Silver continued the measurement of his plots until 1968. In this paper I analyze Silver's full 9-year record and develop equations that describe the probability of a tree being attacked based on leader length and on weevil population level.

## MATERIALS AND METHODS

### Silver's 1960s Study

Four plots were established in the fall of 1959 in an area of natural Sitka spruce regeneration which originated after clearcut logging, near Nitinat Lake on Vancouver Island. The plots were rectangular, had a combined area of 1 ha, and initially included 692 trees which were marked with metal tags. One plot was left untreated and the others treated in certain years with insecticides. At the time of establishment, average tree age and height were 7 years and 1.3 m, respectively. In the early spring of every year, from 1960 until 1968, each tree was examined and tree height, the length of all leaders (including multiple leaders), and attack status (i.e., whether it was attacked or not) were recorded. Since the examinations were conducted before growth started, they represented tree condition at the end of the previous growing season.

### Data Analysis

The data used in this paper were obtained from Silver's check plot; they therefore represent uncontrolled damage levels. This plot occupied 0.32 ha and initially included 231 trees.

To describe the stand and trees being attacked each year, the distribution of tree heights and leader lengths were tested for normality using the Kolomogorov test (Stephens 1983). This test was also applied to tree heights and leader lengths sorted by attack status. The data for every year were tested (Student's t-test) for significant differences in height or leader length between attacked and unattacked trees.

A logistic model (Hamilton 1974) was fitted to the binary attack data to relate the probability of a tree being attacked to its leader length. Leader lengths were converted to percentiles (Mendenhall 1975) of the leader length distribution for each year to allow comparisons between years, which were independent of the mean value. This is important because leader length increases with tree height and age up to a maximum which varies by site quality. Therefore, a particular length of leader may be considered long or short depending on plantation height and age at the time.

The probability of attack might depend not only on leader length but also on the level of the weevil population in a particular year. For this reason, in addition to the logistic model, separate linear models were calculated to describe the relationship between the percentage of attack in trees sorted by leader length percentile class in years of different attack severity. Severity classes were as follows:

LIGHT: the percentage of trees attacked in the year was 10% or less;
MODERATE: the percentage of trees attacked in the year was between 10% and 20%;
SEVERE: the percentage of trees attacked in the year was greater than 20%.

The percentage of trees attacked refers to the percent of the stand trees attacked. Trees with multiple leaders were considered attacked if they had an attack in at least one of the leaders.

## RESULTS

Tree height at the end of the 1959 and 1968 growing seasons averaged 1.3 and 4.6 m, respectively; the trees grew an average 3.3 m in the period. Leader length increased linearly with tree height until the trees were 3 to 4 m tall; it then reached a plateau at about 60 cm of growth per year (Figure 1). Fewer than 20% of the trees were attacked in the years from 1959 to 1961. The percentage of trees attacked reached a maximum of 36% in 1964; thereafter, the attack rate oscillated around 30% per year (Table 1).

The tests of normality indicated that, in every year, tree heights were distributed normally. Separate analysis of tree height distribution by attack status (attacked *versus* non-attacked) indicated no significant departure from normality (Kolomogorov D statistic test, P› 0.05). The distributions of the lengths of all leaders departed significantly from the normal distribution in four of the nine years studied. The difference, however, was only minor (probability of the D statistic was barely significant) and consisted of an excess frequency in the larger length classes. The distribution of leader lengths in leaders sorted by attack status were generally normal (Figure 2) with only two years in each class where a marginal departure from normality occurred, again due to an excess number of long leaders. The distributions of tree heights and leader lengths in attacked and non-attacked trees overlapped widely. In 1962, for example, the weevil attacked leaders as short as 25 cm but declined to attack many trees with 50- to 80-cm leaders.

*Pissodes strobi* preferred the tallest trees with the longest leaders in all years (Table 1). The difference in height and leader length between attacked and non-attacked trees averaged 0.8 m and 17.1 cm, respectively, over all years.

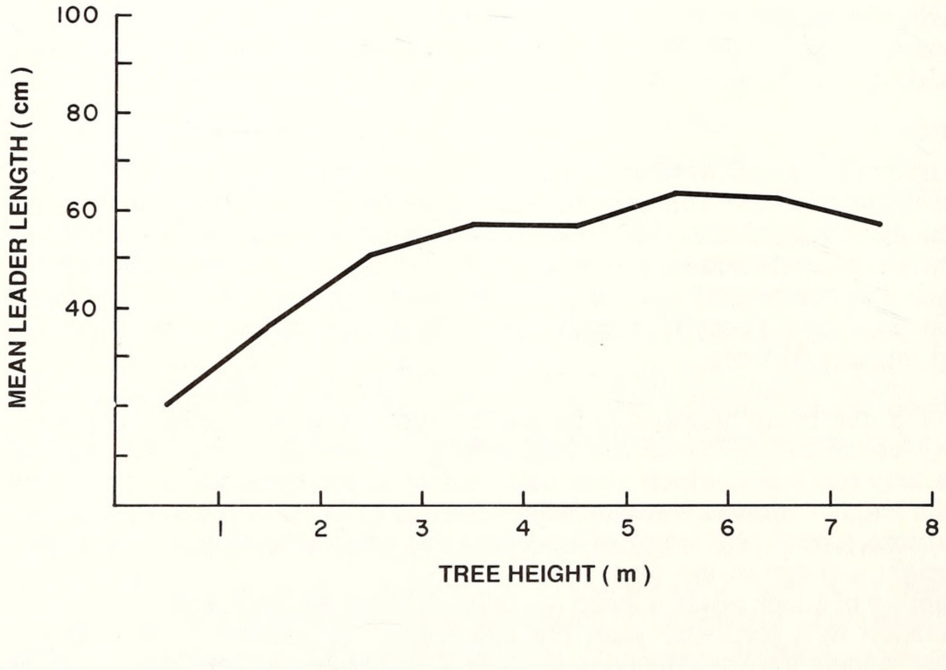


FIGURE 1. Average leader growth of Sitka spruce tabulated by height at the start of the season (trees grouped by 1-m height class)

TABLE 1. Percentage of Sitka spruce trees attacked by the Sitka spruce weevil and height and leader length of attacked and unattacked trees.

| Year[a] | Attack[b] (%) | Mean tree height (m) attacked | Mean tree height (m) not-attacked | Mean leader length (cm) attacked | Mean leader length (cm) not-attacked |
|---|---|---|---|---|---|
| 1959[c] | 18 | 2.0 | 1.4 **[d] | 37.0 | 22.0 ** |
| 1960 | 9 | 2.3 | 1.8 ** | 48.0 | 33.0 ** |
| 1961 | 14 | 2.9 | 1.9 ** | 56.7 | 33.6 ** |
| 1962 | 28 | 3.1 | 2.2 ** | 58.6 | 37.0 ** |
| 1963 | 33 | 3.5 | 2.3 ** | 62.5 | 44.0 ** |
| 1964 | 36 | 3.7 | 2.6 ** | 62.6 | 55.1 ns |
| 1965 | 35 | 3.9 | 3.1 ** | 64.0 | 42.3 ** |
| 1966 | 29 | 4.3 | 3.6 * | 58.7 | 39.9 ** |
| 1967 | 29 | 4.6 | 3.9 * | 61.6 | 48.9 ** |

[a] Year of leader formation
[b] Attacks occurred 1 year after leader formation
[c] Average age in 1959 was 7 years.
[d] Significance of difference between mean tree heights or leader lengths were tested by the Student t-test, and are indicated by *=P< 0.05, **=P< 0.01, and ns= P> 0.05.

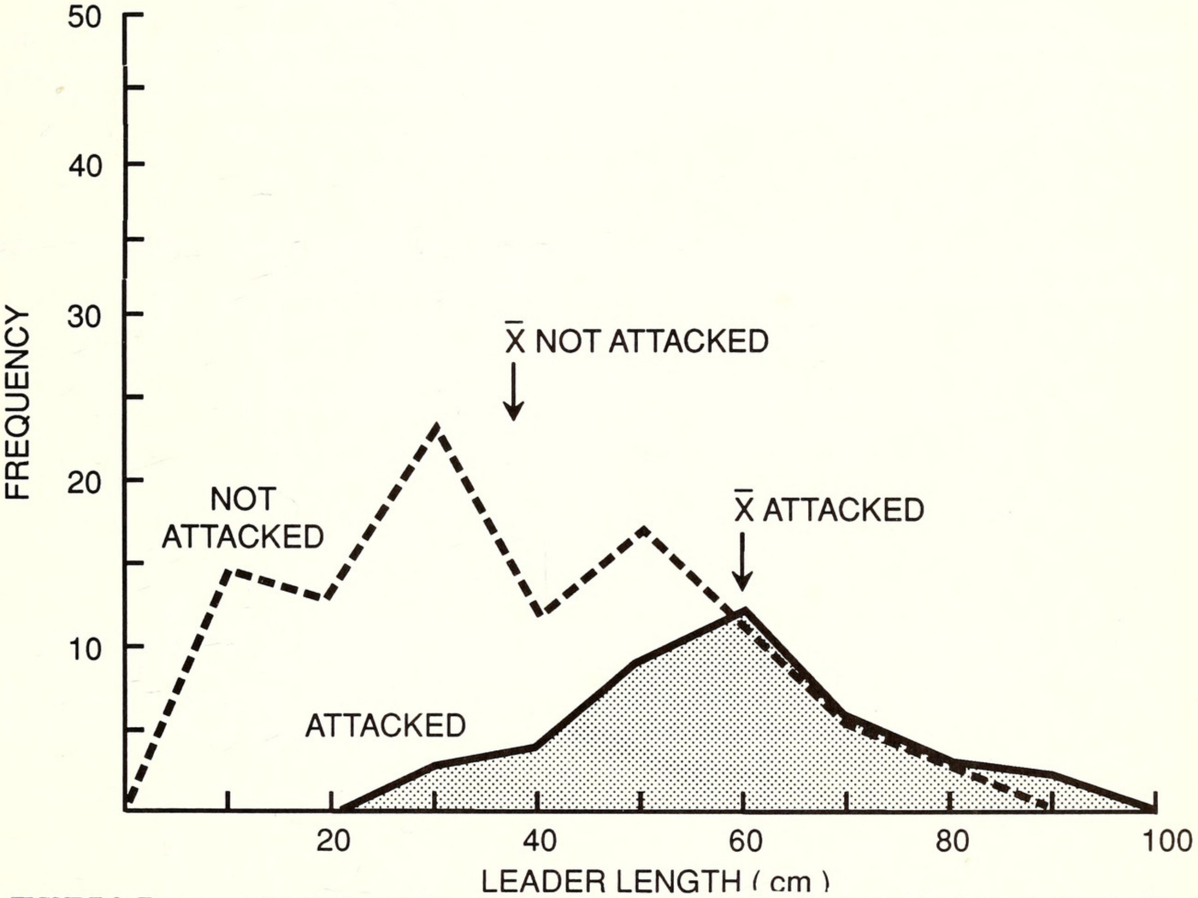


FIGURE 2. Frequency distribution of Sitka spruce leader lengths of trees attacked and not attacked by the Sitka spruce weevil, *Pissodes strobi*, in a representative year (1962), near Nitinat Lake, Vancouver Island.

The logistic model:

$$P = \{1 + EXP\ (A + B \times LLENGTH)\}^{-1} \quad (1)$$

where *P* is the probability of a tree being attacked in a particular year, and *LLENGTH* is the length of the leader as percentile of the leader length distribution for that year, and *a* = 2.816, and *b* = -3.118, was highly significant (F=273, P<0.01). However, although this model provided a good estimate of the average probability of attack in any year (Figure 3), considerable variation remained unexplained (correlation coefficient = 0.33). This variation is due, in part, to the fact that the probability of attack on a tree depends not only on the length of the leader, but also on the population level of the weevil: in years of low population, a tree with a given leader length will have a lower probability of attack than in years with a high population.

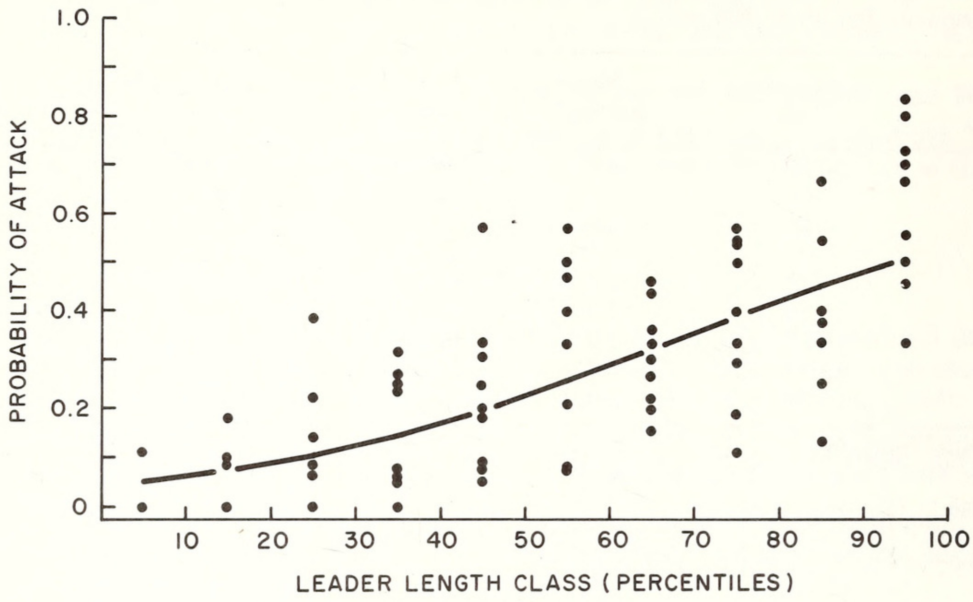


FIGURE 3. Percentage of attack (dots) and probability of attack (solid line) by *Pissodes strobi* weevils in Sitka spruce leaders sorted by leader length class. Lengths were expresed as percentiles of the leader length distribution for each year. The width of the percentile length class was 10%. These data were collected over 9 years near Nitinat Lake, Vancouver Island.

The linear models for each severity class were highly significant (Fig. 4). The models were refitted to eliminate non-significant intercepts, yielding the functions:

Population level LIGHT:
P= 0.002 x LCLASS
$r^2$=0.68, F= 23.8

Population level MODERATE
P= -0.121 + 0.006 x LCLASS
$r^2$= 0.77, F= 60.9

Population level SEVERE:
P= 0.006 x LCLASS
$r^2$= 0.71, F= 145.2

where *P* is the probability of a tree being attacked in a particular year; *LCLASS* is the midpoint of leader length class (Length is expressed as a percentile of the leader length distribution. Length classes have a width of 10% of the total length distribution, with mid-points at 5%, 15%, 25%, etc.); and LIGHT, MODERATE and SEVERE are population levels as defined in the Methods section.

## DISCUSSION

The attack rates increased from less than 20% to a maximum between 30% and 40% of the trees per year. This epidemiological pattern is very similar to that reported by Alfaro (1982) for a severely attacked plantation at Green Timbers, near Surrey, British Columbia and by McMullen *et al.* (1987) in plantations in the Klanawa River area of Vancouver Island. Alfaro (1982) indicated that attacked trees take 2 or 3 years to develop a new leader. During this period, the tree is generally not available for re-attack, unless the tree has developed multiple tops or the tree is re-attacked in the internode below the previous year's attack. In the Prince George area, Cozens (1987) found that in interior spruce *(Picea glauca* x *engelmanni)* up to 20% of the attacks were re-attacks on trees attacked in the previous year. Therefore, attack rates of 30 to 40%, such as the ones reported here, are probably near the maximum attack rate that a weevil population may sustain in a stand. Higher attack rates would deplete the oviposition sites and would lead to a reduction in the weevil population.

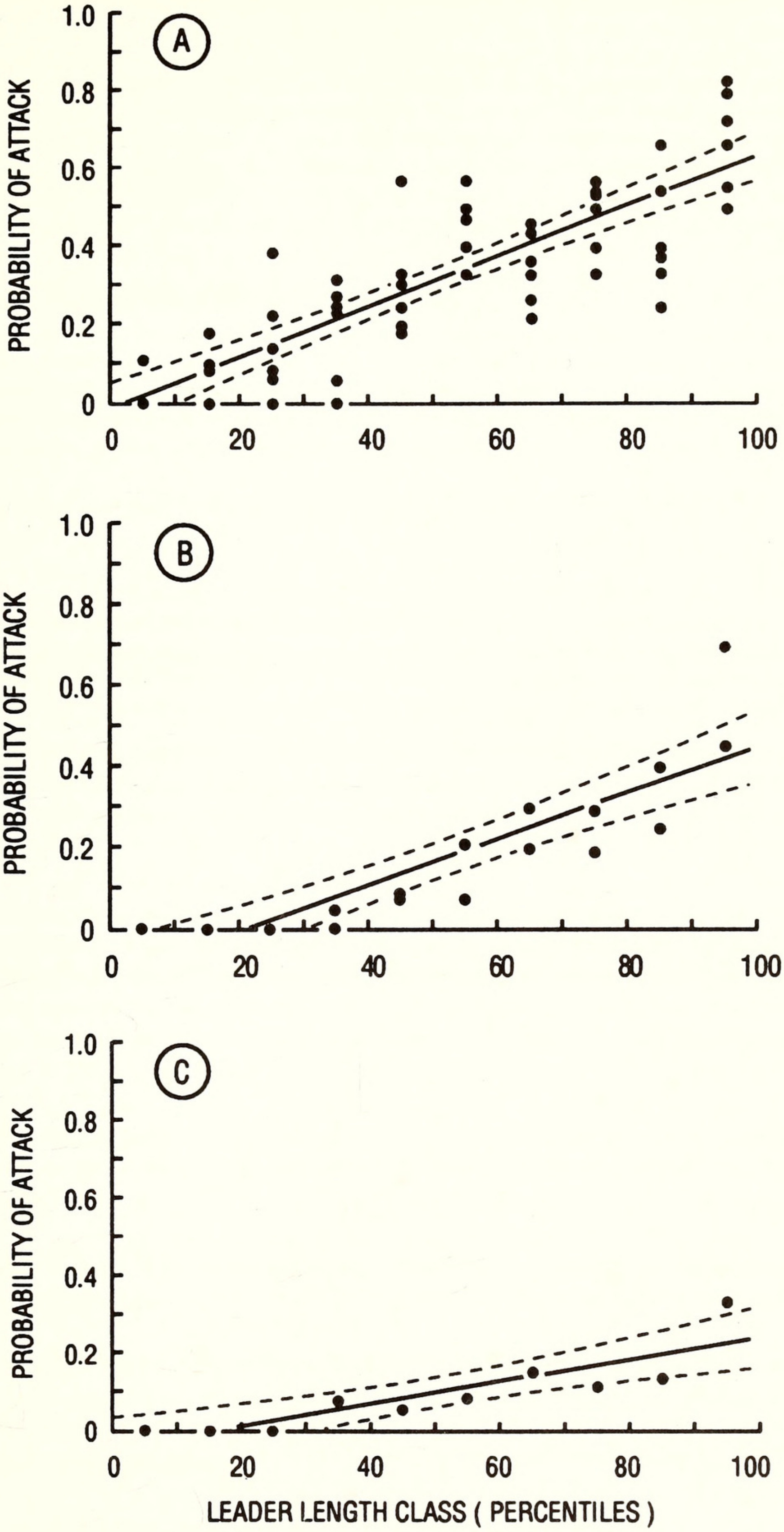


FIGURE 4. Percentage of attack (dots) and probability of attack (solid line) by *Pissodes strobi* weevils in Sitka spruce leaders sorted by leader length class. A) When attack intensity is LIGHT i.e. the percentage of trees attacked in a stand is 10% or less; B) When attack intensity is MODERATE i.e. the percentage of trees attacked in a stand is greater than 10% but less than or equals to 20%; C) When attack intensity is SEVERE i.e. the percentage of trees attacked in a stand is greater than 20%. Lengths were expresed as percentiles of the leader length distribution for each year. The width of the percentile length class was 10%. These data were collected over 9 years near Nitinat Lake, Vancouver Island. Dotted line represents the 95% confidence interval.

The fact that the frequency distributions of attacked and non-attacked leaders overlap widely (Figure 2) suggests that, in addition to leader length and population level, other factors determine whether a tree is attacked or not. My own unpublished observations indicate that the spatial distribution of the weevil population and of the attacks in young plantations is clumped. Attack intensity in trees within population clumps would be higher than that between clumps, forcing the weevils to attack smaller leaders in the clump areas and leaving relatively longer leaders unattacked in the areas between clumps.

The preference of *P. strobi* for the longest leaders in the stand is an adaptation of significance to the survival of a weevil population. It ensures that the leaders with the maximum food supply (more phloem in longer leaders) will be colonized; offspring production per leader is therefore optimized.

The equations developed here could form an integral part of a pest management model such as the one presented by McMullen *et al.* (1987), to predict the damage caused by the Sitka spruce weevil to Sitka spruce in British Columbia.

## REFERENCES

Alfaro, R.I. 1982. Fifty-year-old Sitka spruce plantations with a history of intense weevil attack. J. Entomol. Soc. B.C. 79:62-65.

Alfaro, R.I. 1989. Stem defects in Sitka spruce induced by Sitka spruce weevil attack. Pages 177-186 in Alfaro, R.I. and S. Glover, eds. Insects affecting reforestation: biology and damage. Proceedings of a IUFRO symposium held on July 3-9, 1988, in Vancouver, B.C. Canada, under the auspices of the XVIII International Congress of Entomology.

Cozens, R.D. 1987. Second broods of *Pissodes strobi* (Coleoptera: Curculionidae) in previously attacked leaders of interior spruce. J. Entomol. Soc. B.C. 84:46-49.

Gara, R.I., R.L. Carlson and B.F. Hrutfiord. 1971.Influence of some physical and host factors on the behaviour of the Sitka spruce weevil, *Pissodes sitchensis,* in southwestern Washington. Ann. Entomol. Soc. Am. 64:467-471.

Graham, S. 1918. The white pine weevil and its relationship to second growth white pine. J. For. 16:192-202.

Graham, K. 1951. The Sitka spruce weevil. Bi-monthly Prog. Rep., Can. Dept. Agric. 7:3-4.

Hamilton, D.A., Jr. 1974. Event probabilities estimated by regression. USDA. For. Serv. Res. Pap. INT-152. 18 p.

Harris, J.W.E., J.C.V. Holms and A.C. Molnar. 1968. Status of the Sitka spruce weevil on Vancouver Island, 1967. Can. Dept. For. and Rural Development, Forest Res. Lab., Victoria, B.C., Inf. Rep. BC-X-15, 19 p.

Heppner, D.G. and P.M. Wood. 1984. Vancouver Region Sitka spruce weevil survey results (1982-1983), with recomendations for planting Sitka spruce. British Columbia For. Serv. Int. Rep. PM-V-5.

Mendenhall, W. 1975. Introduction to probability and statistics. Duxbury Press. 460 p.

McLean, J.A. 1989. Effect of red alder overstory on the occurrence of *Pissodes strobi* (Peck) during the establishment of a Sitka spruce plot. Pages 167-176 in R.I. Alfaro, and S. Glover, eds. Insects affecting reforestation: biology and damage. Proceedings of a IUFRO symposium held on July 3-9, 1988, in Vancouver, B.C. Canada, under the auspices of the XVIII International Congress of Entomology.

McMullen, L.H. 1976. Spruce weevil damage. Ecological basis and hazard rating for Vancouver Island. Can. For. Serv. Pac. For. Res. Cent. Inf. Rep. BC-X-141. Victoria, B.C. 7 p.

McMullen, L.H. and S.F. Condrashoff. 1973. Notes on dispersal, longevity and overwintering of adult *Pissodes strobi* (Peck) (Coleoptera: Curculionidae) on Vancouver Island. J. Entomol. Soc. B.C. 70:22-26.

McMullen, L.H., A.J. Thomson and R.V. Quenet. 1987. Sitka spruce weevil *(Pissodes strobi)* population dynamics and control: A simulation model based on field relationships. Can. For. Serv. Pac. For. Cent. Inf. Rep. BC-X-288. Victoria, B.C. 20 p.

Overhulser, D., R.I. Gara and R. Johnsey. 1972. Emergence of *Pissodes strobi* (Coleoptera:Curculionidae) from previously attacked Sitka spruce. Ann. Entomol. Soc. Am. 65:1423-1424.

Silver, G.T. 1968. Studies on the Sitka spruce weevil, *Pissodes sitchensis,* in British Columbia. Can. Entomol. 100:93-110.

Stephens, M.A. 1983. Kolomogorov-Smirnov statistic. P. 393-396, in S. Kotz and N.L. Johnson (Chief editors), Encyclopedia of Statistical Sciences, Vol.4. John Wiley and Sons, New York.

VanderSar, T.J.D and J.H. Borden. 1977. Visual orientation of *Pissodes strobi* Peck (Coleoptera: Curculionidae) in relation to host selection behaviour. Can. J. Zool. 55:2042-2049.

Wallace, D.R. and C.R. Sullivan. 1985. The white pine weevil, *Pissodes strobi* (Coleoptera: Curculionidae): a review emphasizing behaviour and development in relation to physical factors. Proc. Entomol. Soc. Ont. Suppl. 116:39-62.